Improving CMAQ Wildfire Prediction

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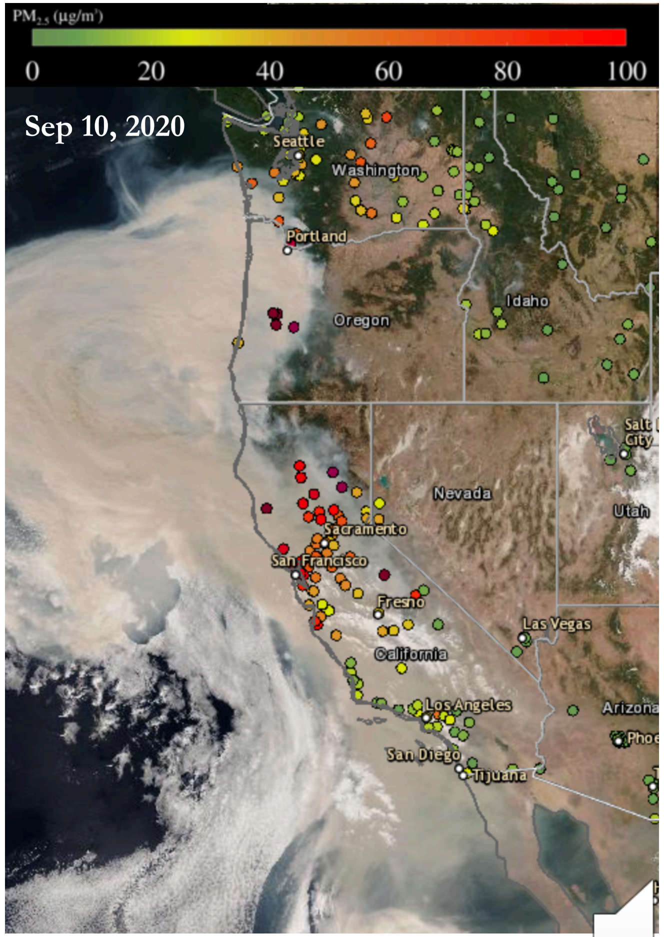
BACKGROUND

- Biomass burning releases a vast amount of aerosols into the atmosphere, often leading to **severe air quality and health problems**.
- Wildfires pose an **increasing threat to human lives and properties**, as shown in the 2018 CA Camp Fires, and 2020 CA-OR-WA wildfires.
- Wildfire forecasting provides critical information to air quality and public health managers.
- In this study, **two improvements** related to **wildfire emission transport** are added to the CMAQ V5.3.1.
  - **New Plume rise scheme**
  - **New emission species and chemistry reactions**



(Source: NOAA AerosolWatch)

I. NEW PLUME RISE SCHEMES

- Previous studies (Li et al., 2020) found that plume injection height has great impact on wildfire emission transport.
  - A **higher**/**lower** plume injection height will **decrease**/**increase** surface polluted level.
  - A **higher**/**lower** plume injection height will **increase**/**decrease** the size of the polluted area.
- The default plume rise scheme in the CMAQ is based on **Briggs** (1969).
- We added the **Sofiev** et al. (2012) plume scheme which is designed for wild-land fires to the CMAQ model.
  - The Sofiev scheme uses fire Radiative Power (FRP) and Planetary Boundary Layer (PBL) height to calculate the plume injection height

I. NEW PLUME RISE SCHEMES

A. SCHEME COMPARISON

- Default: Based on Briggs (1969)

$$H_p = \begin{cases} 1.33\, B\, U^{-1}\, x^{*-2} & neutral \\ 2.6(B\, U^{-1}\, s^{-1})^{\frac{1}{3}} & stable \\ 30\, (B\, U^{-1})^{0.6} & unstable \end{cases}$$

B: Heat Flux

U: wind speed

x^*: friction velocity

s: static stability

- New: Sofiev et al. (2012)

$$H_p = \alpha H_{PBL} + \beta \left(\frac{FRP}{P_{f0}}\right)^{\gamma} \exp\left(-\frac{\delta N_{FT}^2}{N_0^2}\right)$$

α, β, γ, δ: parameters
H_{PBL}: PBL Height
FRP: Fire Radiative Power
N_0: reference N
P_{f0}: reference FRP (Pf0=10 W)
N_{FT}: Brunt–Vaisala frequency at Free Troposphere;

Step 1: using parameter set 1 (α=0.15; β=102; γ=0.49; δ=0) to calculate a temporary injection height (H_t).

Step 2: If $H_t < PBL_h$ then use parameter set 2 (α=0.24; β=170; γ=0.35; δ=0.6) to calculate H_p; if $H_t > PBL_h$, then use parameter set 3 (α=0.93; β=298; γ=0.13; δ=0.7) to calculate H_p.

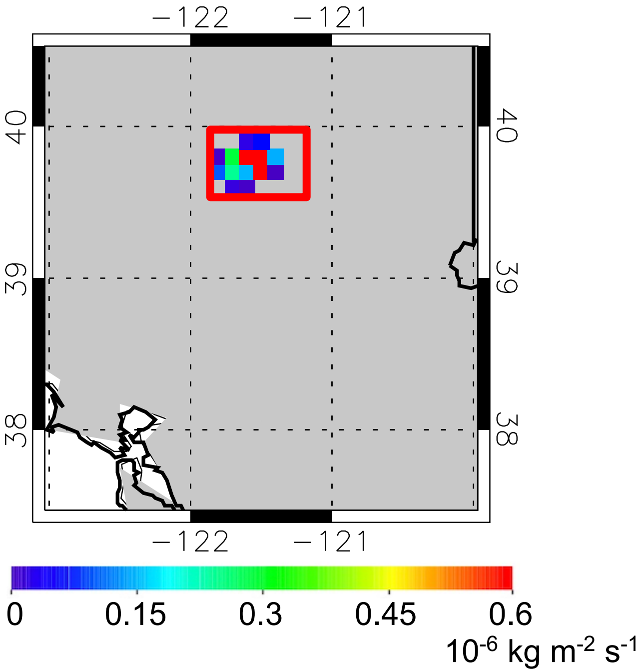
I. NEW PLUME RISE SCHEMES (CONTINUE)

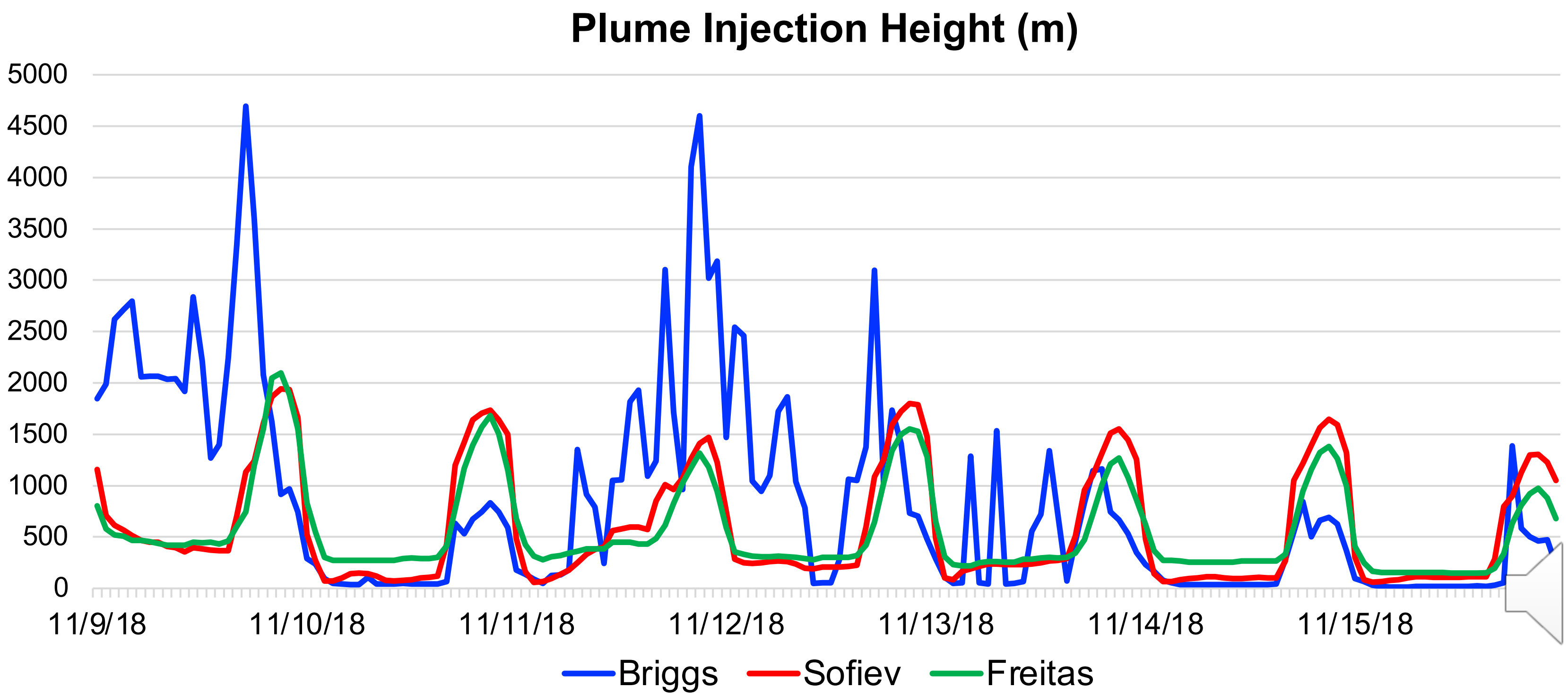
- We are going to add another widely used plume rise scheme - **Freitas** et al. (2006, 2007) – to CMAQ.
  - **Freitas** plume rise scheme is a 1-D sub-gird plume rise scheme, which was built upon governing equations for the first law of thermodynamics, continuity, and vertical motion.
- Box models were used to calculate the plume injection heights with CMAQ default (hereafter **Briggs**), **Sofiev**, and **Freitas** plume rise schemes.
- We compare the plume injection height results for three wildfire cases:
  1. Camp Fire: Nov 2018
  2. FIREXAQ: Aug 2019
  3. 2020 CA-OR-WA wildfire: Sep 2020
- The GBBEPx biomass burning emission dataset was used in this study.

I. NEW PLUME RISE SCHEMES
B. CAMP FIRE

- We calculated the averaged plume injection height within the red box from Nov 9-Nov 15, 2018.
- **Briggs** produces the highest injection height, and has more variations than **Sofiev** and **Freitas**.
- The results for **Sofiev** looks close to **Freitas**, except **Freitas** are higher than **Sofiev** during night.

PM2.5 Emission on Nov 9, 2018

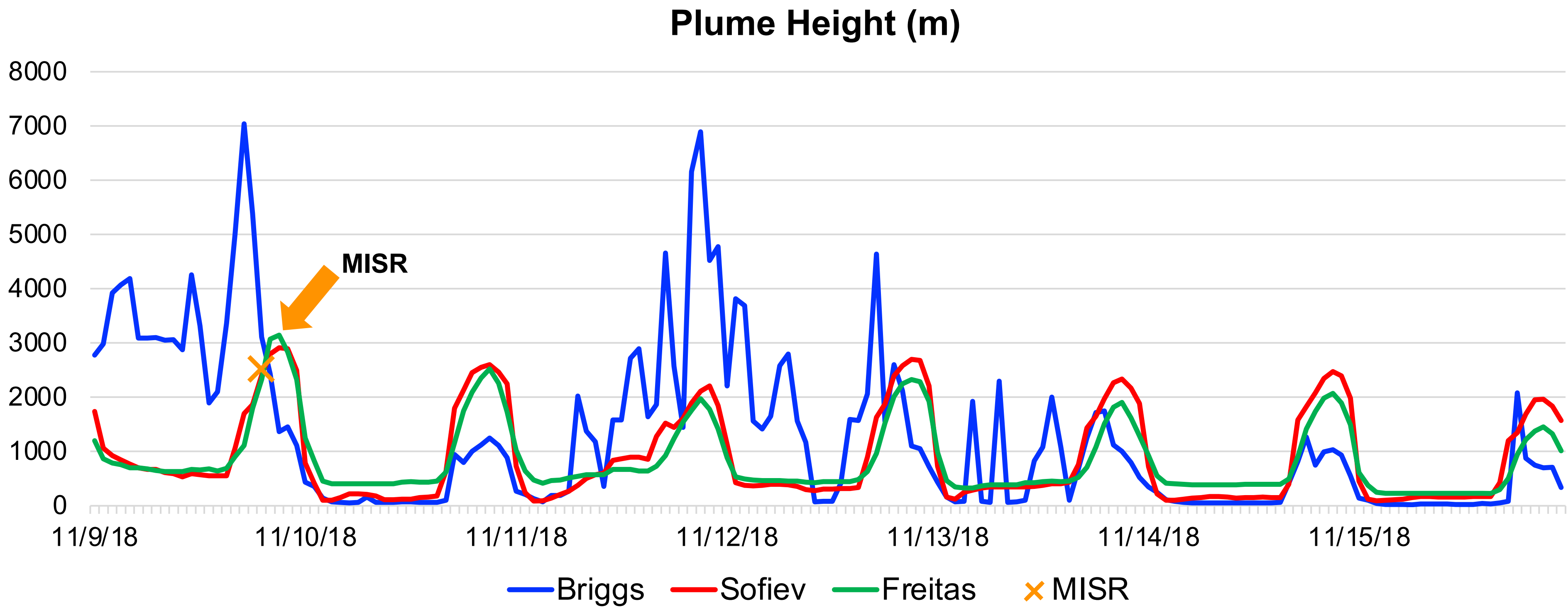




I. NEW PLUME RISE SCHEMES

B. CAMP FIRE (CONTINUE)

- The calculated plume height is compared with MISR observation at 19 UTC on Nov 9, 2018.
- In the CMAQ, the plume is distributed between 0.5-1.5 x Injection Height. Here, we use 1.5xInjection Height as plume height.
- All three results were close to MISR observation at that time.

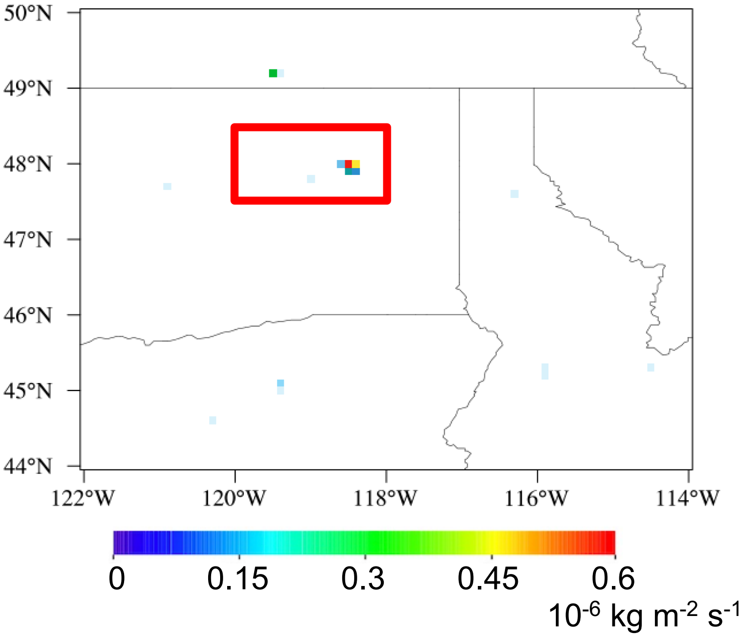


I. NEW PLUME RISE SCHEMES

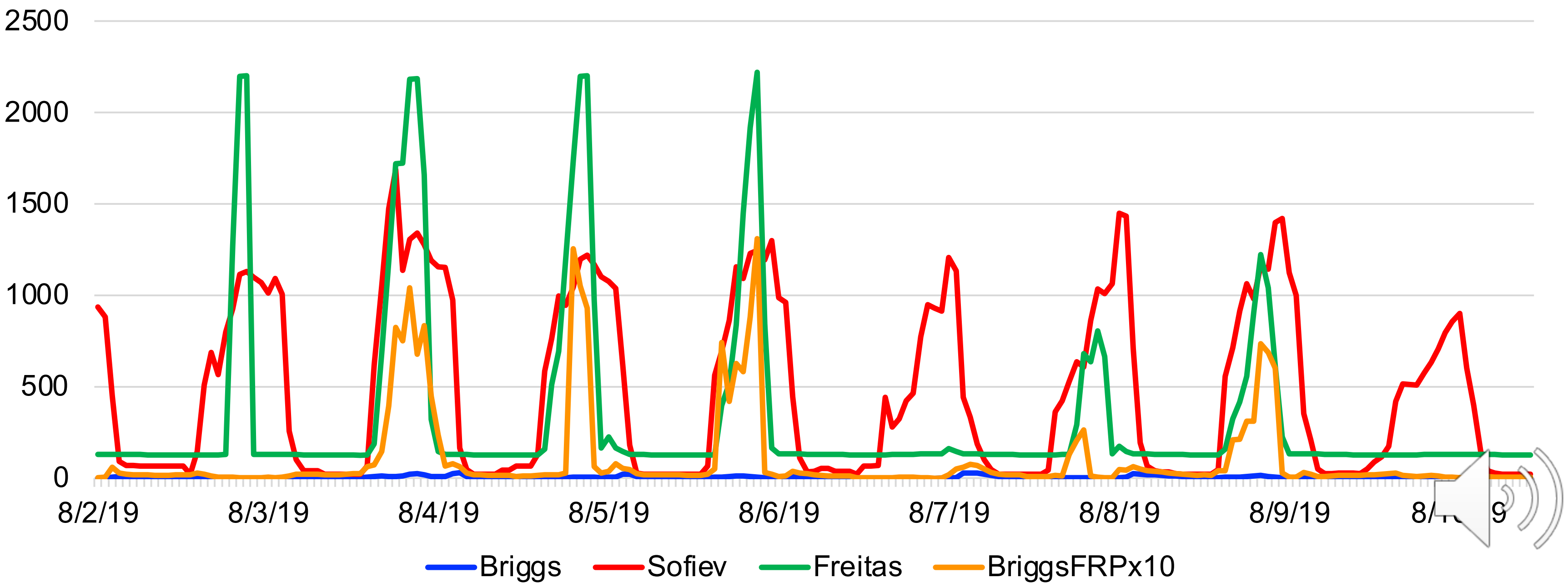
C. FIREX-AQ 2019

- We calculated the averaged plume injection height within the red box from Aug 2-Aug 10, 2019.
- **Briggs** is too low. Therefore, we use **FRPx10** as heat (Val Martin et al., 2012) to calculate plume injection height. The new injection heigh is comparable to **Sofiev**, but still lower than **Sofiev**.
- **Freitas** injection height is higher than **Sofiev** in the first several days, then becomes lower.

PM2.5 Emission on Aug 8, 2019



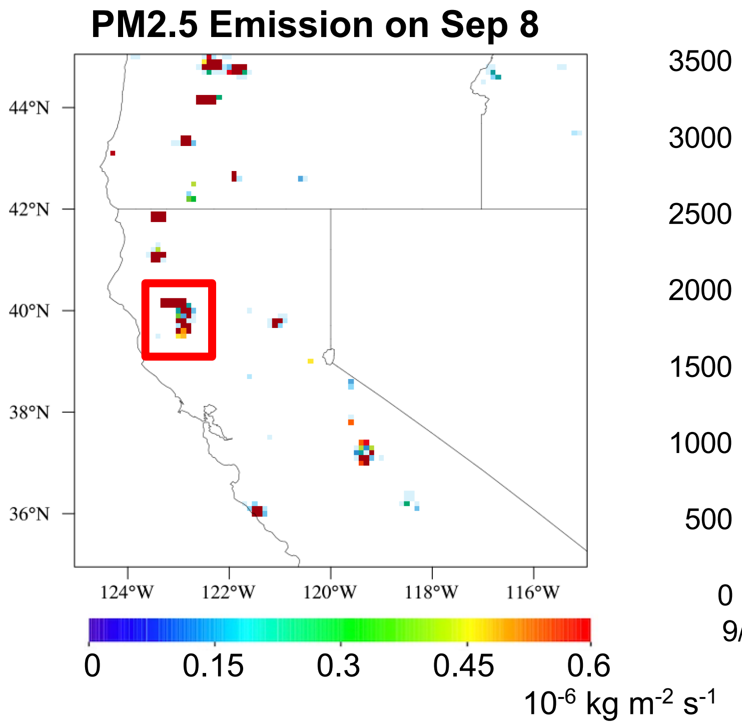
Plume Injection Height (m)

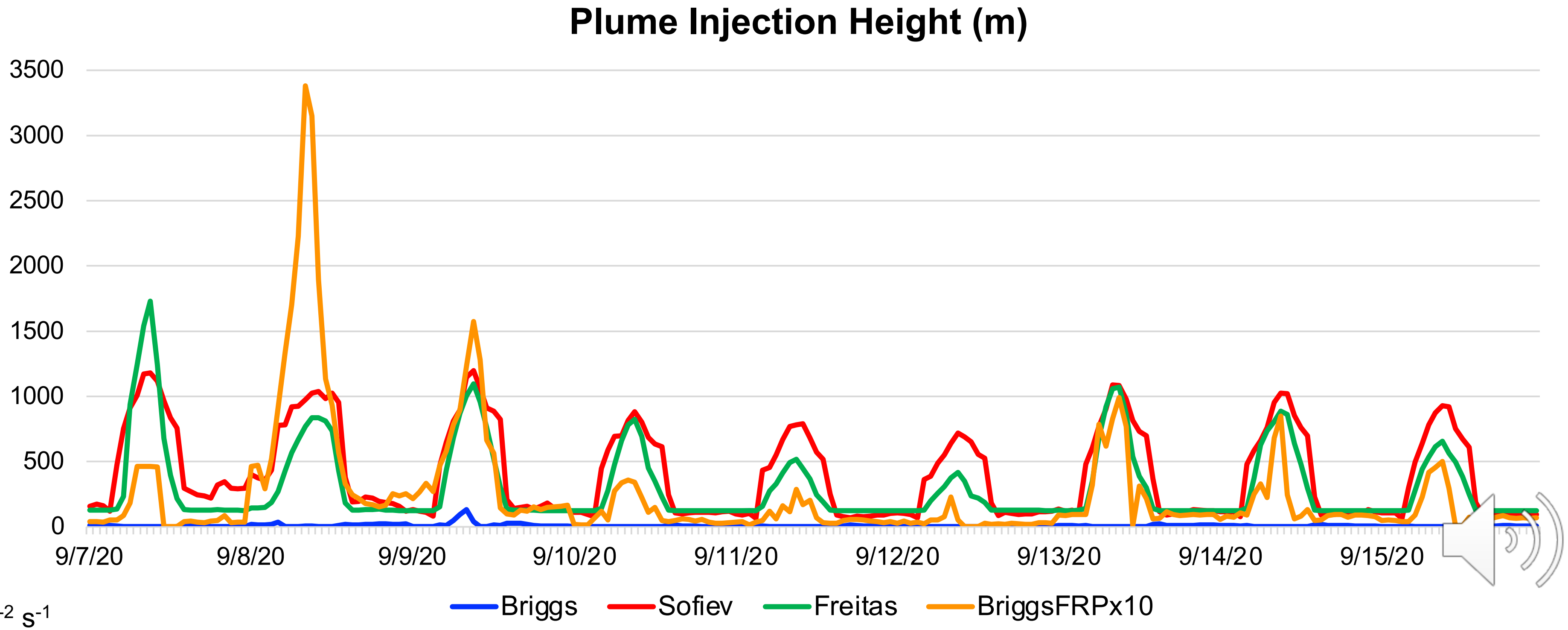


I. NEW PLUME RISE SCHEMES

D. 2020 CA-OR-WA WILDFIRE

- We calculated the averaged plume injection height within the red box from Aug 2-Aug 10, 2019.
- **Briggs** injection height is too low. The **FRPx10 Briggs** produce an injection height higher than 3km on Sep 08, 2020, which is twice as high as the injection height in the other days.
- The injection height differences among the three schemes are large during the day time.

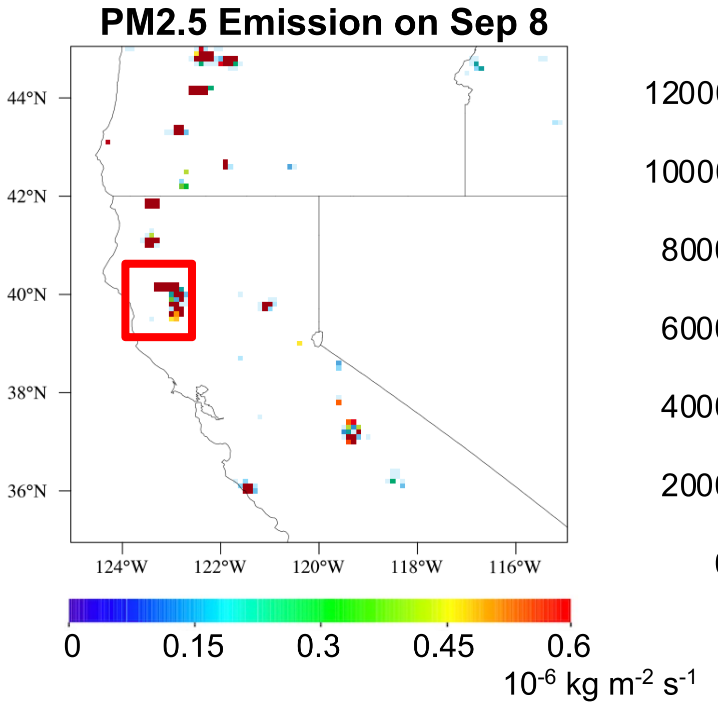


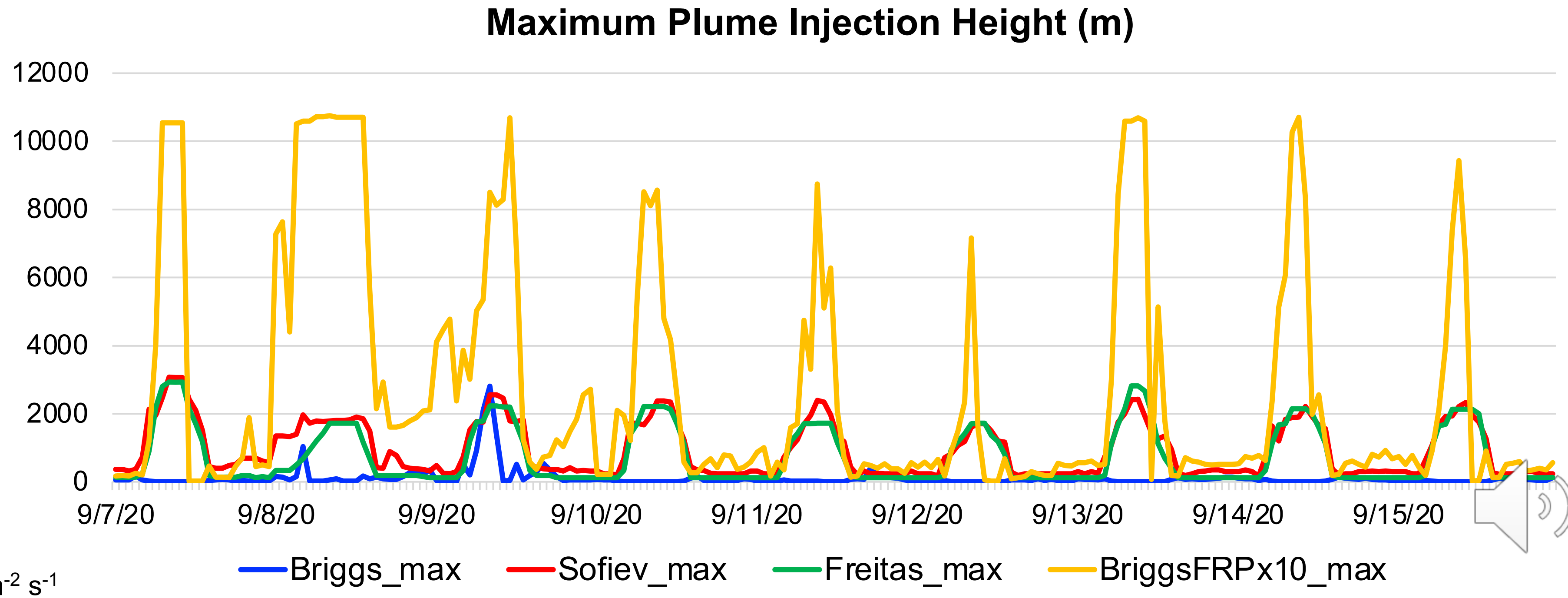


I. NEW PLUME RISE SCHEMES

D. 2020 CA-OR-WA WILDFIRE

- The wildfires in the red box were in different stages. We plot the maximum calculated injection height.
- For **Sofiev** and **Freitas**, the plume injection height is around 2-3 km.
- The **Briggs** maximum injection height is too low except for Sep 10. When using **FRPx10**, the Briggs injection height reaches 10 km during the daytime.

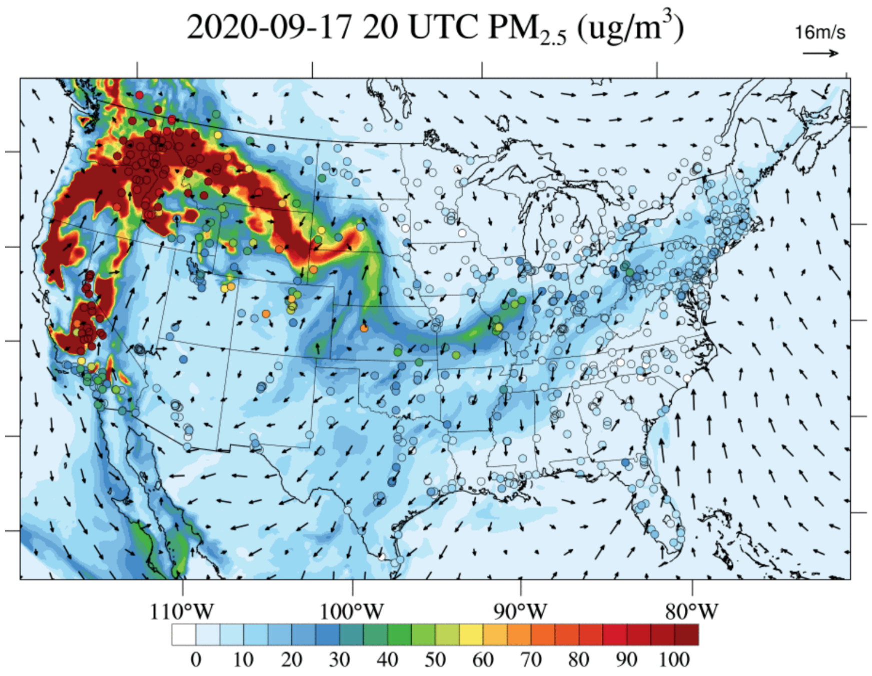


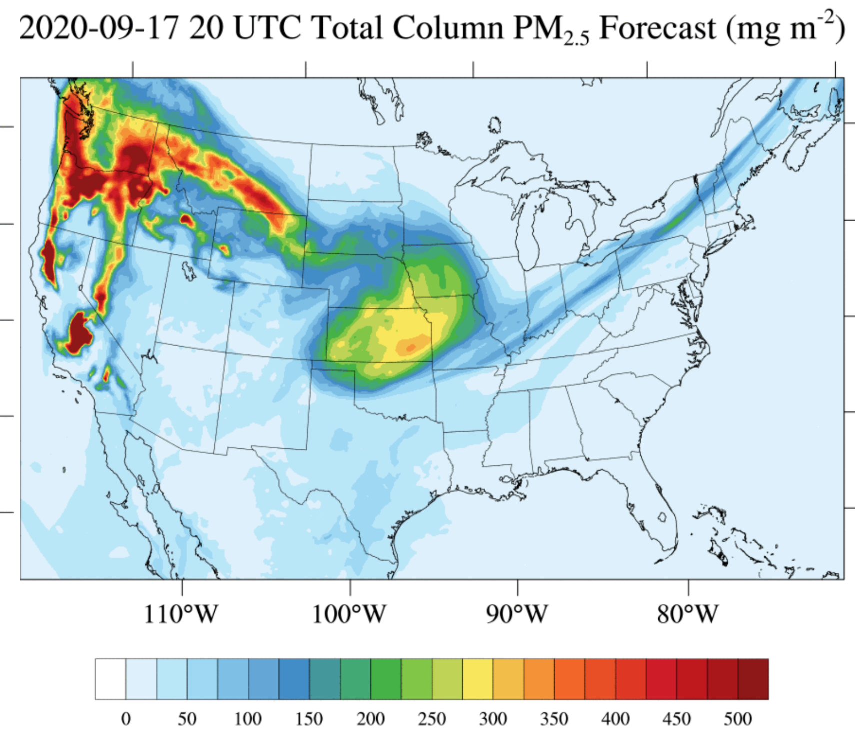


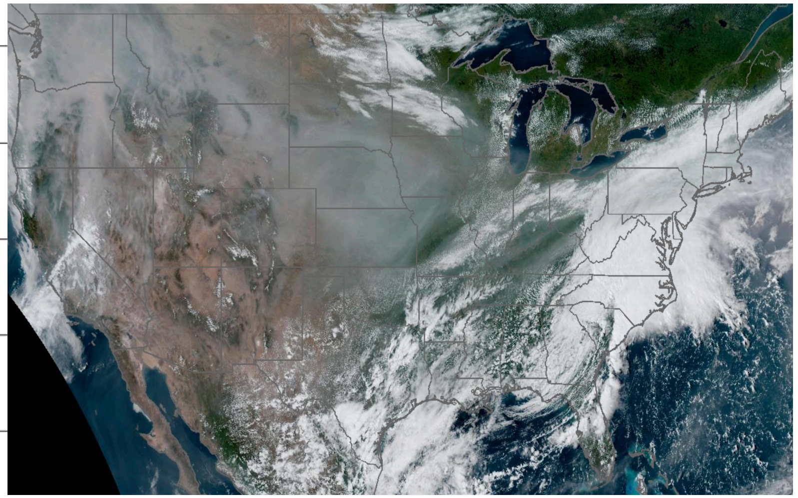
I. NEW PLUME RISE SCHEMES

E. GMU AIR QUALITY FORECAST MODEL

- The Sofiev et al. (2012) plume rise scheme has been used in our GMU air quality forecasting system.
- Our forecasting system successfully reproduced the wildfire pollution transport of the recent west coast wildfires.







Wildfire smoke observed by NOAA GOES-16 satellite (AerosolWatch)

II. NEW BIOMASS BURNING EMISSION AND REACTIONS

- To improve wildfire chemistry, we add new emission species and corresponding chemical reactions in the CMAQ model
- First, we added a new species, intermediate-volatile organic compounds (IVOC), to the CMAQ fire emission input.
  - Following Alvarado et al. (2015), biomass burning IVOC emissions are set to be 6.5 times of the primary organic aerosol (POA) emissions.
  - The GBBEPx BB emission dataset was used in this study.
- Next, we put the following two new wildfire related chemistry reaction into CMAQv5.3.1 cb6r3_ae7_aq mechanism:

$$\text{IVOC} + \text{OH} \rightarrow 0.6\ \text{HO}_2 + \text{IVOC\_RO}_2 \quad (1)$$

$$\text{IVOC\_RO}_2 + \text{NO} \rightarrow 0.5\ \text{NO}_2 + 0.5375\ \text{IVOC\_NIT} + 0.5375\ \text{IVOC} \quad (2)$$

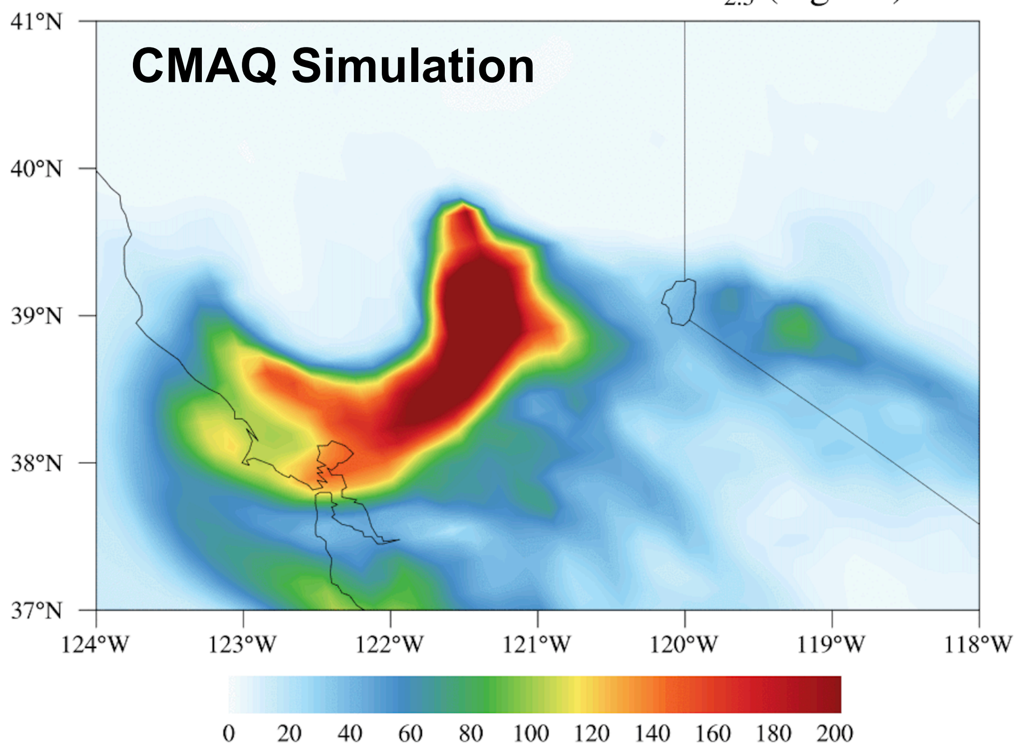
  - The reaction rate for reaction (1) is 1×10^{-11} cm^3/molec/s, for reaction (2) is 4×10^{-12} cm^3/molec/s.

II. NEW BIOMASS BURNING EMISSION AND REACTIONS

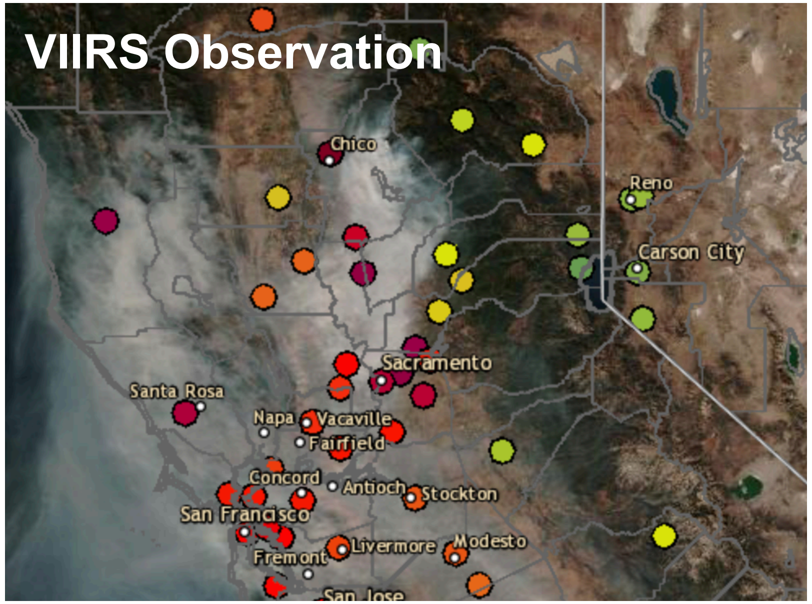
A. CAMP FIRE SIMULATION

- We tested the new BB IVOC emission and reactions by simulating the Camp Fire case.
- The simulation result reproduced the smoke transport of the Camp fire case.

20181110 22 UTC Total Column $PM_{2.5}$ (mg m^{-2})



20181110 21:30 UTC

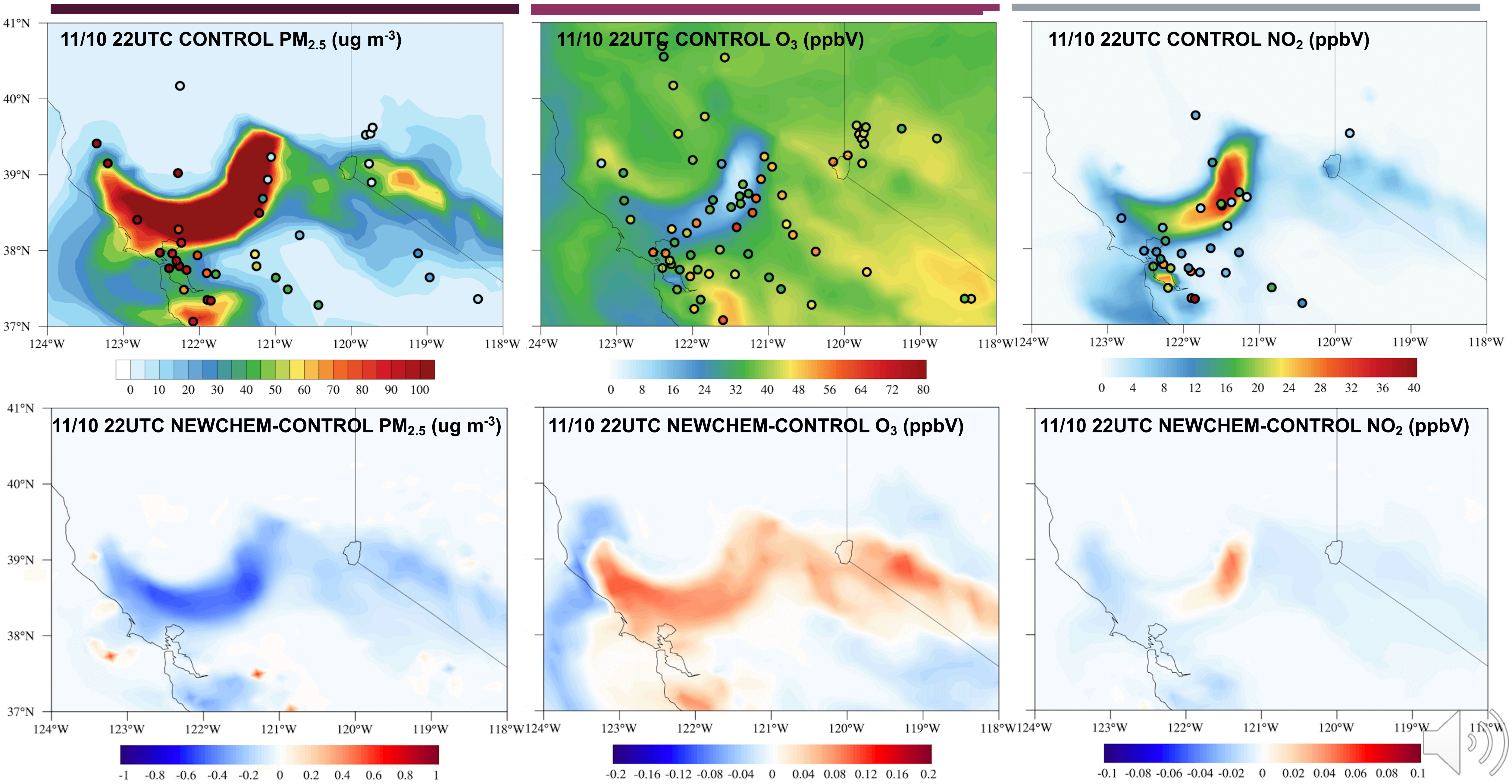


(Source: NOAA AerosolWatch)

II. NEW BIOMASS BURNING EMISSION AND REACTIONS

B.SENSITIVITY TEST

- We conducted two simulations:
  1. **CONTROL:** without biomass burning IVOC emission, and without new reactions;
  2. **NEWCHEM:** with both biomass burning IVOC emission and new reactions.
- We compared the model results at 22 UTC on Nov 10, 2018 (local time: 2 pm, close to VIIRS passing time), when PBL was high, and there were enough sun light.
- Focus on O_3, NO_2, and $PM_{2.5}$


11/10 22UTC CONTROL PM2.5 (ug m-3)
11/10 22UTC CONTROL O3 (ppbV)
11/10 22UTC CONTROL NO2 (ppbV)
11/10 22UTC NEWCHEM-CONTROL PM2.5 (ug m-3)
11/10 22UTC NEWCHEM-CONTROL O3 (ppbV)
11/10 22UTC NEWCHEM-CONTROL NO2 (ppbV)
41°N 40°N 39°N 38°N 37°N
124°W 123°W 122°W 121°W 120°W 119°W 118°W
0 10 20 30 40 50 60 70 80 90 100
0 8 16 24 32 40 48 56 64 72 80
0 4 8 12 16 20 24 28 32 36 40
-1 -0.8 -0.6 -0.4 -0.2 0 0.2 0.4 0.6 0.8 1
-0.2 -0.16 -0.12 -0.08 -0.04 0 0.04 0.08 0.12 0.16 0.2
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1

CONCLUSION & FUTURE WORK

- **New plume rise scheme:**
  - Three plume rise schemes are compared: Briggs, Sofiev, and Freitas schemes.
  - The Briggs scheme is not suitable for wildfire prediction.
  - We added the Sofiev et al. (2012) plume scheme to the CMAQ model.
  - **Future:** considering implementing the Freitas scheme to CMAQ.
- **New wildfire emission species and corresponding chemical reactions**
  - Biomass burning IVOC and related reactions added to CMAQ.
  - After adding the new emission species and reactions, the $PM_{2.5}$ concentration decrease; O_3 mixing ratios increase, the NO_2 mixing ratios increase near the plume center and decrease surrounding the center.