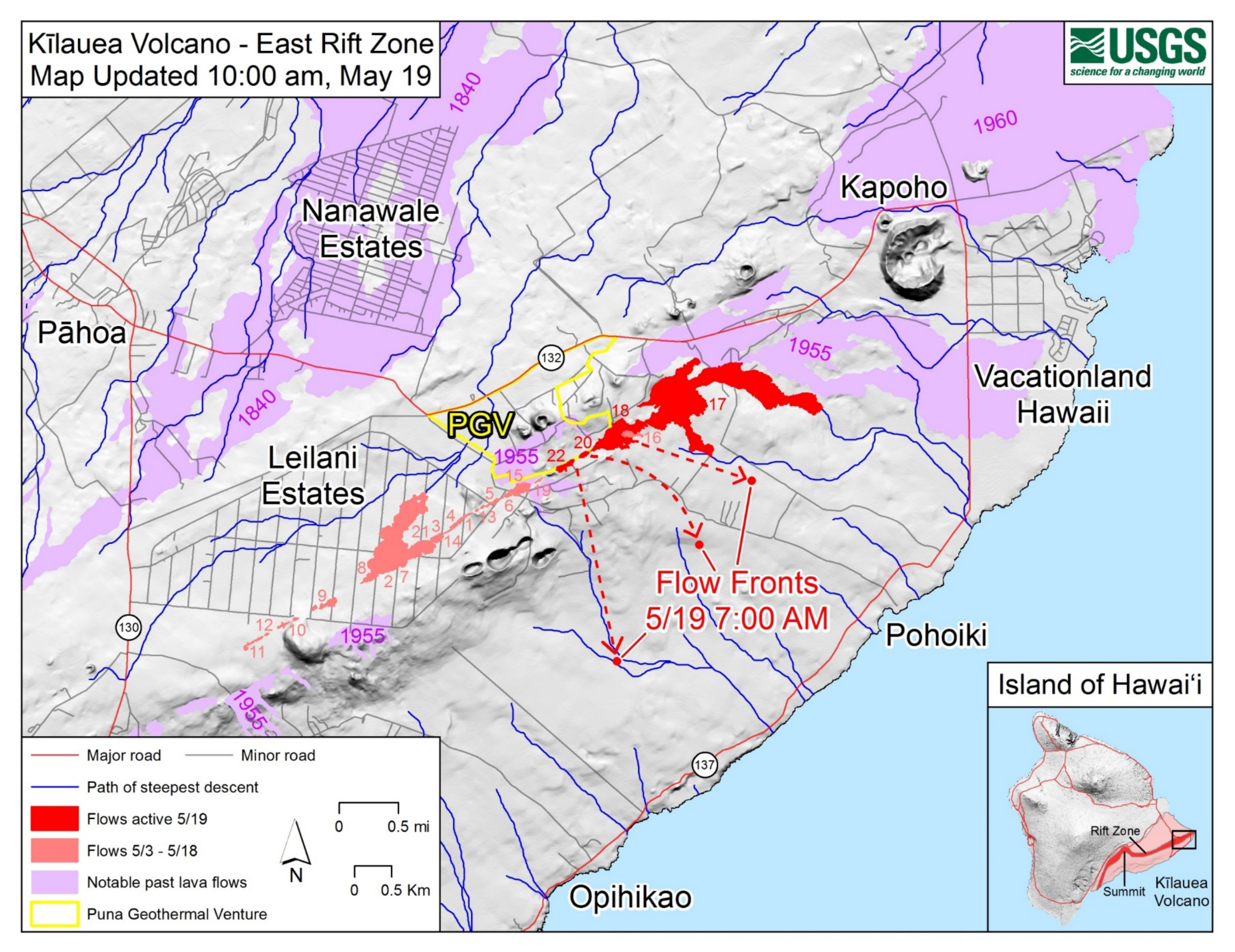
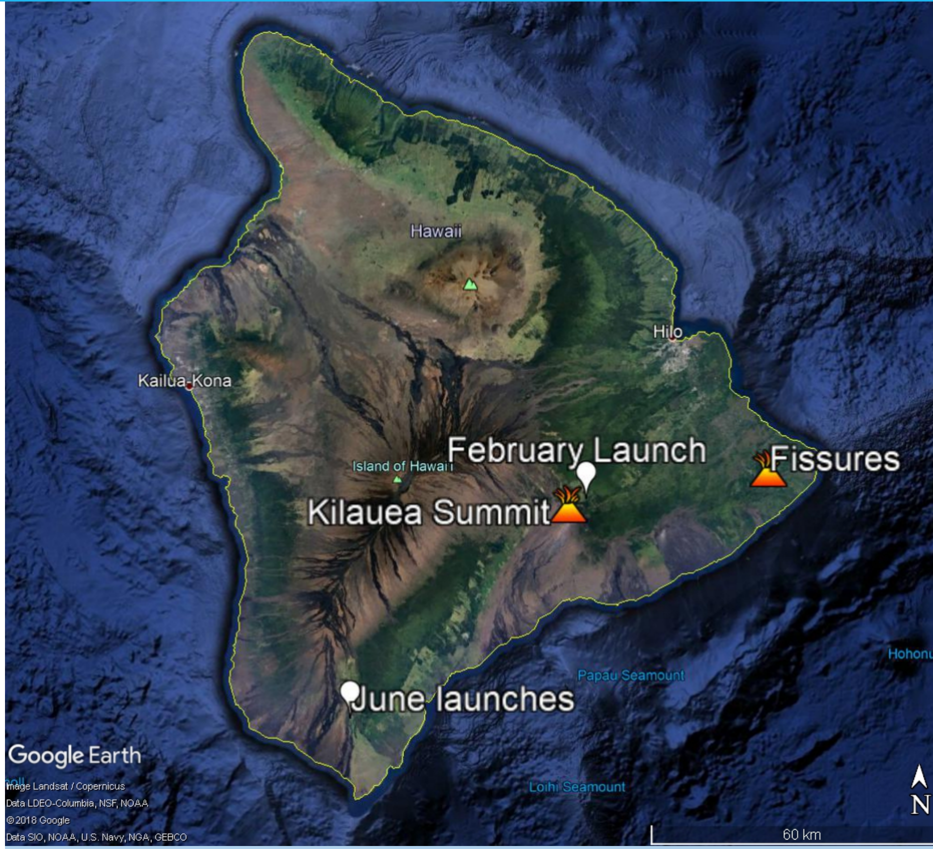
Development of a Fast-Response Volcanic SO_2 Prediction System: A Study for the 2018 Mt. Kilauea Eruption using a Chemical Transport Model and Satellite Data

Youhua Tang[1,2], Daniel Tong[1,3], Kai Yang[2], Pius Lee[1], Barry Baker[1,2], Patrick Campbell[1,3] Alice Crawford[1], Winston Luke[1], Ariel Stein[1], James Flynn[4], Yuxuan Wang[4], Jeff McQueen[5], Li Pan[5,6], Jianping Huang[5,6] and Ivanka Stajner[5]

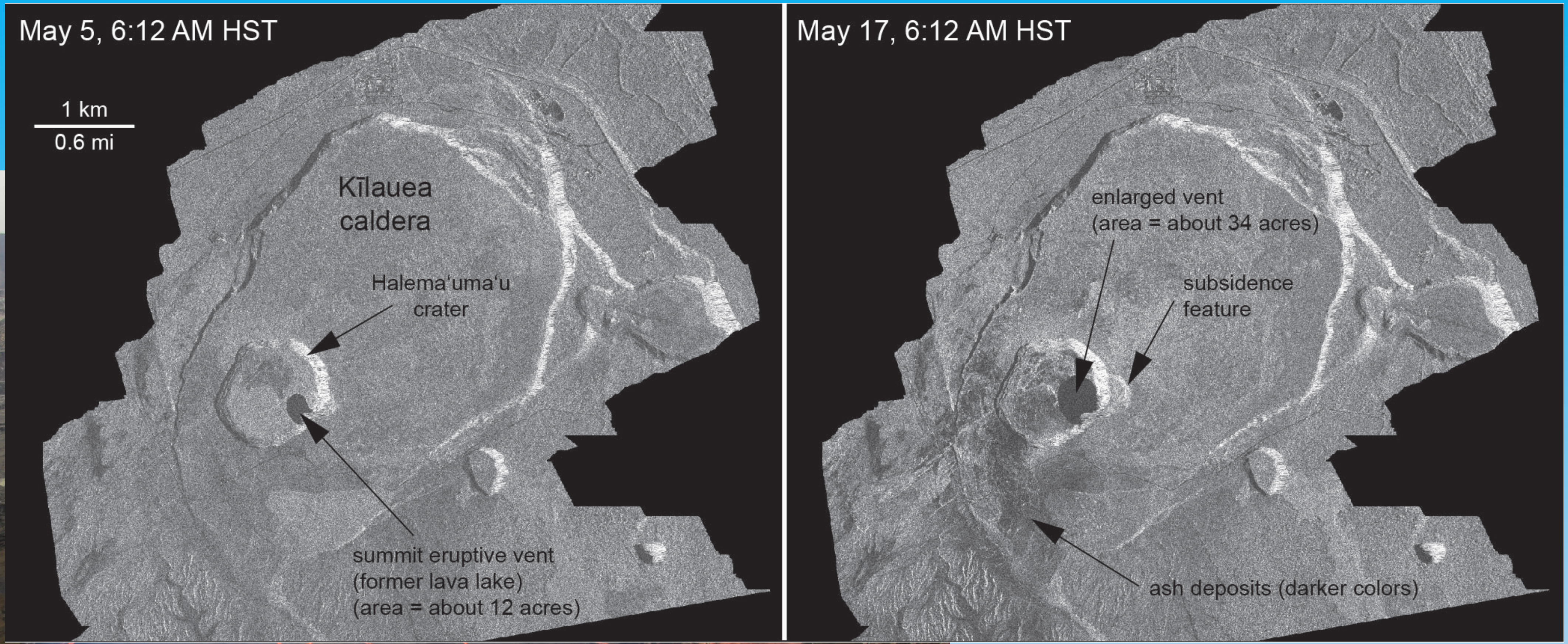
1. NOAA Air Resources Laboratory
2. Cooperative Institute for Satellite Earth System Studies, College Park, MD
3. Center for Spatial Information Science and Systems, George Mason University
4. Dept. of Earth and Atmospheric Sciences, University of Houston, Houston, TX
5. NOAA National Centers for Environmental Prediction (NCEP), College Park, MD
6. I.M. Systems Group Inc., Rockville, MD

Kilauea Volcano 2018 Eruption





Courtesy: USGS



Kilauea Summit Map

Courtesy: USGS

Kilauea East Rift Zone

Courtesy: USGS

In order to simulate this event using model, we need volcano SO_2 emissions. To estimate the emission, we use OMPS satellite data as an indicator. We start from the basic equation, and integrate these terms over 3-d space in the Hawaii surrounding area.

$$\frac{dC}{dt} = \vec{V} \cdot \nabla C + C_{diff} + C_{dep} + C_{chem} + E$$

$$\downarrow$$

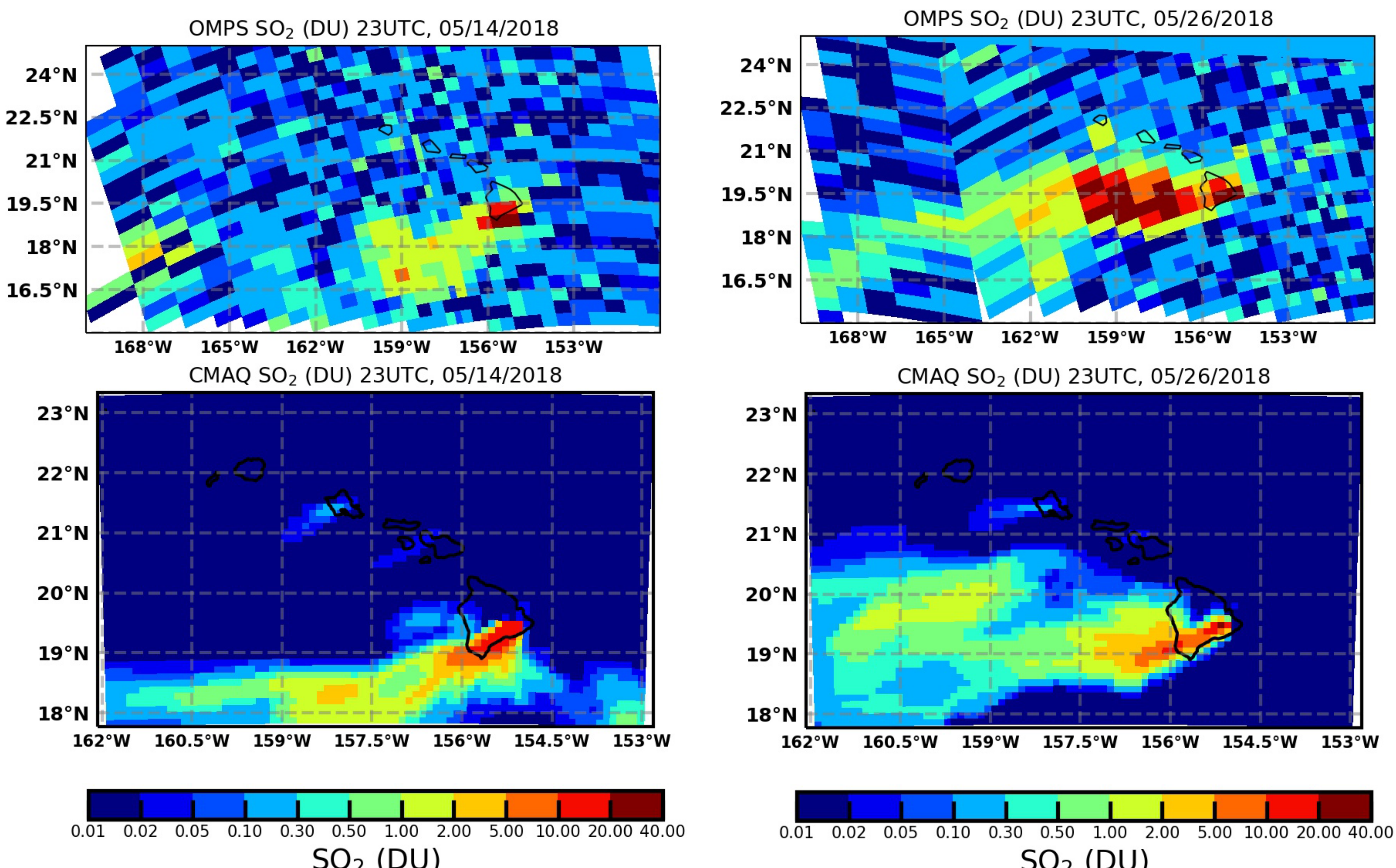
$$\iiint \frac{dC}{dt} dxdydz = \iiint \left(\vec{V} \cdot \nabla C + C_{diff} + C_{dep} + C_{chem} + E\right) dxdydz$$

Assuming the concentration is at pseudo equilibrium during certain period over Hawaii surrounding area.

$$\iiint \frac{dC}{dt} dxdydz = 0 \longrightarrow \iiint -\left(\vec{V} \cdot \nabla C + C_{diff} + C_{dep} + C_{chem}\right) dxdydz = \iiint E dxdydz$$

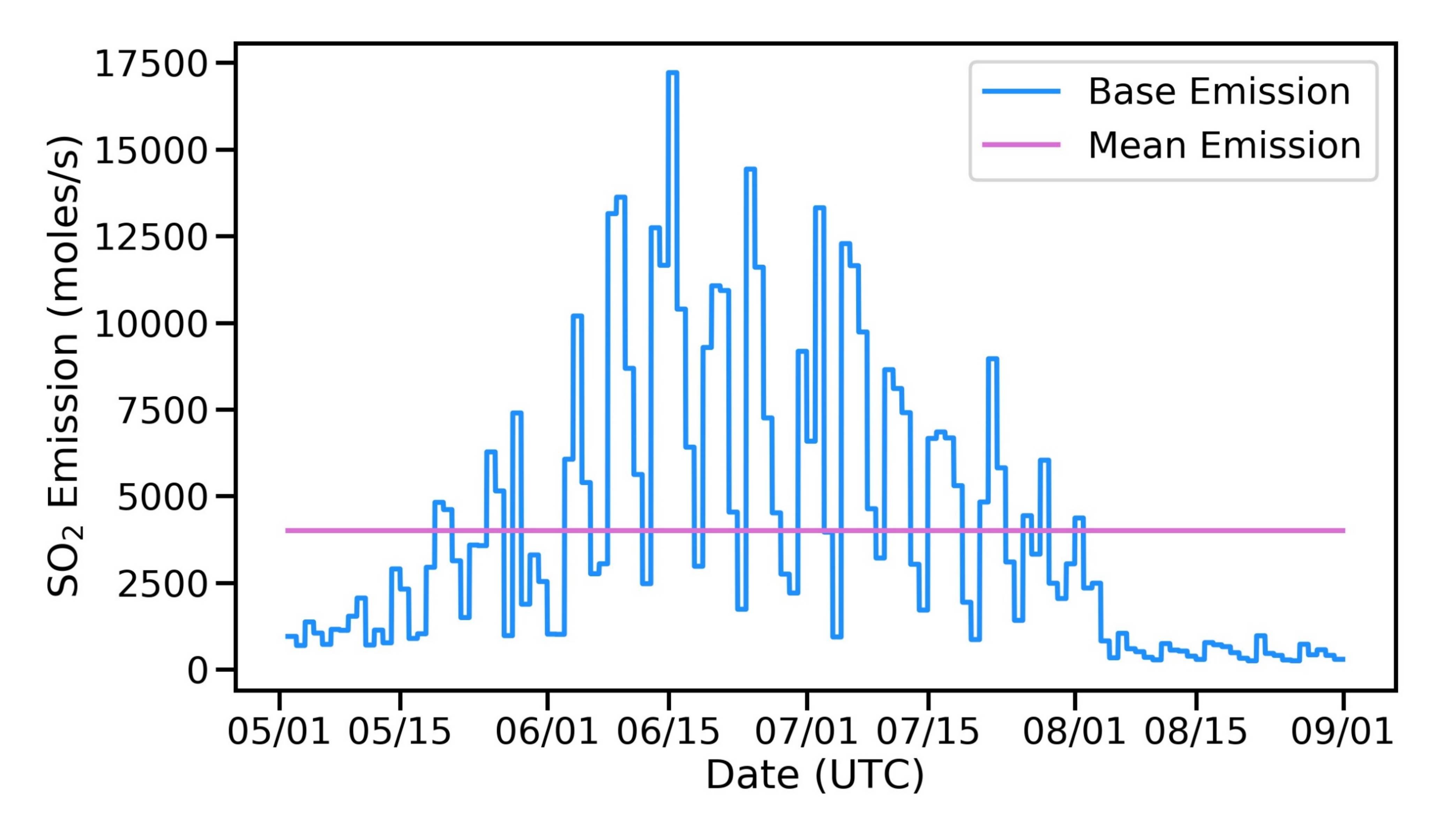
With first-order approximation $$\iiint -\left(\vec{V} \cdot \nabla C + C_{diff} + C_{dep} + C_{chem}\right) dxdydz \approx M C_{total}$$

Where C_{total} is the domain total mass for SO_2. $$C_{total} \propto \iiint E dxdydz$$



OMPS SO2 (DU) 23UTC, 05/14/2018
OMPS SO2 (DU) 23UTC, 05/26/2018
24°N
22.5°N
21°N
19.5°N
18°N
16.5°N
168°W
165°W
162°W
159°W
156°W
153°W
CMAQ SO2 (DU) 23UTC, 05/14/2018
CMAQ SO2 (DU) 23UTC, 05/26/2018
23°N
22°N
21°N
20°N
19°N
18°N
162°W
160.5°W
159°W
157.5°W
156°W
154.5°W
153°W
0.01 0.02 0.05 0.10 0.30 0.50 1.00 2.00 5.00 10.00 20.00 40.00
SO2 (DU)

Estimated Daily Volcano SO_2 Emissions for Two Runs



Plume Rise driven by Lava Heat Flux

- Assuming the lava outflow rate (for East Rift Zone) or circulation frequency (for Kilauea summit) is proportional to their volcano SO_2 emission. The lava initial temperature was around 1250°C, and its lava latent heat of fusion was about 400000 J/kg. Based on that information, we can estimate the heat flux released from the lava cooling.

- Plume Rise algorithm: Briggs scheme for wildfire

$$F = 0.00000258 \times Q$$

$$E_{size} = 0.0703 \times \ln(\,acres\,) + 0.3$$

$$S_{fraction} = 1 - BE_{size}$$

where

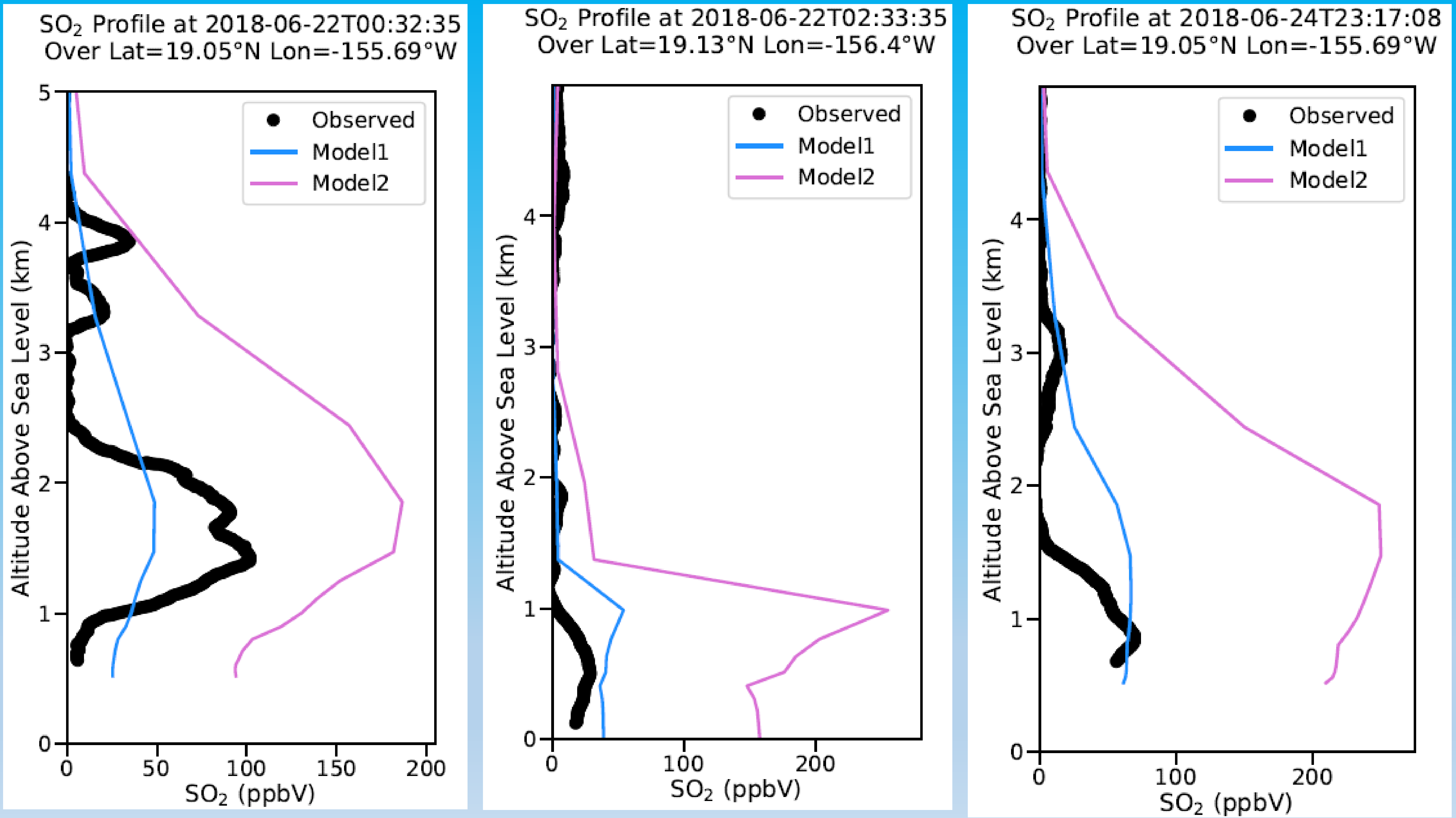
F = Bouyancy flux (m^4/s^3)

Q = Heat flux from Lava (BTU/hr)

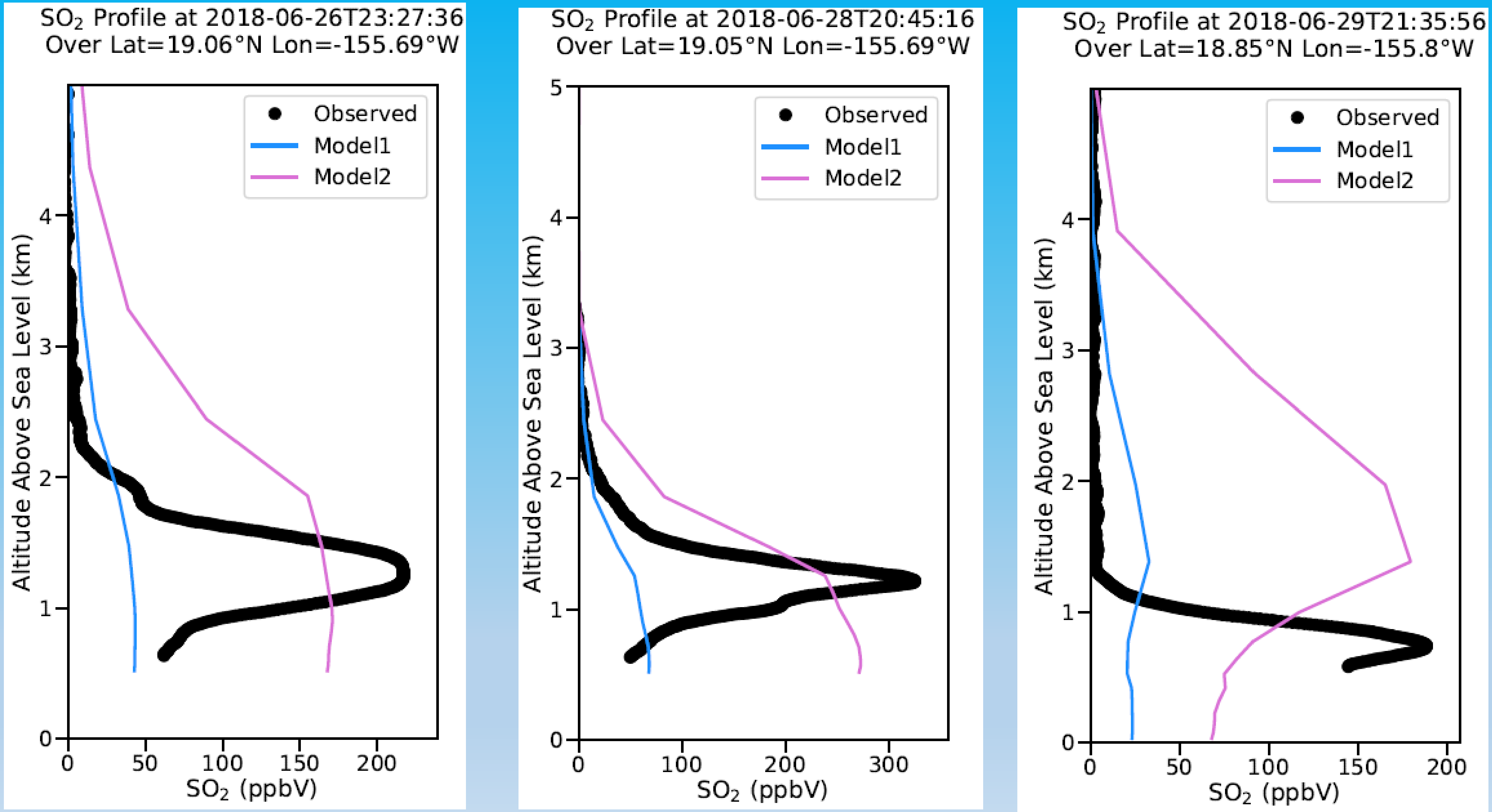
BE_{size} = bouyanct efficiency

acres = lava emission area in acres

$S_{fraction}$ = smoldering fration

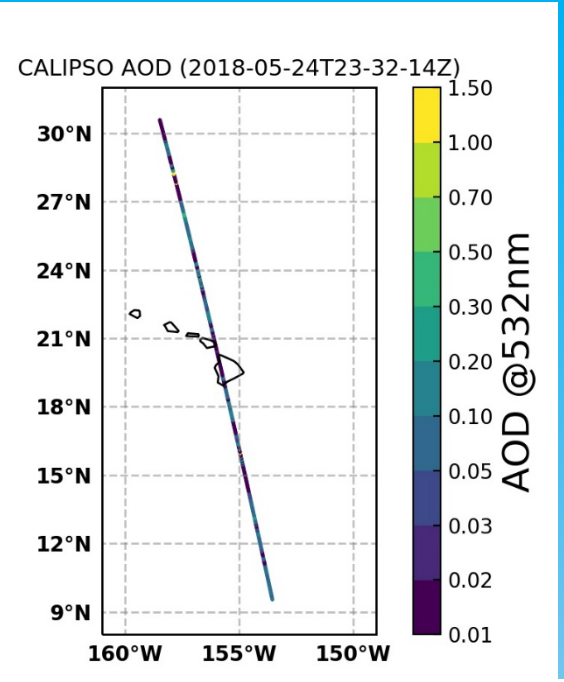


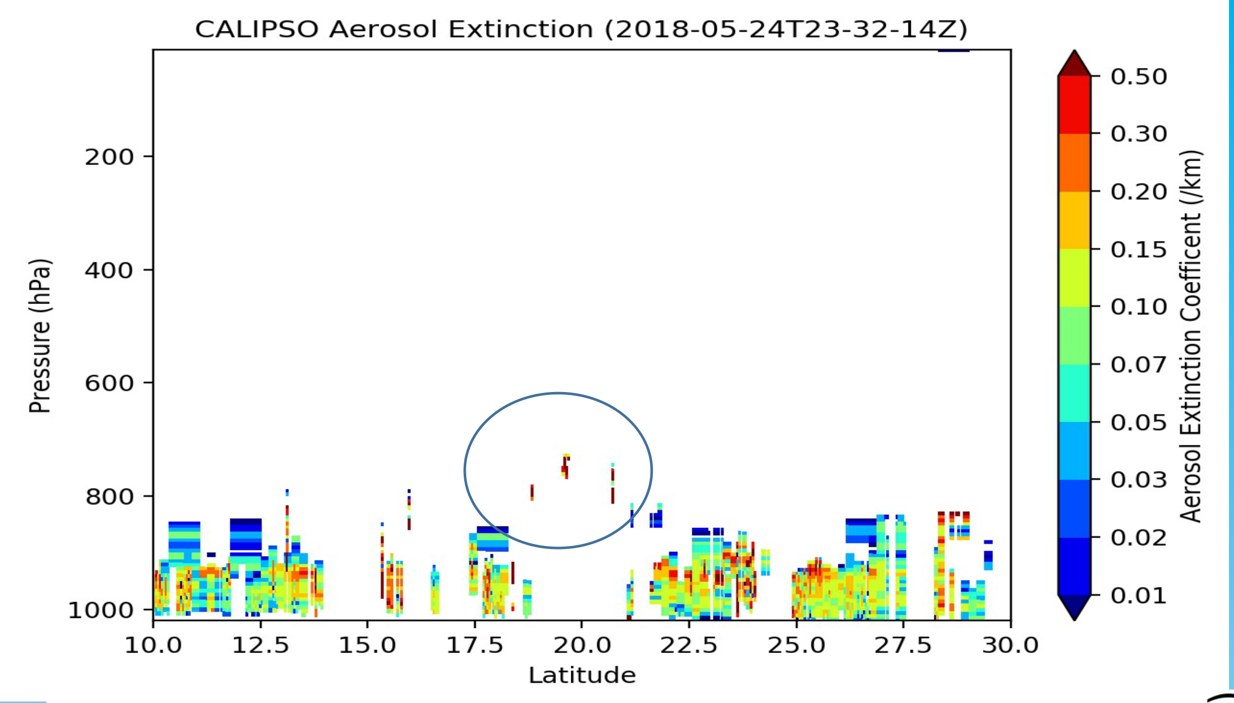
Model1 with base emission, and model2 with mean emission

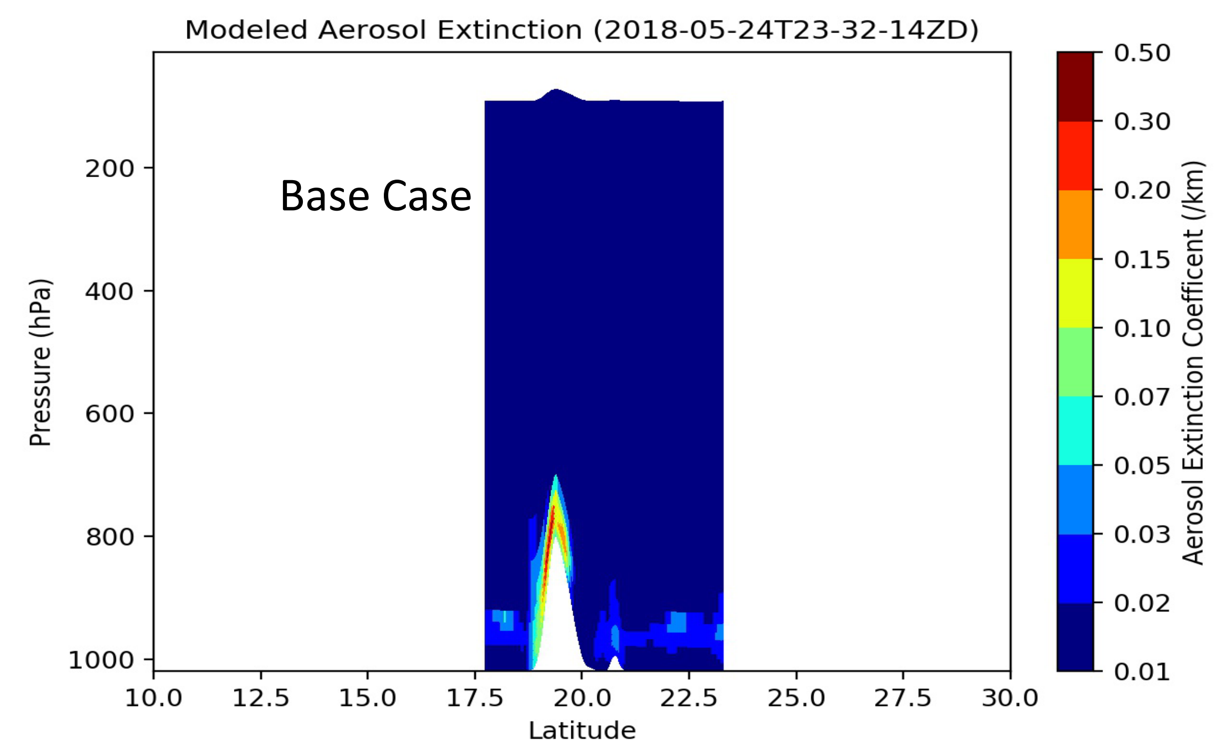


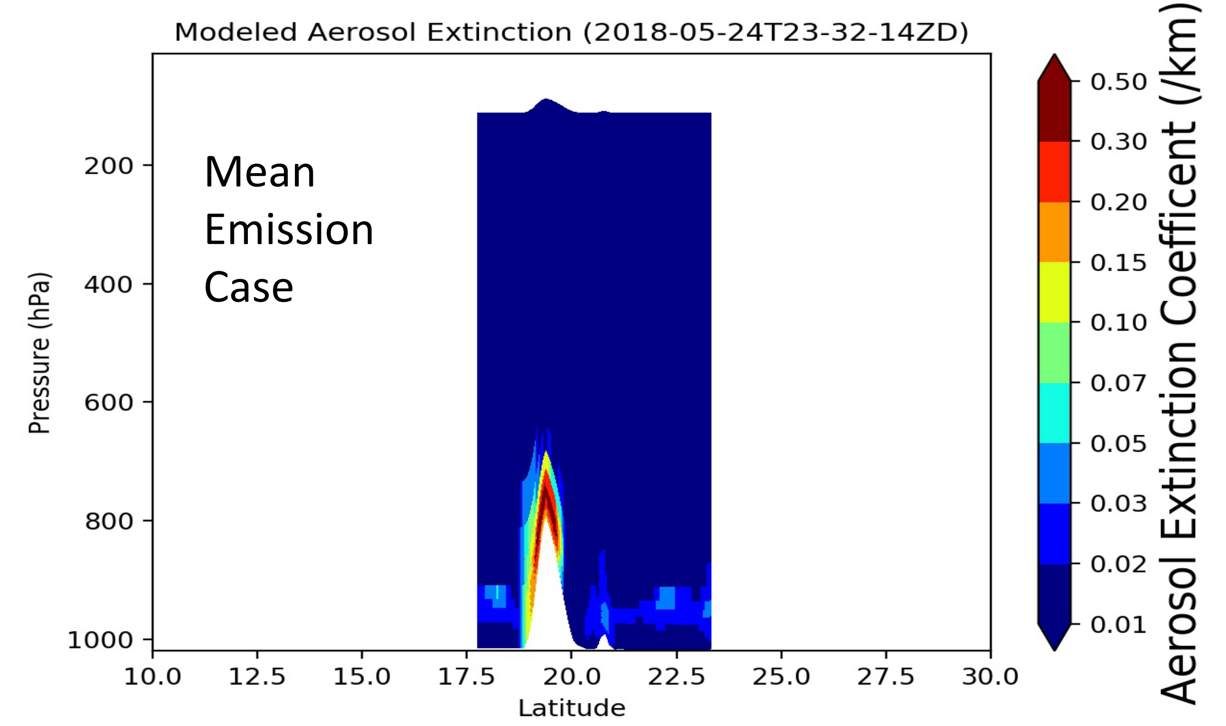
Model1 with base emission, and model2 with mean emission

Compared to CALIPSO data 05/24

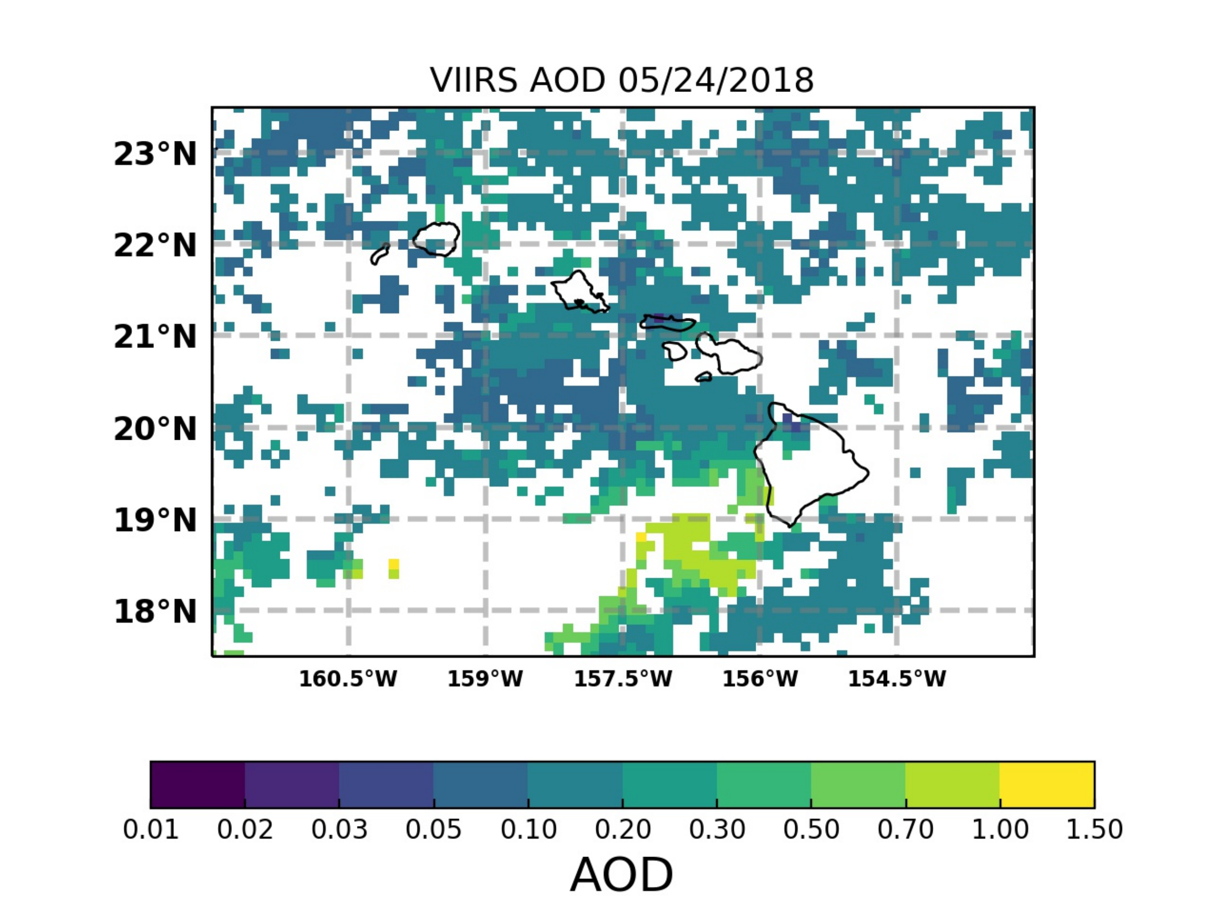


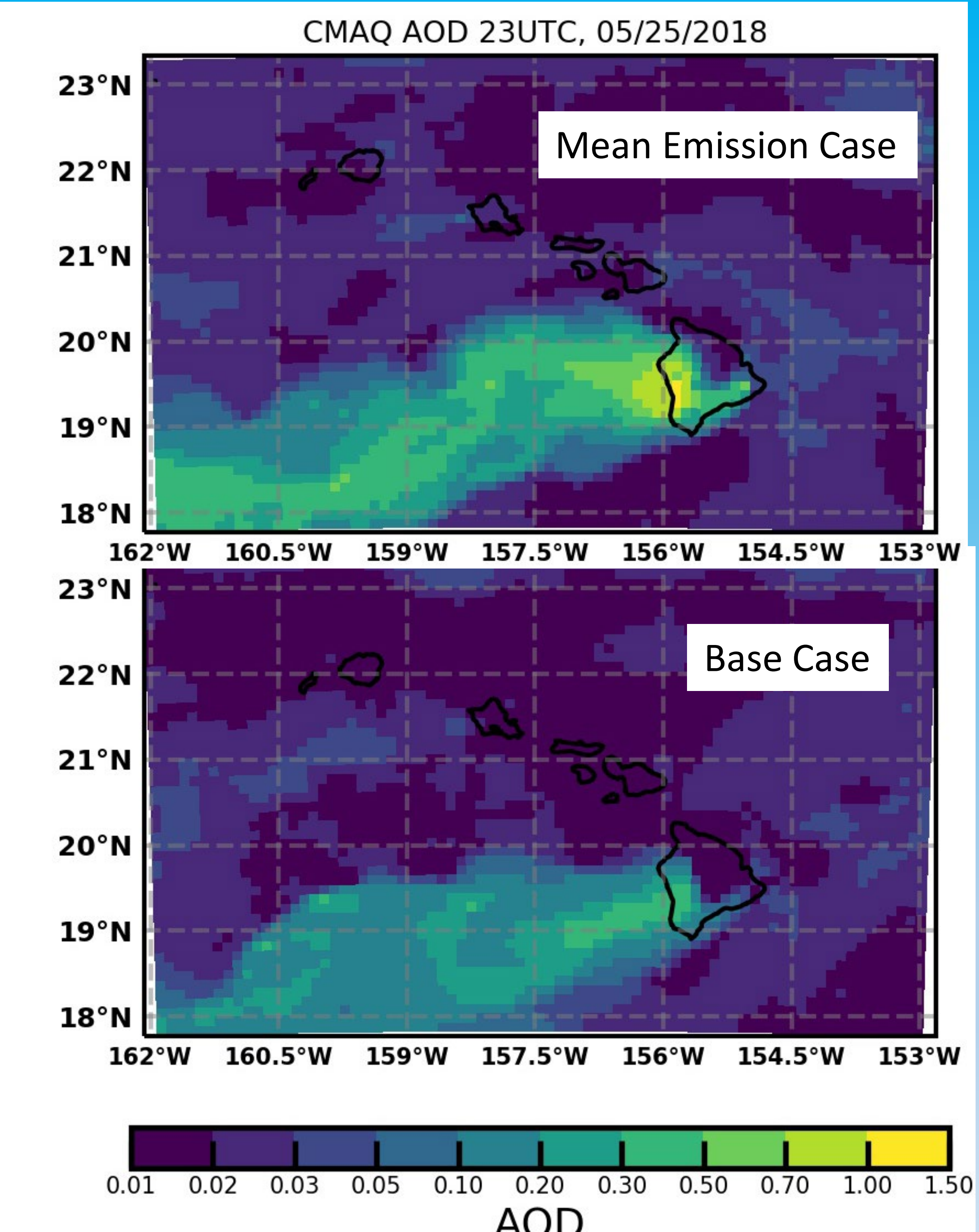




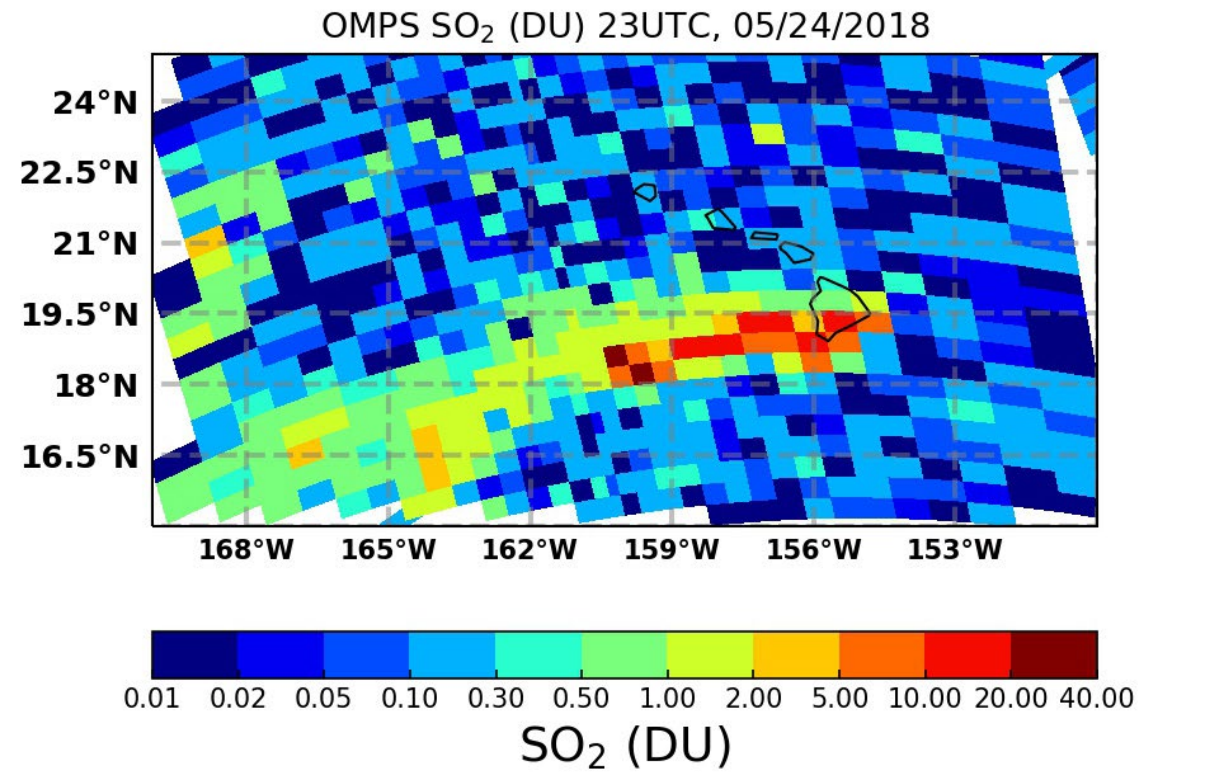


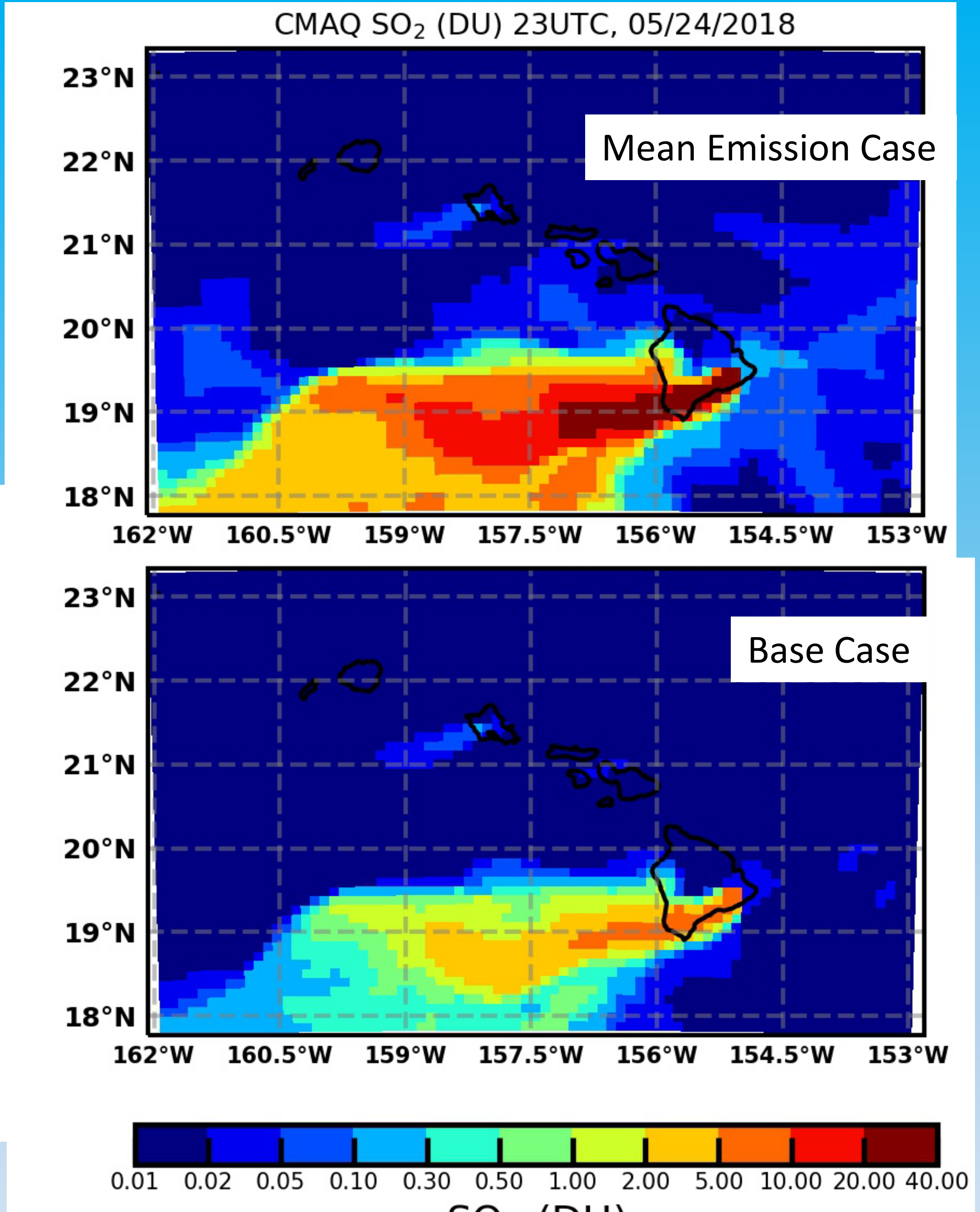
VIIRS AOD Comparison 05/24



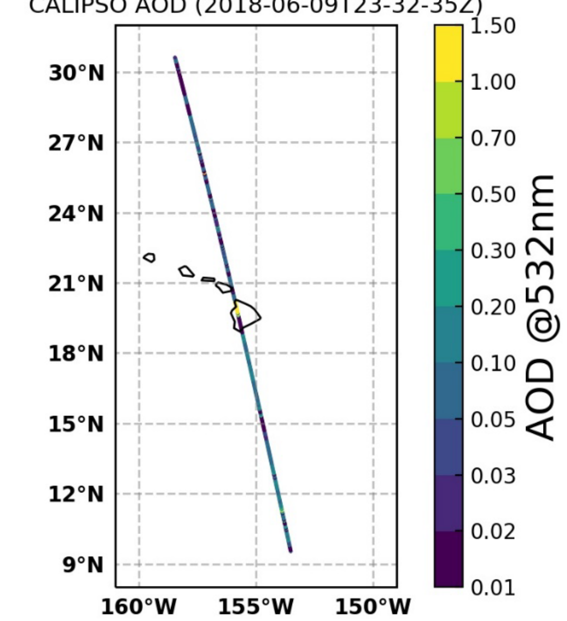


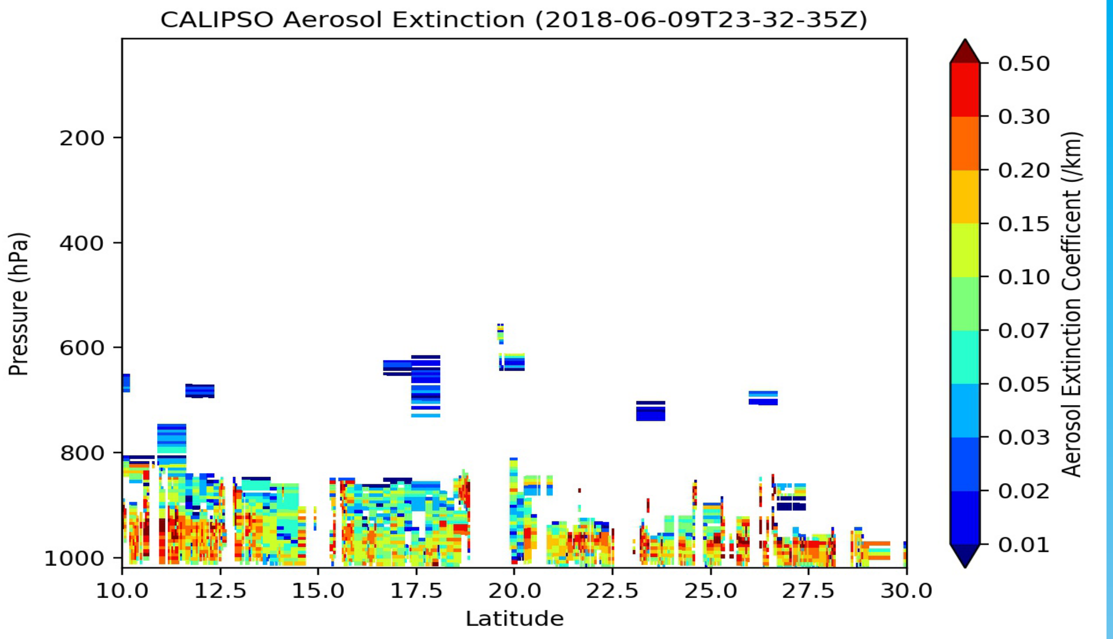
OMPS SO_2 Comparison 05/24

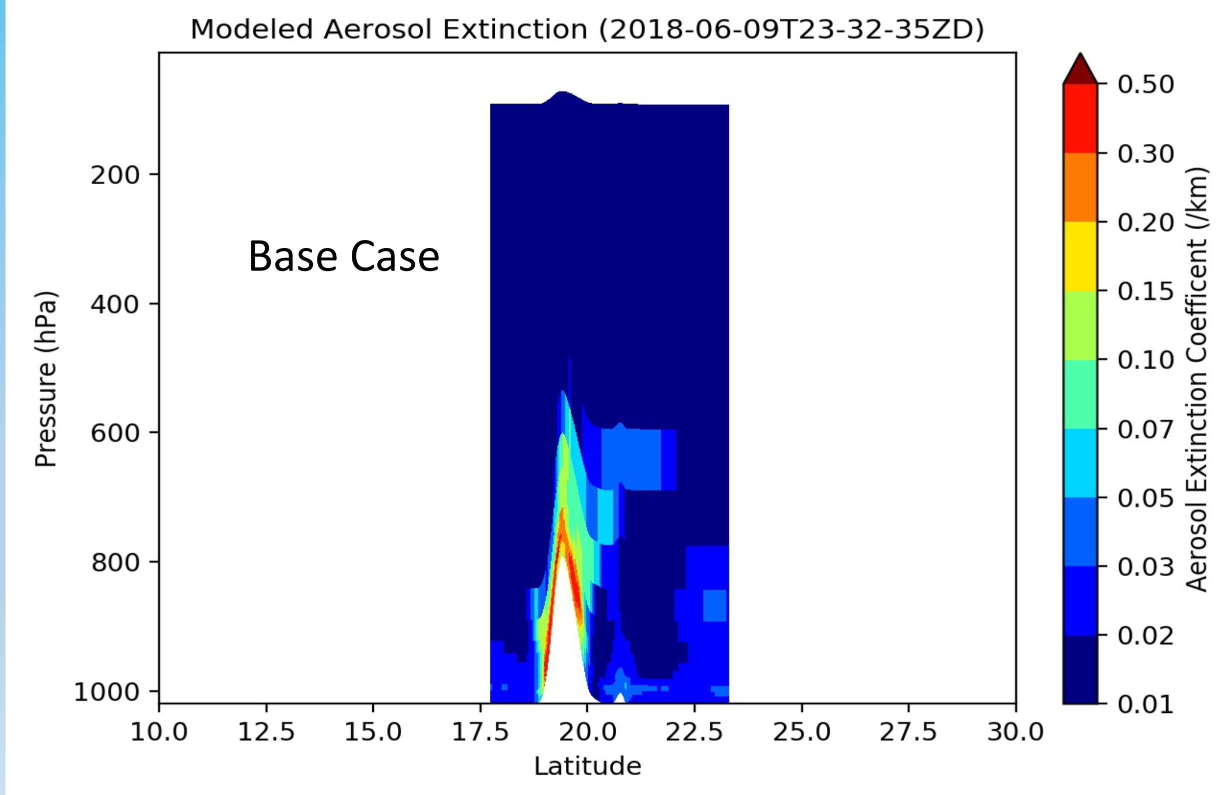


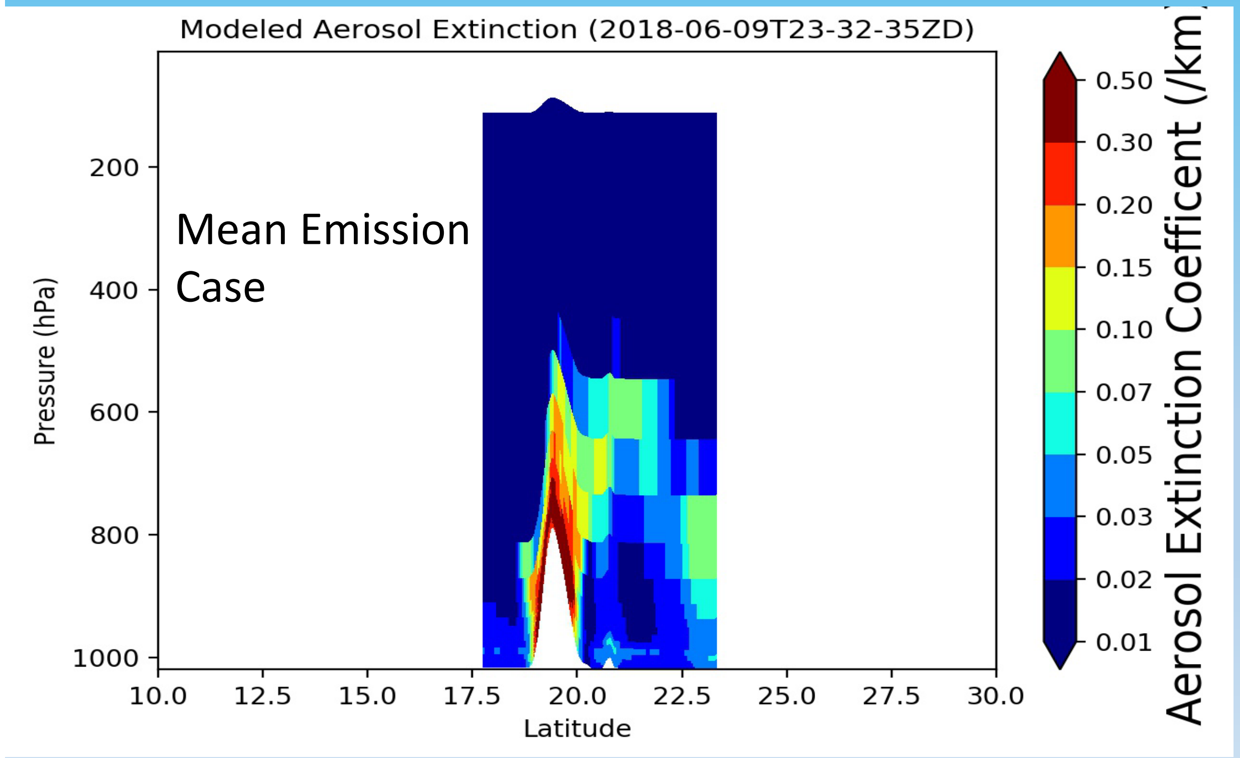


Compared to CALIPSO data 06/09

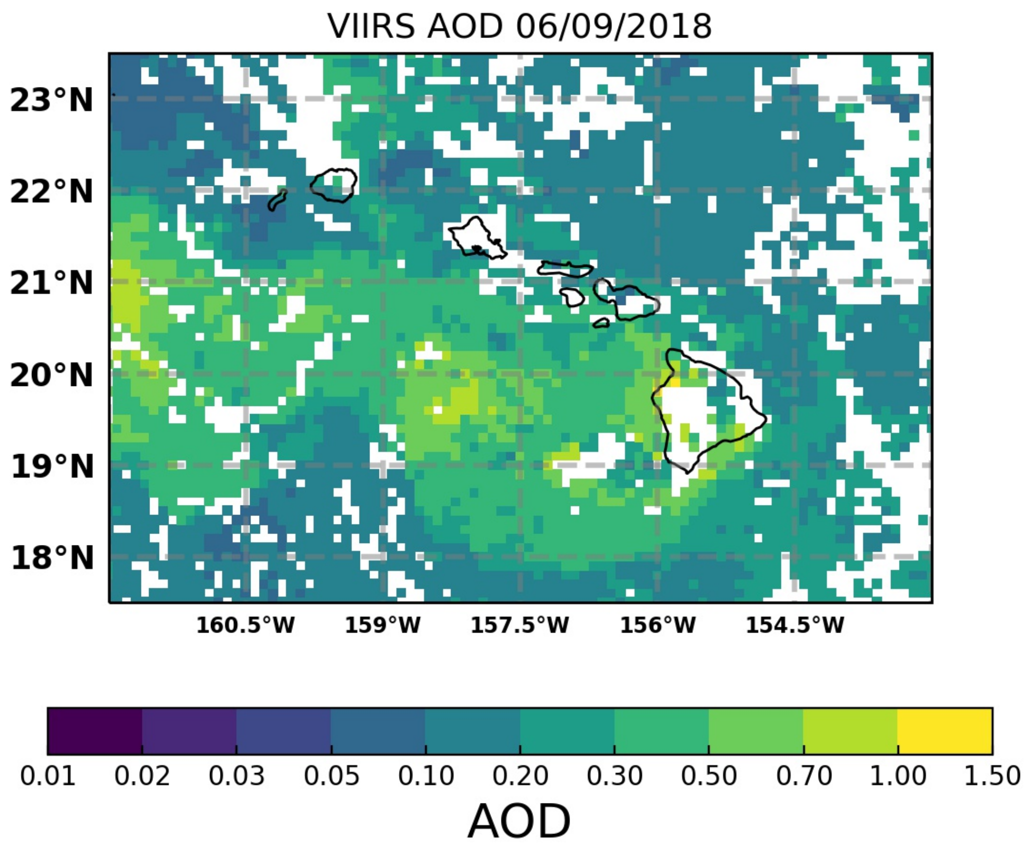


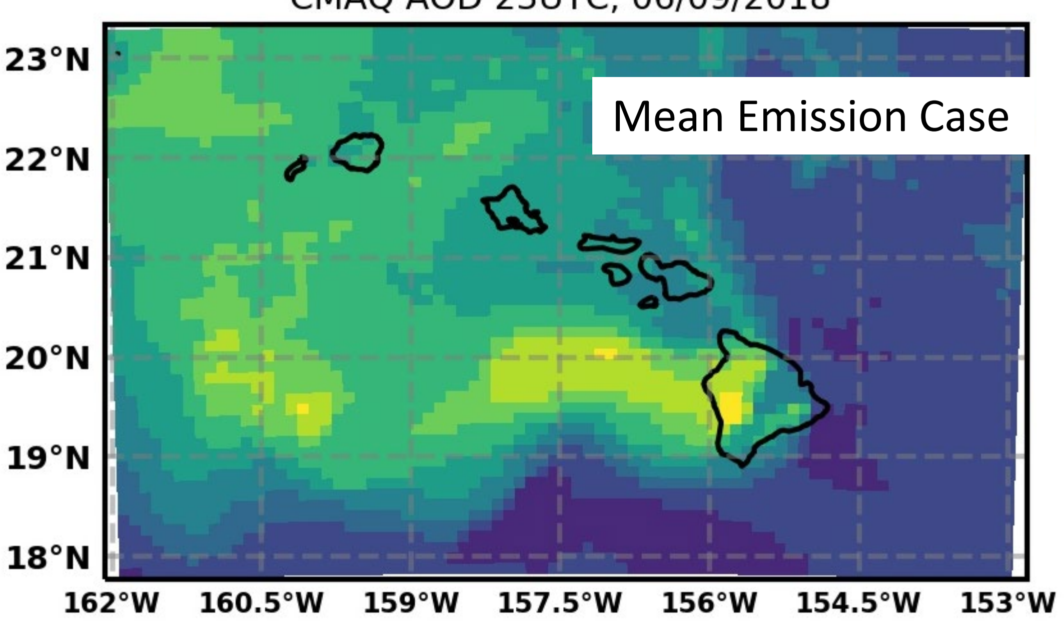


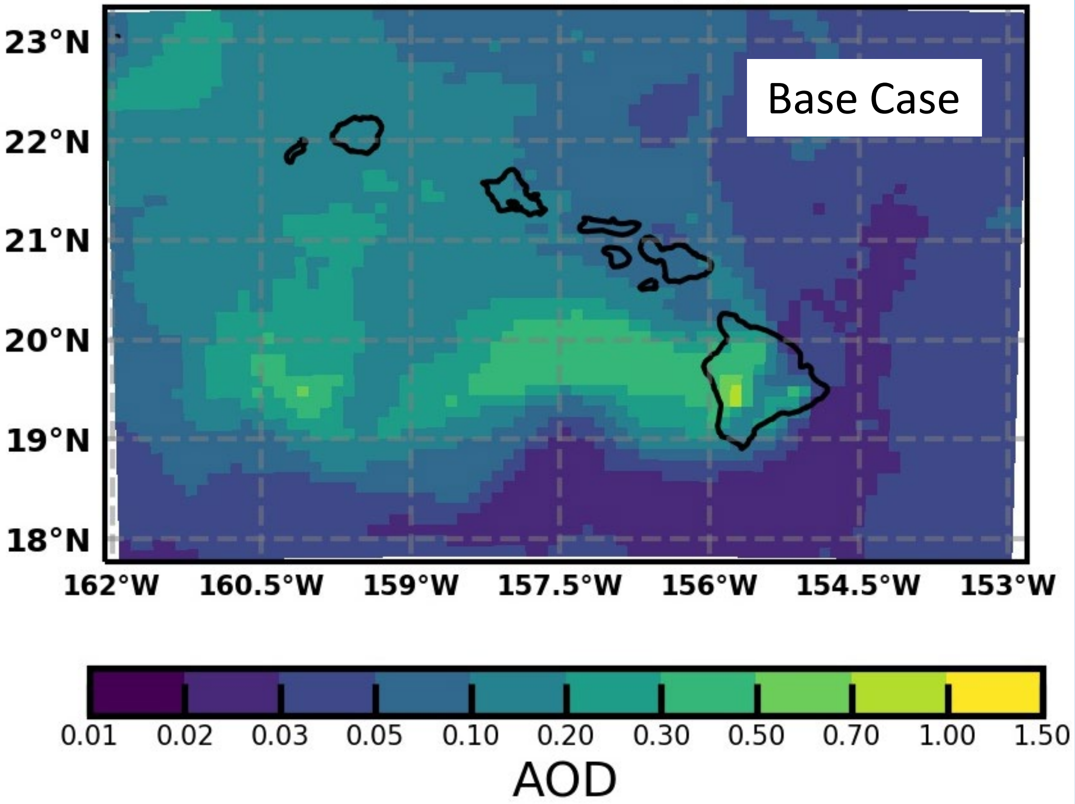




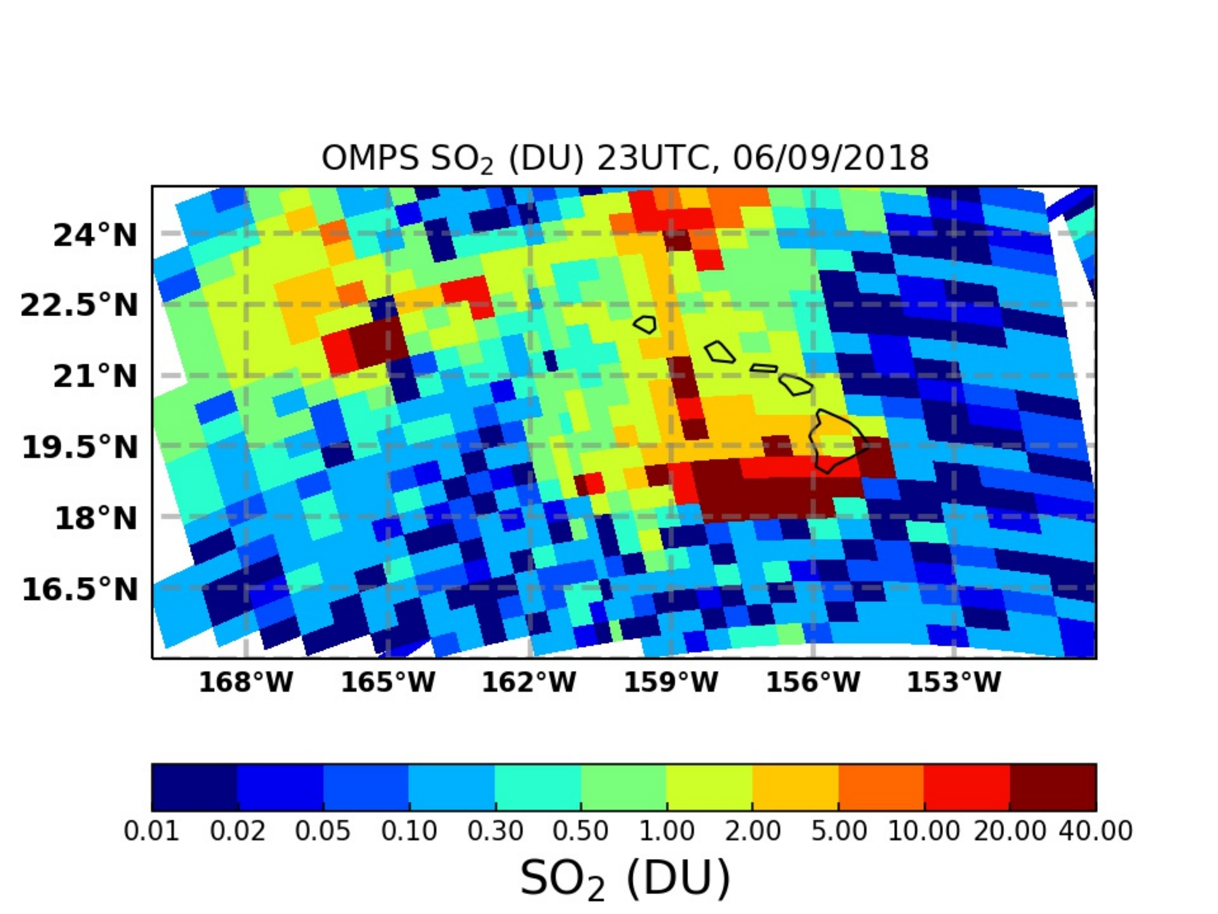
VIIRS AOD Comparison 06/09

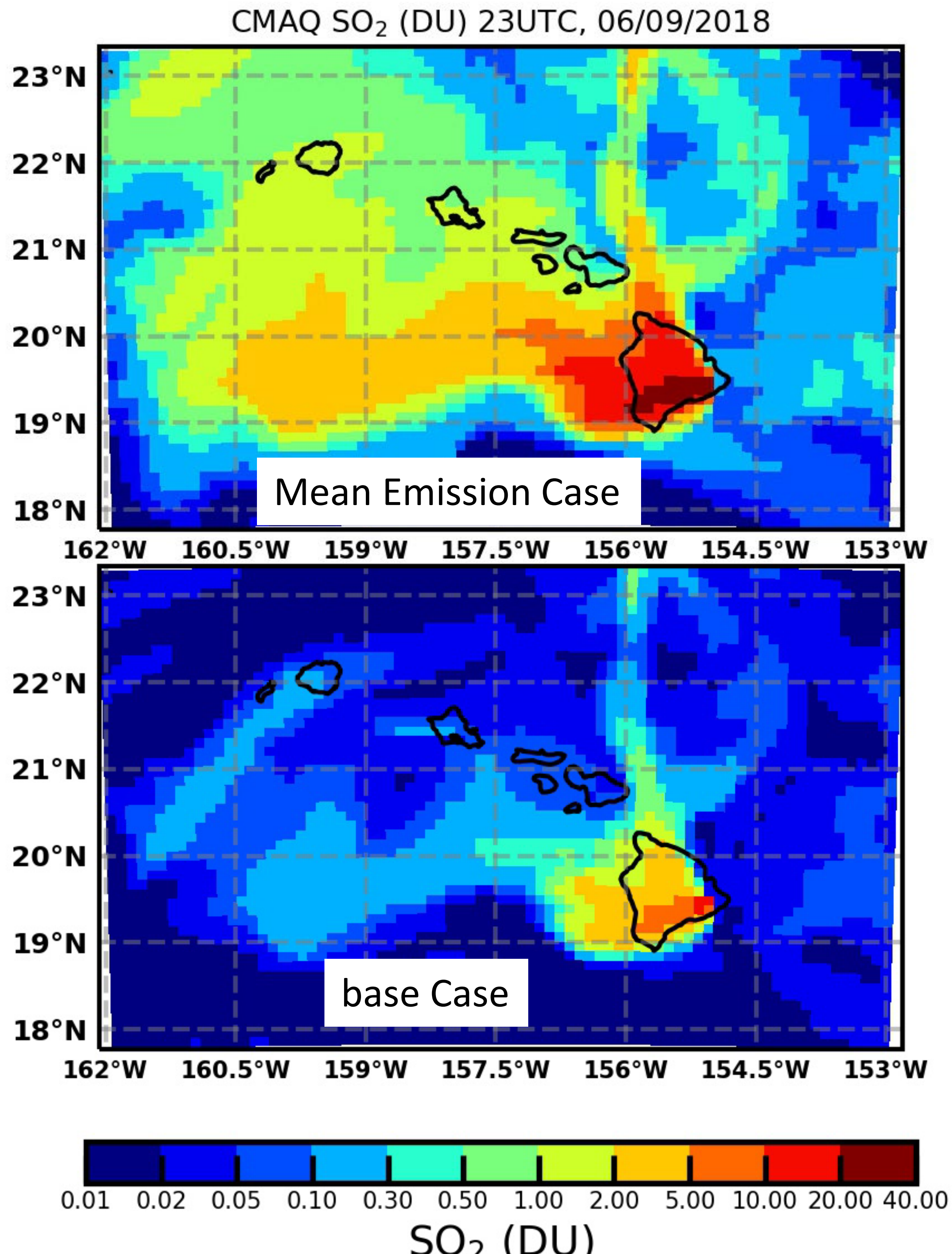




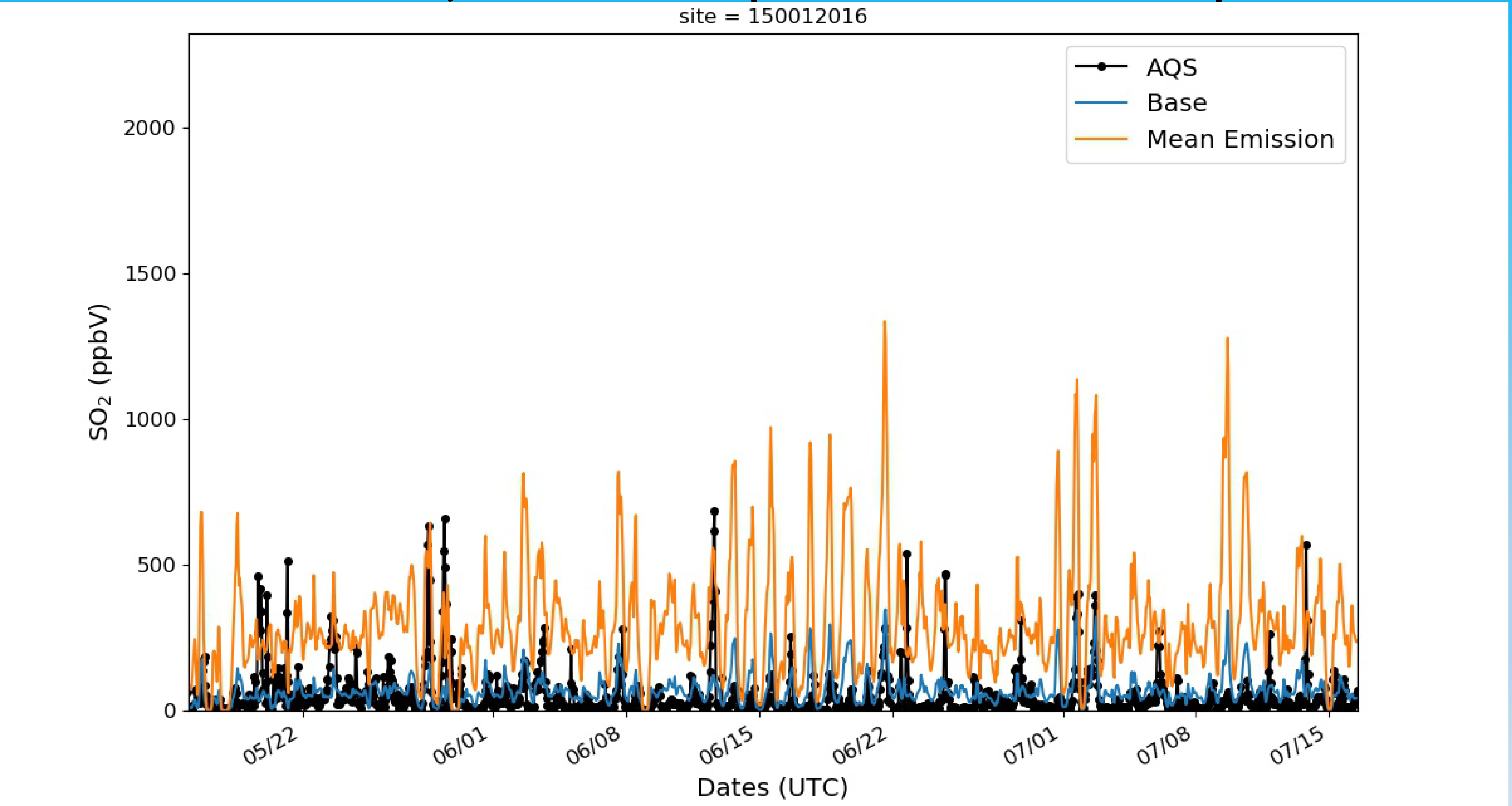


OMPS SO_2 Comparison 06/09

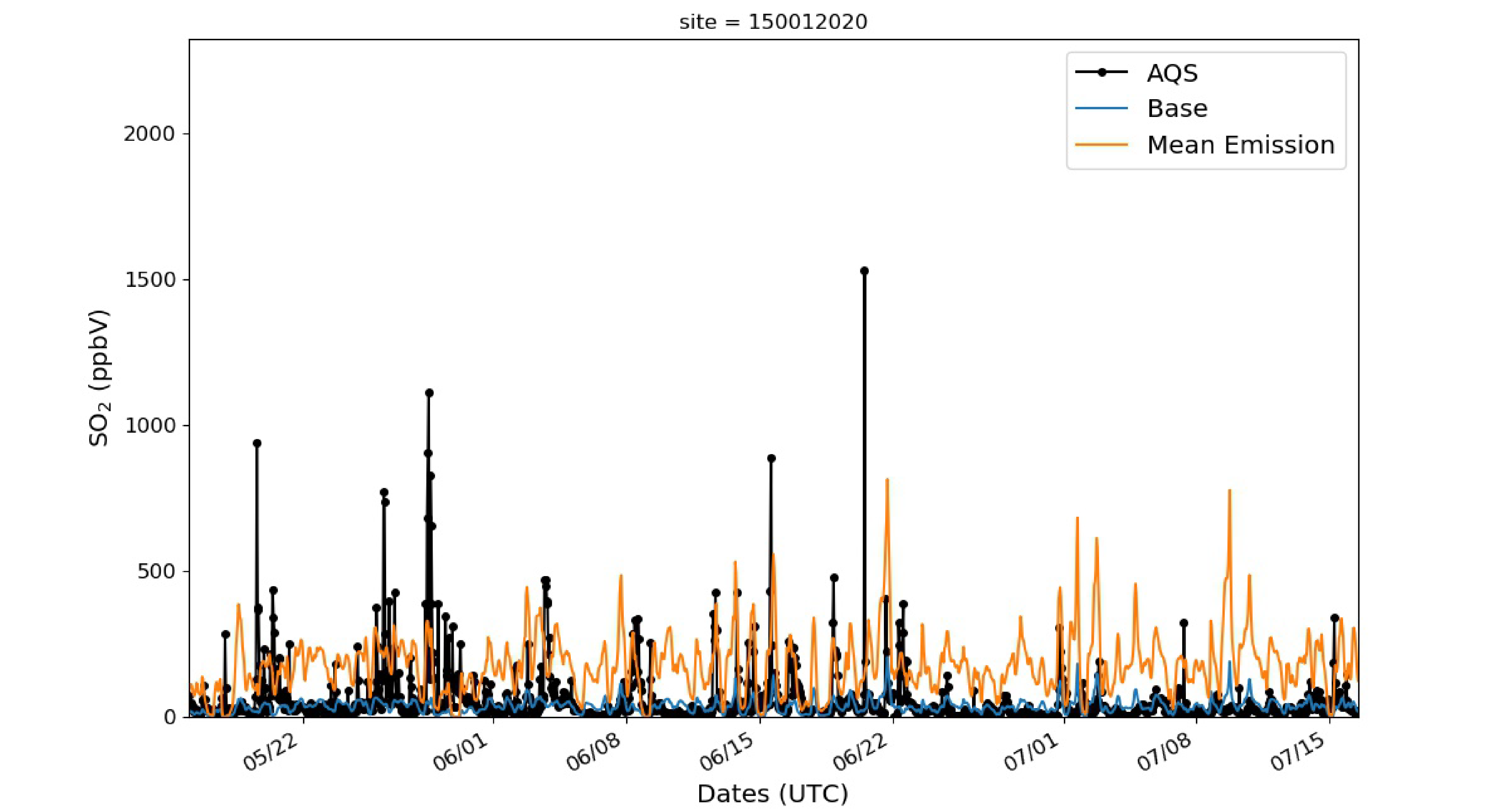




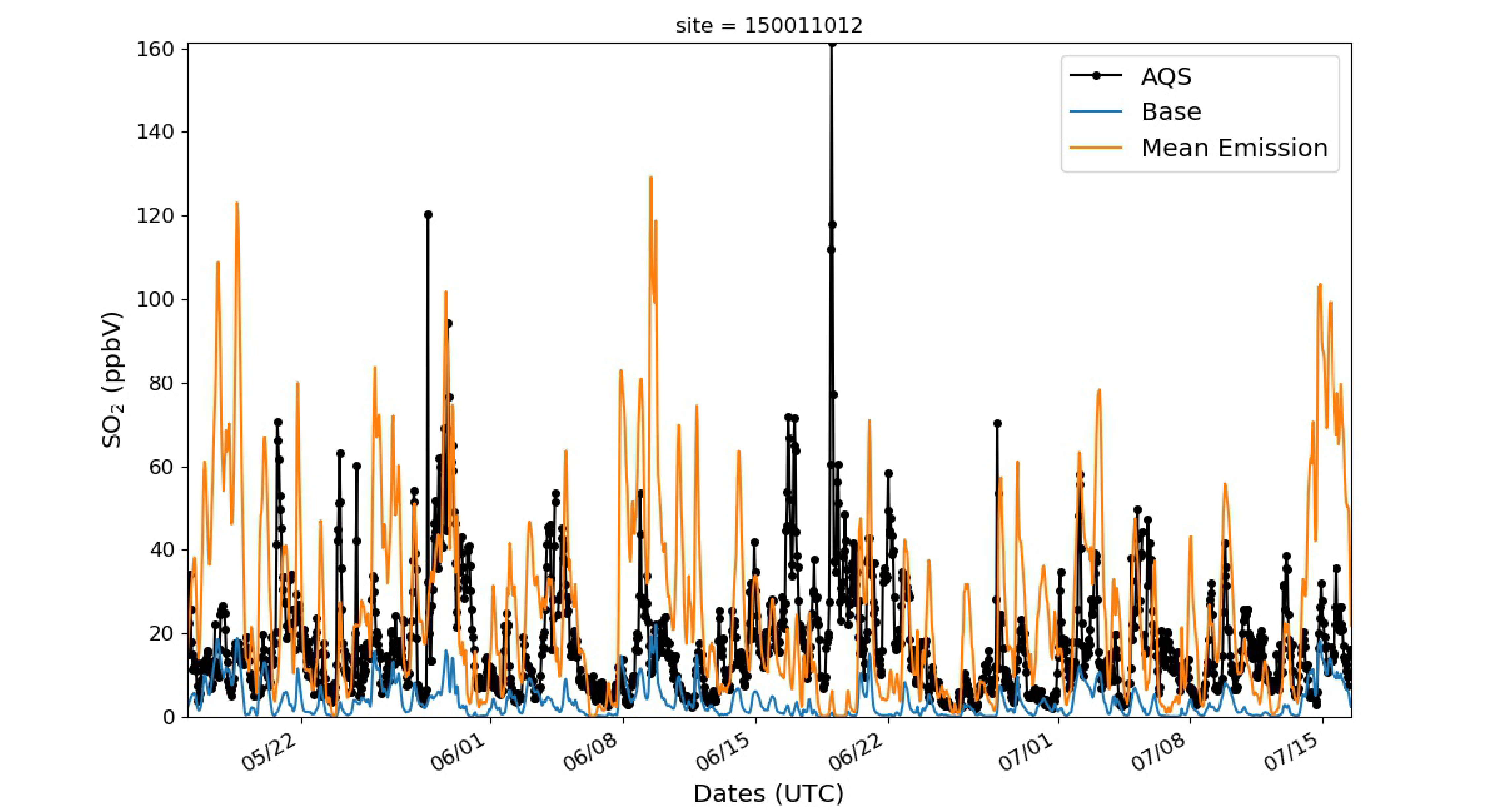
Surface Comparison
Pahala 19.2063N, -155.469 (south of summit)



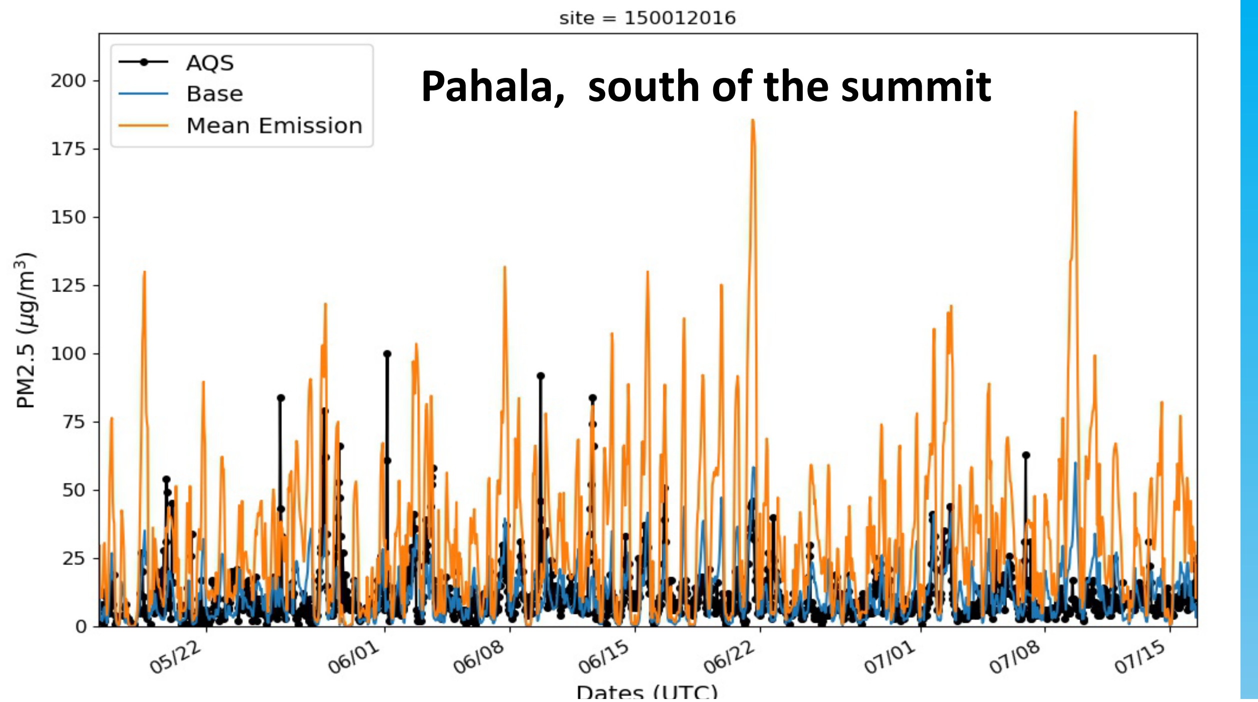
Surface Comparison
Ocean view 19.1175N, -155.778 (Southwestern big Island)

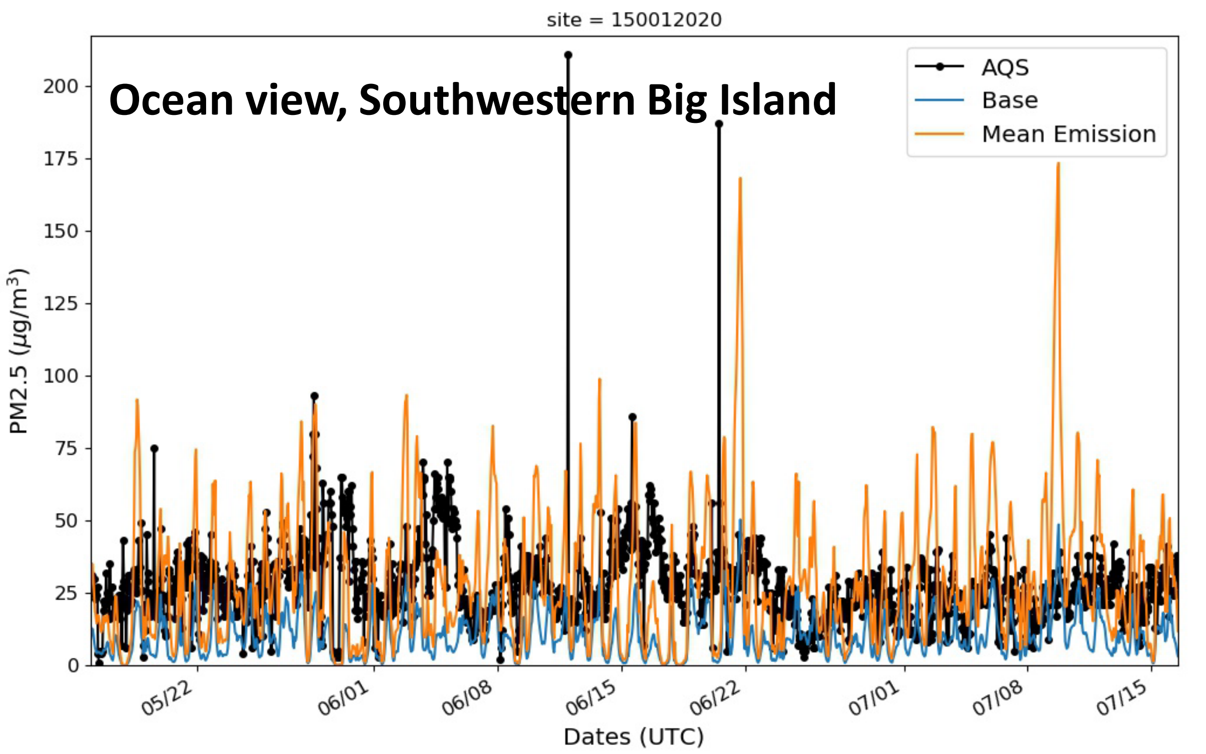


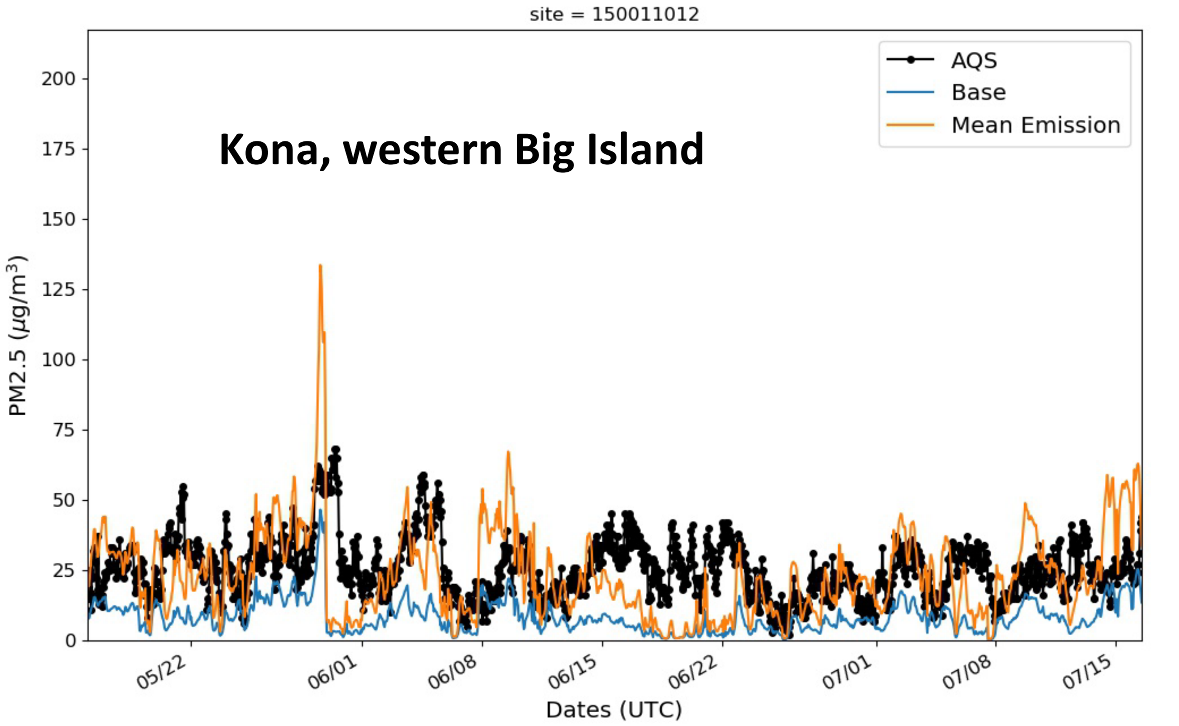
Surface Comparison
Kona 19.5094N, -155.913 (western big island)



Surface PM2.5 Comparison







Summary

- We tested the method of using satellite retrievals, OMPS-NM SO_2, to estimate the daily volcano emission, including the SO_2, ashes, and heat flux, with some assumptions, during the Kilauea Volcano's 2018 eruption. The result generally agree well with the various measurements.
- Our sensitivity study with the period-mean emission and heat flux generally yield higher SO_2 and aerosols than the base emission case, mainly due to different temporal distribution of emission and plum rises, as the base case has higher plume ejecting height co-located with the higher emission.
- The surface concentration at near-source area, e.g. near summit, is more sensitive to this temporal co-variation of emission and plume rise than that in downwind areas.
- Some discrepancies, such as satellite vs in-situ measurement, and SO_2 vs aerosol prediction biases, still need to be addressed in the future.