

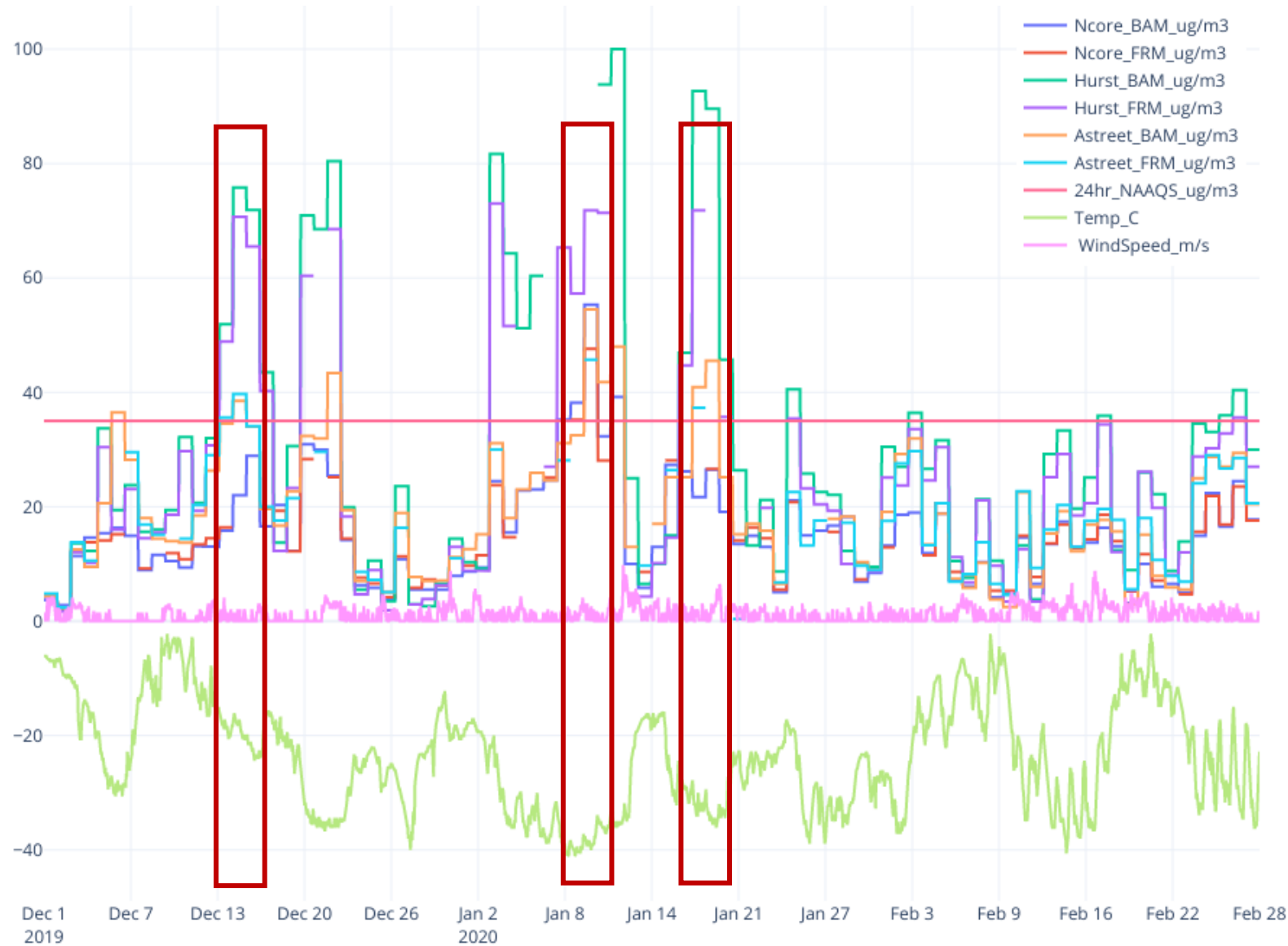


Emissions and Meteorology for the Fairbanks PM 2.5 modeling episode

Deanna Huff , Alaska Department of Environmental Conservation

Collaborators: Chao-Jung Chien & Pradeepa Vennam, Ramboll, Tom Carlson, Trinity

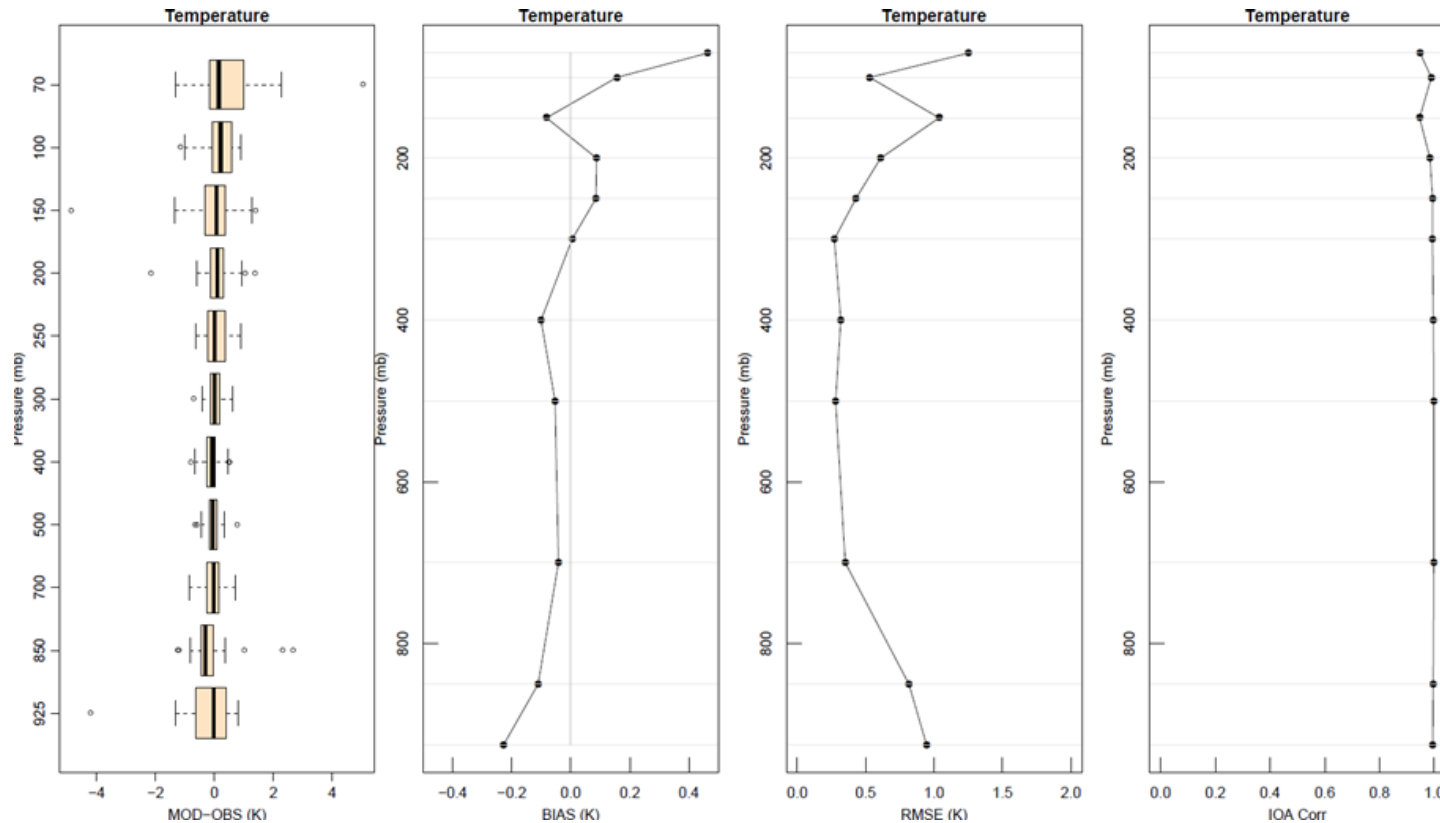
5/3/2023



Well defined strong inversions, Dec 14th at 3am 26 degrees C/100m

Figure 2-3. Observed PM_{2.5} (µg/m³), Temperature (°C) and Wind Speed (m/s) in the Fairbanks area.

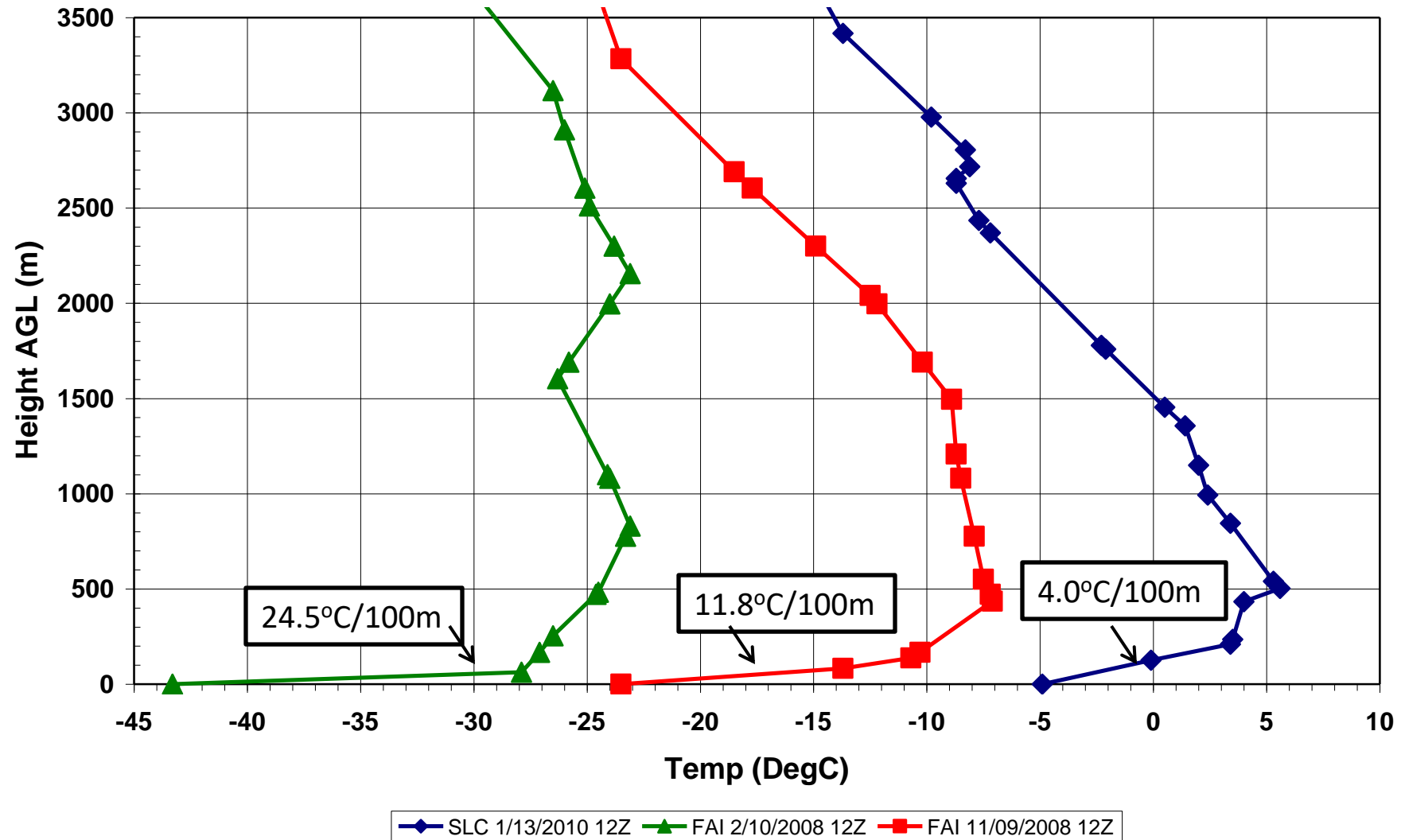
Figure 3: Temperature profile statistics for the modeling period at PAFA. Tiles include the distribution of temperature difference (mod-obs), model bias, error (RMSE) and index of agreement.



Key metrics in this evaluation is the temperature near the surface. Evaluation has been done in the past on how PAFA RAOB compares with WRF using observation nudging and the twice daily sounding indicates solid if not outstanding model performance on average over winter period. An indication that observational nudging is effective. Figure 3 is an example using temperature where RMSE is near 1 K at the surface and decreases aloft to around 0.50 K. The bias is also low and distribution of model difference with the observed temperature show tight distribution where the model is almost never more than 1 deg from the observed profile. WRF similarly performed well for moisture and wind.

Utah vs. Fairbanks: Strong vs. Extreme Inversions

Example Inversions from Fairbanks and Salt Lake City



Fairbanks Modeling Inventory – Overview of Key Source Sectors

- Presentation of data sources/methods/workflow used to produce episodic model-ready gridded emissions
- Discussion focuses on two key source sectors for Fairbanks PM_{2.5} SIP modeling:
 - 1) Point Sources (18% direct PM_{2.5}, 38% SO₂ – NAA, 5% SIP)
 - 2) Space Heating Sources (60% direct PM_{2.5}, 26% SO₂ – NAA, 5% SIP)
 - Residential Wood Combustion (RWC) contributes 56% of direct PM_{2.5} & 1% of SO₂
- Emissions from both key sectors input to SMOKE as gridded day-specific, hour specific episodic inputs for modeling

Point Sources

Data Sources & Methods

- ADEC obtained **actual day-specific, hourly** fuel use/activity data over the 2019-2020 episode
- Data were collected from six facilities in the non-attainment area by individual **emission unit** and included:
 - Annual emissions
 - Seasonal and weekly/daily activity fractions
 - Stack parameters (height, diameter, exit temp, velocity/flowrate)
 - Mapping/throughput allocations between emission units & release points
 - Location coordinates and underlying building dimensions
 - Notes identifying sources not operated during modeling episode

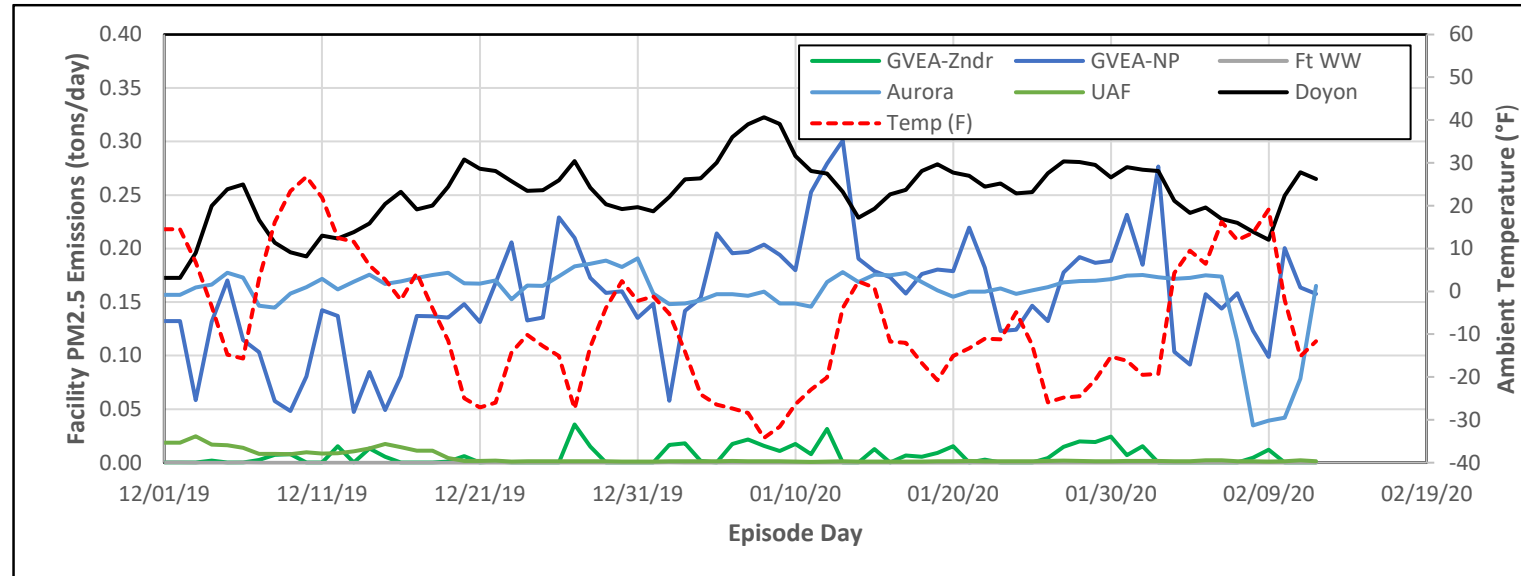
Point Sources

Summary of Facilities During 2019-2020 Episode

Facility ID	Facility Name	Primary Equipment/Fuels
109	GVEA Zehnder (Illinois St) Power Plant	Two gas turbines burning distillate #2 (2,940 ppm S), one diesel generator burning ultra low sulfur distillate (~30 ppm S)
110	GVEA North Pole Power Plant	Three gas turbines, two burning distillate #2 (2,940 ppm S), one ultra low sulfur distillate (~ 30 ppm S), plus an emergency generator and building heaters not used during episodes)
236	Fort Wainwright	Backup diesel boilers & generators (3 each) moderately operated during episode, all burn ultra low sulfur distillate (<30 ppm S)
315	Aurora Energy Chena Power Plant	Four coal-fired boilers (1 large, 3 small), all exhausted through tall common stack, subbituminous coal (1,100 ppm S)
316	UAF Campus Power Plant	Two coal-fired boilers, one oil-fired boiler, one dual oil/natural gas boiler, one dual coal/natural gas boiler (plus backup generators & incinerator not operated during episodes) – subbituminous coal (1,100 ppm S), distillate oil (3,500 ppm S)
1121	Doyon Utilities (private Ft Wainwright units)	Six coal-fired boilers, subbituminous coal (1,100 ppm S)

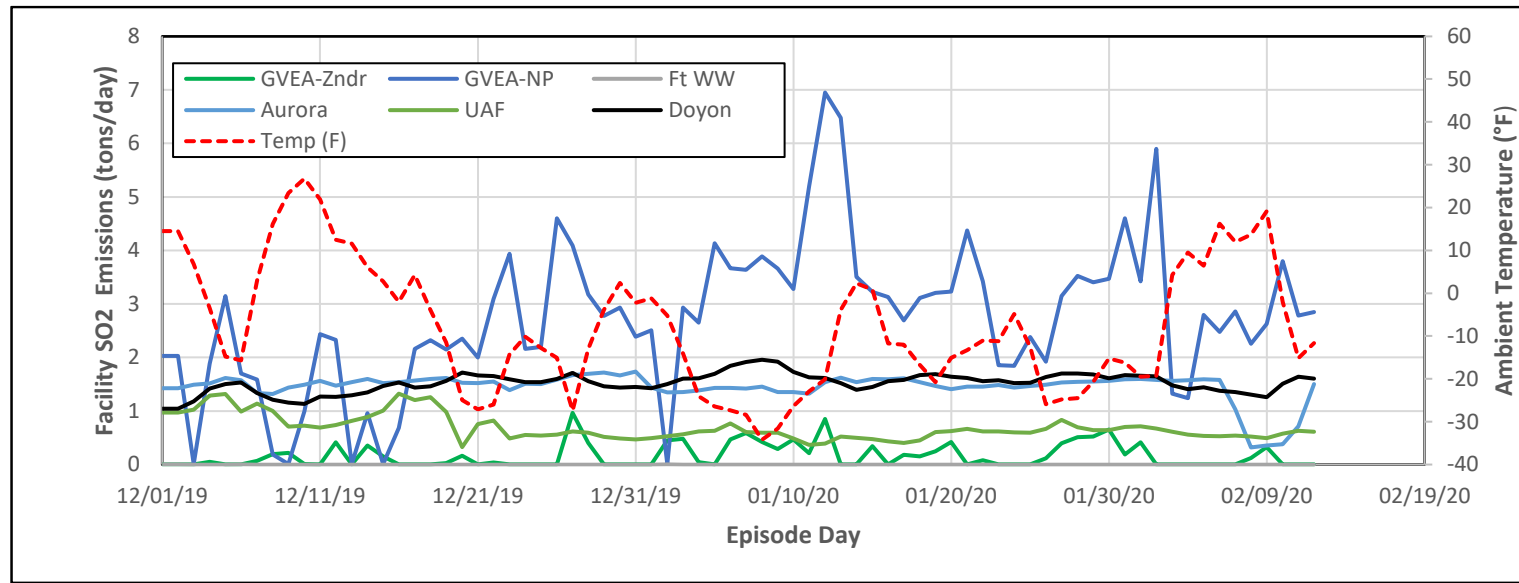
- GVEA distillate oil units used to burn Heavy Atmospheric Gas Oil (HAGO) with a sulfur content of 7,600 ppm S, now burn lower sulfur distillates as shown above
- Emission factors based on latest valid source test measurements where available, SCC-specific AP-42 emission factors where not available

Point Source Emissions – PM_{2.5} Time Series by Facility



- Daily PM_{2.5} emissions by facility across 2019-2020 modeling episode
- Facility emissions loosely correlated with ambient temperature since their energy used for electricity and heating
- All facilities (except Aurora and Doyon) use multiple fuels (or distillate grades)

Point Source Emissions – SO₂ Time Series by Facility



- Similar plot of daily SO₂ emission by facility over 74-day episode, also showing loose correlation with ambient temperature
- GVEA-North Pole (NP) generally has highest emissions due to regular use of 2,940 ppm S distillate, but their emissions also vary significantly since they often fire a third gas turbine burning ultra low sulfur distillate (<30 ppm S)

Space Heating Inventory Overview

- Episodic (day & hour) residential space heating inventory driven by energy demand developed for wintertime in Fairbanks
- Device usage
 - Along with temperature this gives temporal variability
- Home size and type
 - Determines the amount of heating required
 - Includes spatial variability based on Fairbanks Home Heating survey
- Device mixes (by 4 km x 4 km Grid 2 cell)
 - Spatial variability of emissions
 - Heating efficiency differences reflected in fuel use and pollutant emissions
- Fuel Usage
 - With device mix and energy demand

Home Heating Inventory Overview (cont.)

- Household Instrumentation study -> Temperature driven energy demand model
- Winter home heating device and fuel surveys -> fuel and device mixes
- Parcel database -> house size and type
- Enables emission inputs to SMOKE by day, hour and grid cell to preserve high spatial and temporal resolution
- Residential building height data used to allocate home heating emissions into lowest 4 vertical layers

Space Heating – Key Data Sources

- CCHRC Household Instrumentation Study (Phase II):
 - 30 homes instrumented from mid Dec 2010 – mid Feb 2011
 - Homes selected based on target sampling matrix – device usage by candidate household from preceding phone survey
 - \$150 participation incentive, homes classified as Oil (100% oil), Wood (>80% wood), Mixed (mixed oil-wood)
 - Five devices sampled: 1) woodstove; 2) fireplace; 3) OWB; 4) central oil furnace and 5) direct-vent (DV) oil heater
 - Central oil use measured directly (furnace rating, on/off time)
 - DV oil and wood use measured by thermocouples (proxy) and oil or wood use logs (oil tank levels/fills, wood weighed for first 1-2 weeks of instrumentation)
 - Hourly ambient temperature collected from local stations
 - Notes kept on known instrumentation problems

Space Heating – Key Data Sources (cont.)

- **Hays Research Home Heating Telephone Surveys:**
 - Random household phone surveys in 2006, 2007, 2010, 2011, 2012, 2013, 2014 and 2015.
 - First three ~ 300 households each, zip code-based sampling targets from household distributions in 2000 Census
 - Later 2011-2015 surveys (~3,500 households combined sample) used in Serious SIP modeling inventories
 - New 2023 online survey being conducted (ends 5/15) - 3,000 household target sample size
- **2020 U.S. Census Block-Level Database:**
 - Block-level GIS layers used to calculate number of residential households in each modeling grid cell
- **FNSB Assessor Parcel Database:**
 - Separate data tables linked by parcel number that provided dwelling size info (sq ft)
 - Average dwelling size then calculated for each grid cell

Space Heating – Home Instrumentation Data Analysis (cont.)

CCHRC 2011 Home Heating Device Instrumentation Study Summary of Measured/Estimated Heating Energy Use by Household

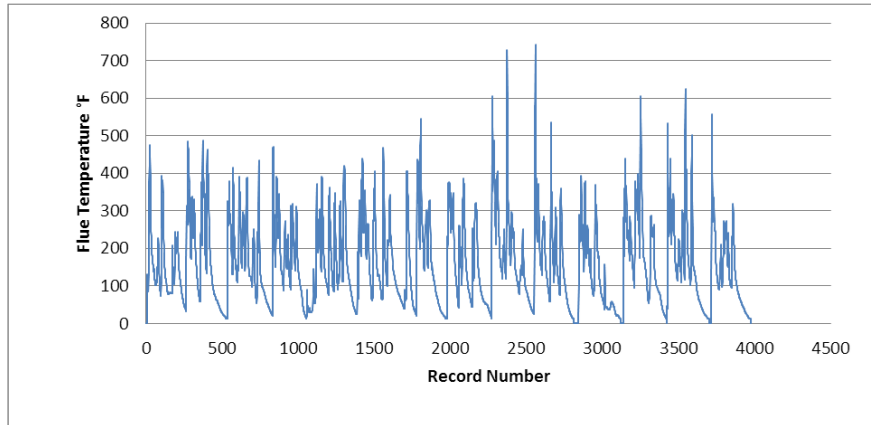
HHID	ft ²	Average Household Daily Energy Use by Device (BTU/day)						Wood
		Woodstove	Fireplace	OWB	CentOil	DirectVent	Total	Fraction
M-02	2900	246,679			715,474		962,153	26%
M-03	2500	236,436			824,195		1,060,630	22%
M-04	1770	189,519			393,639		583,159	32%
M-05	1900		279,360		968,286		1,247,647	22%
M-06	3000	414,787			769,853		1,184,639	35%
M-08	1760	70,251			739,382		809,633	9%
M-09	2600	153,027			583,960		736,987	21%
O-01	2448				794,107		794,107	0%
O-02	1500				975,973		975,973	0%
O-03	2775				1,082,992		1,082,992	0%
O-04	2912				914,106		914,106	0%
O-05	1400					373,452	373,452	0%
O-06	1000					235,415	235,415	0%
O-07	1200				651,937		651,937	0%
O-08	2200				954,585		954,585	0%
O-09	2100				953,530		953,530	0%
O-10	2200				456,031		456,031	0%
W-01	1250	842,805			173,183		1,015,988	83%
W-03	2488			1,672,442	114,024		1,786,465	94%
W-04	2100	367,664			961,297		1,328,962	28%
W-05	5000	1,063,552			40,229		1,103,781	96%
W-06	915	258,873				2,350	261,224	99%
W-07	4580			425,338	431,168		851,015	50%
W-08	1400	190,263				93,450	283,714	67%
W-09	884	257,989					257,989	100%
W-10	575	251,863				26,695	278,558	90%
Sample Average:							813,257	

Space Heating – Home Instrumentation Data Analysis

- Detailed review/validation of as-received data from CCHRC:
 - Assembled into master spreadsheet database
 - Checked time series plots, recorded notes by household
 - Thermocouples sometimes observed to have fallen off or provided spotty results (e.g. anomalies near room temperature)
 - Wood log suspect/missing for two households
 - Discarded 4 of 30 households where data were invalid/missing
 - Removed selected portions for remaining households where data were incomplete (rare)
 - Determined 3 Wood households were Mixed fuel households

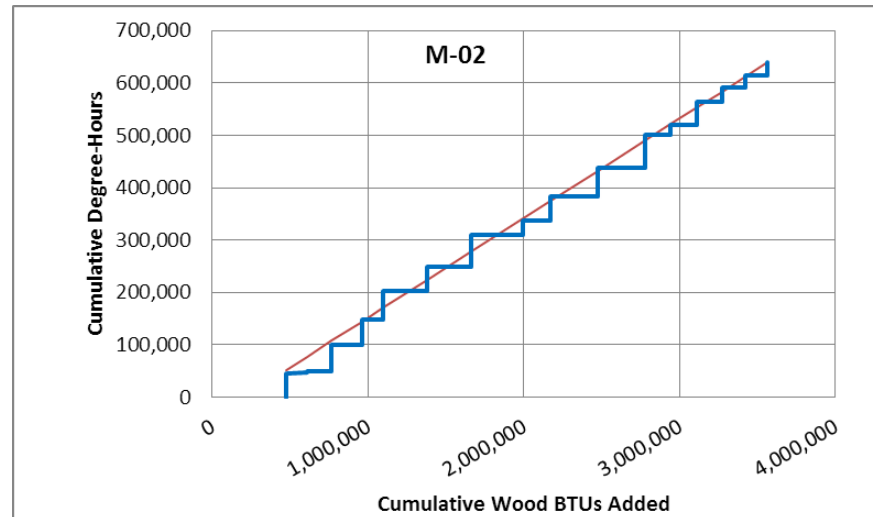
Space Heating – Home Instrumentation Data Analysis (cont.)

Wood Stove Flue Temperature



Record number resolution is 5 min

Cumulative Wood Stove BTUs vs. Flue Degree-Hours

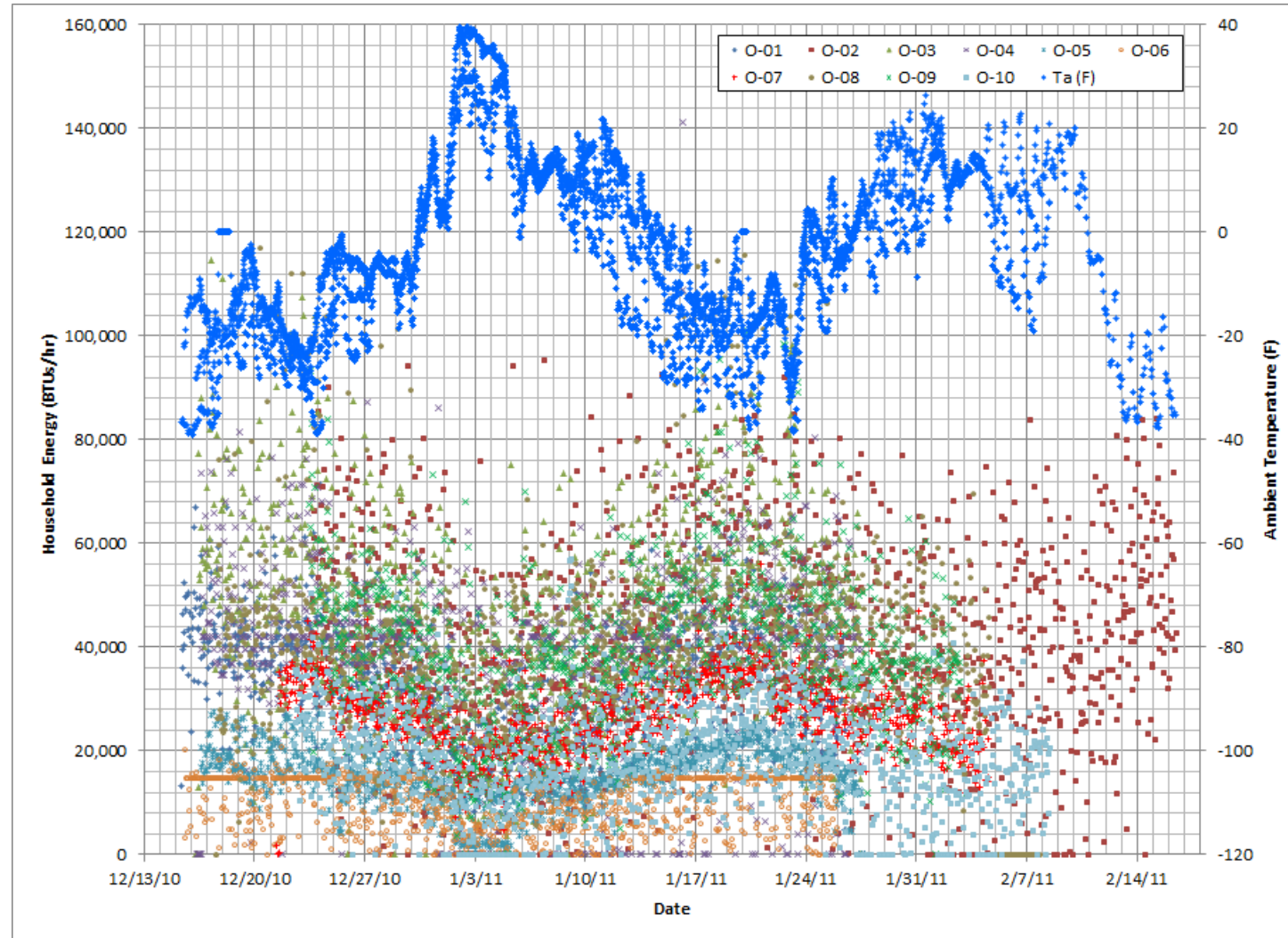


Integrating average flue temperature from known time scale x degrees

Calculations fully explained in the appendix of the Moderate Area SIP

Space Heating – Home Instrumentation Data Analysis (cont.)

Household Energy vs. Time - Oil Only Households



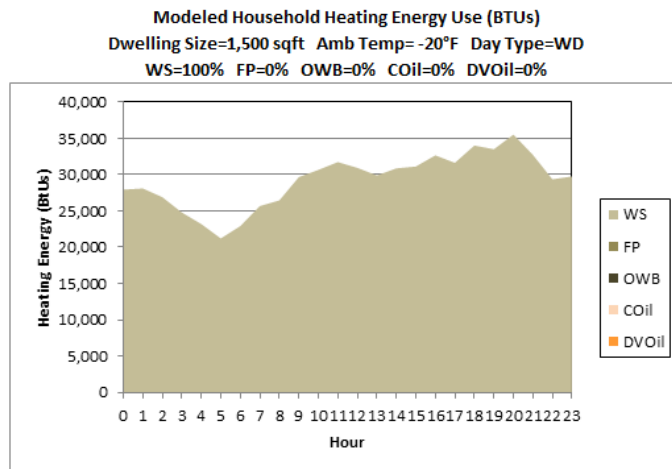
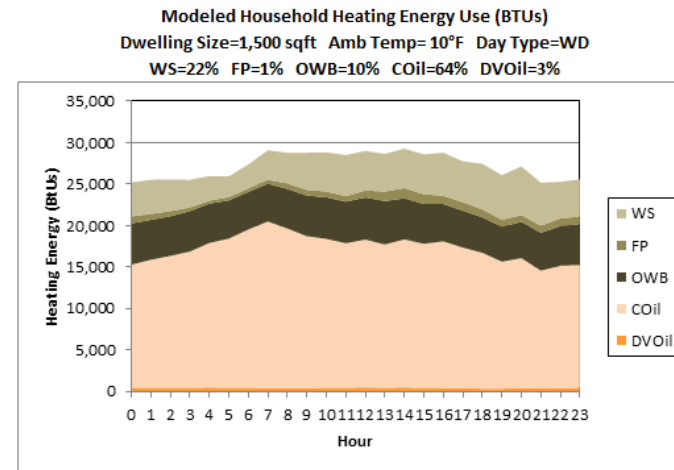
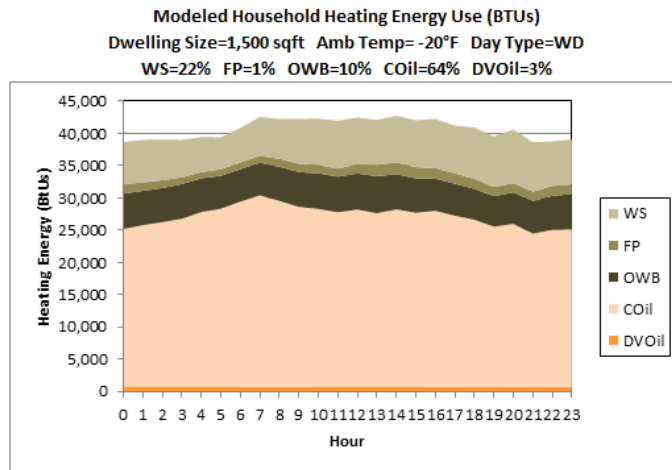
Space Heating – Home Instrumentation Data Analysis (cont.)

- Fairbanks Household Heating Energy Demand Model

- Predict Home Heating BTUs as a function of:
 - Building size (sq ft)
 - Mix of devices (five from instrumented study)
 - Ambient temperature
 - Hour of day
 - Day of week (weekday/weekend)
- Two-step (combined model) multivariate regression:
 - $\text{Daily BTUs} = C1 + C2 * \text{Size} + C3 * \text{UseFracdev1} + C4 * \text{UseFracdev2} \dots + C7 * \text{UseFracdev5}$
 - $\text{BTU/Hri,j} = (C1 + C_{ii=2..24}) + C25 * \text{Temp(F)} + C26 * \text{weekday}=0 | \text{weekend}=1$
- Uses daily average ambient temperature

Space Heating – Home Instrumentation Data Analysis (cont.)

Household Energy Prediction Model Scenarios



Space Heating – Episodic Emission Inventory

- Heating energy (BTUs) calculated by grid cell, day and hour:
 - Households in cell (per block level US census database)
 - Average household size
 - Zip code-specific device usage fractions
 - Ambient temperature (daily)
 - Household energy prediction model
- Energy estimates (BTUs) translated to fuel use (from energy content) and combined with device-specific emission factors to calculate space heating emissions (by cell, SCC, day, hour).
- Local devices and wood species (birch and spruce) tested (uncertified and certified, OWBs, oil furnaces, etc.) and superseded AP 42 emission factors and the local emission factors were used in the emissions inventory.

Section 2

- CMAQ ready emissions input
- Emissions time series

Development of CMAQ Emissions Inputs (SMOKE Processing)

- CMAQ-ready emissions inputs generated by SMOKE v4.81 modeling system (released in Jan 2020).
- Most ancillaries used in SMOKE are from EPA 2016v1 (2016fh_16j) emissions modeling platform except temporal and spatial surrogates are provided by Trinity.
- Speciation profiles for all sectors are based on EPA 2016v1 defaults.
- Emission sectors processed through SMOKE:
 - Aircraft (3D 4-layer vertically allocated; SCC-specific temporal*)
 - Area (SCC-specific temporal*)
 - Nonroad (SCC-specific temporal*)
 - Point (hour- and day-specific inventory; CMAQ point in-line processing)
 - On-road (SMOKE-MOVES processing including RPD, RPH, RPP and RPV)
 - SpaceHeat (processed as hourly point source; 3D 4-layer vertically allocated)
- Hourly CMAQ files are produced for each day for entire episode (12/2019 – 2/2020) and for all sectors.
- Emission QA through SMOKE reports and model-ready summaries.

**ancillary files provide by Trinity*

PM₂₅ Speciation Profiles for Space-Heating emissions (EPA Default vs. OMNI)

- EPA 2016v1 speciation profiles for Space-heating related inventory:

91105 (Residential Oil Heating)
91115 (Wood Combustion)

EPA profile	pollutant	species	ratio
91105	PM2_5	PAL	0.0001
91105	PM2_5	PCA	0.0001
91105	PM2_5	PCL	0.0030
91105	PM2_5	PEC	0.0558
91105	PM2_5	PFE	0.0001
91105	PM2_5	PK	0.0097
91105	PM2_5	PMG	0.0001
91105	PM2_5	PMOTHR	0.0245
91105	PM2_5	PNA	0.0009
91105	PM2_5	PNCOM	0.3697
91105	PM2_5	PNH4	0.0015
91105	PM2_5	PNO3	0.0019
91105	PM2_5	POC	0.5282
91105	PM2_5	PSI	0.0003
91105	PM2_5	PSO4	0.0041
91115	PM2_5	PCA	0.0002
91115	PM2_5	PEC	0.1000
91115	PM2_5	PFE	0.0009
91115	PM2_5	PK	0.0004
91115	PM2_5	PMOTHR	0.3505
91115	PM2_5	PNCOM	0.1000
91115	PM2_5	POC	0.2500
91115	PM2_5	PSI	0.0080
91115	PM2_5	PSO4	0.1900

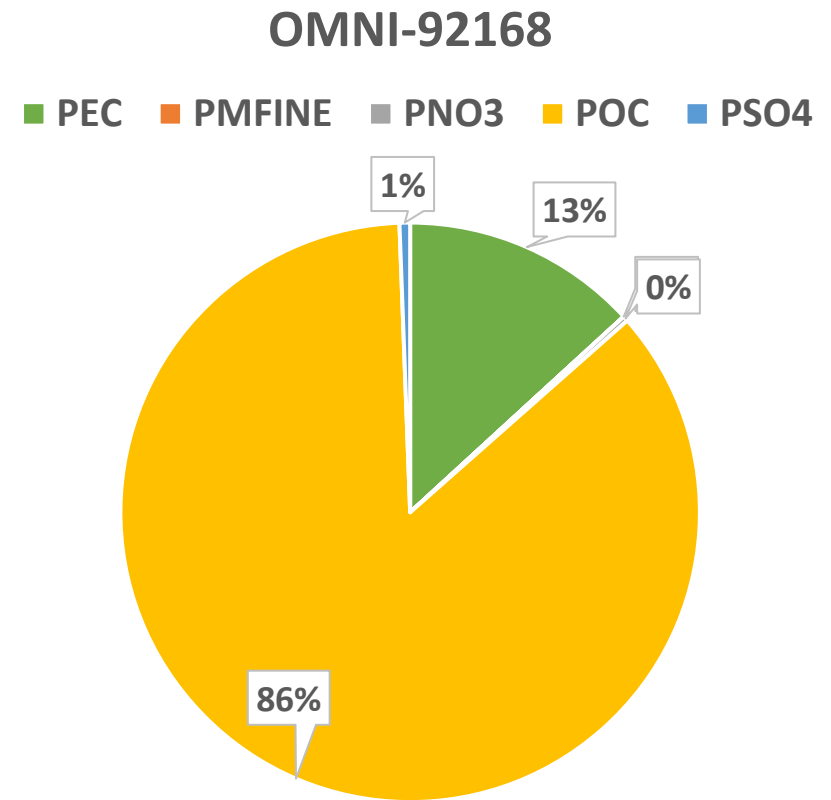
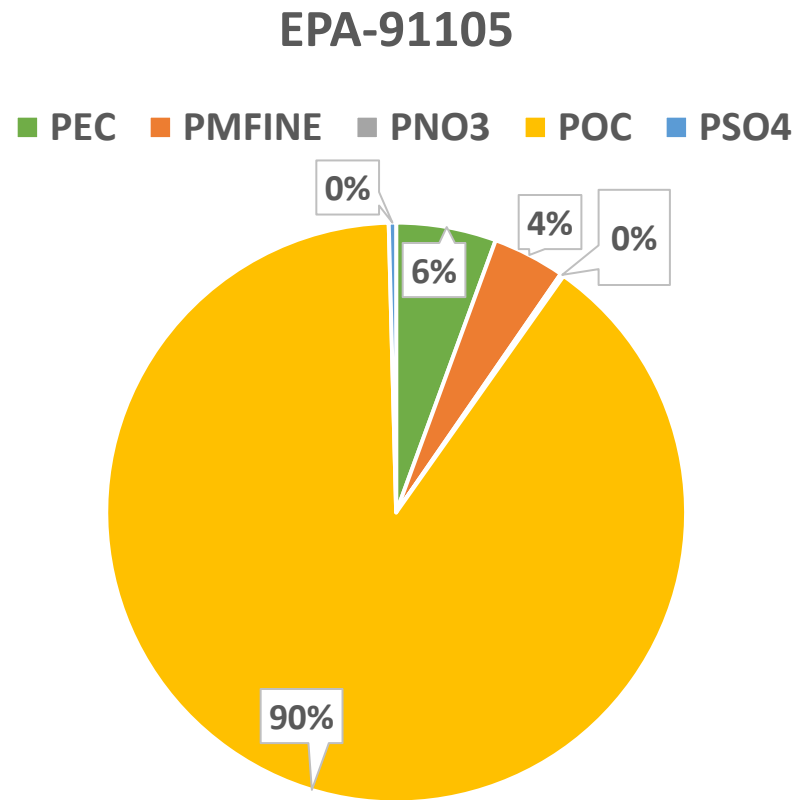
PM₂₅ Speciation Profiles for Space-Heating emissions (EPA Default vs. OMNI)

- OMNI speciation profiles for
Space-heating related
inventory

92168 (Residential Oil Heating)
92125 (Wood Combustion)

Profile ID	Pollutant	Species	Split Factor
92125	PM2_5	PEC	0.063063
92125	PM2_5	PMFINE	0.177007
92125	PM2_5	PNO3	0.013501
92125	PM2_5	POC	0.411216
92125	PM2_5	PSO4	0.335213
92168	PM2_5	PEC	0.131921
92168	PM2_5	PMFINE	2.1E-05
92168	PM2_5	PNO3	0.002905
92168	PM2_5	POC	0.859243
92168	PM2_5	PSO4	0.00591

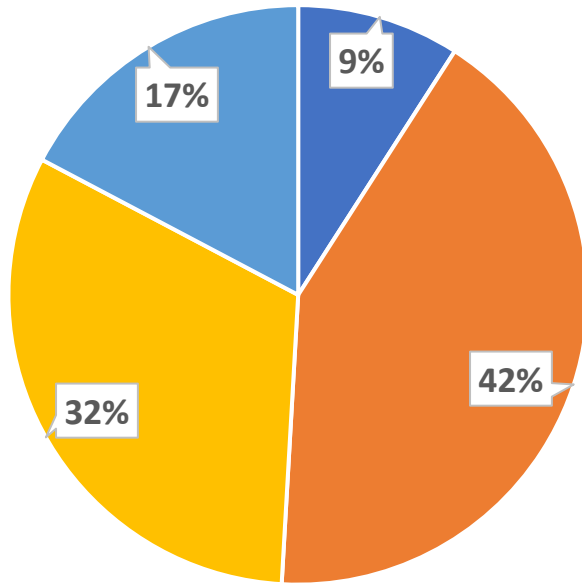
Speciation Profile for Residential Wood Combustion (SCCs: 2104008xxx)



Speciation Profile for Residential Oil Heating (SCC: 2104004000)

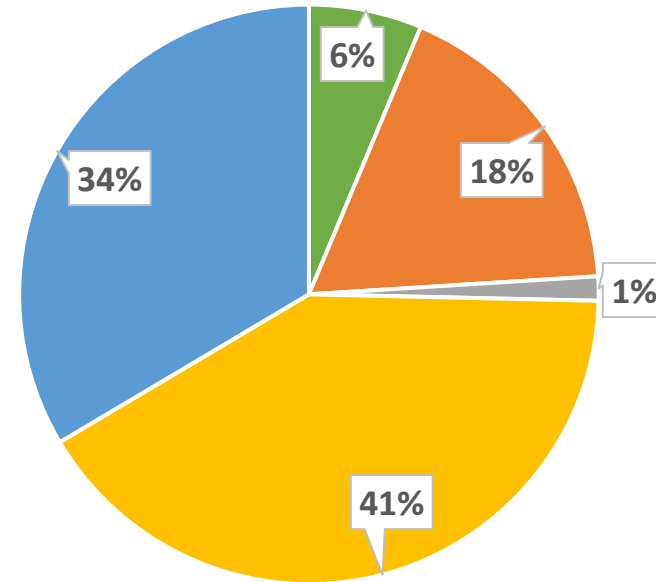
EPA-91115

■ PEC ■ PMFINE ■ PNO3 ■ POC ■ PSO4

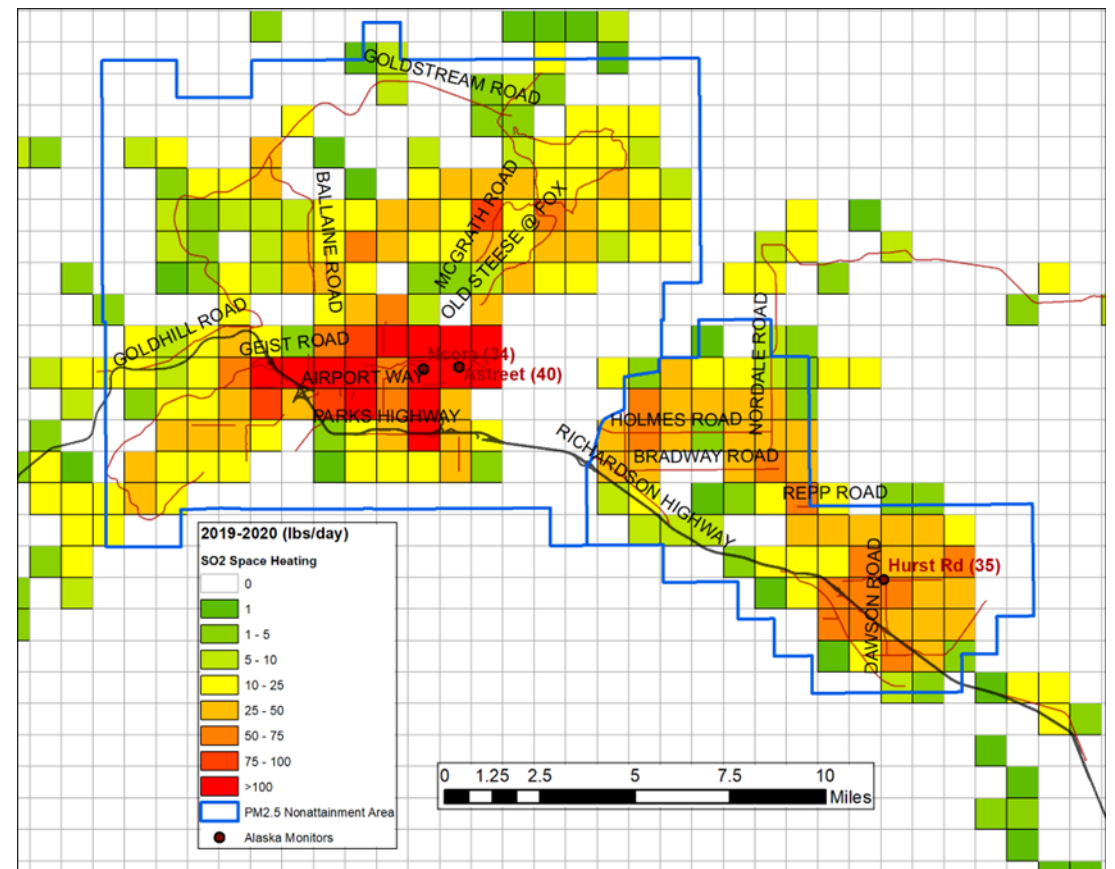
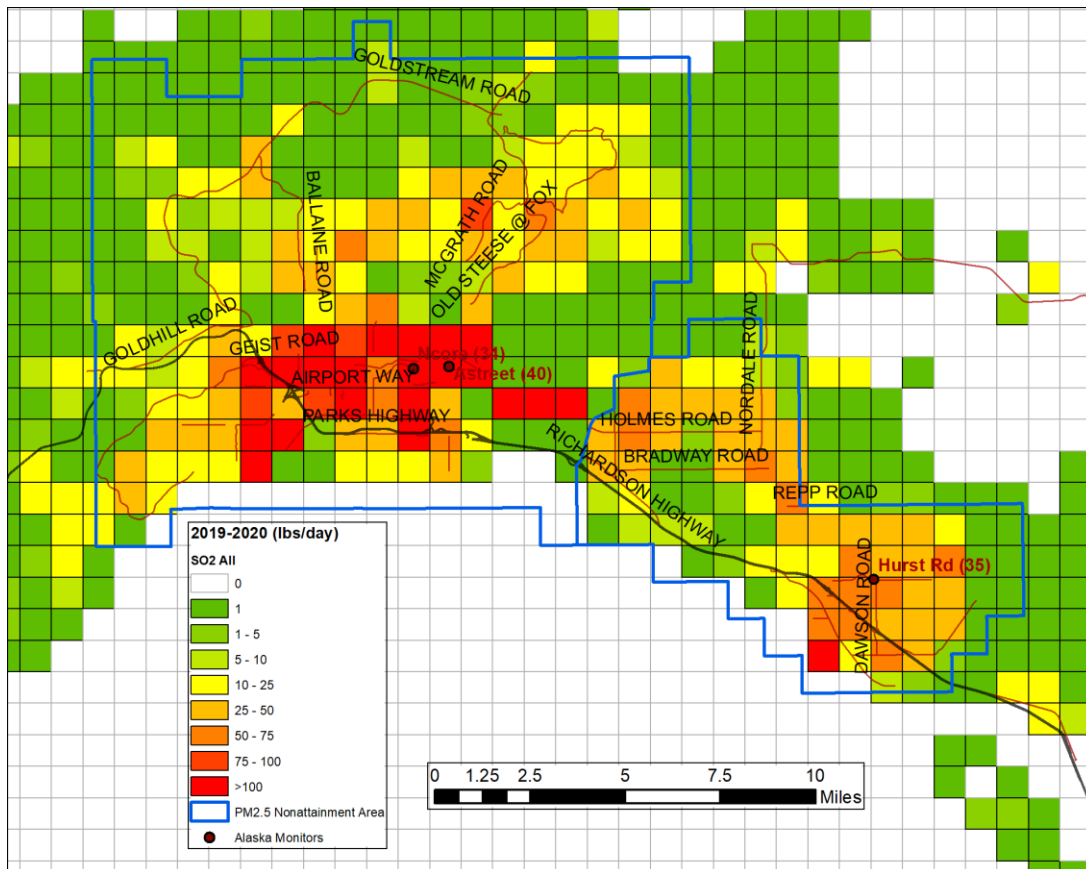


OMNI-92125

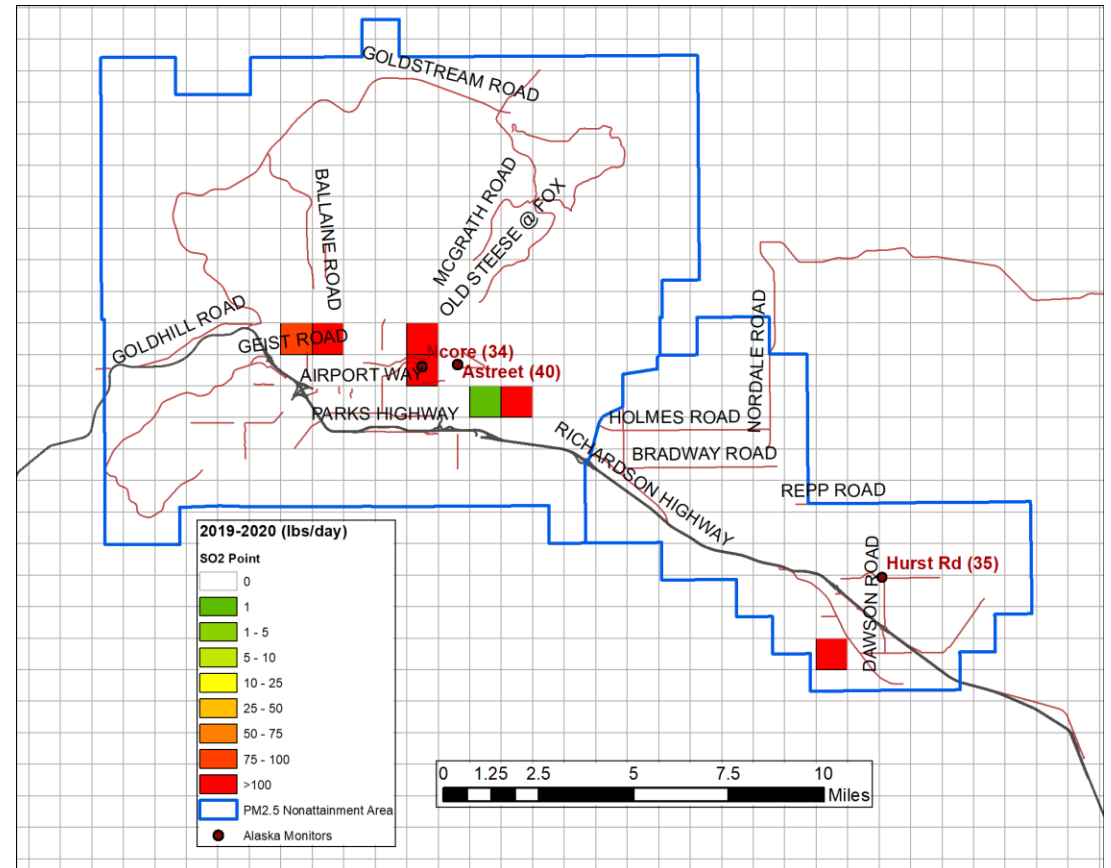
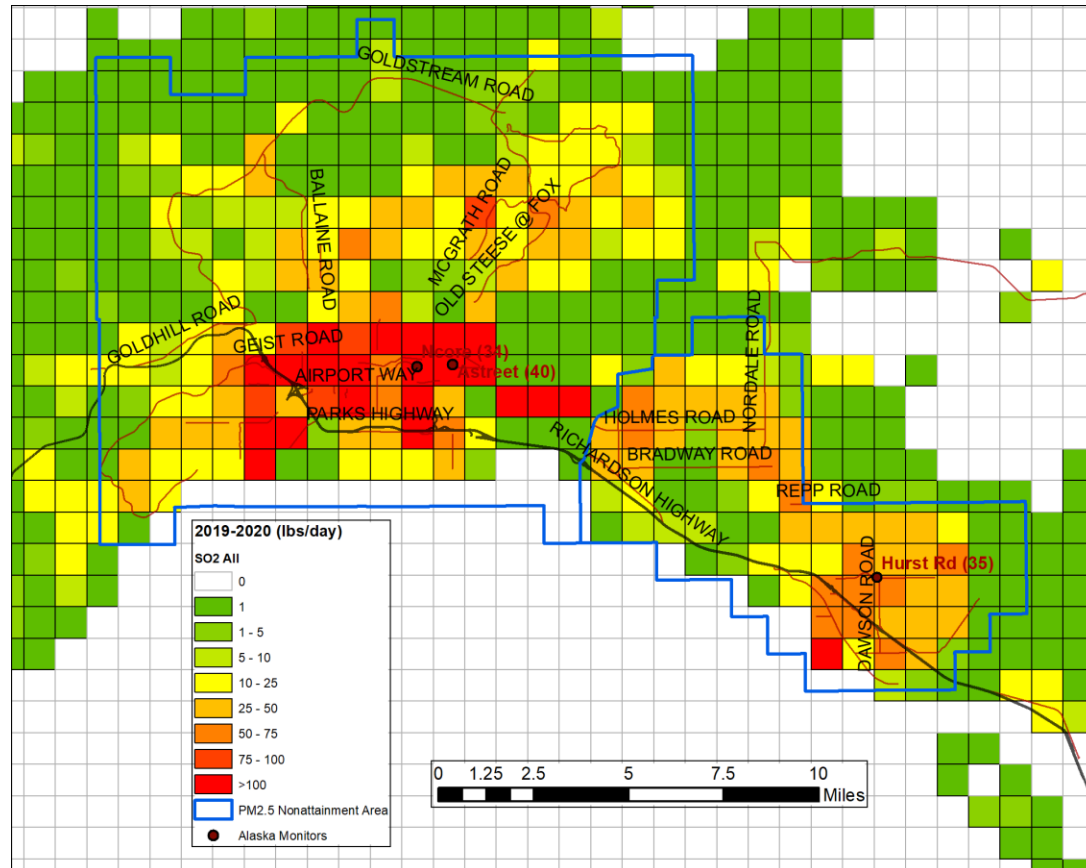
■ PEC ■ PMFINE ■ PNO3 ■ POC ■ PSO4



Spatial Plots – Fairbanks Non-Attainment episode average emissions into all layers

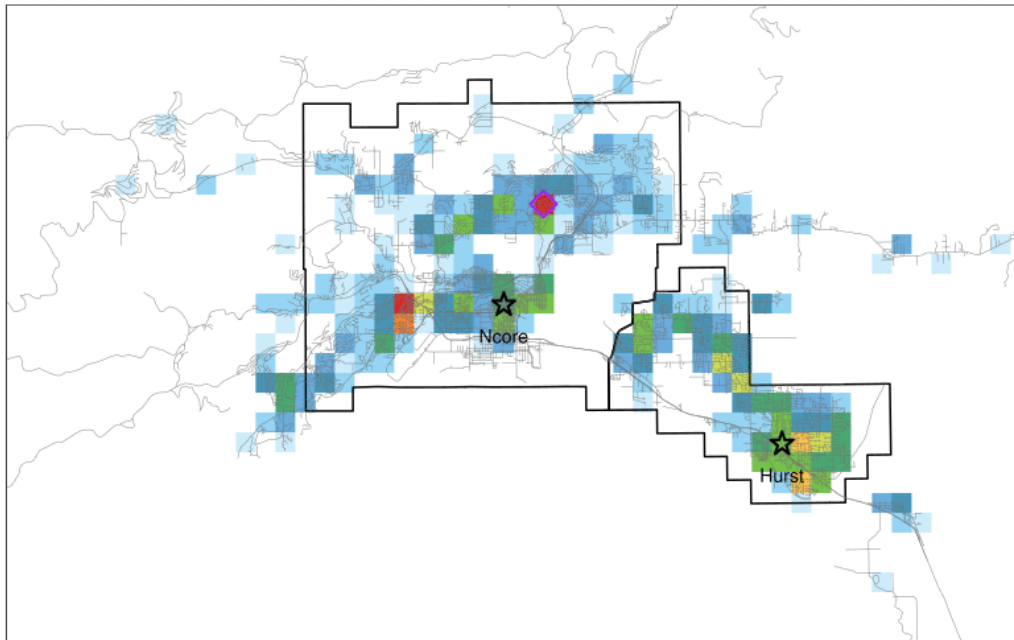


Spatial Plots – Fairbanks Non-Attainment episode average emissions into all layers



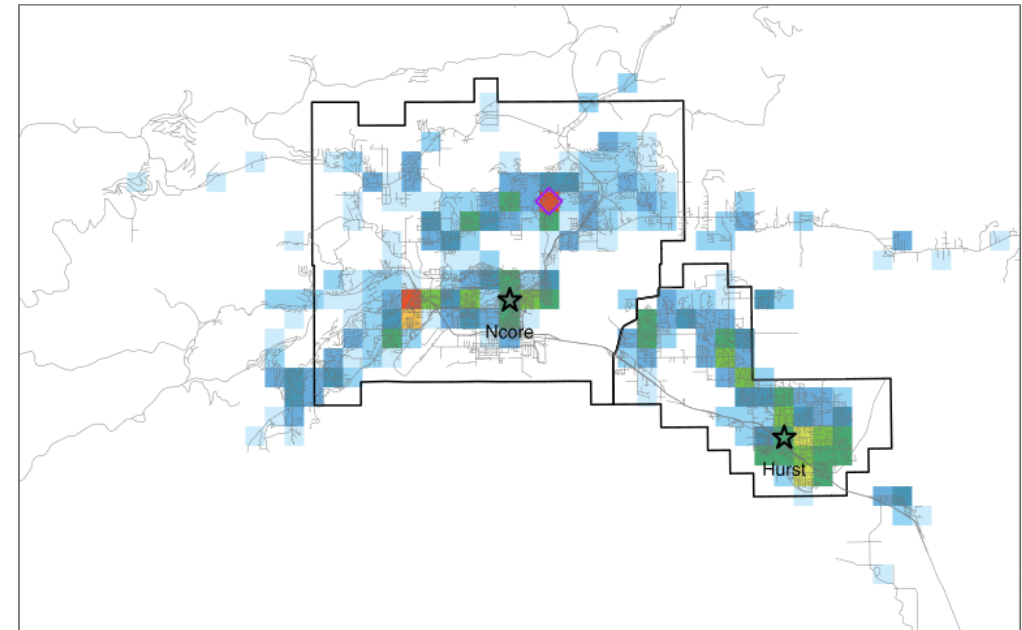
RWC Emissions Spatial Distributions

PM25
Daily Tot: 20191201
Sector: rwc



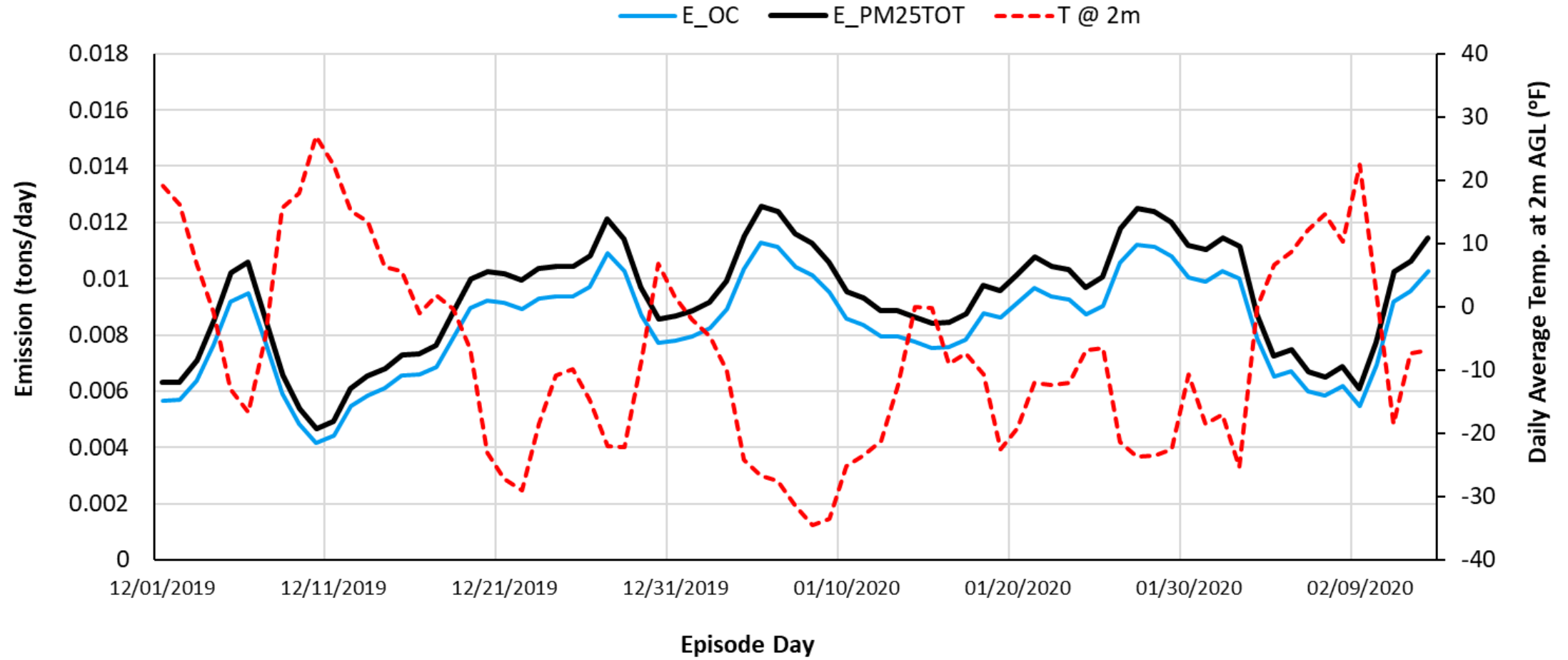
◇ max = 0.021 tons/day

POC
Daily Tot: 20191201
Sector: rwc

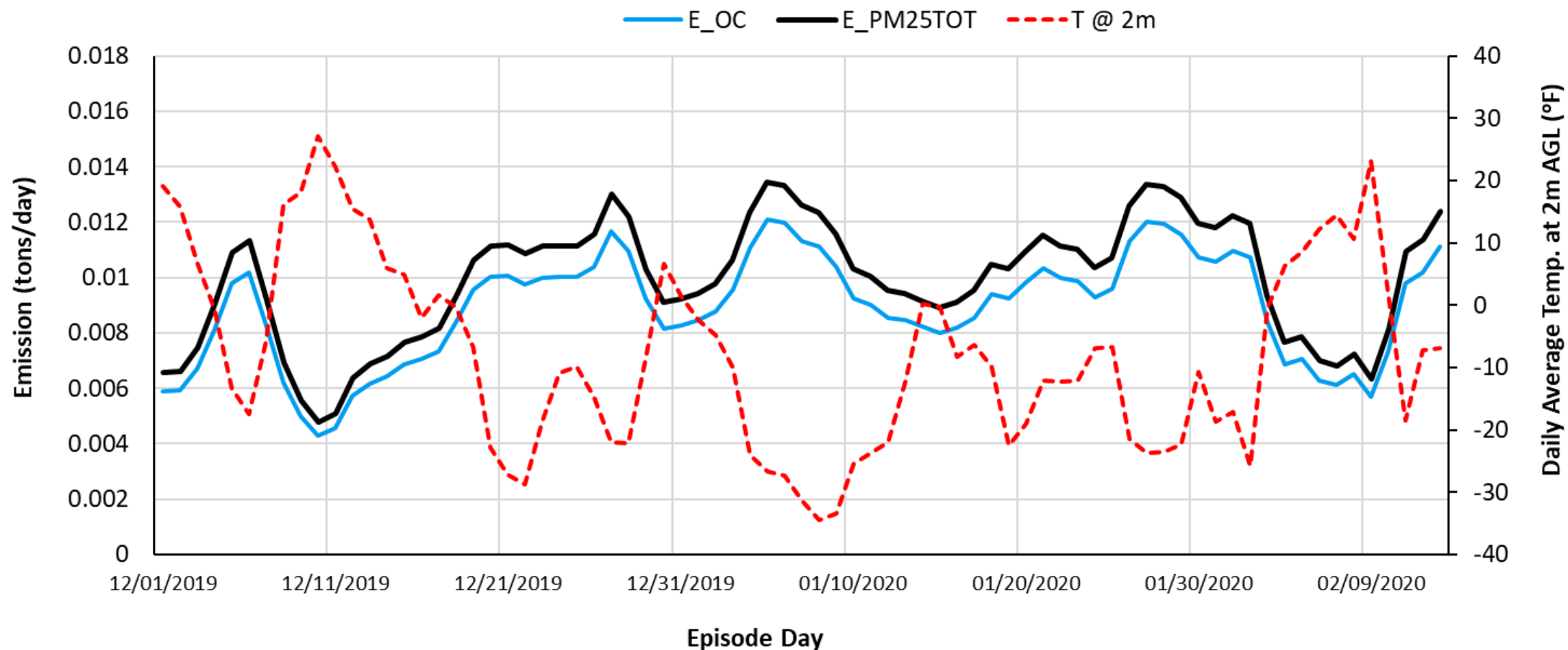


◇ max = 0.019 tons/day

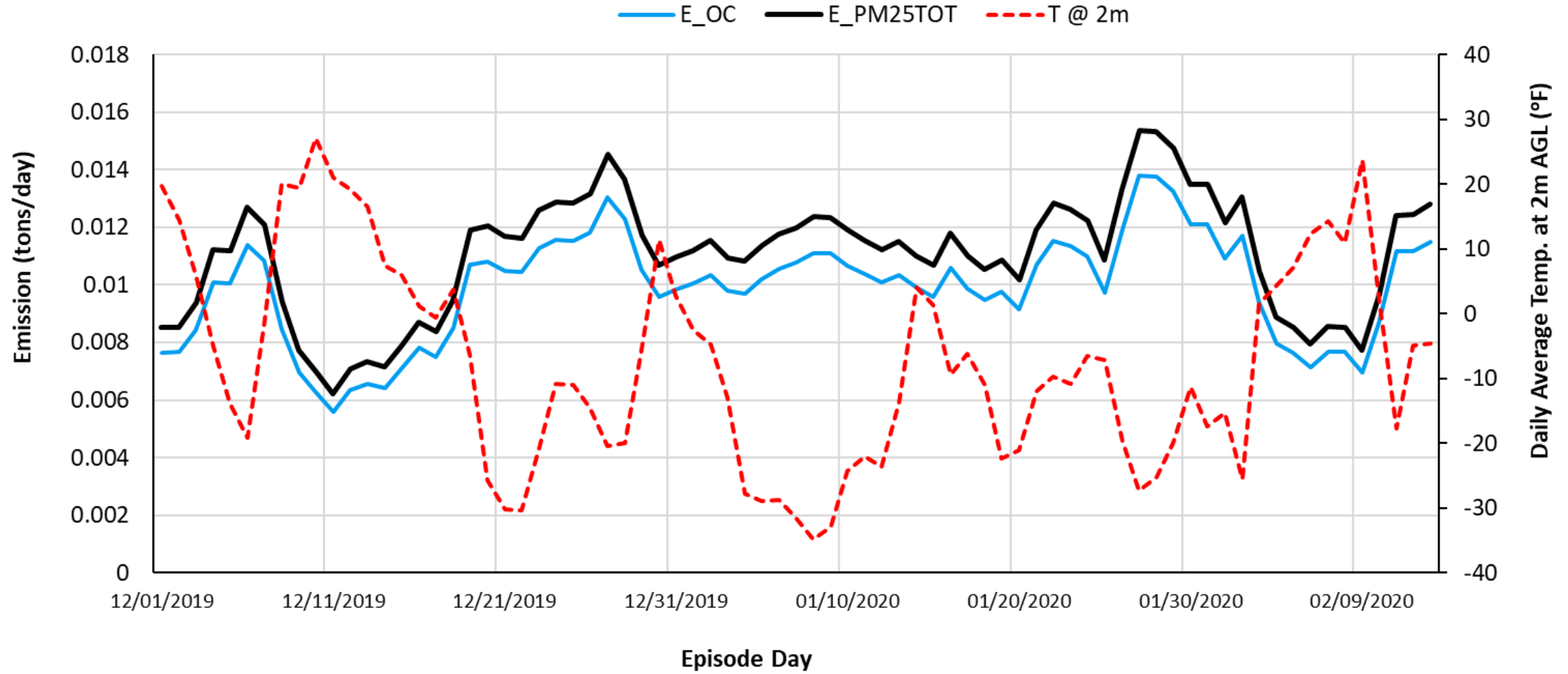
Daily RWC fine particle emission (tons/day) averaged over 9 grids centered by NCORE monitor



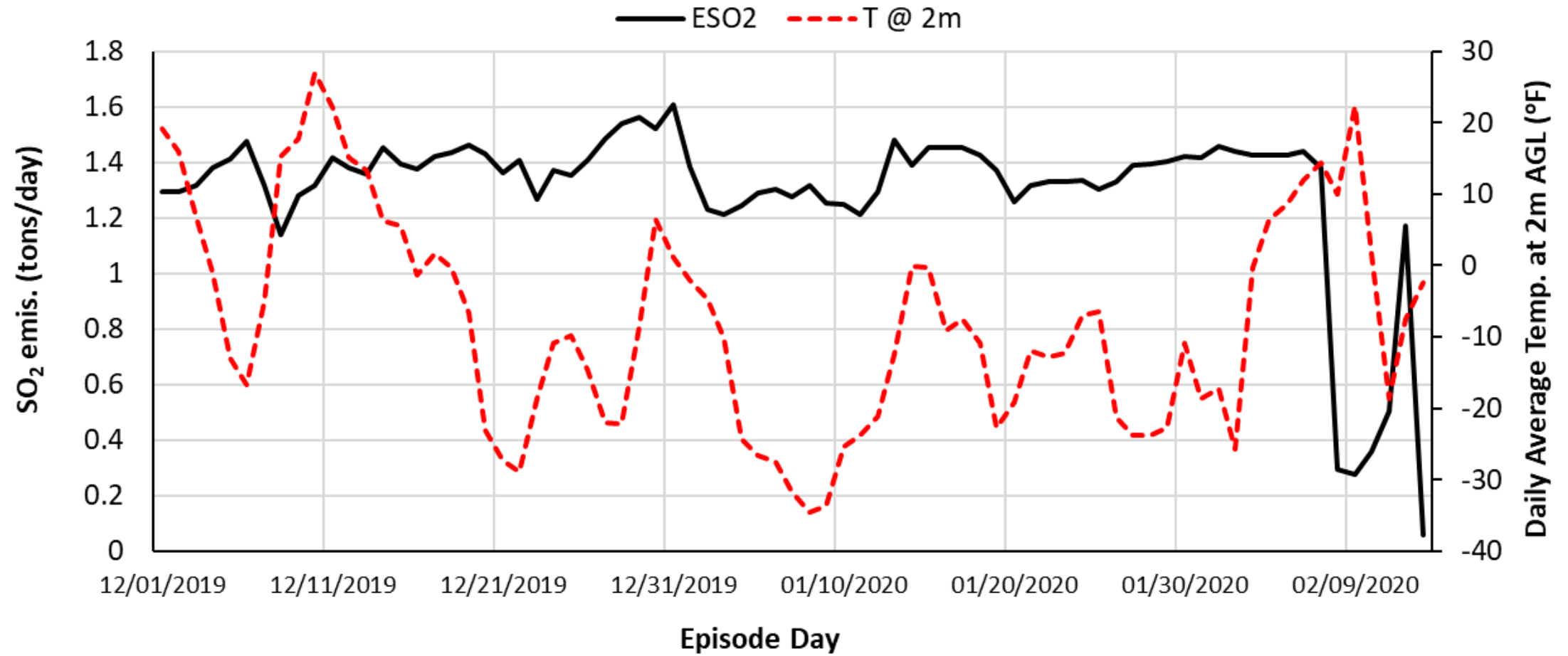
Daily RWC fine particle emission (tons/day) averaged over 9 grids centered by NCORE monitor



Daily RWC fine particle emission (tons/day) averaged over 9 grids centered by HurstRd monitor

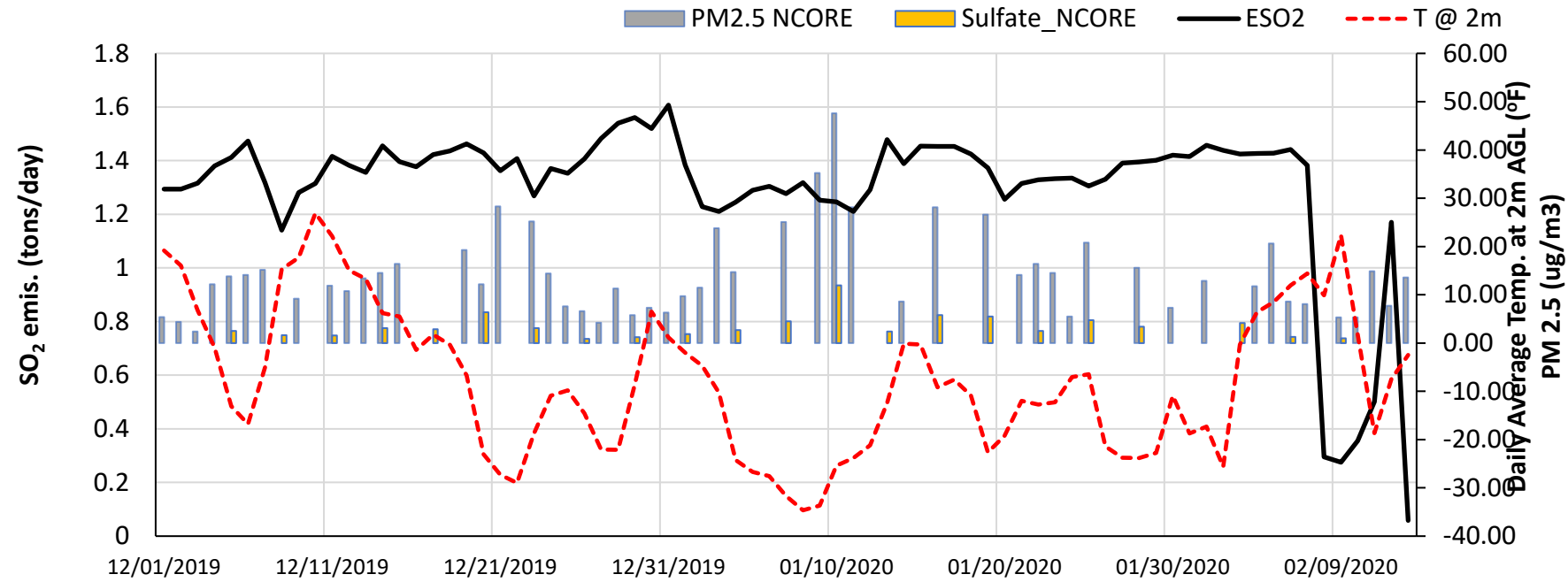


Daily SO₂ point emission (tons/day) at NCORE monitor

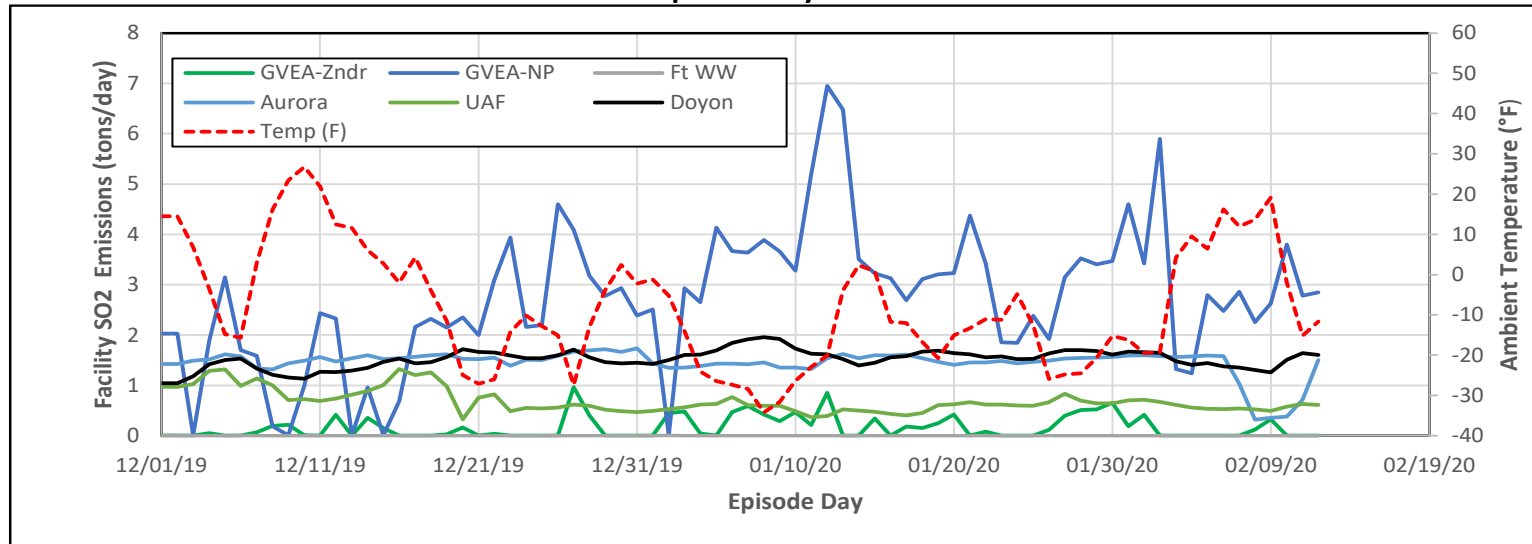


Daily SO₂ point emission (tons/day) at NCORE monitor

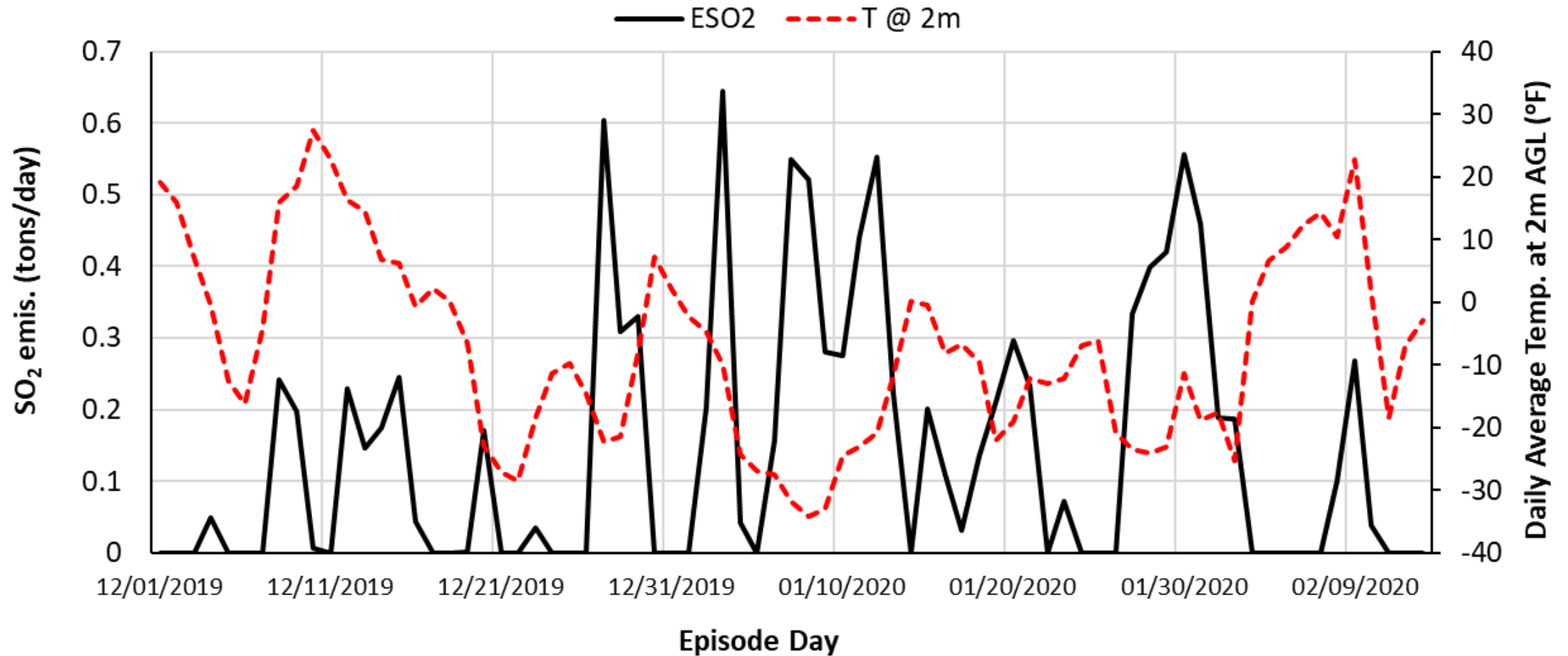
Grid cell (108,93) Aurora



Episode Day

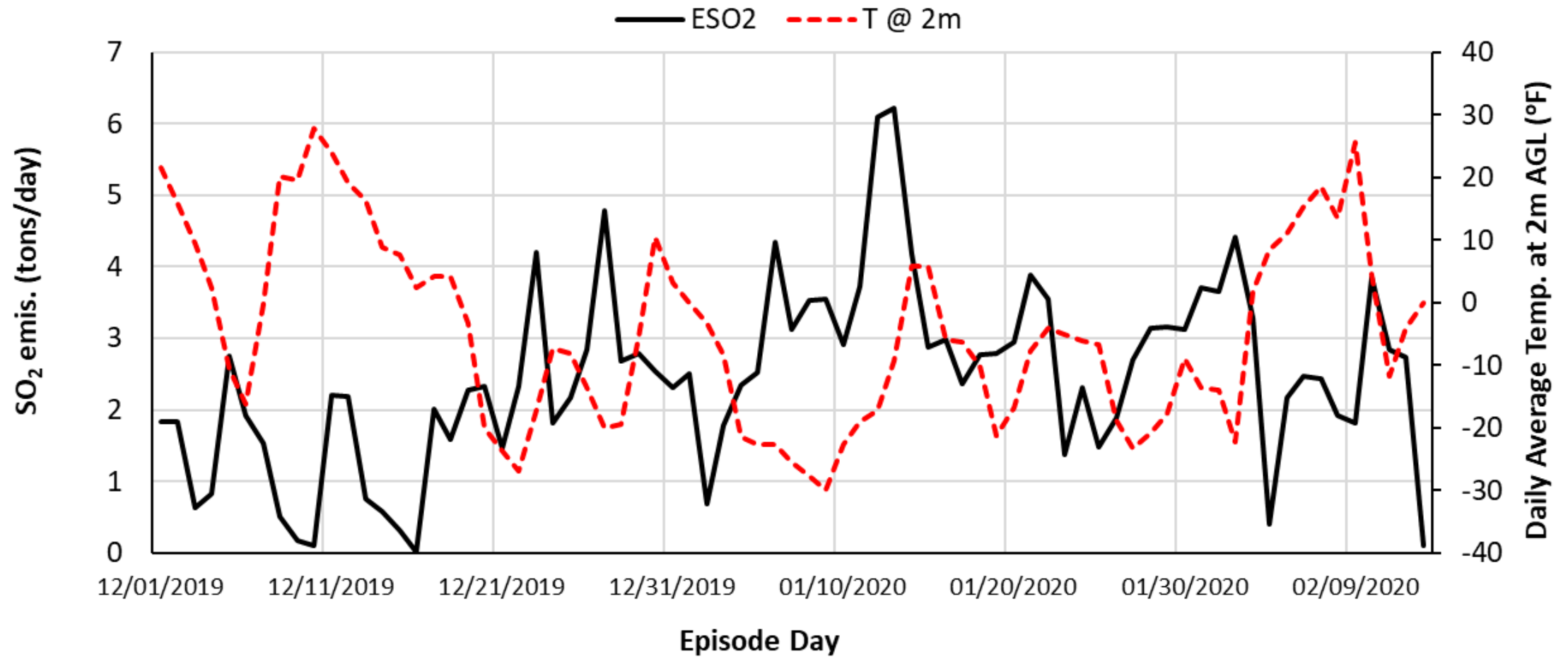


Daily SO₂ point emission (tons/day) at grid cell close to A Street monitor

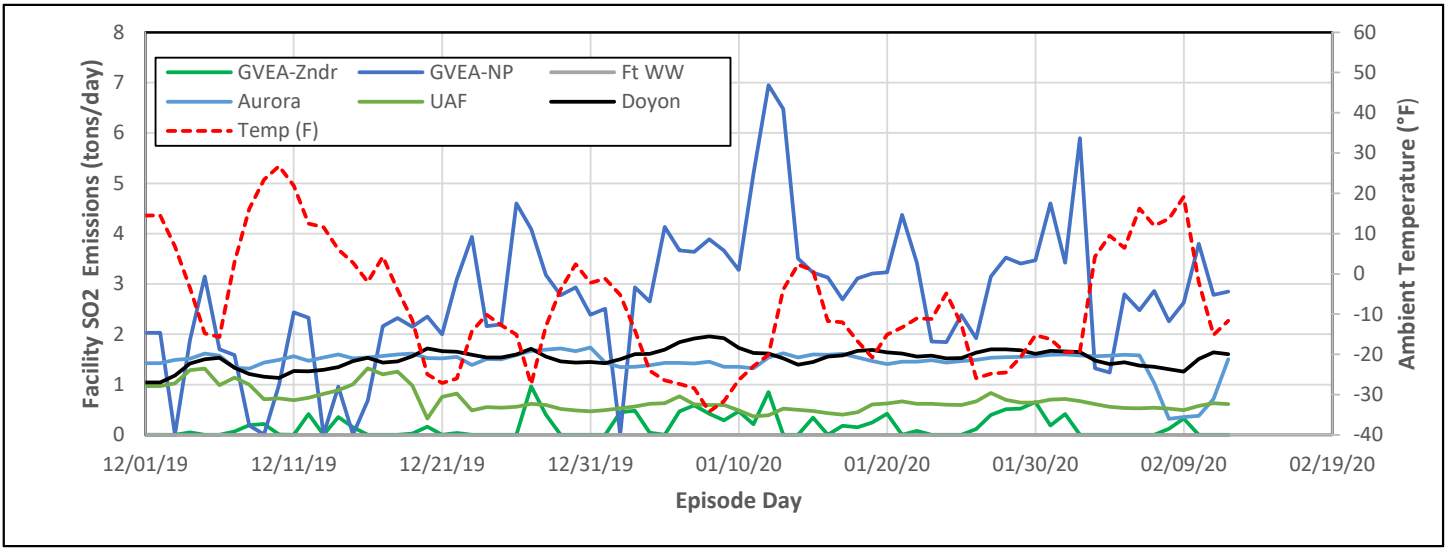
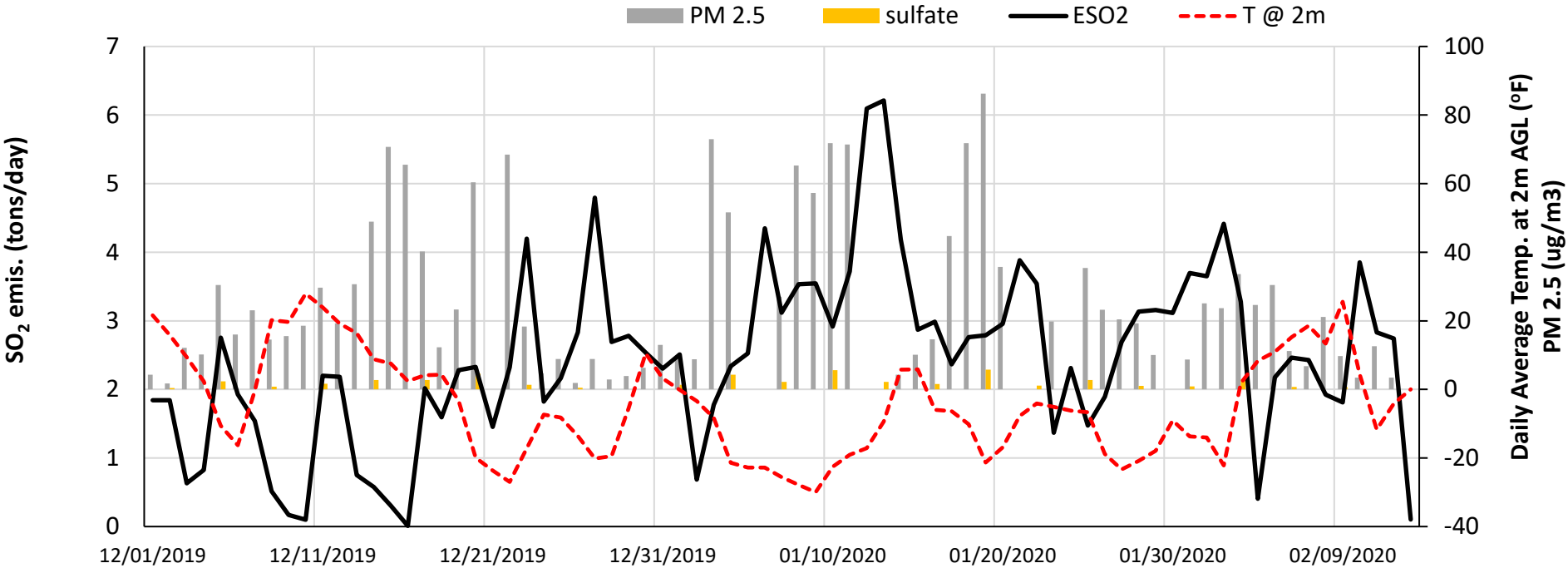


For A-Street site (109, 93), we extract emis from grid cell at (108, 94), where the point facility **GVEA Zehnder** is located.

Daily SO₂ point emission (tons/day) at grid cell close to Hurst Rd monitor



Daily SO₂ point emission (tons/day) at grid cell close to Hurst Rd monitor



For Hurst site (123, 87), we extract from grid cell at (121,84), where the point facility **GVEA North Pole** is located.

Thank you