A Preliminary Empirical Study on the Influence of Rainfall on Urban Air Quality

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Background

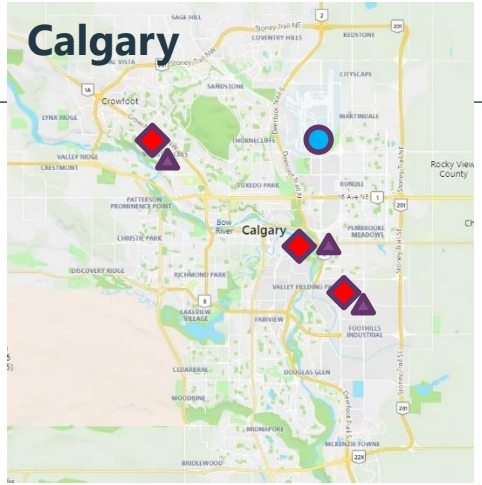
- Precipitation can theoretically improve air quality through scavenging or washout of pollutants
- Washout is quantified in dispersion modelling (CALPUFF) to calculate wet deposition rates, e. g. Potential Acid Input
- Although wet deposition is a pollutant sink, CALPUFF does not account for the decrease in concentration it causes
- Original study objective: can the effect of rainfall be incorporated in model predictions through regression equations?

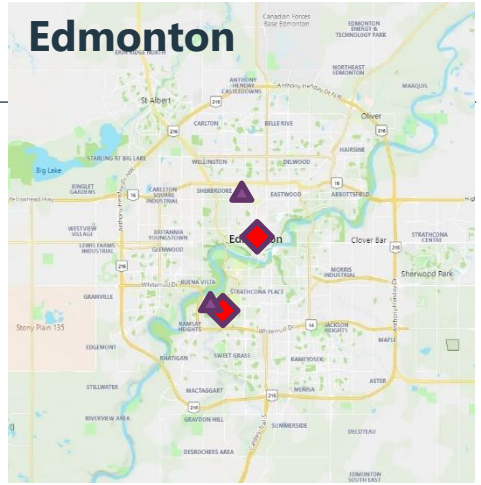
Previous Studies

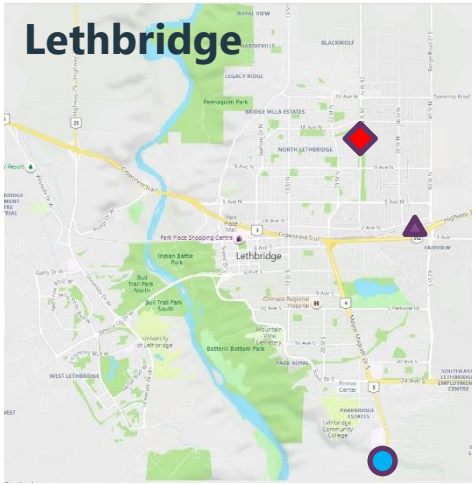
- Lab and field studies of washout efficiency of different pollutants
  - MacMahon and Denison (1979) – compilation of washout coefficients
  - Larger particles more easily removed by rain than smaller particles and gases
  - Soluble gases like H_2S and SO_2 are more easily washed out
  - Most studies are in areas with higher concentrations and rainfall
  - $PM_{10} > SO_2 > NO_2 > CO > O_3$ (Yoo et al 2014)
- Studies on the topic are somewhat limited because hourly rainfall is not routinely measured

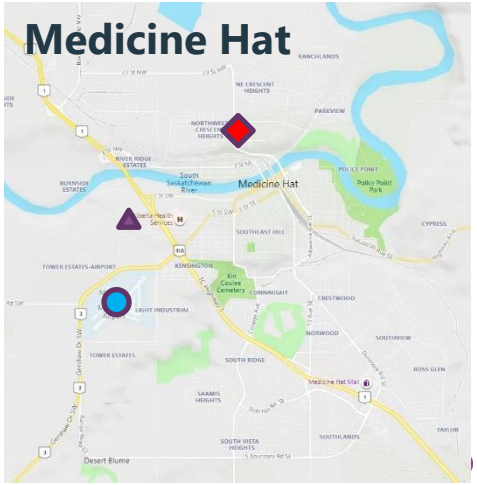
Stations

Finding hourly rainfall and cloudiness data near air quality stations is a challenge









- Air Quality
- Rainfall
- Cloudiness

Data sources:
Air Quality: airdata.alberta.ca/reporting
Calgary Rainfall: data.calgary.ca/Base-Maps/Rain-Gauge-Map
Alberta Rainfall: acis.alberta.ca/weather-data-viewer.jsp
Cloudiness: https://www.weatherstats.ca/

Data

- Hourly air quality data from urban Alberta stations (2015 – 2019)
- Hourly summer rainfall (May to September)

	$PM_{2.5}$	SO_2	O_3	NOx	NO_2	NO	CO	THC	CH_4	H_2S	NH_3
Calgary NW	✓		✓	✓	✓	✓	✓	✓	✓		
Calgary Central	✓		✓	✓	✓	✓	✓	✓	✓		
Calgary SE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Edmonton Central	✓		✓	✓	✓	✓	✓	✓	✓		
Edmonton South	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Medicine Hat	✓	✓	✓	✓	✓	✓	✓	✓			
Lethbridge	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

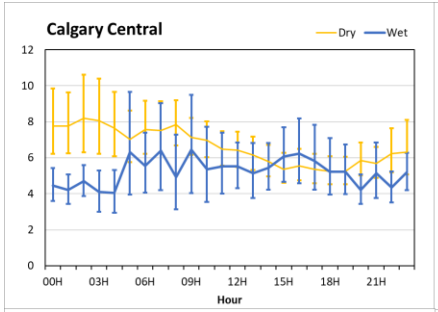
Methodology

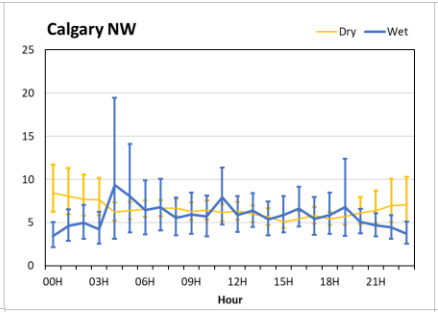
- Separate wet hours (hours with rain) from dry hours
- Calculate hourly average concentrations
- Limit comparisons to days with *some* rain
  - N wet hours ~ 5% N dry hours
  - Improves likelihood that emissions and other conditions are similar between the hours being compared
- Calculate 95% CI and p-values of differences using bootstrap resampling

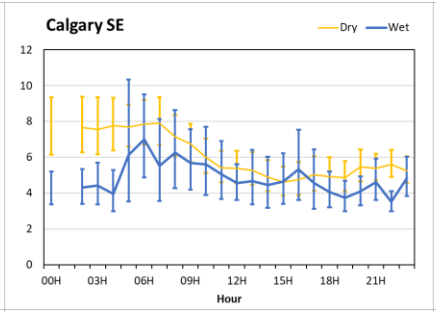
Bootstrap Resampling - A Rough Description

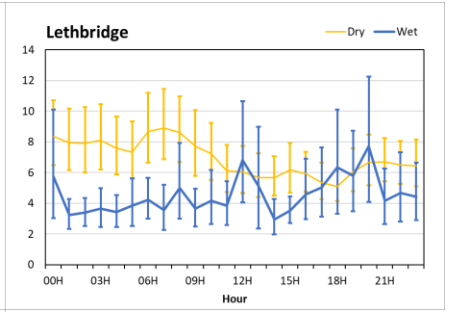
- Used when data are not normally distributed
- Estimates uncertainty in a statistical property (e.g., mean or standard error) by creating a large artificial population out of the original data, then repeatedly calculating that property from a sample of the artificial population
- For 95% CI of mean of data set with N values:
  - Randomly draw N values out of the data set, calculate mean of random values, record the value, repeat 10,000 times
  - Rank the 10,000 recorded values, CI will be the 250th and 9750th value
- For p-value of differences between the means of two data sets:
  - Combine the two data sets into one large set, randomly draw two sets each with same N as original sets, calculate difference of the means of each random set, record each value, repeat 10,000 times
  - P-value will be the number of values in the recorded differences that are larger than the original difference

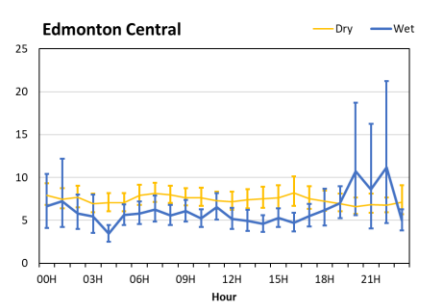
Results – Dry vs Wet $PM_{2.5}$ ($\mu g/m^3$)

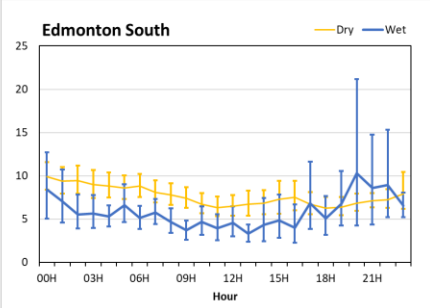


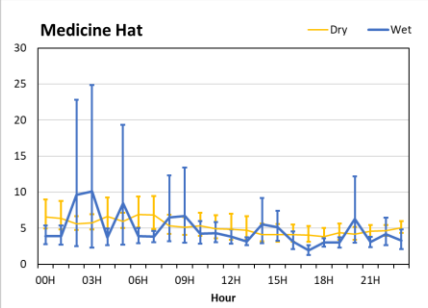








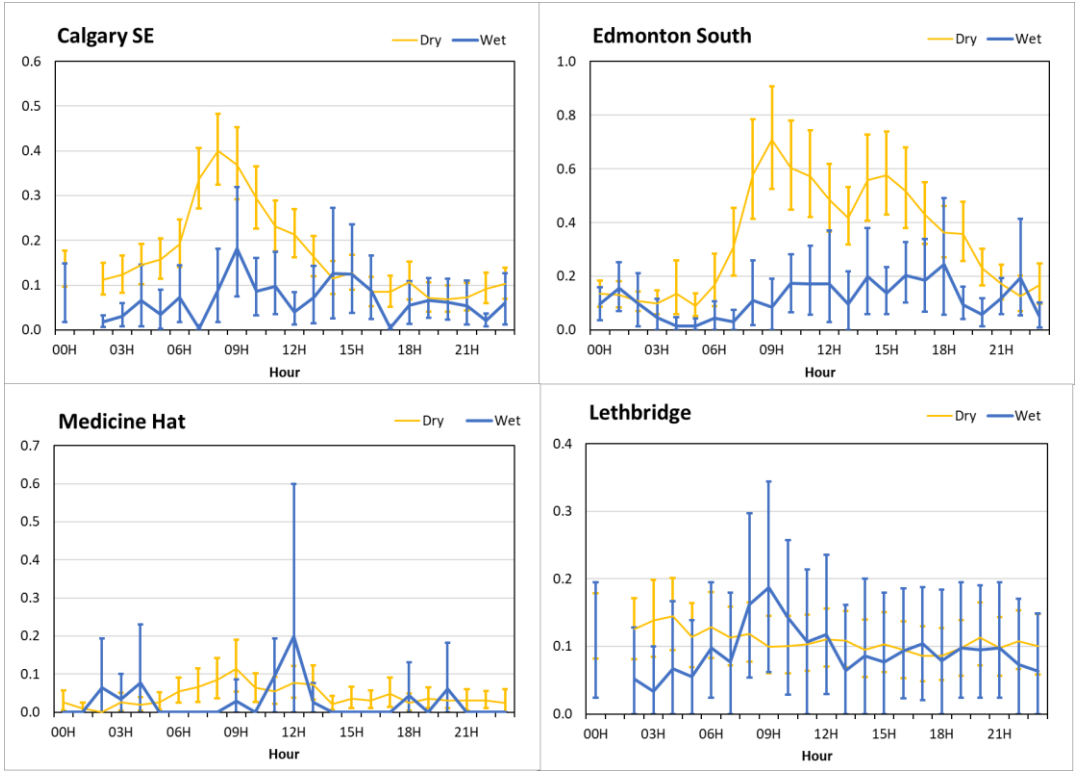




- Error bars represent 95% CI
- Separation between error bars generally reflect p-values of differences

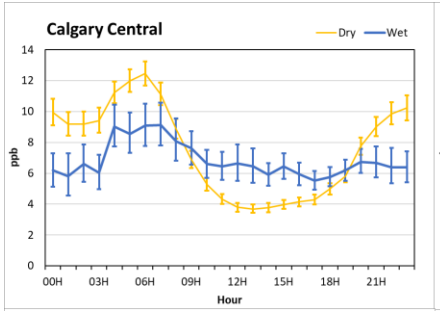
- Dry concentrations generally higher than wet, with exceptions

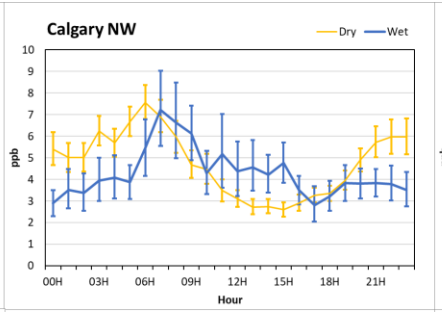
Results – Dry vs Wet SO_2 (ppb)

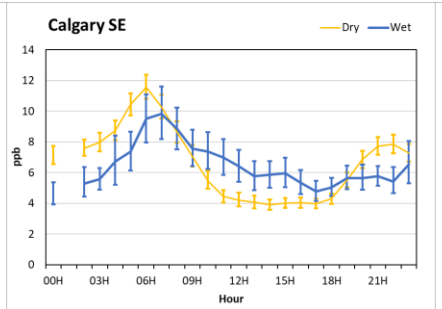


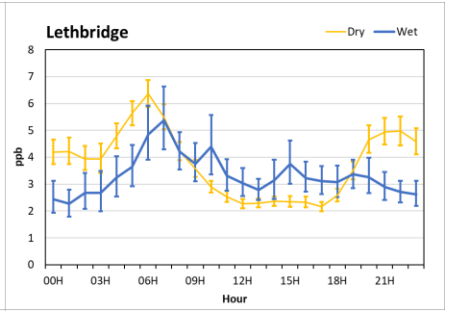
- Dry SO_2 concentrations generally higher than wet, but not at low concentrations

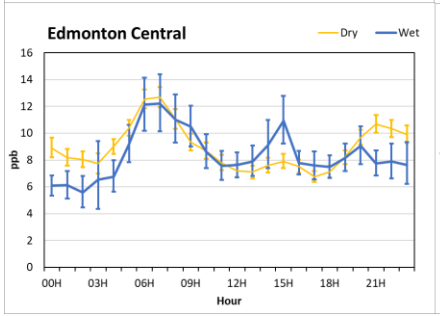
Results – Dry vs Wet NO_2

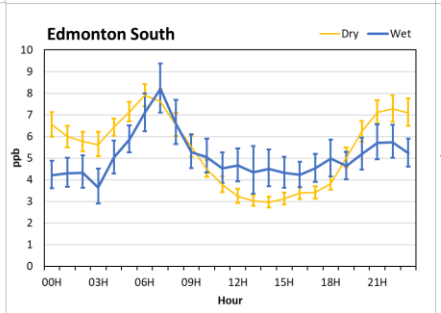


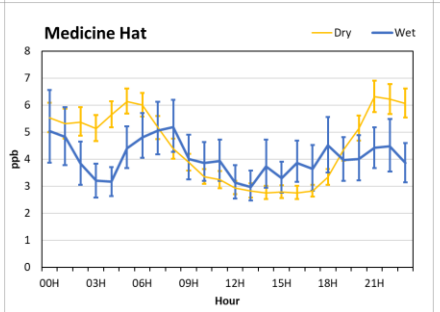






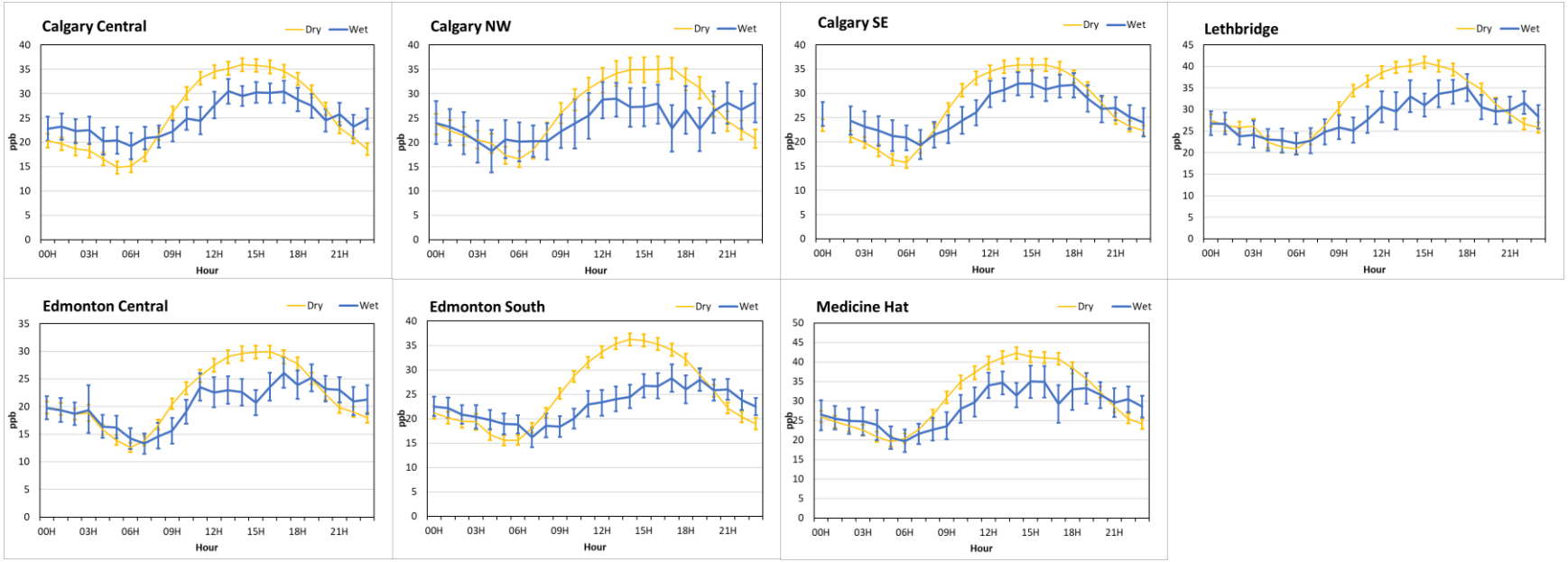






- Dry concentrations higher than wet at night but *lower* during the day

Results – Dry vs Wet O_3



- Opposite pattern as NO_2 – dry concentrations lower than wet at night but higher during the day

Ozone and NO_2 (Finlayson-Pitts and Pitts 2012)

- Daytime: emitted NO_2 dissociates in sunlight, forming NO and ozone
  - Cloudiness associated with rain reduces O_3 and increases NO_2
- At night:

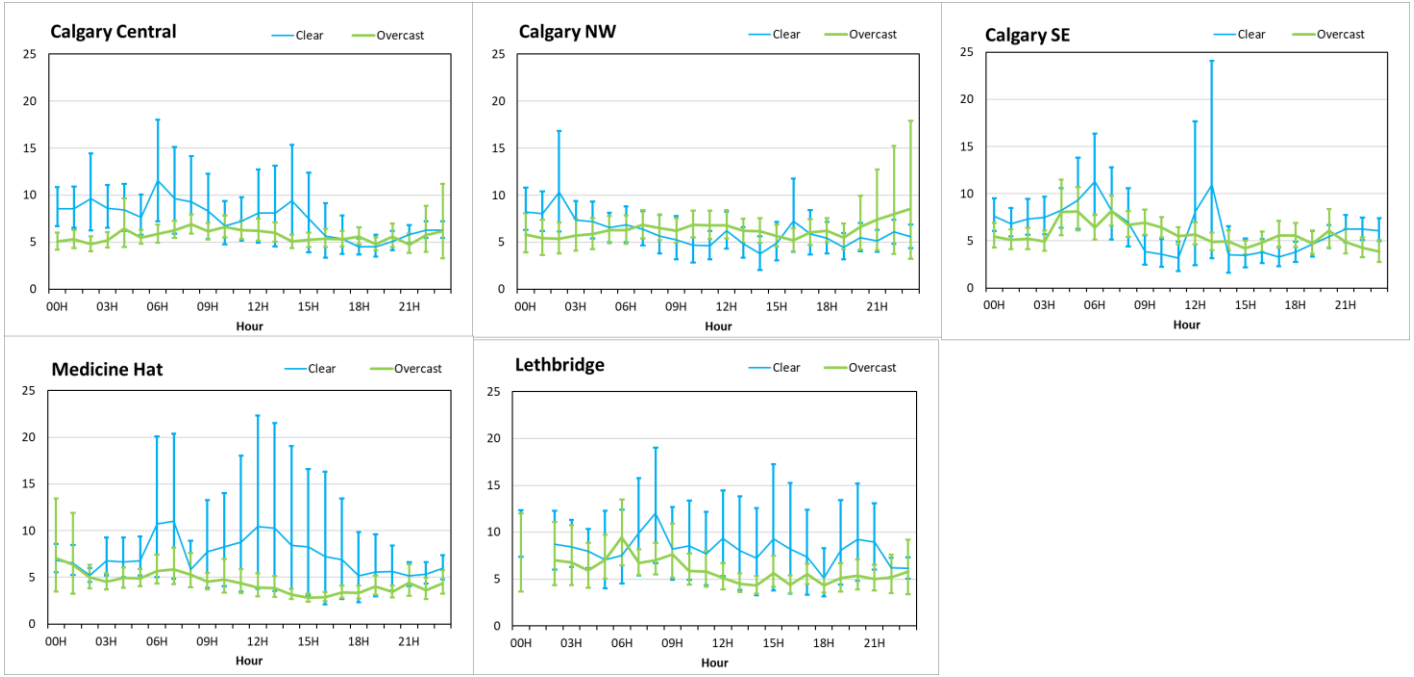
  $NO_2 + O_3 \rightarrow NO_3 + O_2$

  $NO_3 + NO_2 \rightarrow N_2O_5$

  $N_2O_5 + H_2O \rightarrow 2HNO_3$

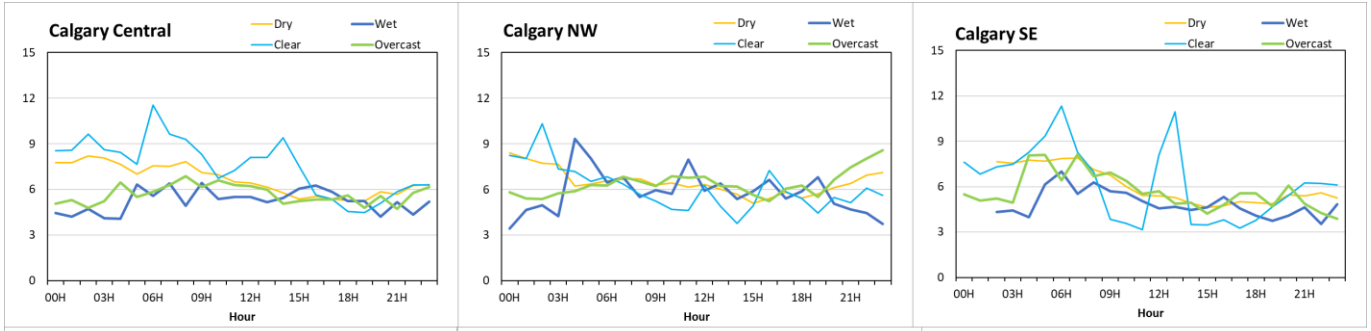
  ➢ Net effect is lower NO_2, more O_3 during rain

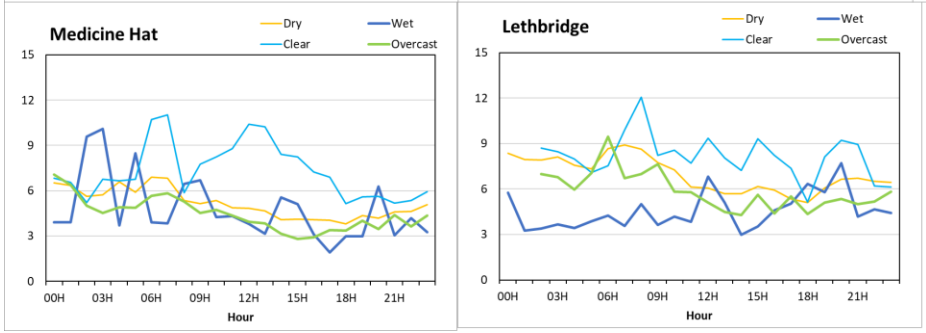
Effect of Cloudiness – $PM_{2.5}$ (Dry hours only)



Mean $PM_{2.5}$ concentrations ($\mu g/m^3$) appear to be higher during clear skies

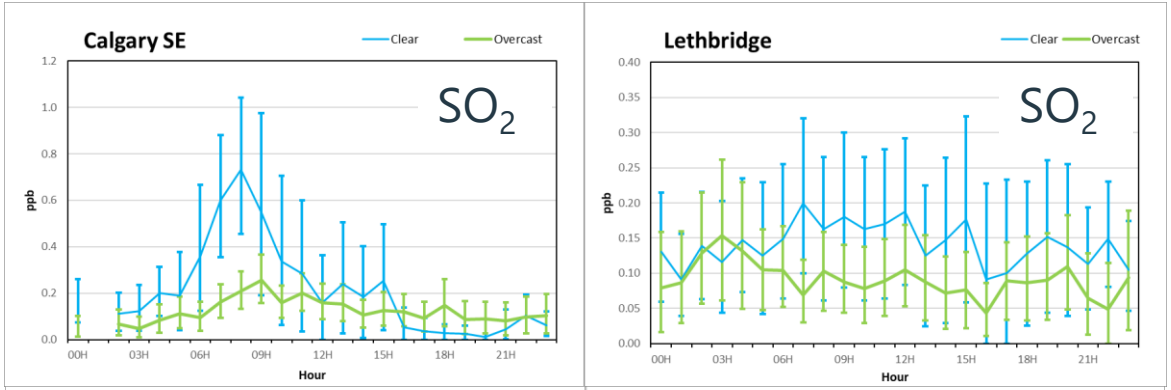
Clear vs. Overcast skies – $PM_{2.5}$ (Dry hours only)

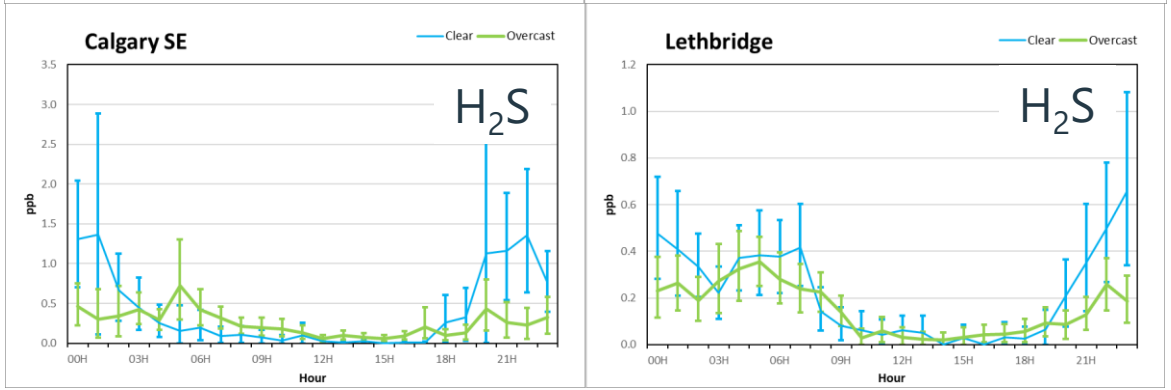




- Clear skies have generally equal or higher $PM_{2.5}$ concentrations($\mu g/m^3$) than dry periods – possibly a result of dust resuspension
- $PM_{2.5}$ concentrations during overcast hours and wet hours are nearly equal (except at Lethbridge)
- Even if clear skies enhance dispersion during the day, it gets more dusty

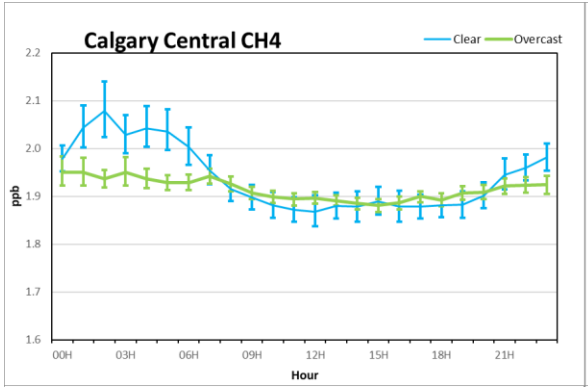
Clear vs. Overcast skies – SO_2 and H_2S (Dry hours only)

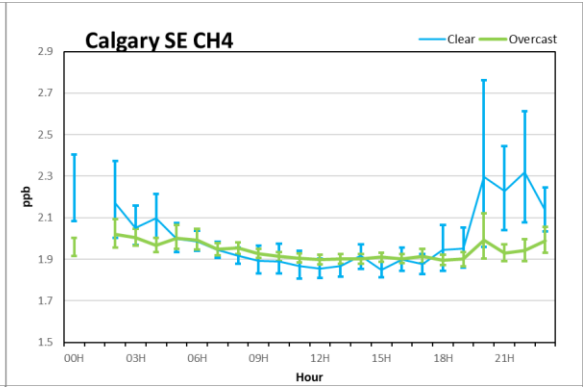


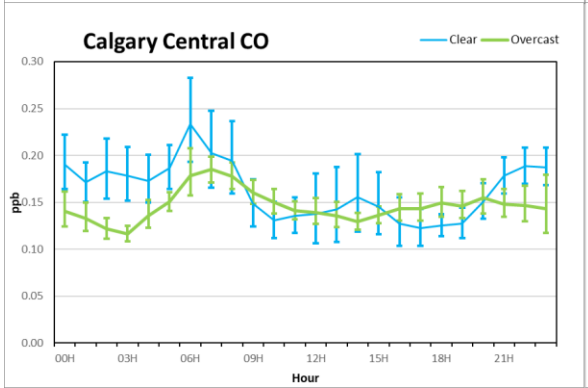


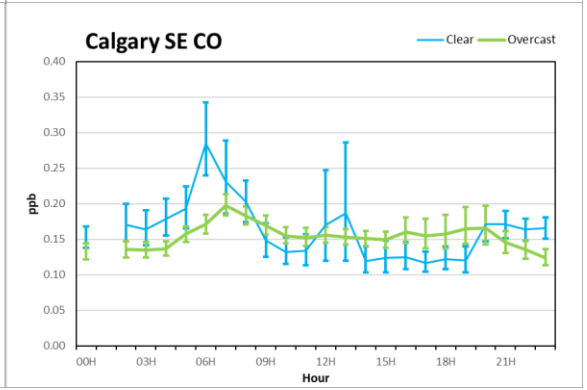
- As with $PM_{2.5}$, clear skies have higher SO_2 concentrations than overcast skies
- With H_2S, clear skies have higher concentrations at night – likely due to higher stability

Clear vs. Overcast skies – CH_4 and CO (Dry hours only)



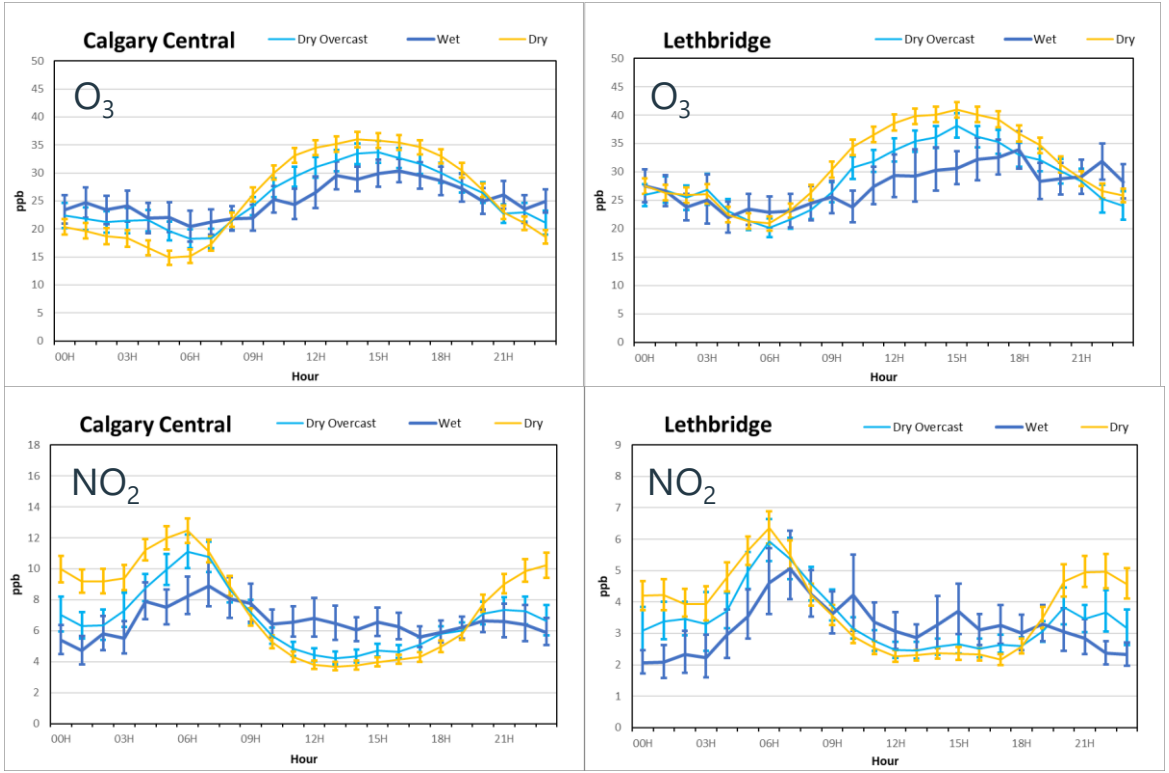






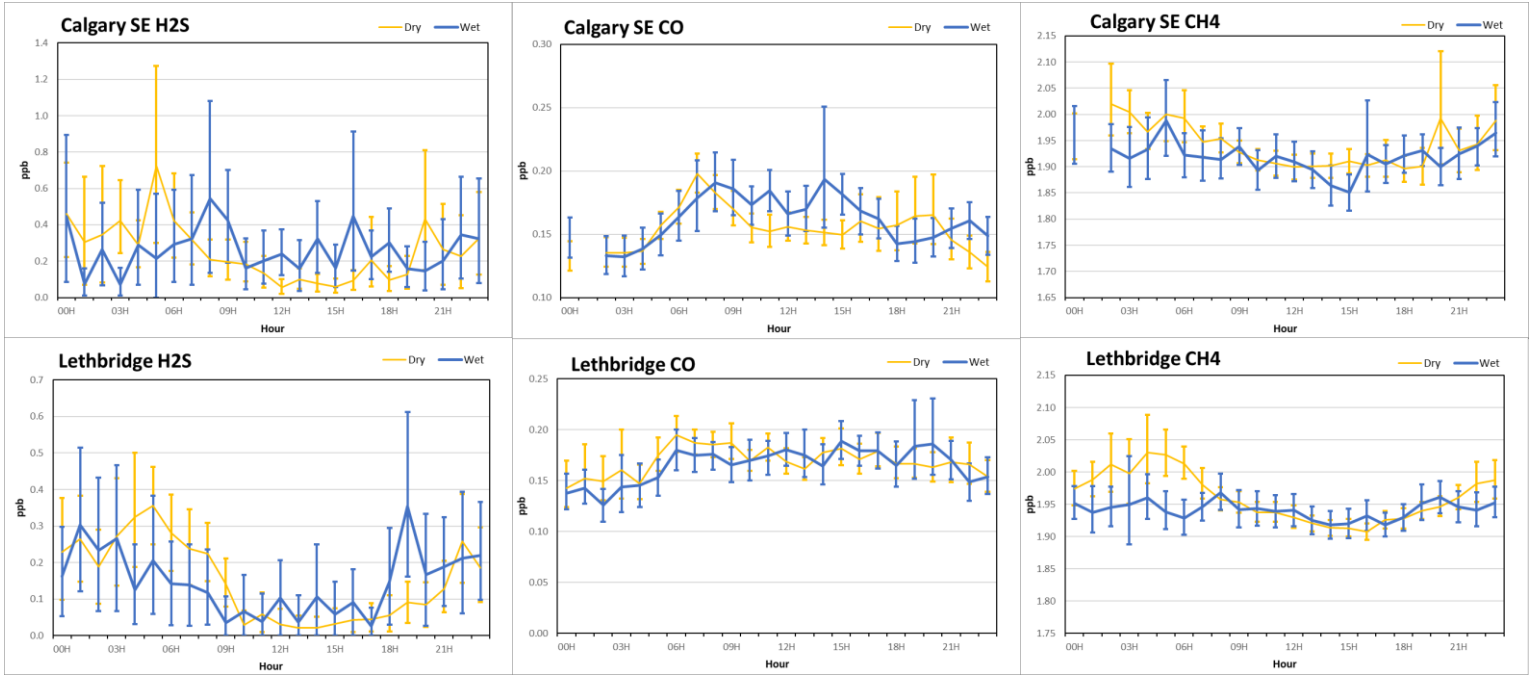
- Like H_2S, clear skies have higher concentrations of CO and CH4 at night – likely due to higher stability
- **Cloudiness need to be controlled for in drawing out the effect of rain**

Wet vs. Dry – Overcast Skies



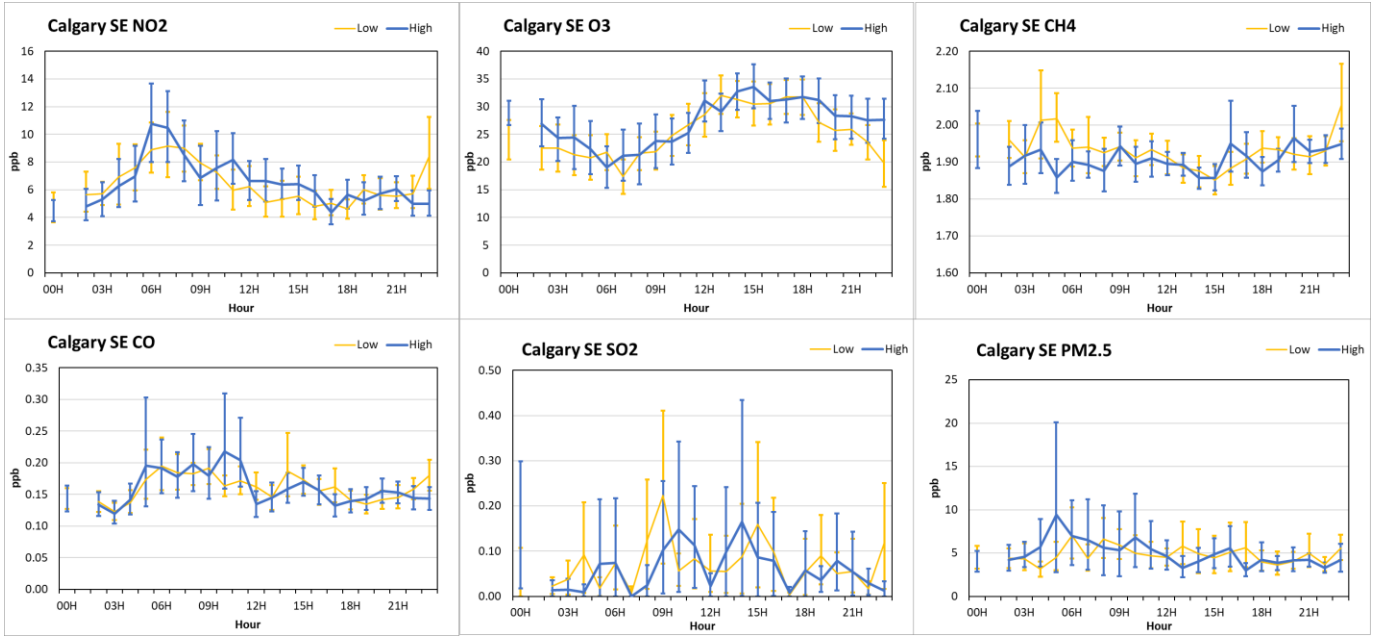
- Dry overcast concentrations move closer to wet concentrations, but the effect of rainfall remains:
  - Reduce O_3 in the daytime, increase it at night
  - Increase NO_2 in the daytime, reduce it at night

Wet vs. Dry – Overcast Skies only



- Rainfall seems to have limited effect on these pollutants

Effect of Rainfall Intensity



- Wet hours were divided into low (<1 mm/hr) and high rainfall intensity
- Very little difference in average concentrations

Concluding Notes

- $PM_{2.5}$ and SO_2 do appear to be the most sensitive to rainfall, but effect is weaker than expected
- Cloudiness is a major confounding factor
  - Stronger than rainfall effect in case of O_3 and NOx
  - Unexpected lowering effect in the daytime
- Why is rainfall effect weak? Some possibilities:
  - Alberta rain is usually too light and infrequent to affect concentrations
  - High concentrations are too few
  - Contact between pollutants and droplets in the lower troposphere is too brief

Thank You!

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