19th Annual

CMAS Conference

Effect of Atmospheric Stability on Modeling Air Quality In and Around a Major Airport

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Airport Dispersion Model

- Motivation
  - Airports need dispersion modeling system that incorporates all physical and chemical processes related to LAQ (Local Air Quality) around airports
  - AERMOD is current regulatory model for airport LAQ studies

- Known limitations in AERMOD *(Arunachalam et al, 2017; ACRP Report 179)*
  - Problems identified in issues related to:
    - Source representation: area vs. volume vs. line
    - Lack of plume rise for hot buoyant plumes
    - Limited treatment of chemistry, etc.

- Objective
  - To develop an improved aircraft dispersion model which addresses the above issues for U.S. regulatory compliance purposes

Aircraft Dispersion Modelling (Background)

- Air quality degradation in the locality of airports poses a public health hazard *(Arunachalam et al, 2011; Barrett et al, 2013)*

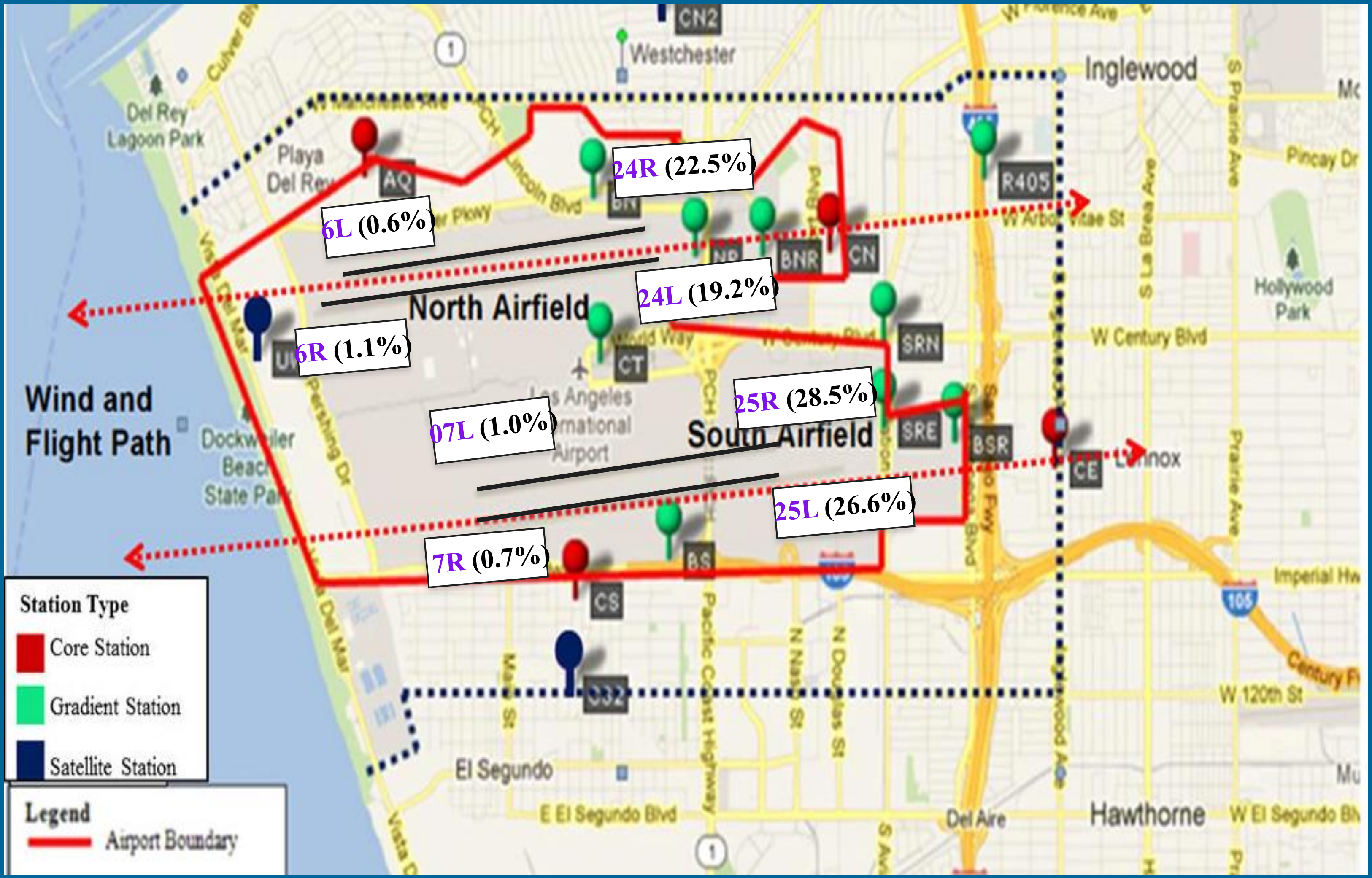
- Aircraft activities at airports generate CO_2 emissions that affect climate as well as other pollutants (NO_x, SO_x, and $PM_{2.5}$) that impact local air quality *(Woody et al, 2011; 2015; 2016, Stettler et al., 2011; Levy et al, 2012; Ashok et al, 2017)*

- Emission inventories are uncertain and dispersion models may not capture aircraft plume complexity *(Penn et al., 2015)*

- Emissions from aircraft sources are transient, buoyant, and occur at different heights from the ground and modeling the governing processes is challenging

- An added complexity occurs when the airport is situated near a shoreline where meteorological conditions are far from being spatially uniform *

LAX Air Quality Source Apportionment Study



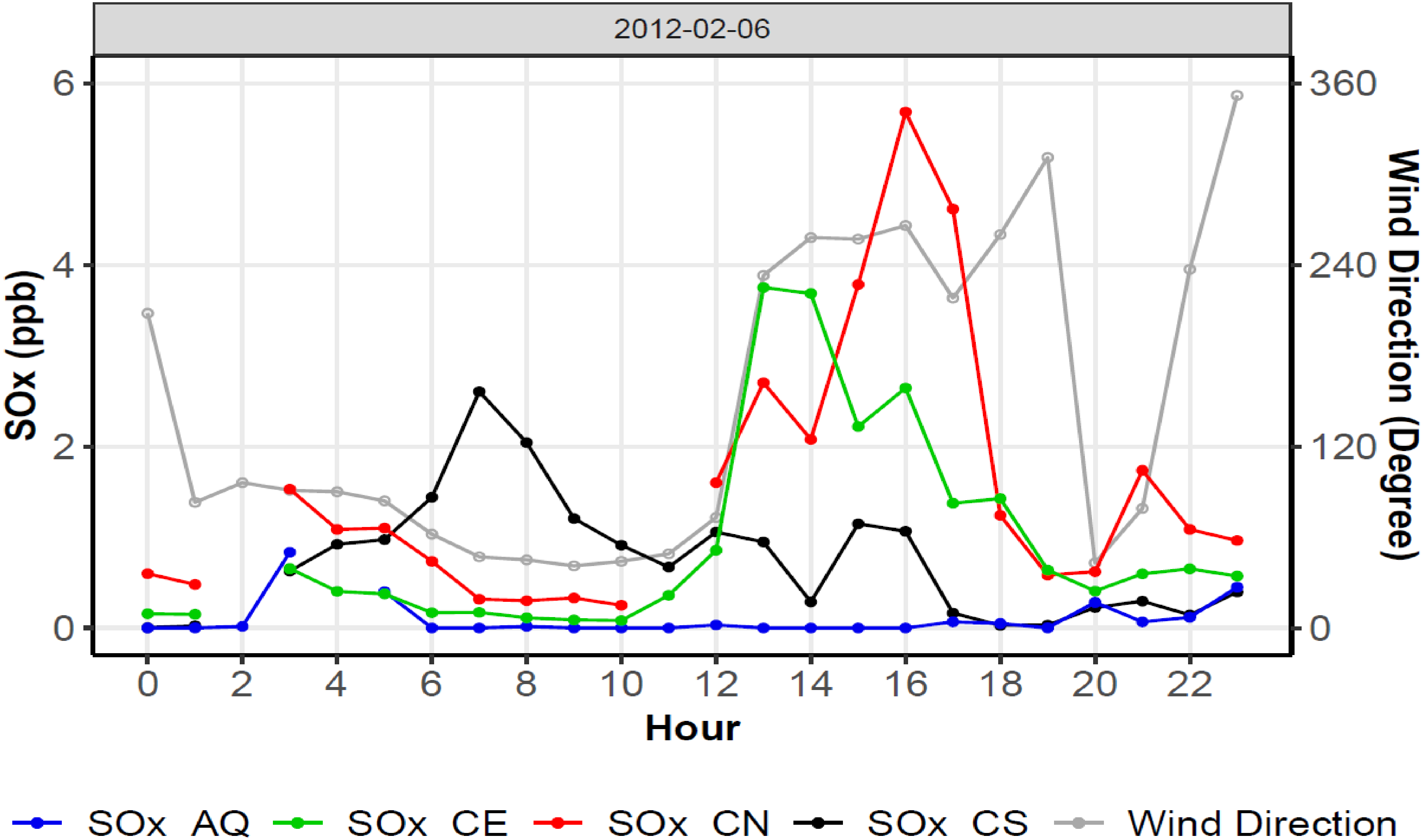
- Winter (Jan 31 – Mar 13, 2012)
- Summer (Jul 18 – Aug 28, 2012)
- 17 Locations: 4 "core", 4 "satellite", 9 "gradient"

Over 400 compounds measured

- Source-based and Receptor-based modeling
- Subsequently used in Multi-model intercomparison study

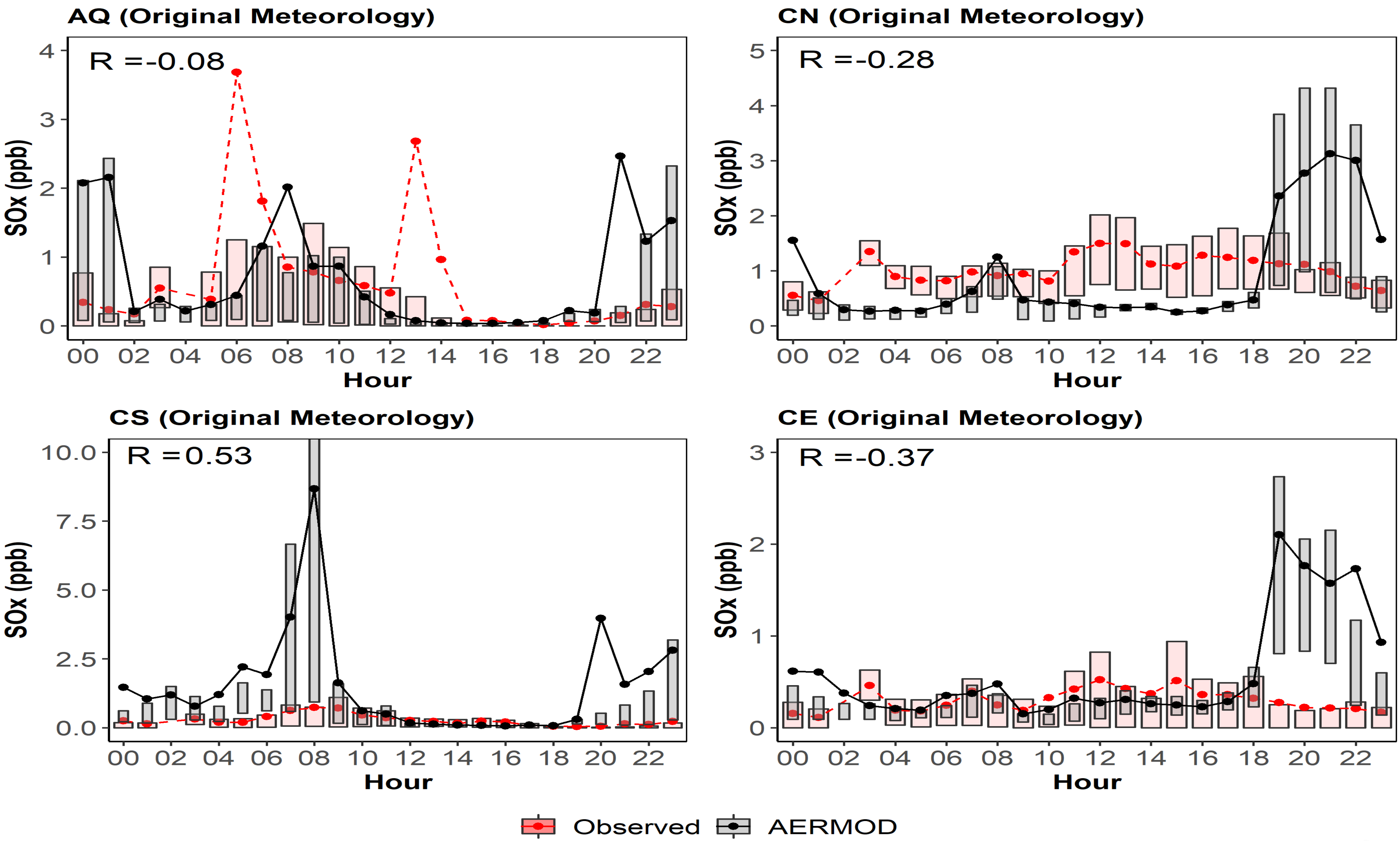
(*Arunachalam et al, 2017, ACRP Report 179*)

Daily Observed SOx at four core sites (AQ, CN, CS, & CE) for Winter Season



SO_x peaks associated with aircraft runway operations at CN; non-airport sources affect CS

Diurnal Variability in Observed and Modeled SOx Concentrations



AERMOD overpredicts concentrations at all 4 sites during evening hours

Some Reasons of poor prediction by AERMOD

- ✓ Airport Sources do not consider the plume rise
- ✓ Wake impacts on plume behavior in horizontal and vertical directions are not included in AERMOD, which lead to overprediction

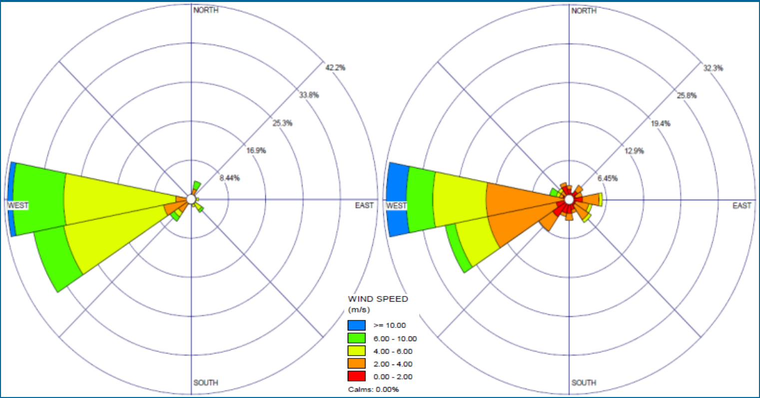
Airflow behind an aircraft taking off
(Source: NASA Langley)

- ✓ AERMET does not account for important features of the boundary layer that occur on the shoreline where many of the large USA airports are situated *
- ✓ Modified meteorological outputs from AERMET to account for formation of the internal boundary layer when stable air from the ocean flows onto the warmer land surface of the airport*

*Sensitivity to Meteorological Conditions in AERMOD

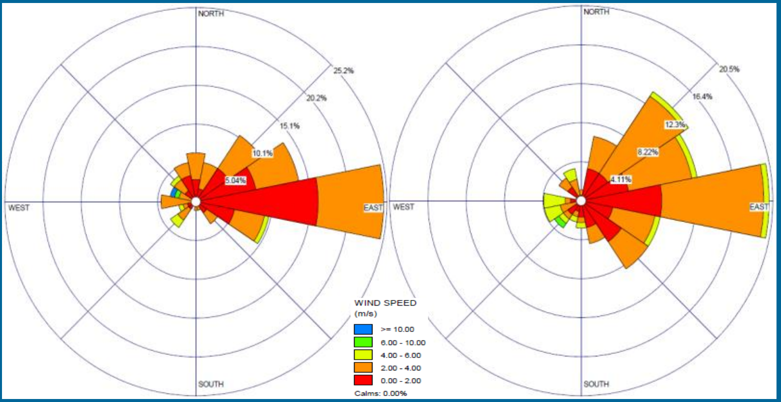
1. To account for the shoreline effect at LAX, stable and convective conditions replaced by neutral conditions

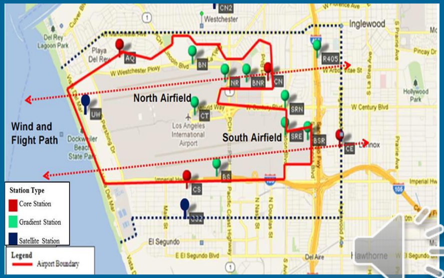
12-17 Hours 18-23 Hours



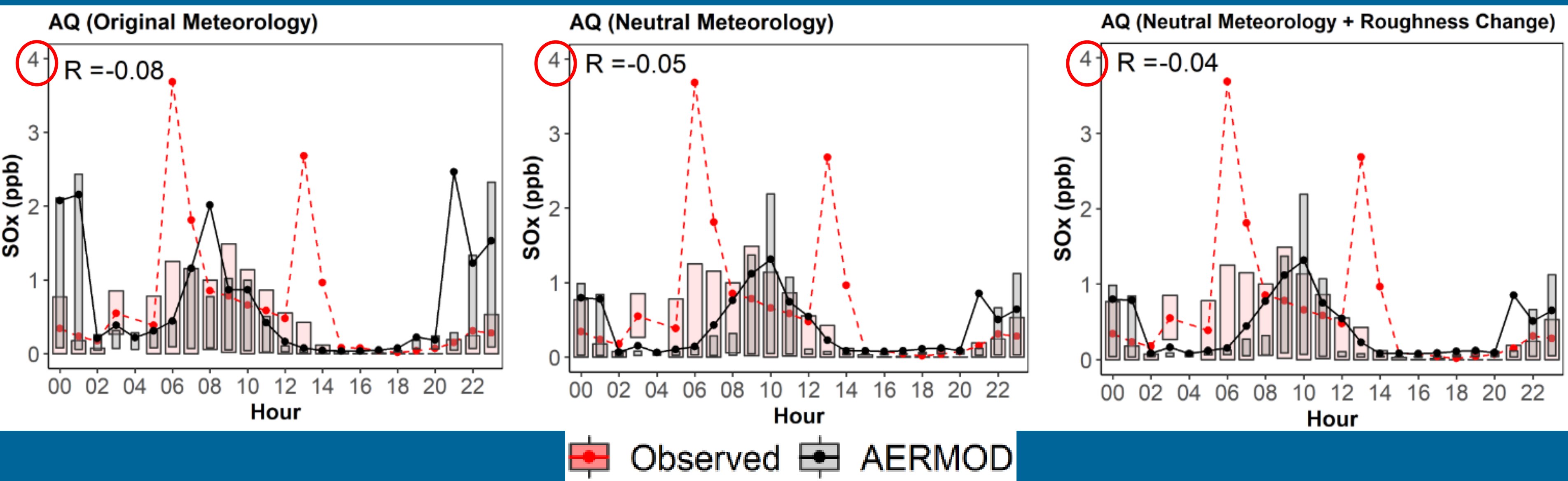
2. Roughness lengths (Zo) altered when the winds blew from the northeast quadrant to reflect flow passing over Los Angeles urban core with tall buildings

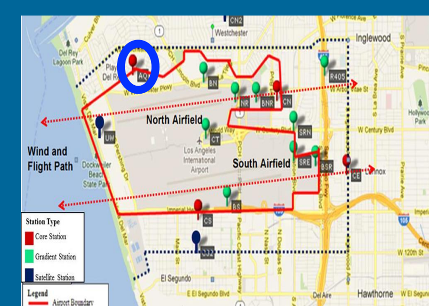
00-05 Hours 06-11 Hours





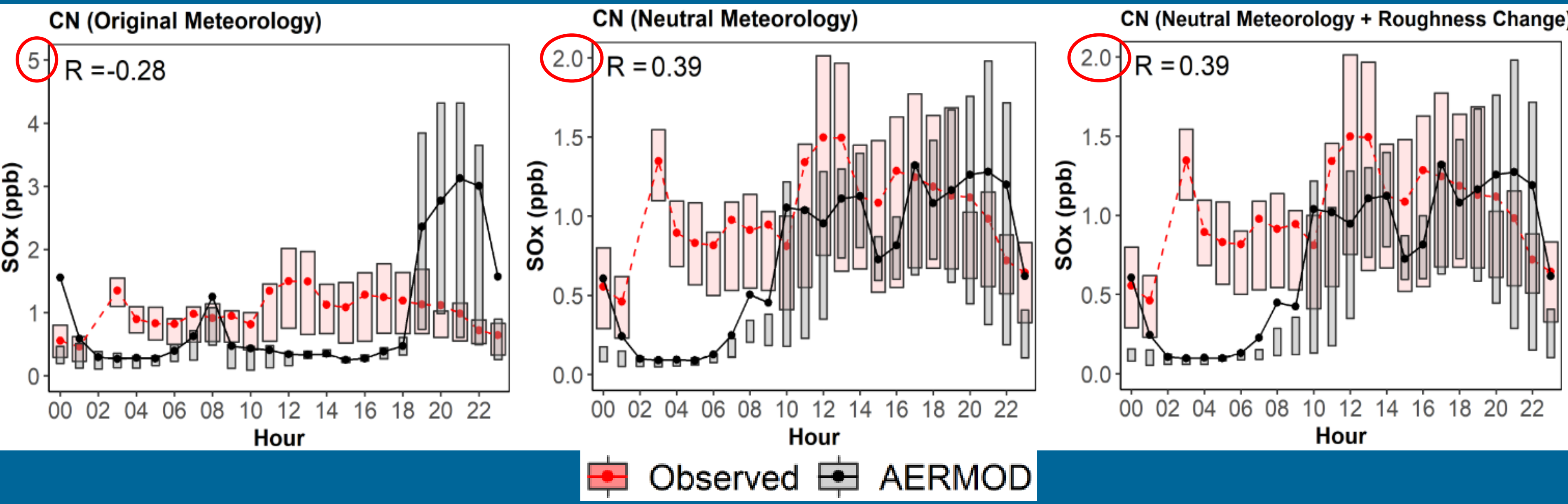
Diurnal Variability in Observed and Modeled SOx Concentrations at site AQ



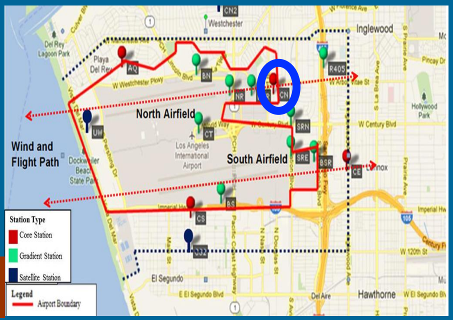


AQ was affected by some other background sources too

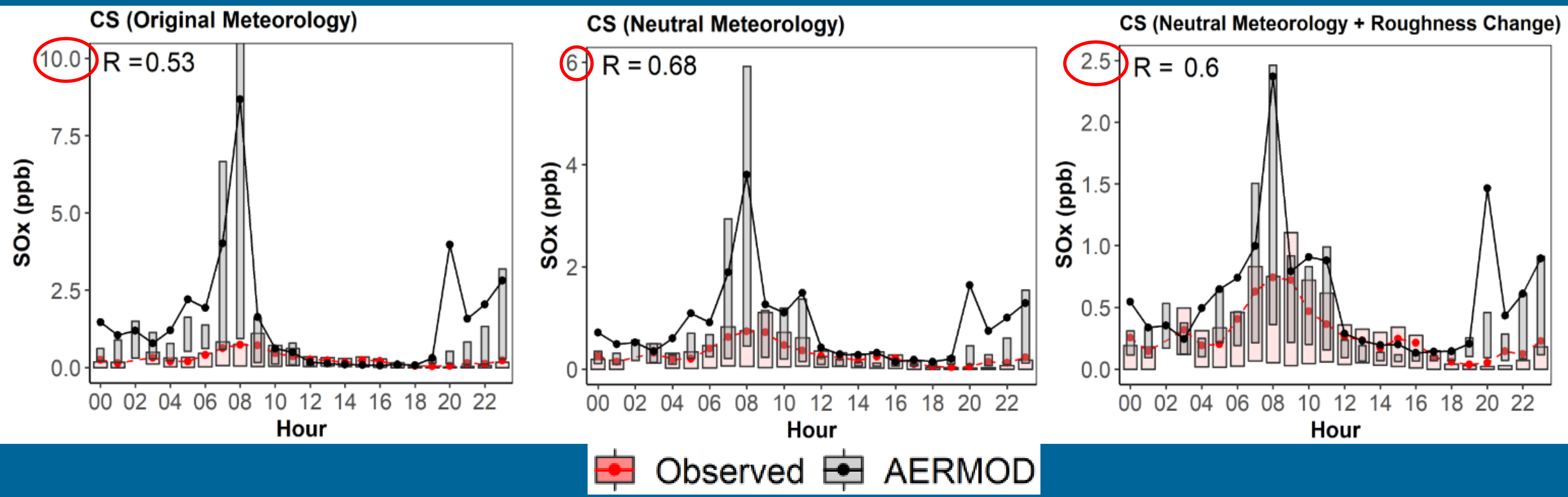
Diurnal Variability in Observed and Modeled SOx Concentrations at site CN

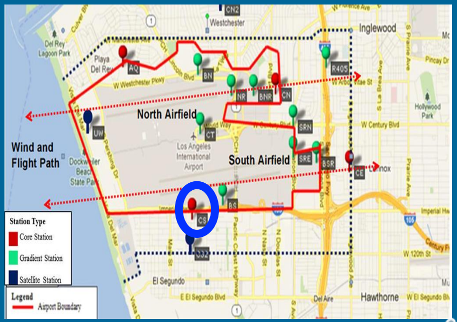


CN was downwind of North runway during consistent westerly winds from about 11 AM to 11 PM.



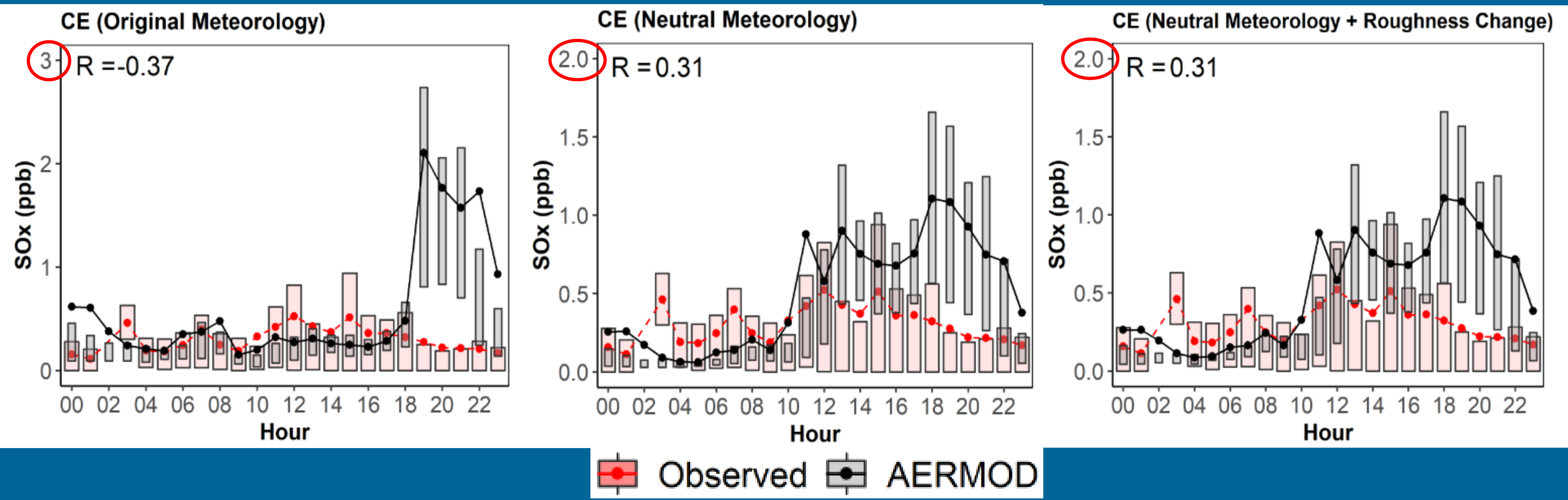
Diurnal Variability in Observed and Modeled SOx Concentrations at site CS



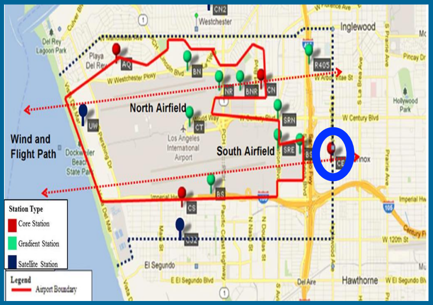


The winds were typically from the Northeast in the early morning.

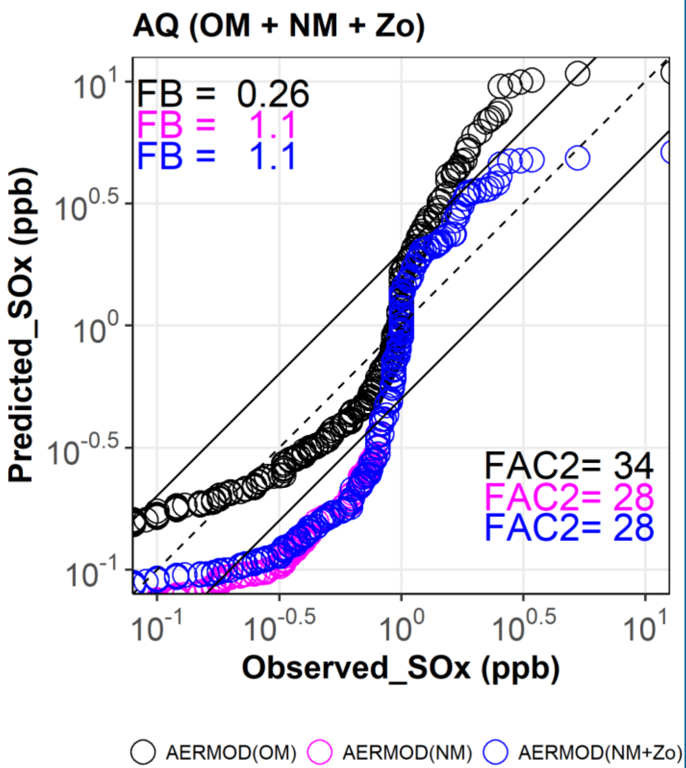
Diurnal Variability in Observed and Modeled SOx Concentrations at site CE



CE was downwind of South runway during consistent westerly winds from about 11 AM to 11 PM.



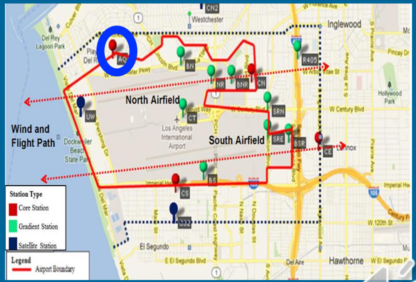
Quantile-Quantile Distribution of Modeled SOx Concentrations at site AQ



OM – Original Meteorology
NM – Neutral Meteorology
Zo – Surface Roughness Change

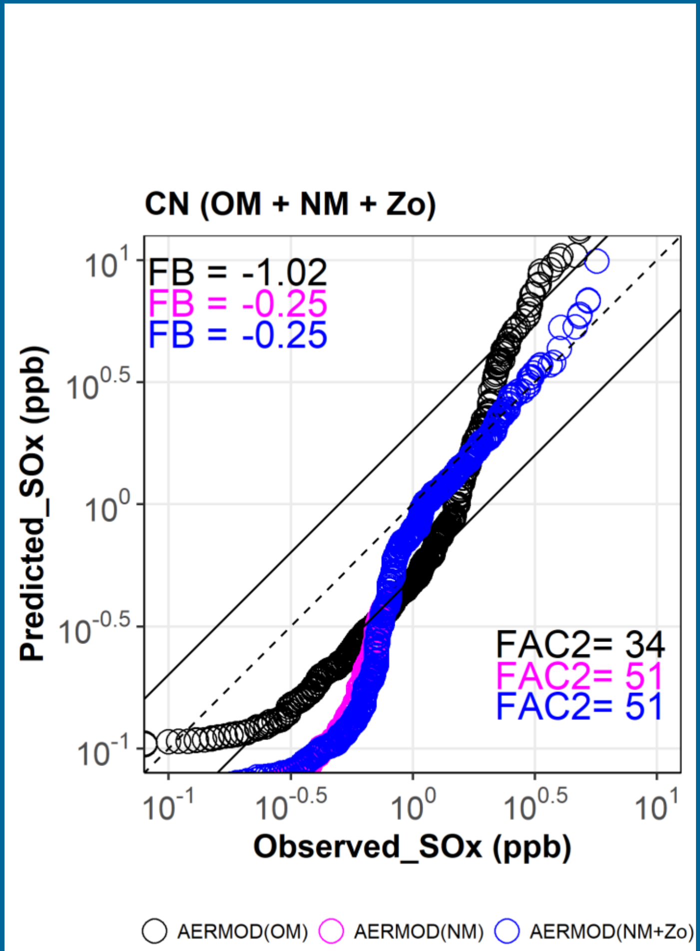
$$FB = 2.\left(\frac{RHC\_O - RHC\_M}{RHC\_O + RHC\_M}\right)$$

FB = Fractional Bias
FAC2 = Fraction of predictions within 2x of observations



Note: FB is based on Robust Highest Concentrations (Cox and Tikvart, 1990). *Ideal Values*: FB = 0, FAC2 = 100%

Quantile-Quantile Distribution of Modeled SOx Concentrations at site CN



OM – Original Meteorology

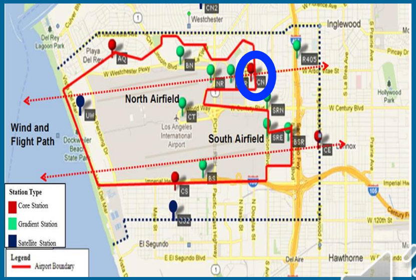
NM – Neutral Meteorology

Zo – Surface Roughness Change

$$FB = 2.\left(\frac{RHC\_O - RHC\_M}{RHC\_O + RHC\_M}\right)$$

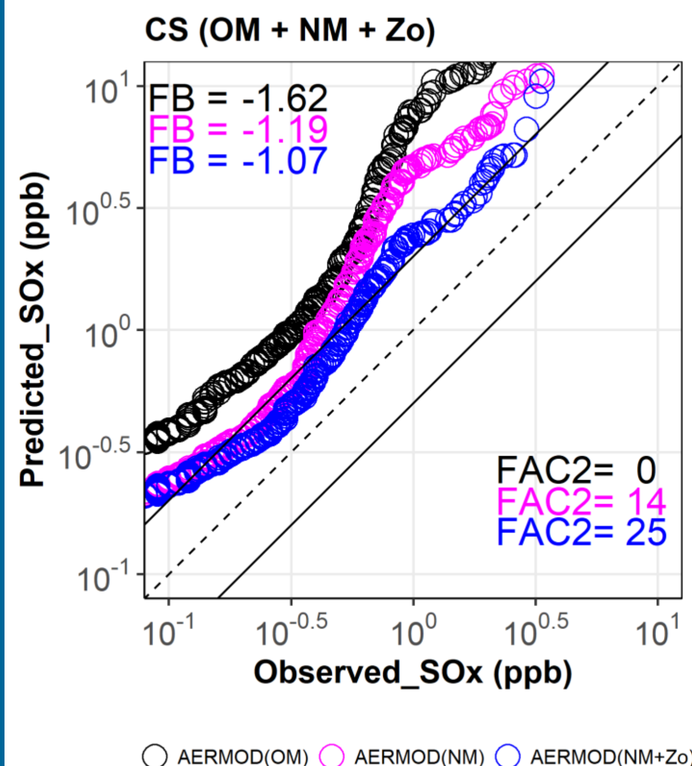
FB = Fractional Bias

FAC2 = Fraction of predictions within 2x of observations



Note: FB is based on Robust Highest Concentrations (Cox and Tikvart, 1990). *Ideal Values*: FB = 0, FAC2 = 100%

Quantile-Quantile Distribution of Modeled SOx Concentrations at site CS



OM – Original Meteorology

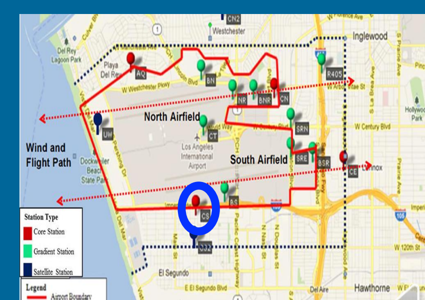
NM – Neutral Meteorology

Zo – Surface Roughness Change

$$FB = 2.\left(\frac{RHC\_O - RHC\_M}{RHC\_O + RHC\_M}\right)$$

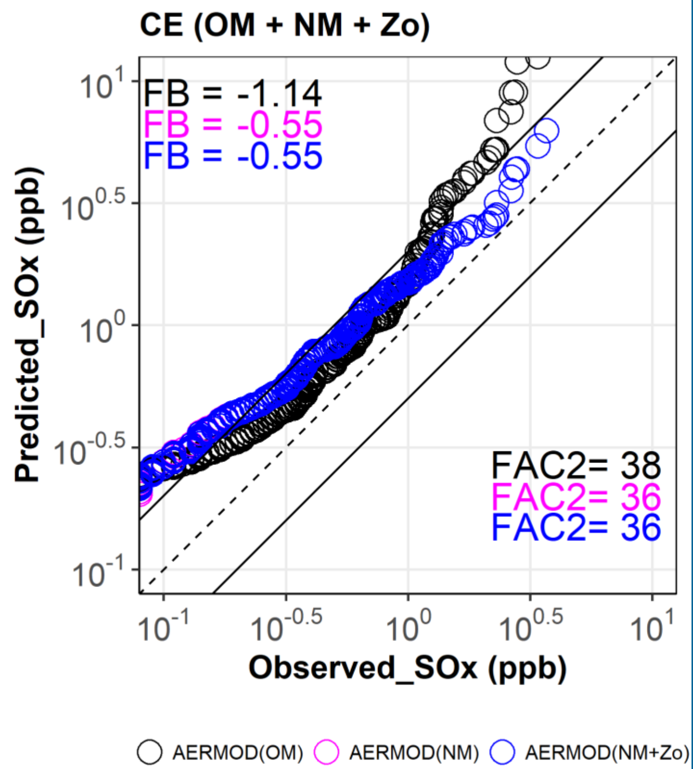
FB = Fractional Bias

FAC2 = Fraction of predictions within 2x of observations



Note: FB is based on Robust Highest Concentrations (Cox and Tikvart, 1990). *Ideal Values*: FB = 0, FAC2 = 100%

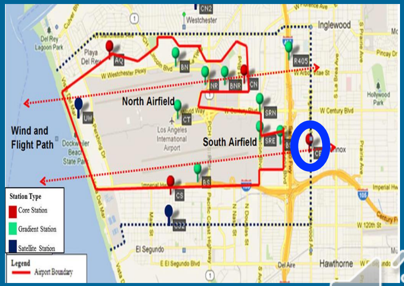
Quantile-Quantile Distribution of Modeled SOx Concentrations at site CE



OM – Original Meteorology
NM – Neutral Meteorology
Zo – Surface Roughness Change

$$FB = 2.\left(\frac{RHC\_O - RHC\_M}{RHC\_O + RHC\_M}\right)$$

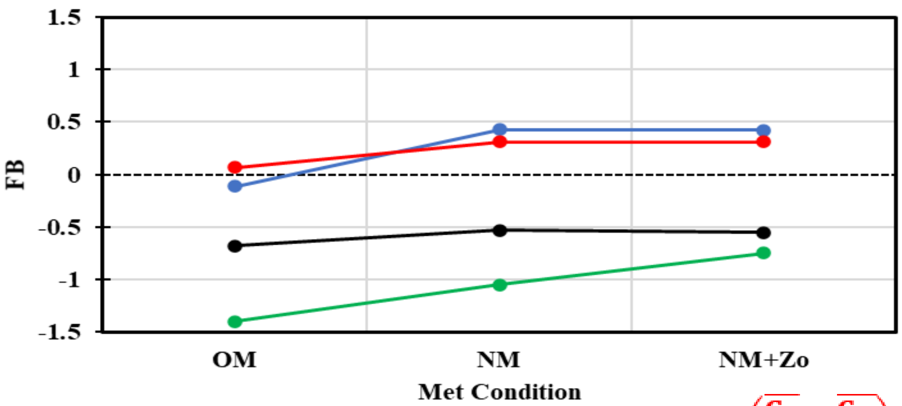
FB = Fractional Bias
FAC2 = Fraction of predictions within 2x of observations



Note: FB is based on Robust Highest Concentrations (Cox and Tikvart, 1990). *Ideal Values*: FB = 0, FAC2 = 100%

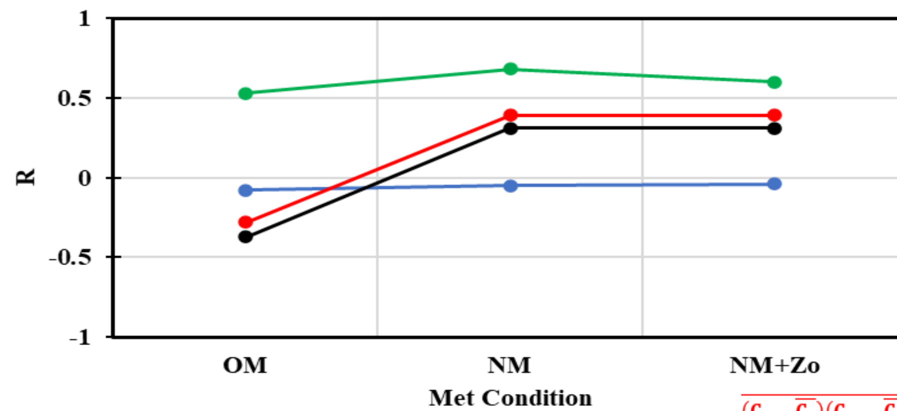
Quantitative Analysis of AERMOD Model Predictions (Monthly Averaged Diurnal Profiles)

Fractional Bias (FB)



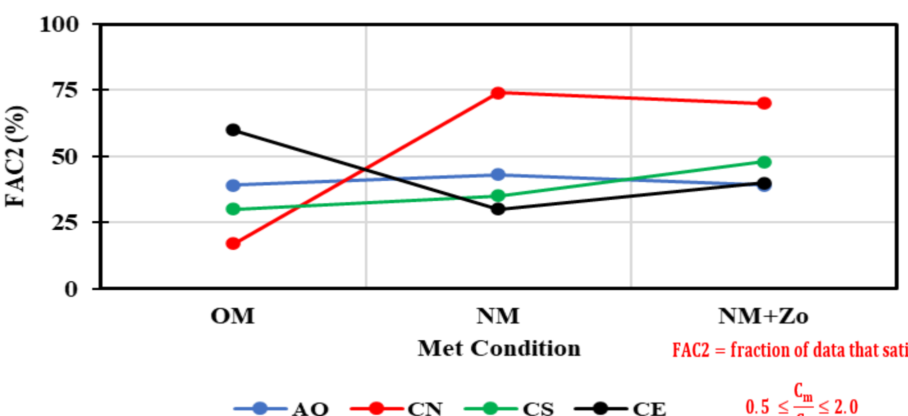
$$FB = 2\left(\frac{\overline{C_o} - \overline{C_m}}{\overline{C_o} + \overline{C_m}}\right)$$

Correlation Coefficient (R)



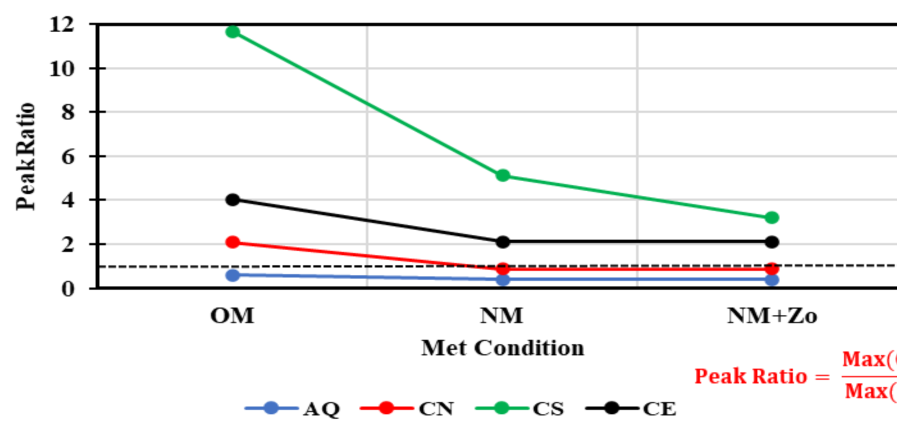
$$R = \frac{\overline{(C_o - \overline{C_o})(C_m - \overline{C_m})}}{\sigma_{C_o}\sigma_{C_m}}$$

Factor of two (FAC2)



FAC2 = fraction of data that satisfy $0.5 \le \frac{C_m}{C_o} \le 2.0$

Peak Ratio (Model/Observed)



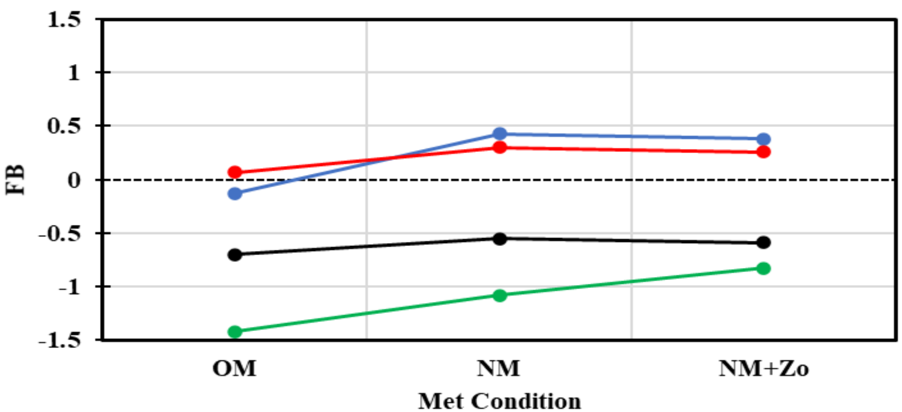
$$\text{Peak Ratio} = \frac{Max(C_m)}{Max(C_o)}$$

OM – Original Meteorology, NM – Neutral Meteorology, NM + Zo – Neutral Meteorology + Surface Roughness Change

Ideal Values: **FB = 0; R = 1; FAC2 = 100%; Peak Ratio = 1**

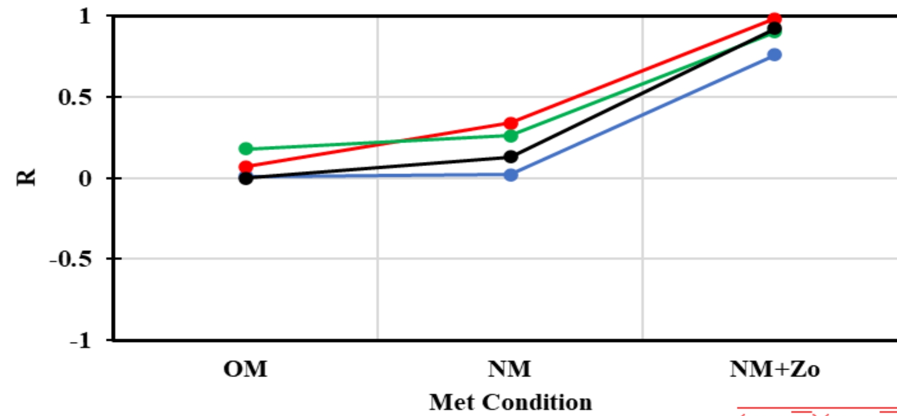
Quantitative Analysis of AERMOD Model Predictions (Overall Distribution)

Fractional Bias (FB)



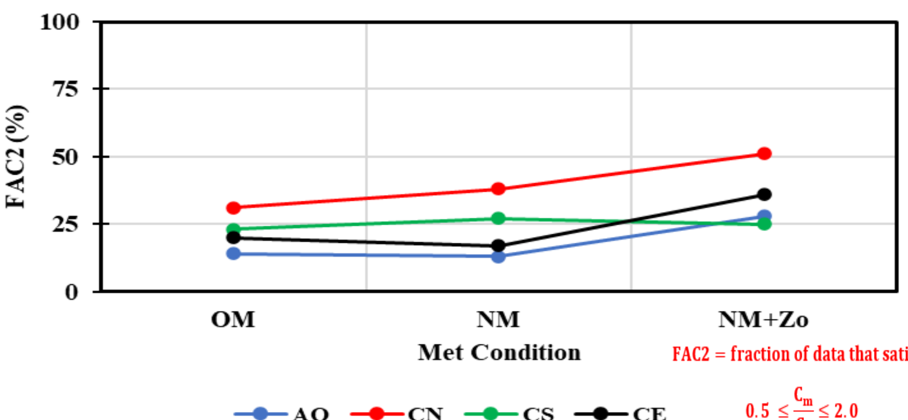
$$FB = 2\left(\frac{\overline{C_O} - \overline{C_m}}{\overline{C_O} + \overline{C_m}}\right)$$

Correlation Coefficient (R)



$$R = \frac{\overline{(C_o - \overline{C_o})(C_m - \overline{C_m})}}{\sigma_{C_o}\sigma_{C_m}}$$

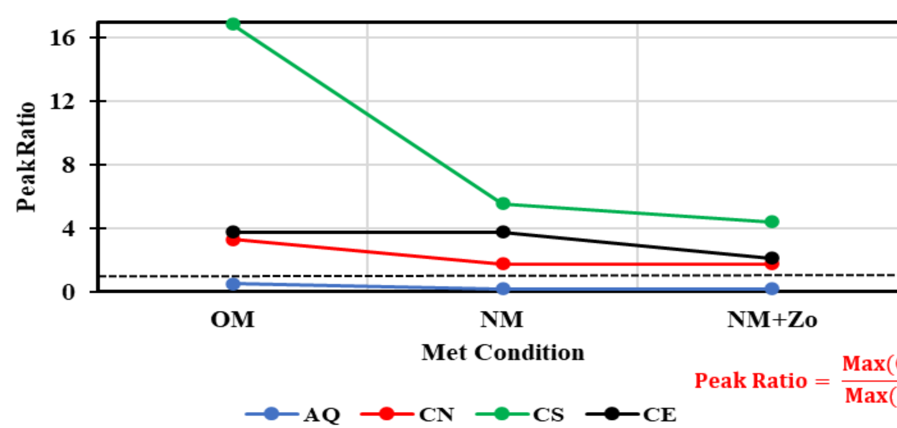
Factor of two (FAC2)



FAC2 = fraction of data that satisfy

$$0.5 \le \frac{C_m}{C_o} \le 2.0$$

Peak Ratio (Model/Observed)



$$\text{Peak Ratio} = \frac{Max(C_m)}{Max(C_o)}$$

OM – Original Meteorology, NM – Neutral Meteorology, NM + Zo – Neutral Meteorology + Surface Roughness Change

Ideal Values: FB = 0; R = 1; FAC2 = 100%; Peak Ratio = 1

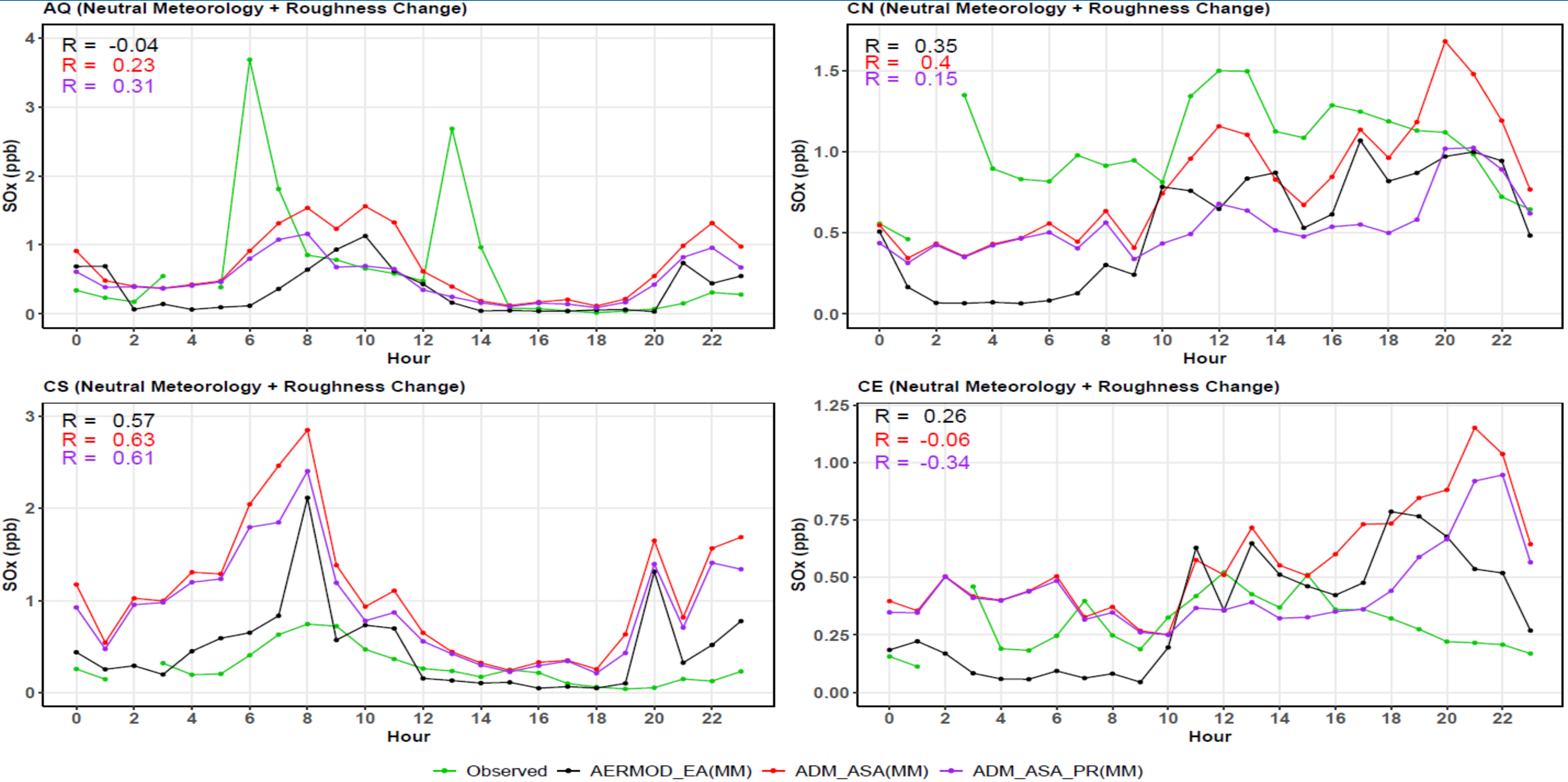
Conclusions

- Current AERMET files have been derived assuming there is no ocean (land-sea effects)
- Meteorology matters!*
- Meteorology is not only factor, there are some other factors such as
  - Source representation: area vs. volume vs. line
  - Lack of plume rise for hot buoyant plumes
  - Limited treatment of chemistry, etc.
- These issues are being addressed in our new Airport Dispersion Model being developed*

  See preliminary results next*

Some Preliminary Results of New Airport Dispersion Model

Diurnal Variability in Observed and Modeled SOx Concentrations



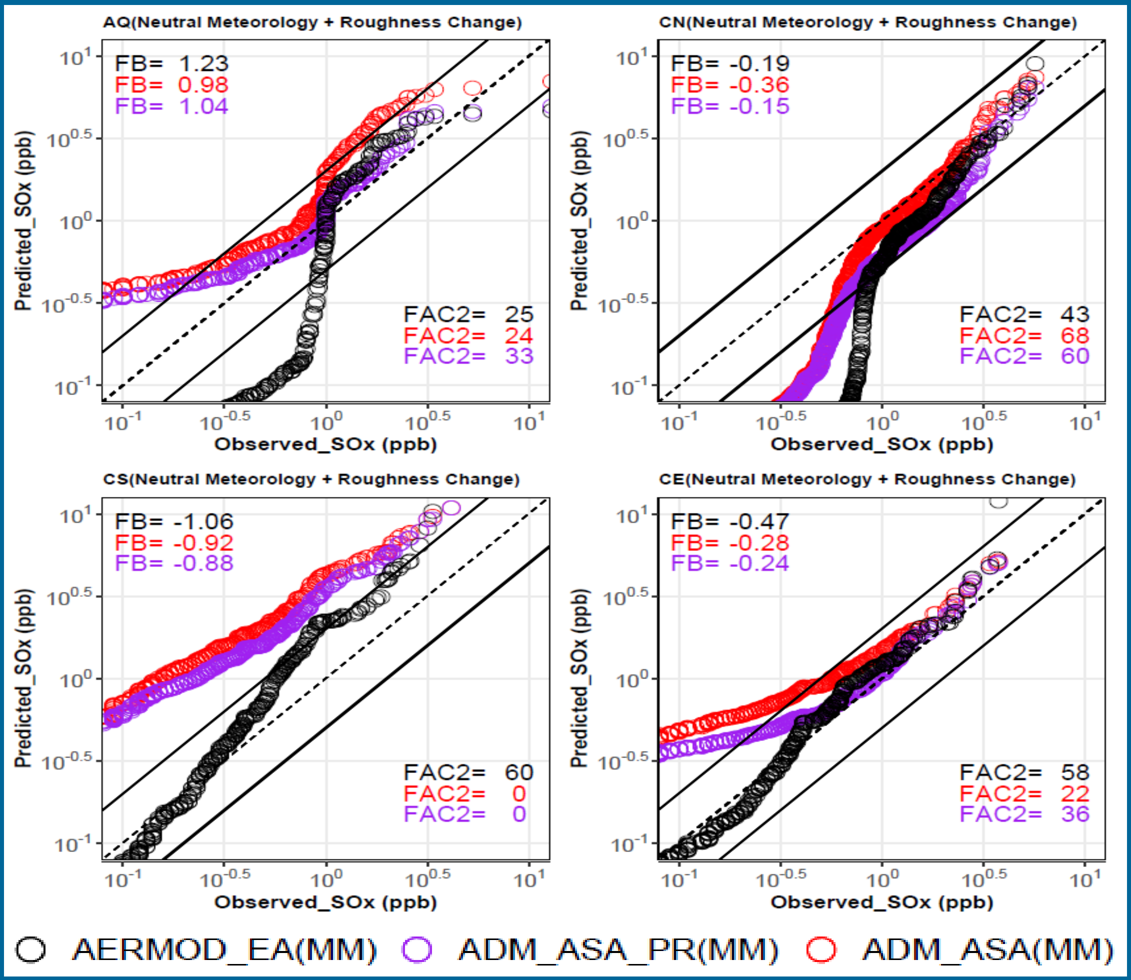
EA – EDMS AREA
ASA – AEDT SEGMENT AREA

ADM – Airport Dispersion Model
MM – MODIFIED MET
PR – PLUME RISE

Plume rise is important

Note: Aircraft Sources plus Chevron refinery modeled.

Some Preliminary Results of New Airport Dispersion Model
Q-Q Distribution of Modeled SOx Concentrations



EA – EDMS AREA
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- Opinions, findings, conclusions and recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of ASCENT sponsor organizations.

References

- *Arunachalam, S., A. Valencia, M. Woody, M. Snyder, J. Huang, J. Weil, P. Soucacos and S. Webb (2017). Dispersion Modeling Guidance for Airports Addressing Local Air Quality Concerns. Transportation Research Board Airport Cooperative Research Program (ACRP) Research Report 179, Washington, D.C. Available from: http://nap.edu/24881.*
- *Arunachalam S., Woody M., Baek B.H., Shankar U., Levy J.I. (2011) An Investigation of the Impacts of Aviation Emissions on Future Air Quality and Health. In: Steyn D., Trini Castelli S. (eds) Air Pollution Modeling and its Application XXI. NATO Science for Peace and Security Series C: Environmental Security. Springer, Dordrecht.*
- *Ashok, A., Balakrishnan, H., Barrett, S. R. H., 2017. Reducing the air quality and CO2 climate impacts of taxi and take-off operations at airports. Transportation Research Part D 54, 287-303.*
- *Barrett, S. R. H., Britter, R. E., and Waitz, I. A., 2013. Impact of aircraft plume dynamics on airport local air quality. Atmospheric Environment, 74, 247–258.*
- *Cox, W.M., Tikvart, J.A., 1990. A statistical procedure for determining the best performing air quality simulation model. Atmos. Environ. Part A. Gen. Top. 24, 2387–2395*
- *Levy, J.I., Woody, M., Baek, B.H., Shankar, U., Arunachalam, S., 2012. Current and future particulate-matter-related mortality risks in the United States from aviation emissions during landing and takeoff. Risk Anal. 32 (2), 237-249.*
- *Penn, S. L., Arunachalam, S., Tripodis, Y., Heiger-Bernays, W., Levy, J. I., 2015. A comparison between monitoring and dispersion modelling approaches to assess the impact of aviation on concentrations of black carbon and nitrogen oxides at Los Angeles International Airport. Science of the Total Environment 527-528, 47-55.*
- *Stettler, M., Eastham, S., Barrett, S., 2011. Air quality and public health impacts of UK airports. Part I Emiss. Atmos. Environ. 45 (31), 5415-5424.*
- *Woody, M., Baek, B.H., Adelman, Z., Omary, M., Lam, Y.F., West, J.J., Arunachalam, S., 2011. An assessment of aviations contribution to current and future fine particulate matter in the United States. Atmos. Environ. 45 (20), 3424-3433.*
- *Woody, M.,West, J., Jathar, S., Robinson, A., Arunachalam, S., 2015. Estimates of nontraditional secondary organic aerosols from aircraft SVOC and IVOC emissions using CMAQ. Atmos. Chem. Phys. 15 (12), 6929-6942.*