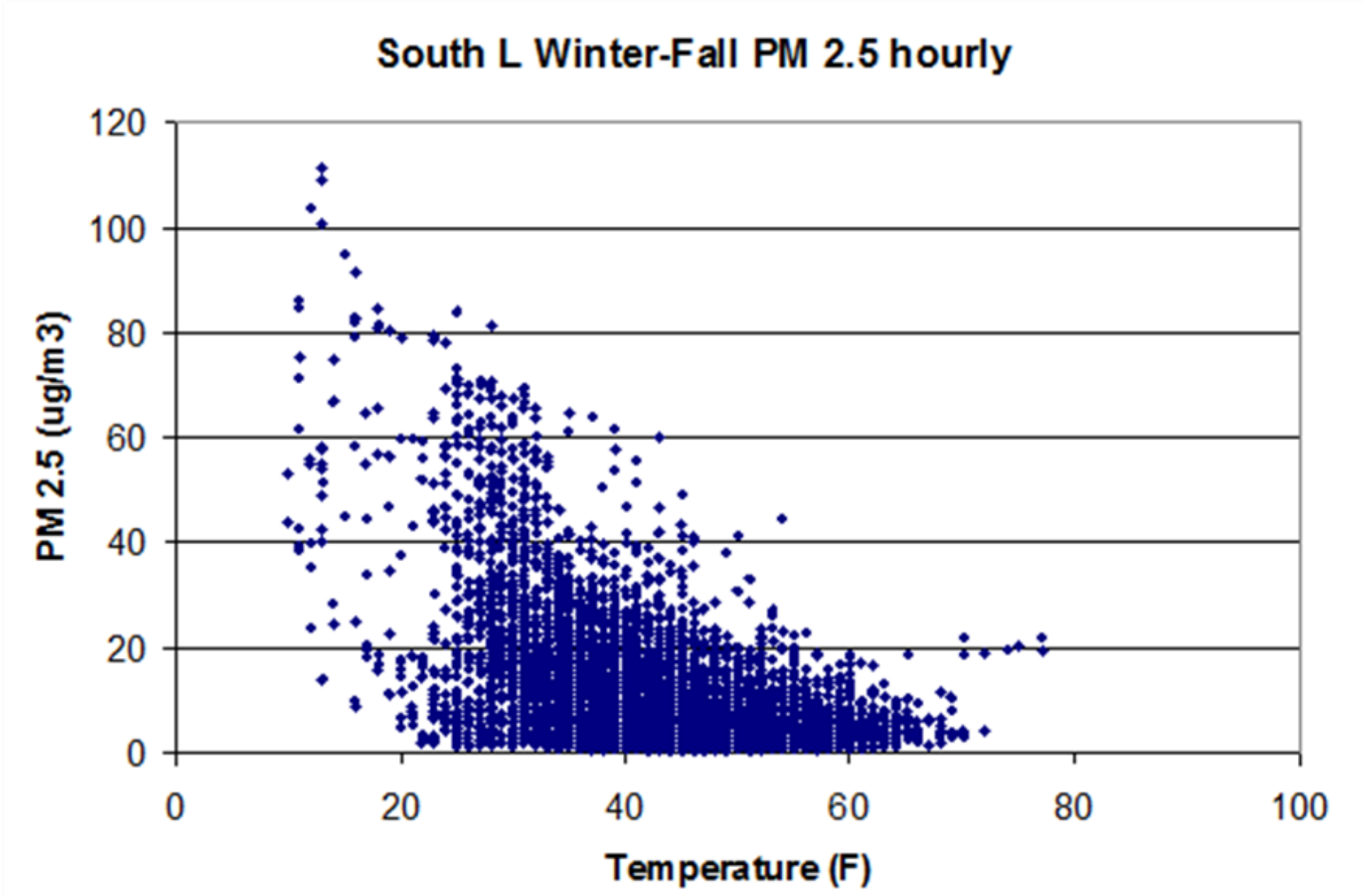
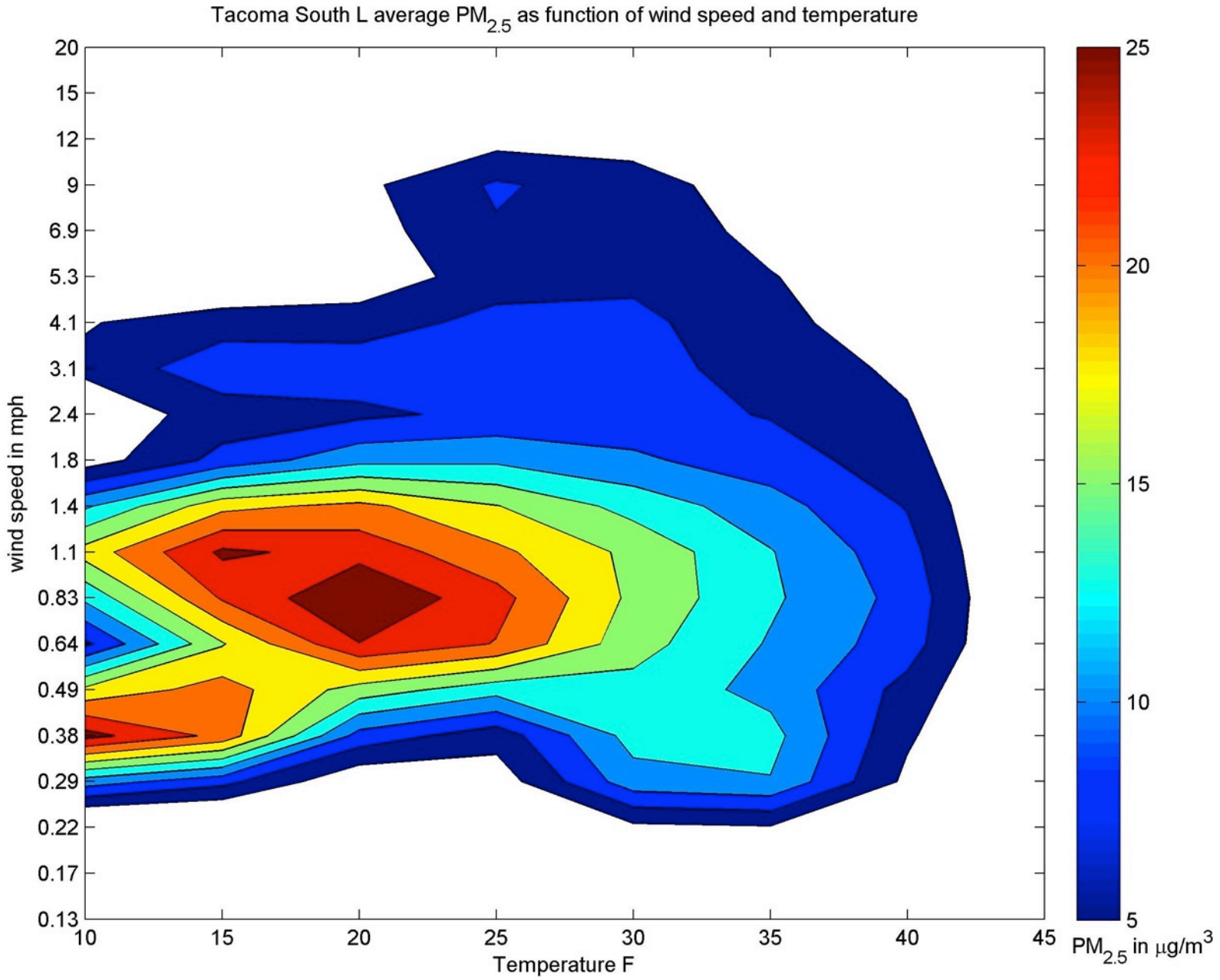
A Semi-Mechanistic Statistical Air Quality Model (SAQM) for wintertime PM2.5 in Tacoma, WA

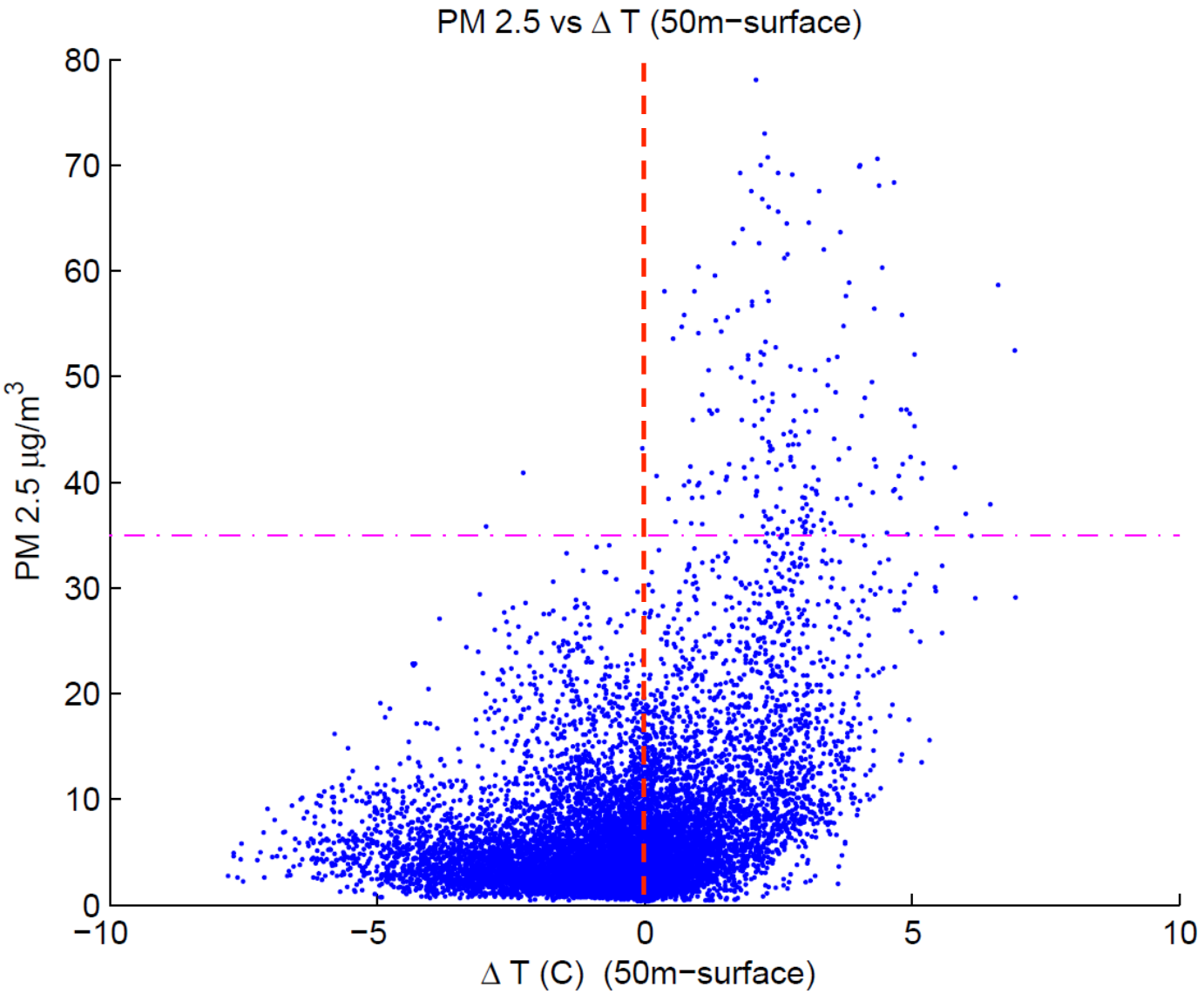
Phil Swartzendruber
Puget Sound Clean Air Agency
NW-AIRQUEST 2013 Annual Meeting

Background

- Tacoma, WA (South L) is in nonattainment for PM2.5 for the 24-hour (daily) standard
- residential wood combustion in the winter is the largest single source type
- PM2.5 levels have a strong diurnal pattern – even on the worst days
- there are good relationships between temps, winds, inversions, and PM 2.5 levels
- violations require winds < 1.5 mph, temps <35 F, and inversion > 0.5 C


South L Winter-Fall PM 2.5 hourly
PM 2.5 (ug/m3)
120
100
80
60
40
20
0
0
20
40
60
80
100
Temperature (F)


Tacoma South L average PM2.5 as function of wind speed and temperature
wind speed in mph
20
15
12
9
6.9
5.3
4.1
3.1
2.4
1.8
1.4
1.1
0.83
0.64
0.49
0.38
0.29
0.22
0.17
0.13
10
15
20
25
30
35
40
45
Temperature F
25
20
15
10
5
PM2.5 in μg/m3


PM 2.5 vs Δ T (50m−surface)
PM 2.5 µg/m3
80
70
60
50
40
30
20
10
0
−10
−5
0
5
10
Δ T (C) (50m−surface)

Motivation

- we prefer to make burn ban decisions by about 10 am and account for 48-72 hours in the future
- AIRPACT 3/4 goes out 48/24 hours
- night time low winds, stagnations, inversions not well modeled by WRF, so even harder for AP
- helpful to look at various scenarios if winds and temps are off, effect of burn ban, etc
- Hypothesis: a simple, heuristic, semi-mechanistic model could have skill in forecasting

Model Overview

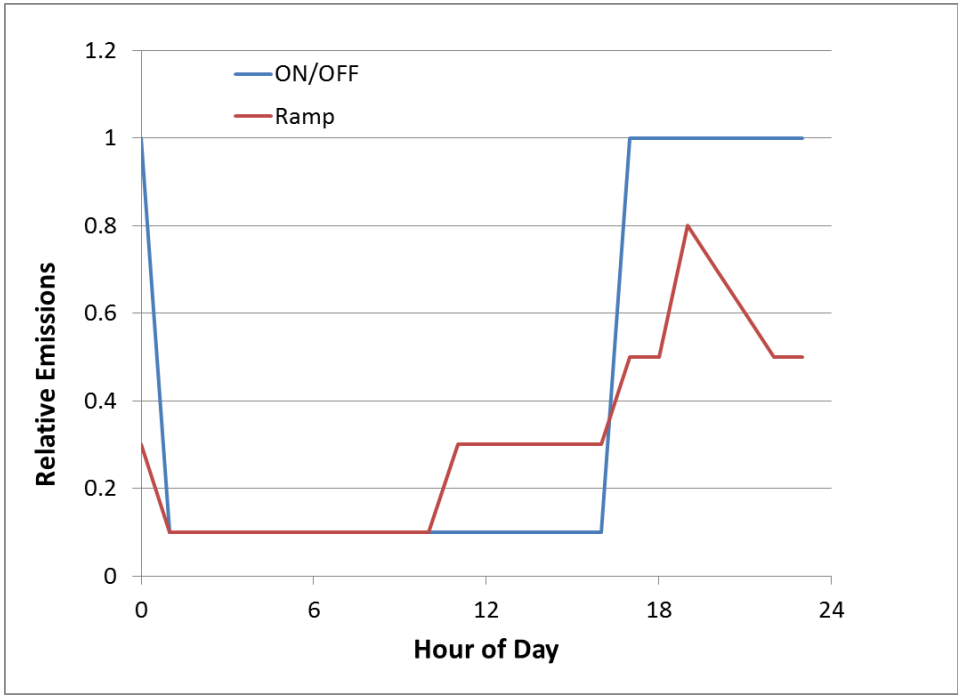
- single box, 100 x 100 m, 50 m high
- assume emissions are instantly, perfectly mixed
- governing equation in concentration [x]:

$$d[x]/dt = E - k\downarrow dil\ ([x] - [x\downarrow b])$$

- E is emissions
- k_{dil} is a dilution(mixing/entrainment) factor
- $[x_b]$ is the background concentration
- hourly steps solved analytically
- use historic data to fit parameters
- only looking at Oct-Mar of each year

Emissions and Dilution

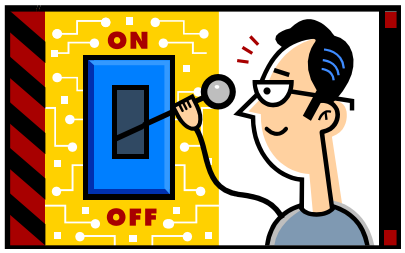
- emissions (area) function of temperature and temporal profile



- k_{dil} dilution/mixing scaled by wind speed
  - scales the wind speed
  - can be different daytime and nighttime

(a few of the) Limitations

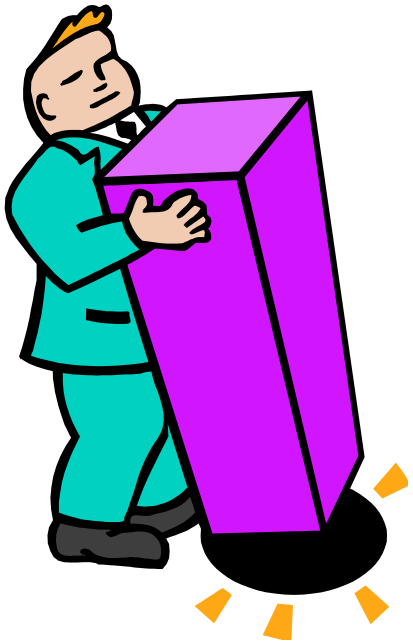
- the physics scheme is grossly simplistic



$$\frac{\partial}{\partial t}u_j(x,t) + \sum_{k=1}^{d}\frac{\partial}{\partial x_k}\Big(a_k(x,t)u_j(x,t)\Big) =$$

$$\sum_{k=1}^{d}\frac{\partial}{\partial x_k}\Big(d_k(x,t)\frac{\partial}{\partial x_k}u_j(x,t)\Big) + f_j(u_1(x,t),...,u_s(x,t),x,t) \quad , \quad j = 1,2,...,s$$

- emissions are only temp. dependent not source type specific



fitted values: ranges used, units

- k_{dil} dilution/entrainment constant (0.01-0.4)
  - time to switch day to night (1500)
- emission (area) rate scaled (0.2-0.4 ug/m^2/s)
- temperature (heating) ref point (50-60 F)
- temperature averaging window (24 hr)
- wind speed averaging window (1-3 hr)
- background PM level (2 ug/m3)

Observations on performance

- first version seemed to miss a few events rather discreetly, also used old data (pre 2010)
- now have four versions with different quasi-physical parameters
  - training data
  - emission profiles
  - wind dilution dependencies (offset, v^2)
  - HDD ref temp

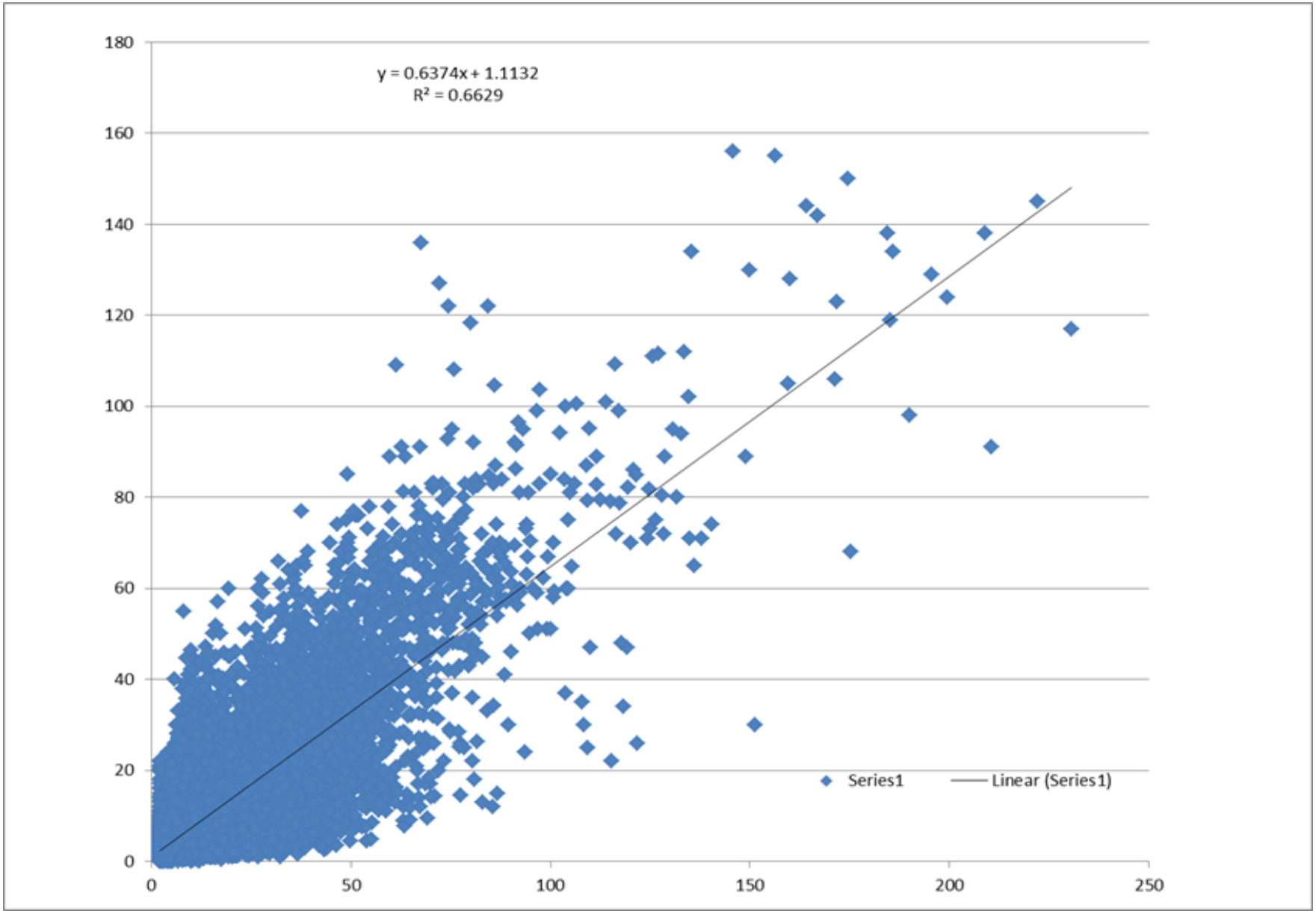
Issues and questions under consideration and for future

- may be small weekend effect in emissions
- uncertain if burn ban has effect prior to 2012
  - unclear how to model future burn ban compliance
- clouds/precip seem likely to have impact, but no clear sign yet of simple way to incorporate
- can temp profile or BL height improve or validate any of this?

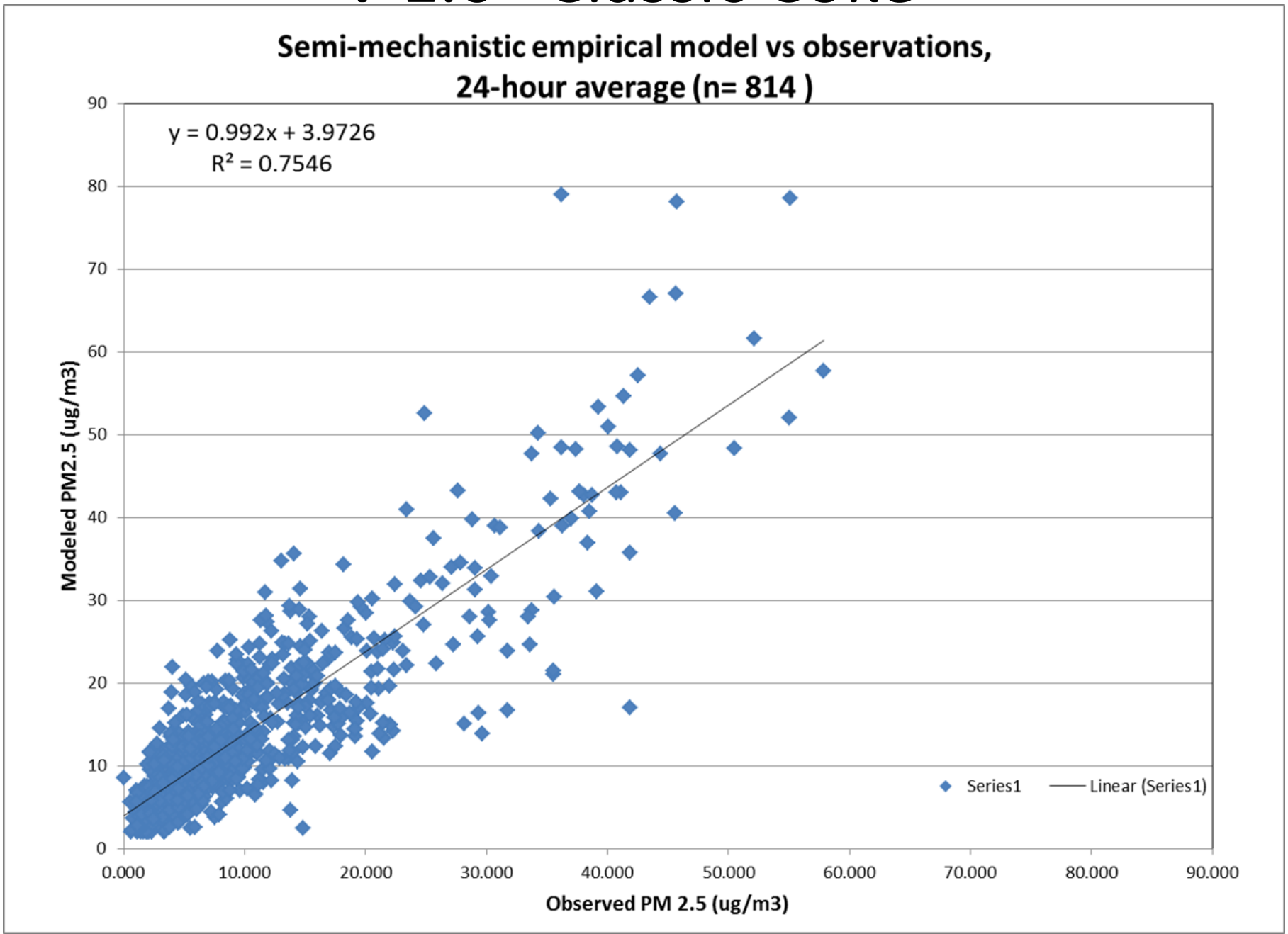
stats/physical schemes, key differences

Version	Training Data	Wind-Dilution Scheme	Emission profile	HDD ref	Wind Ave. Period	R^2 of daily mod v obs
1.0 “Classic Coke”	2006-9	-	ON/OFF	50	3	0.76
2.0 “higher res.”	Oct 09 – Feb 12	Scaled	ON/OFF	50	1	0.81
2.1 “New Coke”	Oct 09 – Feb 12	Offset and scaled	ON/OFF	60	1	0.80
2.2 “Winds^2”	Oct 09 – Feb 12	Offset and v^2	Temporally variable	60	2	0.81

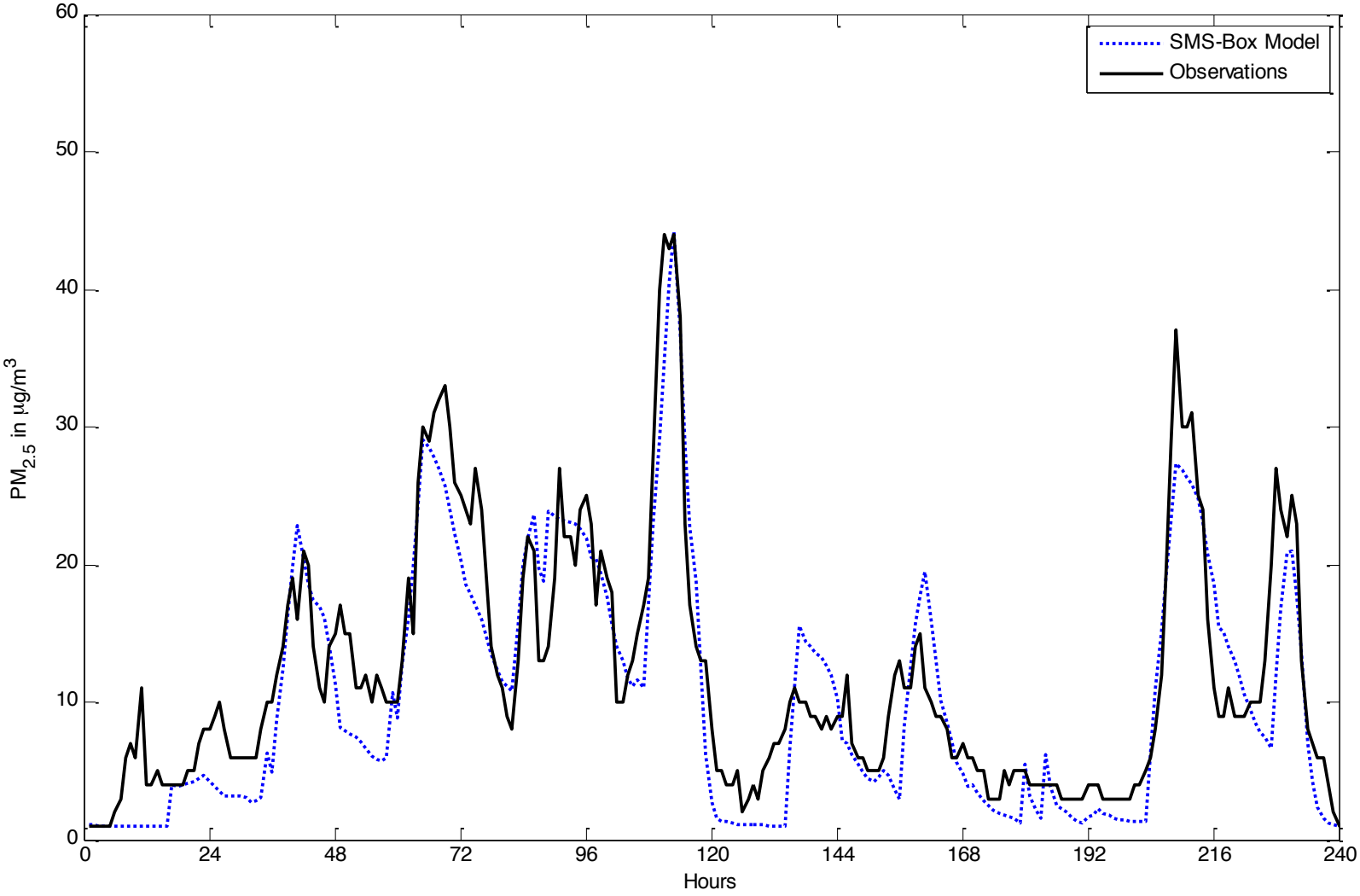
V 1.0 “Classic Coke”: Hourly Performance



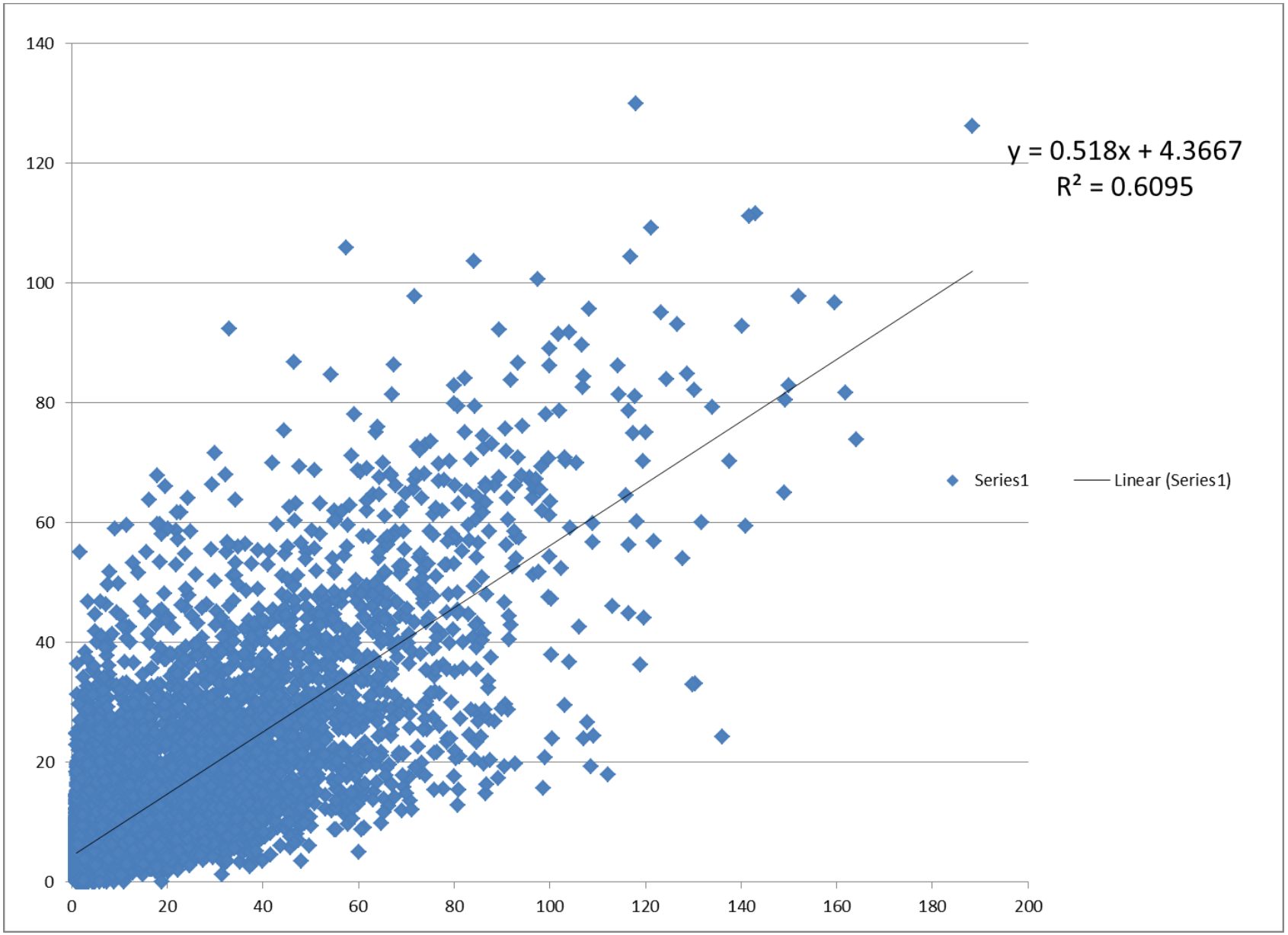
V 1.0 “Classic Coke”



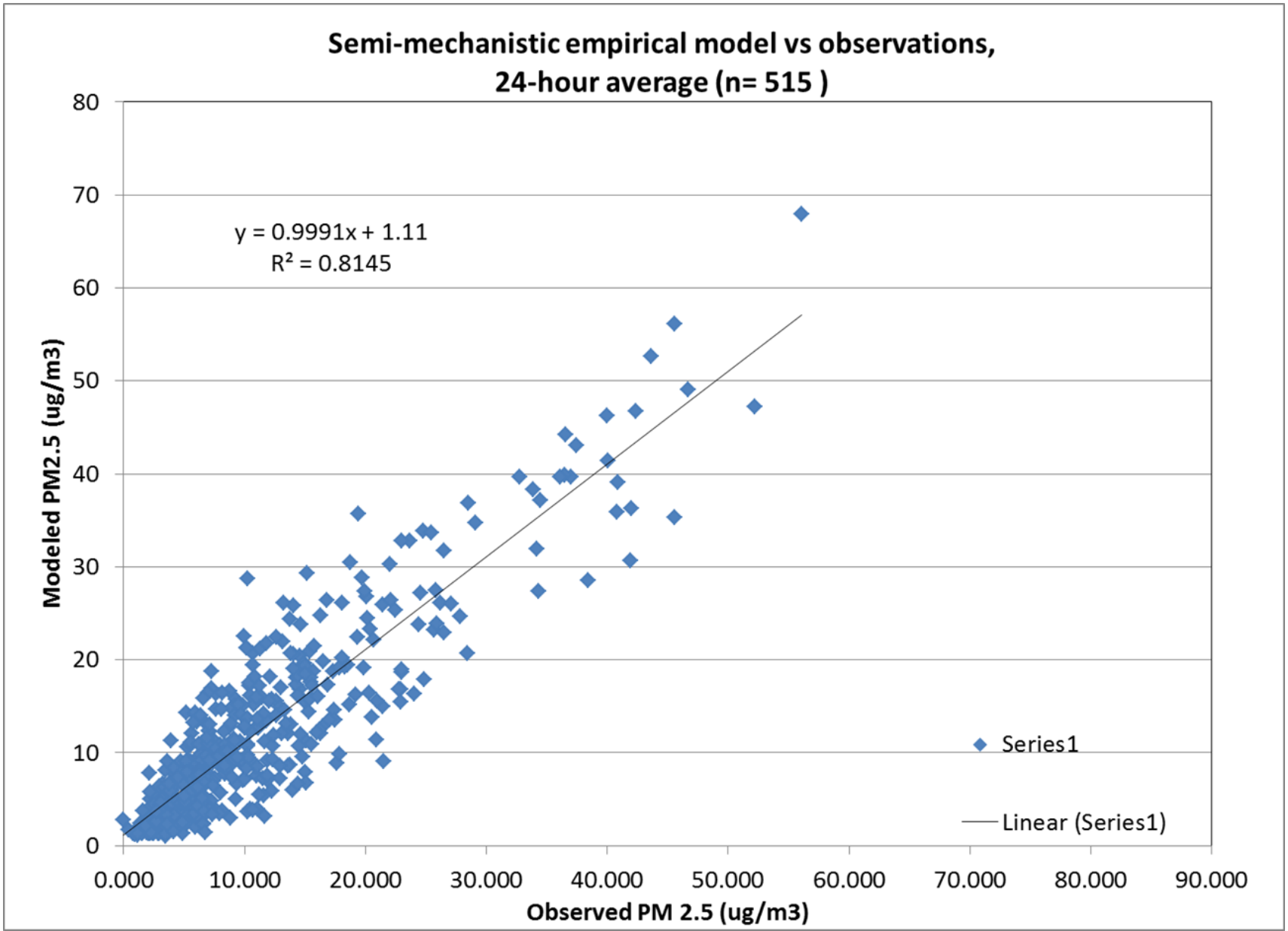
A cherry-picked performance figures

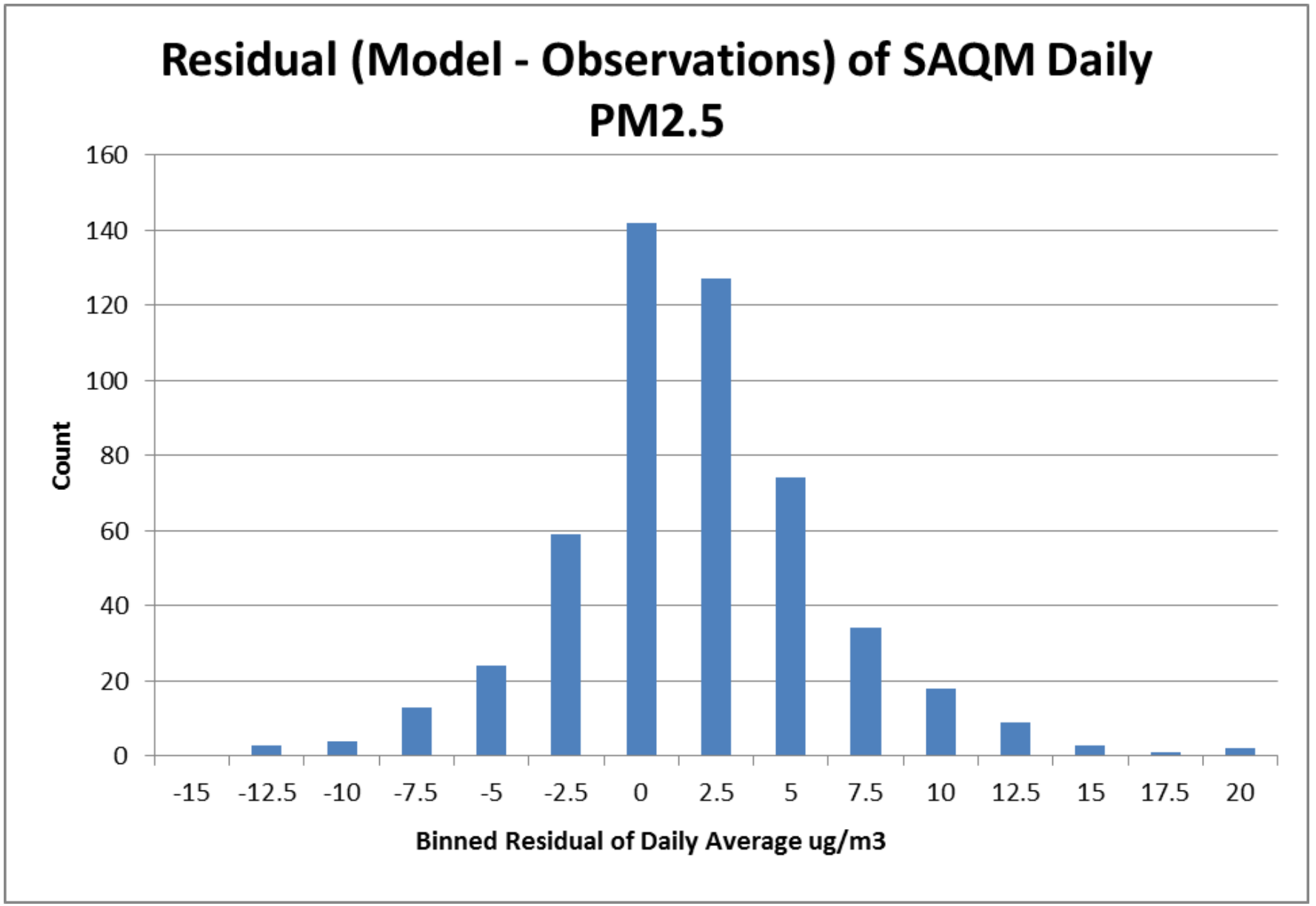


V 2.2 “Winds^2”

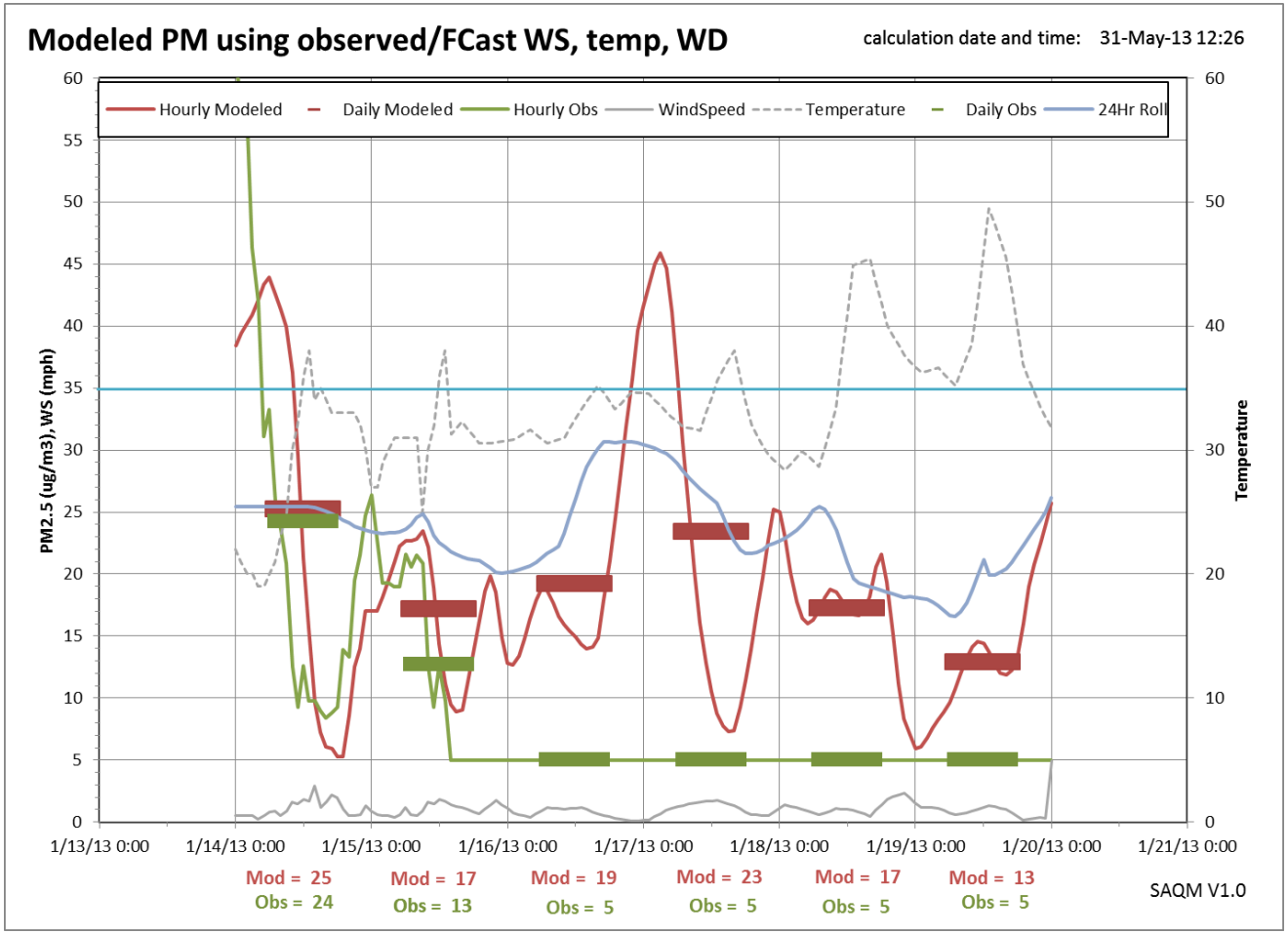

y = 0.518x + 4.3667
R² = 0.6095
Series1
Linear (Series1)
0
20
40
60
80
100
120
140
160
180
200

V 2.2 “Winds^2”

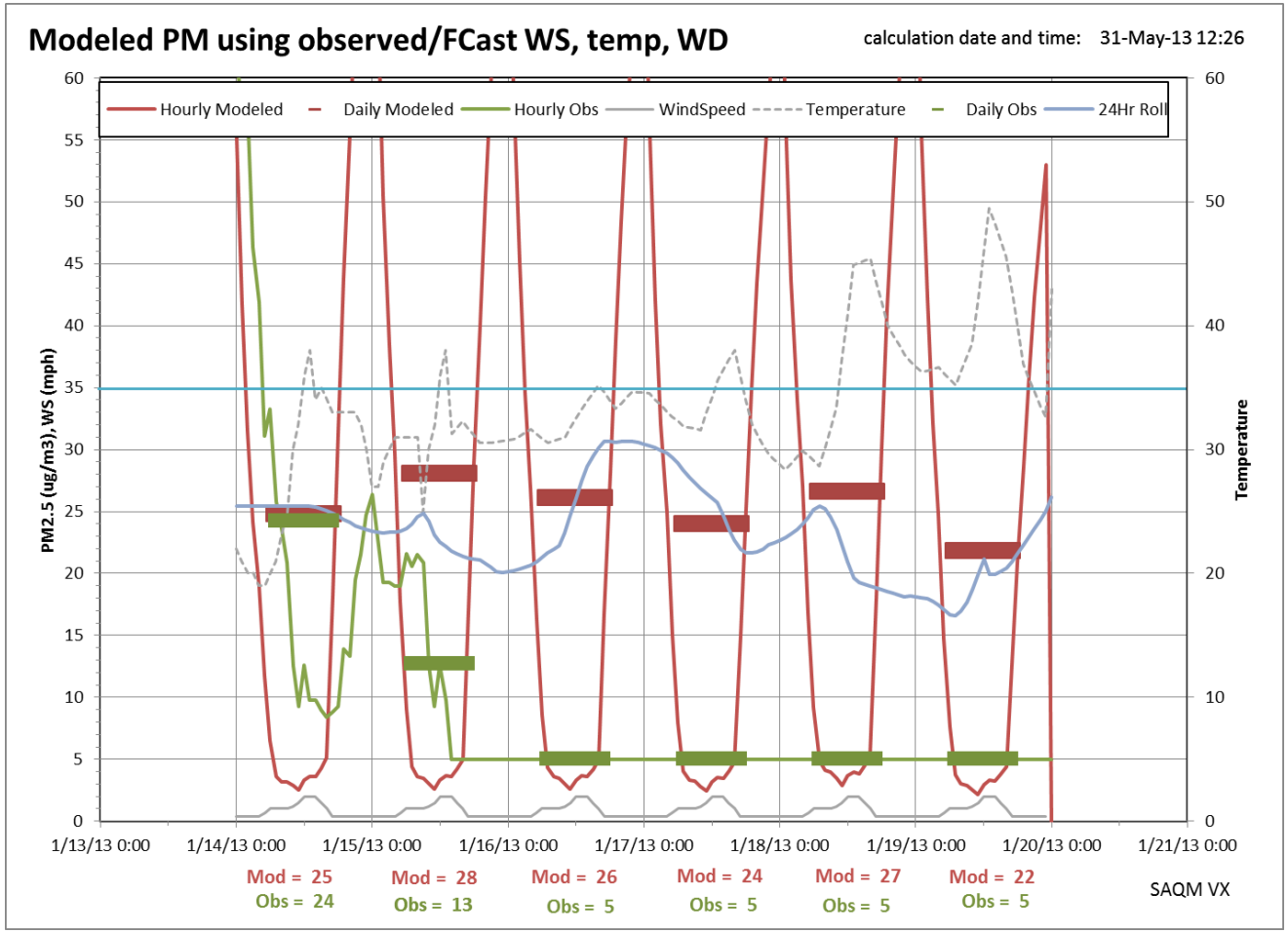

Semi-mechanistic empirical model vs observations,
24-hour average (n= 515)
y = 0.9991x + 1.11
R² = 0.8145
Modeled PM2.5 (ug/m3)
Observed PM 2.5 (ug/m3)
0
10
20
30
40
50
60
70
80
0.000
10.000
20.000
30.000
40.000
50.000
60.000
70.000
80.000
90.000
Series1
Linear (Series1)


Residual (Model - Observations) of SAQM Daily PM2.5
160
140
120
100
80
60
40
20
0
Count
-15
-12.5
-10
-7.5
-5
-2.5
0
2.5
5
7.5
10
12.5
15
17.5
20
Binned Residual of Daily Average ug/m3

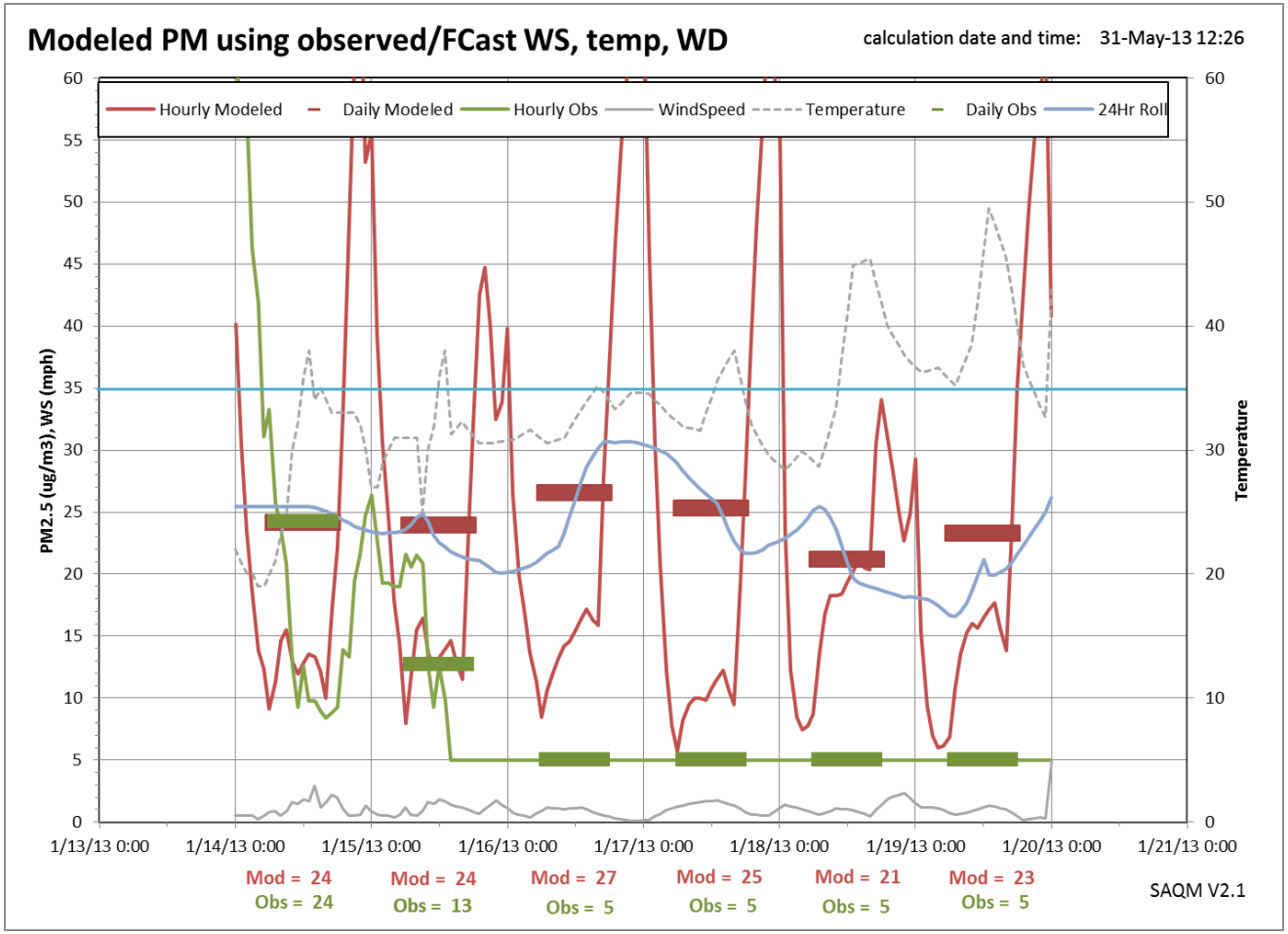
v 1.0 – “Classic Coke”



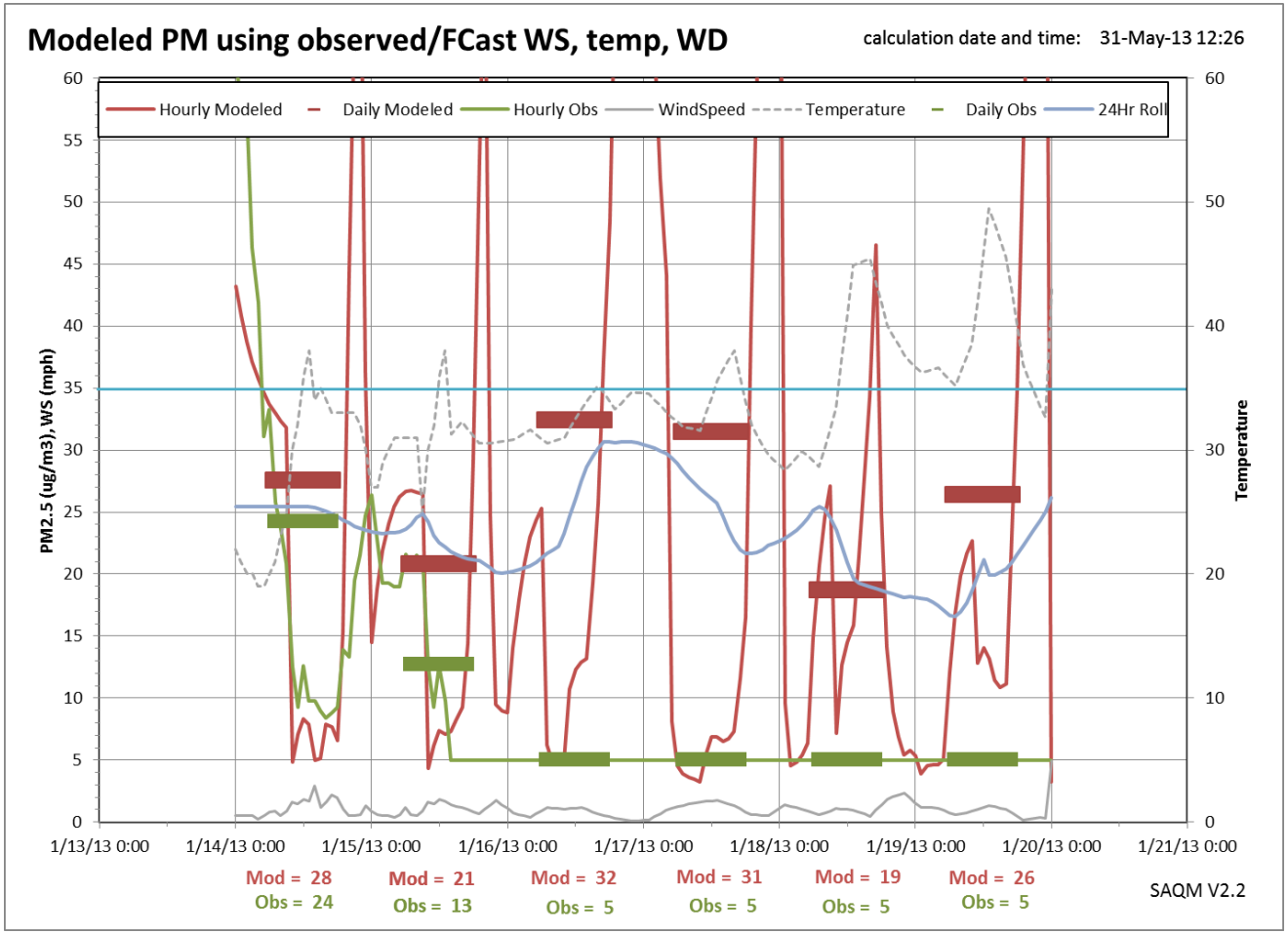
v 2.0 – “high res” used as worst case



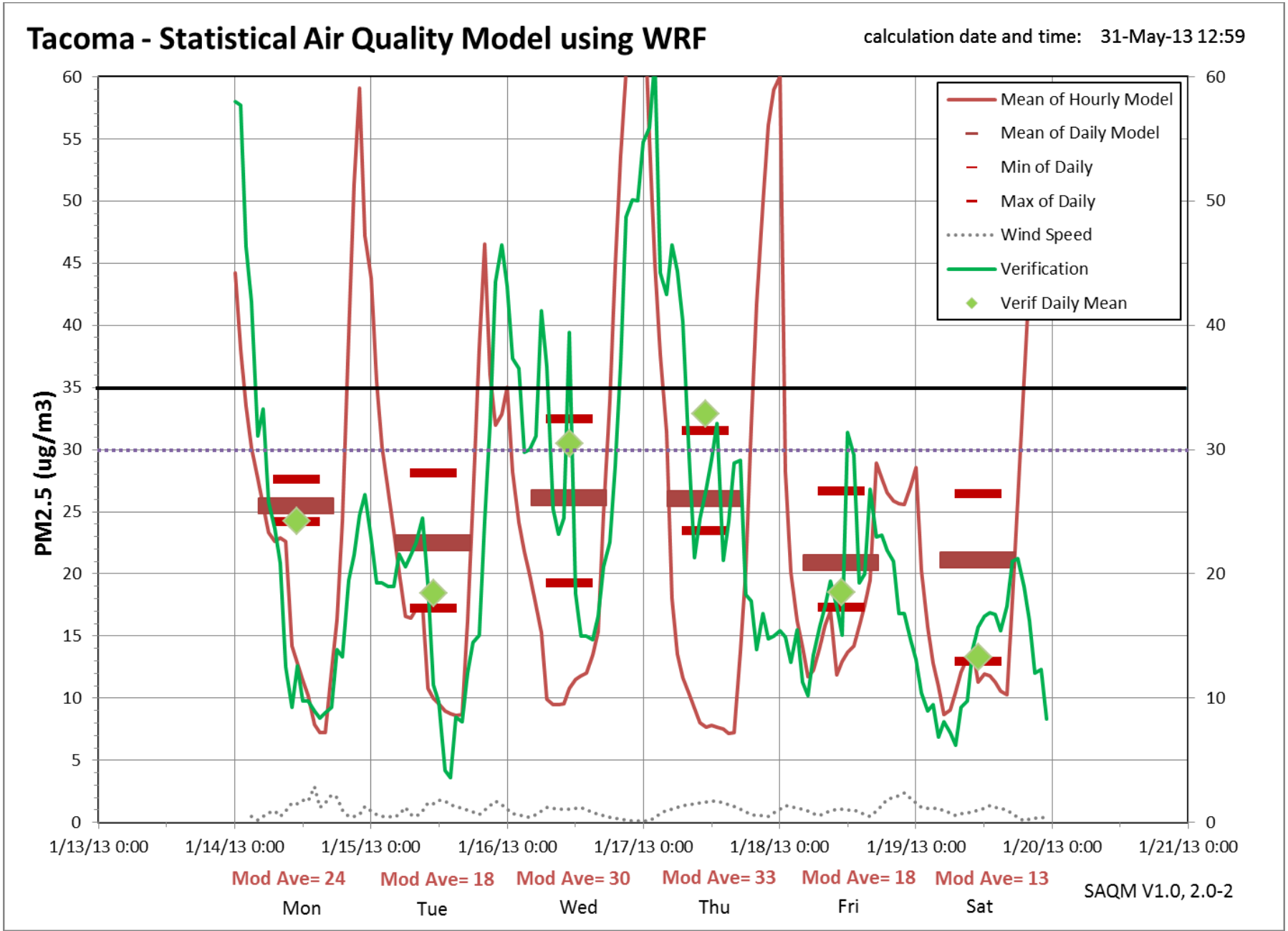
v 2.1 – “New Coke”

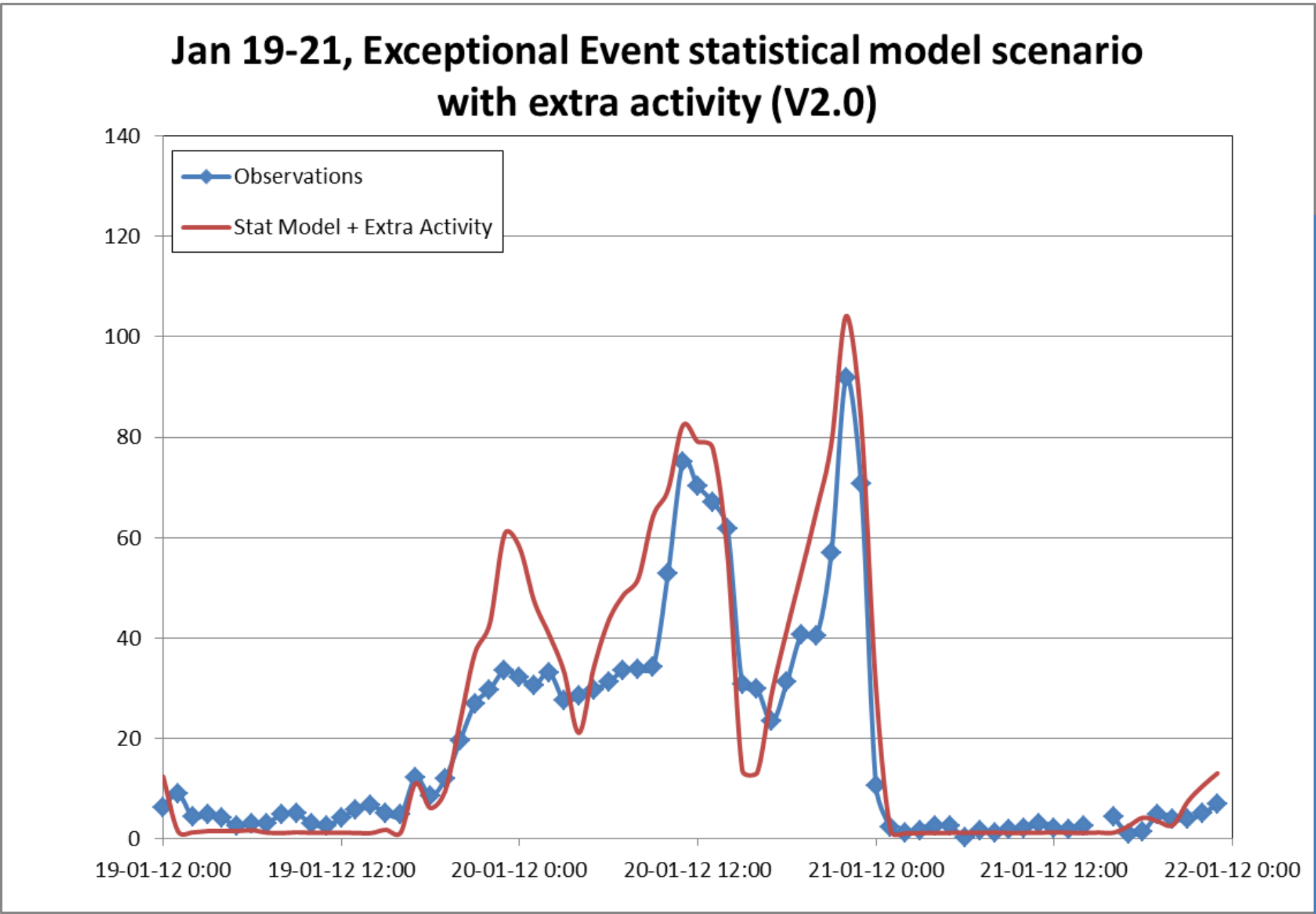

Modeled PM using observed/FCast WS, temp, WD
calculation date and time: 31-May-13 12:26
Hourly Modeled
Daily Modeled
Hourly Obs
WindSpeed
Temperature
Daily Obs
24Hr Roll
PM2.5 (ug/m3), WS (mph)
Temperature
1/13/13 0:00
1/14/13 0:00
1/15/13 0:00
1/16/13 0:00
1/17/13 0:00
1/18/13 0:00
1/19/13 0:00
1/20/13 0:00
1/21/13 0:00
Mod = 24
Obs = 24
Mod = 24
Obs = 13
Mod = 27
Obs = 5
Mod = 25
Obs = 5
Mod = 21
Obs = 5
Mod = 23
Obs = 5
SAQM V2.1

v 2.2 – “winds^2”

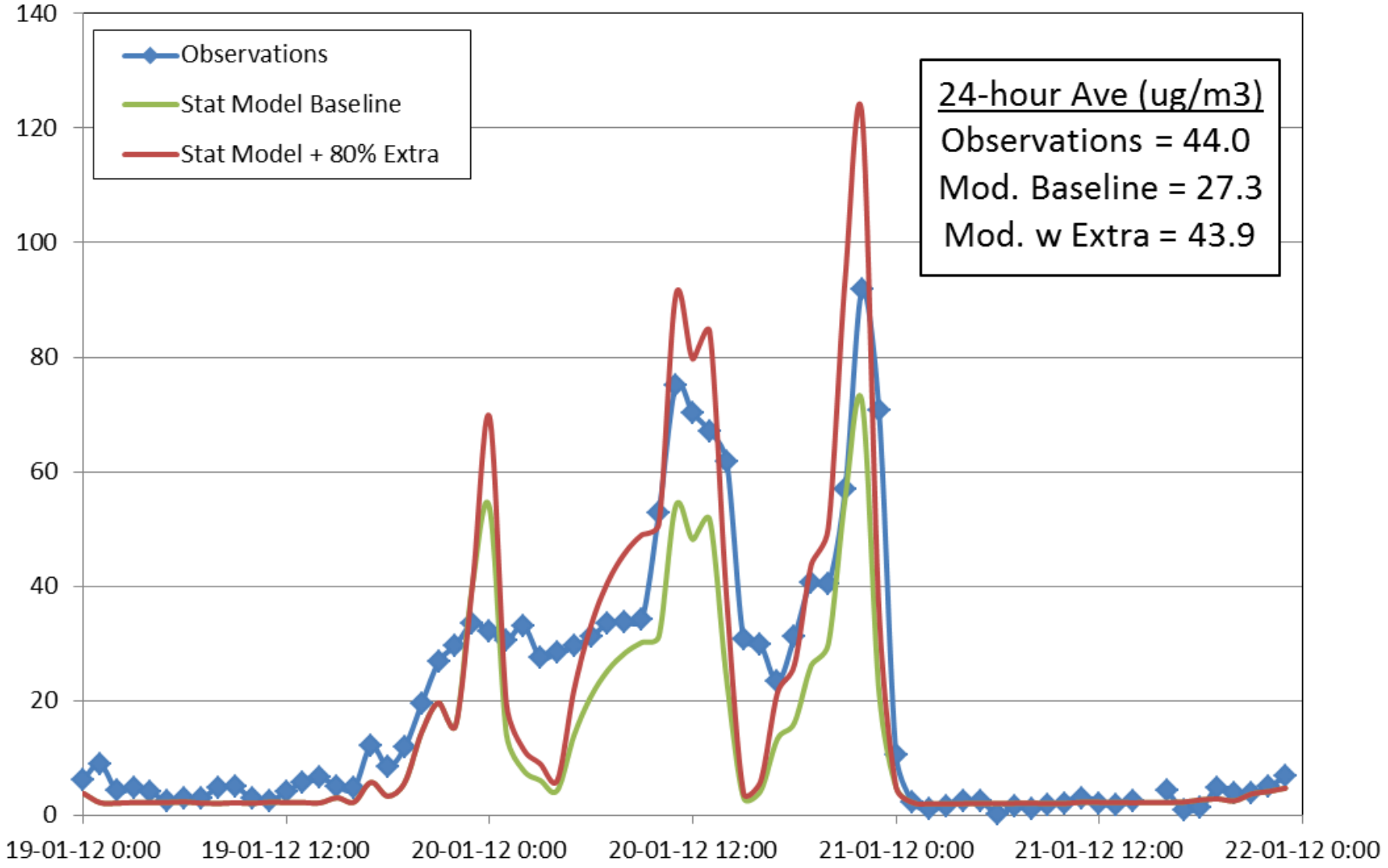

Modeled PM using observed/FCast WS, temp, WD
calculation date and time: 31-May-13 12:26
Hourly Modeled
Daily Modeled
Hourly Obs
WindSpeed
Temperature
Daily Obs
24Hr Roll
PM2.5 (ug/m3), WS (mph)
Temperature
1/13/13 0:00
1/14/13 0:00
1/15/13 0:00
1/16/13 0:00
1/17/13 0:00
1/18/13 0:00
1/19/13 0:00
1/20/13 0:00
1/21/13 0:00
Mod = 28
Obs = 24
Mod = 21
Obs = 13
Mod = 32
Obs = 5
Mod = 31
Obs = 5
Mod = 19
Obs = 5
Mod = 26
Obs = 5
SAQM V2.2

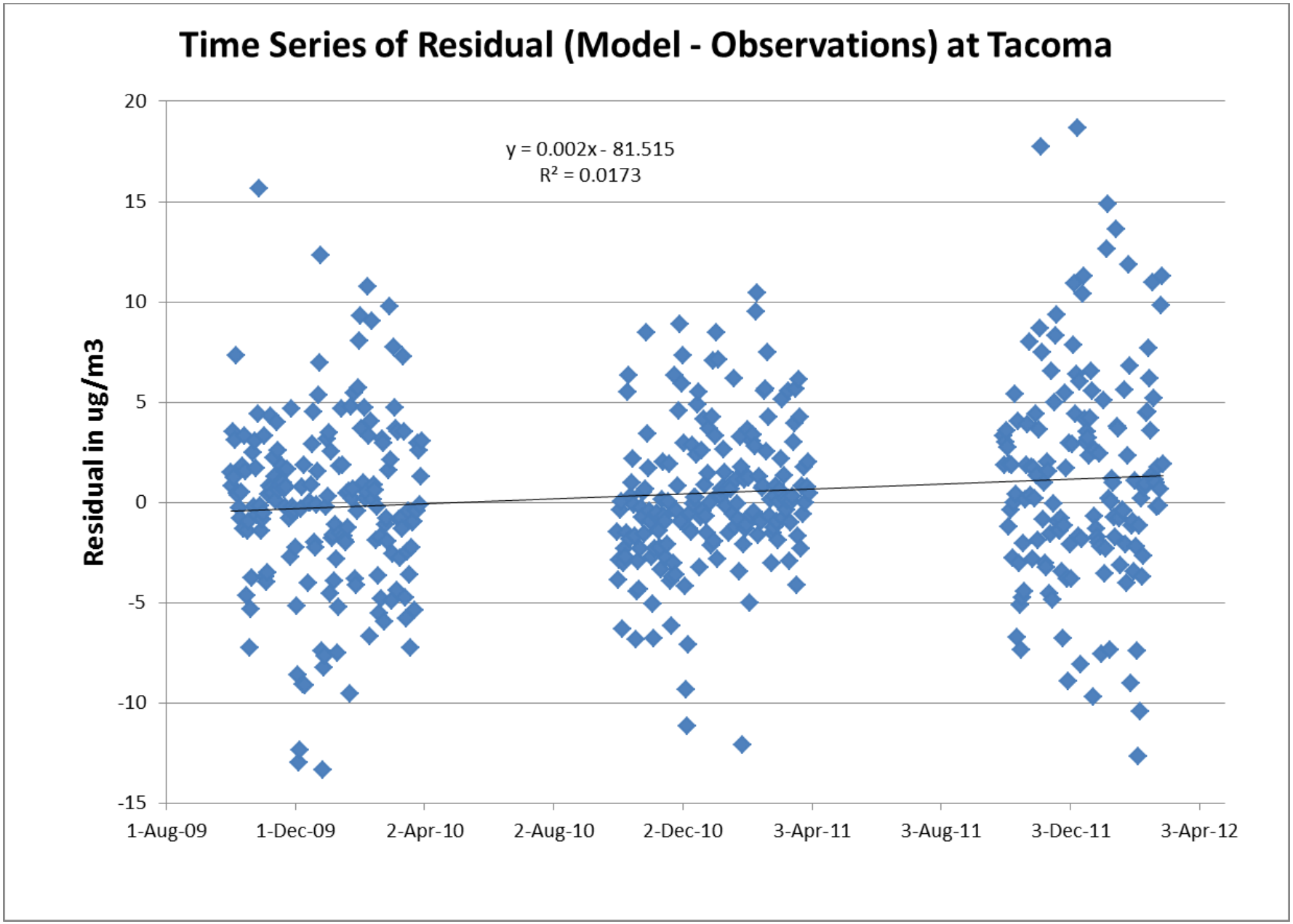
Verification




Jan 19-21, Exceptional Event statistical model scenario with extra activity (V2.0)
Observations
Stat Model + Extra Activity
140
120
100
80
60
40
20
0
19-01-12 0:00
19-01-12 12:00
20-01-12 0:00
20-01-12 12:00
21-01-12 0:00
21-01-12 12:00
22-01-12 0:00

Jan 19-21, Exceptional Event statistical model scenarios: baseline and extra activity (V2.2)

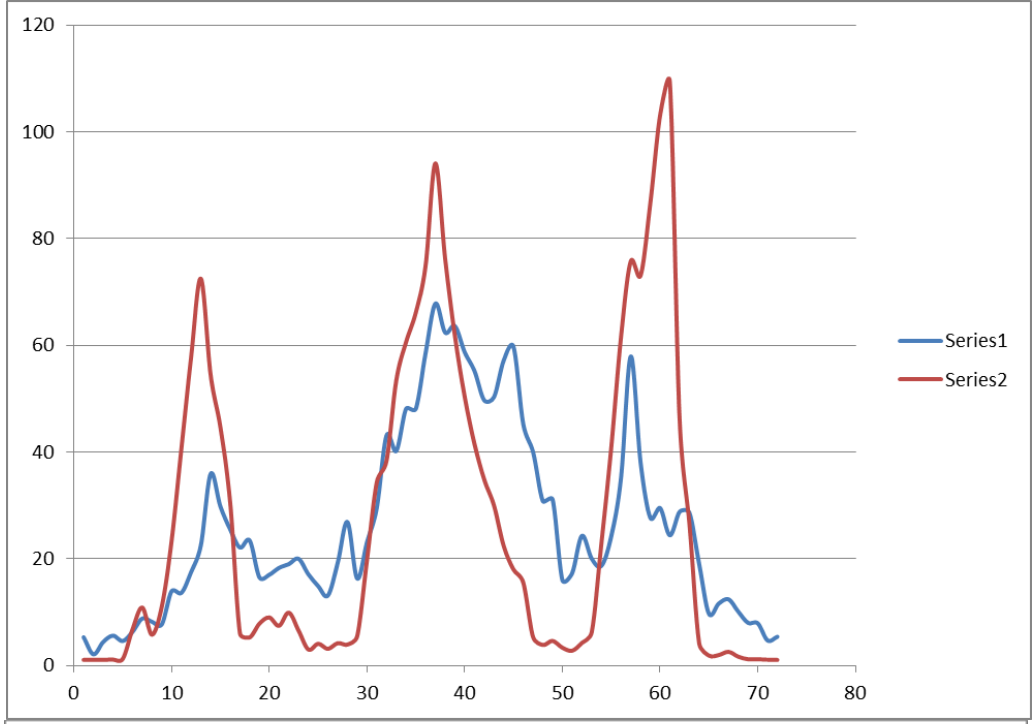



Time Series of Residual (Model - Observations) at Tacoma
y = 0.002x - 81.515
R² = 0.0173
Residual in ug/m3
20
15
10
5
0
-5
-10
-15
1-Aug-09
1-Dec-09
2-Apr-10
2-Aug-10
2-Dec-10
3-Apr-11
3-Aug-11
3-Dec-11
3-Apr-12

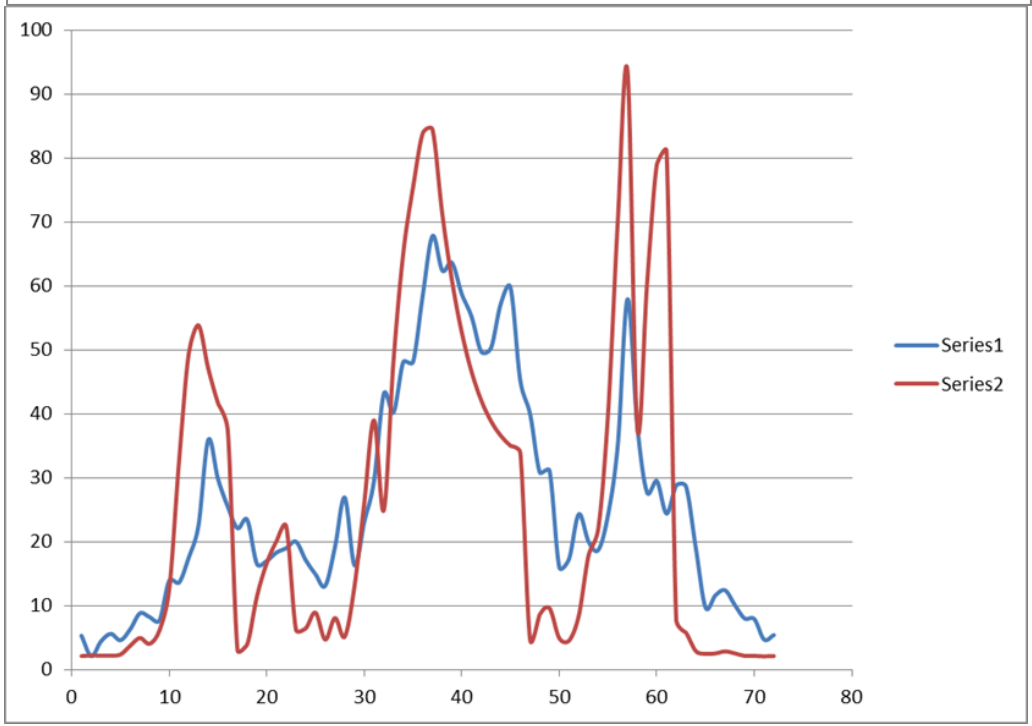
Conclusions

- the model appears to have some skill in predicting South L PM2.5, under the present circumstances
- more work is needed to test if other factors can or need to be included
  - precipitation or clouds
  - inversion characteristics
  - burn bans

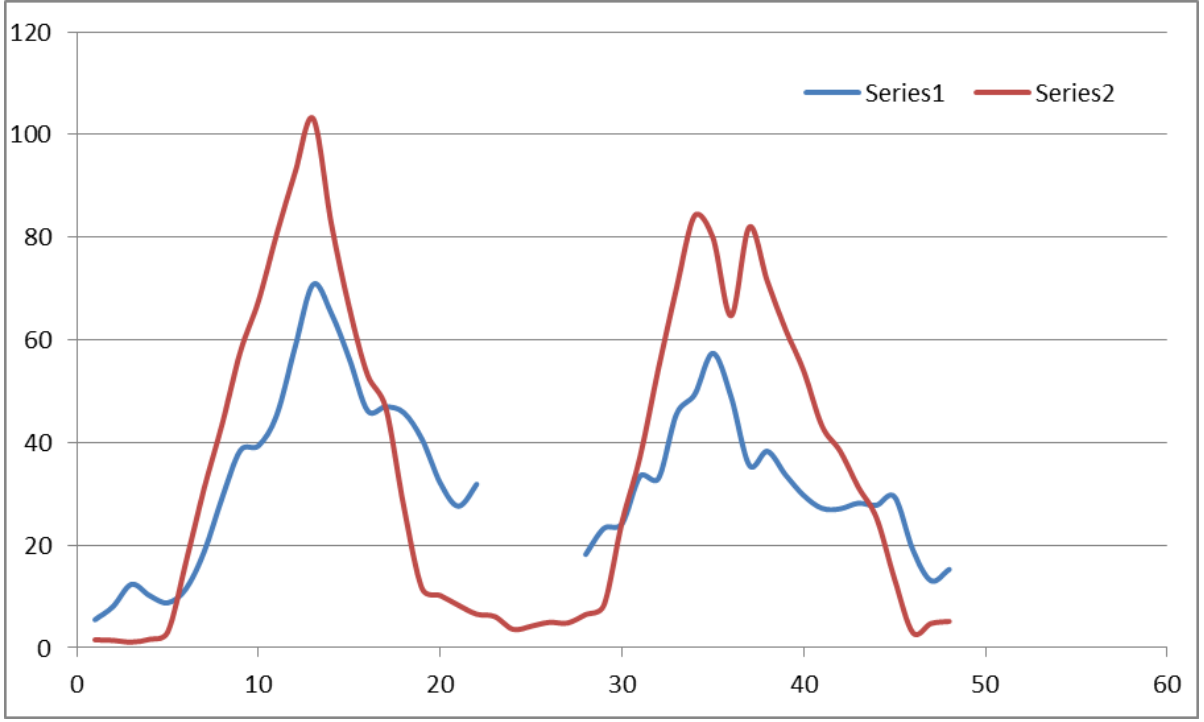
V 2.0


120
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
Series1
Series2

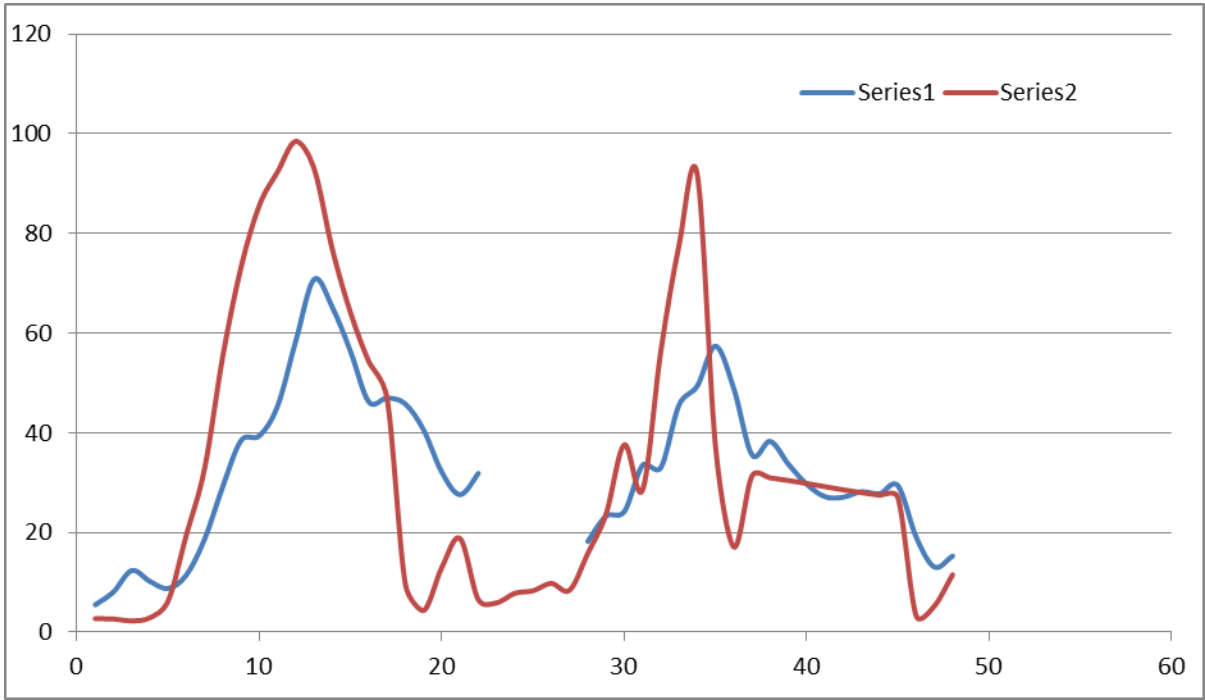
V 2.1


100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
Series1
Series2

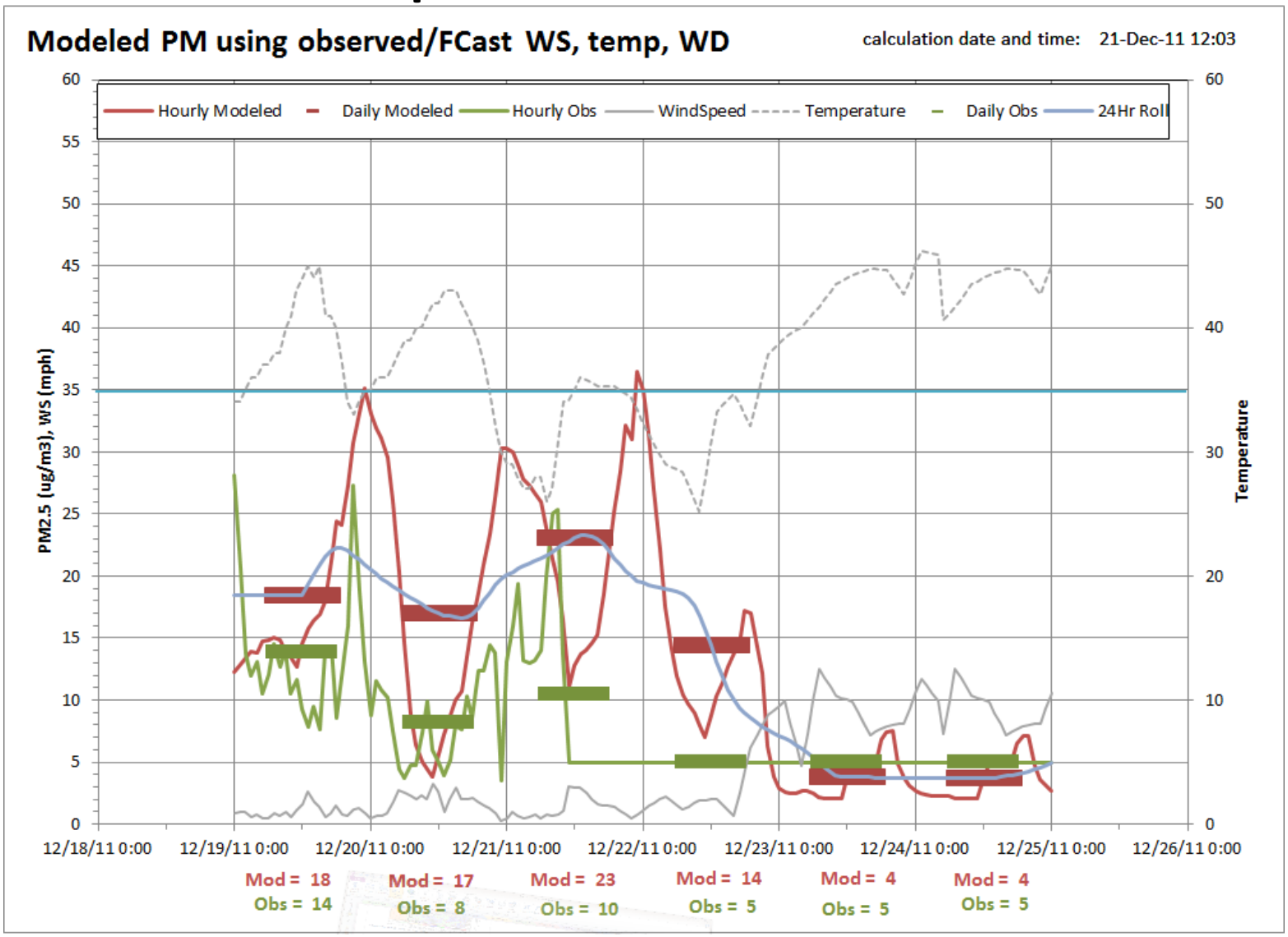
V 2.0


120
100
80
60
40
20
0
0
10
20
30
40
50
60
Series1
Series2

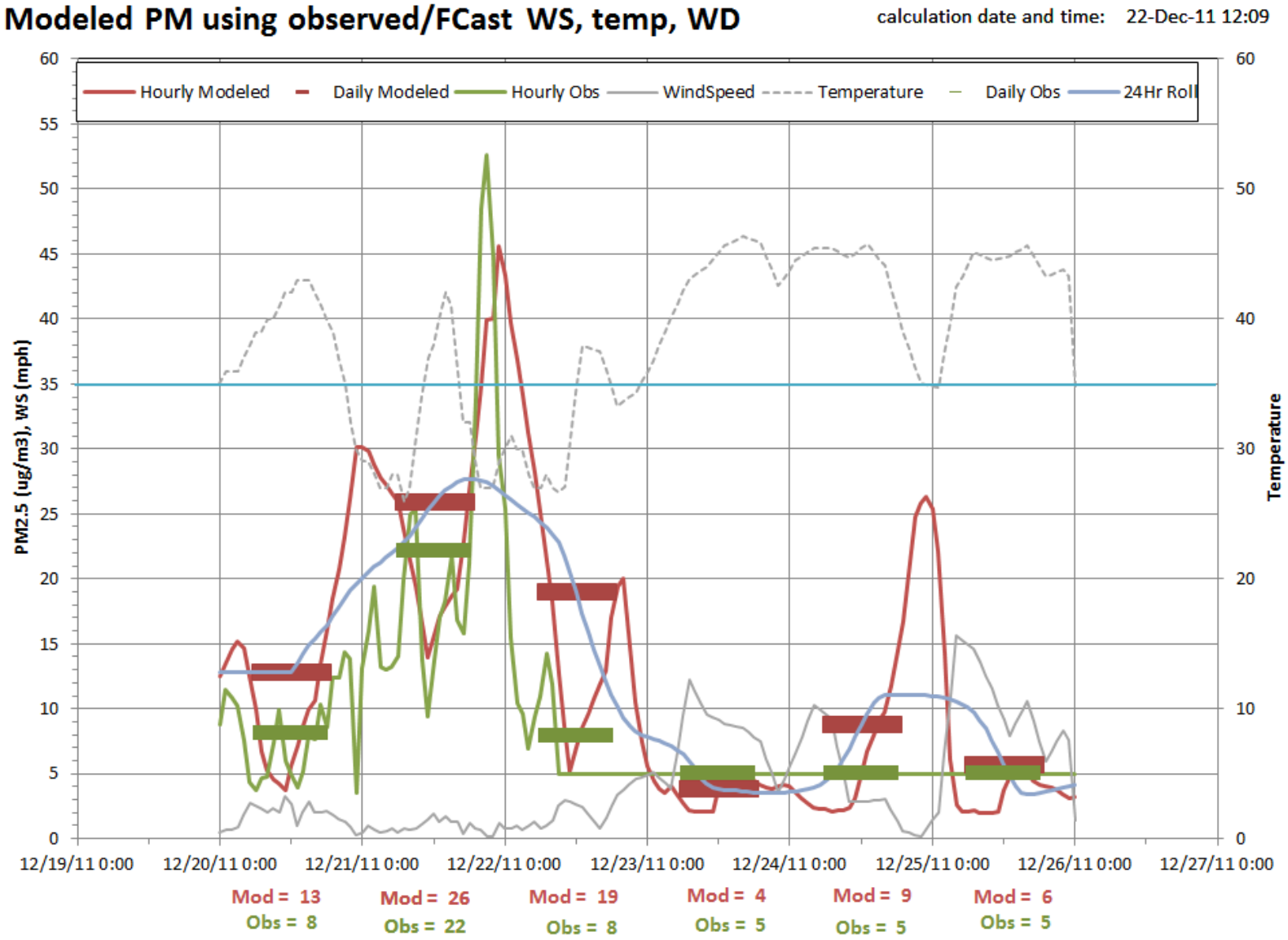
V 2.1


120
100
80
60
40
20
0
0
10
20
30
40
50
60
Series1
Series2

applied for forecasting, 4km WRF forecast input 24-36 hours ahead



applied for forecasting, 4km WRF forecast input 12-24 hours ahead



verification for 12/21, 12/22, and part of 12/23