Aerosol Particles in Power Plant Plumes Measured at Night

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NOAA CLIMATE PROGRAM OFFICE

Advancing scientific understanding of climate, improving society's ability to plan and respond

Aerosol Particles in Power Plant Plumes Measured at Night

Are ultrafine (<0.1 μm) particles formed in power plant plumes only from photochemical production (of H_2SO_4), or are they sometimes directly emitted/formed from SO_3 emissions?

How does production/emission affect downstream properties such as number, size, CCN concentration?

Nighttime plumes aloft a significant source of particles to the morning PBL?

Daytime Process

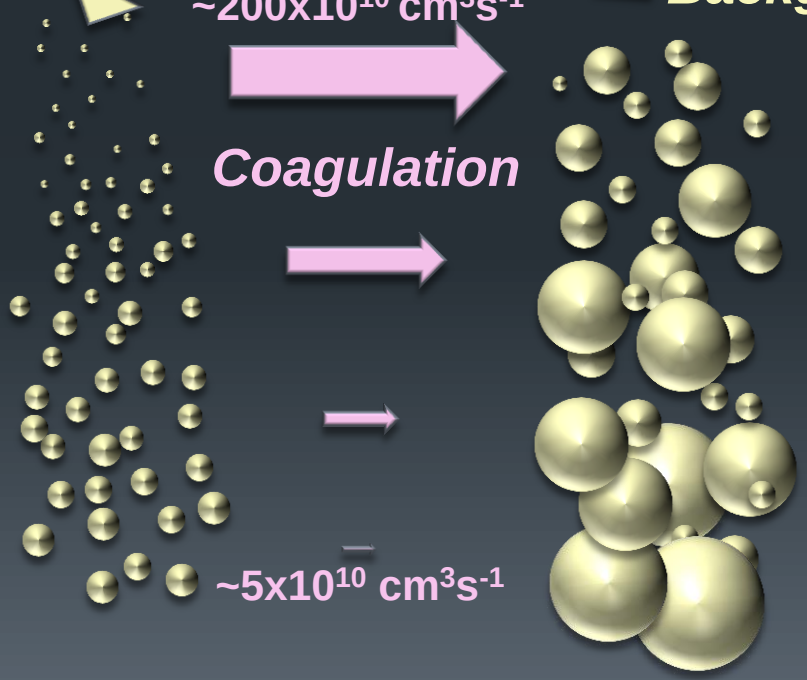
- SO2 emission, oxidation by OH →production of H2SO4
- New particle formation (sometimes on edges of plume first)
- Growth to climate-relevant (>50 nm) size
- Condensation sink on background aerosol surface important

Gas-phase precursor:

SO_2+OH→H_2SO_4

New Particle Formation

Condensation onto Background Aerosol



Growth by Condensation (and Coagulation)

Net Increase in CCN

Growth by Condensation

No or Small Net Increase in CCN

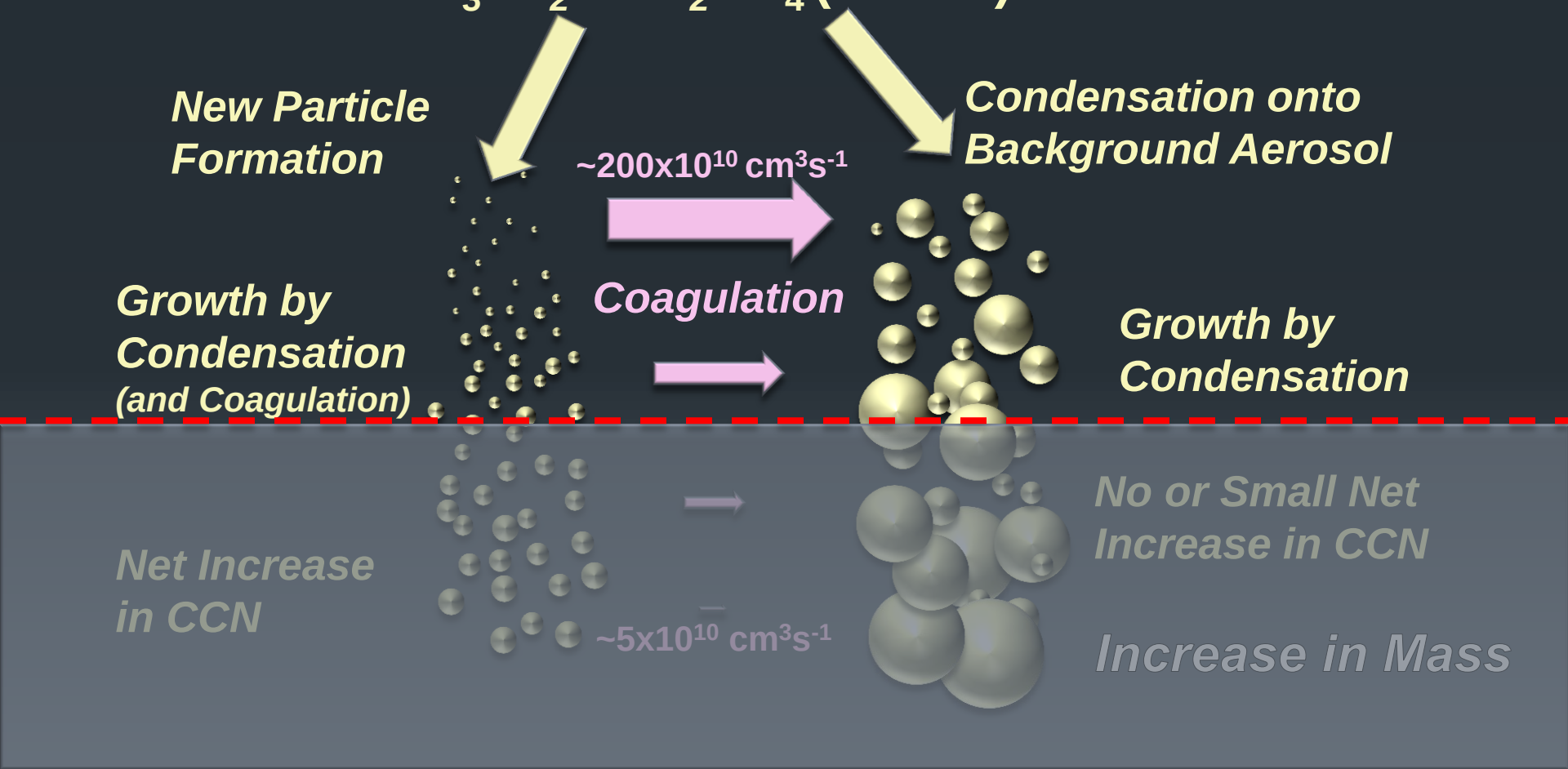
Increase in Mass

Nighttime Process

- SO_3 emission, production of H_2SO_4
- New particle formation (sometimes in stack?)
- Growth to climate-relevant (>50 nm) size (but SO_3 consumed; not replenished)
- Condensation sink on background aerosol surface important

Gas-phase precursor:

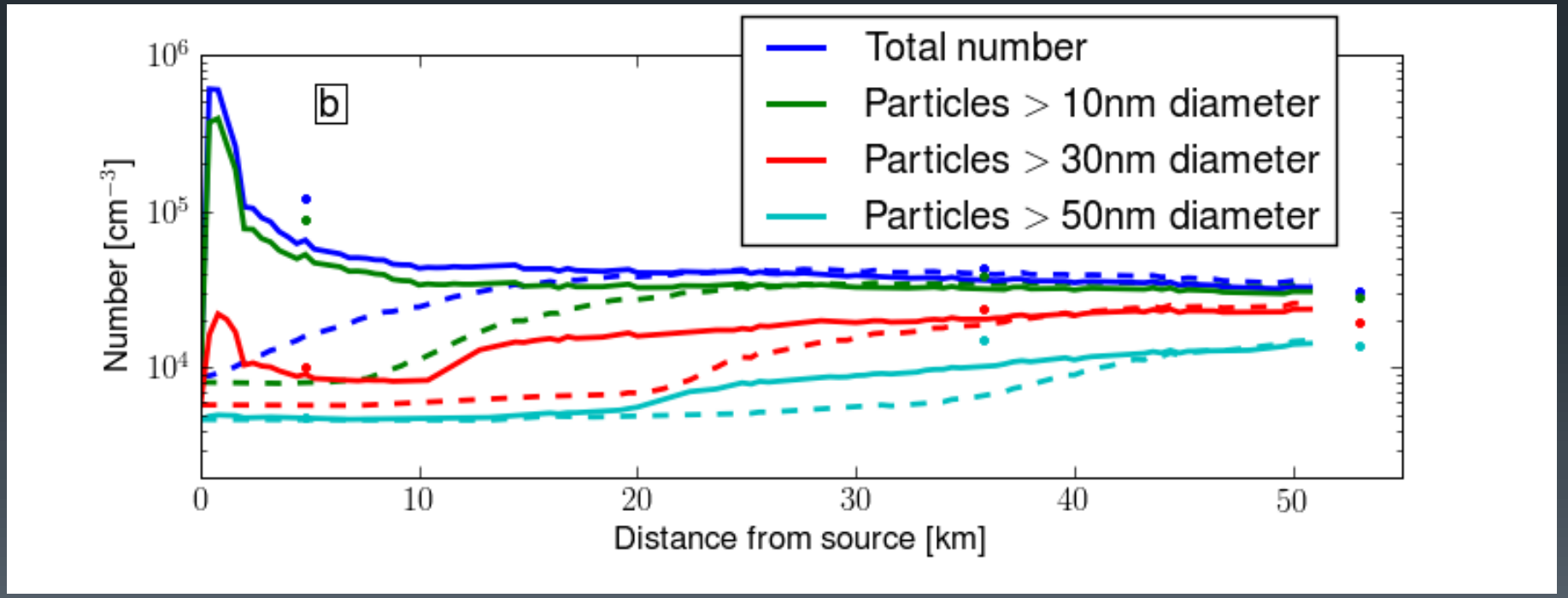
$SO_3 + H_2O \rightarrow H_2SO_4$ ($\sim 10^{-4}$ s)



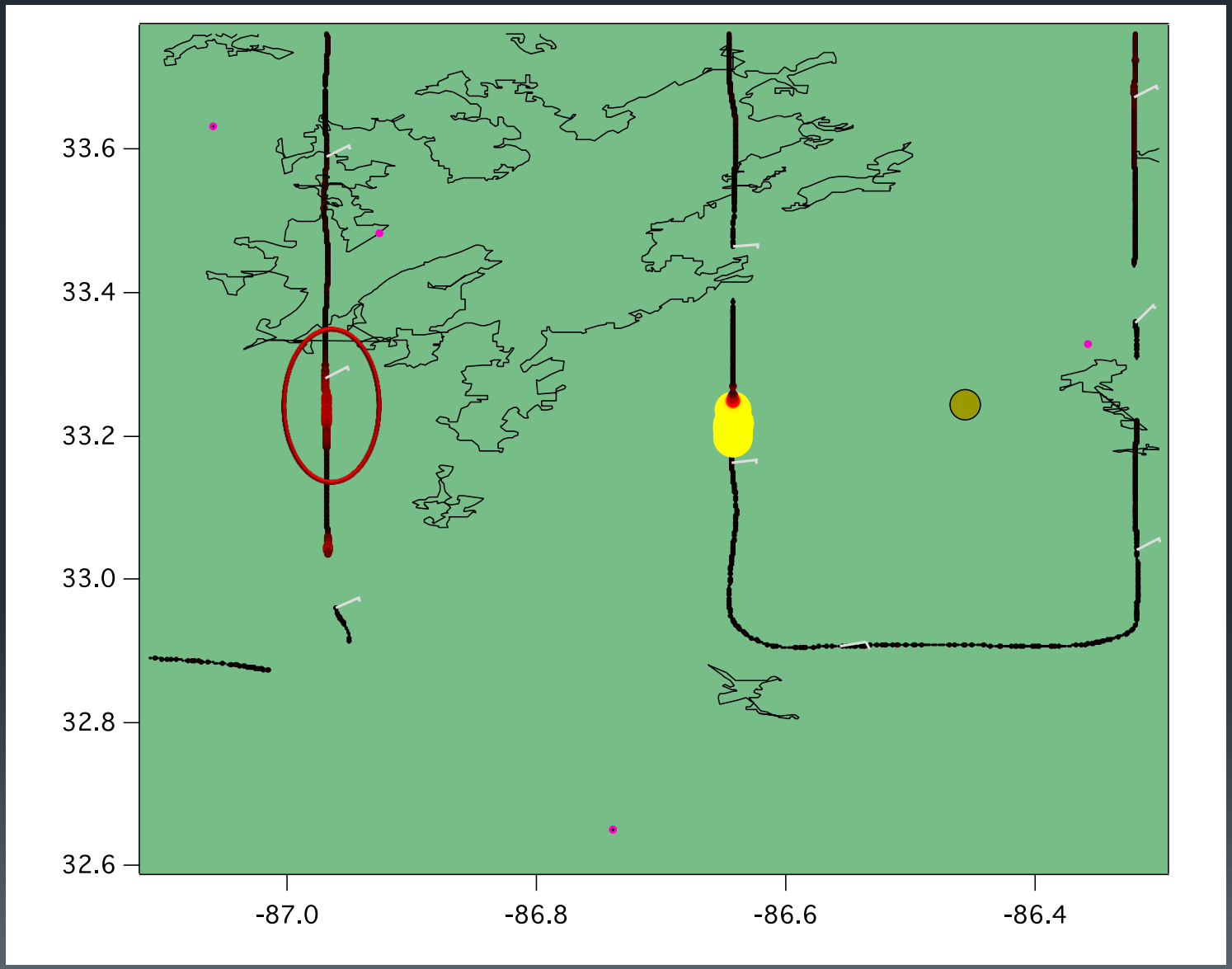
Observations constrain occurrence, properties, and processes

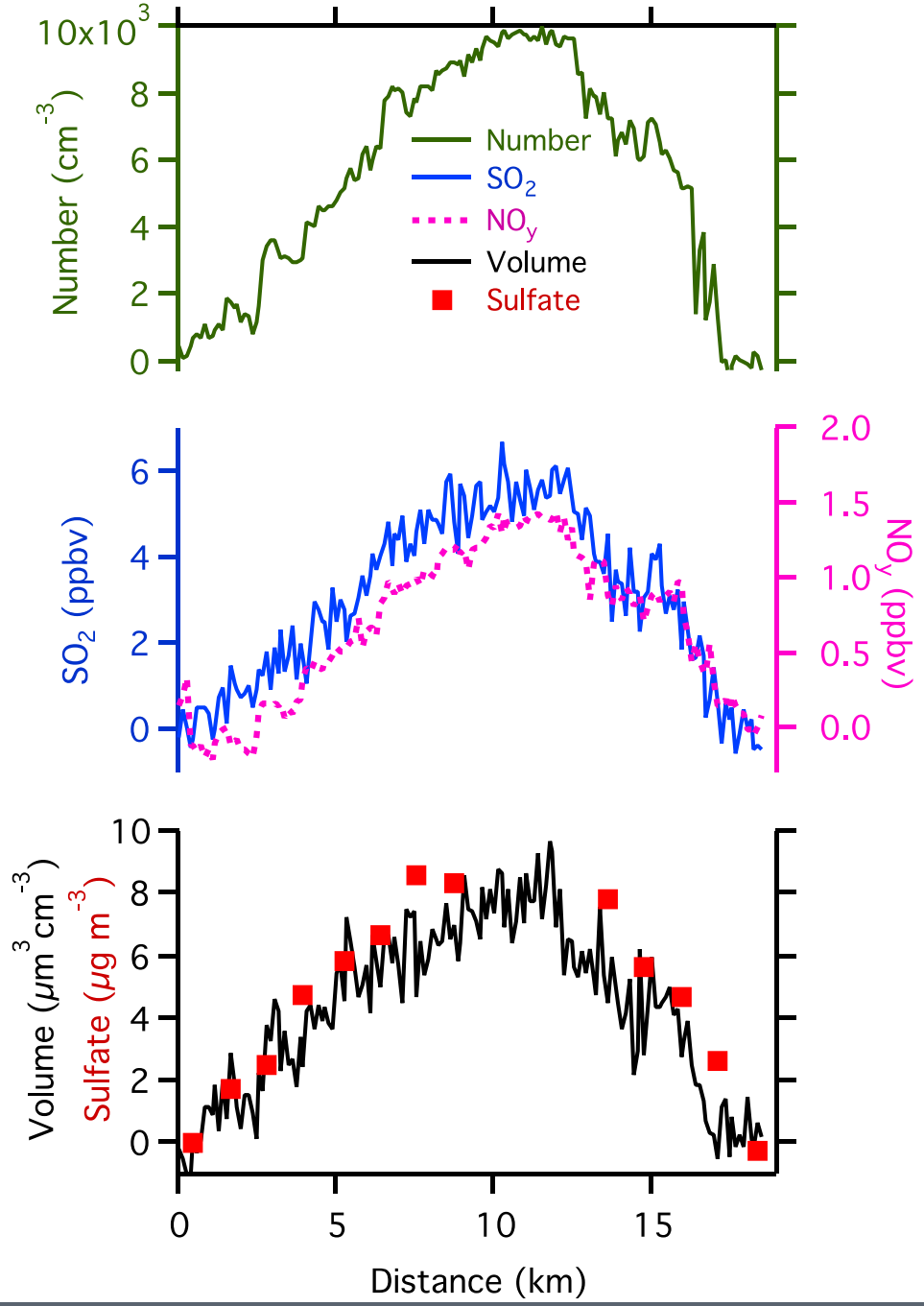
Models explore sensitivities and evaluate climate relevance

Symbols—data from NOAA P-3 in TexAQS 2006; WA Parish Plant
Dashed—Pierce/Stevens model with no particle emission
Solid—model with particle emissions adjusted to match observations



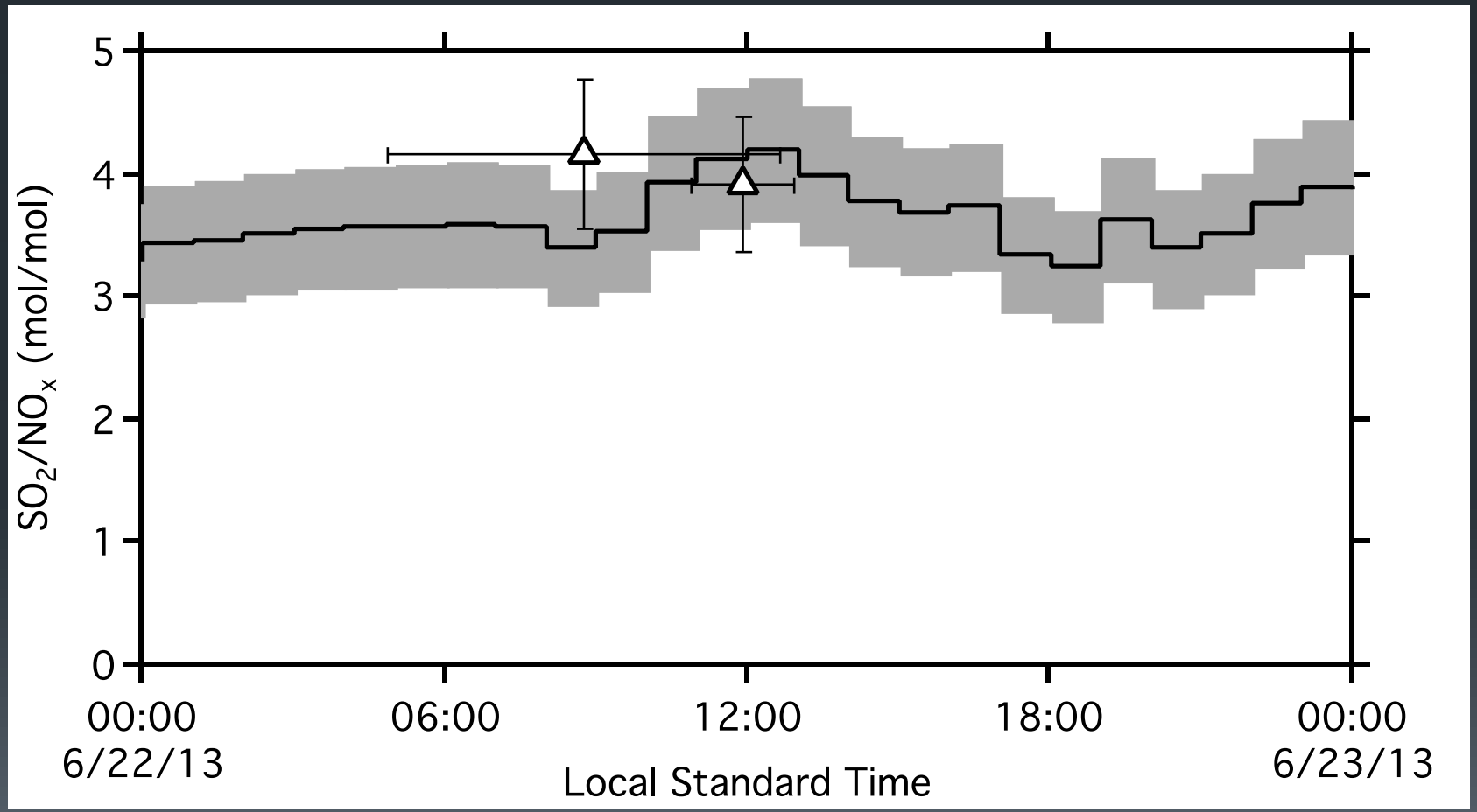
E. C. Gaston Power Plant, Wilsonville, Alabama
2013/06/22 Daytime



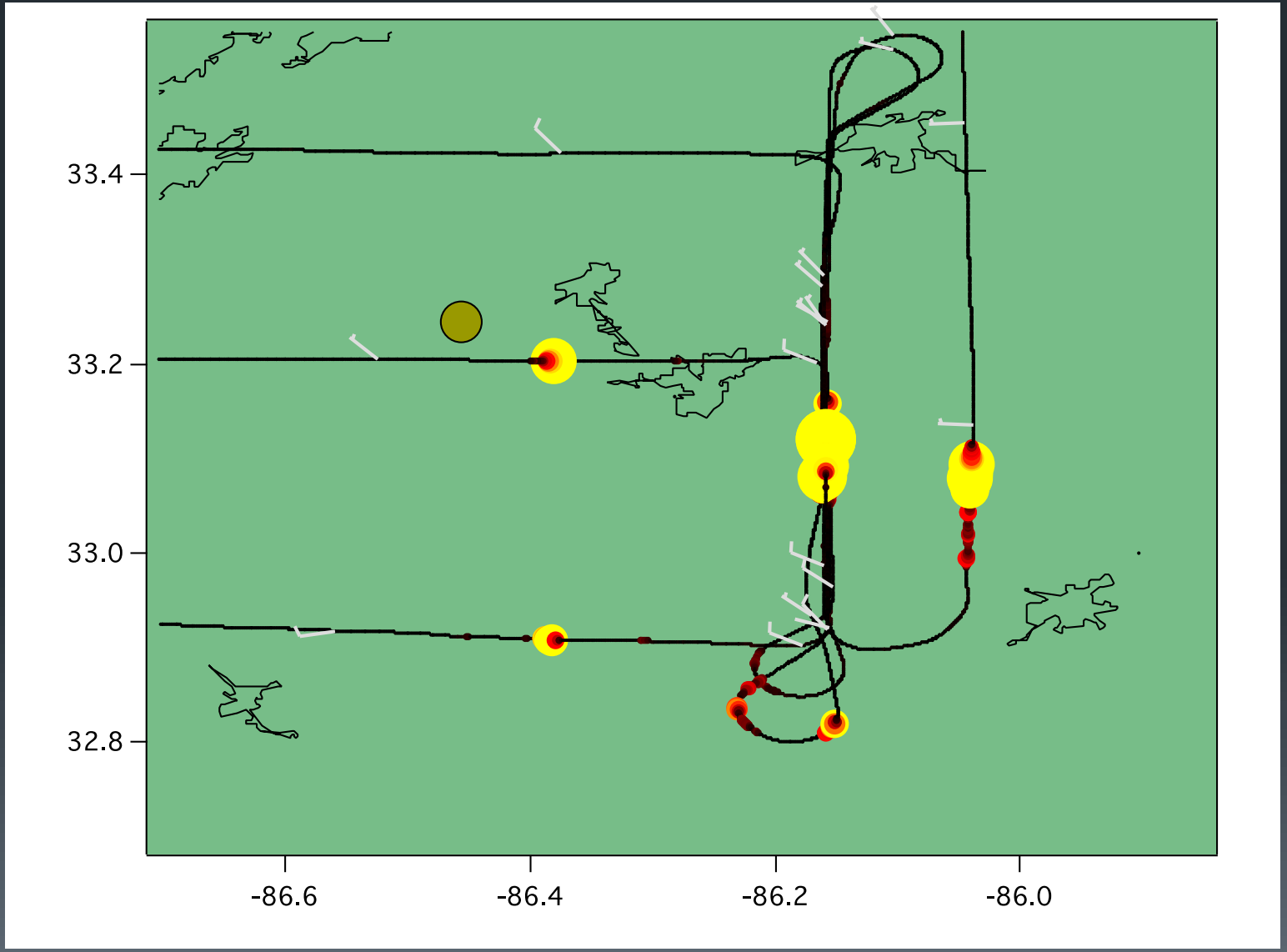


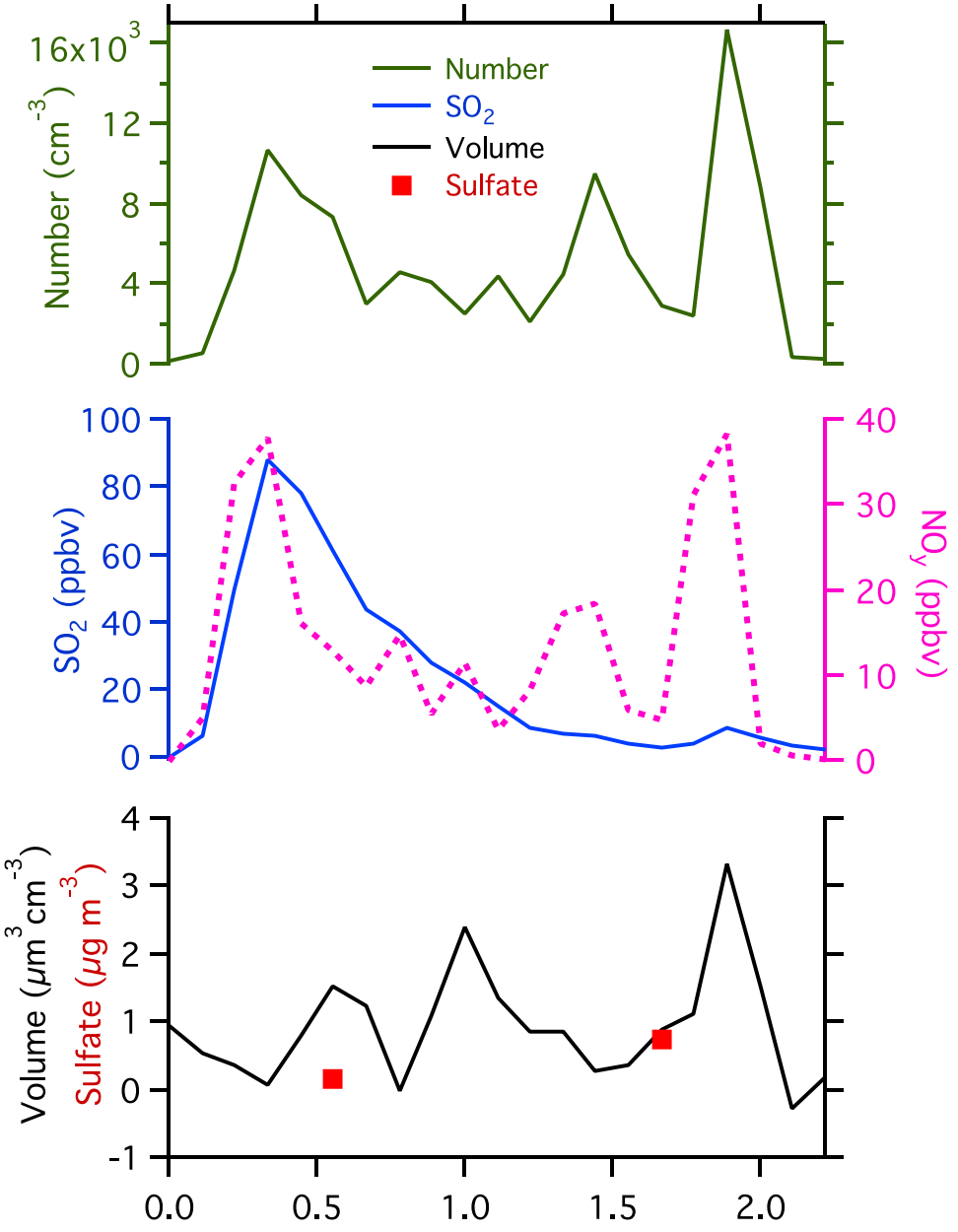
- **Broad, Gaussian plume**
- **Aerosol number correlated with SO2 and NOy**
- **Particle volume and sulfate production**

Compare measured SO2/NOy slope against continuous emissions monitoring system values reported by power plant operator to EPA

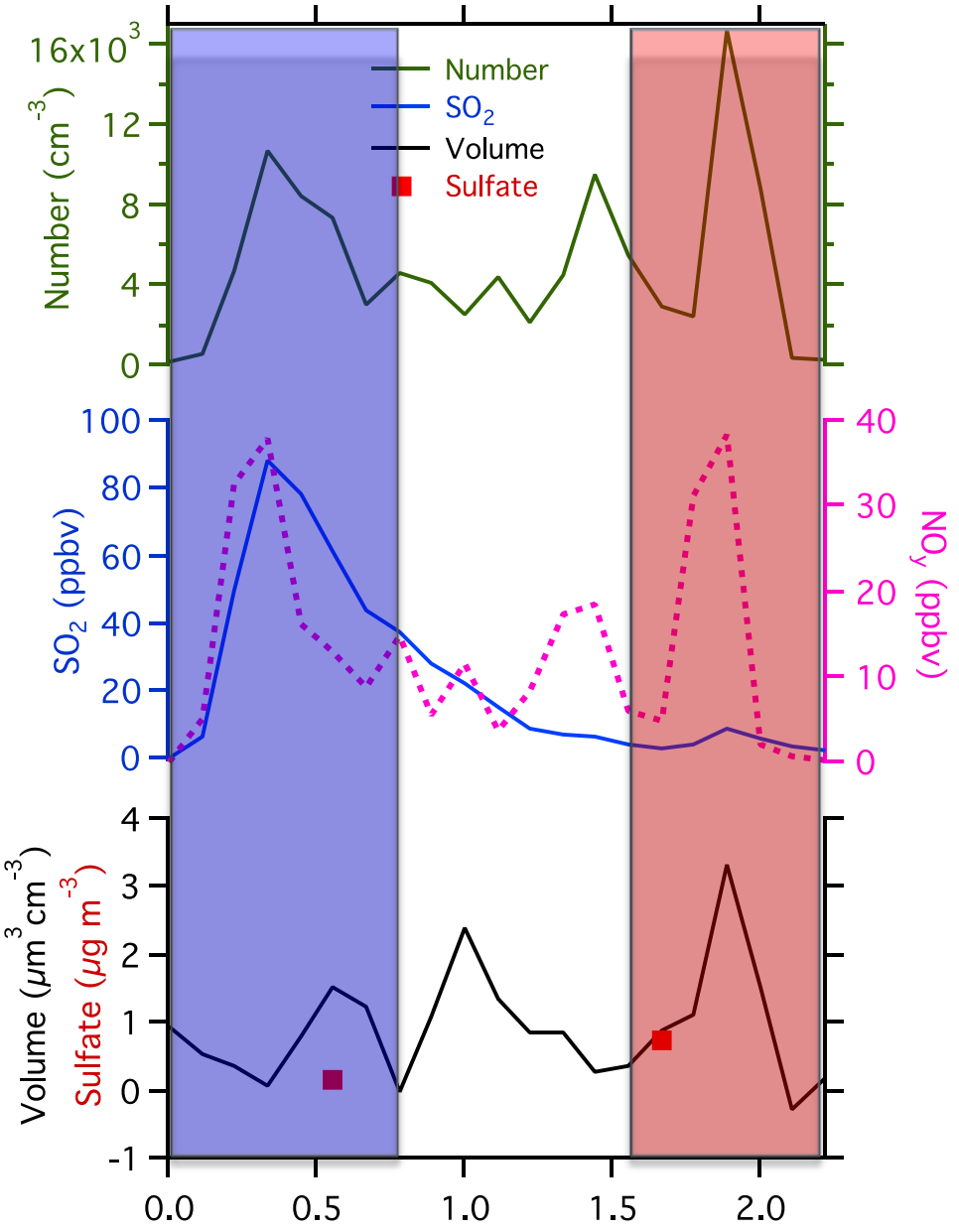


E. C. Gaston Power Plant, Wilsonville, Alabama
2013/07/03 Nighttime





- Narrow, variable plume
- Aerosol number has variable relationship with SO2 and NOy
- Little particle production/emission evident
- No signficant sulfate production
- Particle number probably associated with SO3 emissions
- SO3 emissions <1% of SO2 emissions?

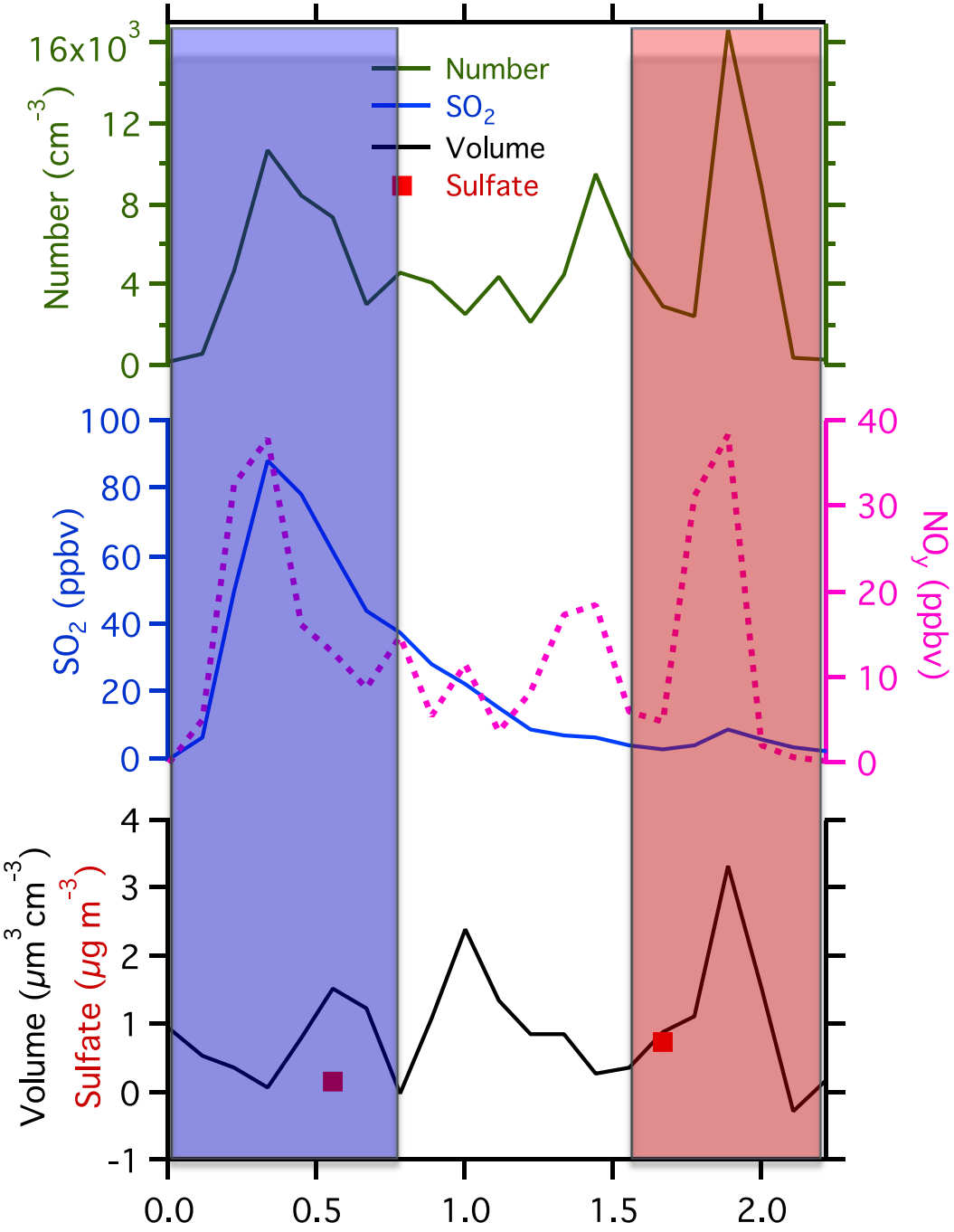


- **Separate into two plumes + mixing region**
- **SO2 associated with one plume**
- **Particle production/emission in both plumes**
- **Particle number/SO2 ratio higher in low-SO2 plume**

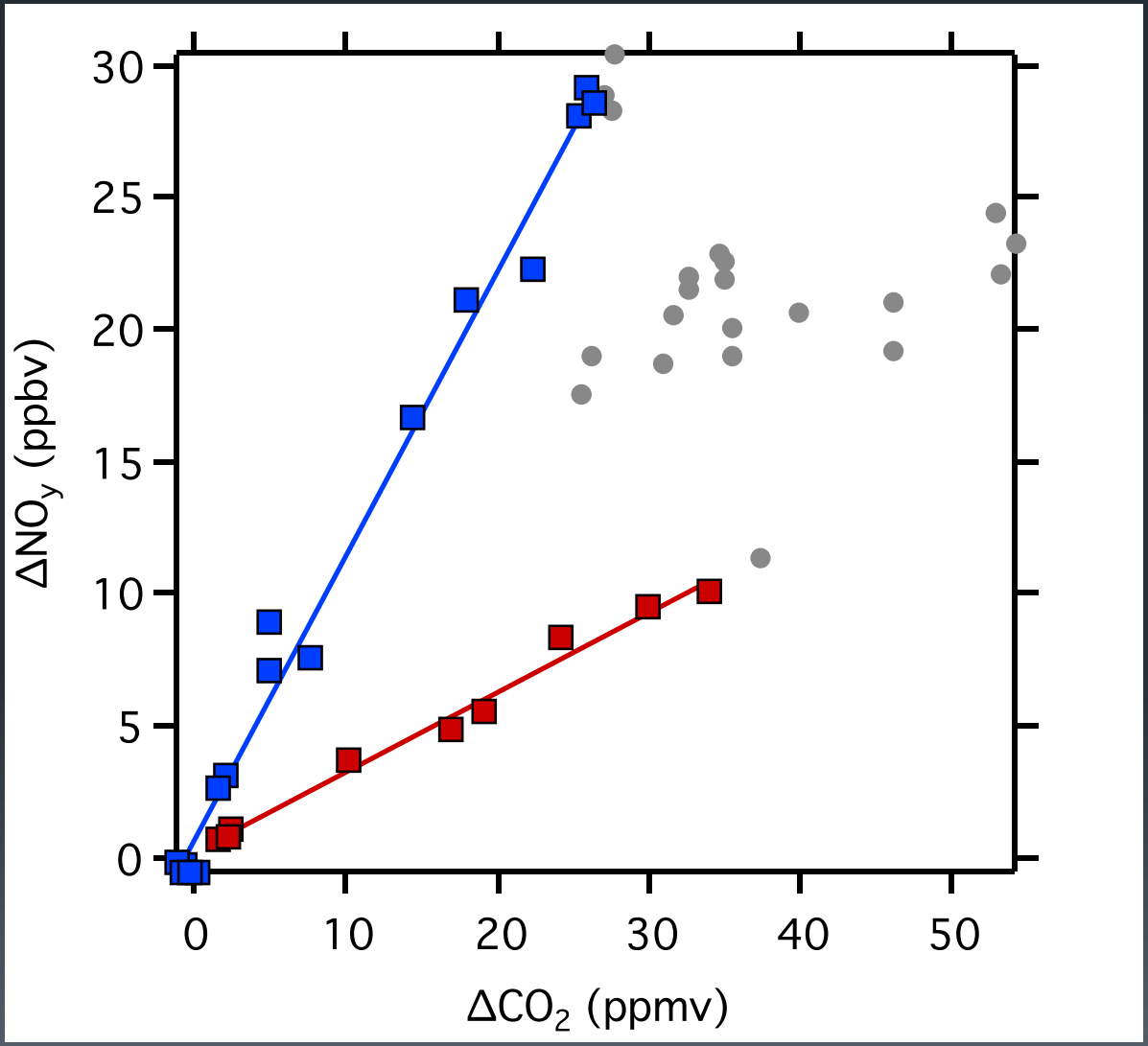
Gaston Power Plant

Stack A: Units 1-4
NOx control: wall-fired low-NOx burner w/overfire air
SO2 control: none
PM control: Baghouse/Electrostatic Precipitator

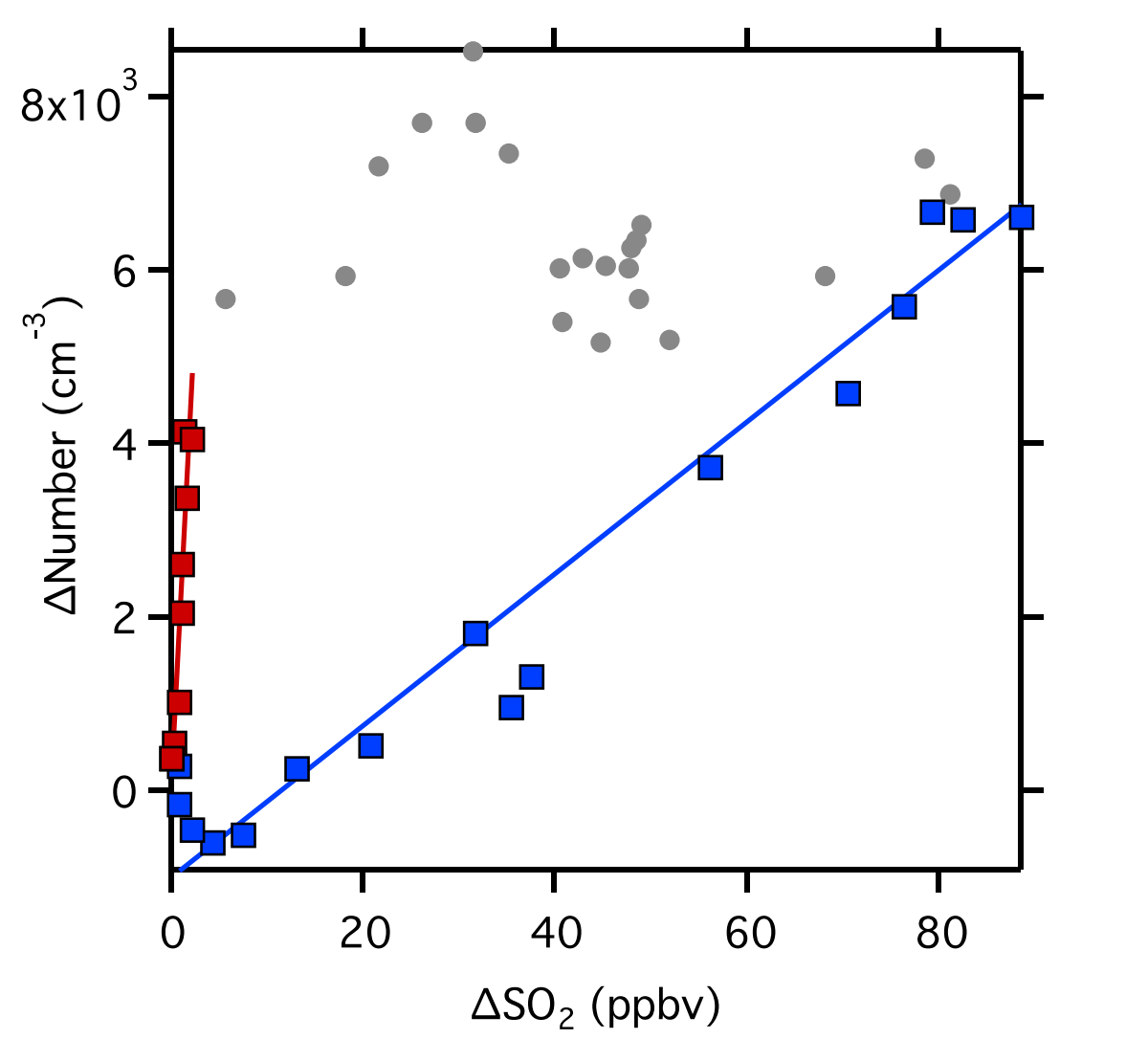
Stack B: Unit 5
NOx control: tangentially-fired low-NOx burner w/overfire air +selective catalytic reduction,
SO2 control: wet limestone scrubber
PM control:Electrostatic Precipitator


16x10^3
Number (cm^-3)
12
8
4
0
Number
SO2
Volume
Sulfate
100
80
60
40
20
0
SO2 (ppbv)
40
30
20
10
0
NOy (ppbv)
4
3
2
1
0
-1
Volume (μm^3 cm^-3)
Sulfate (μg m^-3)
0.0
0.5
1.0
1.5
2.0

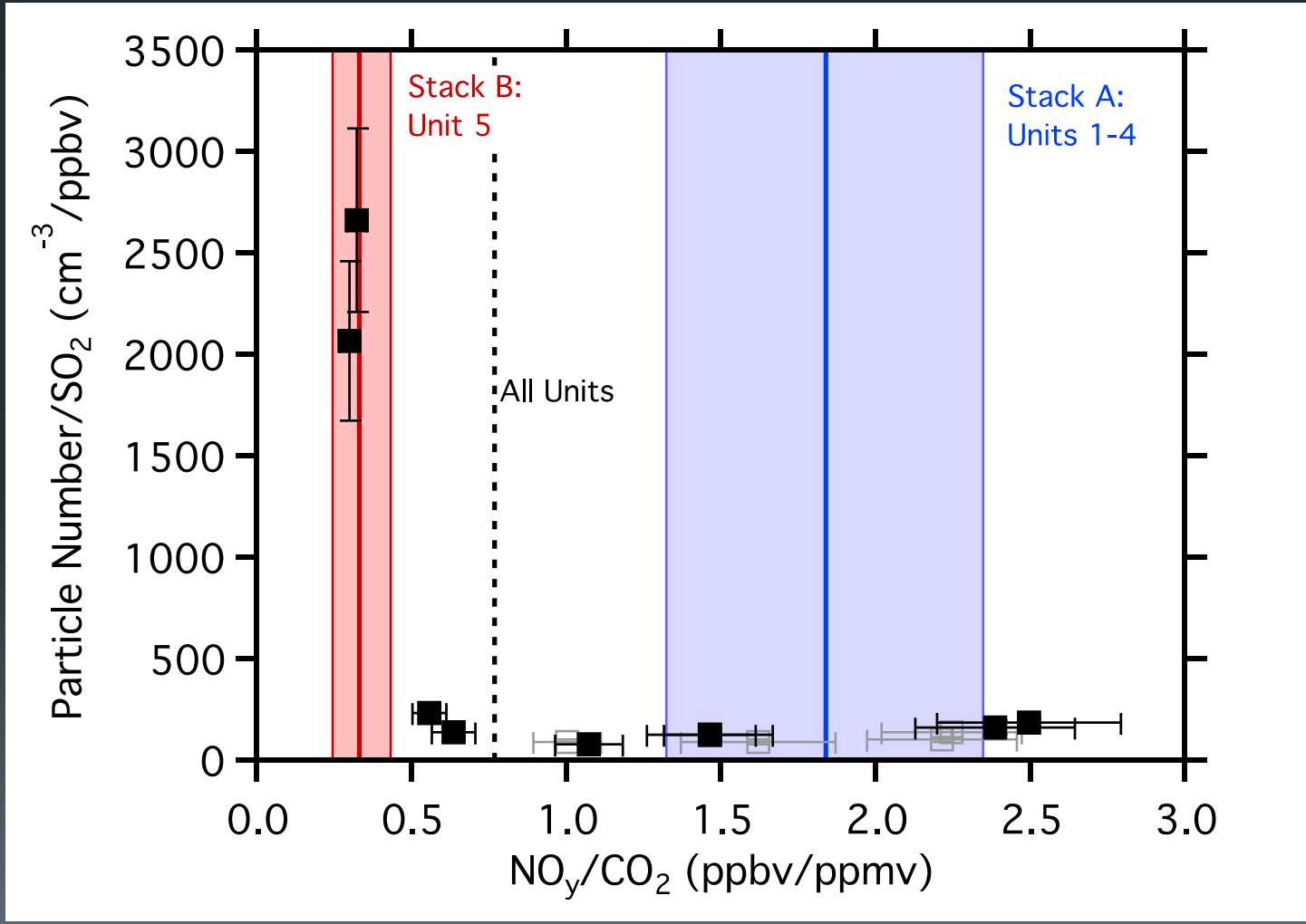
NOy/CO2 ratios consistent with emissions from two stacks + mixing zone



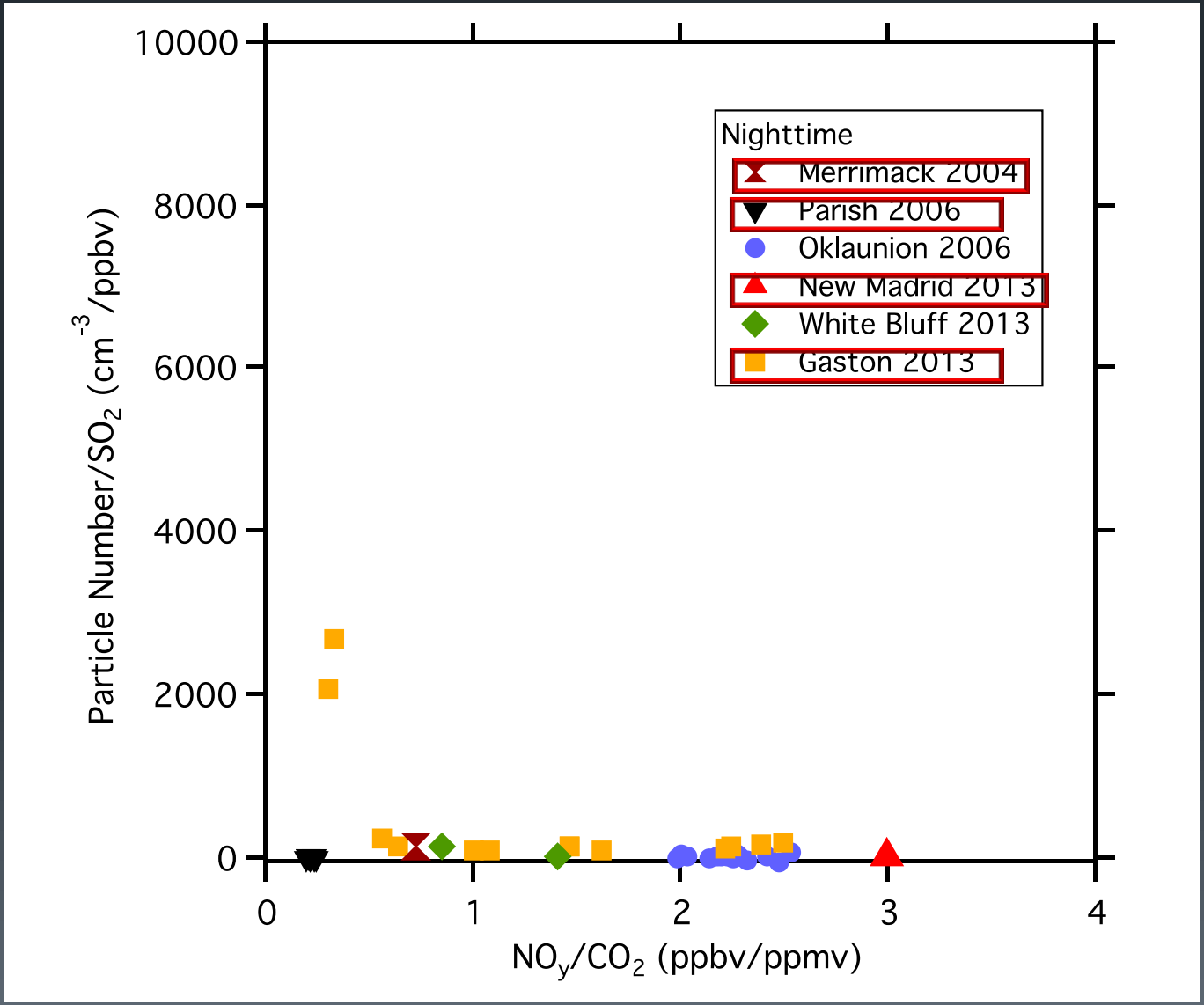
Particle number/SO2 shows very different slopes + mixing zone. More particles produced per SO2 emitted (higher SO3 fraction) in pume with catalytic NOx scrubber.



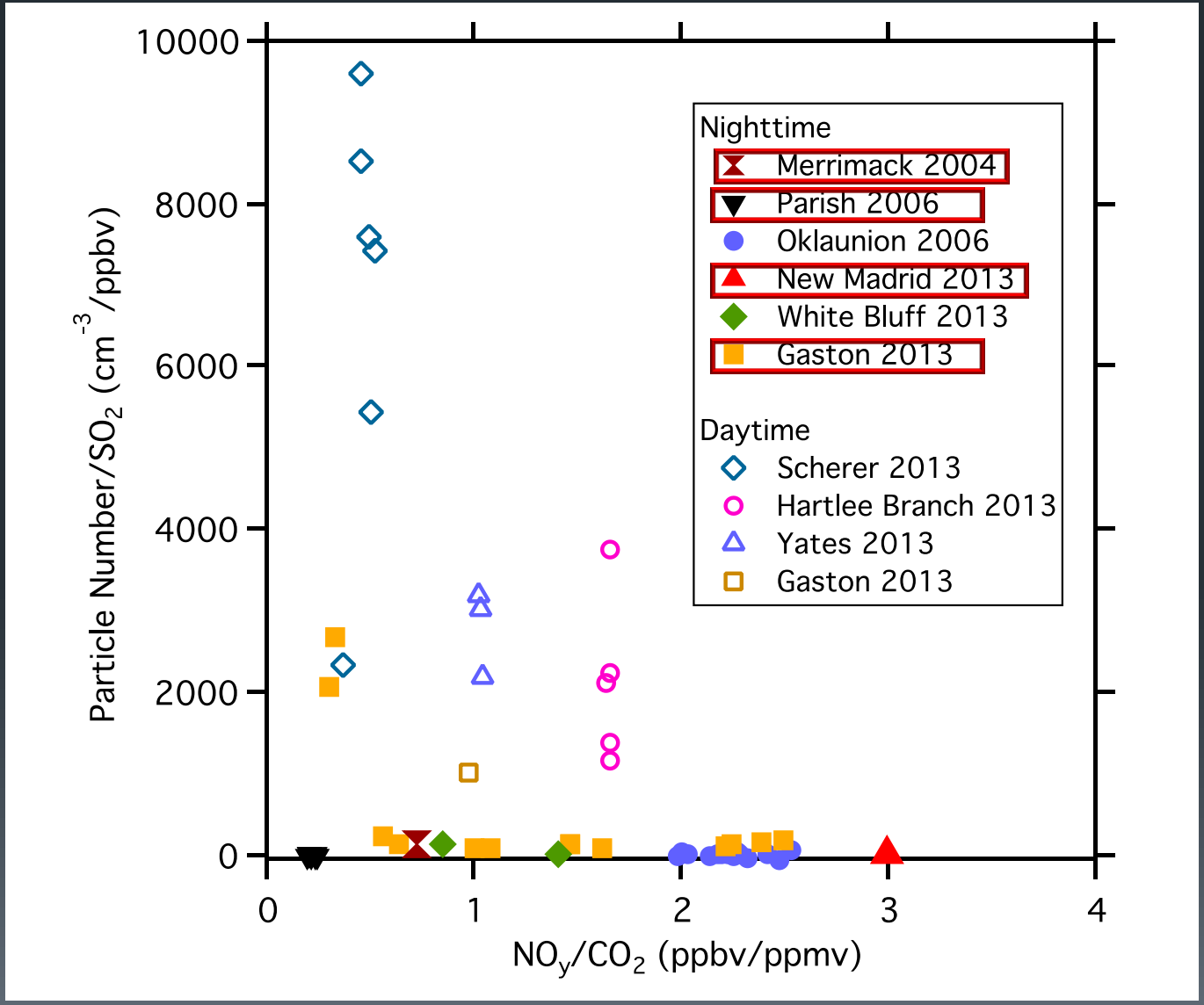
More particles produced per SO2 emitted (higher SO3 fraction) in pume with catalytic NOx scrubber. Why no intermediate particle enhancements in mixed plumes?



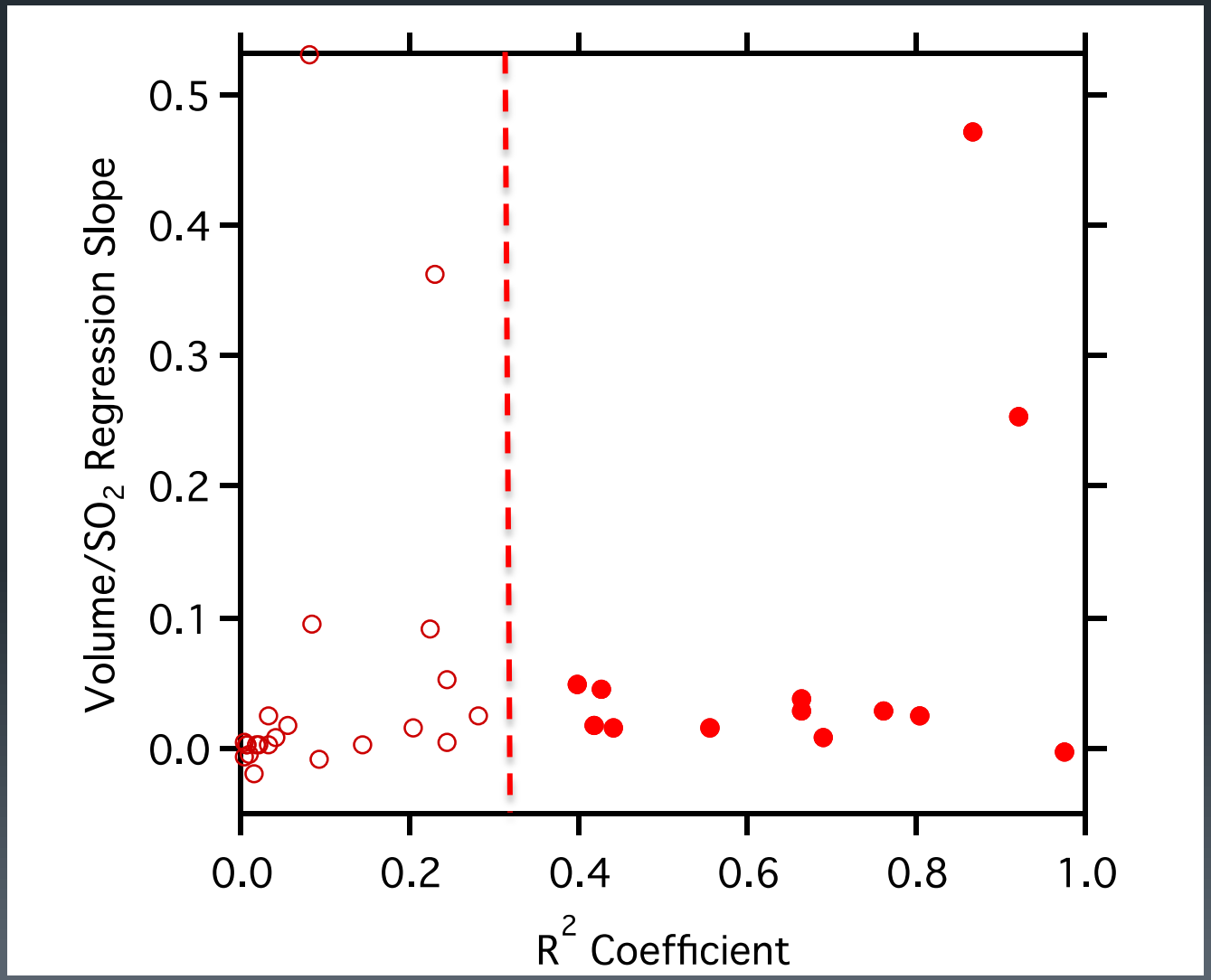
Gaston particle number/SO2 is anomalous compared with all other plumes sampled at night from 2004-2013.
SCR-equipped plants in red boxes.



Daytime transects in 2013 show much greater particle number/SO2 compared with nighttime cases.

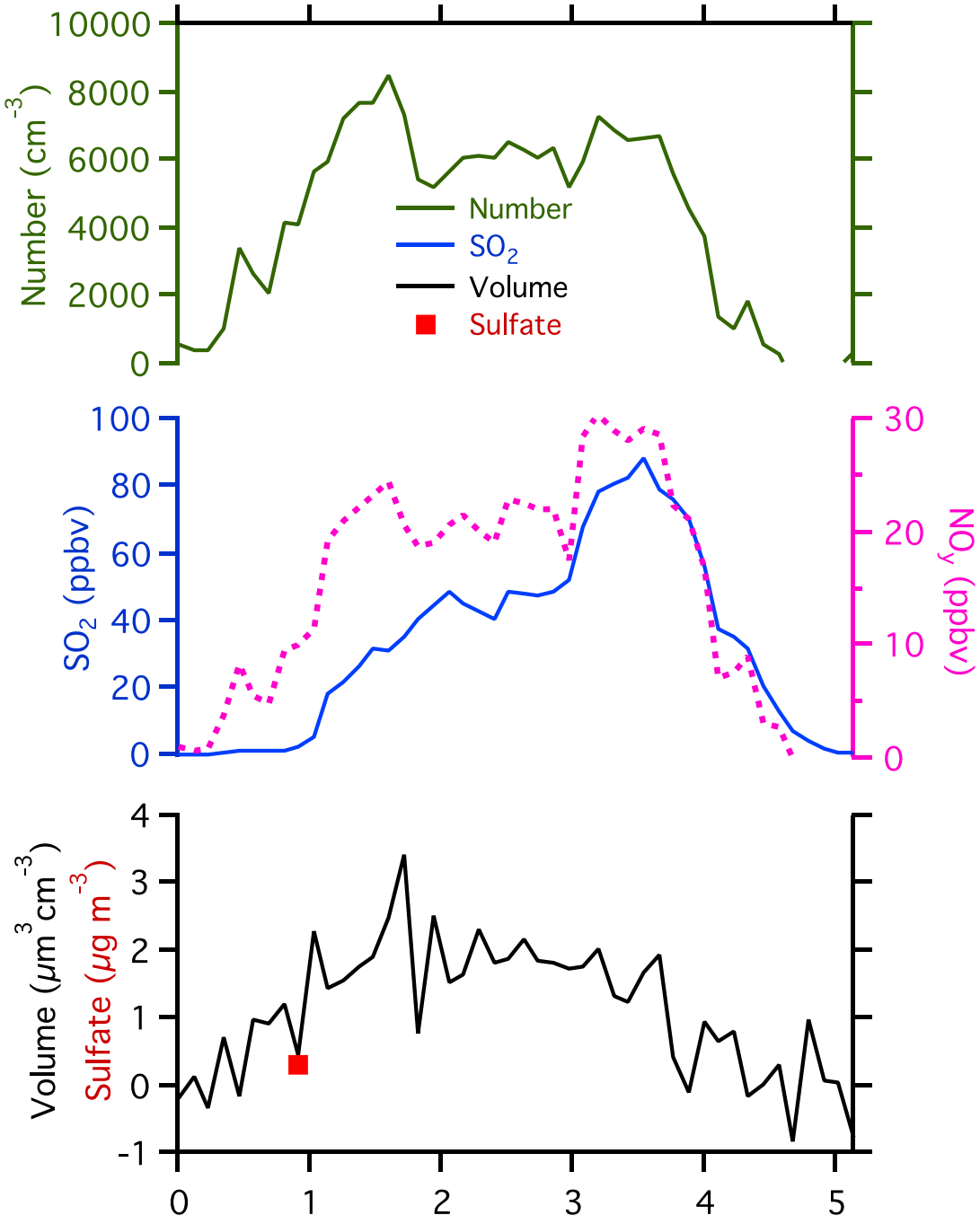


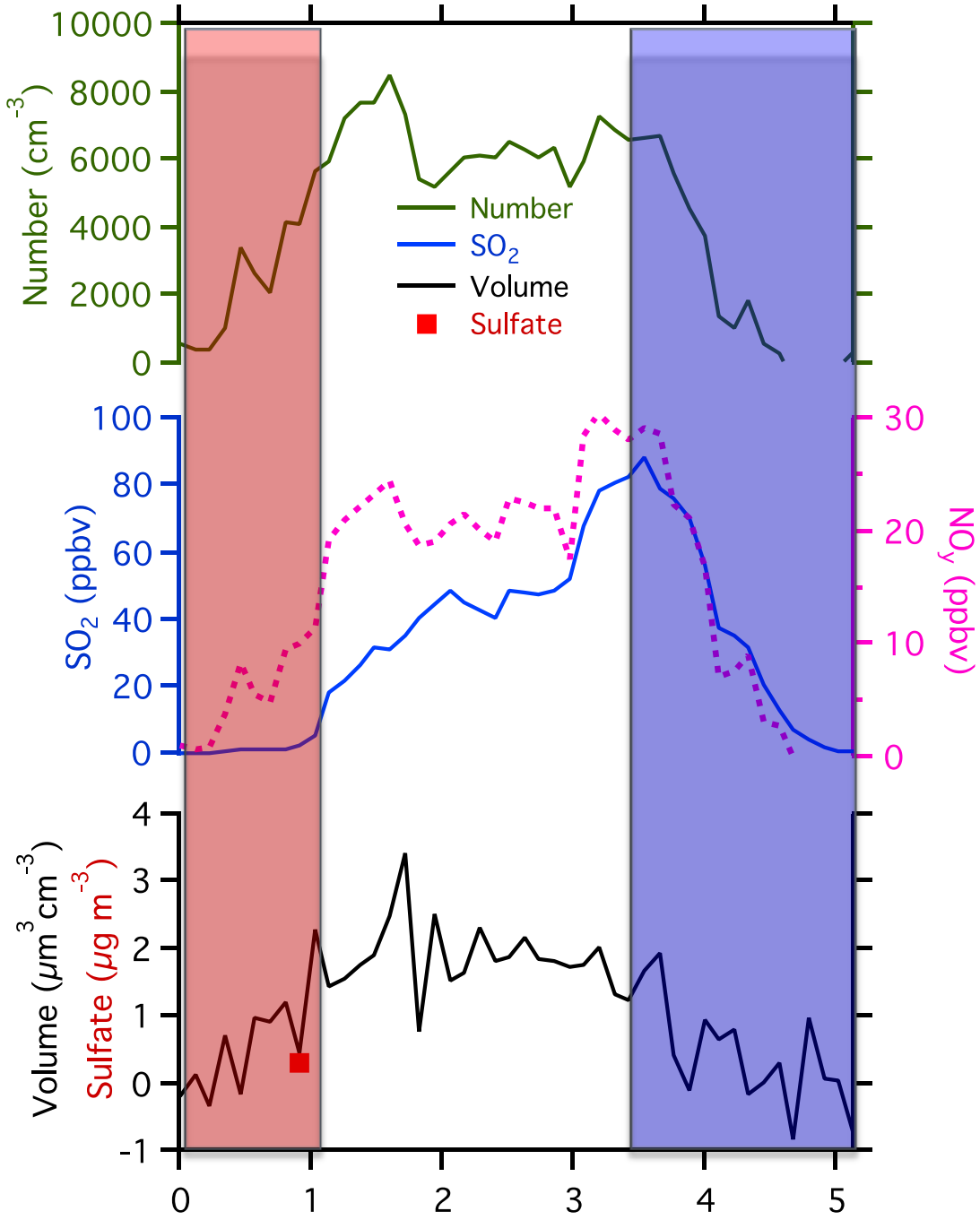
How about particle volume (mass) at night?
Many plumes have poor correlation between volume and SO2.
Those that are correlated show only very small volume enhancements.
Two exceptions: One Gaston transect and Merrimack in 2004.



Conclusions

- Limited evidence for significant role of production of newly formed particles from SO3 emissions
- Rare plumes with newly formed particles present in substantial quantities relative to SO2
- No evident association with particular plant characteristics (burner, NOx control, PM control)
- Puzzling why two cases show substantial number enhancement and two cases show substantial volume/surface enhancement.
- All other cases of enhancement found include some time spent in daylight.
- Given negligible volume increases, hard to see room for a substantial role for organic production (a la Zaveri et al., 2010)


10000
8000
6000
4000
2000
0
Number (cm-3)
Number
SO2
Volume
Sulfate
100
80
60
40
20
0
SO2 (ppbv)
30
20
10
0
NOy (ppbv)
4
3
2
1
0
-1
Volume (μm3 cm-3)
Sulfate (μg m-3)
0
1
2
3
4
5


Number (cm^{-3})
10000
8000
6000
4000
2000
0
Number
SO_2
Volume
Sulfate
SO_2 (ppbv)
100
80
60
40
20
0
NO_y (ppbv)
30
20
10
0
Volume (μm^3 cm^{-3})
Sulfate (μg m^{-3})
4
3
2
1
0
-1
0
1
2
3
4
5