Effects of aircraft source characterization on AERMOD model performance for a major US airport

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Aircraft emission and air quality at airport

- Aircraft's landing and take-off (LTO) emissions contribute to poor surface air quality in and around an airport which affects human health [1,2].
- Dispersion modeling helps to quantify the effects of aircraft emissions on surface air quality.
- Federal Aviation Administration's (FAA's) Aviation Environmental Design Tool (AEDT) currently characterizes the airport sources and produces emission files for AERMOD dispersion modeling
- AEDT-produced emission file typically have ~1000 surface sources and 5,000-8,000 airborne sources[3] which makes the hourly emission file ".HRE" file big for long simulation period (months, years) and difficult to handle.
- A new emission processor can change the number of sources desired by the dispersion model users and produce emission file using the raw AEDT flight segment data
- AERMOD modeling for different source number options may help choose the better source characterization for dispersion modeling for airport sources.

1. Arunachalam et al, 2011, Atmos. Environ. 45, 3294–3300. *3. Arunachalam et al, 2017, ACRP Report 179*

2. Levy, J.I. et al., 2012, Risk Anal. 32, 237–249.

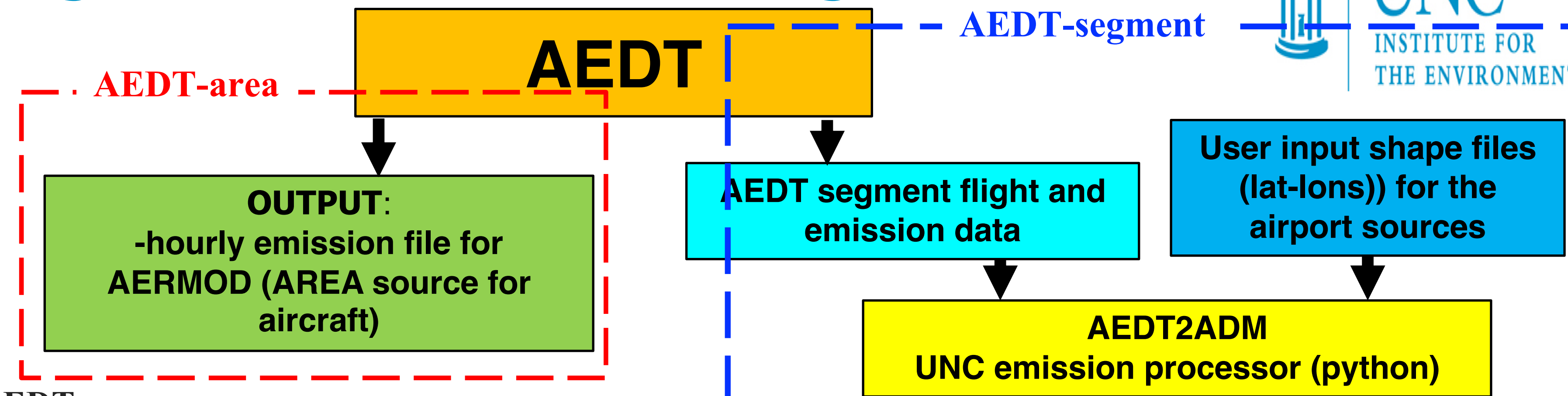
Motivation and objective

- Although there are many studies on the effects of aircraft's surface emission on surface air quality, **effects of airborne emissions on surface air quality** in dispersion modeling remains poorly understood.

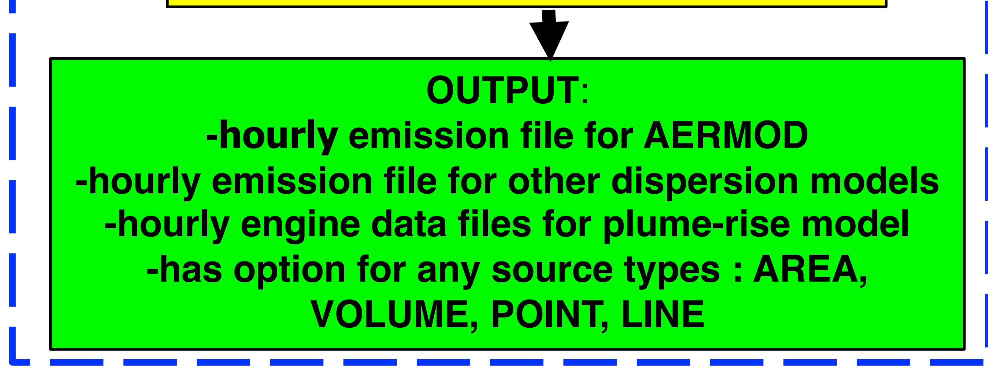
- There is a research need to explore effect of reducing the number of sources in the FAA's AEDT-produced hourly input emission file for AERMOD.

- **Objectives:**
  - Study the effects of air emission on surface air quality by AEDT emission file
  - Develop a python based emission processor, named here after as "**AEDT2ADM**", to produce emission file using AEDT's flight segment data
  - Effects of reduction of number of sources at surface on computation time and model performances by AERMOD dispersion model at LAX Airport.

Background: AEDT and AEDT-segment data



- **AEDT-area**
  - Emissions data processed as AREA sources for AERMOD (from FAA using AEDT)
- **AEDT-segment (Current work at UNC)**
  - Emission data provided by FAA as chorded segments from individual flight movements, and that can be processed for any source type (AREA, LINE, VOLUME, etc.)



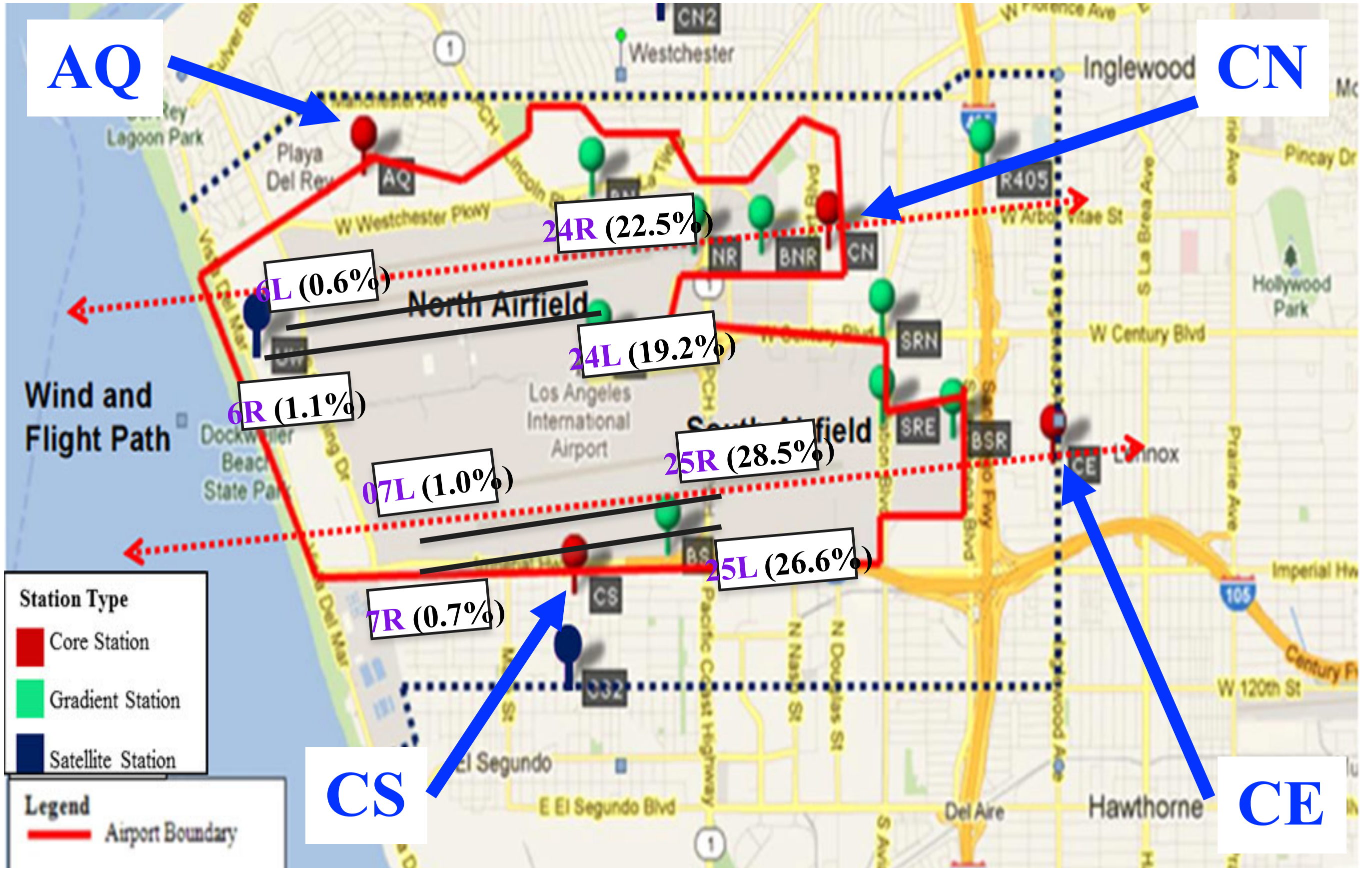
	AEDT-area	AEDT-segment
Inputs	**Aircraft Operations data and ICAO EI**	**Aircraft Operations as 40-75 segments of each flight, and ICAO EI**
Outputs	**emission rate (g/s-m^2) as area sources**	**Emission rate in desired format for the new model**
No. of sources in raw file for 1 day	**5,919**	**70,515 segments (1544 flights, 46 segments/flight)**
No. of sources at surface	**1,170**	**138 (rectangles)**
No. of sources in air	**4,479**	**144**

A new emission processor "AEDT2ADM" has been developed to study aircraft emission in dispersion modeling

Modeling airport

Los Angeles International Airport (LAX)

Receptor Site	Runway	Distance (~m)
AQ	24R (Center)	670
CN	24L (Eastern Edge)	1660
	24R (Eastern Edge)	1677
CS	25L (Center)	517
CE	25R (Eastern Edge)	1715
	25L (Eastern Edge)	1785



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- Most flights' directions are east-west
- Air quality monitors are within 2 km from the nearest runway

1. *Arunachalam et al, 2017, ACRP Report 179*

Method : Model configuration

- Airport : Los Angeles International Airport (LAX)
- Simulation period : February 2012
- Dispersion model : AERMODv21112
- Input emission data :
  - 1) AEDT AERMOD input file
  - 2) AEDT2ADM emission-processor-produced emission files using raw AEDT-flight-segment-data as input
- Meteorology data : Processed through AERMET
- Surface data: KLAX (Los Angeles airport) surface (WBAN 722590)
- Upper air soundings : KNKX (San Diego Marine Corps Air Station) (WBAN 722900) (120 miles from LAX)
- Simulation specie : SO_2 (SO_2 assumed as SOx as 98% fuel sulfur content (FSC) in jet fuel are emitted as SO_2 [1])
  - SO_2 is chosen because jet fuel has high FSC and has less non-aircraft emission source
- Initial vertical dispersion parameters (sigma-Z0) used: 4.1m for runway and taxi sources whereas 3m for GATE sources

Ran AERMOD for 4 cases for the study

1..Barrett, S. R. H et al., Environ. Sci. Technol. 2012, 46, 4275–4282

Wind profile

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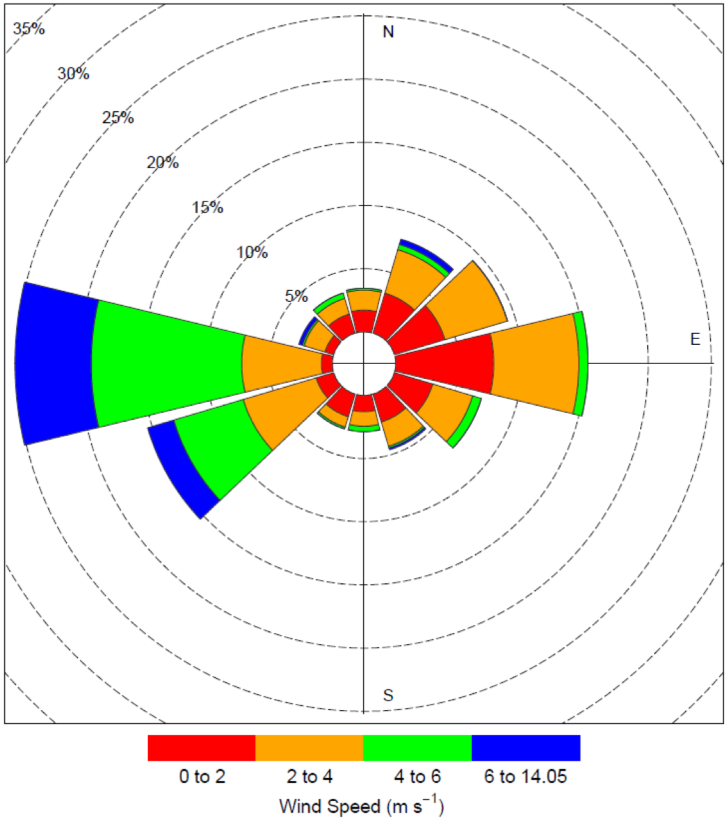
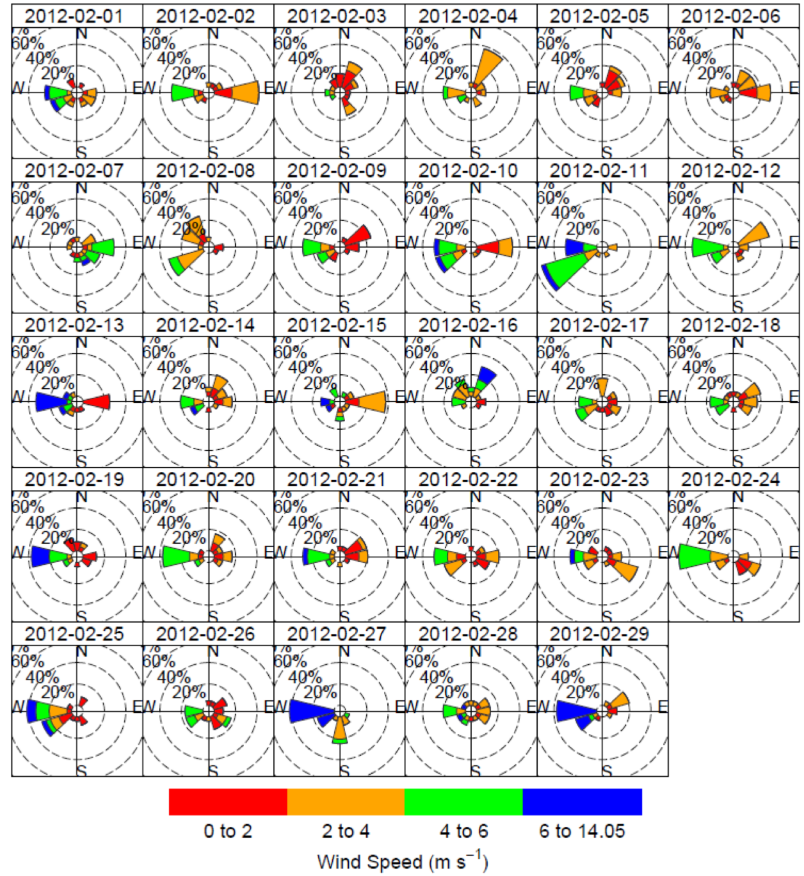


Monthly average



Each day in February 2012

Winds are westerly in daytime and easterly in nighttime

Flight and emission profile of SOx at surface and in air

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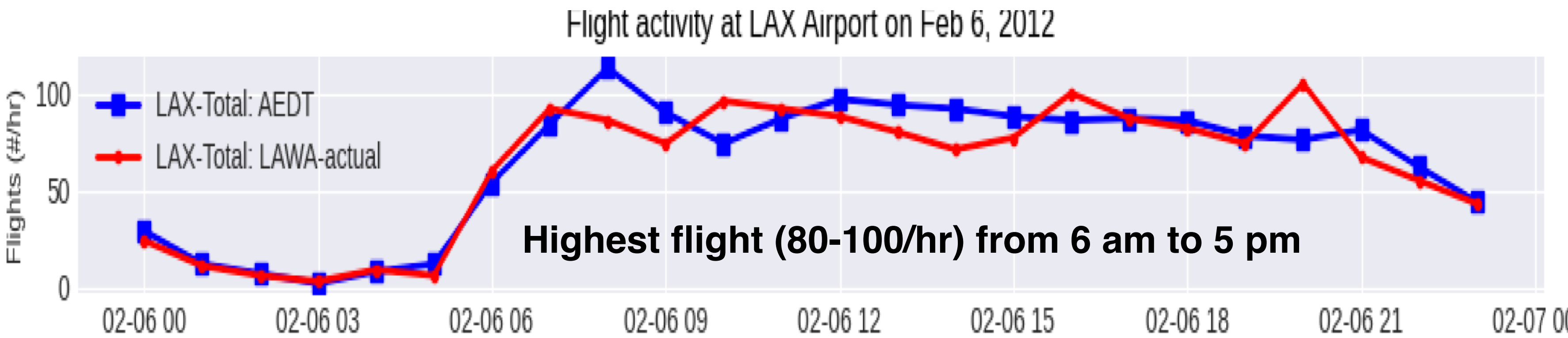
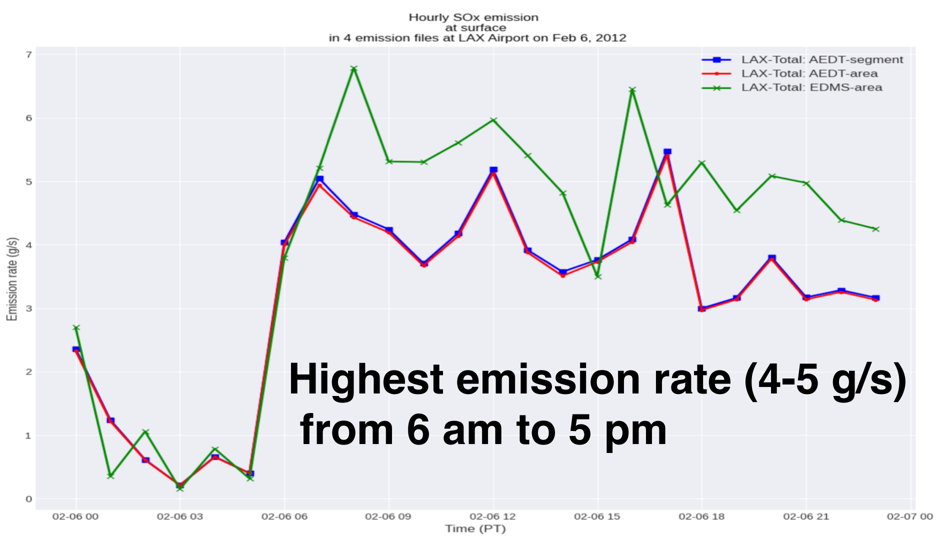
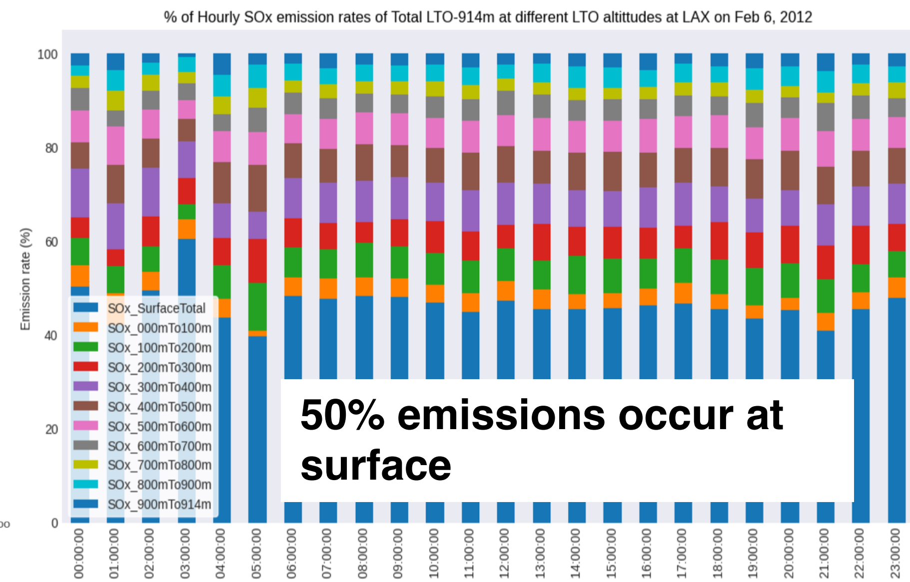
Hourly flight and emission rates of SOx on Feb 6, 2012 at LAX





Total SOx emission rate at LAX



%SOx emission at surface and in different altitudes in air

- **About 50% SOx emissions occur at surface at LAX**
- **Most emissions occur during daytime at LAX**

Sensitivity studies

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Task-1: Sensitivity study 1

- Study the effects of airborne emissions (take-off and landing within LTO altitude of 3000 ft) on surface air quality using the AEDT emission files

Task-2: Sensitivity study 2

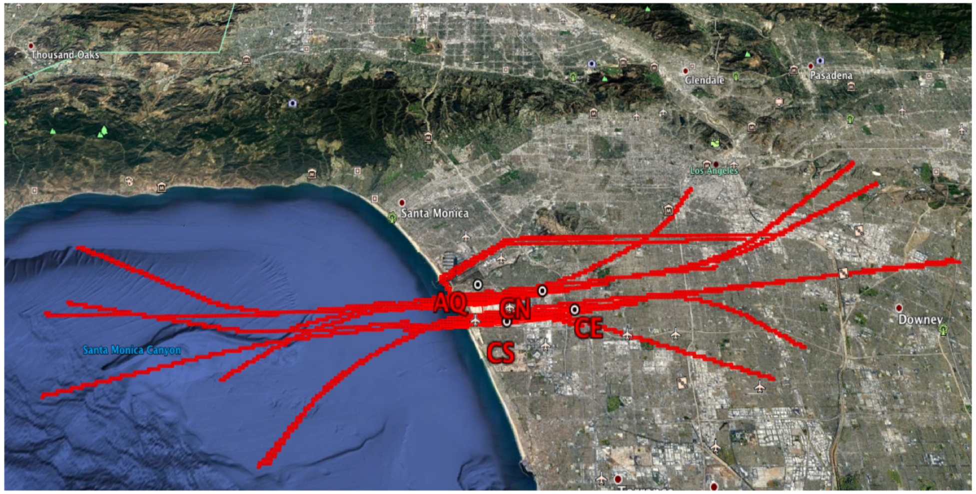
- Develop an emission processor to characterize sources and produce emission file desired by user using the AEDT flight segment data
- Quantify and compare the model performance in different source characterizations (different source numbers) modeled by the new emission processor

Task-1: Effects of airborne emissions on surface air quality

Air emissions = Emissions from aircrafts in air from altitude 12 to 914.4m (3,000 ft) sources

Run case	Description
Case 01	AEDT emission file (1440 surface sources + 4479 air sources)
Case 02	AEDT emission file (1440 surface sources)

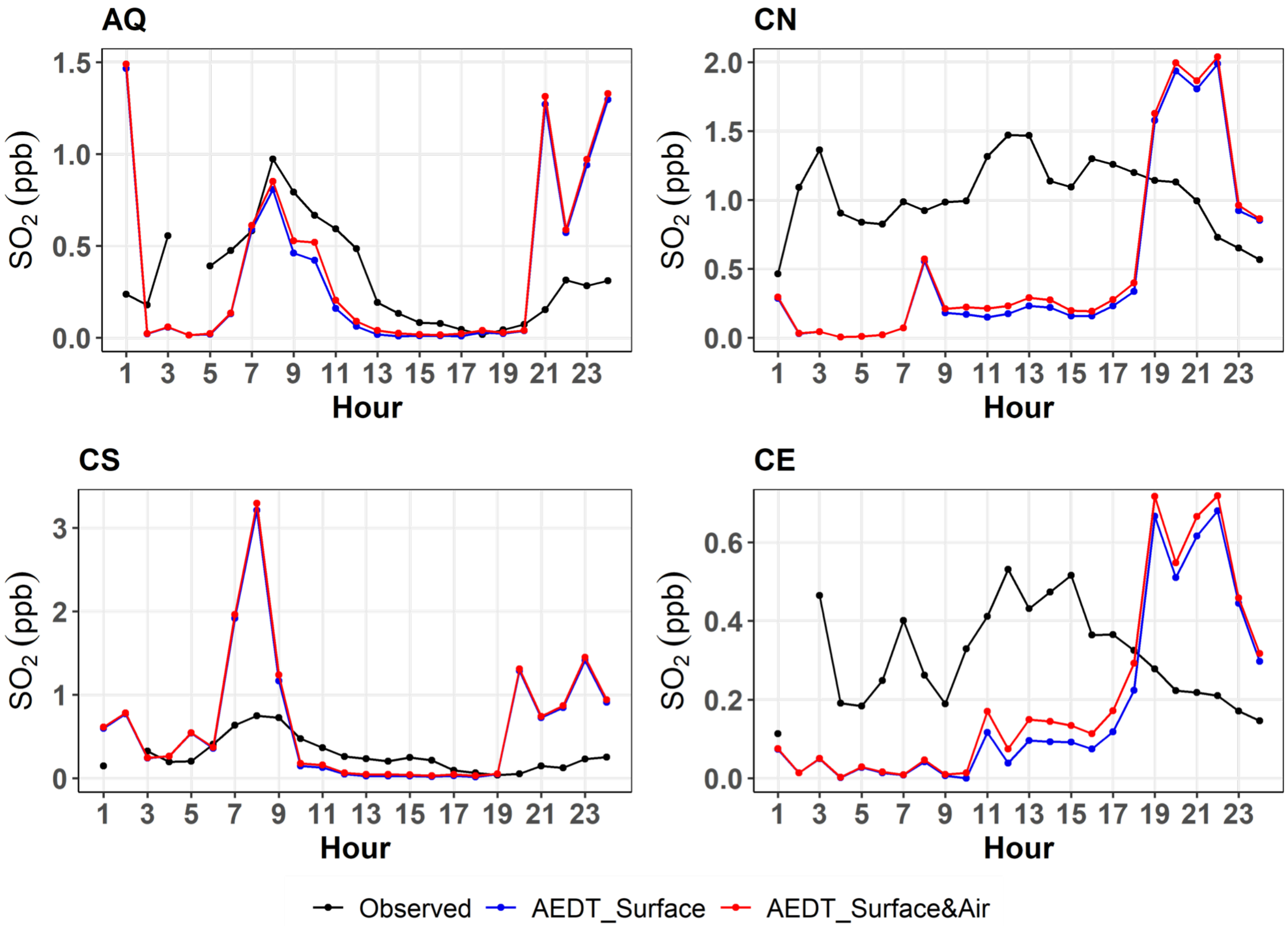
Task	Method	Description
Task 01	Case01 – Case02	Effects of air-emission on surface concentration

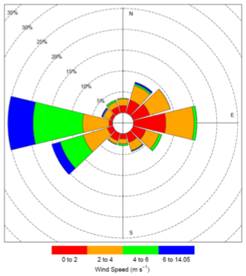


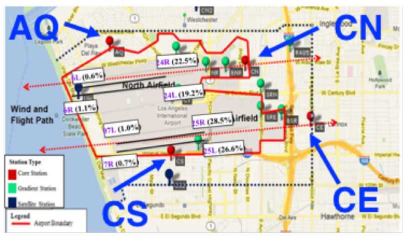
Sources for Case 01 (surface air)

Sources for Case 02 (only surface sources)

Task-1: Results: airborne emissions effects







airborne emissions:

- **has little effects at AQ during 8 to 11 am**
- **effects are negligible at CS,**
- **has little effects at CE and CN during 10 am to 10 pm**

Task-1: Results: Airborne emission effects

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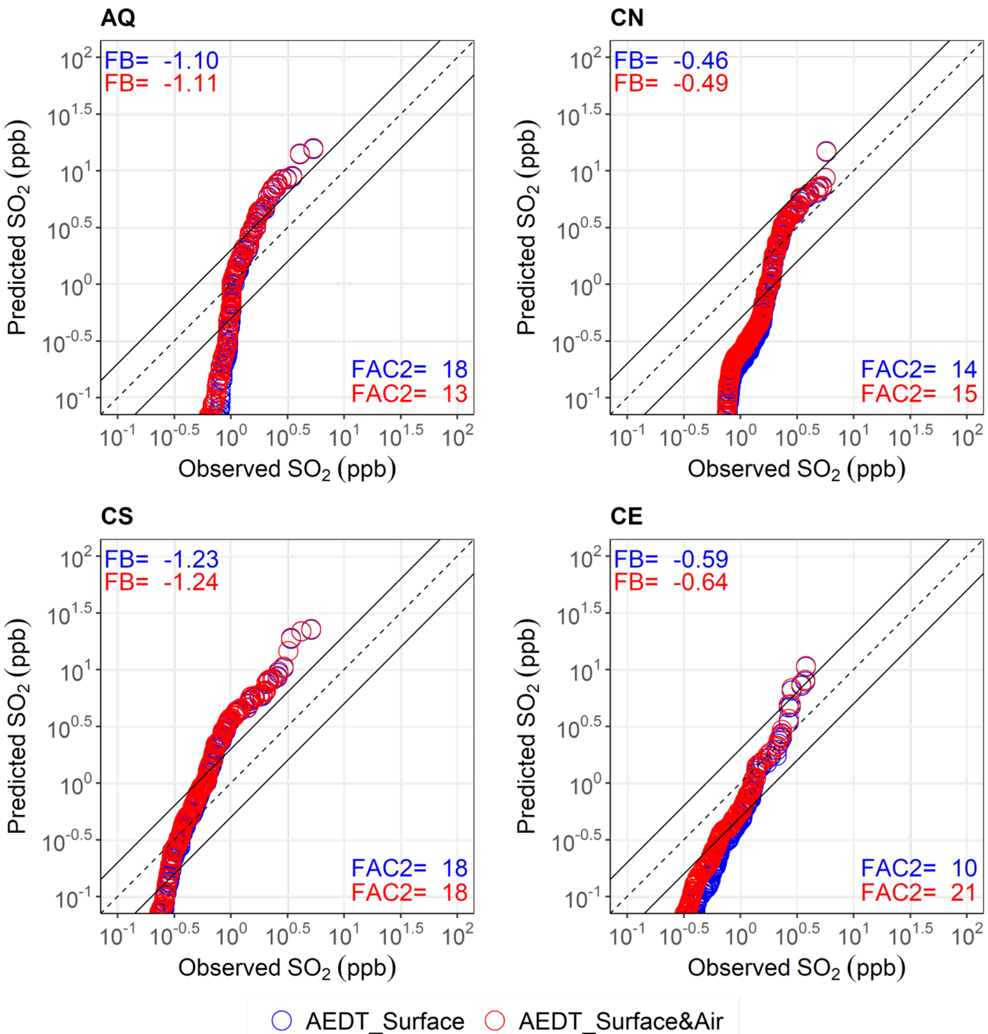
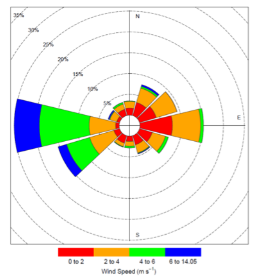
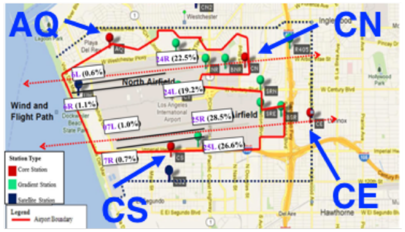


Comparison of model with measurement

Sites	SOx_Mean Concentrations (ppb)			
	Observation	Model AEDT (Surface)	Model AEDT (Surface + Air)	Air emision contrbution to total (%) (Model)
AQ	0.70	0.40	0.42	5.45
CN	1.03	0.58	0.61	6.21
CS	0.27	0.58	0.61	3.77
CE	0.31	0.21	0.24	12.70





- **Model predictions were the best at CE site (both for with and without air emission)**
- **Air emission effects are modest (4-6% of total) at 3 sites (AQ, CN, CS) and are as high as 13% at CE in 1 month's average result**

Task-2: AEDT2ADM-emission processor (surface sources)

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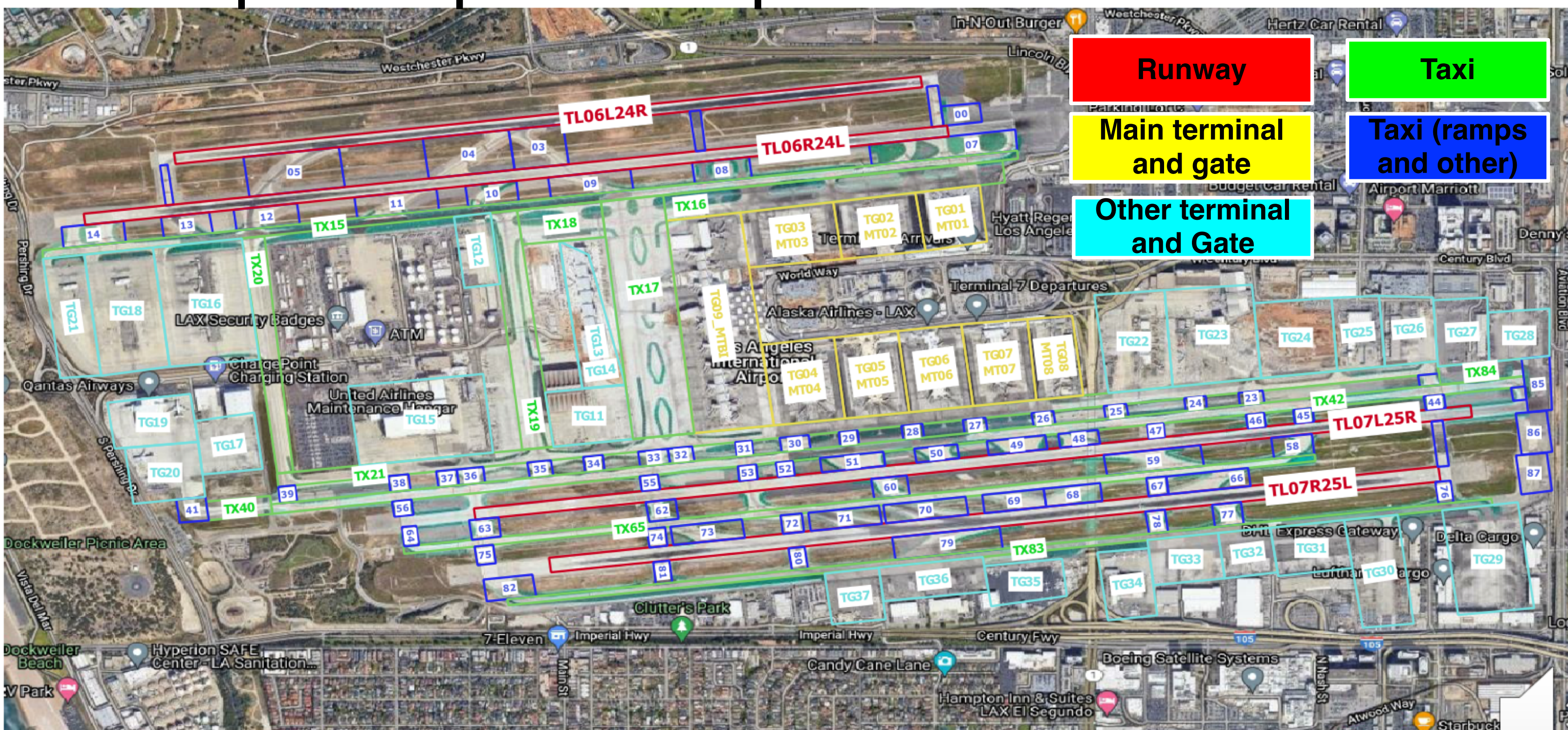
User input shape files (lat-lons)) for the airport sources

AEDT segment flight and emission data

AEDT2ADM emission processor (python)

OUTPUT:
- hourly emission file for AERMOD
- hourly emission file for other dispersion models
- hourly engine data files for plume-rise model
- has option for any source types : AREA, VOLUME, POINT, LINE

Map of user-provided shape file for 138 surface sources



Users can customize sources to their needs

Task-2: Effects of reduction of surface sources on surface air quality

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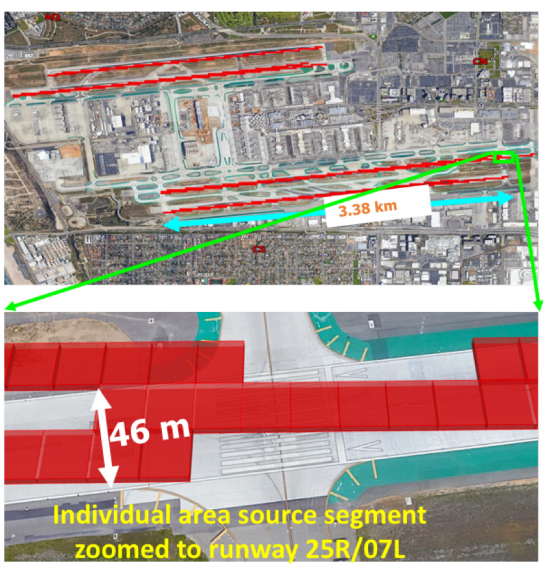
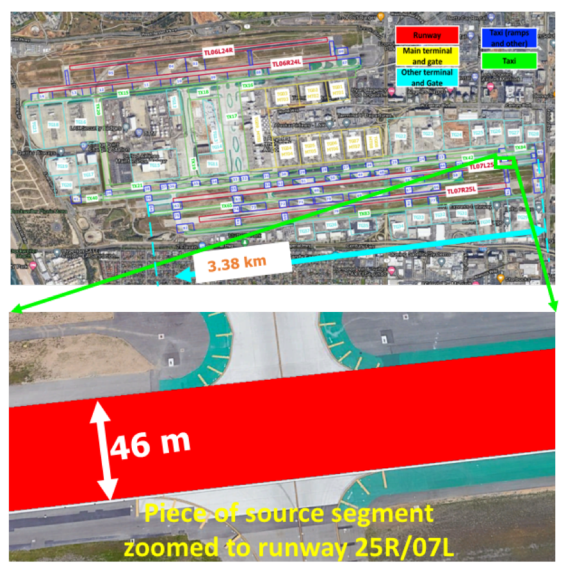
Run case	Description
Case 02	AEDT emission file (1440 surface AREA sources)
Case 03	AEDT2ADM emission processor produced emission file (138 surface AREA sources)
Case 04	AEDT2ADM emission processor produced emission file (31 surface AREA sources)

Task	Method	Description
Task 02a	Case03 – Case02	Effects of 90% (from 1440 to 138) source reduction on surface concentration
Task 02b	Case04 – Case02	Effects of 98% (from 1440 to 31) source reduction on surface concentration

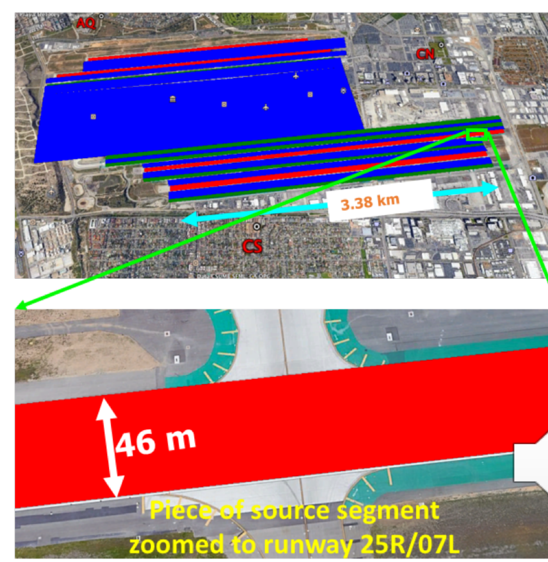
Case 02) AEDT produced 1440 surface sources



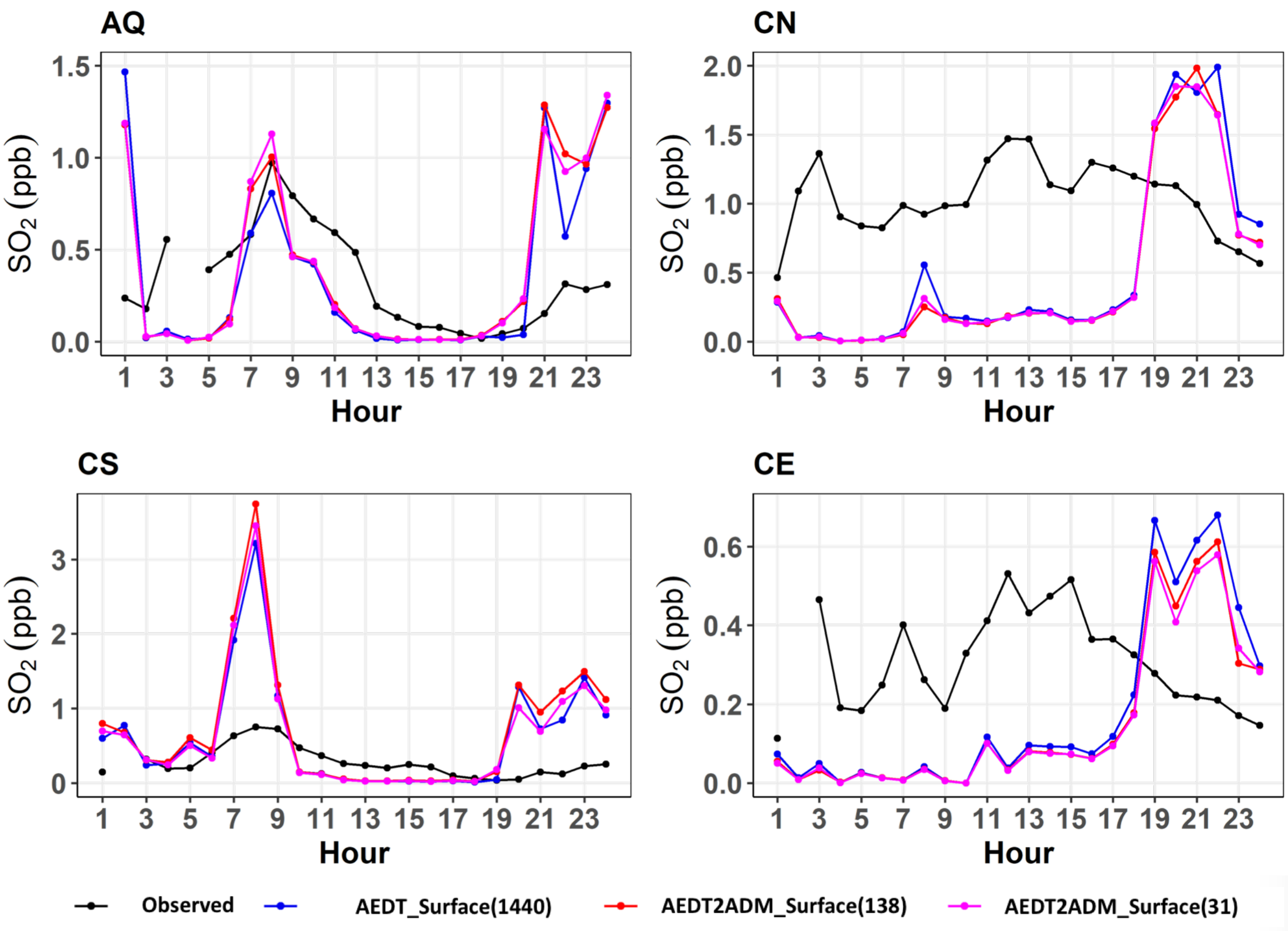
Case 03) AEDT2ADM produced 138 surface sources from AEDT-segment

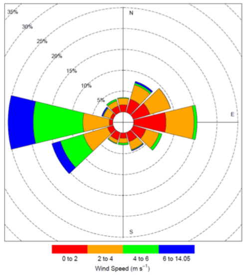


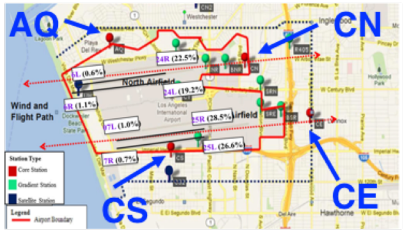
Case 04) AEDT2ADM produced 31 surface sources from AEDT-segment



Task-2: Results of different source characterizations

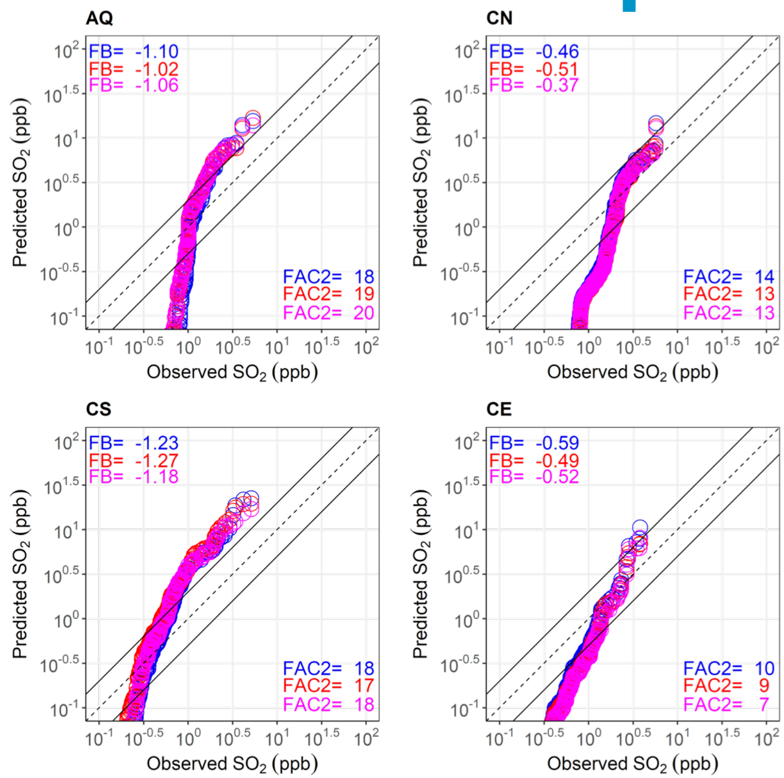


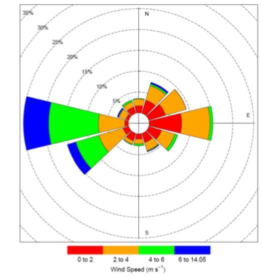


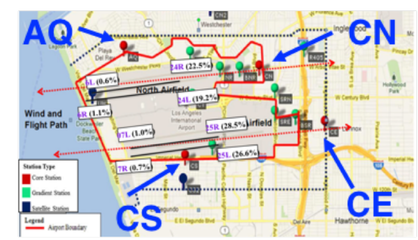


Although number of sources reduced from 1440 to 138 and to as few as 31, diurnal profile did not change much from AEDT (baseline: blue color)

Task-2: Results of different source characterizations : Model performance







○ AEDT_Surface(1440) ○ AEDT2ADM_Surface(138) ○ AEDT2ADM_Surface(31)

Receptor	Mean Abs Error SOx (ppb) 1440 source	Mean Abs Error SOx (ppb) 138 source	Mean Abs Error SOx (ppb) 31 source	Mean Abs Error change (%) from 1440-soruce to 138-source	Mean Abs Error change (%) from 1440-source to 31-source
AQ	0.864	0.894	0.898	3.46	3.96
CN	1.082	1.052	1.048	-2.82	-3.17
CS	0.636	0.715	0.644	12.35	1.17
CE	0.416	0.396	0.395	-4.80	-5.19

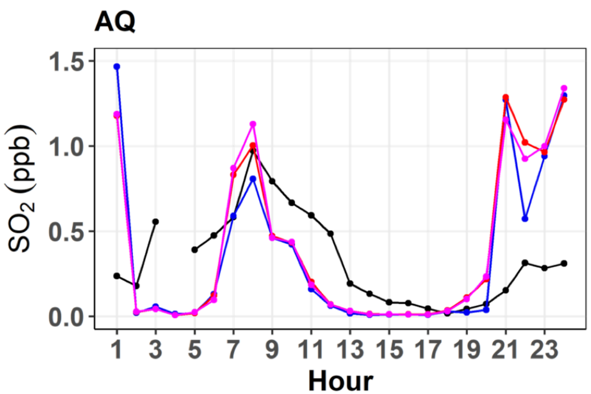
- 90% surface source reduction (from 1440 to 138) increases mean absolute error (MAE) by 3-12% at 2 receptors and decreases by 3-5% at 2 receptors.
- 98% surface source reduction (from 1440 to 31) increases MAE by 1-4% at 2 receptors and decreases by 3-5% at 2 receptors.

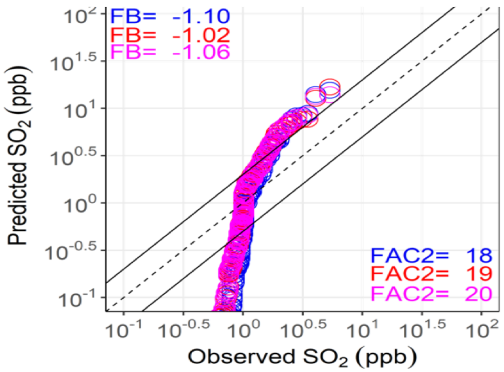
Task-2: Comparison of only-aircraft source with aircraft-and-non-aircraft sources

- Non-aircraft sources (non-aircraft's model results added):
  - **Airport:** GSE, Parking sources, stationary, roadway source (in and outside airport) and other sources
  - **Non-airport**: Chevron Refinery, marine sources

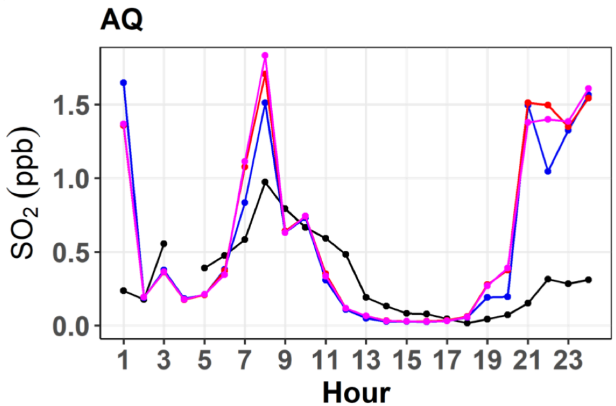
SOx emission in winter 2012 at LAX

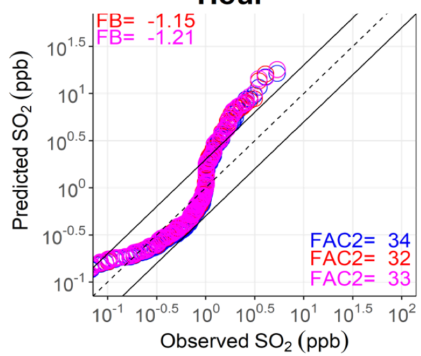
Only aircraft sources

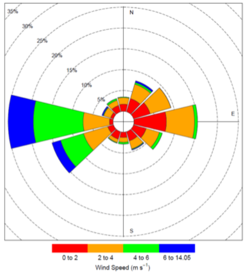




Both aircraft +non-aircraft sources







AEDT_Surface(1440) AEDT2ADM_Surface(138) AEDT2ADM_Surface(31)

Inclusion of non-aircraft sources improves model performance

Task-2: Model performance for both 1) only-aircraft sources and 2) aircraft +non-aircraft sources

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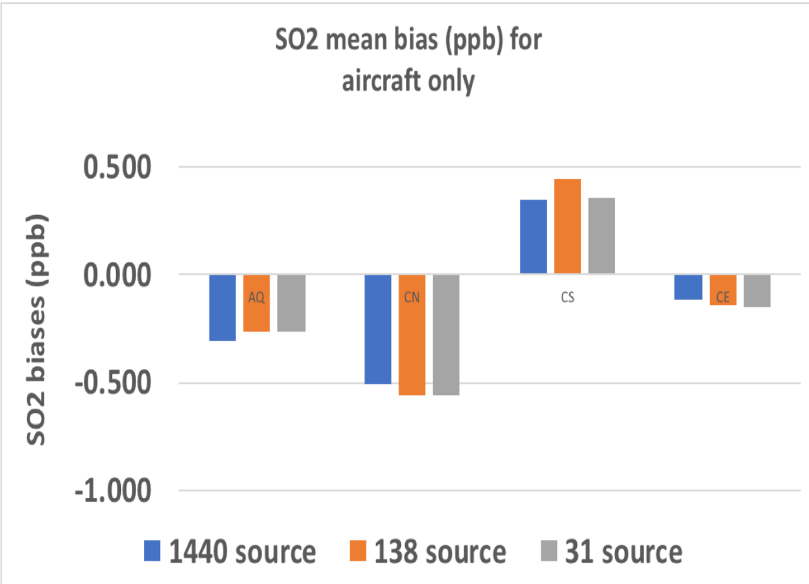
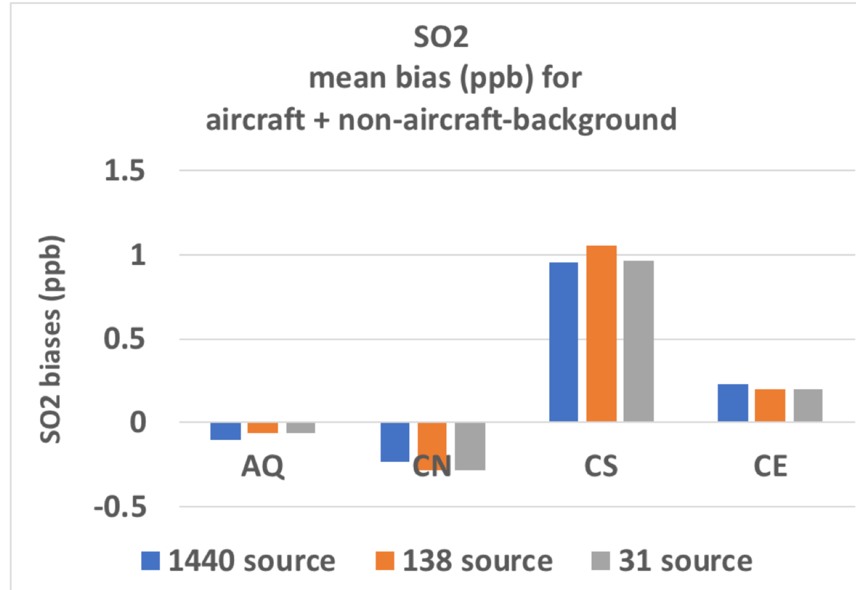
Only aircraft sources



Receptor	Mean Bias change (%) from 1440-souce to 138 source	Mean Bias change (%) from 1440-souce to 31 source
AQ	-12.981	-13.588
CN	9.645	9.678
CS	27.818	2.800
CE	23.588	27.663

Both aircraft +non-aircraft sources



Receptors	Mean Bias change (%) from 1440-souce to 138 source	Mean Bias change (%) from 1440-souce to 31 source
AQ	-38.201	-39.986
CN	20.582	20.652
CS	10.157	1.024
CE	-12.055	-14.137

Inclusion of non-aircraft sources decreases negative biases at AQ, CN and increases biases at CS and CE

Computation time change in reducing number of sources

Computer configuration:
Intel (R) Core (T M) i7-8565U CPU @ 1.80GHz 1.99 GHz , RAM 16 GB

Comp time (s) in AERMOD for for AEDT (Baseline) having 1440 surface sources	Comp time (s) in AERMOD for AEDT2ADM-emis processor using AEDT-segment data having 138 surface sources	Comp time (s) in AERMOD for AEDT2ADM-emis processor using AEDT-segment data having 31 surface sources	Comp time change (%) in AERMOD from 1440 sources to 138 sources	Comp time change (%) in AERMOD from 1440 sources to 31 sources
10.992	1.135	0.558	-89.67	-94.92

- **90% surface source reduction (from 1440 to 138) decreases AERMOD computation time by 90%**
- **98% surface source reduction (from 1440 to 31) decreases AERMOD computation time by 95%**

Summary

- AERMOD modeling shows air emission's contribution to surface concentration is 4 to 6% at 3 monitors (AQ, CN and CS) and 13% at another monitor (CE) where all 4 monitors are within 2 km of the runway.

- A new emission processor "**AEDT2ADM**" has been developed to characterize airport sources and produce emission files for AERMOD and other dispersion models using AEDT-flight-segment data
  - New emission processor provides capability for user-defined source characterization

- AERMOD modeling results for 1 month shows that
  - 90% surface source reduction decreased computation time by 90% and increased MAE by 3.5% and 12.3% at AQ, CS and decreased by 2.8% and 4.8% at CN and CE
  - 98% surface source reduction decreased computation time by 95% and increased MAE by 3.9% and 1.2% at AQ, CS and decreased by 3.2% and 5.2% at CN and CE
  - As 90% source reduction decrease computation time 90% but did not affect model performance significantly in AERMOD, source reduction may be helpful for non-steady sate dispersion models such as SCICHEM and CALPUFF [1]

- As airborne source's contribution is found to be 4-6% at 3 of the 4 sites, the number of airborne sources can be reduced significantly in AEDT for AERMOD modeling

1. *Arunachalam et al, 2017, ACRP Report 179*

Future work

- Model airborne sources as reduced number of sources in AERMOD
- Compare airborne source for POINT (with initial lateral and vertical dispersion parameters) and VOLUME sources
- Estimate model prediction by
  - Source group: runway, taxi-ramp, taxiway, terminal/gate
  - By individual flight pathway for landing and take-off (4 runway, 2 direction, 2 LTOs: Landing and take-off)
    - 4x2x2= 16 flight pathways for LAX)
- Produce sub-hourly emission files for sub-hourly run of dispersion modeling
- Make runway source length smaller by slicing into small pieces
- Run surface sources as volume source
- Produce aircraft's engine input file for the future plume rise model for the AERMOD for airport sources
- Update the emission processor to produce the emission input files for the following models:
  - Other dispersion models
  - CMAQ

Acknowledgements

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Thank You