

# Preliminary Experiences with the Multi-Model Air Quality Forecasting System for New York State

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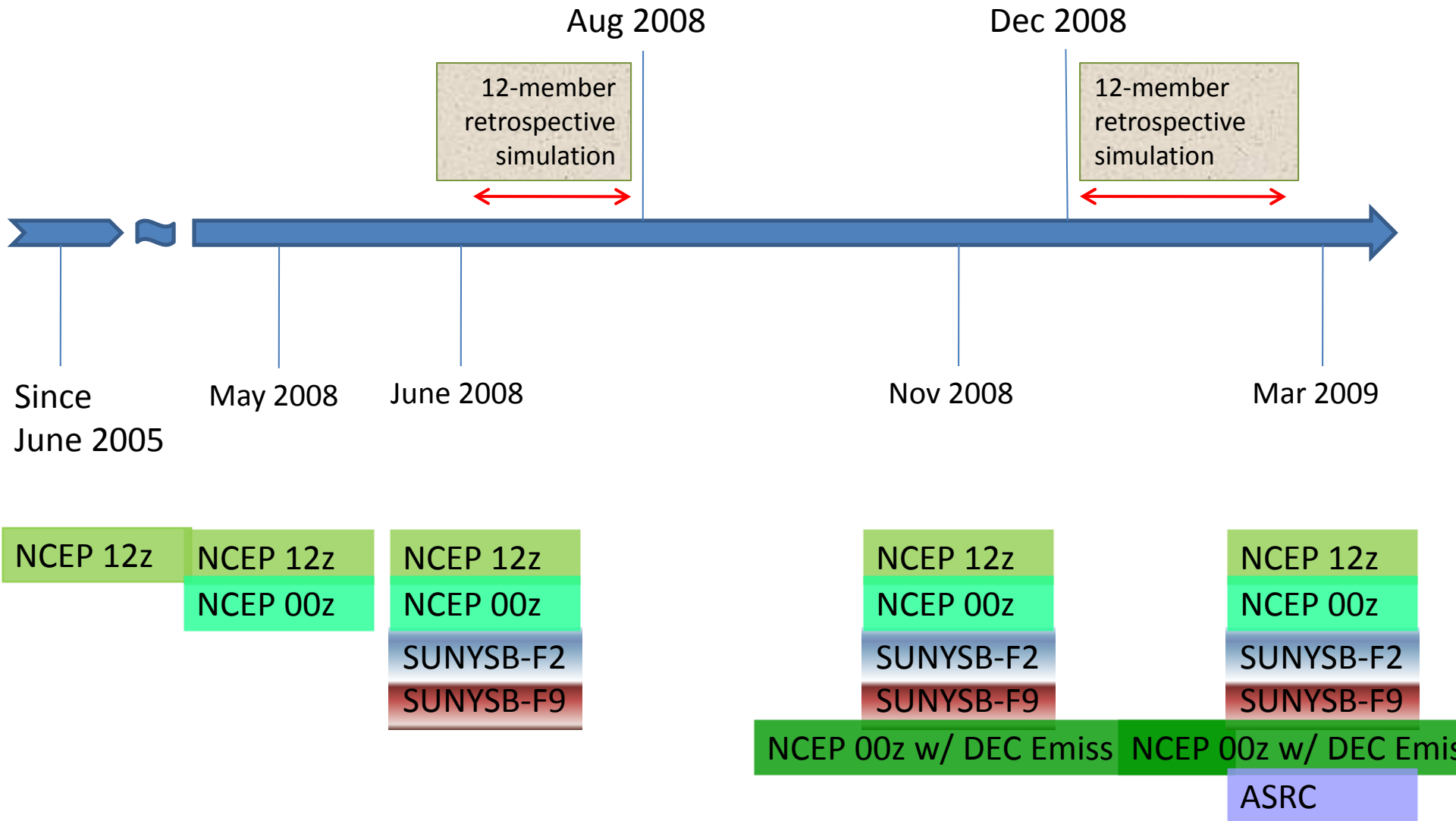
10/19/2009



# Background

- The New York State Department of Environmental Conservation (NYSDEC) has been performing CMAQ model-based air quality forecasts daily since June 2005, based on the NCEP UTC 12z weather forecasts
- Beginning June 2008, NYSDEC, in collaboration with the University at Albany (SUNY-Albany) and Stony Brook University (SUNY-SB), has implemented an ensemble air quality forecasting system in an attempt to better quantify uncertainties associated with the ozone and PM<sub>2.5</sub> forecasts.
- SUNY-SB has established a short-range ensemble weather forecast system (SREF) consisting of 14 members that has been run over the Northeast US for nearly four years ([http://chaos.msrc.sunysb.edu/NEUS/nwp\\_graphics.html](http://chaos.msrc.sunysb.edu/NEUS/nwp_graphics.html))
- Funded by New York State Energy and Research Development Authority (NYSERDA) and NYSDEC through in-kind contributions

# Timeline of Ensemble Forecasting System



# Daily Air Quality Forecast Ensemble Members

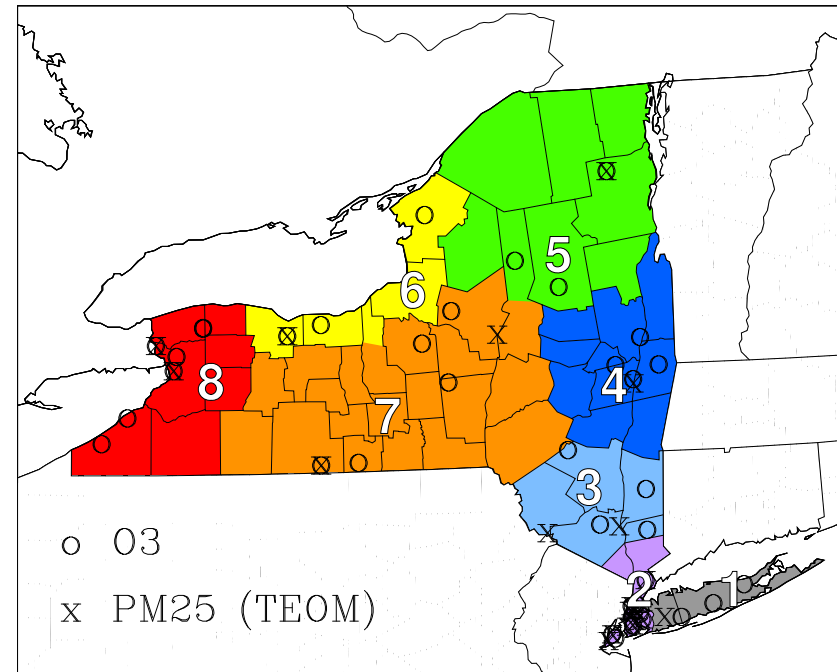
Member Name	Met.	Emis. Inv.	AQM	Grid Res	Initial-ize	Start Date
NCEP_t12z	WRF-NMM	EPA	CMAQ v4.6	12-km	12z	Summer 2004; Winter 2004-2005; everyday since June 2005
NCEP_t00z	WRF-NMM	EPA	CMAQ v4.6	12-km	00z	May 2008
NYSDEC_3x_t00z	WRF-NMM	NYSDEC	CMAQ v4.6	12-km	00z	November 2008
SUNYSB_F2	MM5	NYSDEC	CMAQ v4.6	36-km, 12-km	00z	June 2008
SUNYSB_F9	WRF-ARW	NYSDEC	CMAQ v4.6	36-km, 12-km	00z	June 2008
ASRC	WRF-ARW	NYSDEC	CAMx v4.5.1	12-km	00z	March 2009

# Analysis

- Examined the performance of the daily simulated ensemble system for the following time periods:
  - June - September 2008: 4 members
  - December 2008 – February 2009: 5 members
  - June – August 2009: 6 members
- Compared daily 8-hr maximum Ozone ( $O_3$ ) and 24-hr average  $PM_{2.5}$  model predictions against observations from the AIRNOW database and against the NYSDEC official (human) forecasts
- For the summer 2009 period, comparisons were also made against operational NOAA ozone forecasts that were made available to NYSDEC from June 2009
  - 06z initialization providing same-day forecast: NOAA\_t06z
  - 12z initialization providing next-day forecast: NOAA\_t12z
- Retrospective simulations of CMAQ using 12 SUNYSB short-range ensemble forecasting system (SREF) along with the regular members for the summer and winter time periods
  - June 4, 2008 – July 22, 2008
  - December 1, 2008 – February 28, 2009

# Official DEC Forecasts & Air Quality Forecast Regions in NYS

- Official DEC forecasters use human judgment and a variety of products including this ensemble system while issuing their forecasts
- Model-based forecast guidance is issued and evaluated following the same region-based approach used for the official human-based air quality forecasts issued by NYSDEC
- Each forecast region contains one or more ozone monitor and one or more continuous  $PM_{2.5}$  monitor
- For a given region and day, the forecasted/observed air quality value for ozone ( $PM_{2.5}$ ) is defined as the maximum ozone ( $PM_{2.5}$ ) value among the ozone ( $PM_{2.5}$ ) monitor(s) in that region



- Model values are extracted for the locations of all monitors, and the model air quality value for a region for ozone ( $PM_{2.5}$ ) is defined in the same way as for the observations

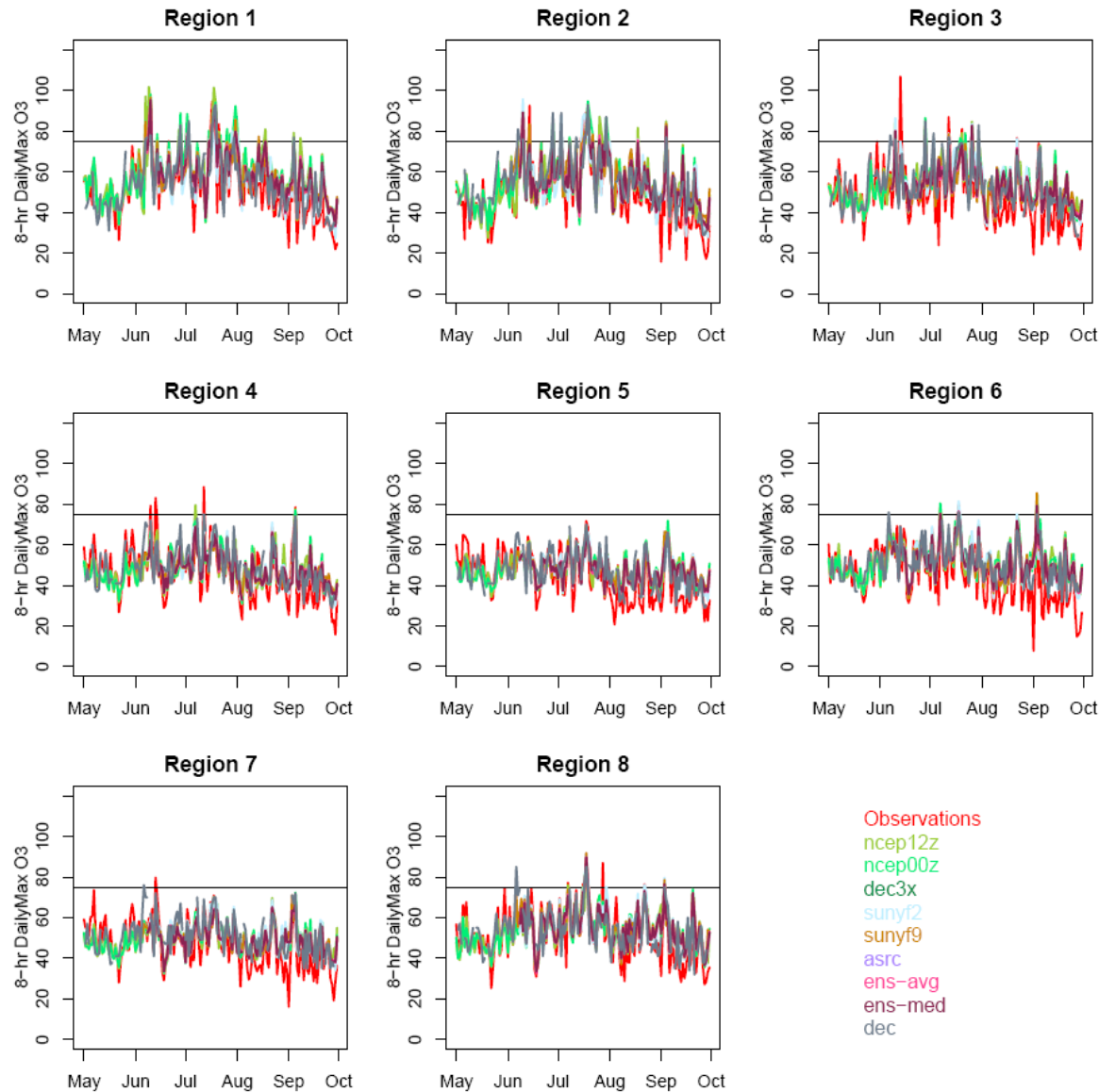
## Daily Forecast Simulations

### Members:

1. NCEP 12z
2. NCEP 00z
3. *(NYSDEC\_3x not in operation)*
4. SUNY-SB F2
5. SUNY-SB F9
6. *(ASRC not in operation)*

# **OZONE PERFORMANCE MAY (JUNE) - SEP 2008**

# Time Series of 8-hr Daily Max O<sub>3</sub> May – Sep 2008

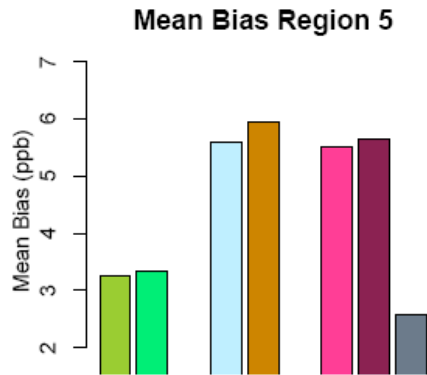
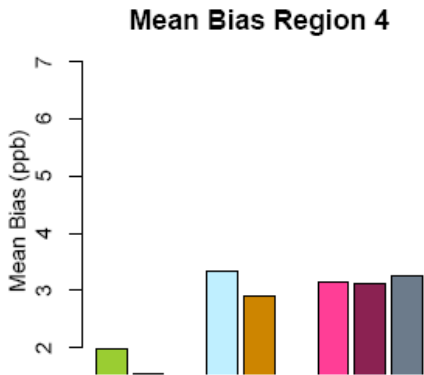
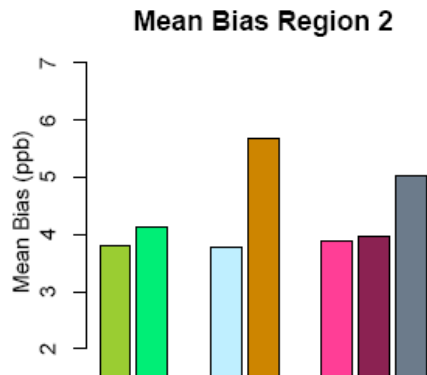
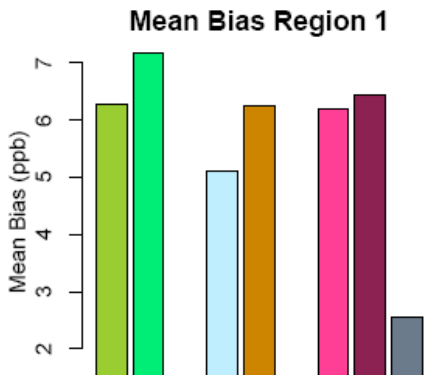


- Model predictions track the observations
- Over-prediction around Aug-Sep particularly in regions 5-8

Observations  
NCEP Members  
SUNY F2 (MM5)  
SUNY F9 (WRF)  
ASRC  
Ensemble Average  
Ensemble Median  
Official DEC Forecasts

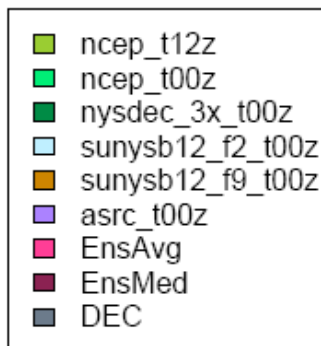


# Mean Bias of 8-hr Daily Max O<sub>3</sub> Jun – Sep 2008



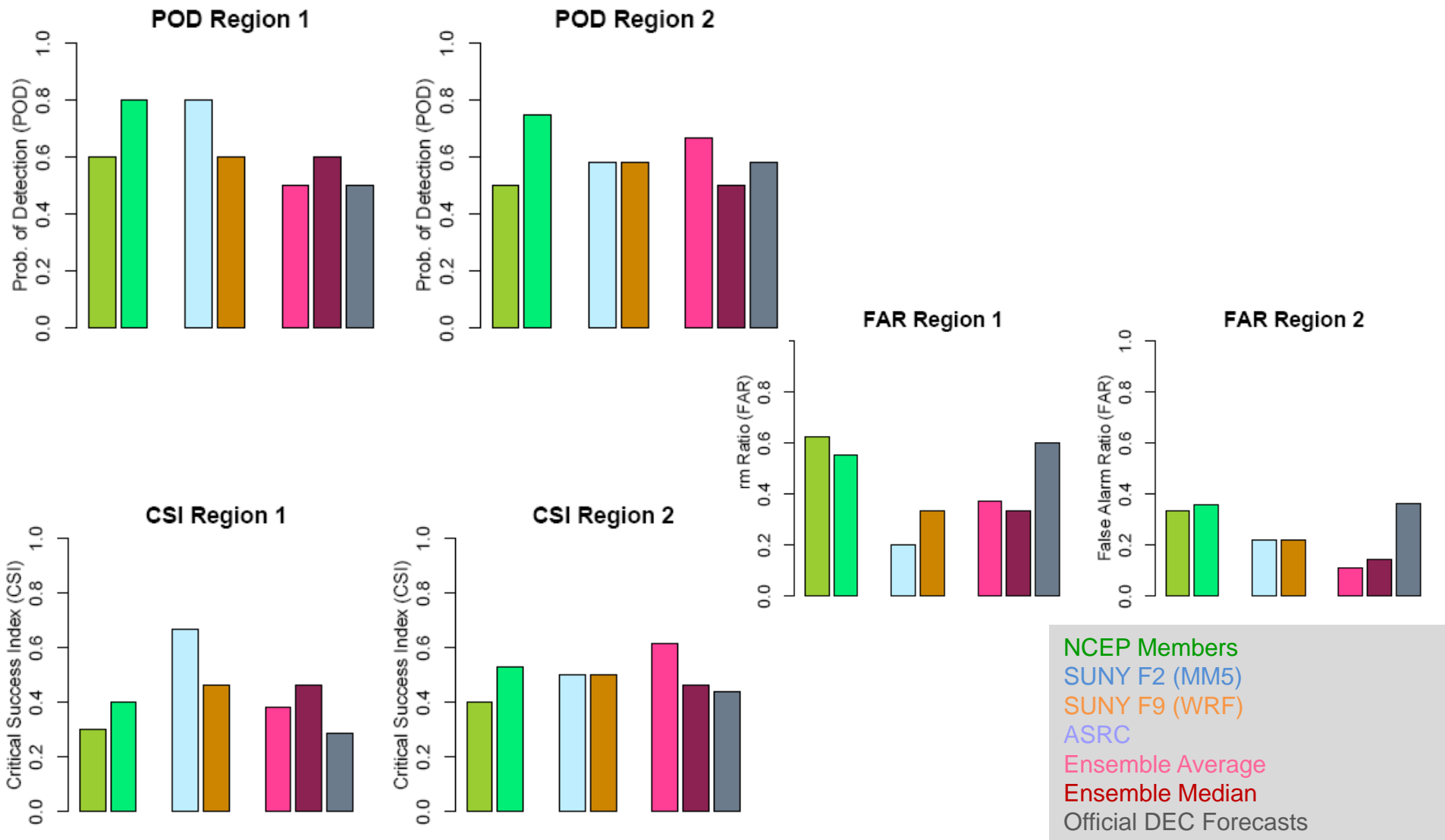
- Bias ~ 2 to 7 ppb
- NCEP-based models: lower bias in upstate regions
- Ensemble average not always the lowest bias
- All models have a RMSE of 9 to 12 ppb, with ensemble average showing similar or lower RMSE

- Official DEC forecasts showed similar or lower bias



NCEP Members  
 SUNY F2 (MM5)  
 SUNY F9 (WRF)  
 ASRC  
 Ensemble Average  
 Ensemble Median  
 Official DEC Forecasts

# Prob. Of Detection (POD), False Alarm Ratio (FAR) & Critical Success Index (CSI): O<sub>3</sub>, Jun – Sep 2008



## Daily Forecast Simulations

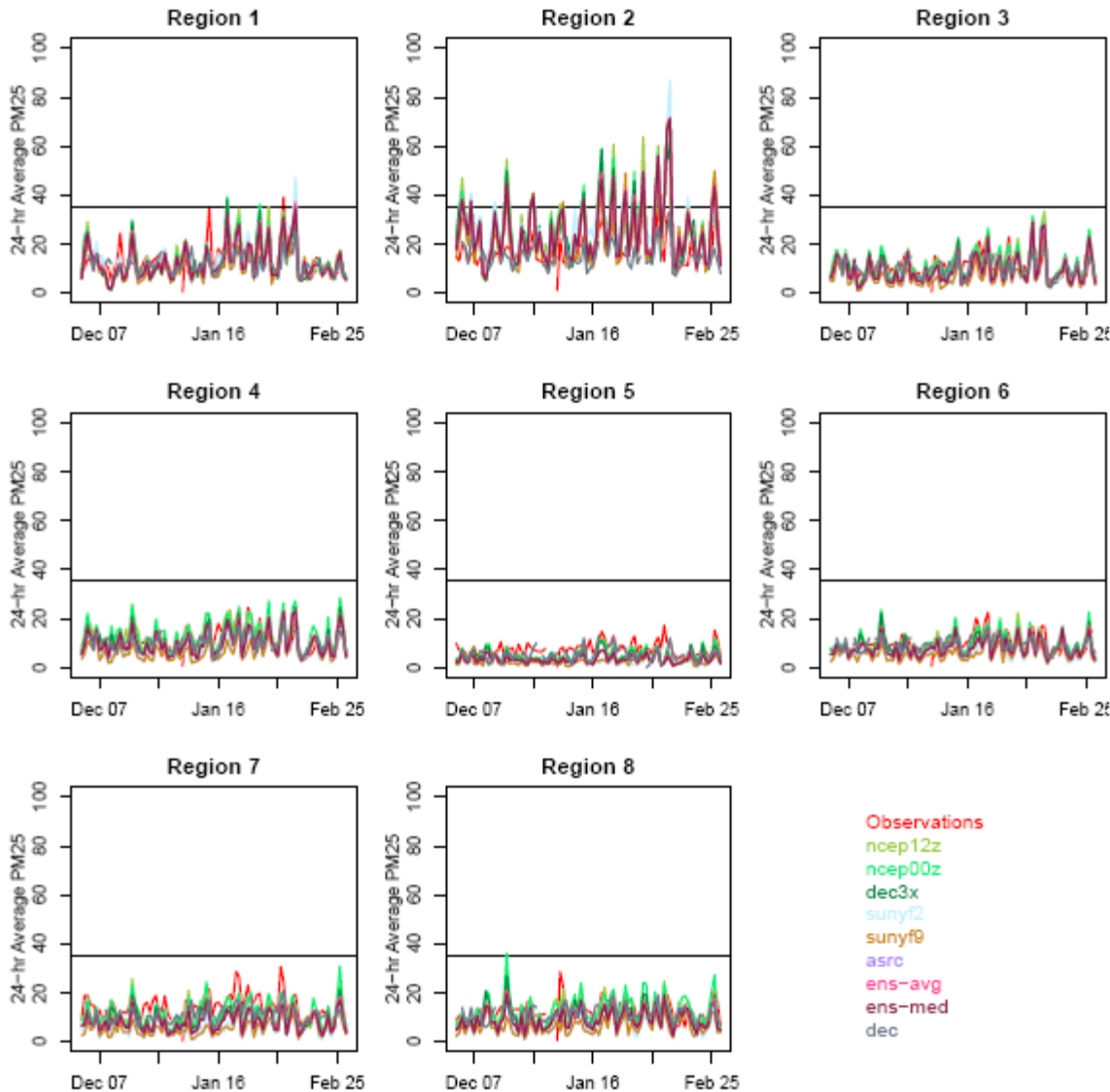
### Members:

1. NCEP 12z
2. NCEP 00z
3. NYSDEC\_3x
4. SUNY-SB F2
5. SUNY-SB F9
6. *(ASRC not in operation)*

# PM<sub>2.5</sub> PERFORMANCE

## WINTER: DEC 2008 – FEB 2009

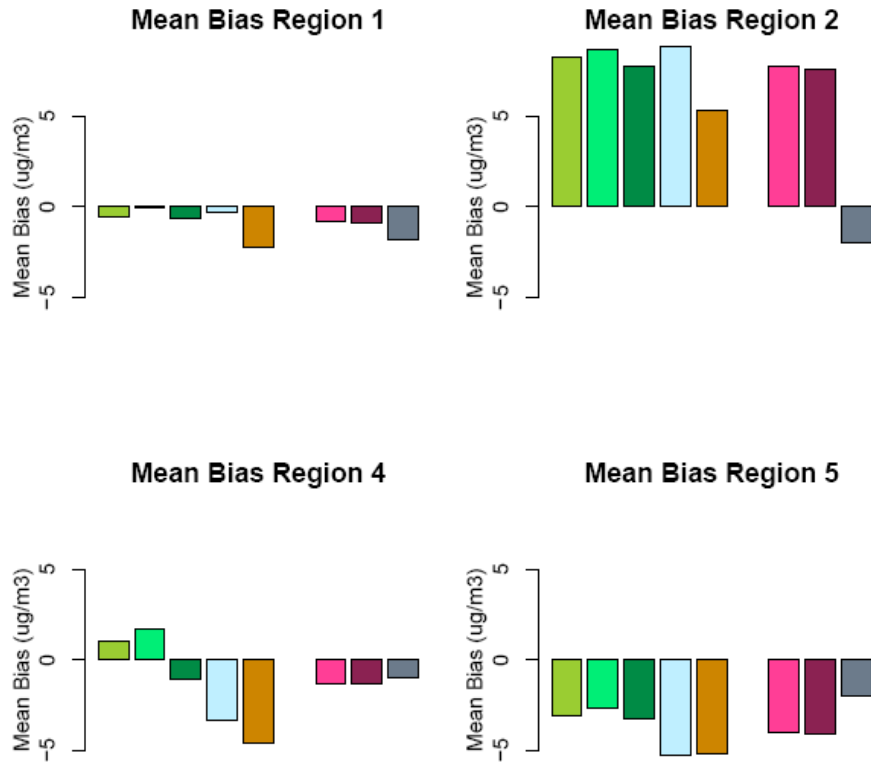
# Time Series of 24-hr Average PM<sub>2.5</sub> Dec 2008 – Feb 2009



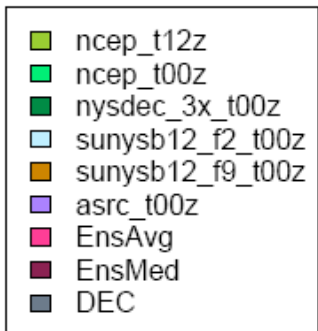
- Model predictions track the observations
- Except for Region 2, no significant over-predictions were found at other regions

Observations  
NCEP Members  
SUNY F2 (MM5)  
SUNY F9 (WRF)  
ASRC  
Ensemble Average  
Ensemble Median  
Official DEC Forecasts

# Mean Bias of 24-hr Average PM<sub>2.5</sub> Dec 2008 – Feb 2009

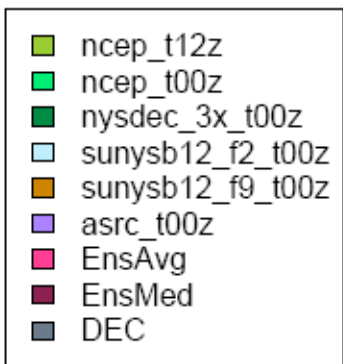
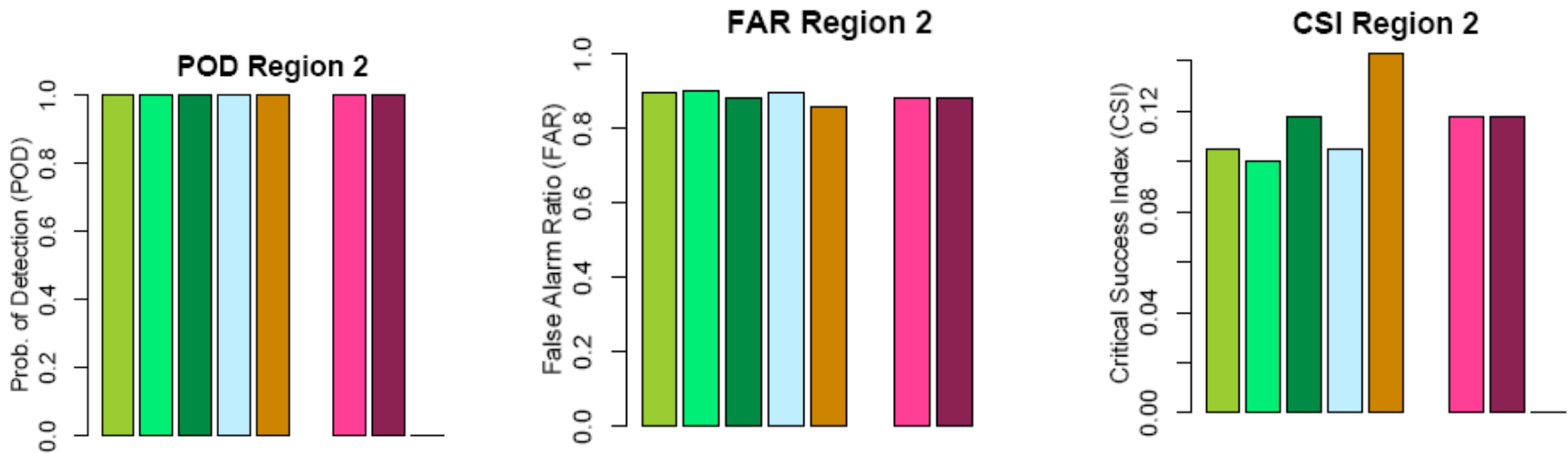


- Over-prediction in Region 2 (NY City) and under-prediction at other regions; Ensemble average similar or lower bias
- All models have a RMSE of 3 to 13  $\mu\text{g}/\text{m}^3$ , with ensemble average showing similar or lower RMSE. SUNY members showed higher RMSE at upstate regions.



NCEP Members  
 SUNY F2 (MM5)  
 SUNY F9 (WRF)  
 ASRC  
 Ensemble Average  
 Ensemble Median  
 Official DEC Forecasts

# Prob. Of Detection (POD), False Alarm Ratio (FAR) & Critical Success Index (CSI): PM<sub>2.5</sub> Dec 2008 – Feb 2009



- Exceedances in region 2 were picked up by all models, but there were false alarms as well, resulting in <15% critical success index
- Official DEC forecasts did not capture any of the observed exceedances

Members:

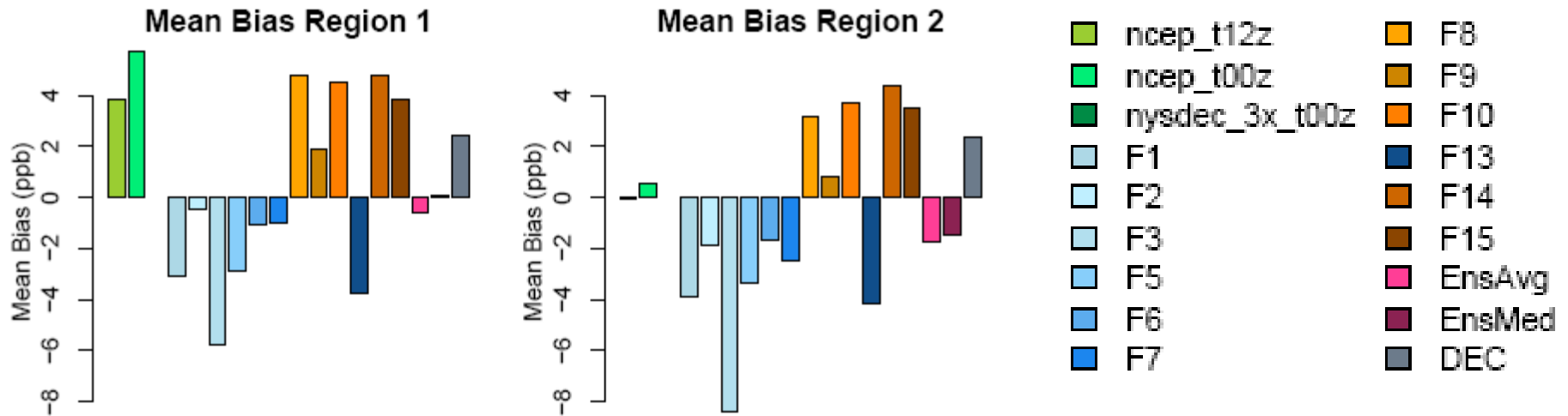
1. NCEP 12z, 00z and NYSDEC\_3x: Shades of green
2. SUNY-SB SREF Members:
  - a. MM5-based: Shades of blue
  - b. WRF-based: Shades of orange

**RETROSPECTIVE SIMULATIONS –**

**SUMMER: JUN – JUL 2008**

**WINTER: DEC 2008 – FEB 2009**

# Mean Bias of 8-hr Daily Max O<sub>3</sub> June – July 2008 (SUMMER)

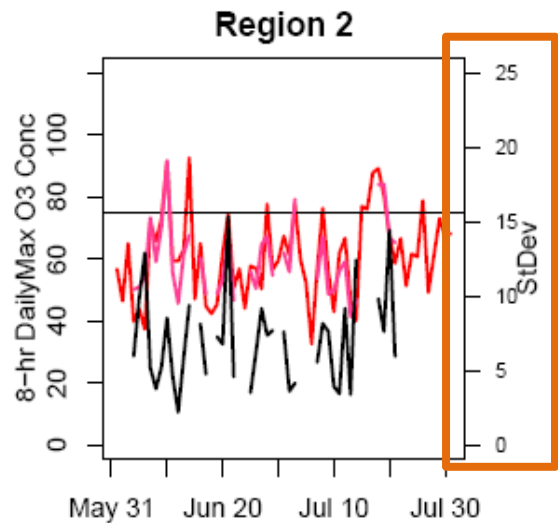
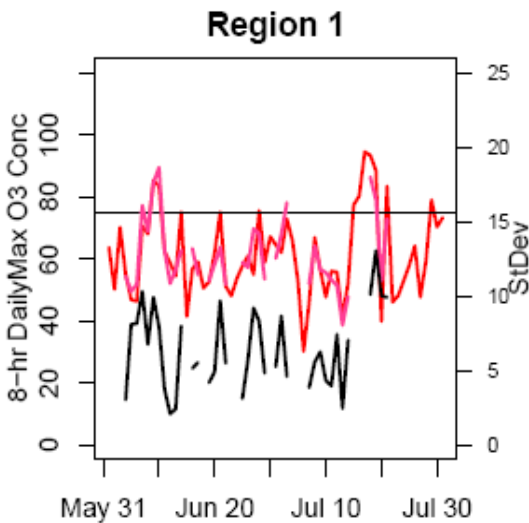


- Overall performance is similar to the 4-member system
- MM5-based members (blue) typically showed a negative bias, while WRF-based members showed a positive bias. (Not noticed in PM<sub>2.5</sub> predictions)
- Ensemble average is most often better than any of the individual models. Mean absolute error is 5-6 ppb compared to 7-11 ppb for the individual models

NCEP Members  
 SUNY-SB MM5-based  
 SUNY-SB WRF-based  
 Ensemble Average  
 Ensemble Median  
 Official DEC Forecasts



# Time Series of Ensemble Mean and Standard Deviation

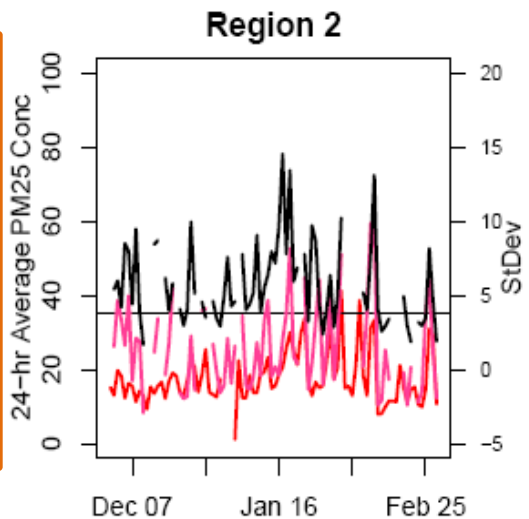
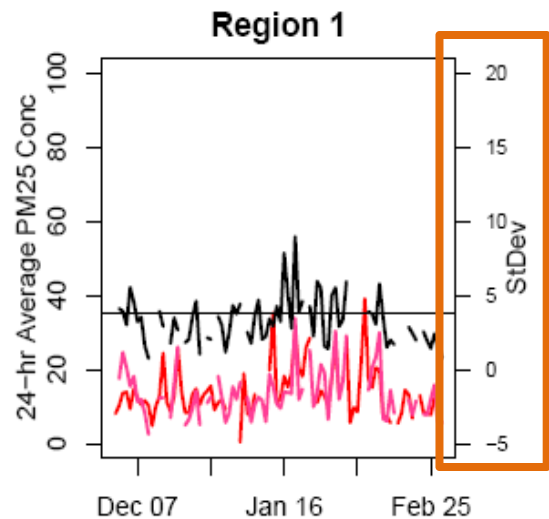


Ozone:  
JUNE -  
JULY 2008

Observations  
ens-avg  
stdev

Standard deviation (black) among the members often, but not always, appears to increase with increase in concentration, suggesting that a higher absolute uncertainty may be associated with episodes

PM<sub>2.5</sub>  
DEC 2008 -  
FEB 2009



## Daily Forecast Simulations

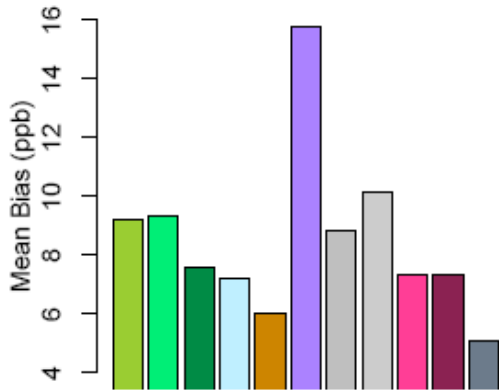
### Members:

1. NCEP 12z
2. NCEP 00z
3. NYSDEC\_3x
4. SUNY-SB F2
5. SUNY-SB F9
6. ASRC
7. NOAA Operational Ozone Forecasts

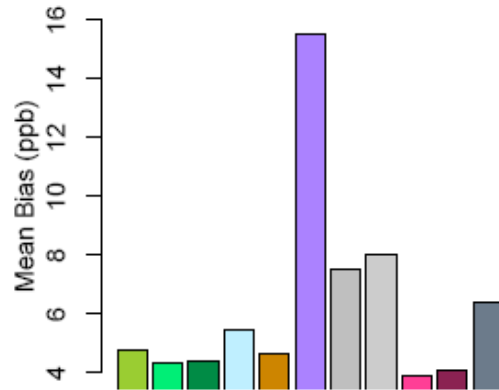
# **PERFORMANCE DURING SUMMER 2009 (JUN- AUG 2009)**

# Mean Bias: Jun – Aug 2009

### Mean Bias Region 1



### Mean Bias Region 2

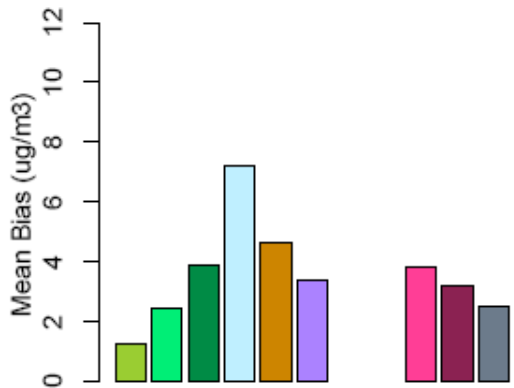


## Ozone

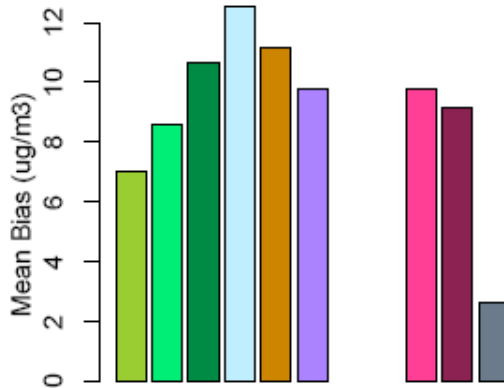
Typical bias of 4-10 ppb; ASRC WRF/CAMx system was an outlier with a bias of 12–17 ppb

- ncep\_t12z
- ncep\_t00z
- nysdec\_3x\_t00z
- sunysb12\_f2\_t00z
- sunysb12\_f9\_t00z
- asrc\_t00z
- noaa\_t12z
- noaa\_t06z
- Ensemble Average
- Ensemble Median
- Official DEC Forecasts

### Mean Bias Region 1



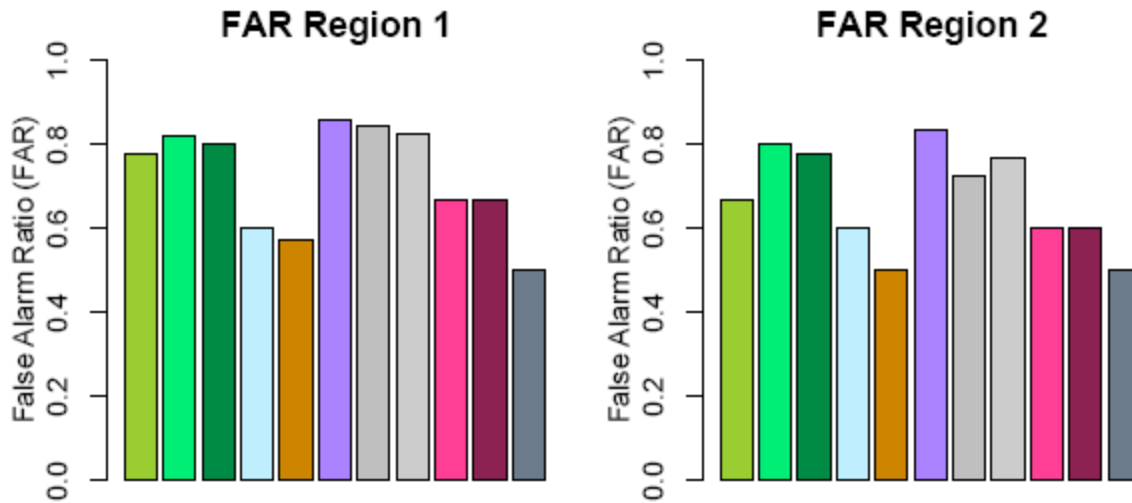
### Mean Bias Region 2



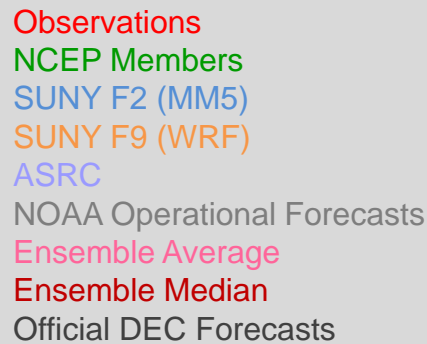
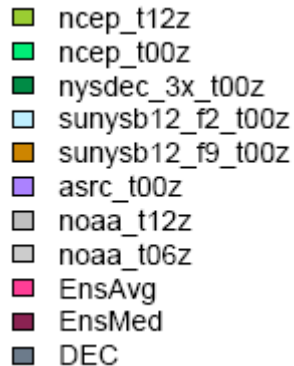
## PM<sub>2.5</sub>

Contrary to previous years, a positive bias was seen at all regions; The ASRC CAMx system was not an outlier for PM<sub>2.5</sub>

# False Alarm Ratio (FAR): O<sub>3</sub>, Jun – Aug 2009



- FAR of ~50 -80%, for Ozone compared to 20-60% during 2008



# Notes on Summer 2009 Performance

- All models over-predicted ozone concentration during summer 2009, including the NOAA model
- FAR was higher than what was observed the previous year
- Contrary to previous summers for  $PM_{2.5}$ , model predictions were positively biased for all regions
- What is different this summer?
  - Meteorology ?
  - Emissions ?

# Meteorology: Cooler and Wetter Summer

## Below Normal Temperature

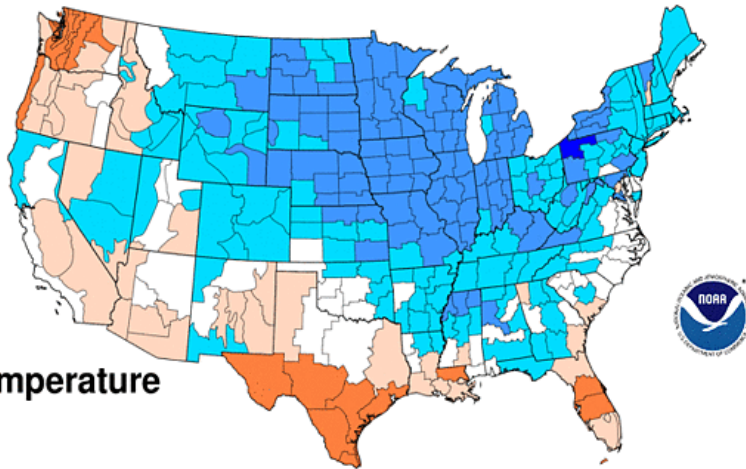
## Above Normal Precipitation

Jun - Aug 2009

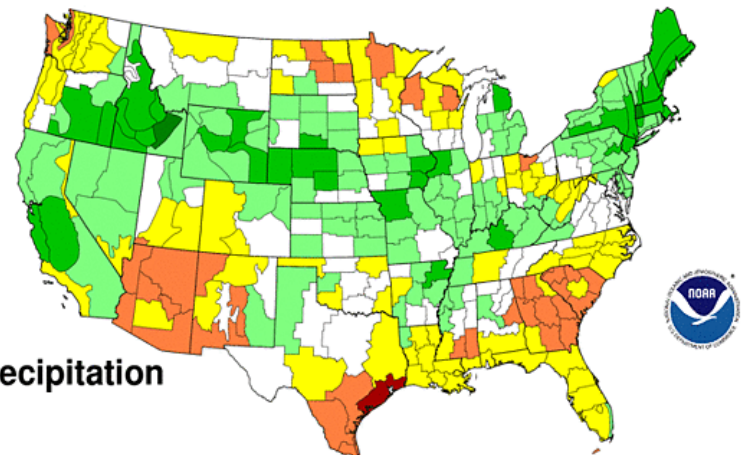
National Climatic Data Center/NESDIS/NOAA

Jun - Aug 2009

National Climatic Data Center/NESDIS/NOAA



Temperature



Precipitation



Courtesy: NCDC/NOAA plots compiled by Tom Downs of  
Maine Department of Environmental Protection

# Emissions

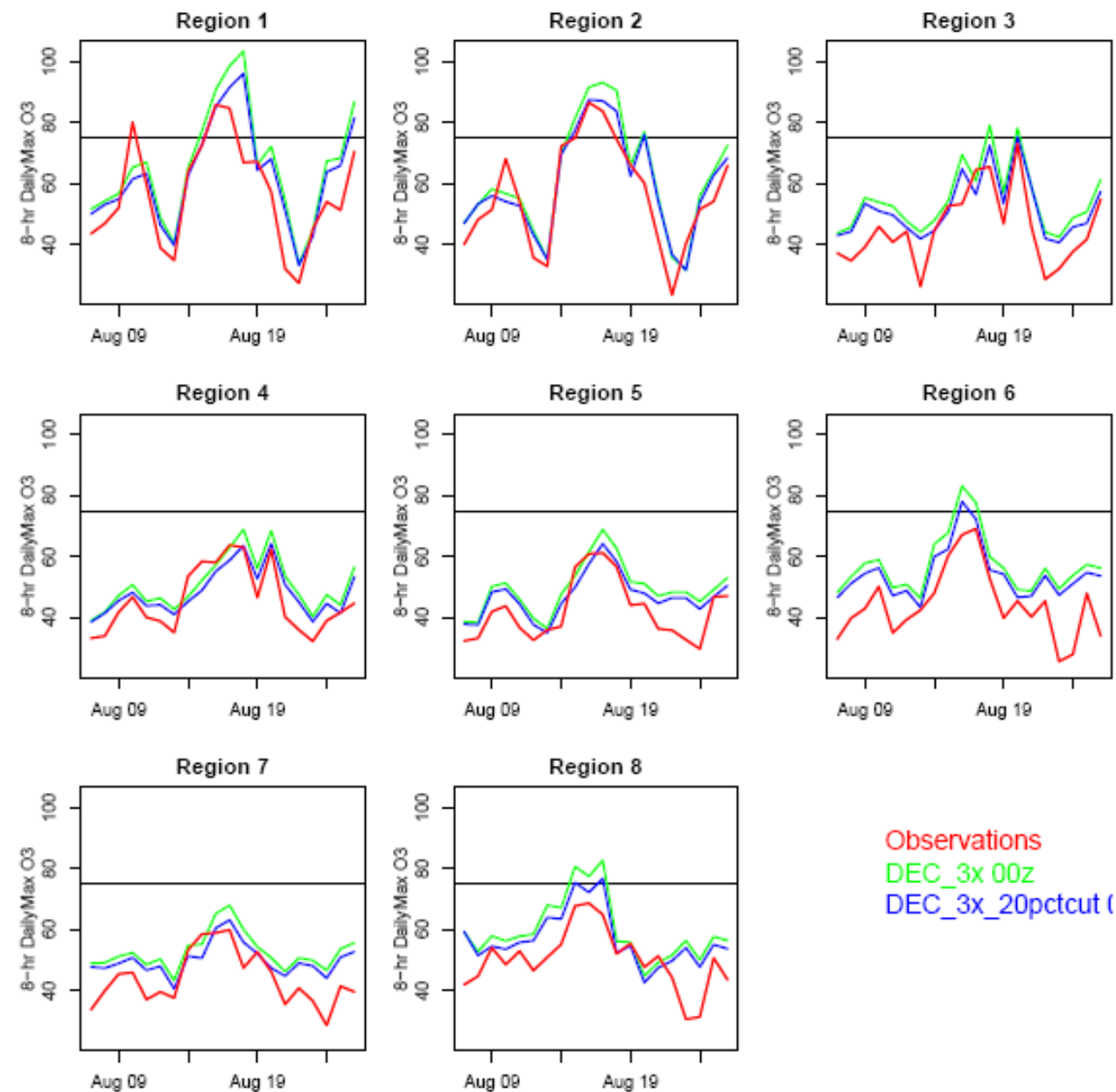
- Cooler and wetter summer may have been less favorable to ozone formation in general
- The weather patterns alone may not fully explain the ozone over-prediction by the models. Even days with observed temperatures greater than 90+ °F did not always result in an observed ozone exceedance.
- So could the model over-predictions be related to differences in emissions between the model and the real-world?
  - Power plant (i.e., electric generating units, EGUs) emissions in the model are based on 2005 measured emissions with no adjustment. Based on the data from the continuous emission monitors, these emissions have decreased by an average of ~15% during the ozone season (May-Sep), and by ~20% on an annual emission basis between 2005 and 2008 in the northeast US
  - Any decrease in emissions due to the current economic recession?

# Emissions Sensitivity Simulation

- To test this, we selected the NCEP member that uses the NYSDEC emission inventory, referred to as “NYSDEC\_3x”
- Reduced all **anthropogenic** emissions of all pollutants from all source categories by 20% over the whole domain
- Reran the CMAQ model with the reduced emissions from August 7 to August 26, 2009, during which high ozone episodes were observed (08/10, 08/16, 08/17) in Regions 1 & 2 (Long Island and New York City). The rerun is referred to as “DEC\_3x\_20pctcut” in the following plots



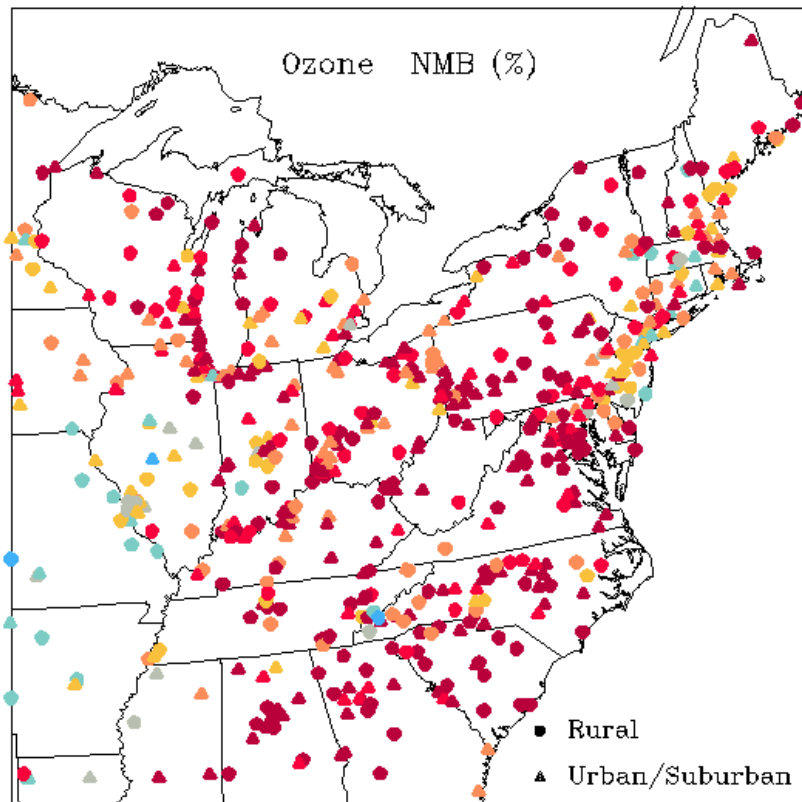
# Time Series of 8-hr Daily Max Ozone



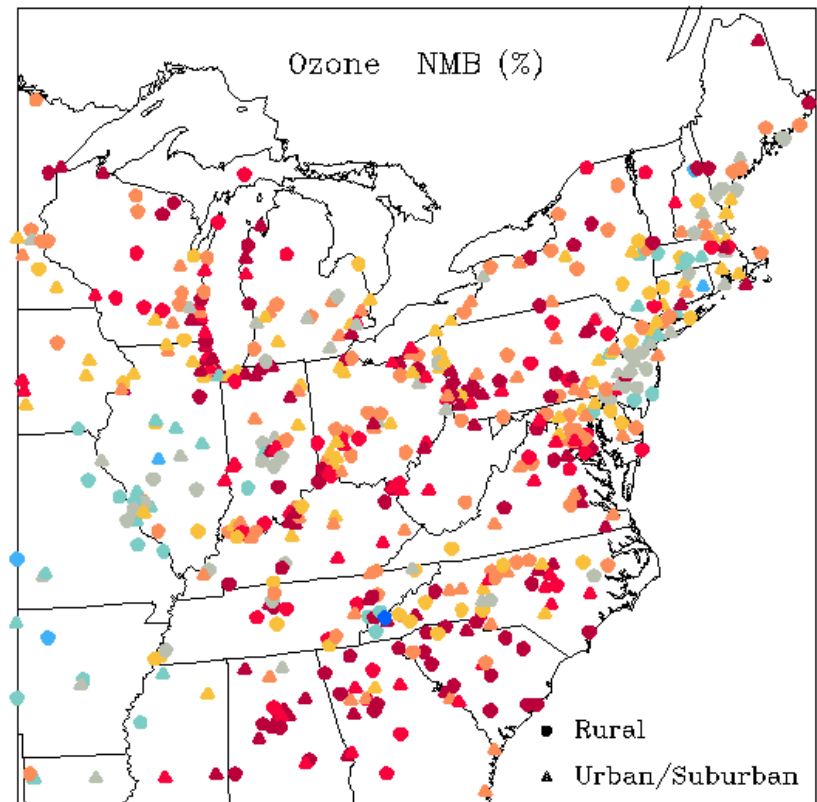
- A 20% cut in anthropogenic emissions (blue) resulted in a maximum of ~7% reduction in the predicted 8-hr daily max ozone concentrations compared to the base case (green) simulation (4.7 ppb in region 5 to 7.3 ppb in region 1).

# Normalized Mean Bias (NMB) Over the Whole Domain

NYSDEC\_3x Original Simulation



NYSDEC\_3x w/ 20% cut in anthropogenic emissions



A 20% cut in emissions shifted the NMB by one color category (for example, 20- $\rightarrow$ 25% to 10-20%) at most locations in the Eastern US. May indicate that the significant over-prediction in ozone concentrations this summer could be partly related to an over-estimated emission inventory.

# Summary

- The 4- to 6- member multi-model system predictions tracked ozone and PM<sub>2.5</sub> observations during summer and winter
- It appeared to capture the range of observed ozone concentrations during summer 2008, but under-predicted PM<sub>2.5</sub> concentrations for all regions except the NY City area
- Winter PM<sub>2.5</sub> concentrations were also under-predicted in most regions, except NY City area. Future work will compare PM<sub>2.5</sub> species concentrations with CSN speciation data.
- Retrospective simulations of a 14- or 15-member system showed similar results as the regular mini-ensemble system.
- Overall for the NY State region, the ensemble average (and median) often, but not always, showed similar or better performance than the individual models.

# Summary...

- Daily variation between the members, as represented by the standard deviation of the ensemble mean, appeared to be mostly (but not always) larger on days with higher observed concentrations. This may suggest that episodic days may sometimes be associated with higher absolute uncertainty.
- On a relative basis, the daily variability in model-predictions based on the multi-model system was ~5 to 15% for 8-hr maximum Ozone in summer and 20-30% or greater for 24-hr average PM<sub>2.5</sub> concentrations in winter.
- Analysis of the summer 2009 season showed over-predictions for both ozone and PM<sub>2.5</sub>. In addition to the cooler and wetter weather patterns that may have contributed partially to model over-predictions, an emissions sensitivity analysis suggests possible over-estimated emissions inventory.

# Summary...

- This indicates the challenges associated with incorporating up-to-date emissions that are reflective of real-world activity in forecasting applications.