20th Annual

CMAS Conference

November 01-05, 2021

Modeling Aircraft Sources at sub-hourly time scales in AERMOD

Gavendra Pandey[1], Chowdhury Moniruzzaman[1], Saravanan Arunachalam[1]
and
Akula Venkatram[2]

[1]Institute for the Environment, University of North Carolina at Chapel Hill
[2]University of California at Riverside

Aircraft Dispersion Modelling (Background)

- Aircraft emissions from an airport are a significant source of total emissions that have an impact on air quality in the airport vicinity (*Arunachalam et al, 2011*).

- Aircraft activities at airports produce 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*).

- Aircraft sources are unique due to the transient nature of the emissions from each source, as well as the buoyant exhaust.

- These sources emit the pollutants in short bursts especially during landing and takeoff operations (LTO) and it is difficult to quantify these short bursts of emissions and model the governing processes.

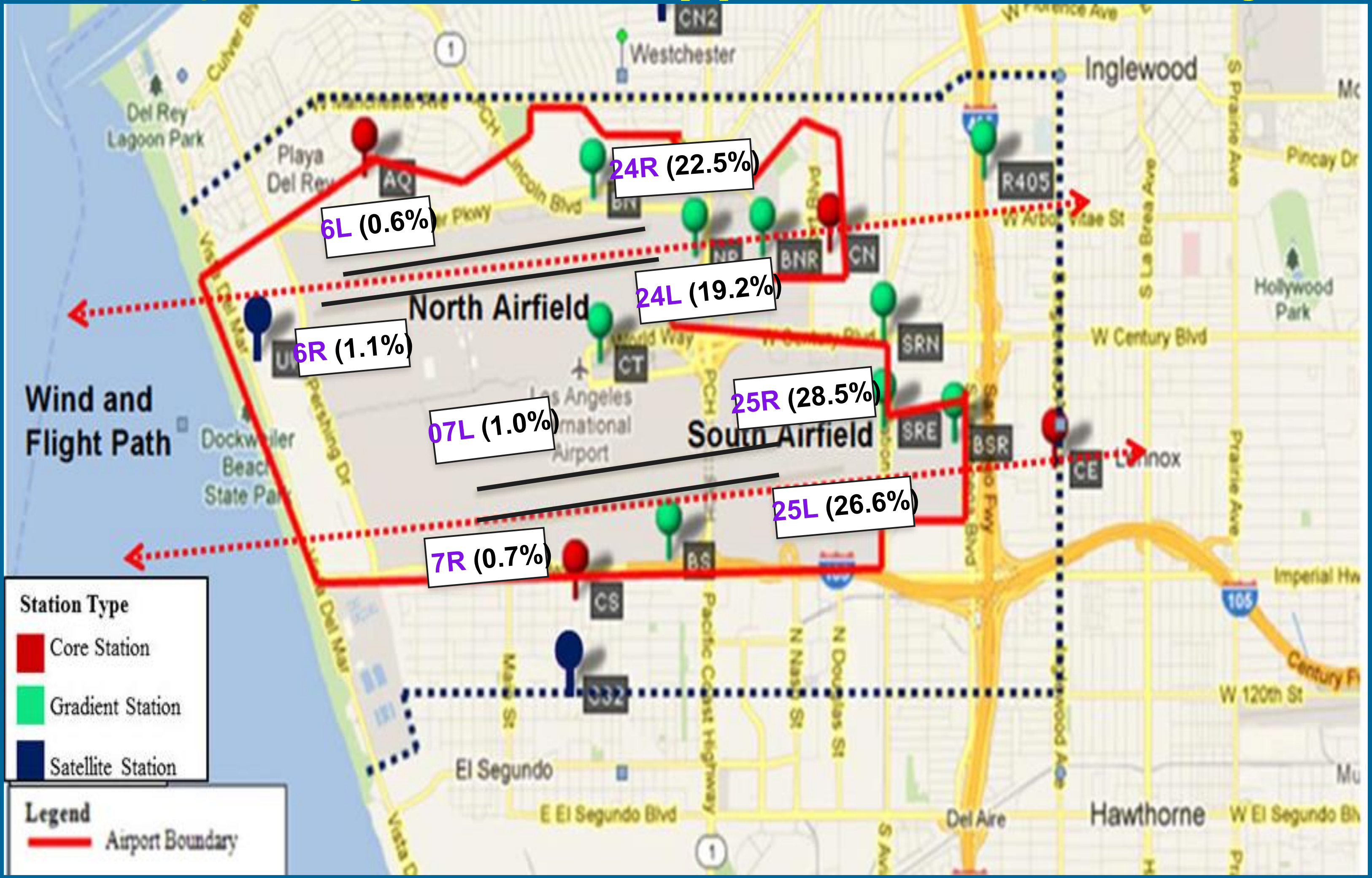
- Added complexity occur when
  - wind speed is low and variable
  - and when the airport is situated near a shoreline where meteorological conditions are far from being spatially uniform.

Modeling Aircraft Sources at sub-hourly time scales in AERMOD

- Motivation
  - Airports need dispersion modeling system that incorporates all physical and chemical processes related to LAQ around airports
  - The horizontal dispersion shape function for stable conditions in AERMOD is formulated with parameterizations derived from the 10-min release and sampling times of the Prairie Grass experiment (*Barad, 1958*), it is appropriate to consider a minimum sub-hourly duration of 10 minutes for such model applications using AERMOD
- Known issues in AERMOD (version 21112) "related to modeling aircraft sources" *(Arunachalam et al, 2017; ACRP Report 179; etc.)*
  - Source representation: area vs. volume vs. line
  - Lack of meandering approach with AREA source
  - Limited to hourly time scale, etc.
- Objective
  - To account meandering effect and short burst features that characterize the dispersion of aircraft emissions, a sensitivity analysis based on the sub-hourly approach is being described here.

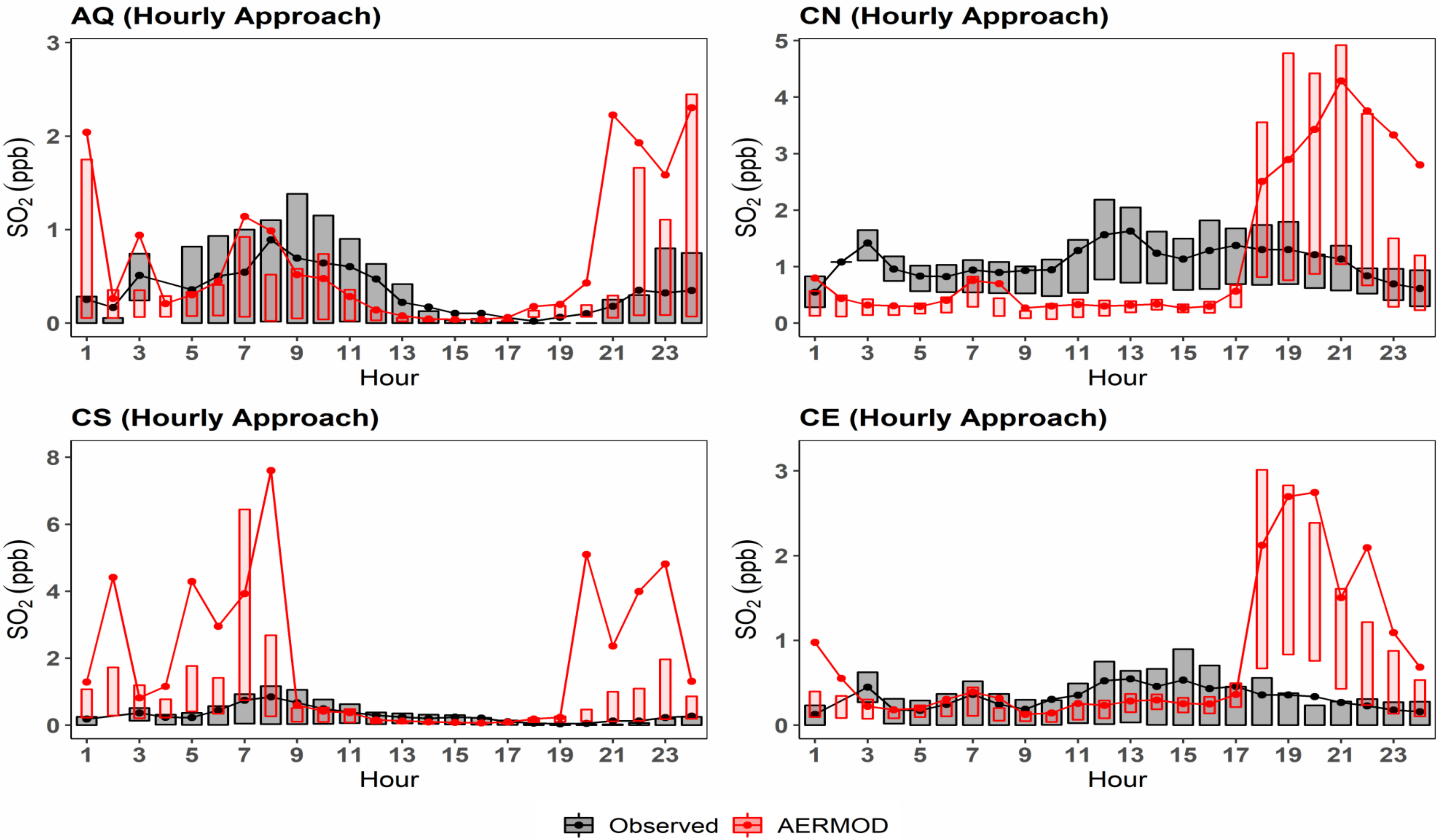
UNC INSTITUTE FOR THE ENVIRONMENT

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*)

Diurnal Variability in Observed and Modeled SO_2 Concentrations (Diel Plot for February 2012)



AERMOD overpredicts concentrations at all four core sites during evening hours

Some Reasons of poor prediction by AERMOD

- ✓ Aircraft 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.
- ✓ AERMOD does not account for the meandering effect and short bursts of aircraft emissions due to the hourly nature of inputs and outputs in typical applications.
- ✓ 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 the results from AERMET to account for the formation of the internal boundary layer formed when stable air from the ocean flows onto the warmer land surface of the airport.

Dispersion behavior in Low and Variable Wind Conditions

Coherent Plume Concentration Footprint from
Idaho Diffusion Experiment 1974

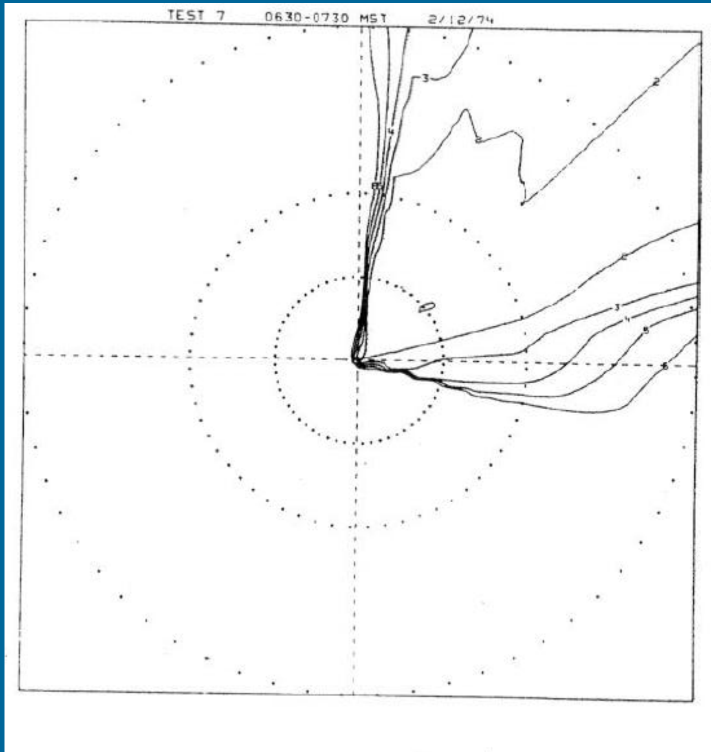


Figure 10. χU/Q (sec^{-2}) isolines. Values are designated as in figure 7.

Test - #7
Wind Speed (U) – 0.90 m/s
Sigma_theta (σ_θ) – 22.28 (degree)
Plume Spread – 96 (degree)

Fluctuating Plume Concentration Footprint from
Idaho Diffusion Experiment 1974

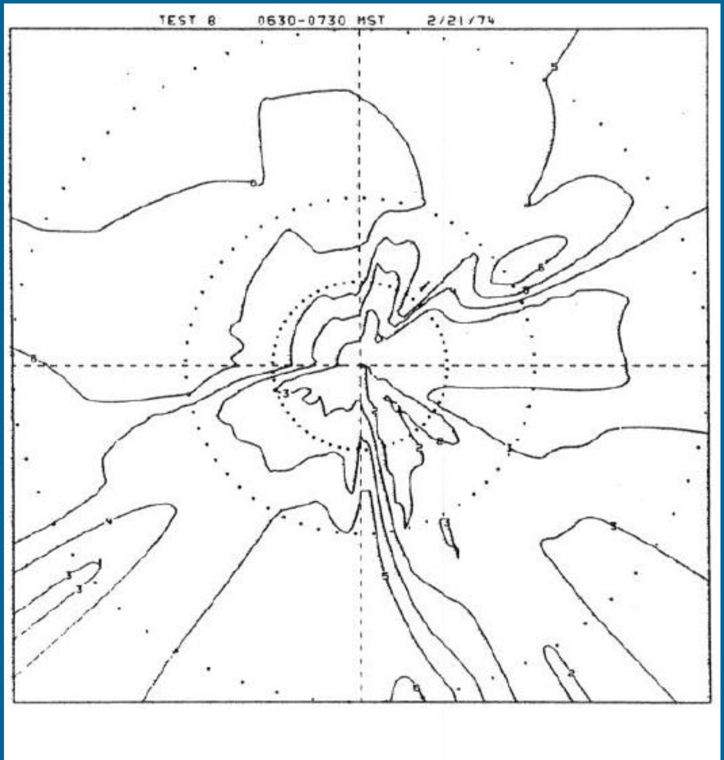


Figure 11. χU/Q (sec^{-2}) isolines. Values are designated as in figure 7.

Test - #8
Wind Speed (U) – 0.75 m/s
Sigma_theta (σ_θ) – 72.08 (degree)
Plume Spread – 360 (degree)

Reference – *Sagendorf, J. D., Dickson, C. R., 1974. Diffusion under Low-Wind Speed, Inversion Conditions, NOAA Technical Memorandum. ERL ARL-52.*

Hourly and Sub-hourly Calculations

Approach

Hourly Approach

Single Wind Field generated by AERMET for an hour

Run AERMOD (Hourly Concentration)

Sub-Hourly Approach

Divide an hour into *n* sub-intervals

Process the 1-minute ASOS wind data using AERMINUTEplus in order to obtain the *n* number of output files of each sub-interval for AERMET stage 2

Run AERMET stages 2 & 3 *n*-times (for each sub-hourly interval)

Run AERMOD using each sub-interval AERMET generated files

Convert these model values for shorter time using the formula

Average the shorter time model values over all the sub-intervals (Hourly Concentration)

The basic output from AERMOD is one-hour average concentration prediction. Further 15-minute or shorter time average predictions are calculated by post processing of the basic one-hour average predictions (*Venkatram, 2002*):

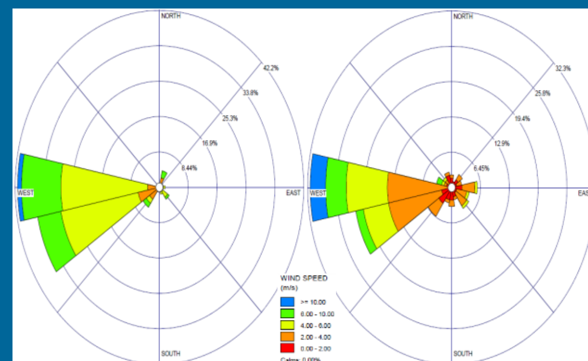
$$C_s(t) = C_s(t_0)\left(\frac{t_0}{t}\right)^{0.2}$$

where t is the short averaging time (minutes) of interest (10 minutes here), and (t_0) is the averaging time consistent with the dispersion rates (60 minutes here).

Modified Meteorological Conditions in AERMOD

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

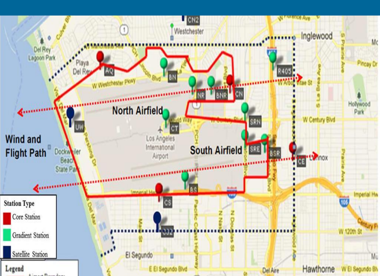
12-17 Hour 18-23 Hour



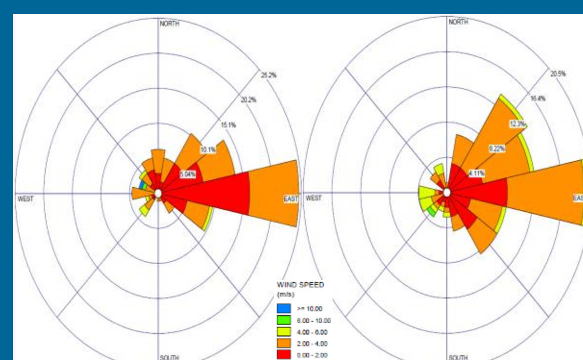
Modified Meteorology

2. Roughness lengths altered when the wind blew from the northeast quadrant to reflect flow passing over LA urban core with tall buildings

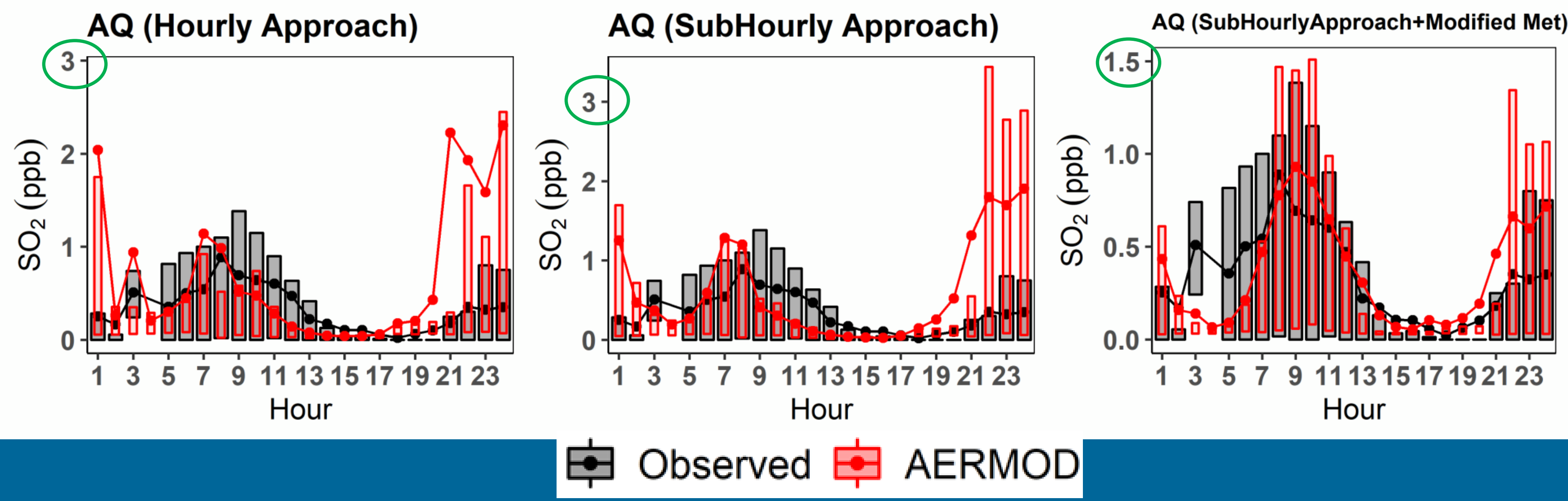
00-05 Hour 06-11 Hour

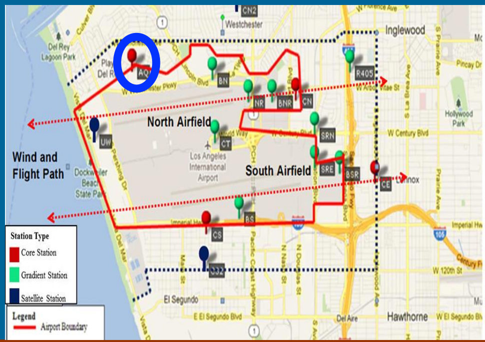


Source: Google Image



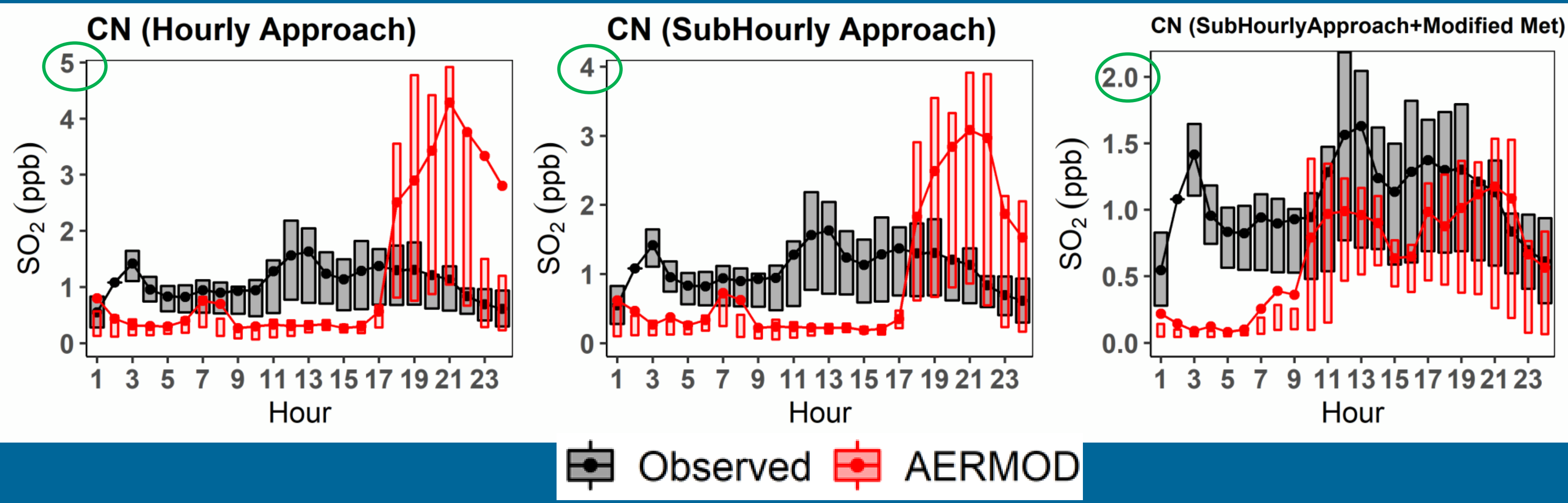
Diurnal Variability in Observed and Modeled SO_2 Concentrations at site AQ

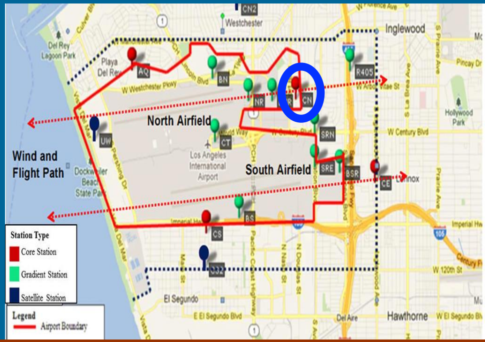




AQ was affected by some other background sources too

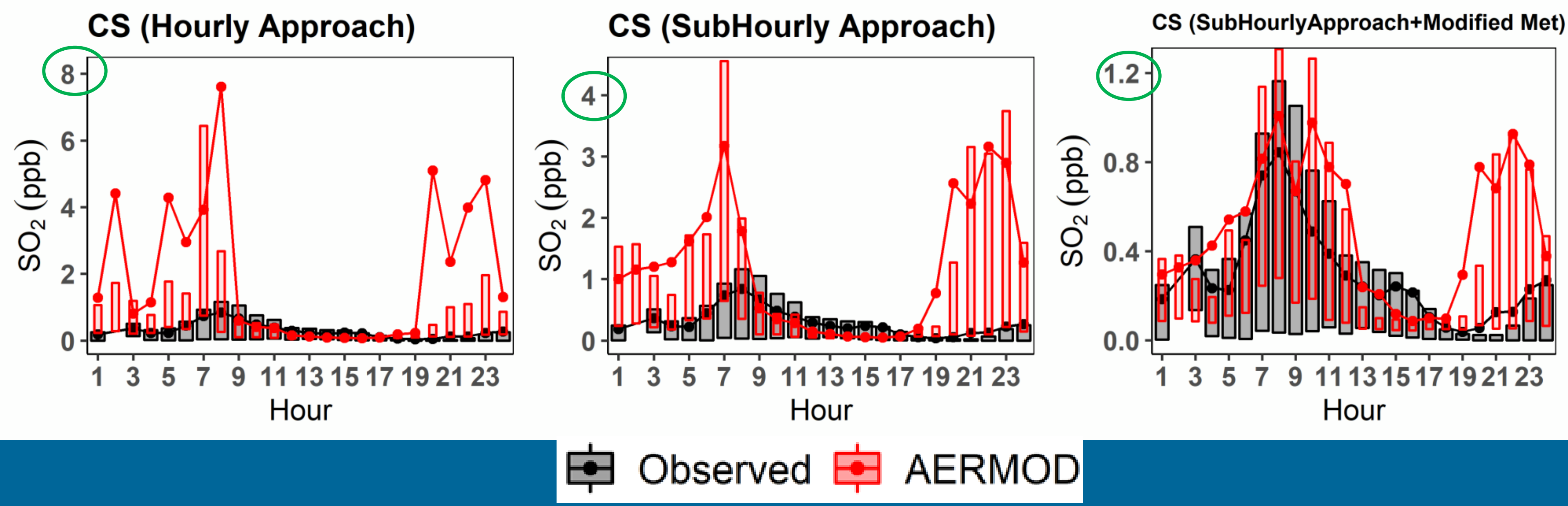
Diurnal Variability in Observed and Modeled SO_2 Concentrations at site CN

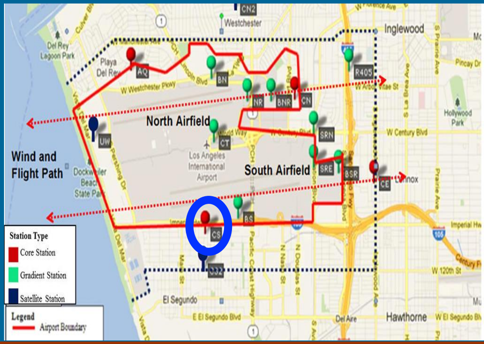




The CN site was downwind of LAX with consistent westerly winds from about 11 AM to 11 PM.

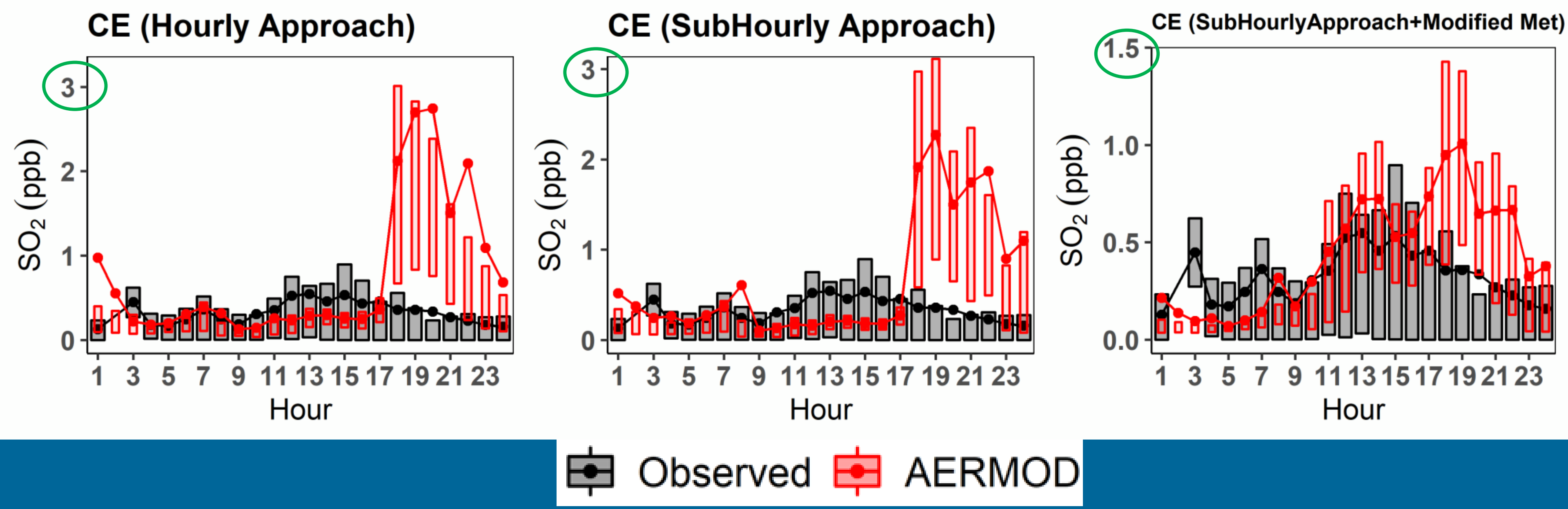
Diurnal Variability in Observed and Modeled SO_2 Concentrations at site CS

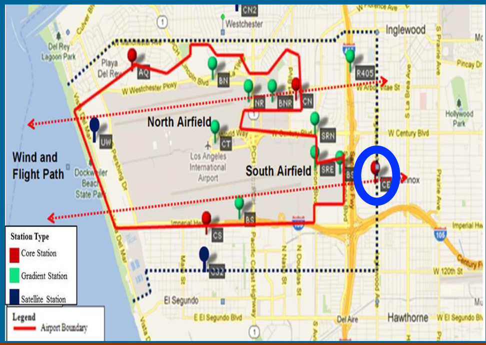




The winds were typically from the northeast in the early morning during February.

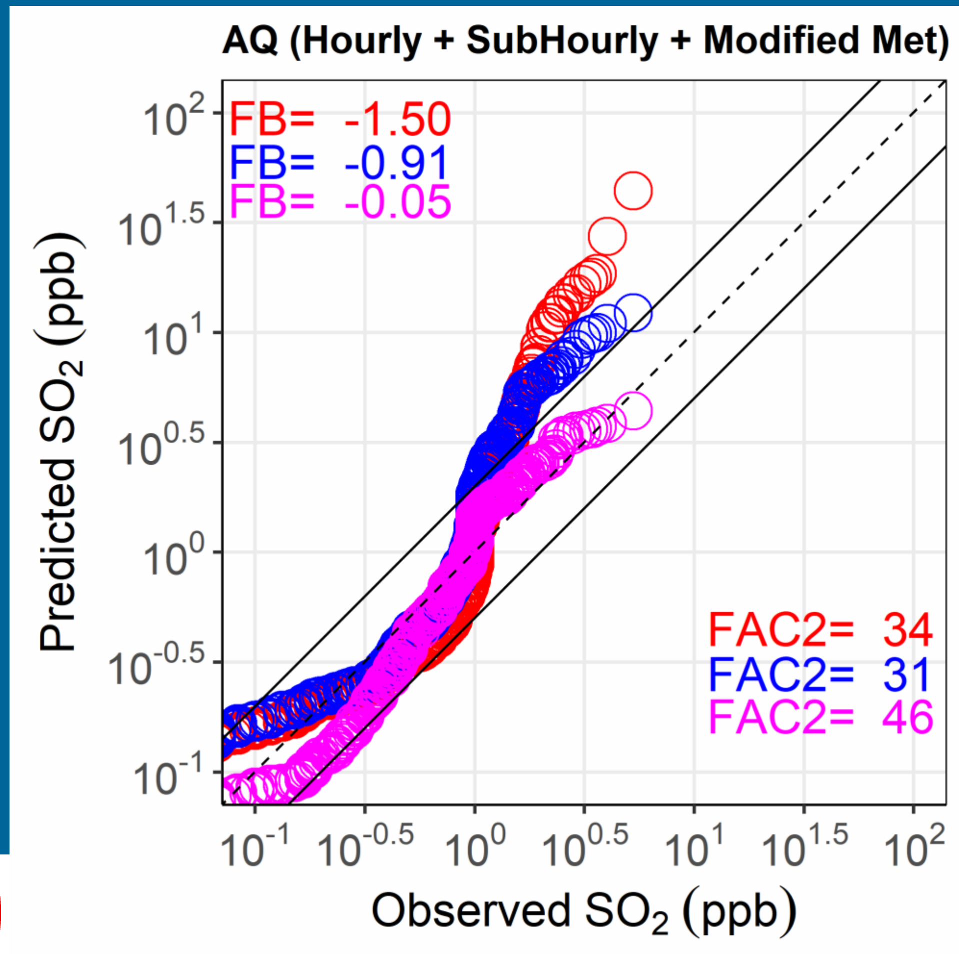
Diurnal Variability in Observed and Modeled SO_2 Concentrations at site CE

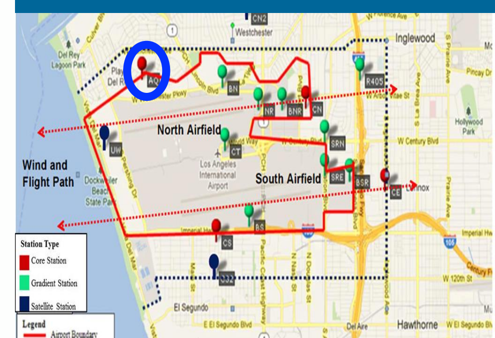




The CE site was downwind of LAX with consistent westerly winds from about 11 AM to 11 PM.

Quantile-Quantile Distribution of Modeled SO_2 Concentrations at site AQ



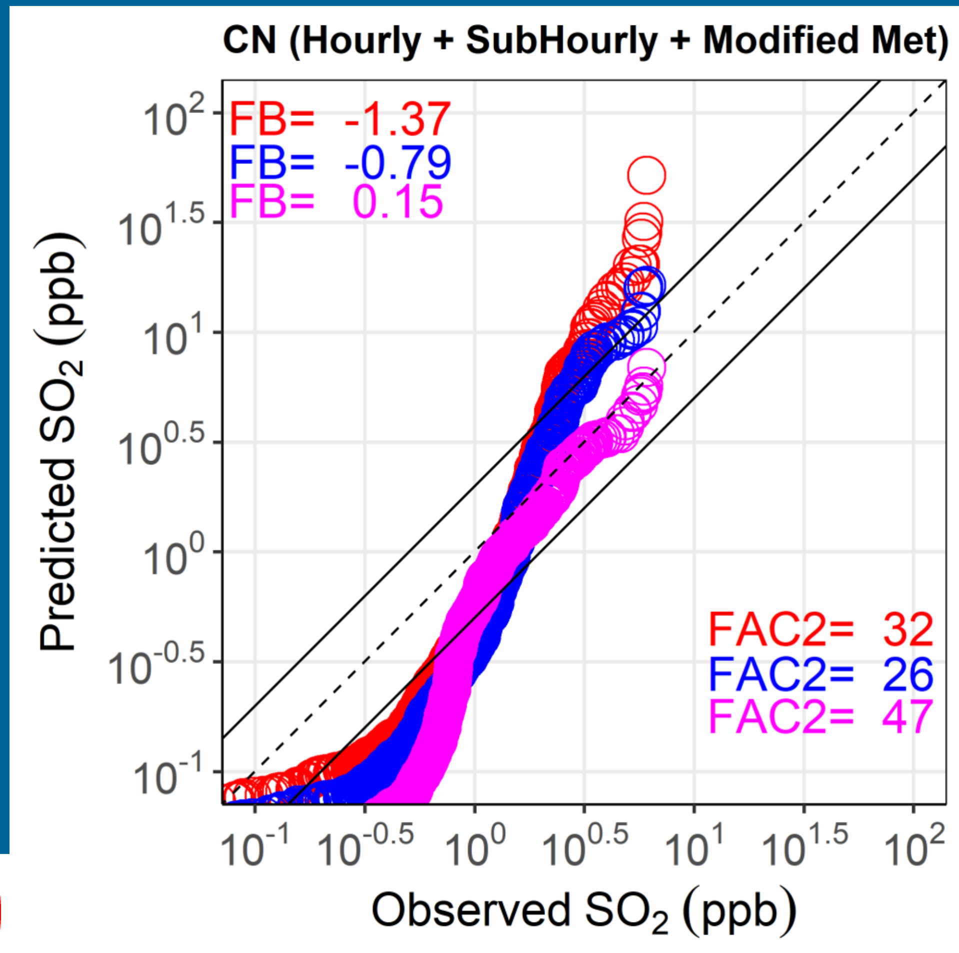


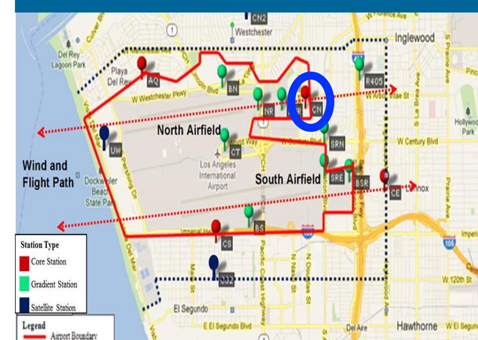
$$FB = 2 \times \left(\frac{RHC\_O - RHC\_M}{RHC\_O + RHC\_M}\right)$$

Note- The FB is based on Robust Highest Concentrations (*Cox and Tikvart, 1990*).

Ideal Values:- FB = 0, FAC2 = 100%.

Quantile-Quantile Distribution of Modeled SO_2 Concentrations at site CN



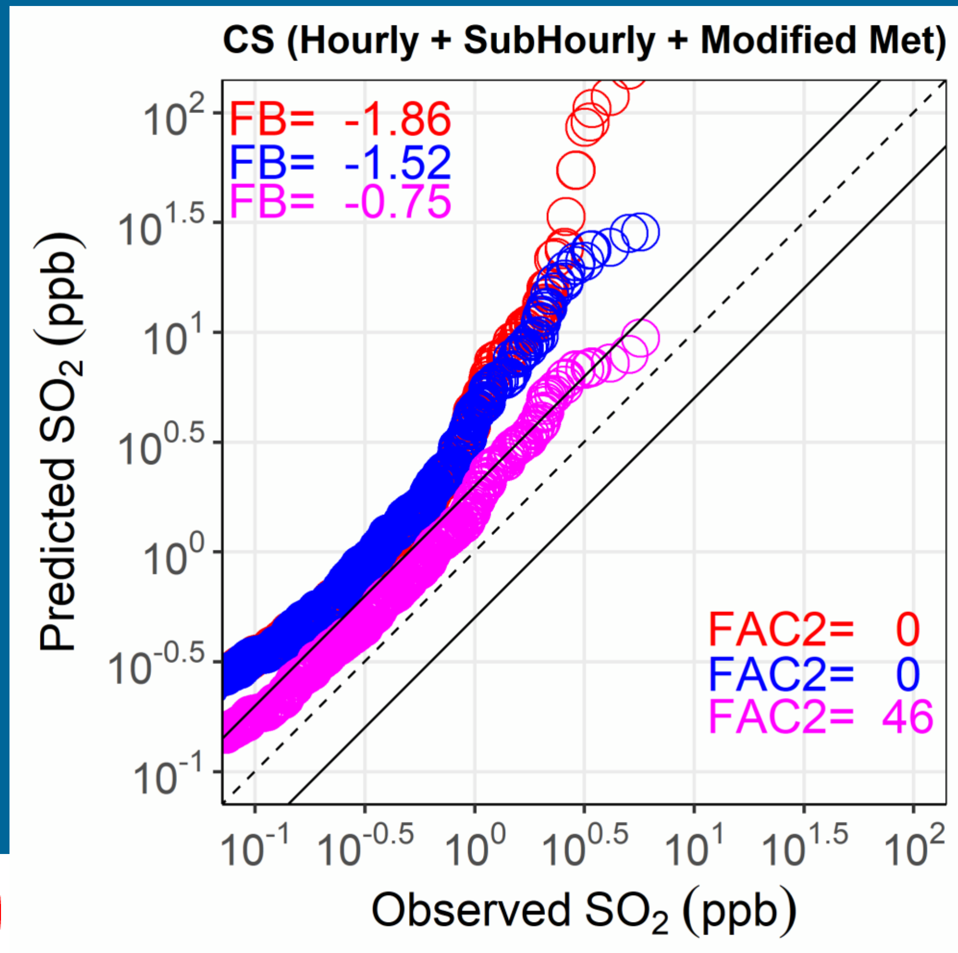


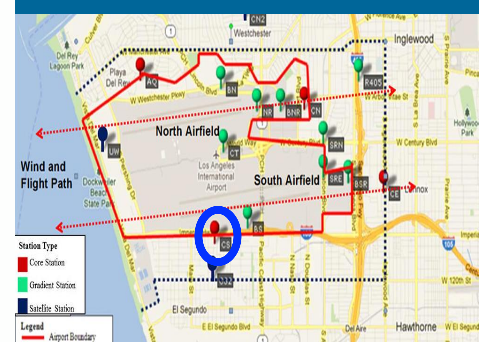
$$FB = 2 \times \left(\frac{RHC\_O - RHC\_M}{RHC\_O + RHC\_M}\right)$$

Note- The FB is based on Robust Highest Concentrations (*Cox and Tikvart, 1990*).

Ideal Values:- FB = 0, FAC2 = 100%.

Quantile-Quantile Distribution of Modeled SO_2 Concentrations at site CS



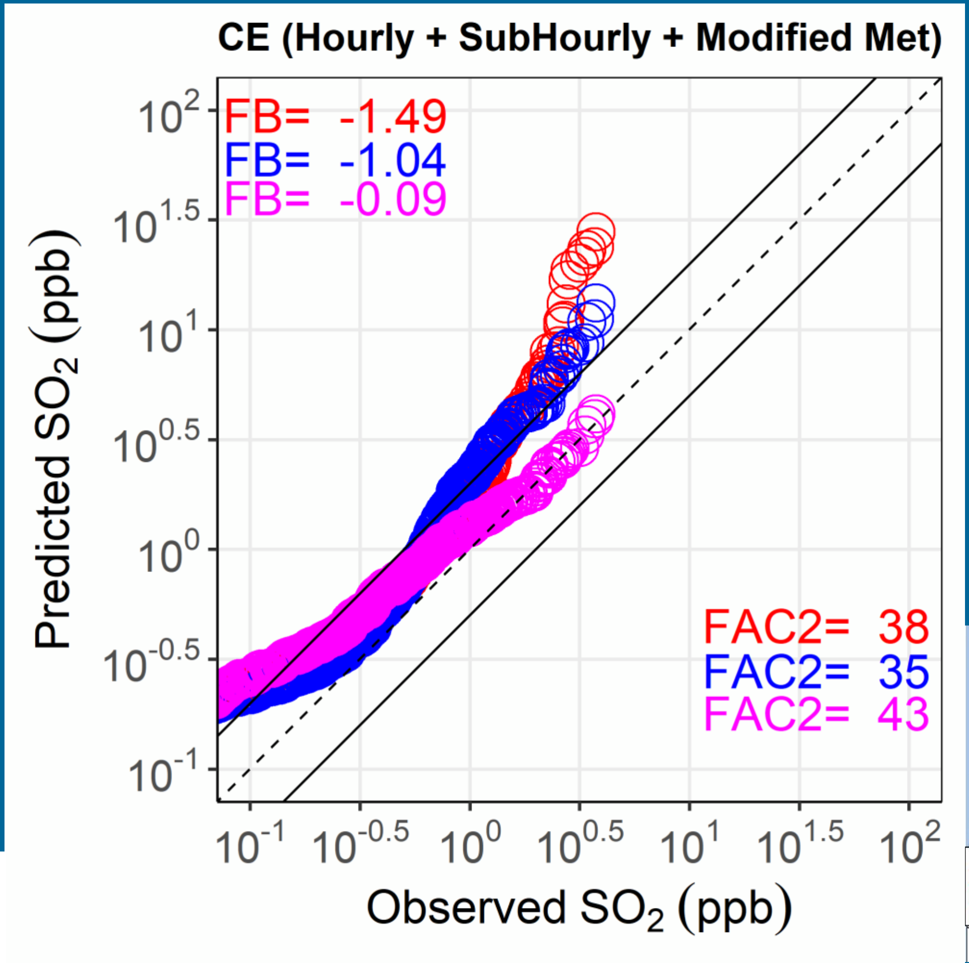


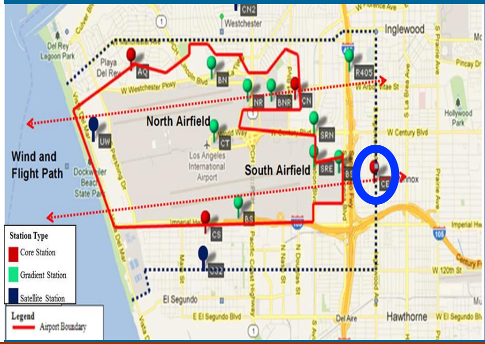
$$FB = 2 \times \left(\frac{RHC\_O - RHC\_M}{RHC\_O + RHC\_M}\right)$$

Note- The FB is based on Robust Highest Concentrations (*Cox and Tikvart, 1990*).

Ideal Values:- FB = 0, FAC2 = 100%.

Quantile-Quantile Distribution of Modeled SO_2 Concentrations at site CE





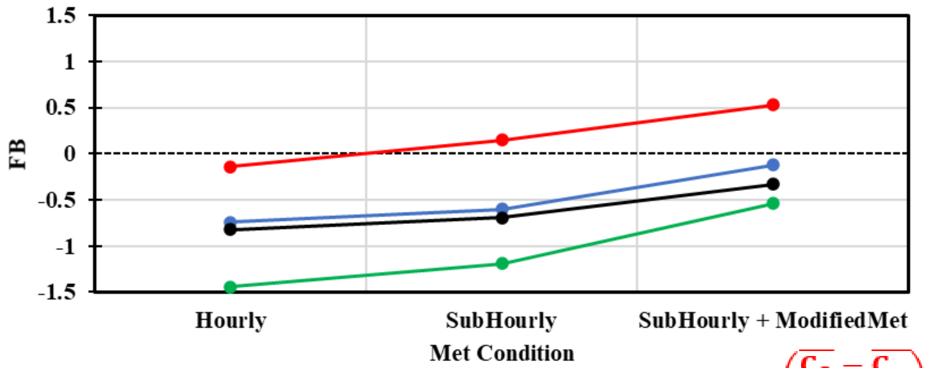
$$FB = 2 \times \left(\frac{RHC\_O - RHC\_M}{RHC\_O + RHC\_M}\right)$$

Note- The FB is based on Robust Highest Concentrations (*Cox and Tikvart, 1990*).

Ideal Values:- FB = 0, FAC2 = 100%.

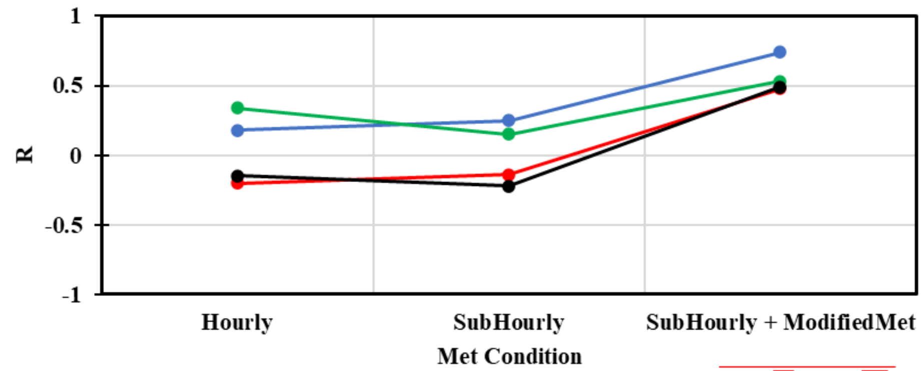
Quantitative Analysis of AERMOD Model Predictions (Monthly Averaged Diurnal Profiles)

Fractional Bias (FB)



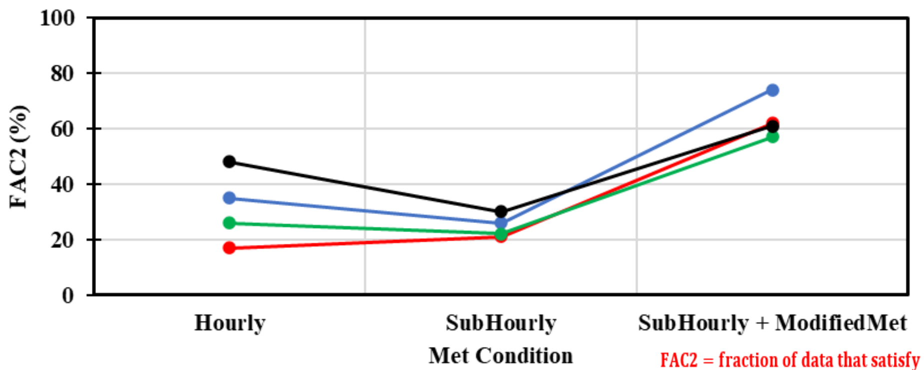
$$FB = 2\left(\frac{\overline{C_o} - \overline{C_m}}{\overline{C_o} + \overline{C_m}}\right)$$

Correlation Coefficient (R)



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

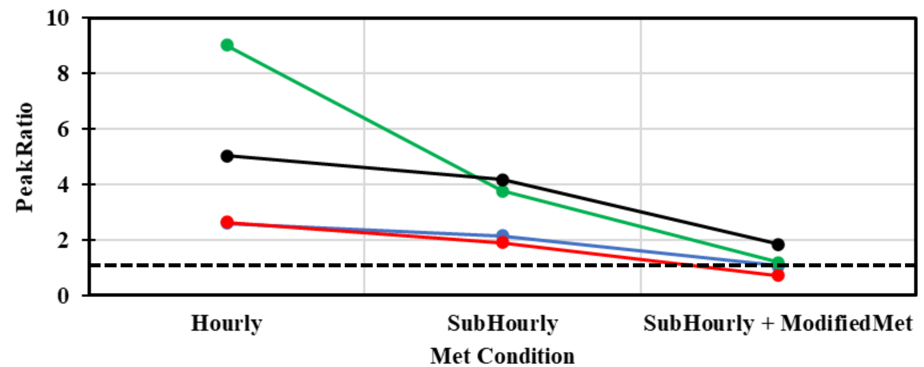
Factor of two (FAC2)



FAC2 = fraction of data that satisfy

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

Peak Ratio (Model/Observed)

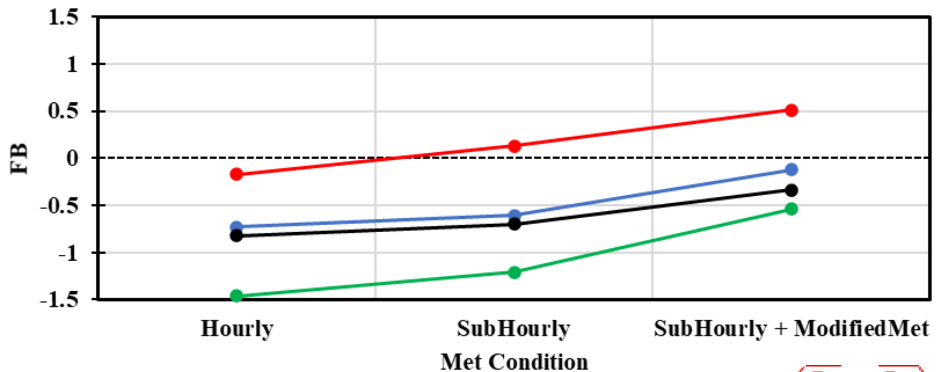


$$\text{Peak Ratio} = \frac{\text{Max}(C_m)}{\text{Max}(C_o)}$$

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

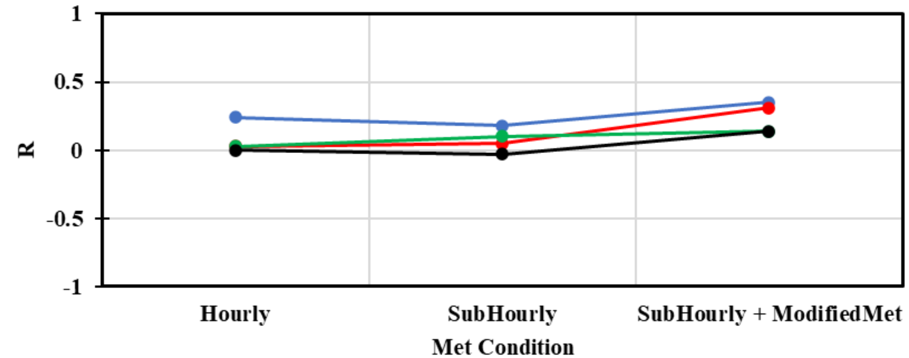
Quantitative Analysis of AERMOD Model Predictions (Overall Distribution)

Fractional Bias (FB)



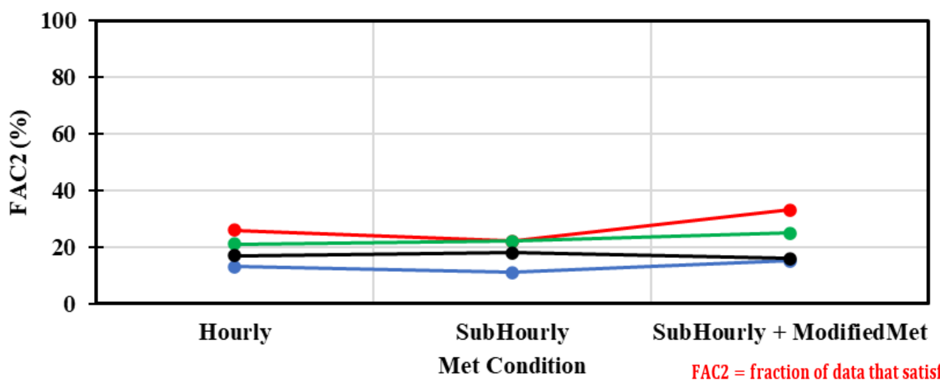
$$FB = 2\left(\frac{\overline{C_O} - \overline{C_m}}{\overline{C_O} + \overline{C_m}}\right)$$

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)

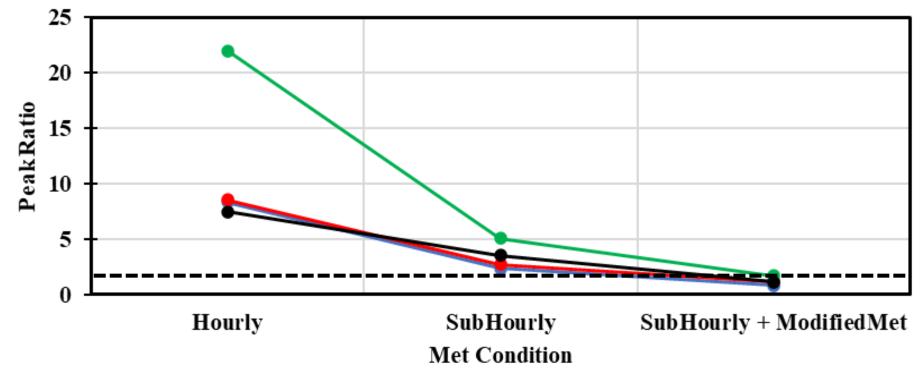


FAC2 = fraction of data that satisfy

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

AQ CN CS CE

Peak Ratio (Model/Observed)

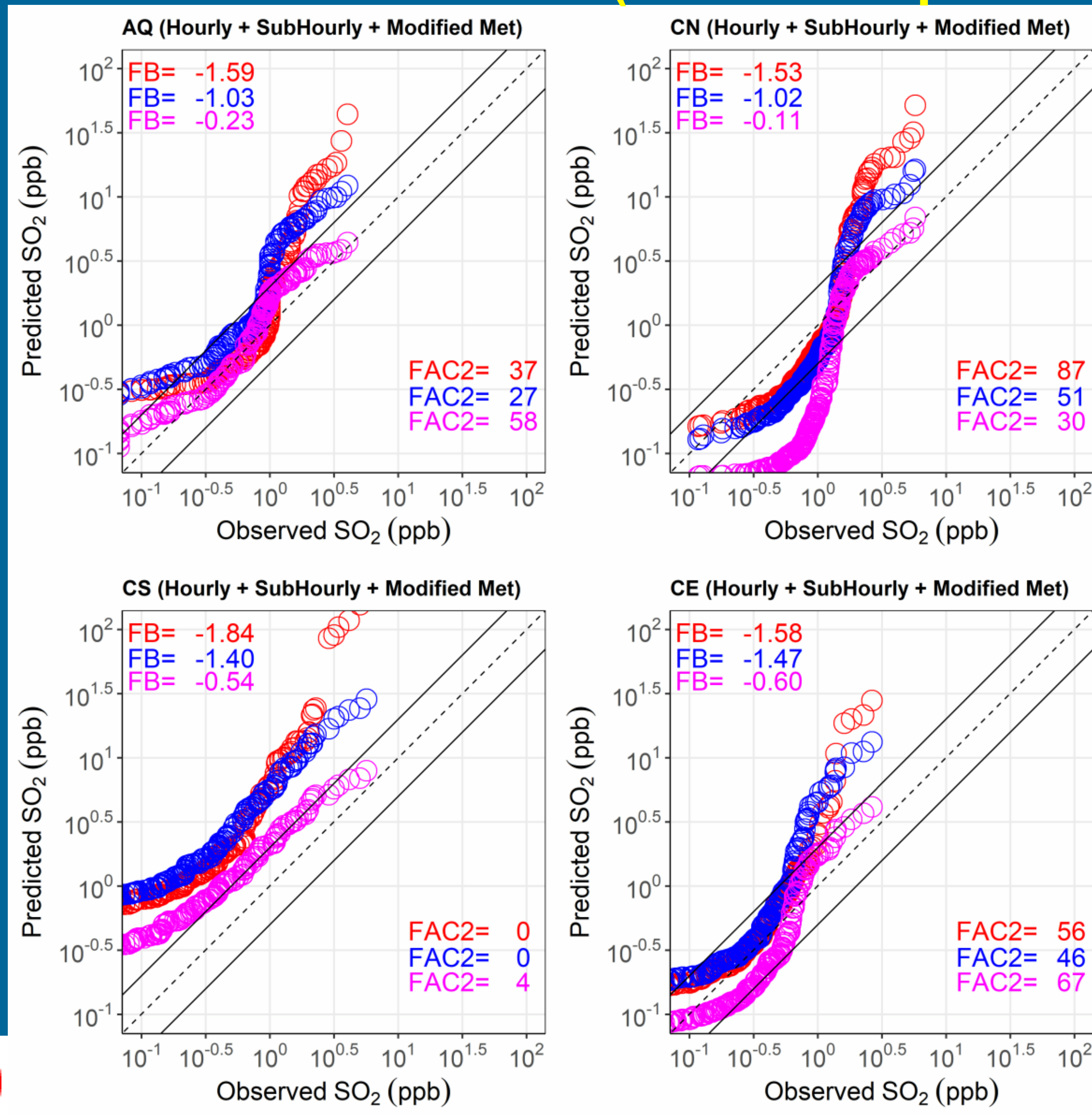


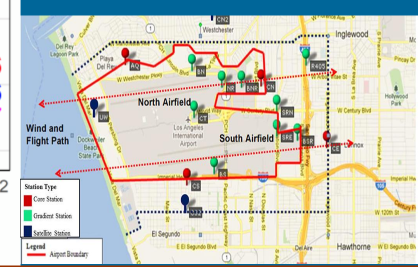
AQ CN CS CE

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

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

Quantile-Quantile Distribution of Modeled SO_2 Concentrations in Low-wind Conditions (0 ≤ Wind Speed ≤ 2)





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

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

Summary and Conclusions

- High overprediction reduces with sub-hourly approach and magnifying the mid to low range concentrations

- The sub-hourly approach can only be used when sub-hourly meteorological data is available.

- Time Scales and Meteorology Matter a lot !

- These are not only factors, there are additional factors listed below that are being investigated
  - Source representation: area vs. volume vs. line
  - Lack of plume rise for hot buoyant plumes
  - Limited treatment of chemistry, etc.

Acknowledgement

- This work was funded by the Federal Aviation Administration through grants under the Aviation Sustainability Center (ASCENT) (http://ascent.aero)) to the University of North Carolina at Chapel Hill. ASCENT is a US DOT-sponsored Center of Excellence

- Jeetendra Upadhyay, FAA Program Manager

- Robert Freeman, Los Angeles World Authority

- 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.

UNC INSTITUTE FOR THE ENVIRONMENT

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.*
- *Barad, M.L., 1958. In: Project Prairie Grass, a Field Program in Diffusion. Geophs. Res. Geophysics Research Directorate. Air Force Cambridge Research Center.*
- *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.*
- *Sagendorf, J. D., Dickson, C. R., 1974. Diffusion under Low-Wind Speed, Inversion Conditions, NOAA Technical Memorandum. ERL ARL-52*
- *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.*
- *Venkatram, A., 2002. Accounting for averaging time in air pollution modelling. Atmos. Environ. 36, 2165–2170.*
- *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.*