Injection Height Perturbation– Sensitivity and Comparative Test for GEOS-Chem CO Model

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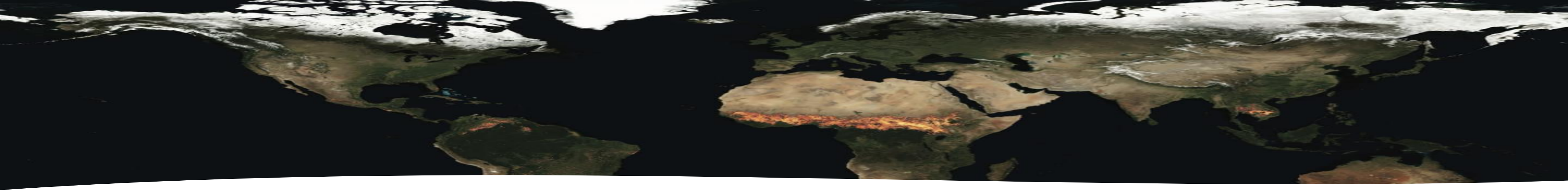


Outline

- Motivation
- Context
- Data & Methods (TCCON Data; Choice of Injection Height Scale)
- Results (GEOS-Chem Outputs; Comparison with TCCON Data)
- Discussions
- Future directions/Next Steps

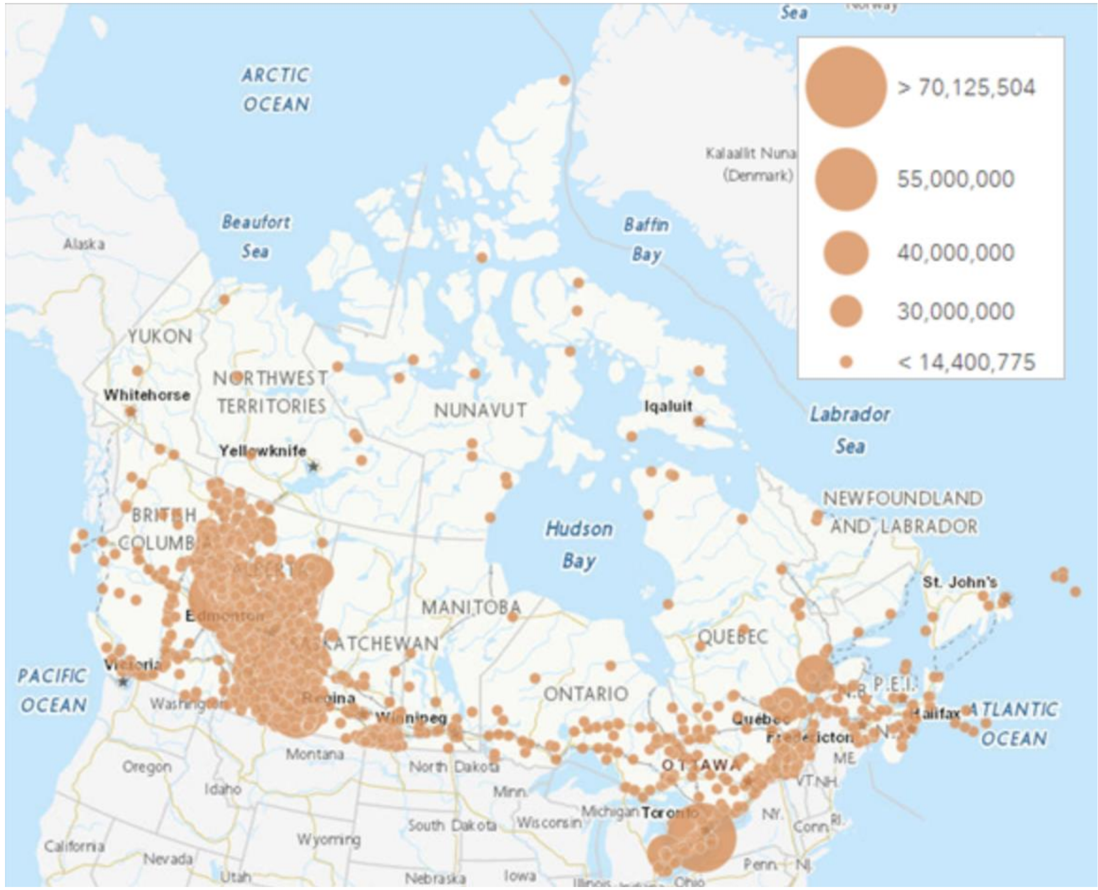
Motivation

- Biomass Emissions
  - Living and once living
  - Everywhere!
- Triggered by
  - Natural processes
  - Human-induced activities
    - Slash-and-Burn

Wild Fire Events in August 2018

What I do in the project

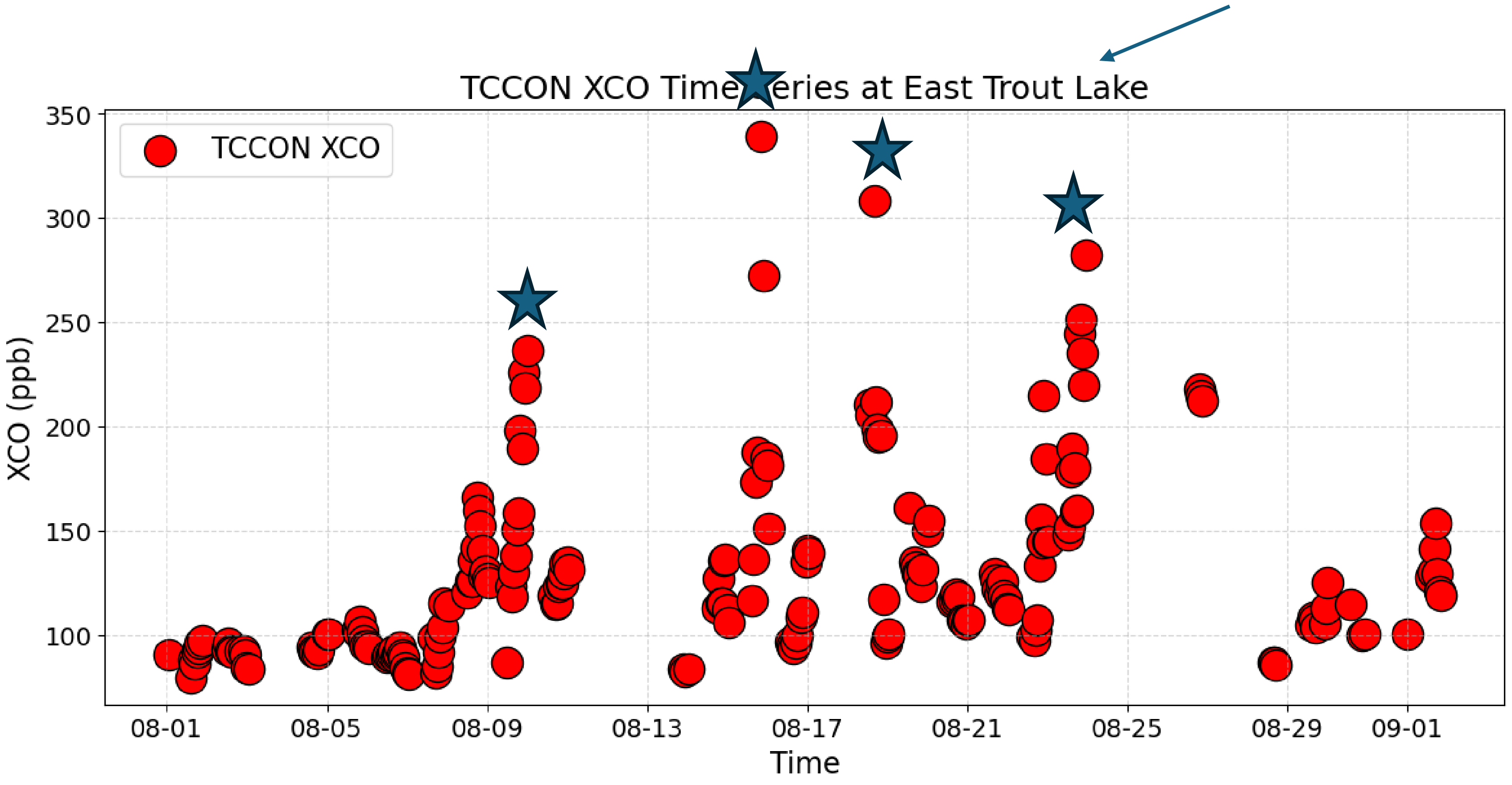
- Look at biomass burning in BC using GEOS-Chem.
- Inject fires at different altitudes to test sensitivity of CO simulation outputs
- Compare the model outputs against TCCON data in East Trout Lake.



Map showing the amount of carbon monoxide in tonnes reported to the NPRI by Canadian facilities in 2018. (Ref. Canada.ca)

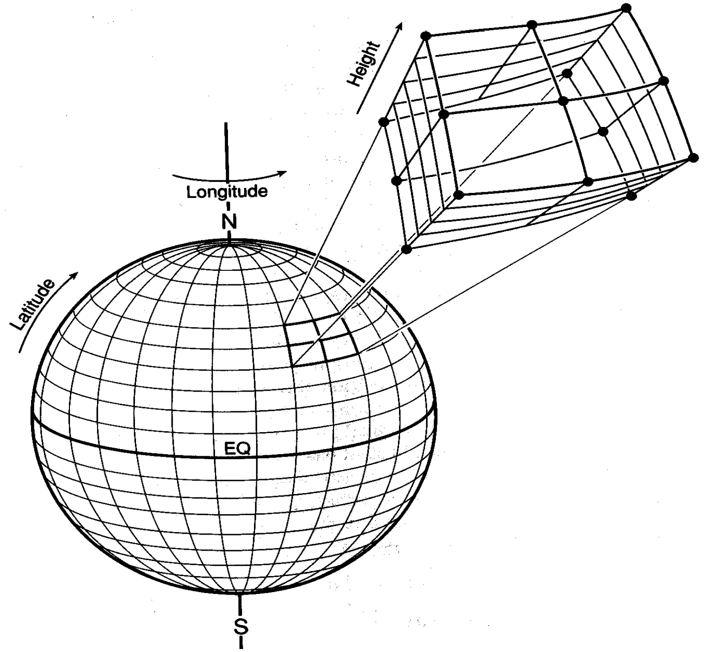
Data & Method: TCCON Observation of CO

TCCON, or the Total Carbon Column Observing Network, is a network of ground-based Fourier Transform Spectrometers that measure the amounts of greenhouse gases in the Earth's atmosphere.



Data & Method: GEOS-Chem

- Horizontal resolution of 2º latitude x 2.5º longitude
- Driven by assimilated meteorology from the NASA Global Modelling and Assimilation Office
- Global anthropogenic emissions are from the Community Emissions Data System (CEDS) (Hoesly et al., 2018).
- Biogenic emissions are from the Model of Emissions of Gasses and Aerosols from Nature (MEGAN) (Guenther et al., 2012), version 2.1.
- **Biomass burning emissions from the Global Fire Assimilation System (GFAS) (Kaiser et al., 2012).**



The GEOS-CHEM global 3-D chemical transport model

GEOS-Chem

Data & Method: Estimating CO Emissions

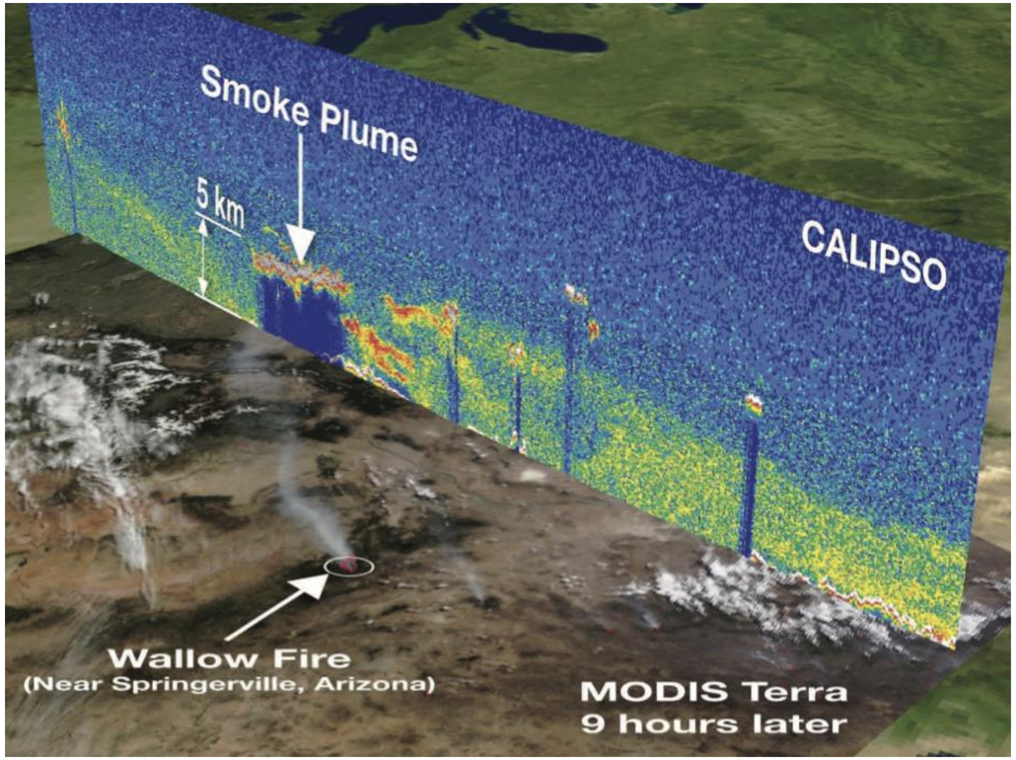
1. **Burned Area Assessment**
2. **Calculation of Emissions**:
3. **Emission Equation**:

$$Emissions = EF \times A$$

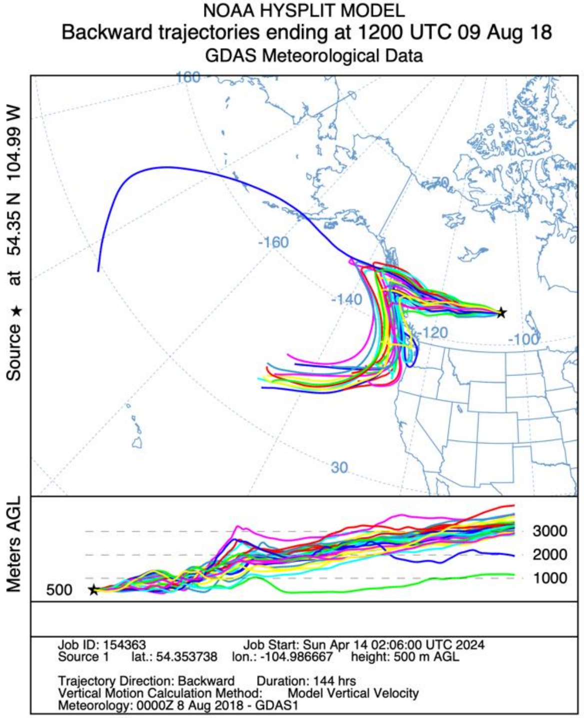
4. **Influencing Factors**:
    1. The intensity of the fire.
    2. The dryness of the vegetation.
5. **Significant Uncertainties**

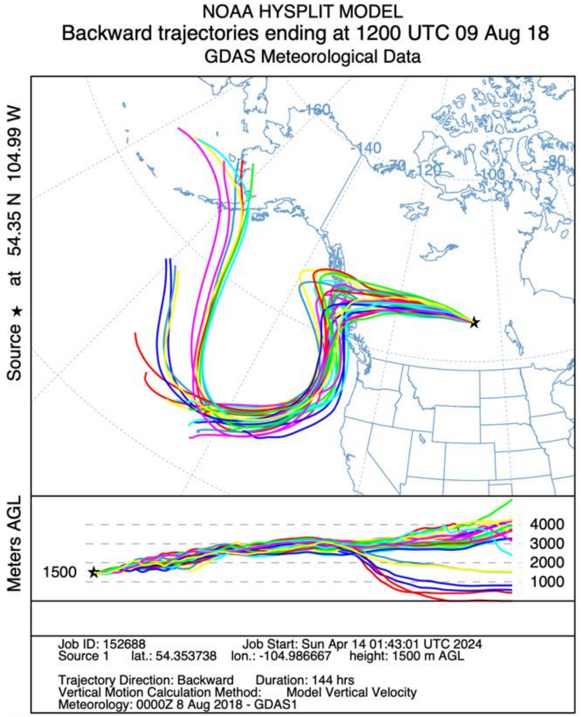
Data & Method: Why Scale the Injection Height?

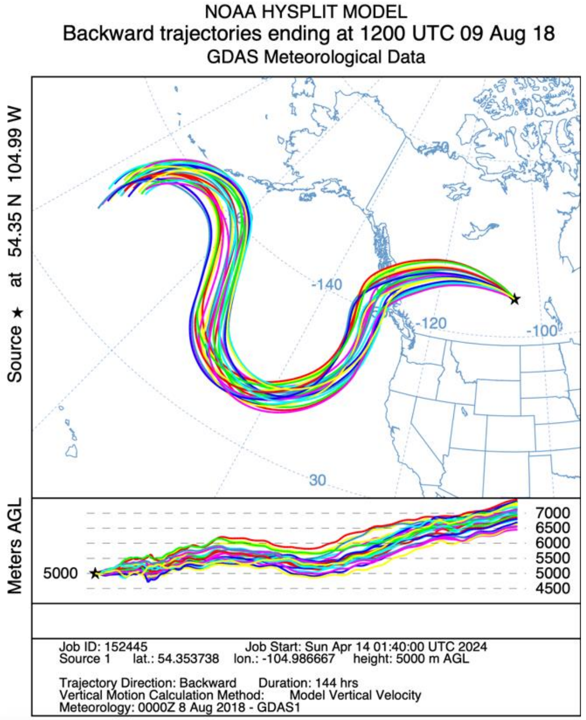
- **Issue: Underestimation**
- The ideal approach would be to use a plume rise model
  - Dynamically simulates the fire plume
  - Considering buoyancy effects and other physical dynamics of the plume.
  - Computationally expensive
- Thus GEOS-Chem Emission factor
  - Other group members are working on inverse modeling, which can improve the model estimates with better emission factors
- I am testing the impact different injection heights can make to the model.

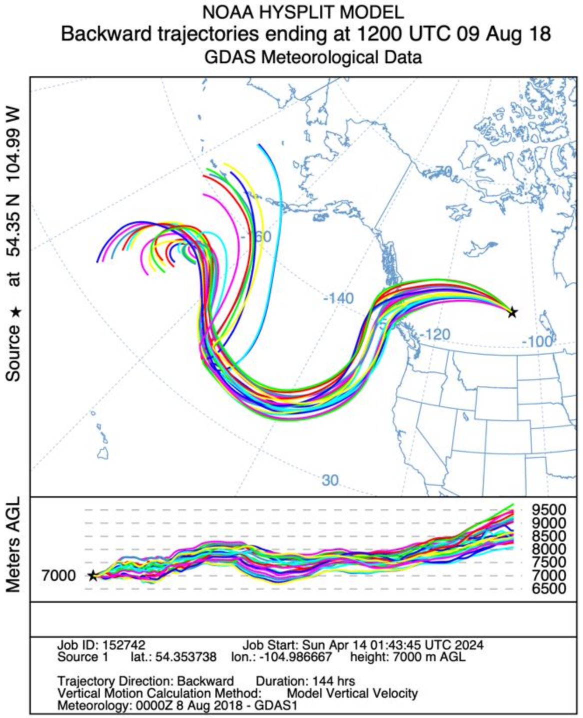


Data & Method: Trace Back the Air (August 9th)

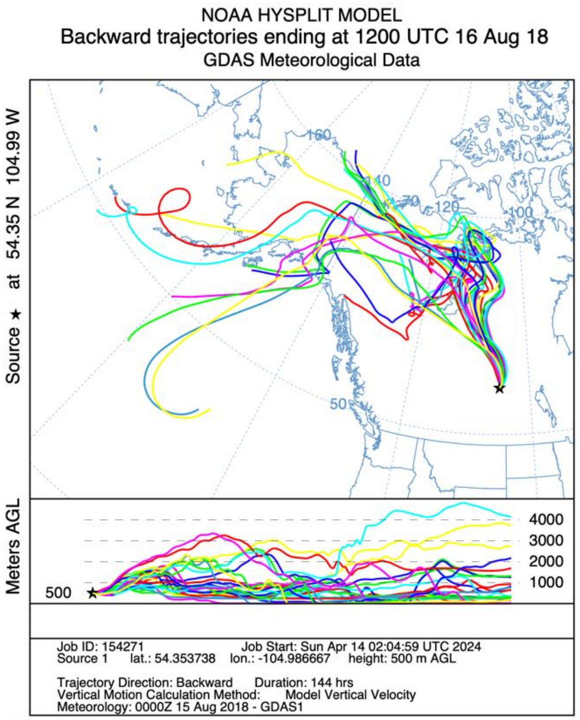


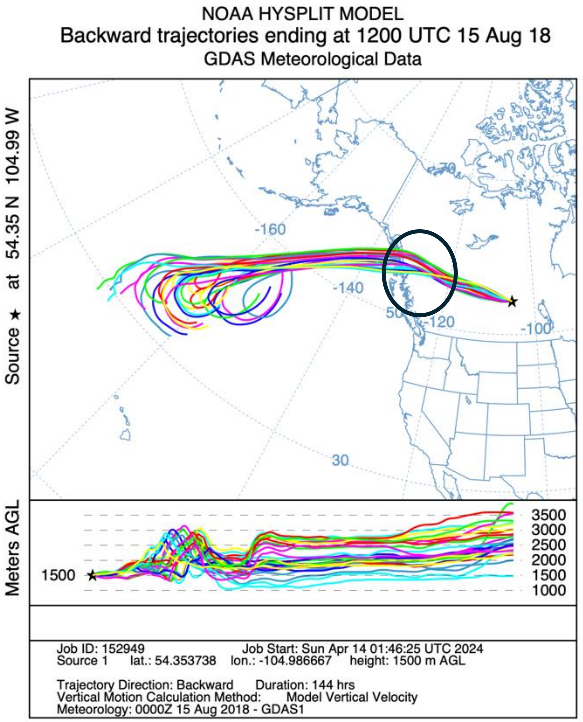


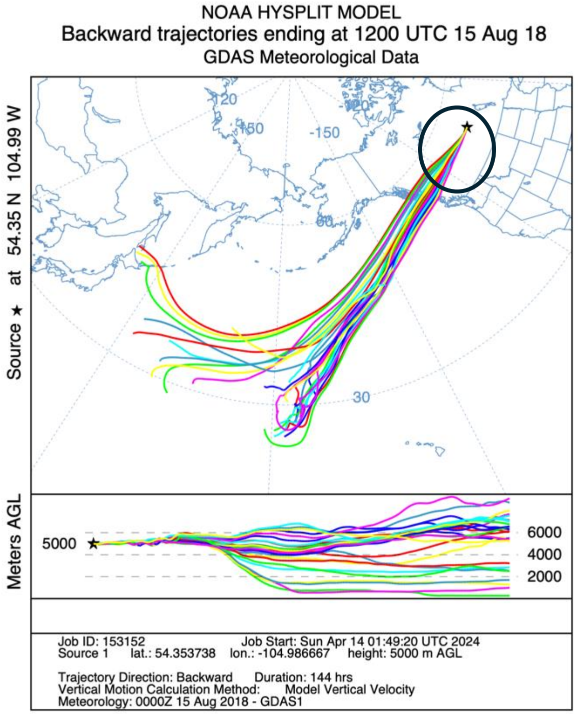


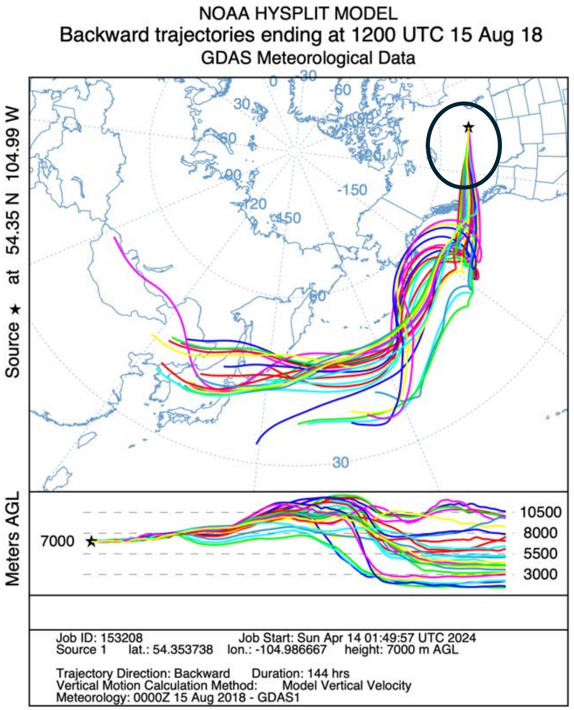


Data & Method: Trace Back the Air (August 15th)

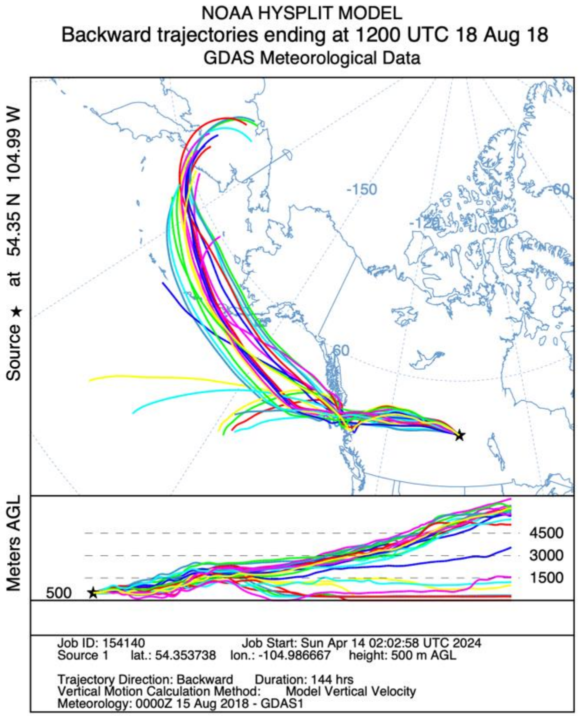


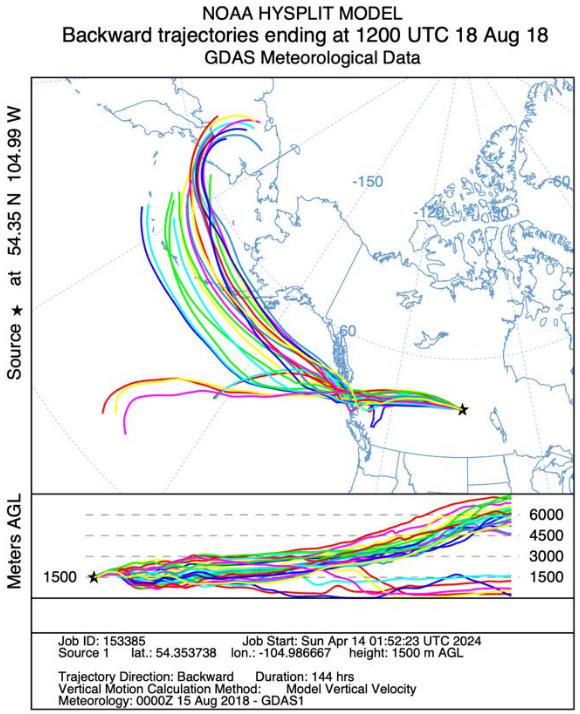


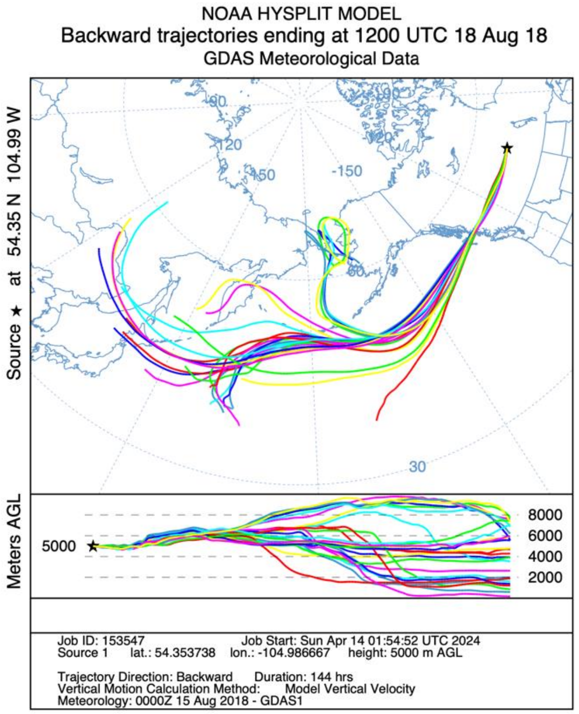


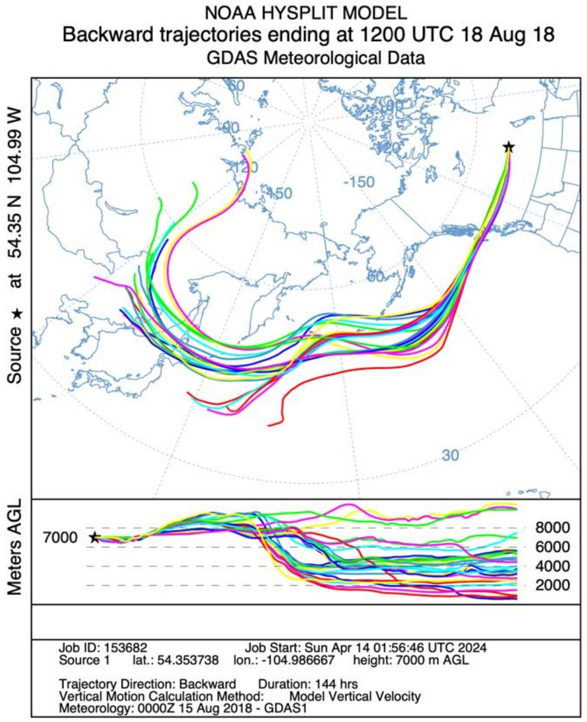


Data & Method: Trace Back the Air (August 19th)

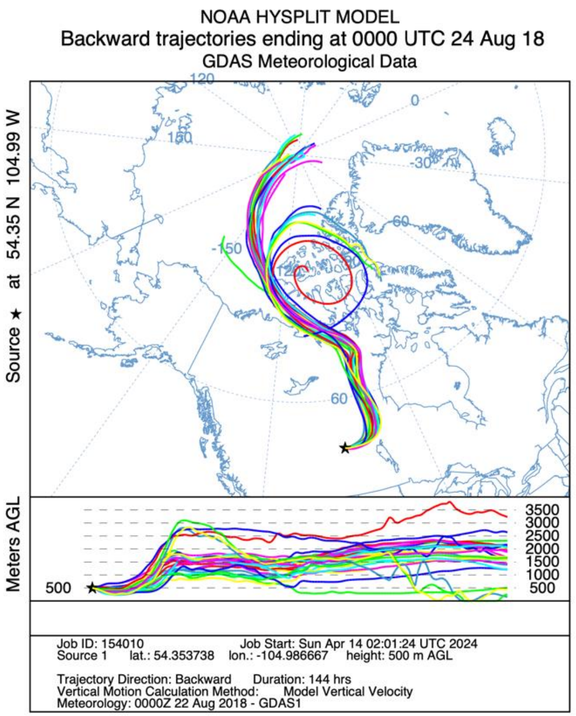


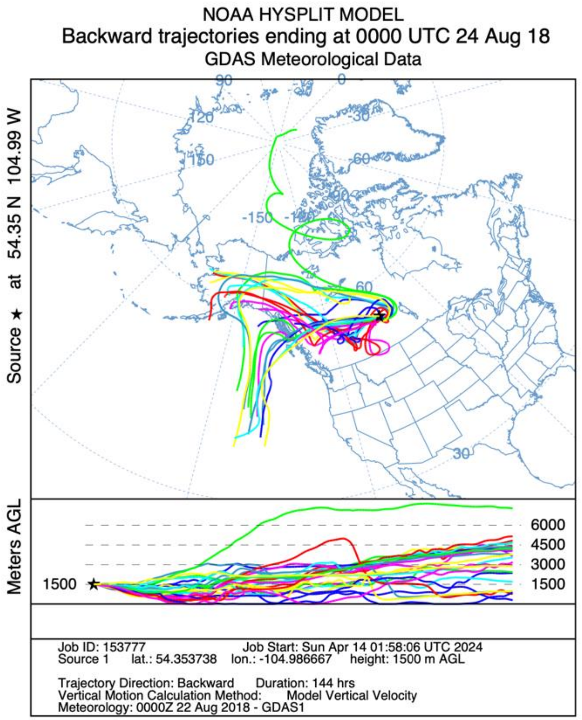


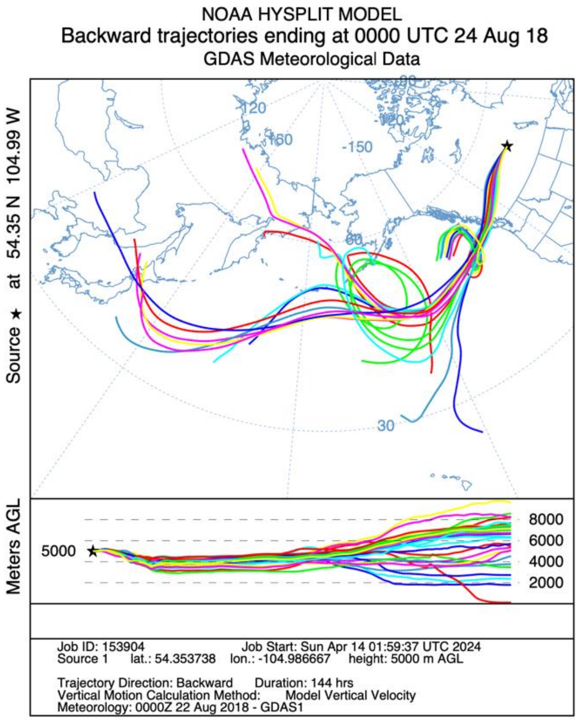


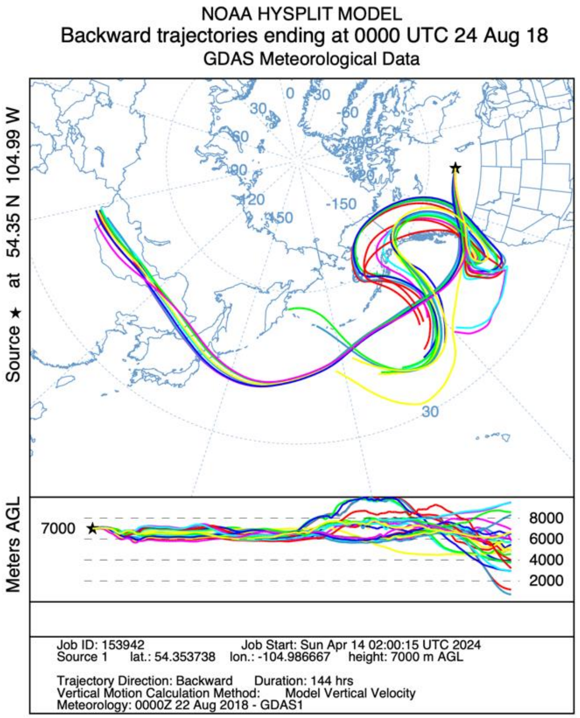


Data & Method: Trace Back the Air (August 24th)

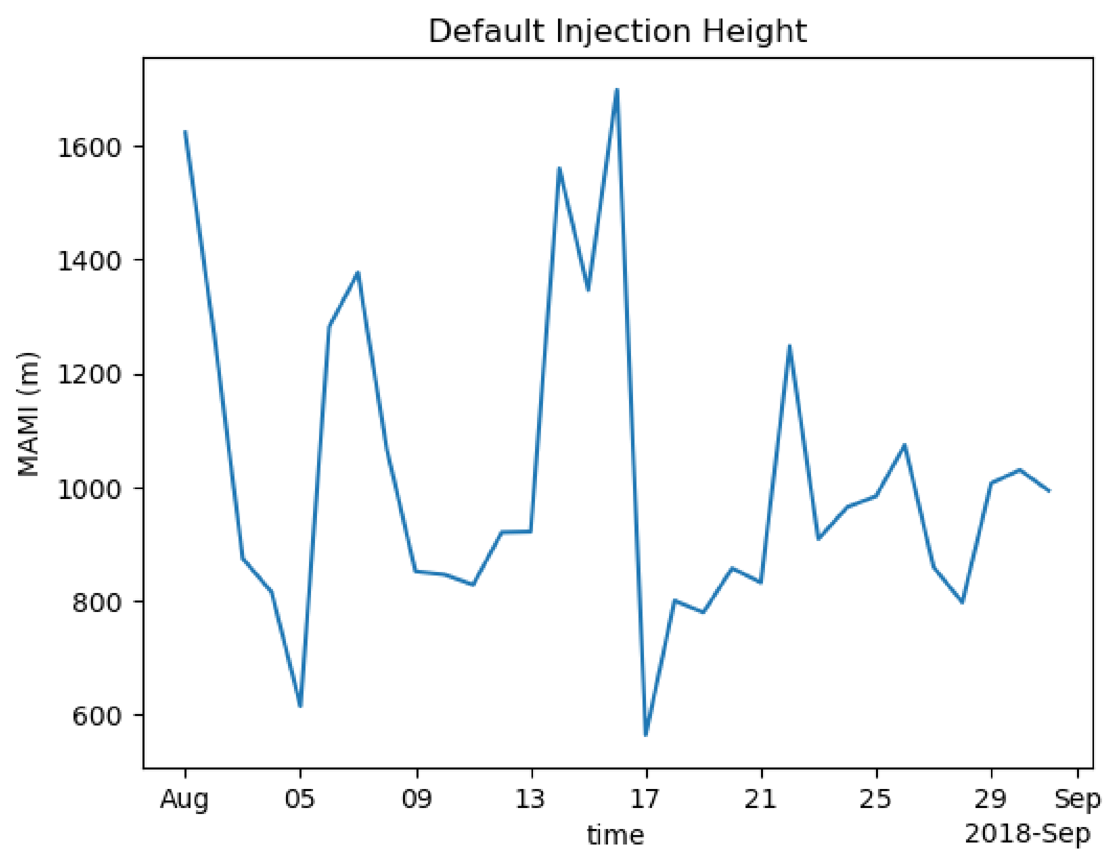


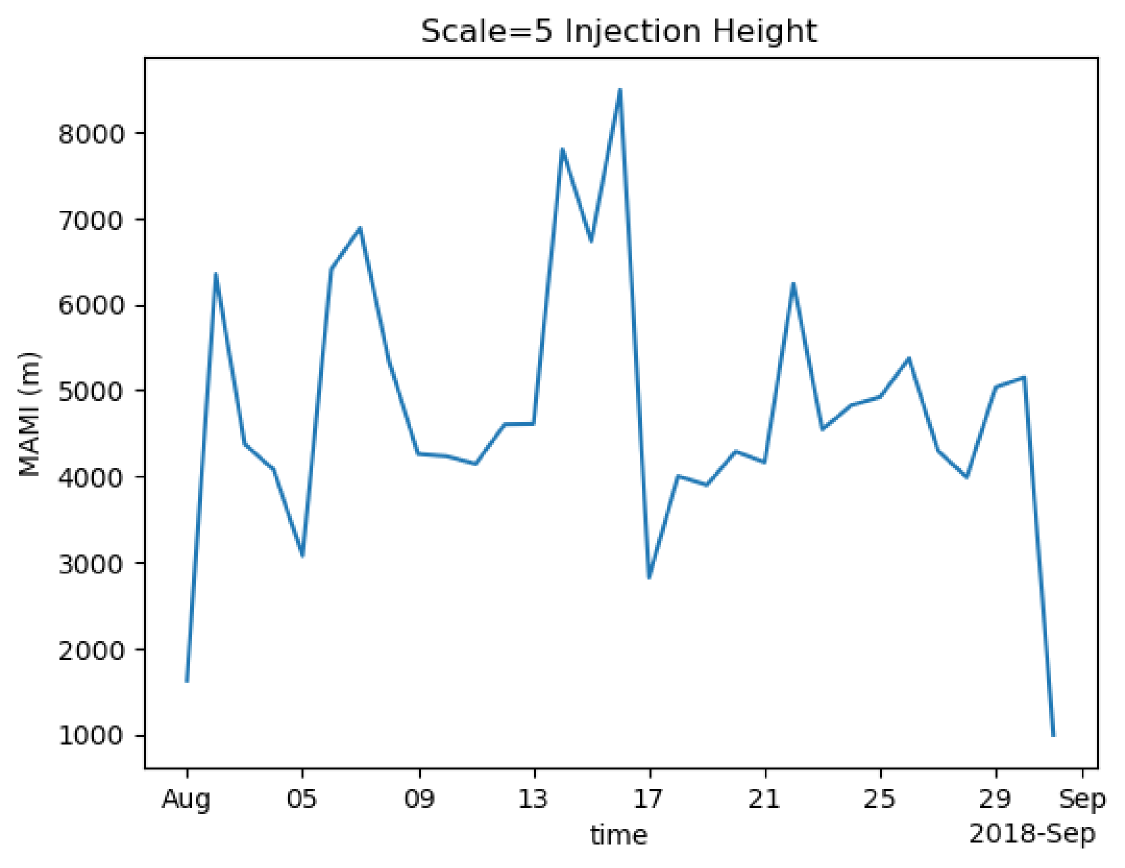




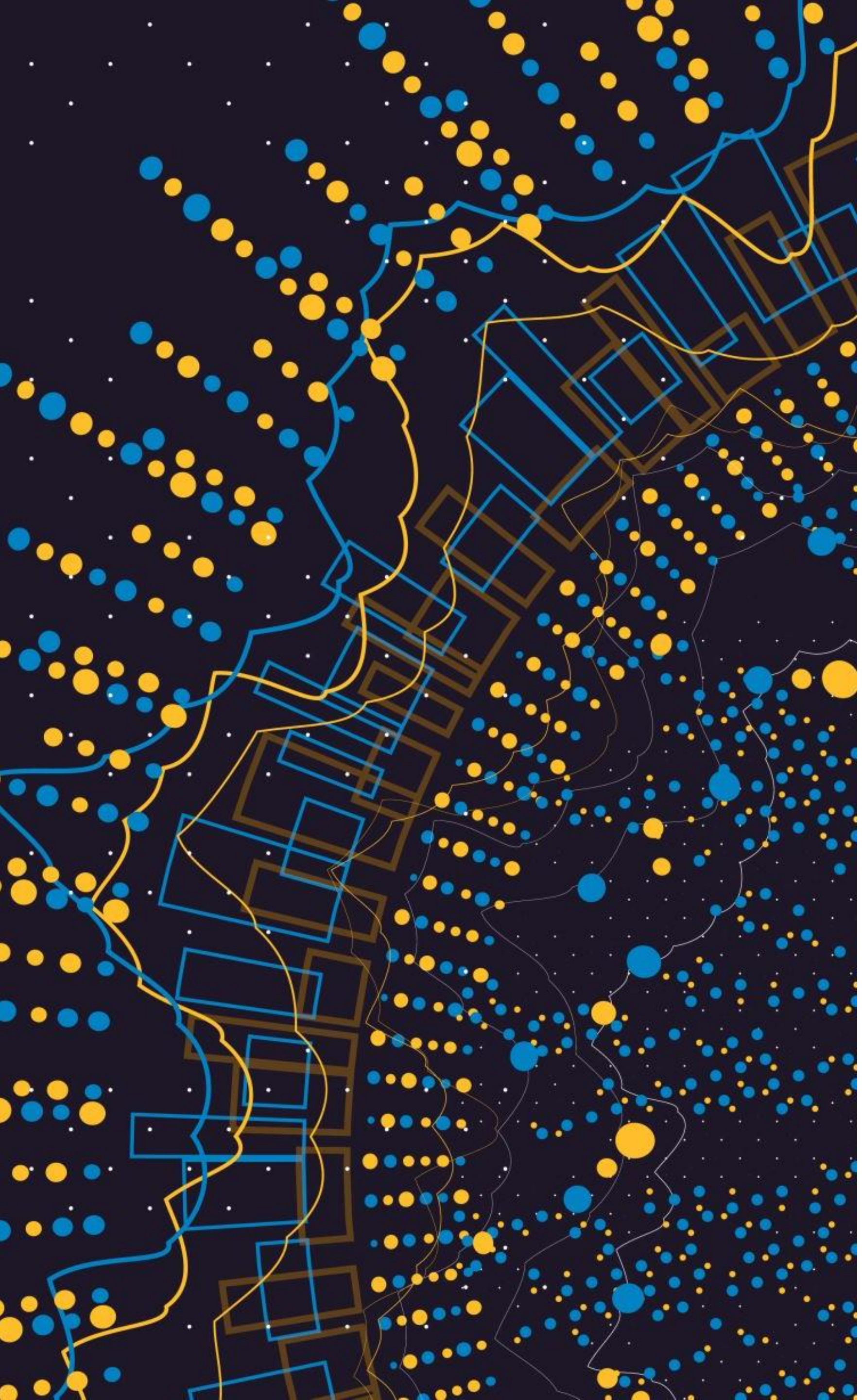


Data & Method: Choice of Injection Heights





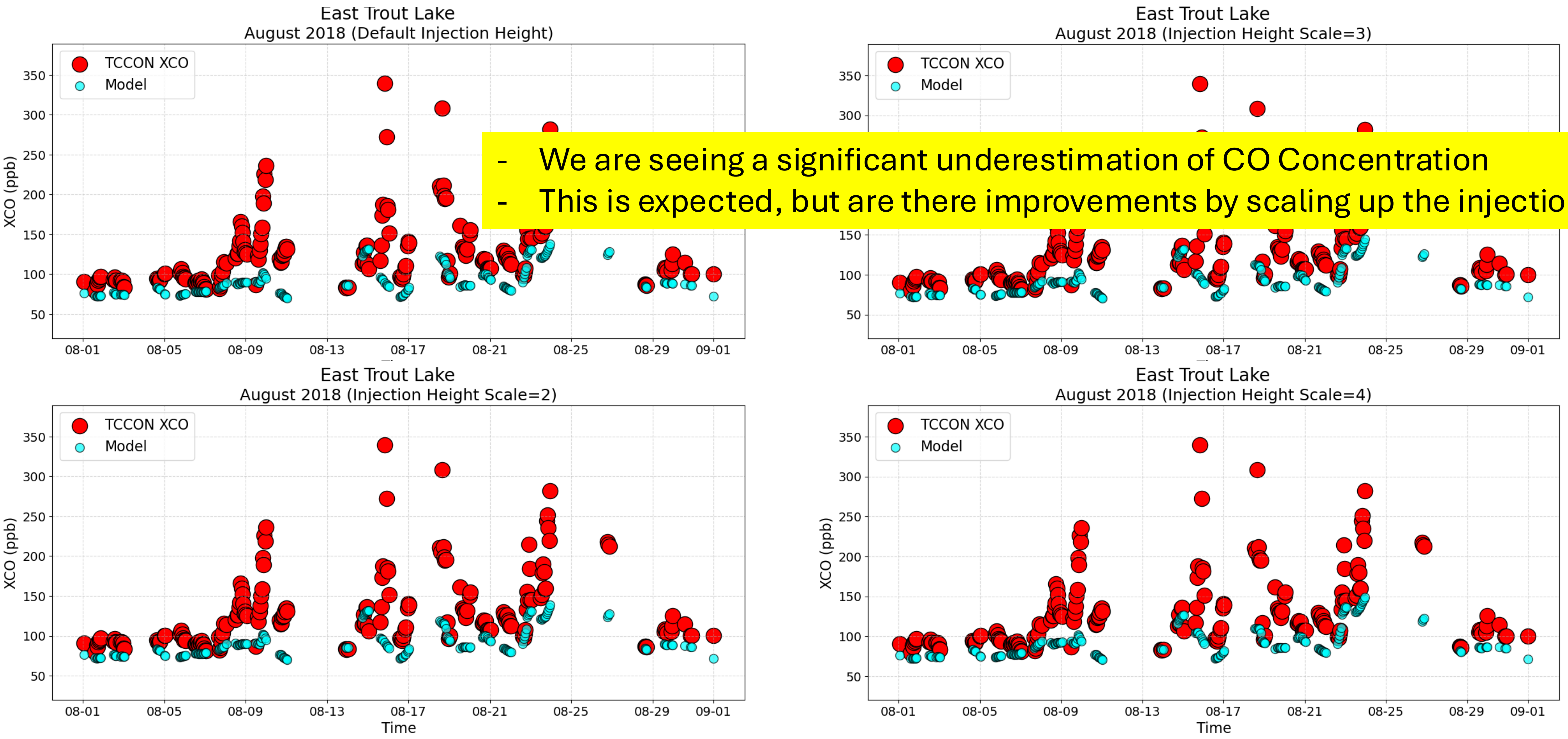
- It's difficult to simulate vertical distribution of fire plumes.
- By scaling the injection height, we can see how the CO concentration varies with the altitude.



GEOS-Chem Output VS. TCCON Data at ETL

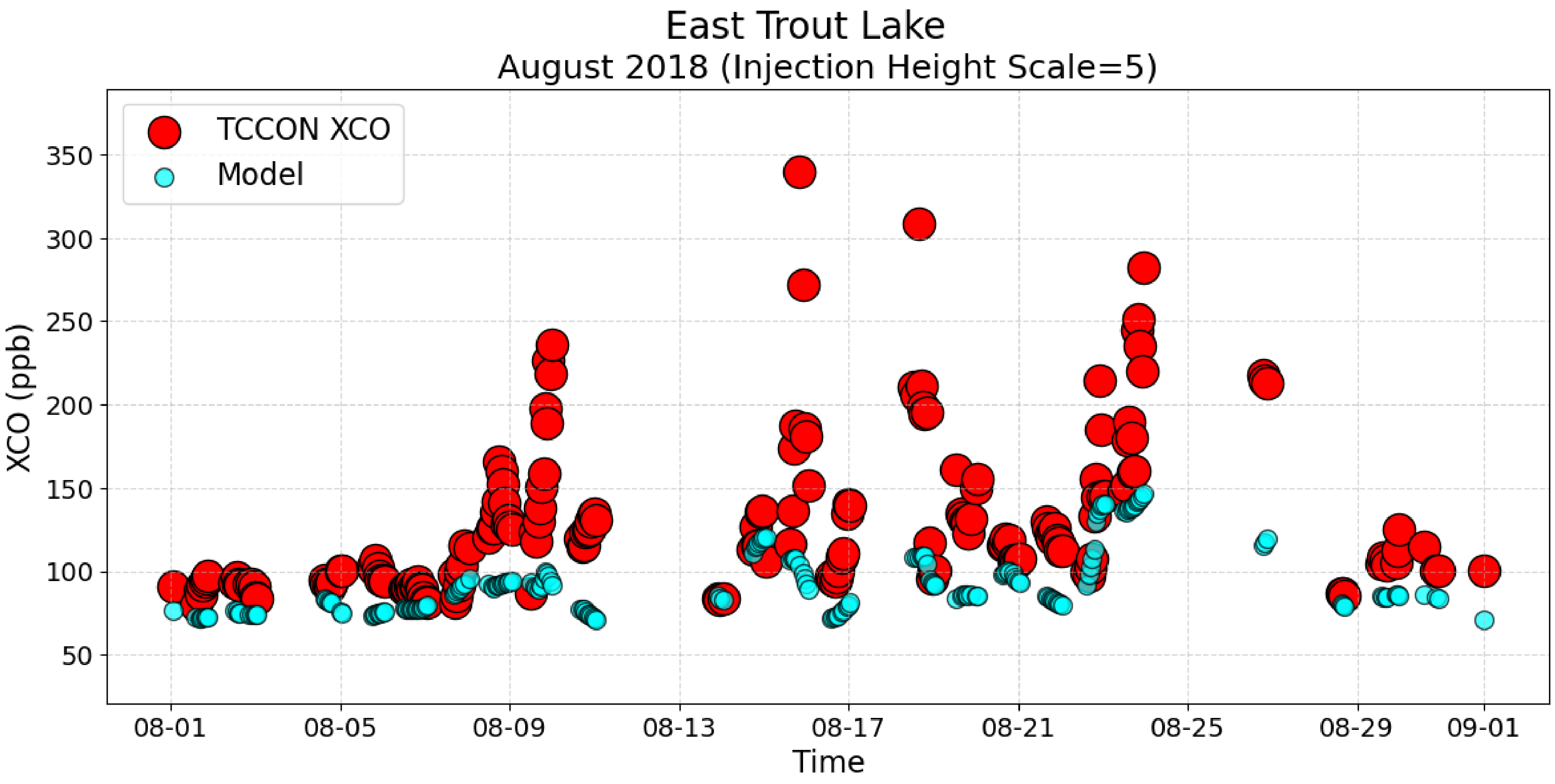
- TCCON data is critical for calibrating and validating satellite sensors, ensuring their accuracy in measuring atmospheric gases from space.
- **How does scaling the injection height change the correlation constant R?**

Results: Plot TCCON vs. Model

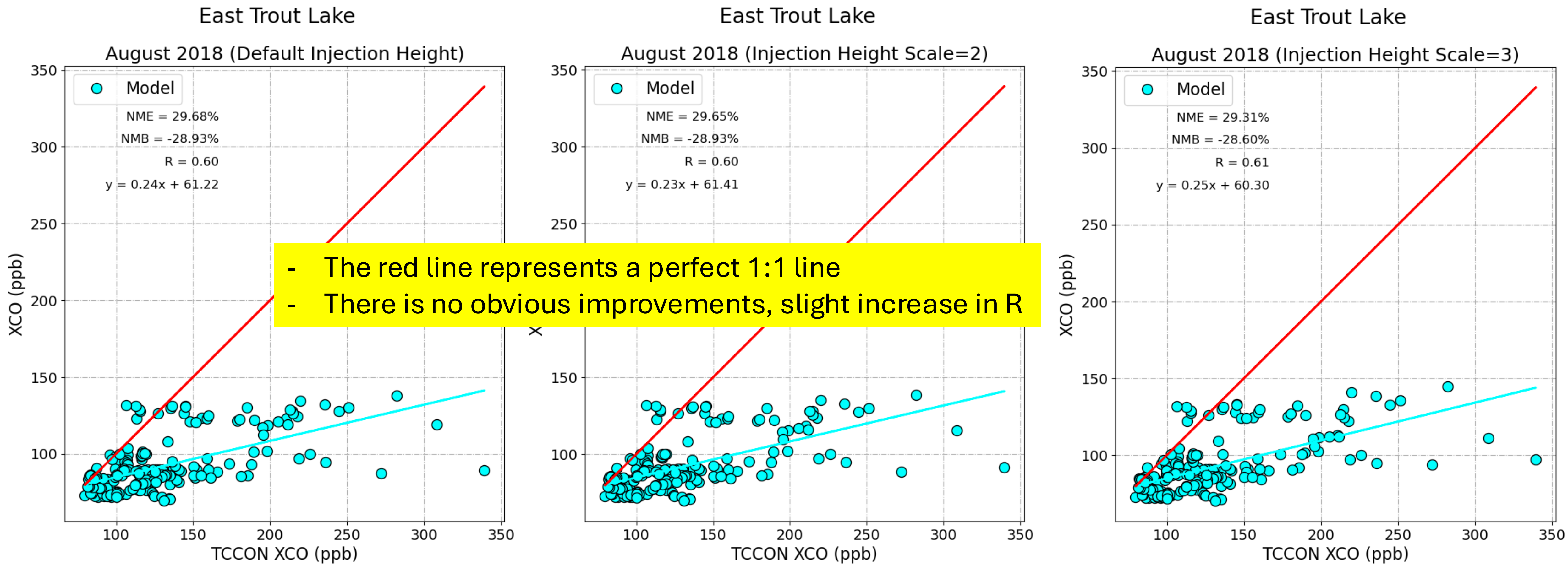


- We are seeing a significant underestimation of CO Concentration
- This is expected, but are there improvements by scaling up the injection height?

Results: Plot TCCON vs. Model

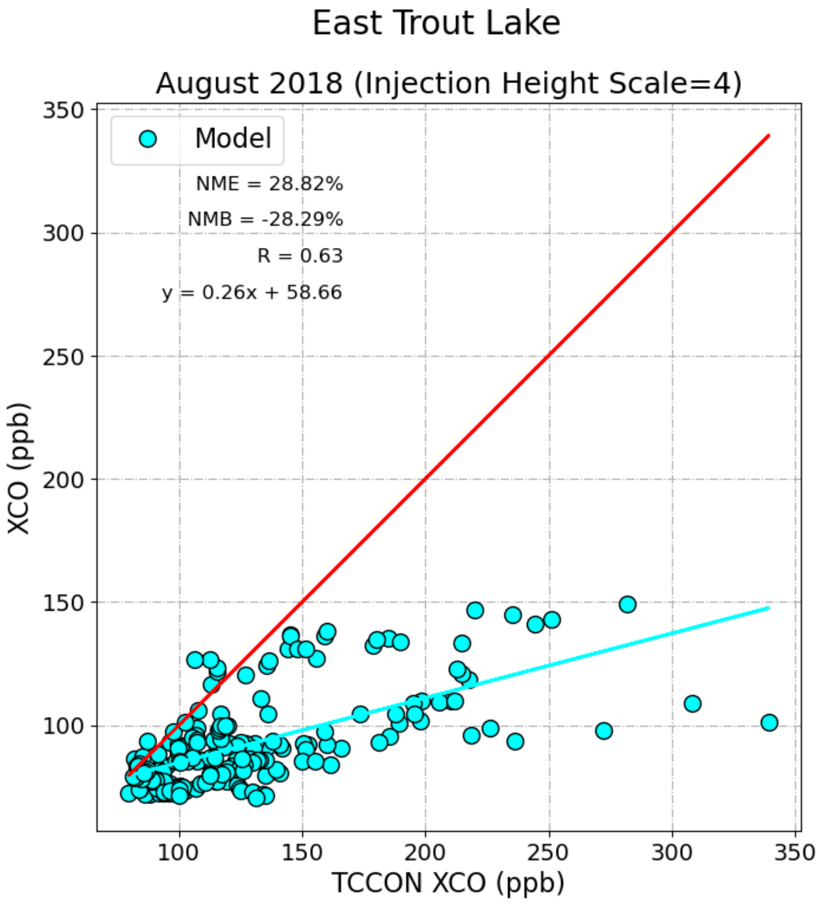


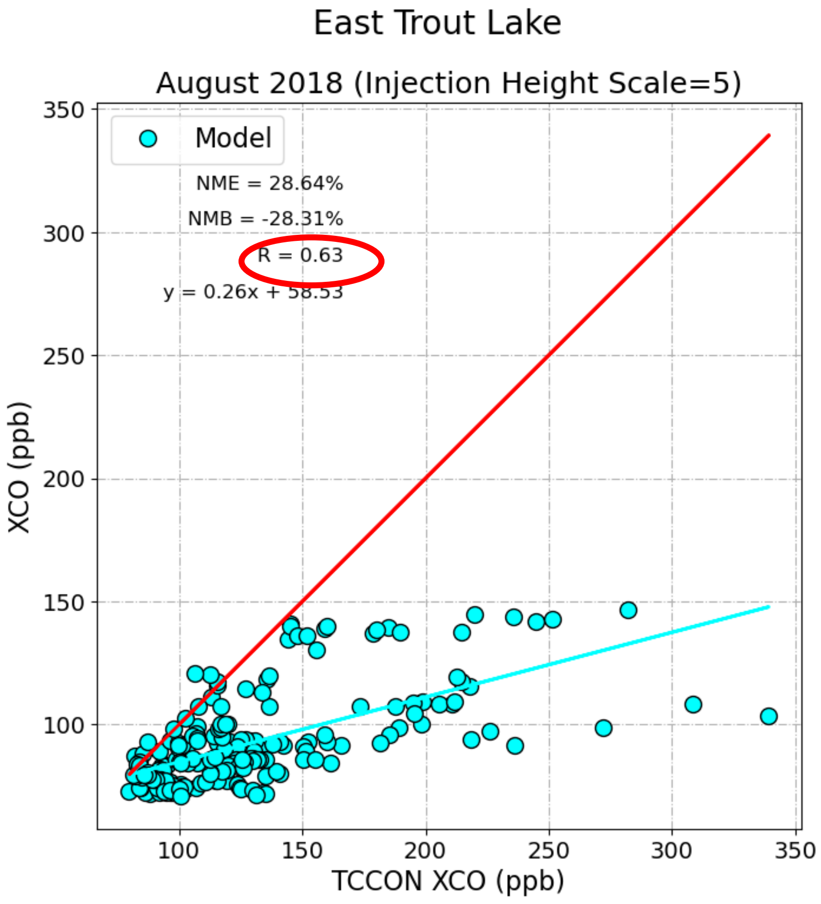
Results: Correlation TCCON vs. Model



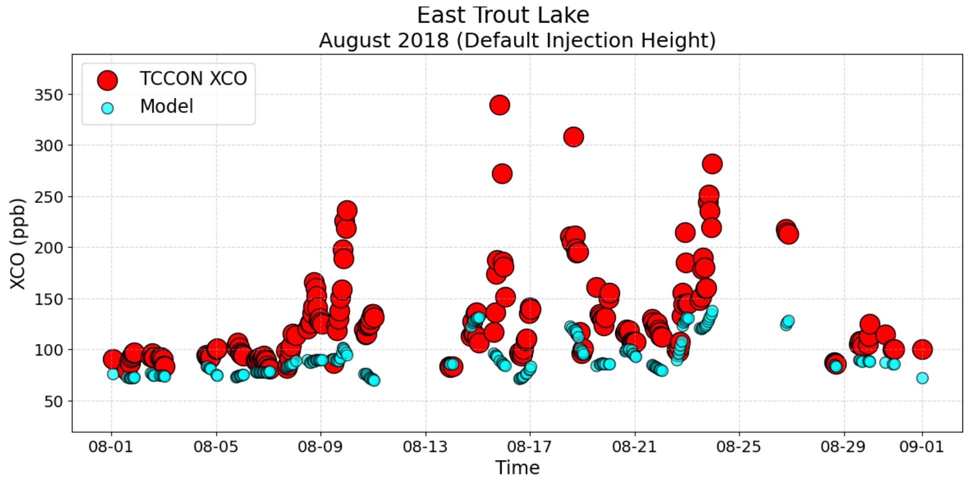
- The red line represents a perfect 1:1 line
- There is no obvious improvements, slight increase in R

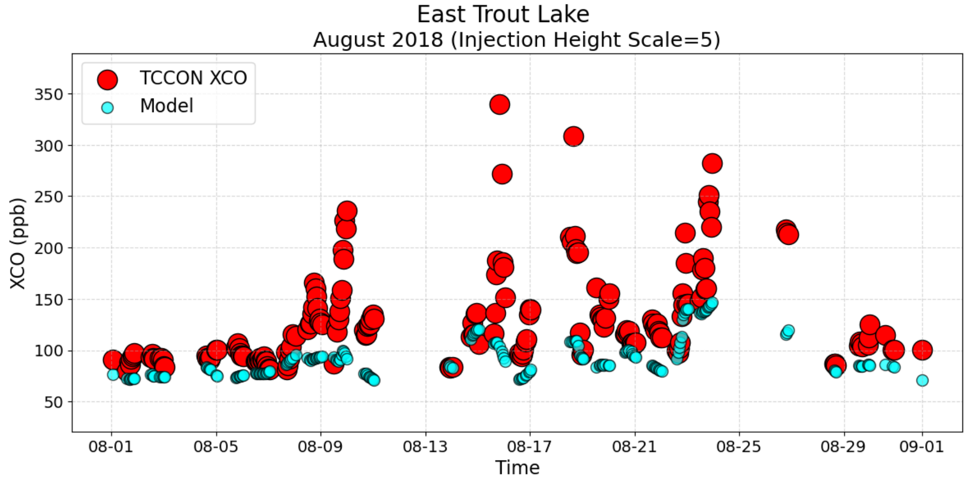
Results: Correlation TCCON vs. Model

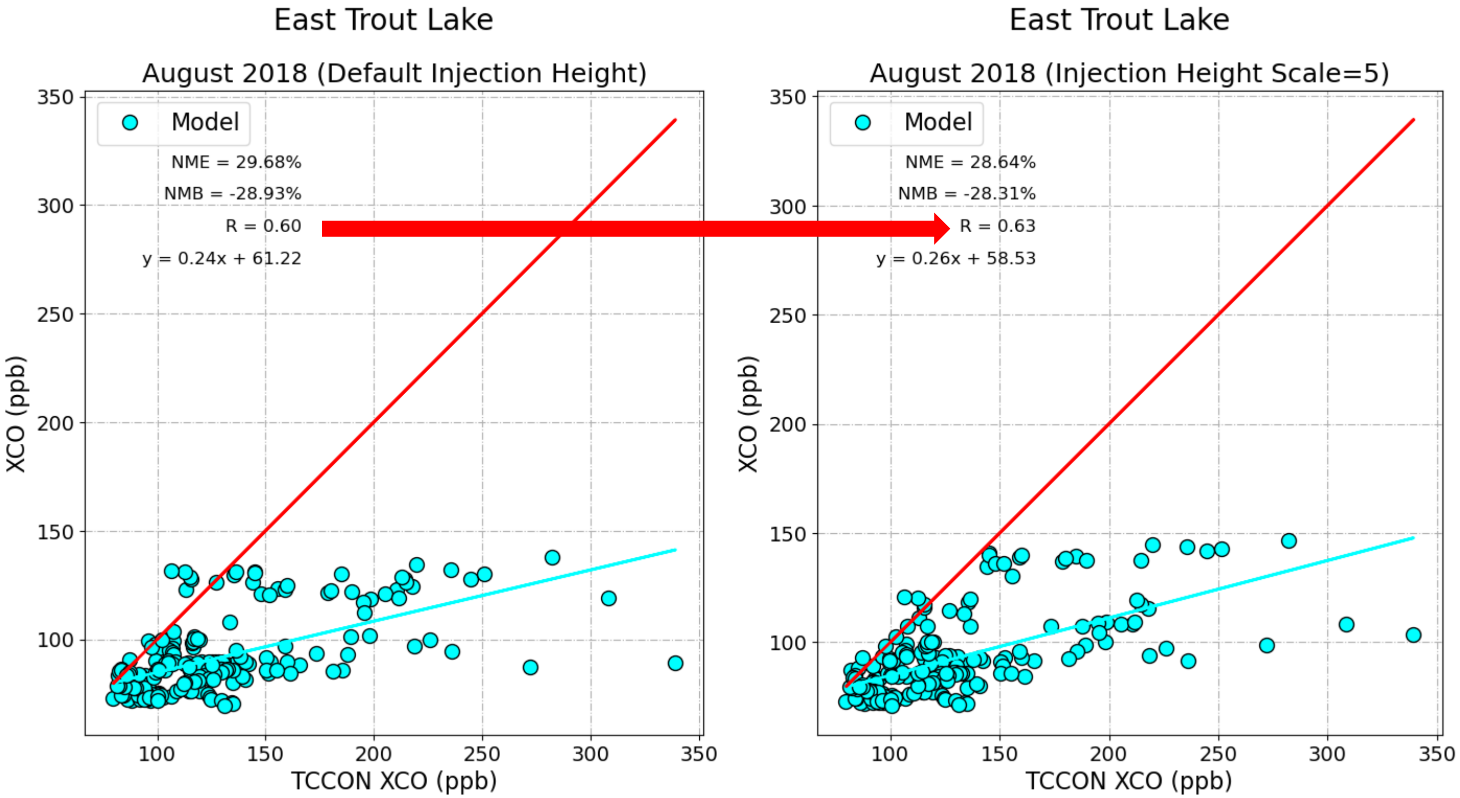




Results: Correlation TCCON vs. Model



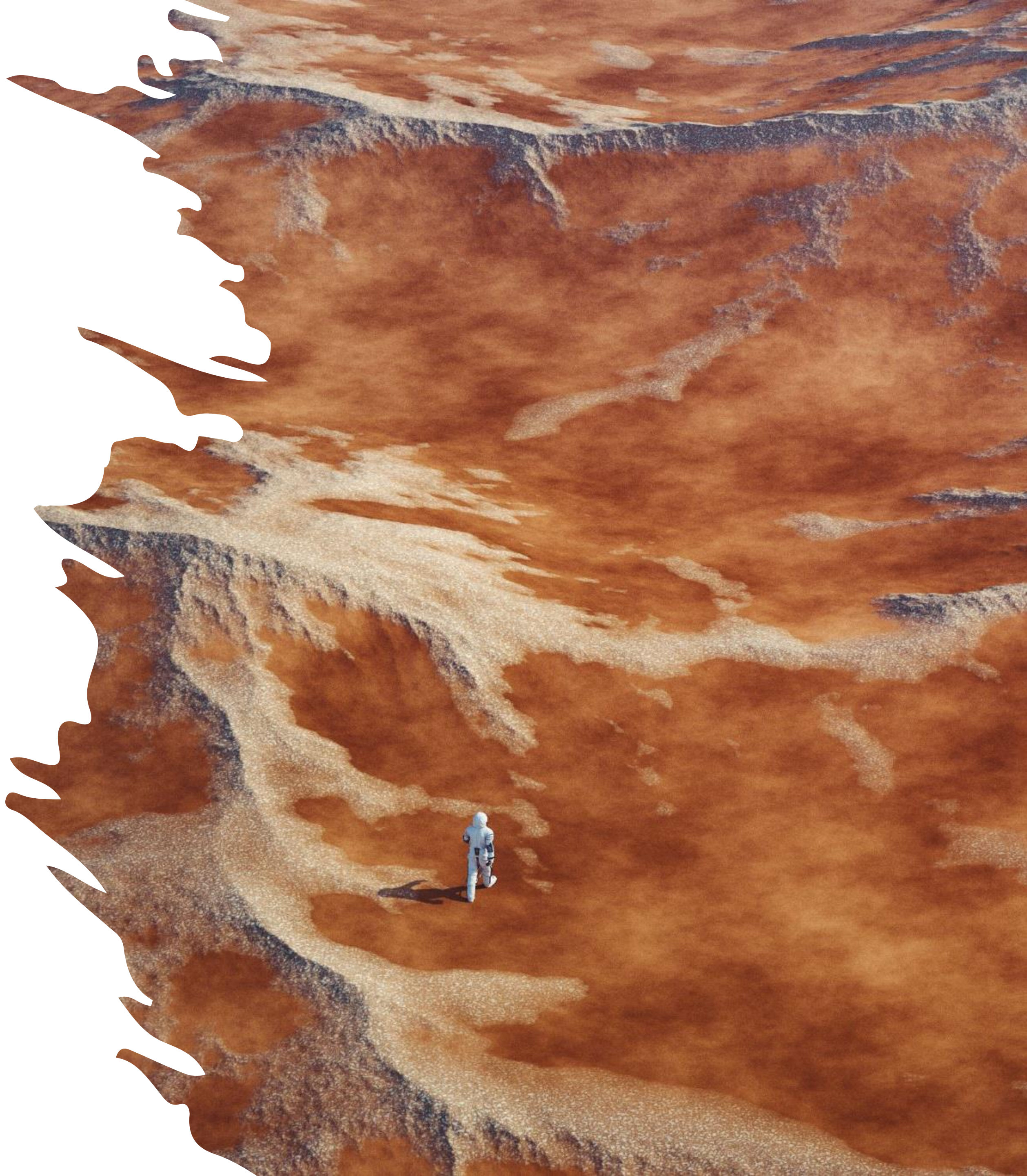




Possible Explanations/Interpretations

- At higher altitudes, atmospheric conditions are more influenced by upper-air patterns and less by direct surface processes.

- The upper troposphere is critical for the development of weather systems. It plays a significant role in the long-range transport of atmospheric pollutants and moisture.



Future Directions

- Run GEOS-Chem model with higher resolution (i.e. GCHP)
- Compare GEOS-Chem against a different source of data on East Trout Lake CO Concentration.
- Look at different locations (other than East Trout Lake)
- Look at different dates (other than August 2018)
- Investigate other possible reasons behind model underestimation

Conclusion

- At lower troposphere, particularly below PBL, we cannot distinguish where the air parcels actually came from.
- The sensitivity test shows a moderate increase in correlation between TCCON data and GEOS-Chem outputs as we scale the injection height to upper troposphere.
- Further tests are needed to investigate the underestimation of CO in GEOS-Chem.

Q & A

Reference

2018 CO Measurement:

https://www.canada.ca/en/environment-climate-change/services/national-pollutant-release-inventory/tools-resources-data/carbon-monoxide.html

What is biomass burning:

https://eospso.nasa.gov/sites/default/files/publications/BiomassBurn_final_508_0.pdf

Wildfire Map:

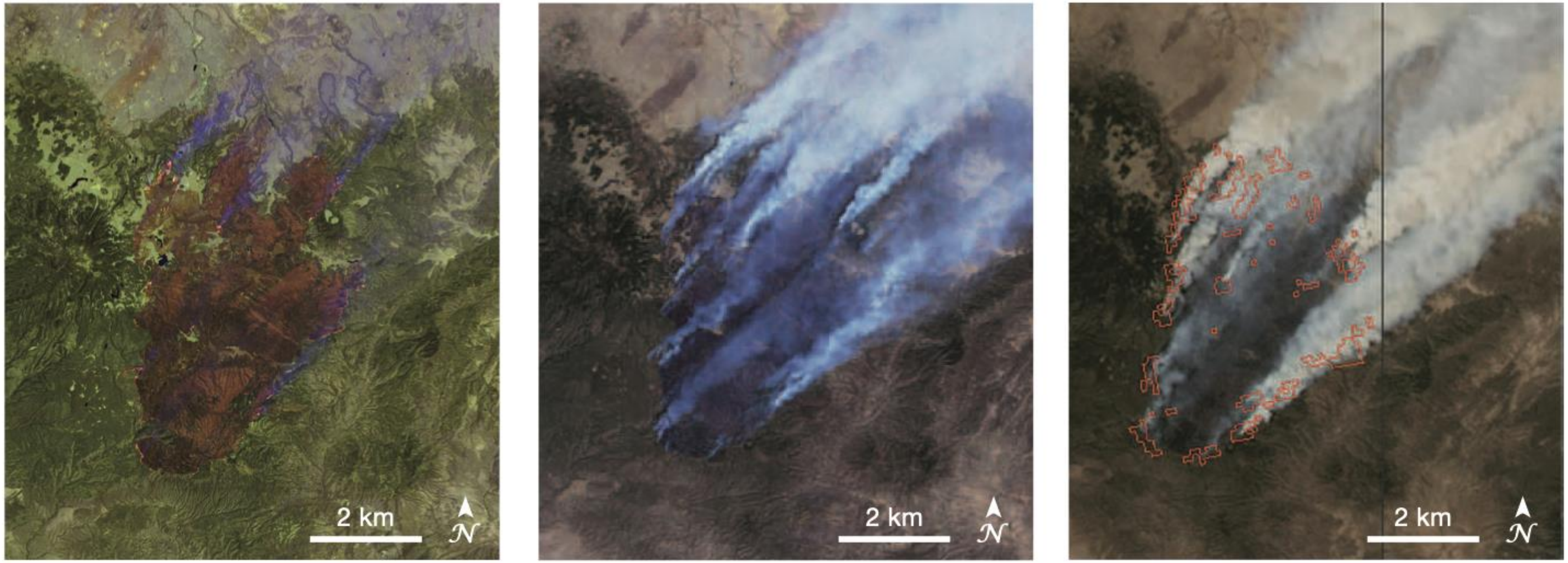
https://firms.modaps.eosdis.nasa.gov/map/#d:2018-08-09..2018-08-15;@-128.1,0.0,2.8z

Air Parcel Backtrace Trajectory:

https://www.ready.noaa.gov/hypub-bin/trajsrcm.pl

TCCON Information:

http://www.tccon.caltech.edu



June 7, 2011—Landsat 7 *June 7, 2011—MISR on Terra* *June 8, 2011—MODIS on Aqua*

Reference– The Wallow Fire

Role of Satellite Imagery:

- Satellite images were pivotal in surveying and documenting the fire's scope and new hotspots.
- They helped differentiate between severely, moderately, and lightly burned areas.

Reference– Carbon Cycle

The Carbon Cycle: An essential process in Earth's system involving the exchange of carbon among the biosphere, geosphere, hydrosphere, and atmosphere. It's driven by plant photosynthesis, which converts CO2 into organic matter, and respiration by animals and microbes, releasing CO2 back into the atmosphere.

1. **Carbon Reservoirs**:
   1. Earth's forests, oceans, and vast grasslands act as "sinks," absorbing more CO2 than they emit.
   2. Forests, in particular, play a major role by storing carbon, and their old-growth forests are significant carbon reservoirs.
2. **Decomposition and Fires**:
   1. Decomposers break down organic matter, enriching the soil with nutrients.
   2. Forest floors accumulate this organic matter, which can fuel forest fires, a natural part of ecosystem balance maintained by periodic fires and regrowth.
3. **Carbon Reservoir Changes**:
   1. Reservoirs are replenished with new vegetation, especially during growing seasons.
   2. Changes in carbon reservoirs can lead to fluctuations in the global carbon cycle and climate.
4. **Human Impact and Natural Processes**:
   1. Activities like burning fossil fuels and natural fires contribute to CO2 emissions, altering atmospheric composition.
   2. Scientists monitor these changes and the impact on Earth's climate system.
5. **Advanced Monitoring**:
   1. Global efforts are underway to develop new instruments for monitoring biomass burning from space and mapping shifts in biomass burning patterns.
   2. These efforts are crucial for understanding and predicting Earth's climate system and the impact of human activities.

Reference– Inverse Modeling

- **Collection of Observational Data**: Gather data on CO concentrations from various sources such as ground monitoring stations, aircraft, or satellites.
- **Set Up a Chemical Transport Model**: Utilize a chemical transport model that can simulate how emitted CO disperses, reacts, and changes under various atmospheric conditions over time and space.
- **Initial Emission Estimates**: Start with estimated emissions based on factors like the type and amount of fuel burned, typical emission factors for different combustion processes, or regulatory data.
- **Run the Model Forward**: Input the initial emission estimates into the model to simulate how these emissions would lead to atmospheric concentrations.
- **Comparison and Adjustment**: Compare the model's output of CO concentrations with the actual observed data. Identify where discrepancies occur.
- **Optimize Emissions**: Adjust the emission parameters iteratively, using optimization algorithms to reduce the discrepancies between modeled and observed CO concentrations. This might involve changing the magnitude, timing, or location of the emissions.
- **Convergence and Validation**: Repeat the process until the model outputs closely match the observational data or until further adjustments do not significantly improve the match. Validate the findings with additional data if available.
- **Interpret Results**: Interpret the adjusted emission parameters to provide insights into the real-world emission scenarios. This might include identifying underestimated sources, verifying emission regulations, or understanding the impact of environmental policies.

Reference- Eulerian vs. Lagrangian Models

- 5.1 Eulerian Form
- Derivation: The chapter starts by deriving the continuity equation in the Eulerian form, which is based on a fixed coordinate system attached to the Earth. It discusses how the number density of a species within an atmospheric volume changes due to transport (flux), sources (emissions and chemical production), and sinks (chemical loss and deposition). The mathematical formulation involves the flux divergence, which is the net flux entering and leaving a control volume.
- Discretization: It then discusses the numerical methods to solve the continuity equation, highlighting the discretization over a spatial grid. This involves separating the continuity equation into advection, turbulence, and chemistry terms, each integrated using different numerical operators. This process, known as operator splitting, helps make the complex calculations tractable by assuming that these processes are independent over small time steps.

- 5.2 Lagrangian Form
- General Description: The Lagrangian form, on the other hand, describes the continuity equation relative to a moving frame of reference, following air parcels or particles as they move through the atmosphere. It involves a transition probability density that describes where a fluid element starting at a specific location and time is likely to be found at a later time.
- Applications and Limitations: The chapter explains that the Lagrangian form is useful for modeling the dispersion of pollutants from a source and can be solved analytically in certain cases, such as when the turbulent motions are Gaussian. However, it also mentions that evaluating the transition probability density (Q) is complex and that the Lagrangian form is less suited for representing non-linear chemical processes because the overlapping trajectories of fluid elements can interfere with each other.

More on Carbon Monoxide

- Sources of CO: Include fossil fuel combustion, biomass burning, vegetation, oceans, and oxidation of methane and other hydrocarbons. The estimates for these sources range broadly, with fossil fuel combustion and biomass burning being substantial contributors.

- Sinks of CO: The primary sink for CO in the troposphere is oxidation by OH, which results in a mean lifetime of about two months. This rapid turnover contributes to CO concentrations that are not well-mixed globally, leading to variability from 50 ppbv in remote areas to several ppmv in urban environments where it poses health risks.