Dense networks and geostationary satellites: A vision for the future of NO_x and air quality observations

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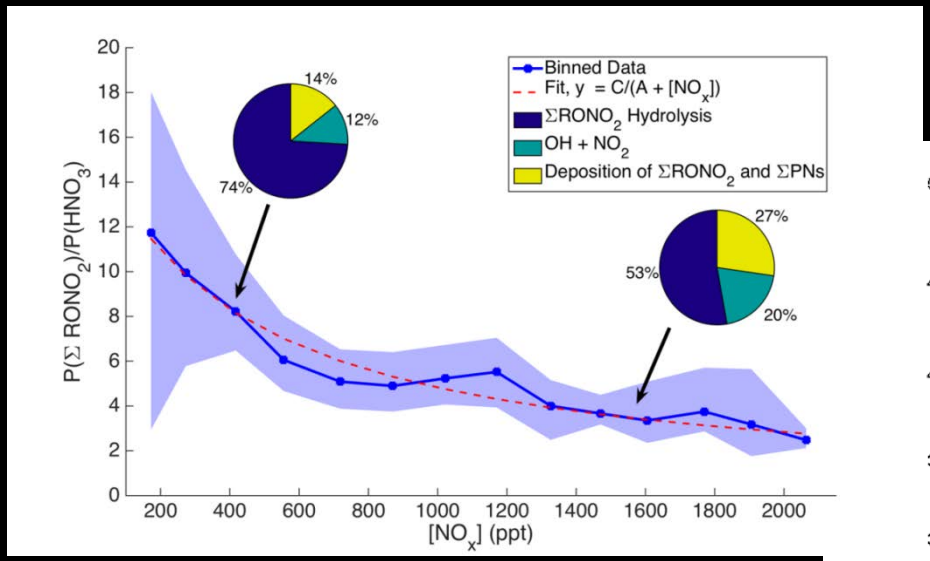
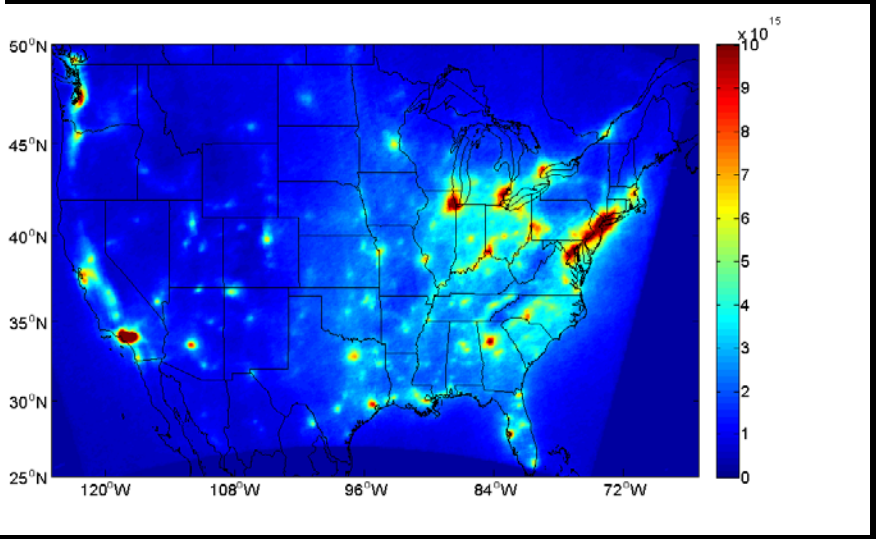
$ BAAQMD, NSF, NASA, UC Berkeley, HEI, Koret Foundation

A different talk

$RONO_2$ chemistry (Day 2/3; night 1/3) governs the lifetime of NO_x and HNO_3 and is a major source of aerosol.

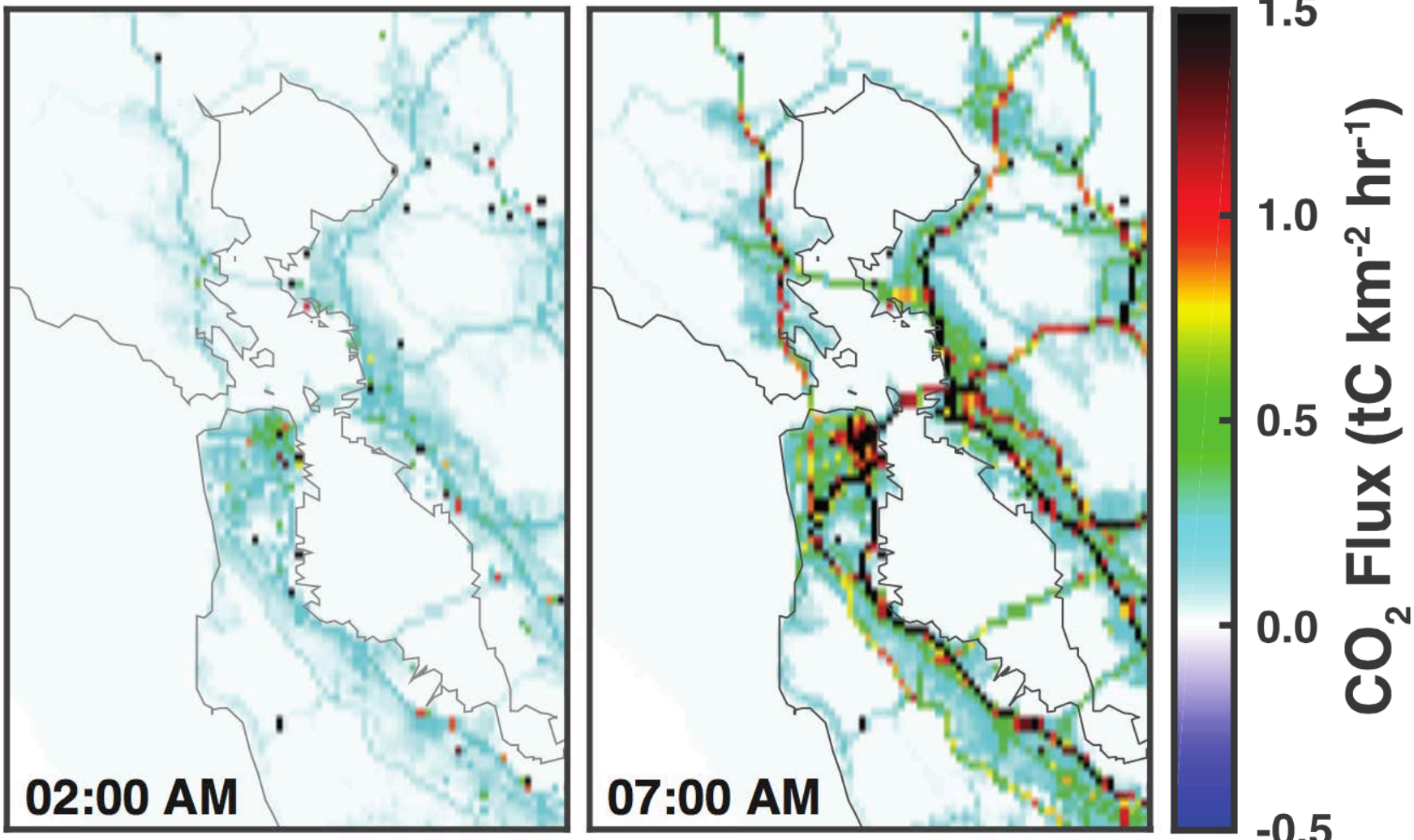




e.g. Romer et al. ACP, 2016, Perring et al. Chem. Rev. 2013, Rollins et al. Science, 2012

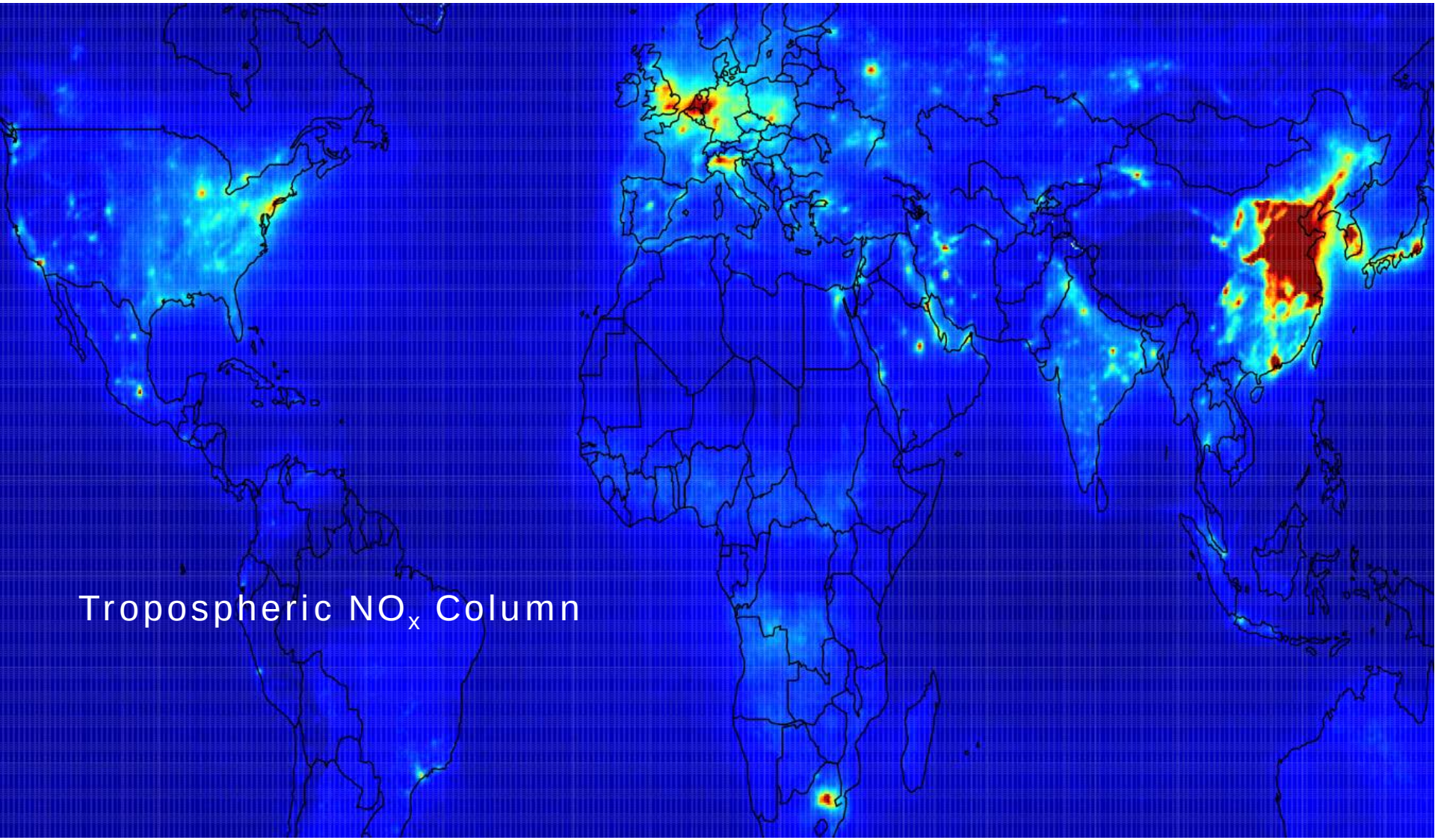
Current models of emissions have few parts that respond to day-to-day variations in human behavior or weather.

CO_2 Emission Inventory

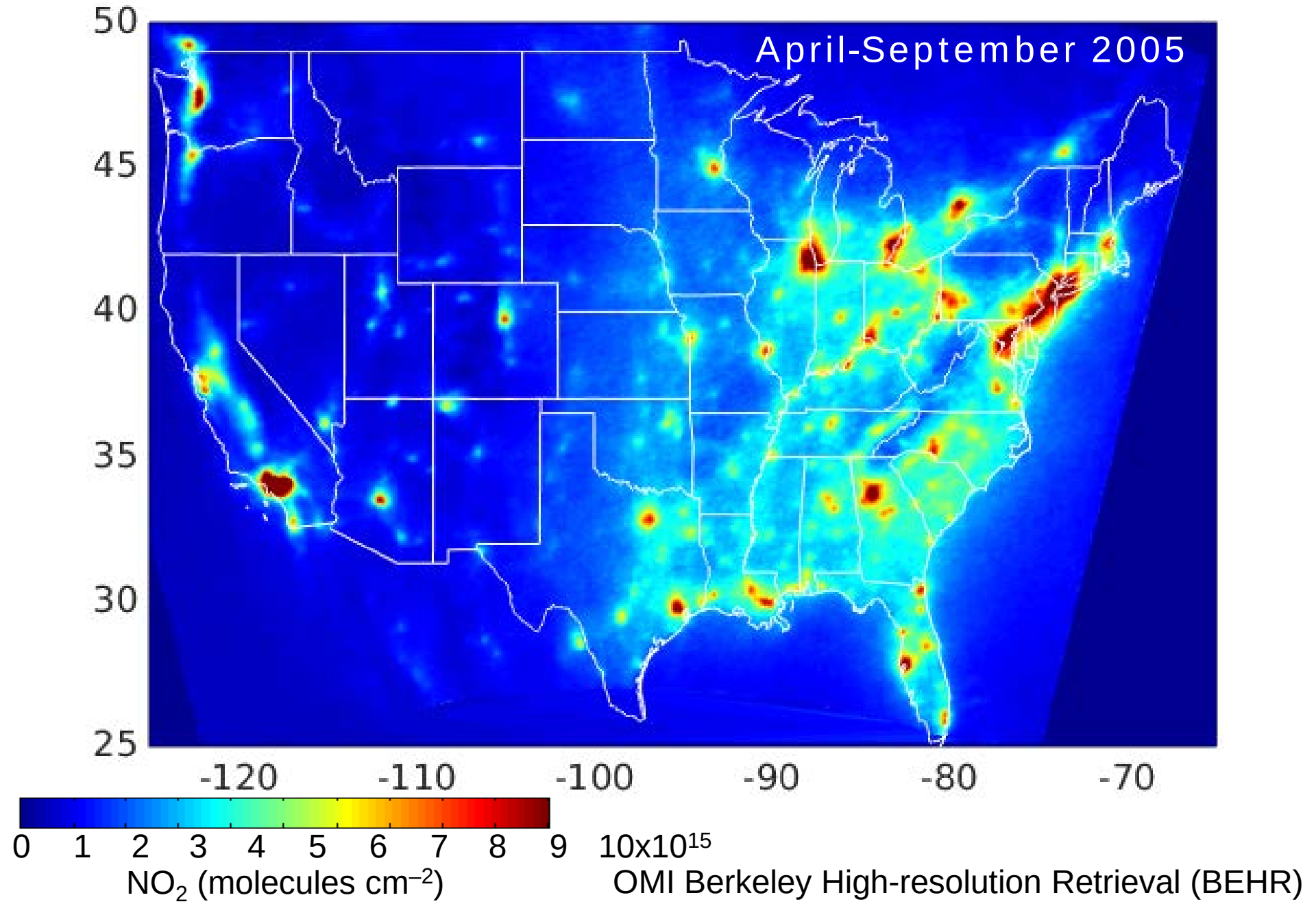


(Turner et al., 2016)

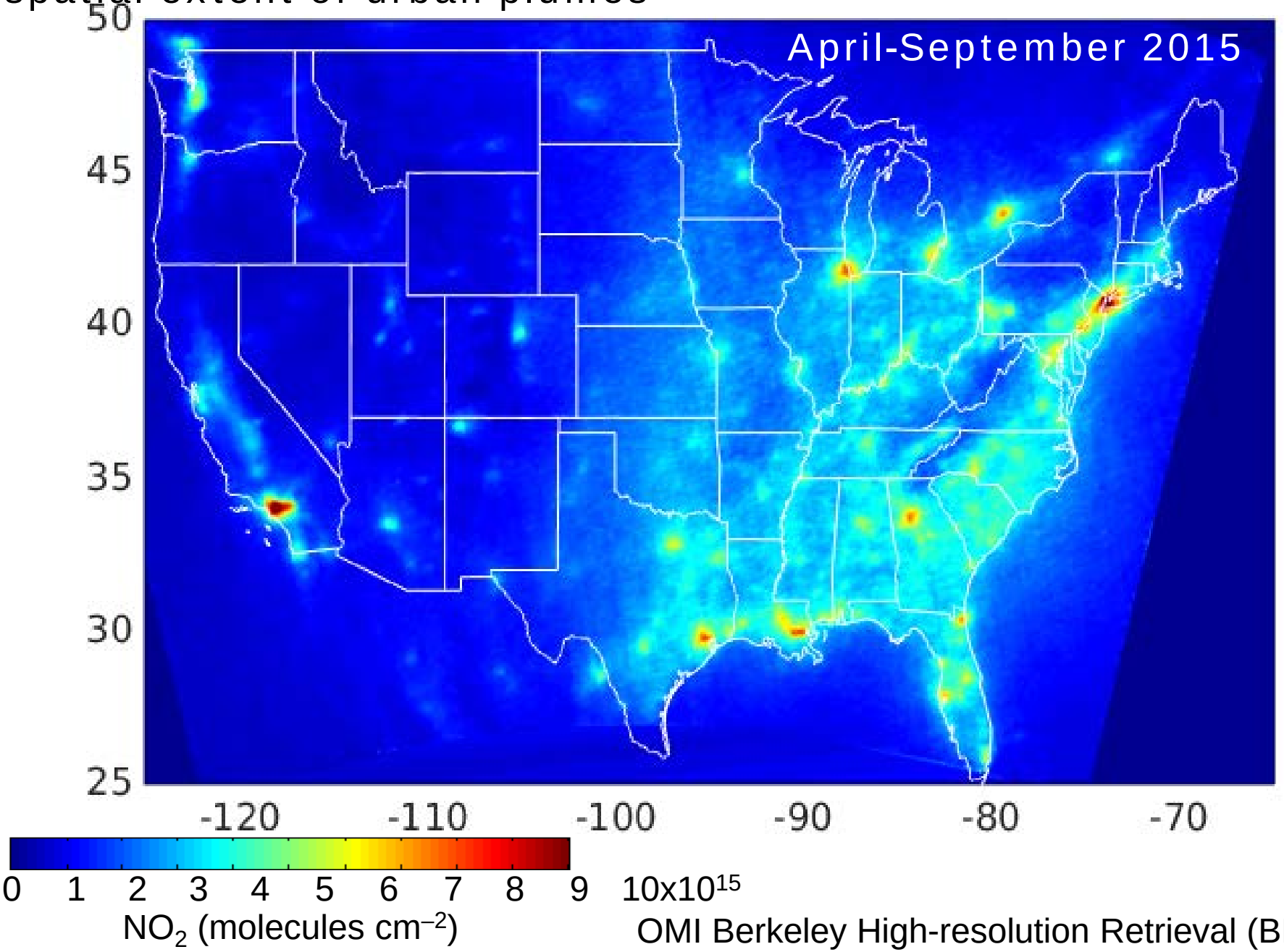
Satellite remote sensing is changing how we think about emissions and air quality



Nitrogen oxides (NO_x) are concentrated over cities

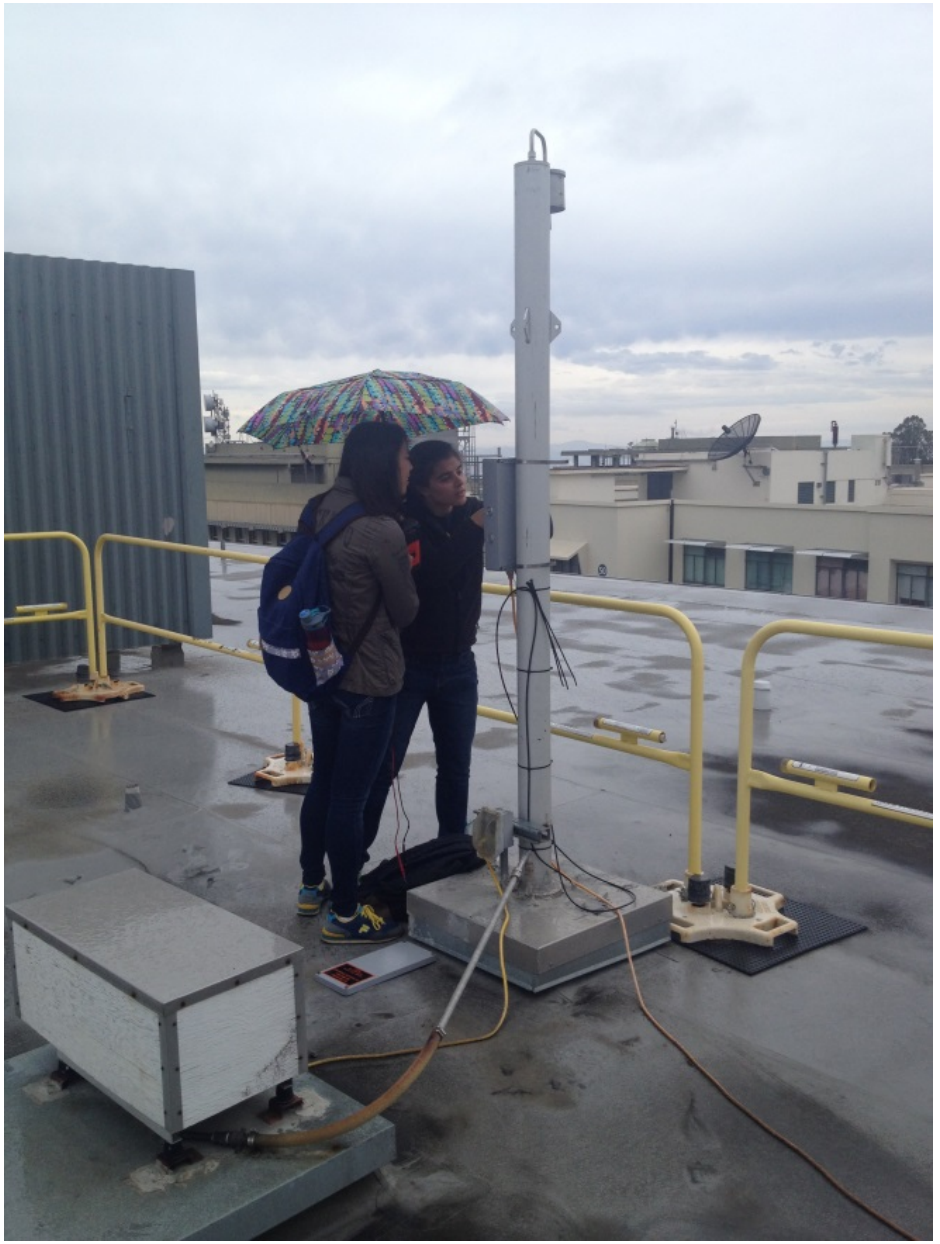


Large decreases over the last decade in U.S. result in smaller spatial extent of urban plumes

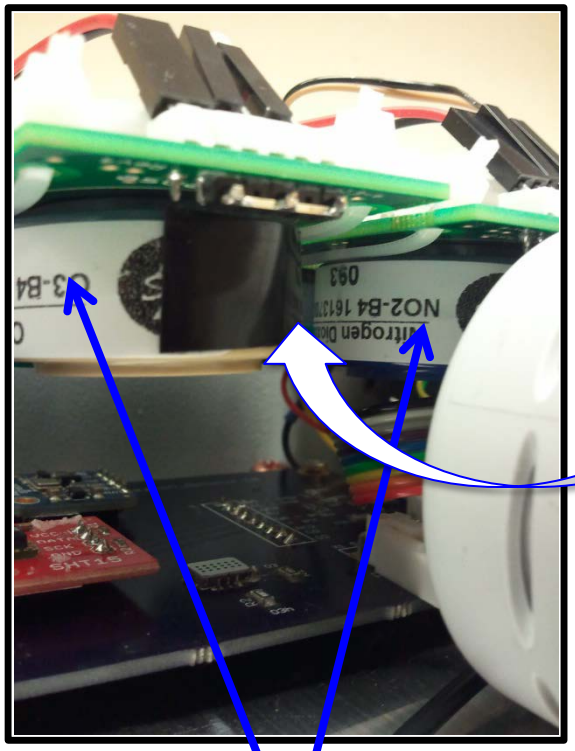


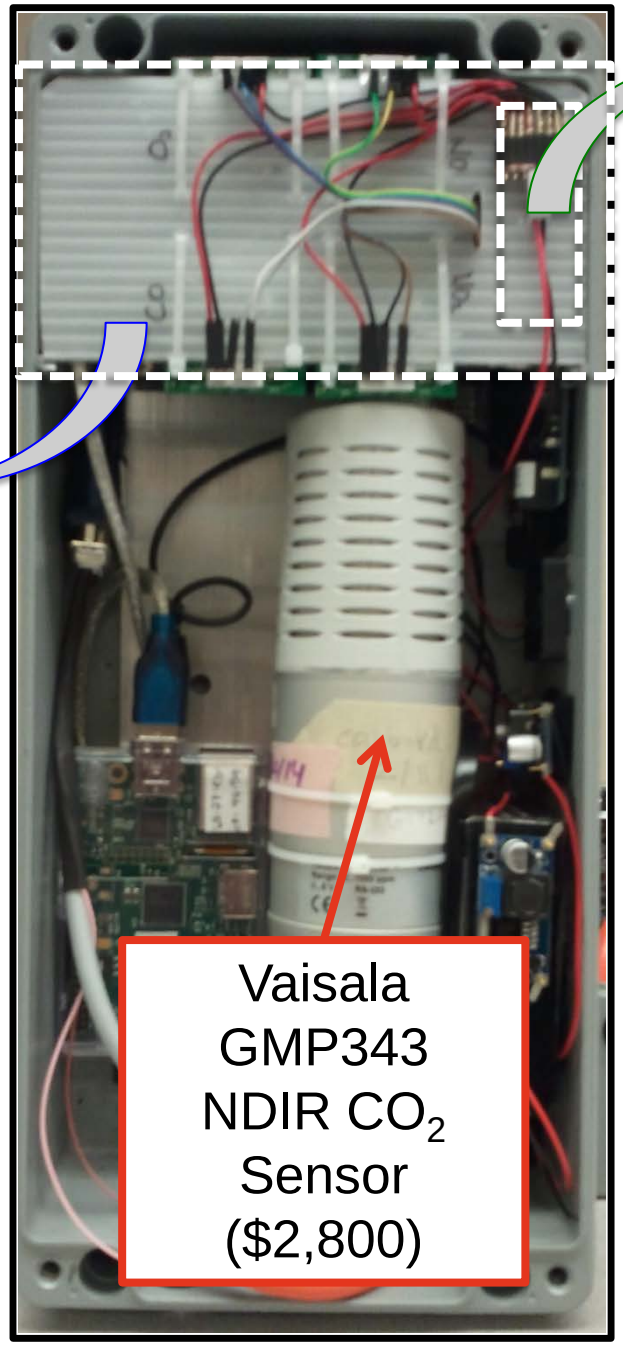
On a neighborhood scale inexpensive sensing might change how we think about emissions and air quality

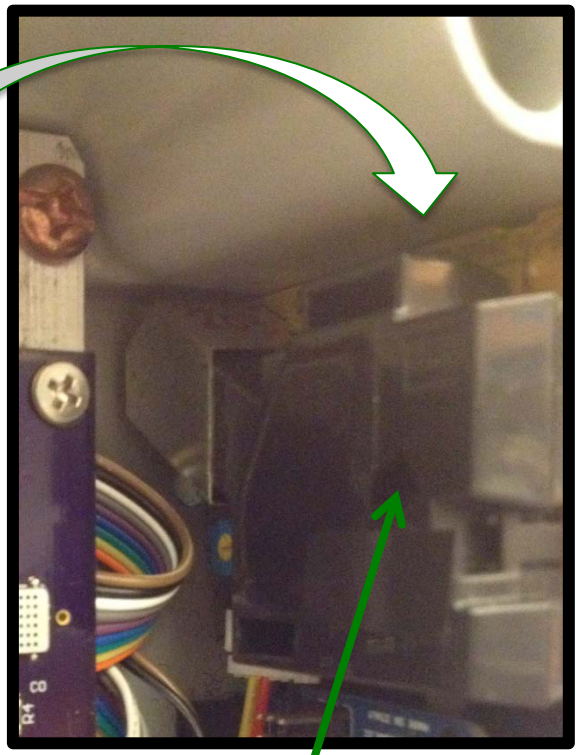
BEACO$_2$N: 2.5m – 130m AGL




San Francisco Bay Ferry





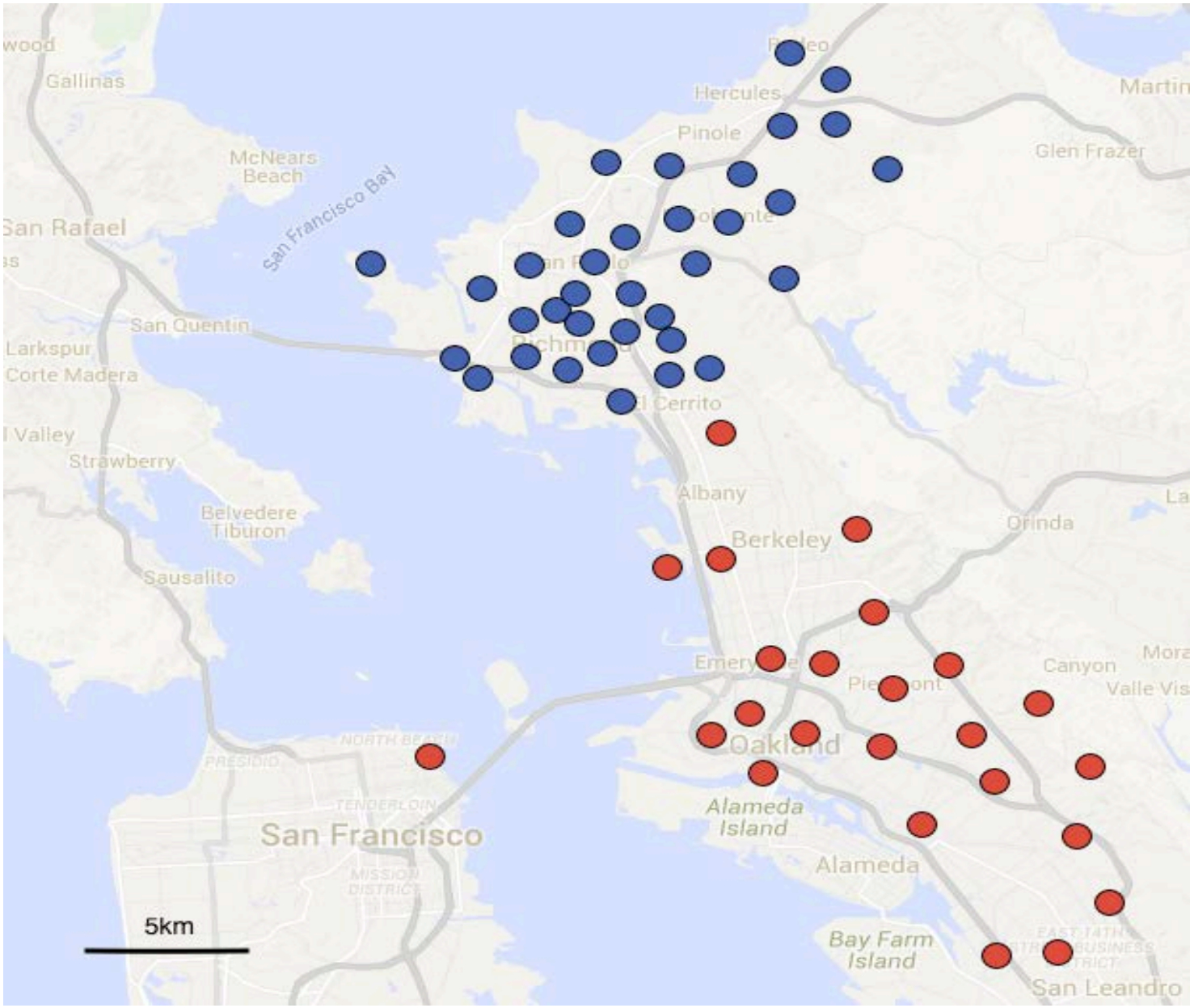


Alphasense B4 Electrochemical O_3, CO, NO & NO_2 Sensors ($216 ea.)

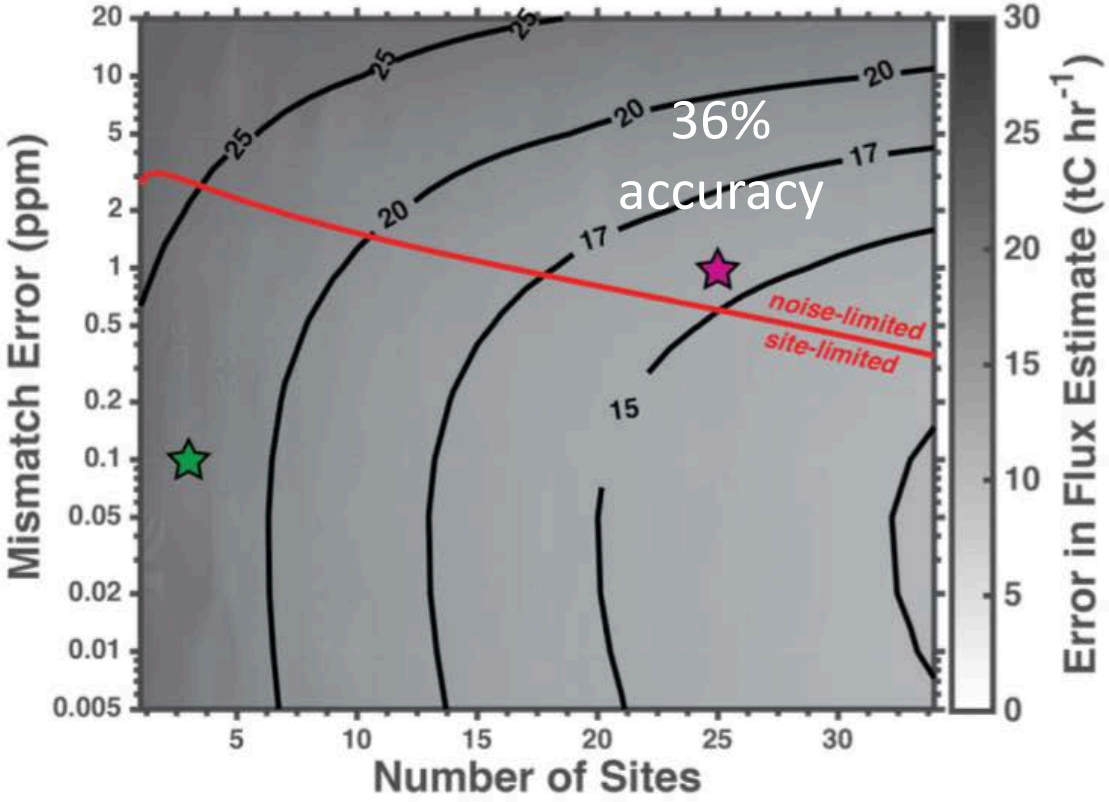
Vaisala GMP343 NDIR CO_2 Sensor ($2,800)

Shinyei PPD42NS nephelometric particulate matter sensor ($16)

BEACO$_2$N


Gallinas
Hercules
Martin
Pinole
McNears Beach
Glen Frazer
San Francisco Bay
San Rafael
San Quentin
Larkspur
Corte Madera
Cerrito
Strawberry
Albany
Belvedere
Tiburon
Berkeley
Orinda
Sausalito
Canyon
Oakland
Alameda Island
San Francisco
Alameda
5km
Bay Farm Island
San Leandro

Quality vs. Quantity

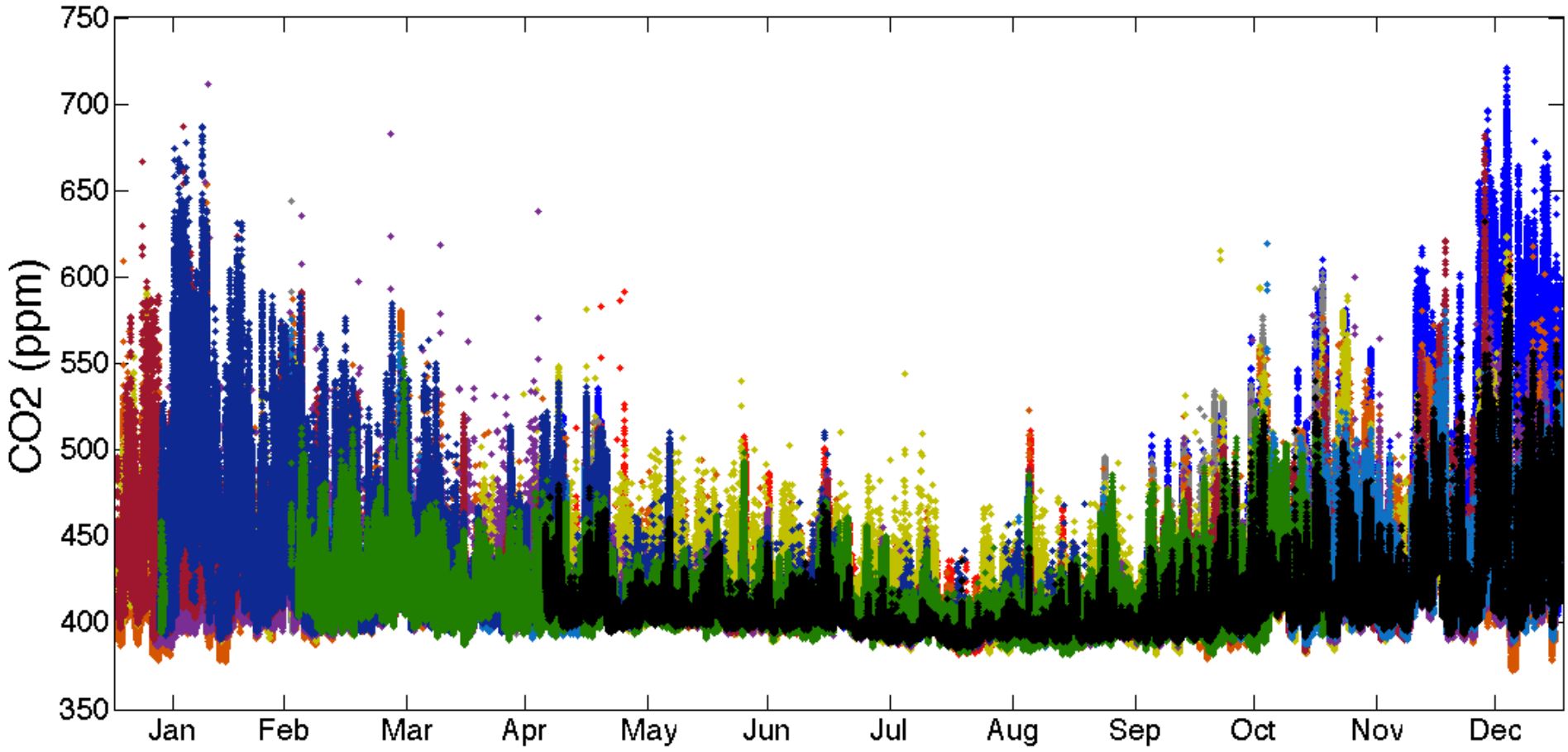


★ Network of roughly BEACO$_2$N's size (25) & precision (1ppm)

★ Network of three much more precise instruments (0.1ppm)

Turner et al. ACP 2016

BEACO$_2$N CO$_2$ 2013



Sites:

Burckhalter
Prescott
Laurel
Kaiser
CollegePrep
Korematsu
ODowd
StLiz
HeadRoyce
ElCerrito
NOakland

Question

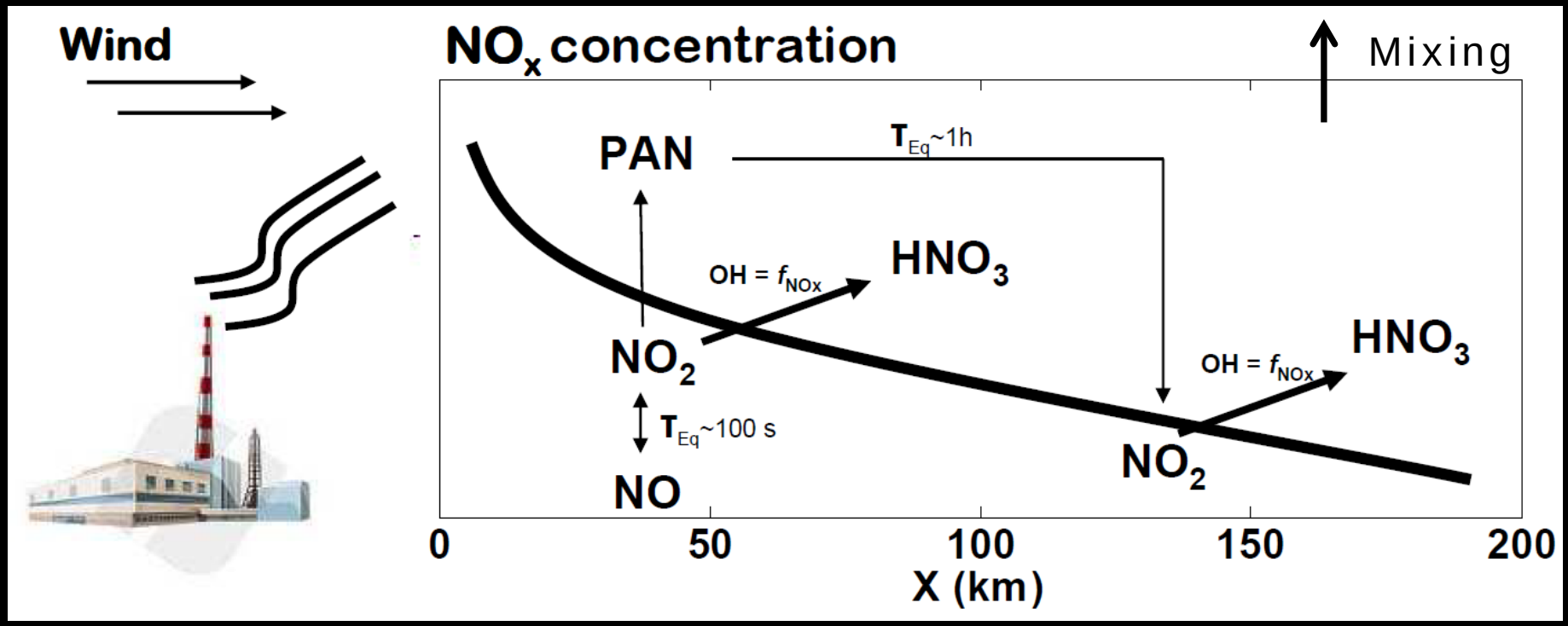
What can we do to understand the processes affecting air quality at the neighborhood scale?

Viewed (mostly) through a lens of NO_x

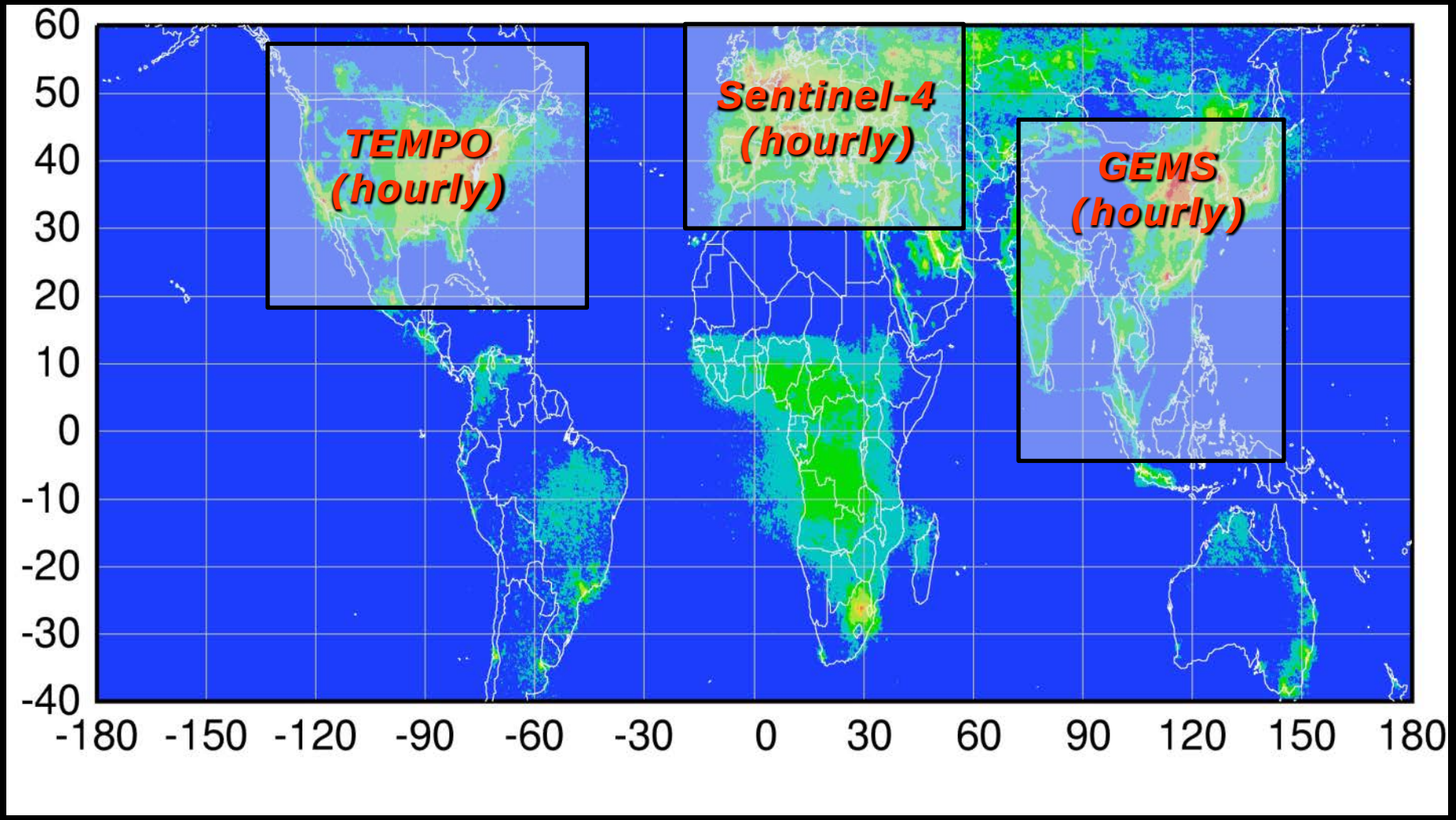
$d[NO_x]/dt \sim$

Emissions – Chemistry

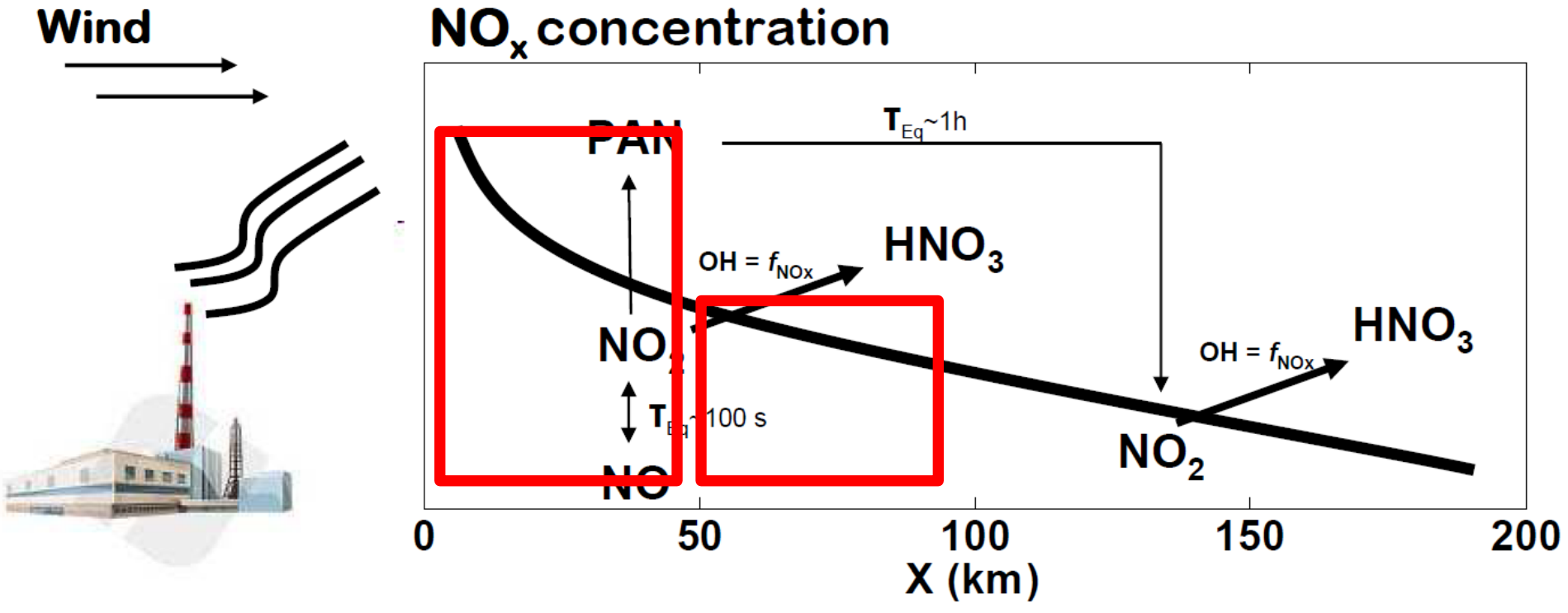
$NO_x \equiv NO + NO_2 \quad \tau \sim 100$ s


Wind
NO_x concentration
Mixing
PAN
T_{Eq}~1h
HNO_3
OH = f_{NOx}
NO_2
HNO_3
OH = f_{NOx}
T_{Eq}~100 s
NO
NO_2
0
50
100
150
200
X (km)

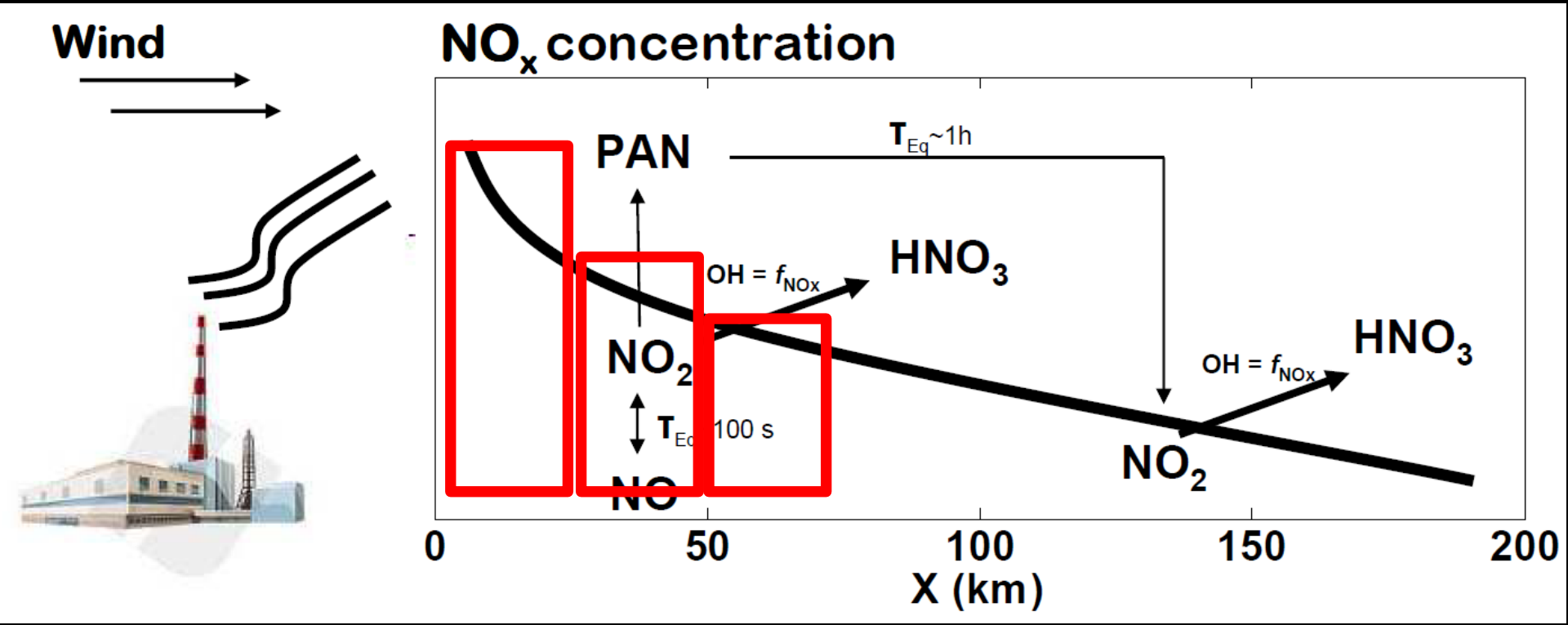
High space and time resolution measurements of NO_2, H_2CO and O_3 will soon (3-4 years?) be routinely available



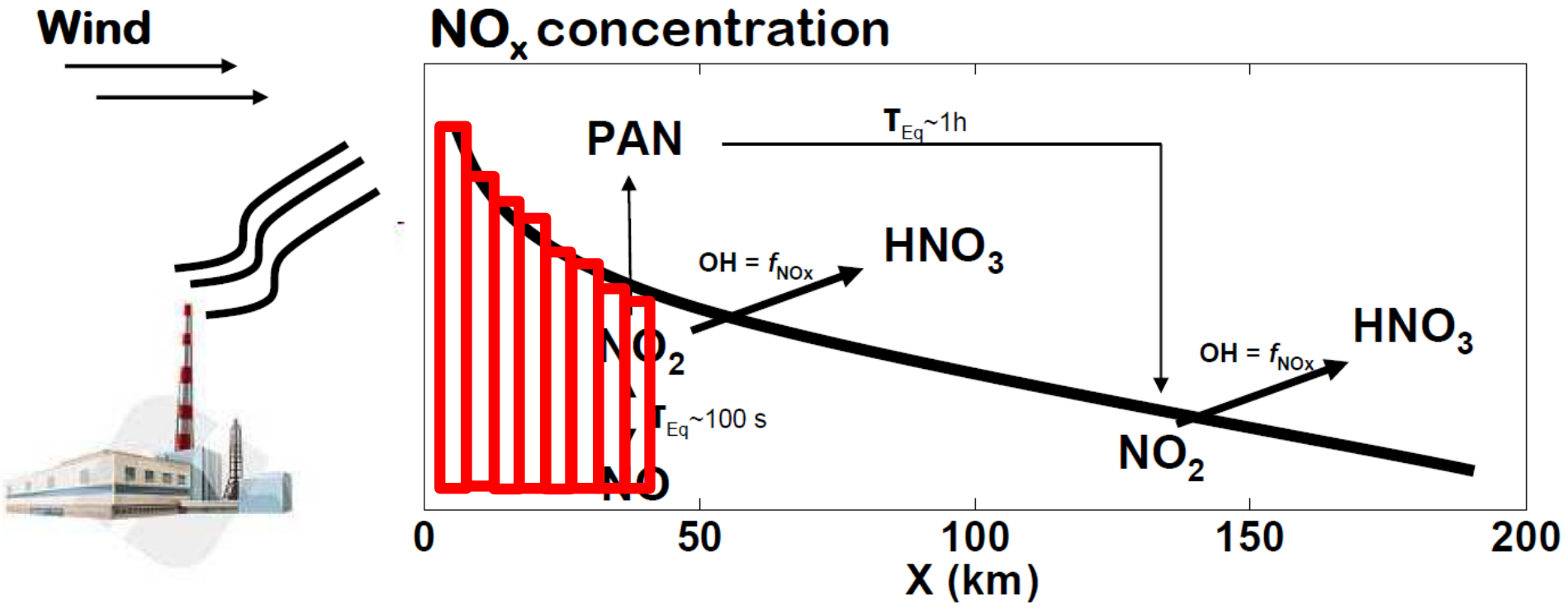
GOME-2


Wind
NO_x concentration
PAN
T_{Eq}~1h
HNO_3
OH = f_{NOx}
NO_2
T_{Eq}~100 s
NO
HNO_3
OH = f_{NOx}
NO_2
0
50
100
150
200
X (km)

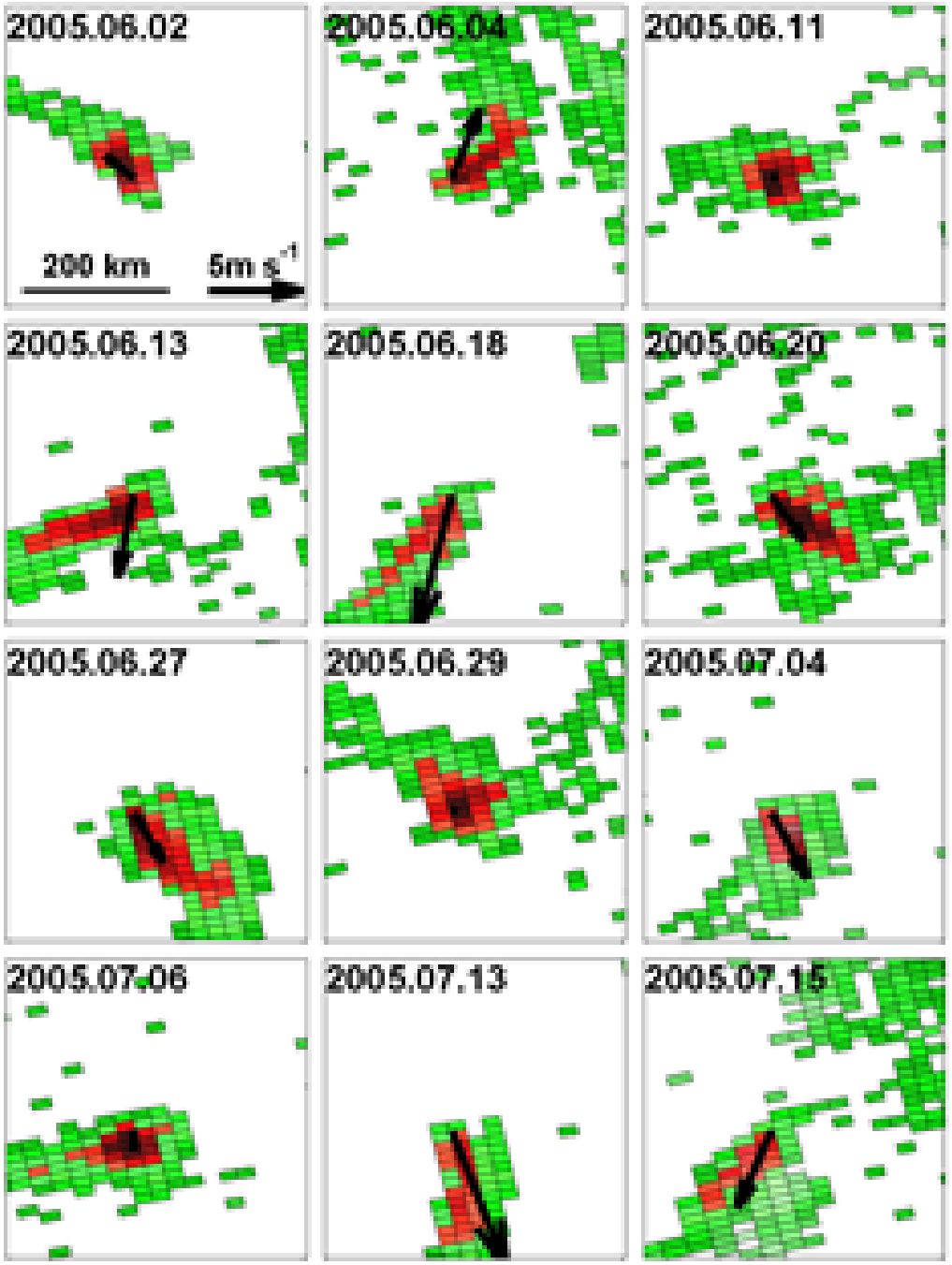
OMI


Wind
NOx concentration
PAN
TEq~1h
OH = fNOx
HNO3
NO2
TEq~100 s
NO
OH = fNOx
HNO3
NO2
0
50
100
150
200
X (km)

TEMPO –
Actual is twice resolution shown



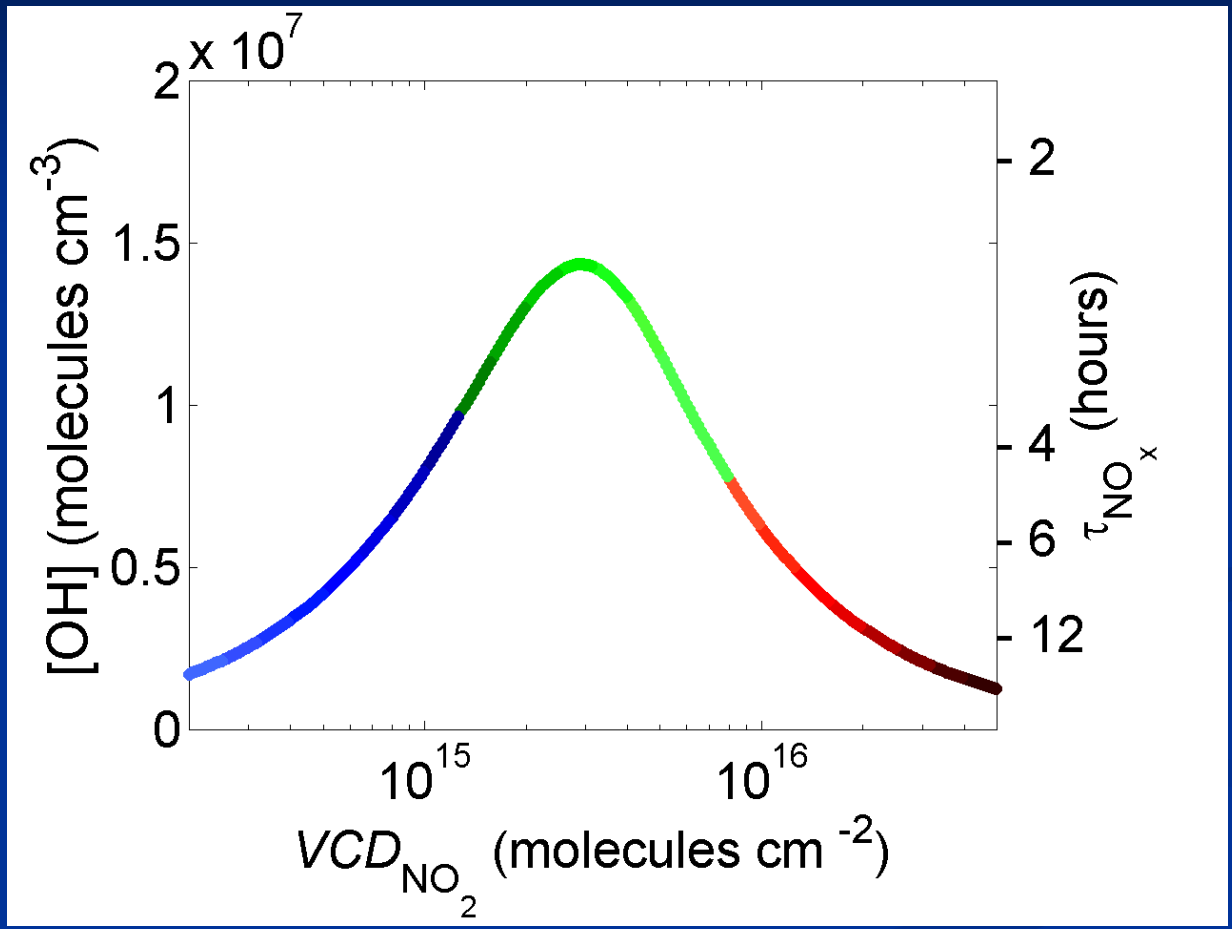
Riyadh



L Valin et al., *GRL* 2013

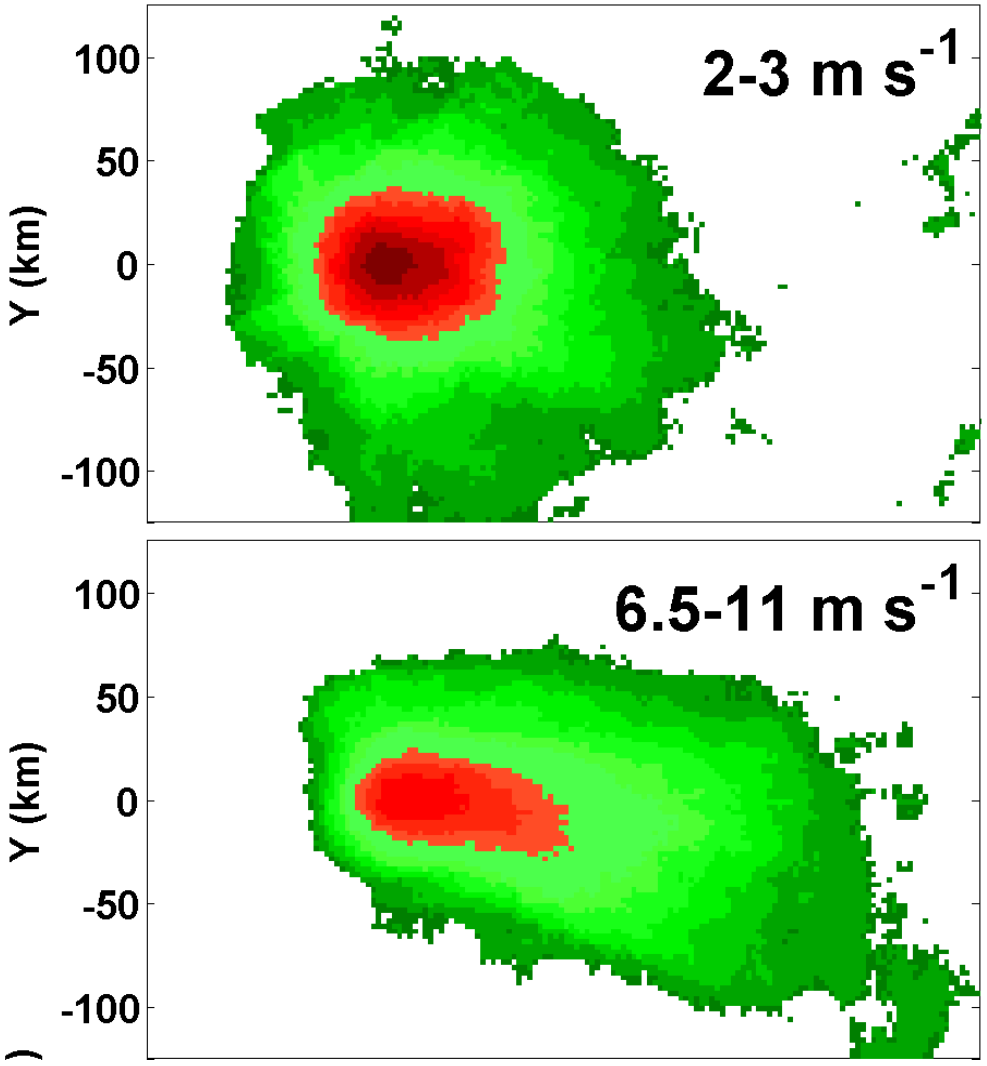
NO_x regulates its own removal rate through its effect on OH

OH (or PO_3) vs. $NO_{2(x)}$



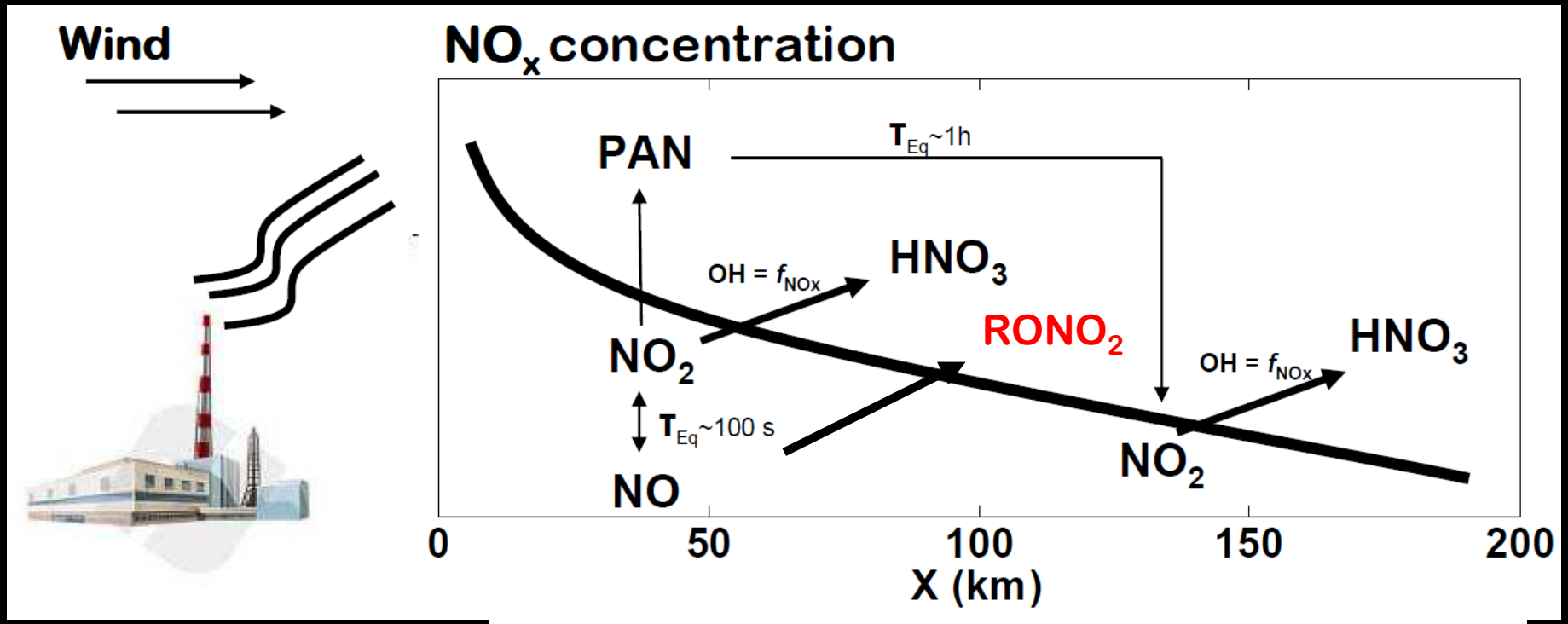
Rural — Suburban — Urban

Emissions don't depend on winds; the burden and lifetime does



L Valin et al., *GRL* 2013

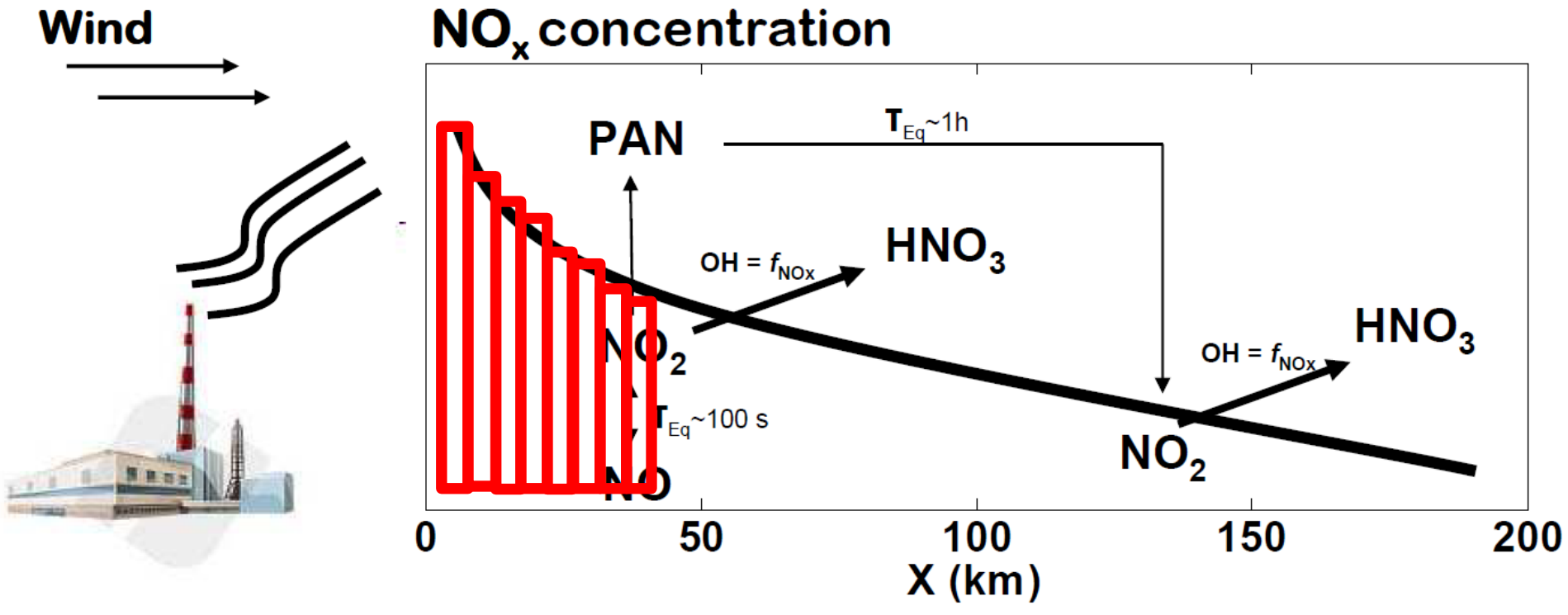
Daytime

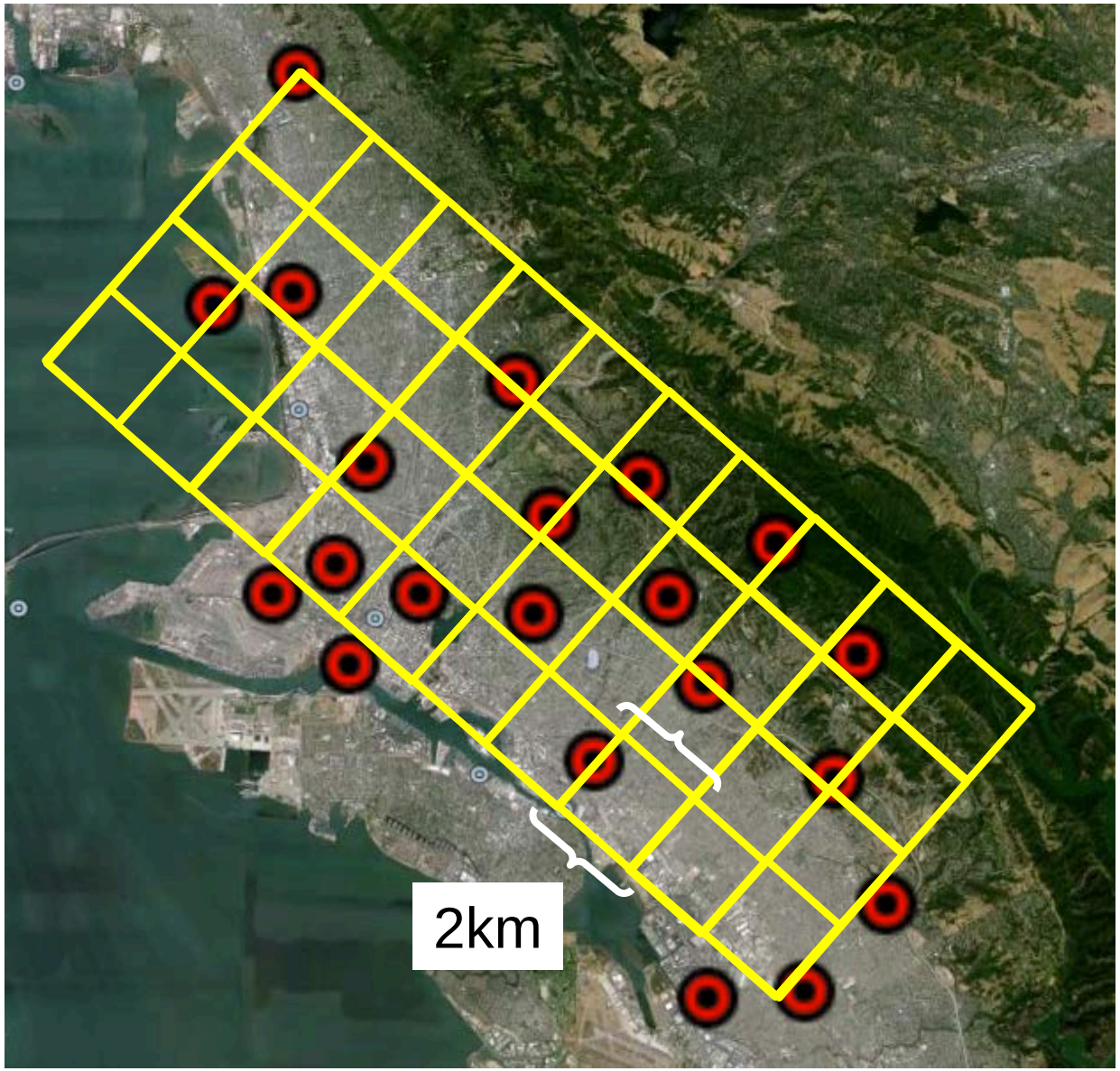


slow fast slow

$\langle xy \rangle \neq \langle x \rangle \langle y \rangle$

$x=NO_2$; $y=OH$





BErkeley

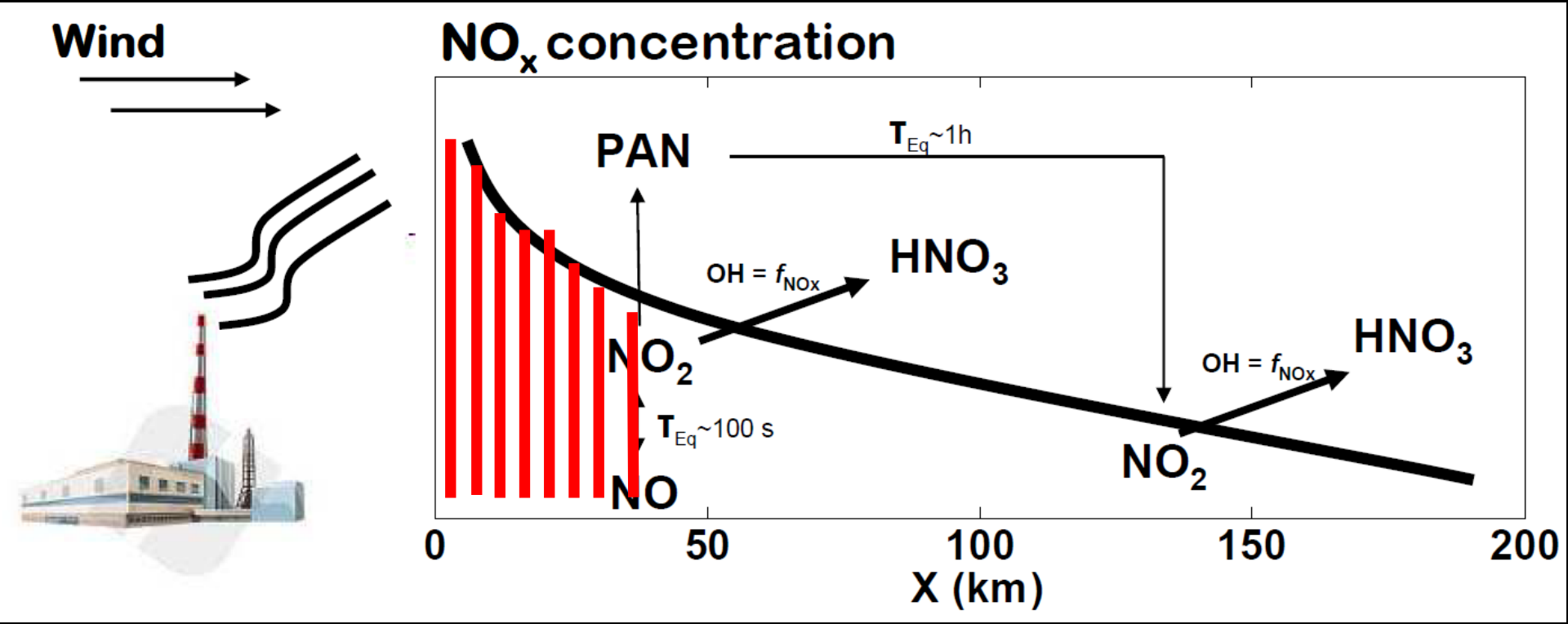
Atmospheric

CO_2

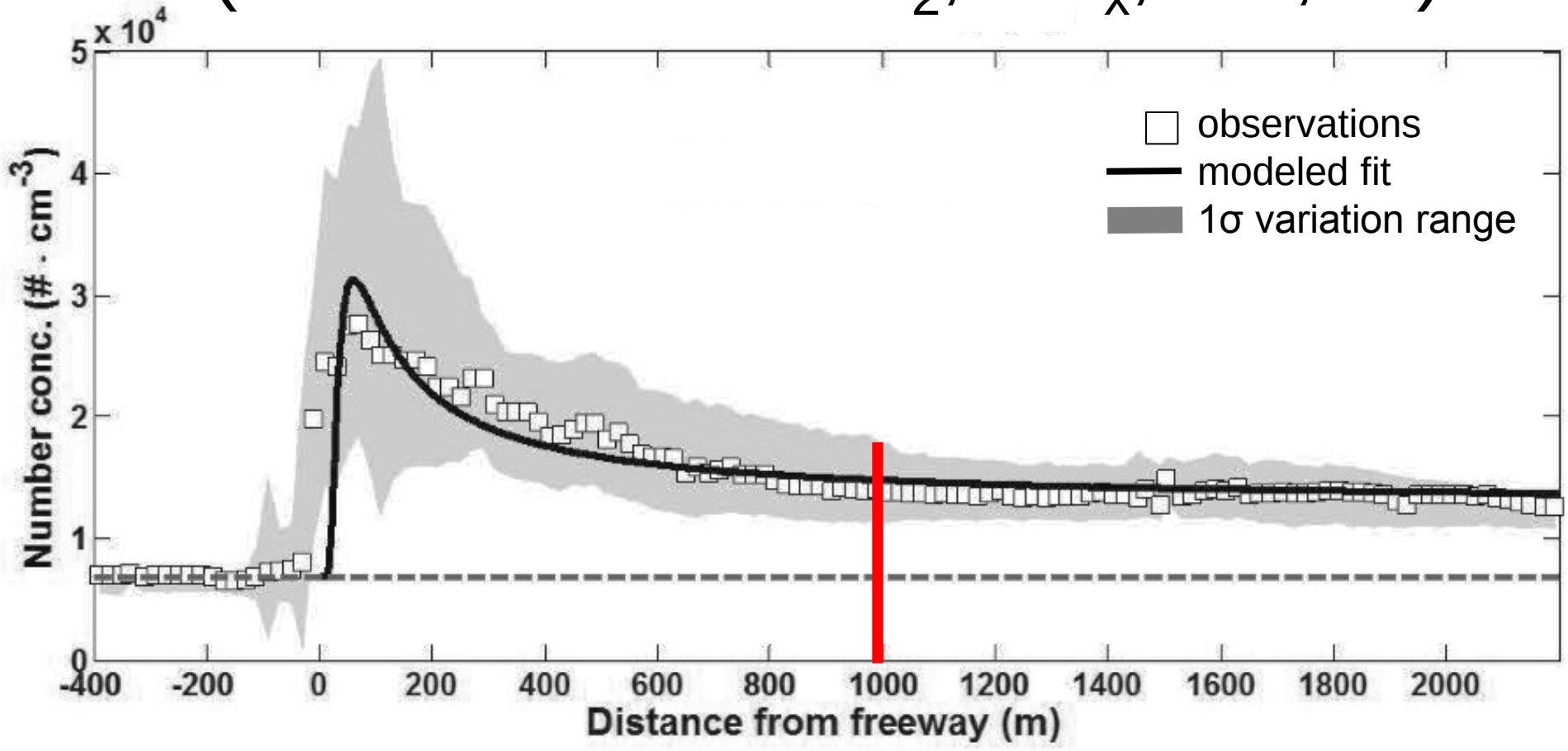
Observation

Network

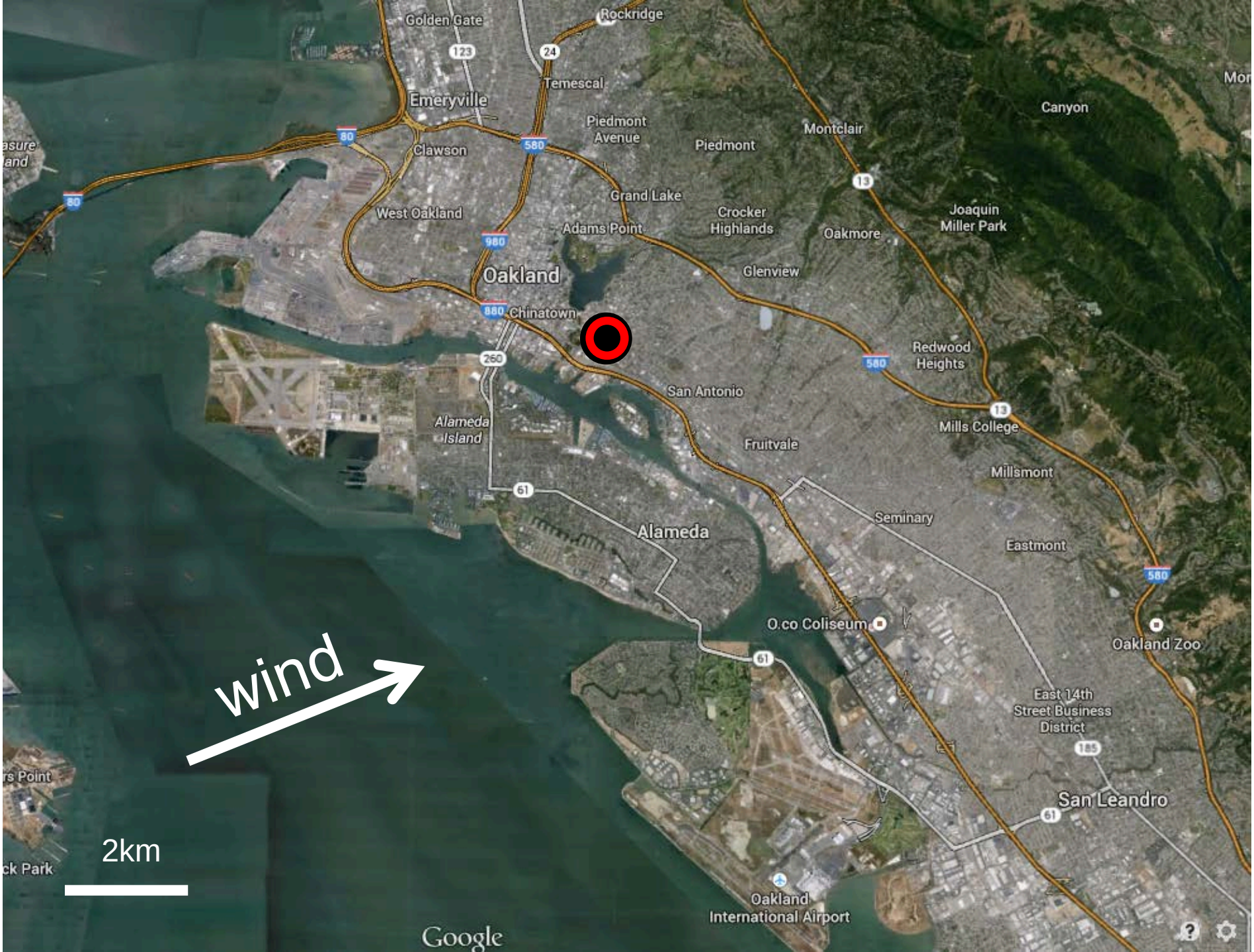
BEACO$_2$N—pointwise surface network at ~2km resolution

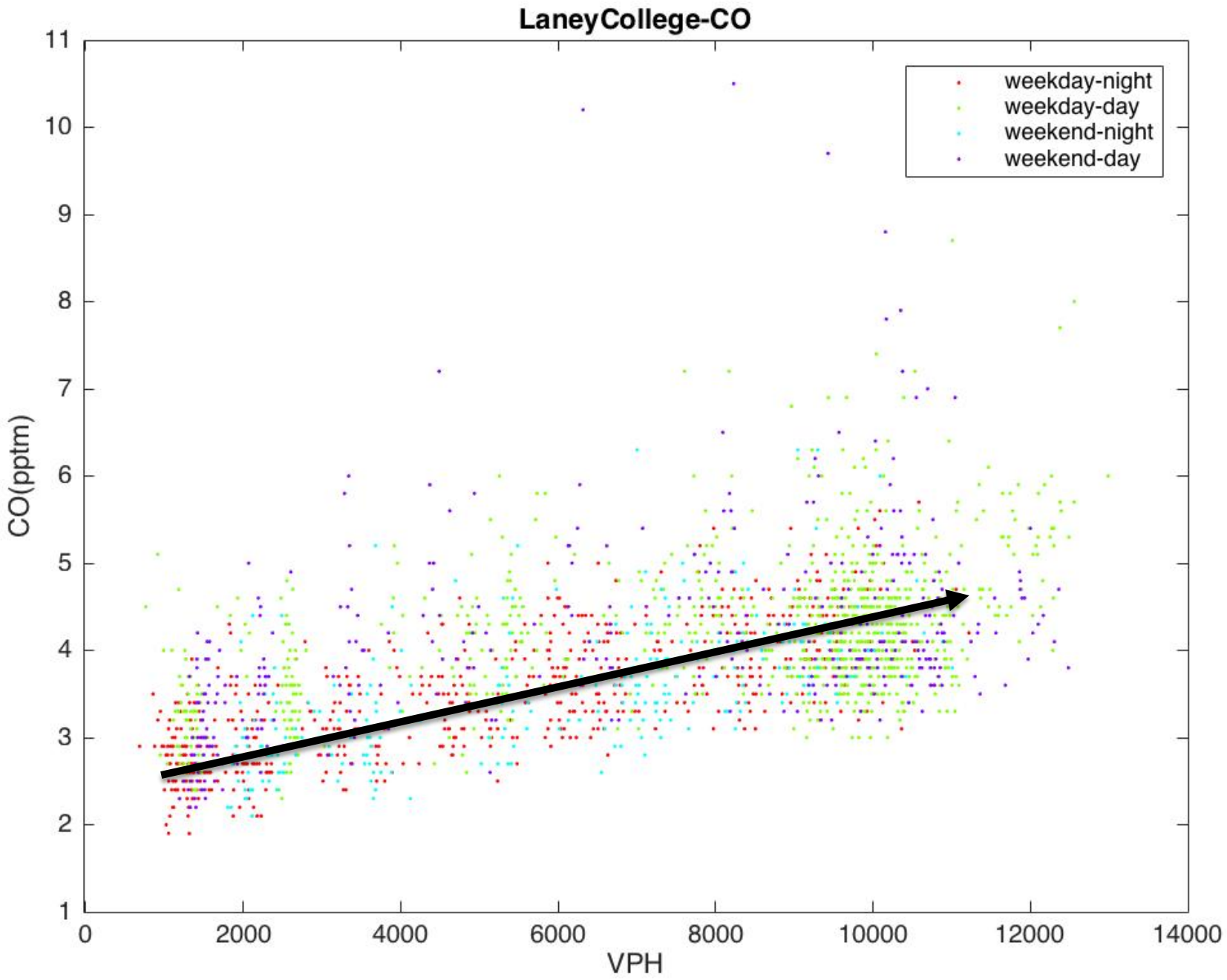


Particulate Matter
(co-emitted with CO_2, NO_x, CO, …)

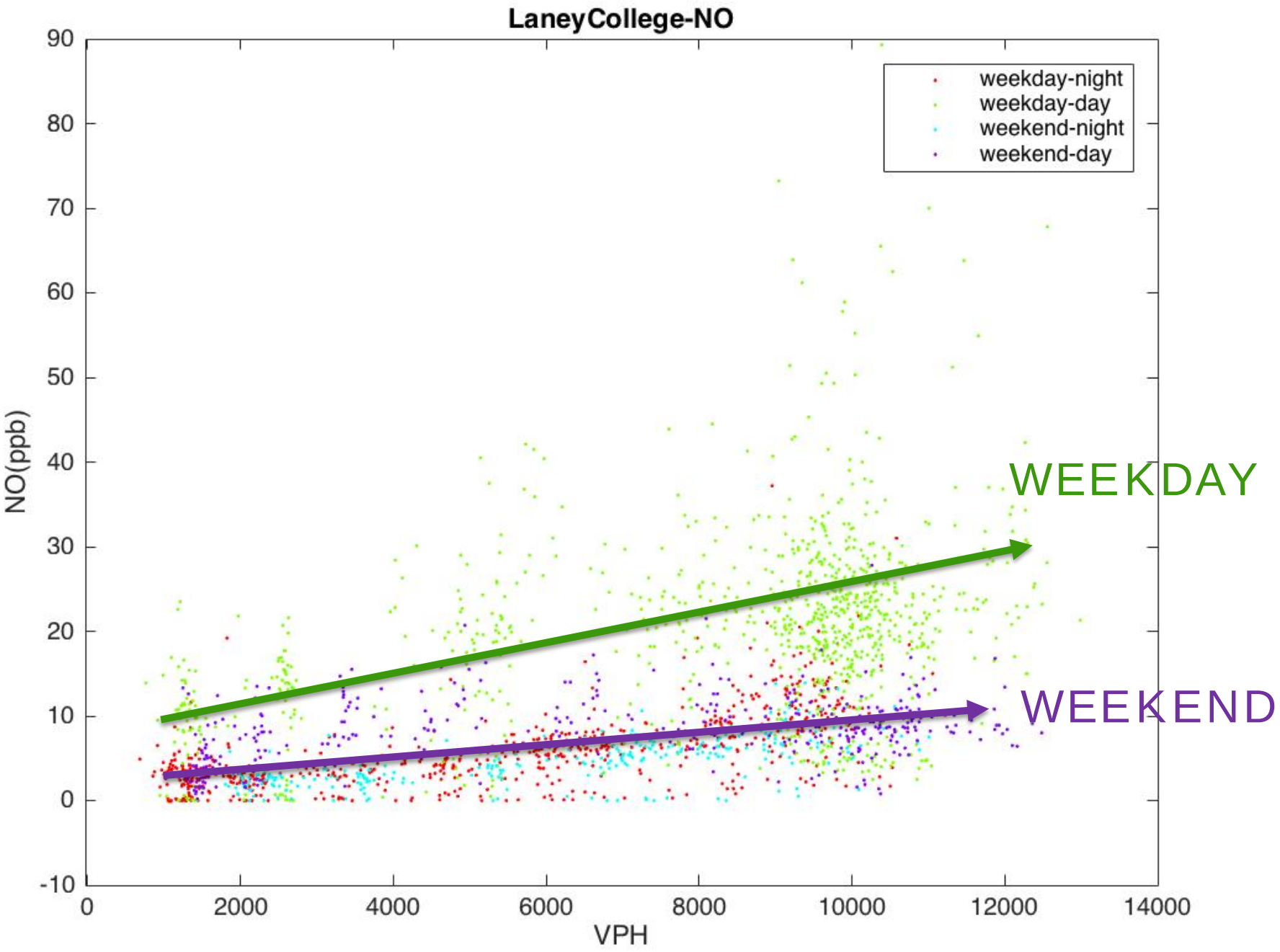


from Choi et al. 2014


Golden Gate
Rockridge
Temescal
Emeryville
Piedmont Avenue
Piedmont
Montclair
Canyon
Clawson
Grand Lake
West Oakland
Adams Point
Crocker Highlands
Oakmore
Joaquin Miller Park
Oakland
Glenview
Chinatown
Redwood Heights
San Antonio
Alameda Island
Fruitvale
Mills College
Millsmont
Seminary
Alameda
Eastmont
O.co Coliseum
Oakland Zoo
East 14th Street Business District
San Leandro
Oakland International Airport
wind
2km
Google

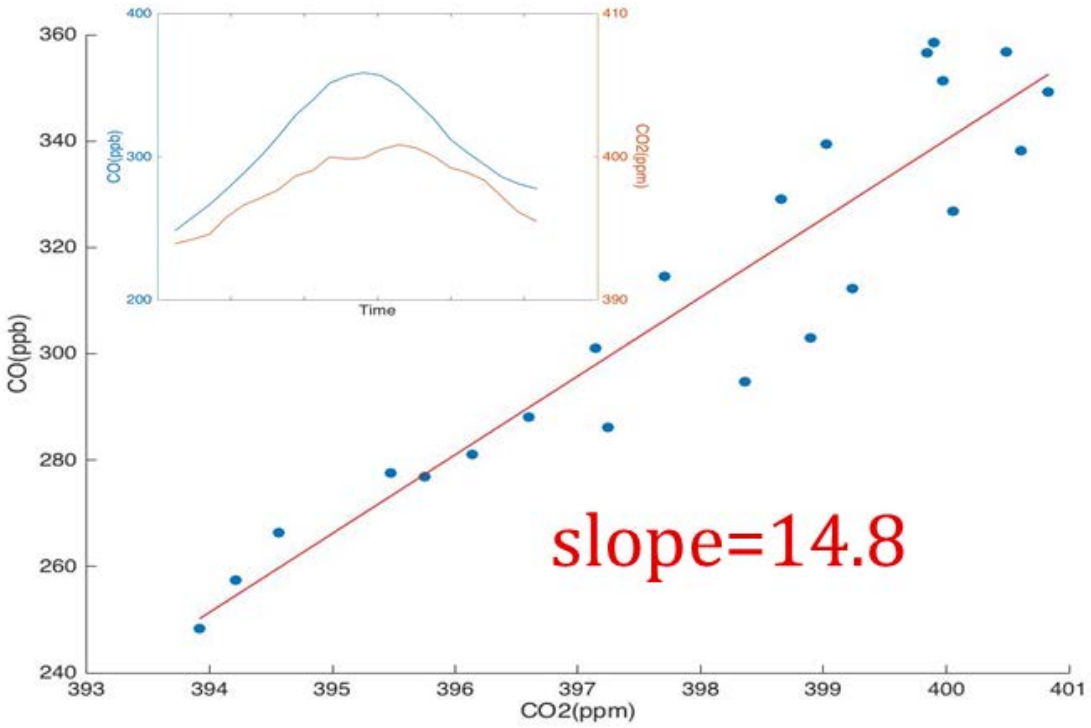


Vehicle # per hour

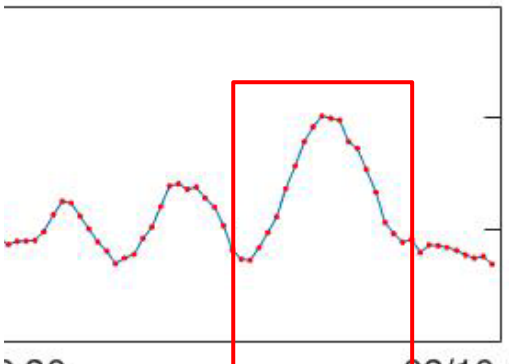


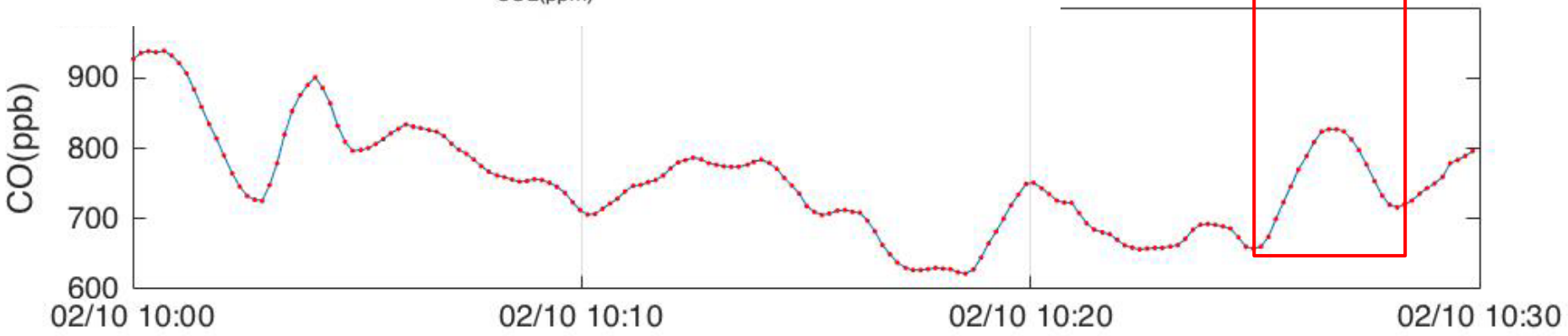
Vehicle # per hour

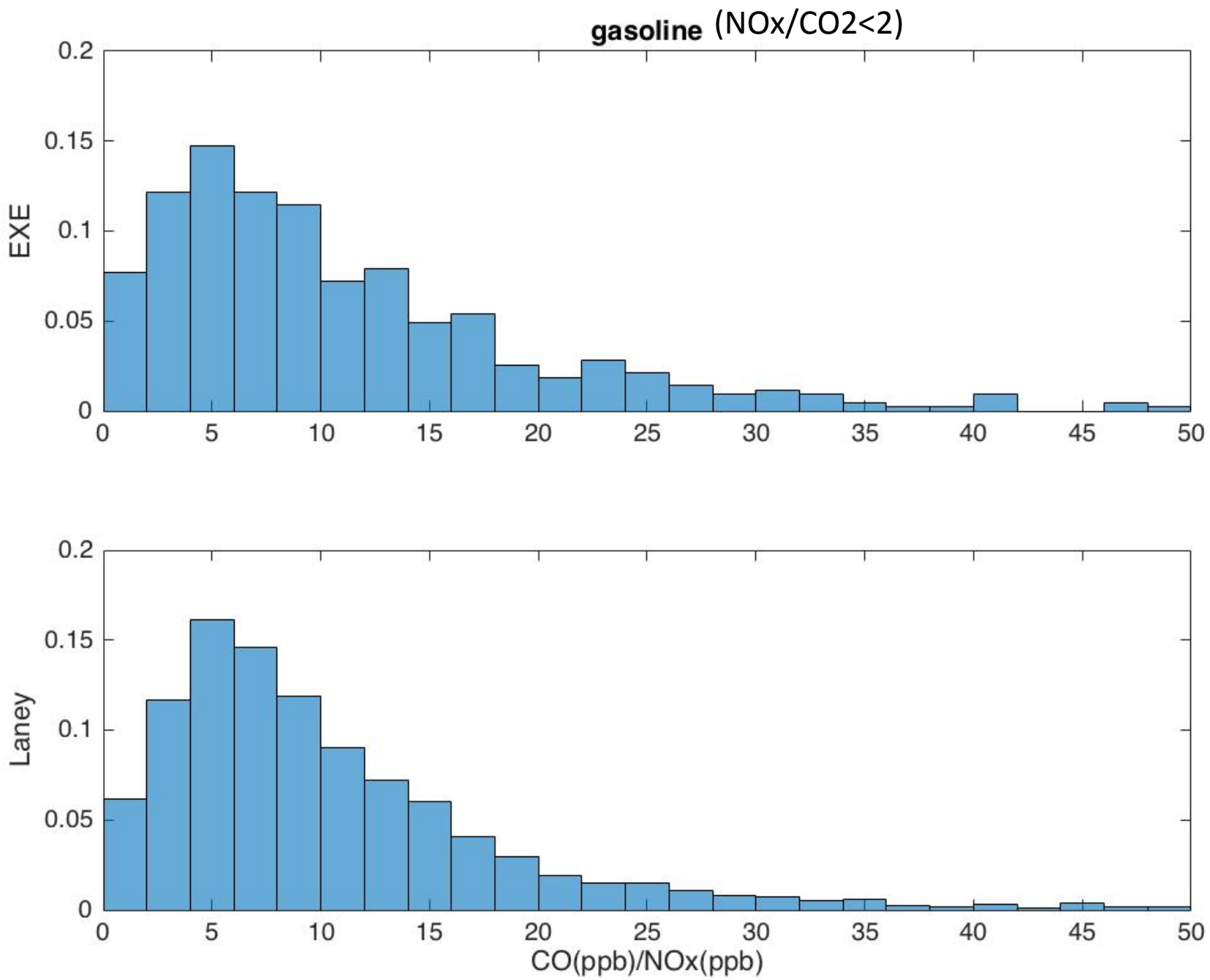
Analyze every plume

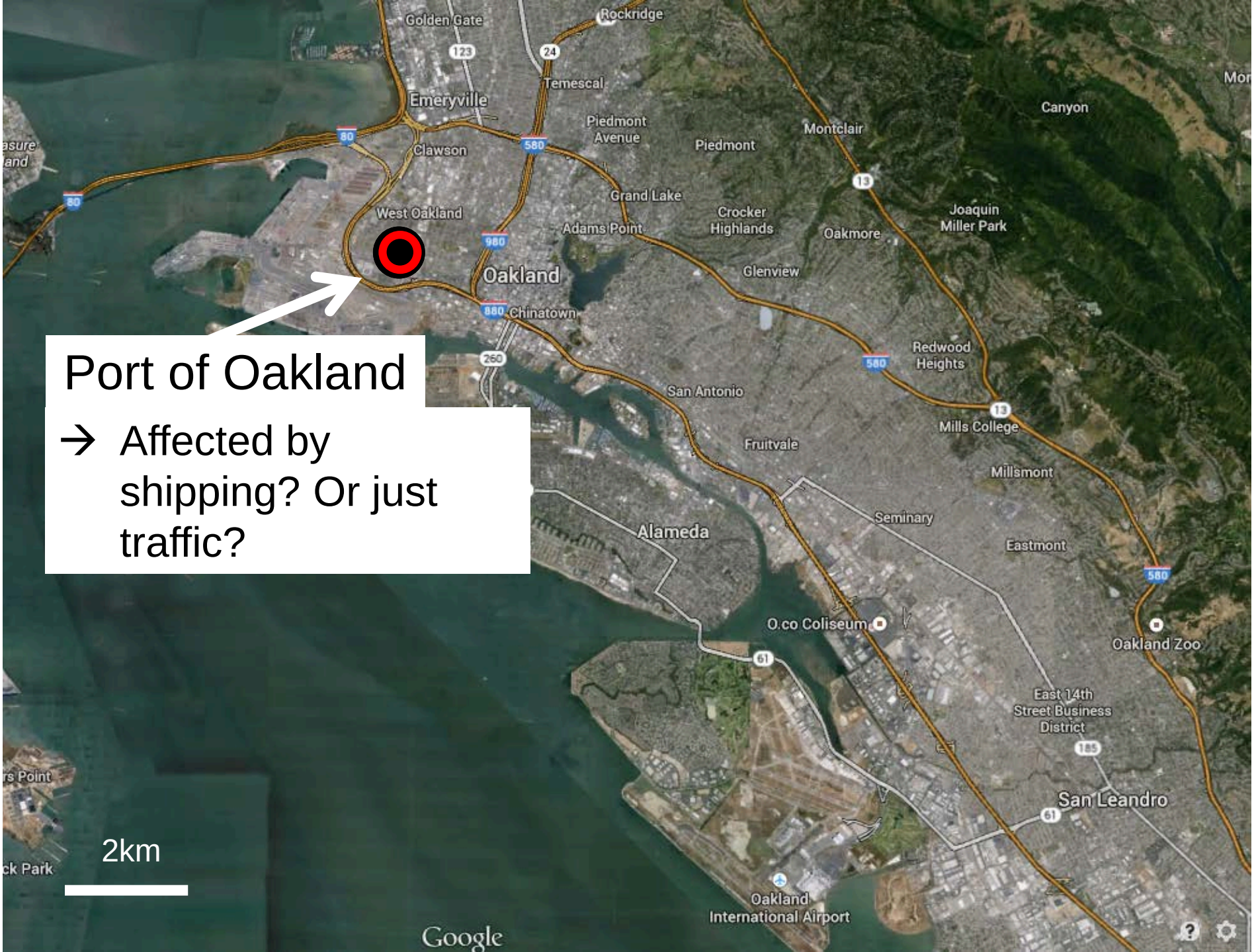


near highway

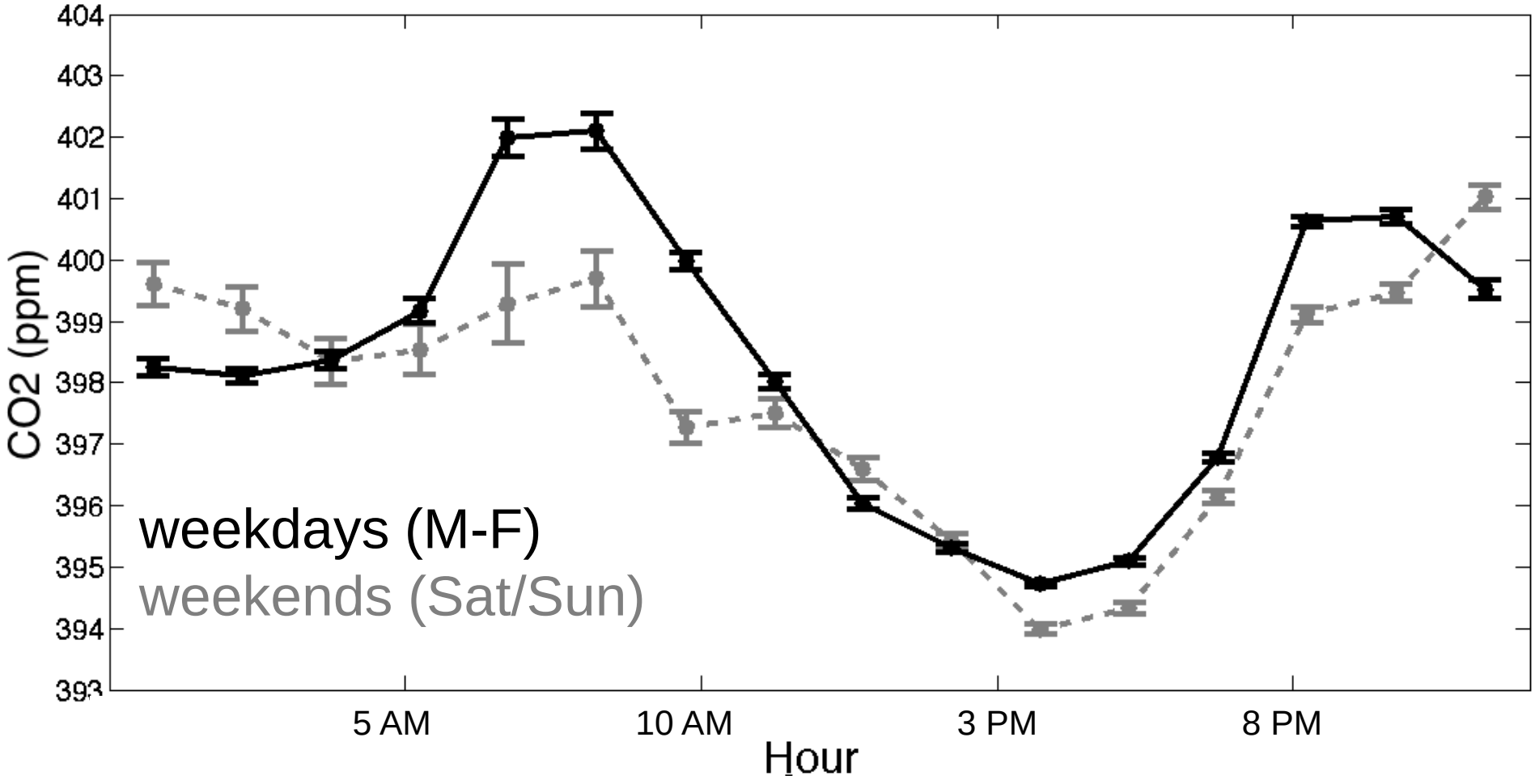




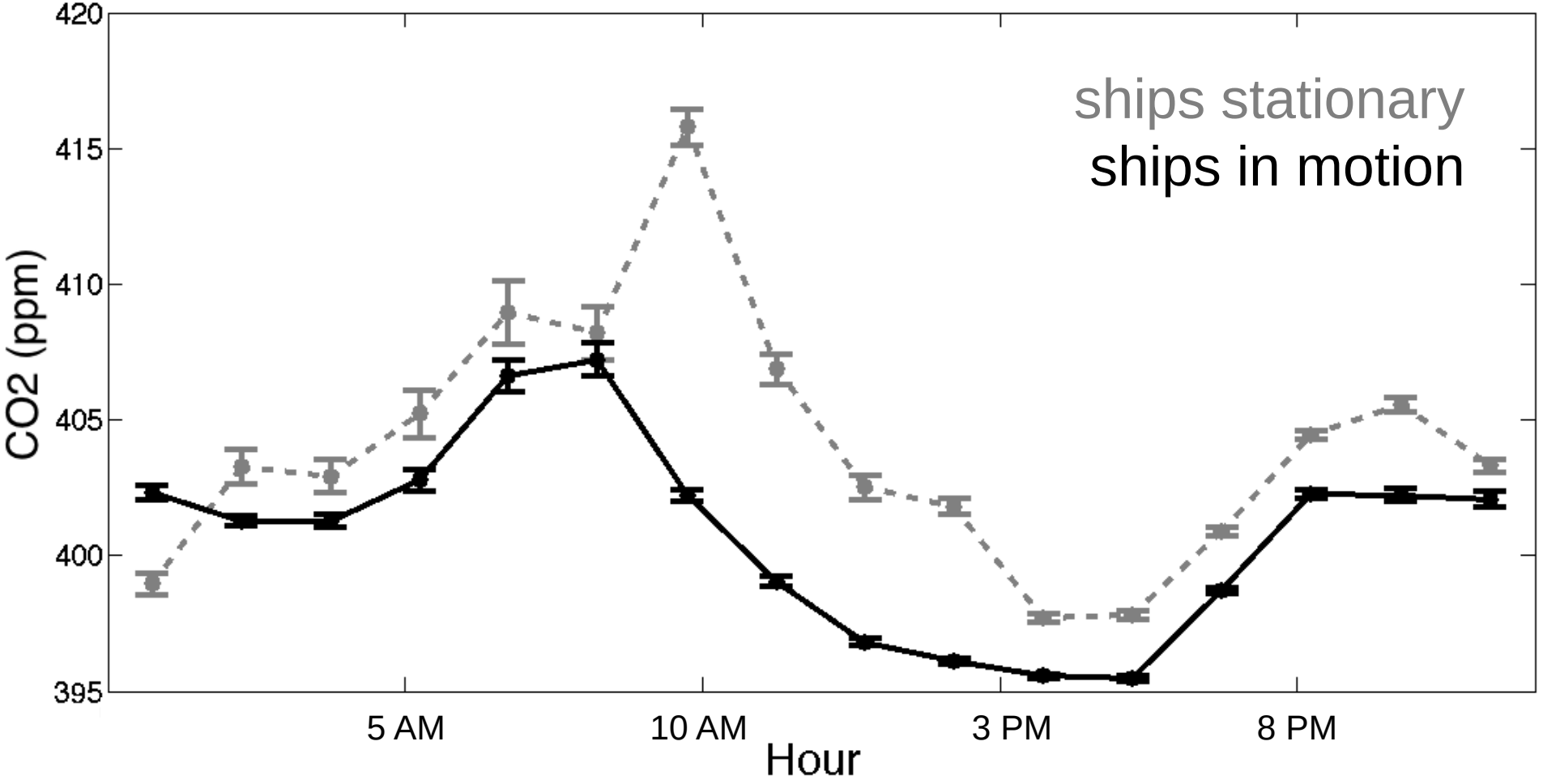

gasoline (NOx/CO2<2)
EXE
Laney
CO(ppb)/NOx(ppb)
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
30
35
40
45
50


Port of Oakland
→ Affected by shipping? Or just traffic?
Golden Gate
Rockridge
Temescal
Emeryville
Piedmont Avenue
Piedmont
Montclair
Canyon
Clawson
Grand Lake
West Oakland
Adams Point
Crocker Highlands
Oakmore
Joaquin Miller Park
Oakland
Glenview
Chinatown
Redwood Heights
San Antonio
Mills College
Fruitvale
Millsmont
Seminary
Alameda
Eastmont
O.co Coliseum
Oakland Zoo
East 14th Street Business District
San Leandro
Oakland International Airport
2km
Google

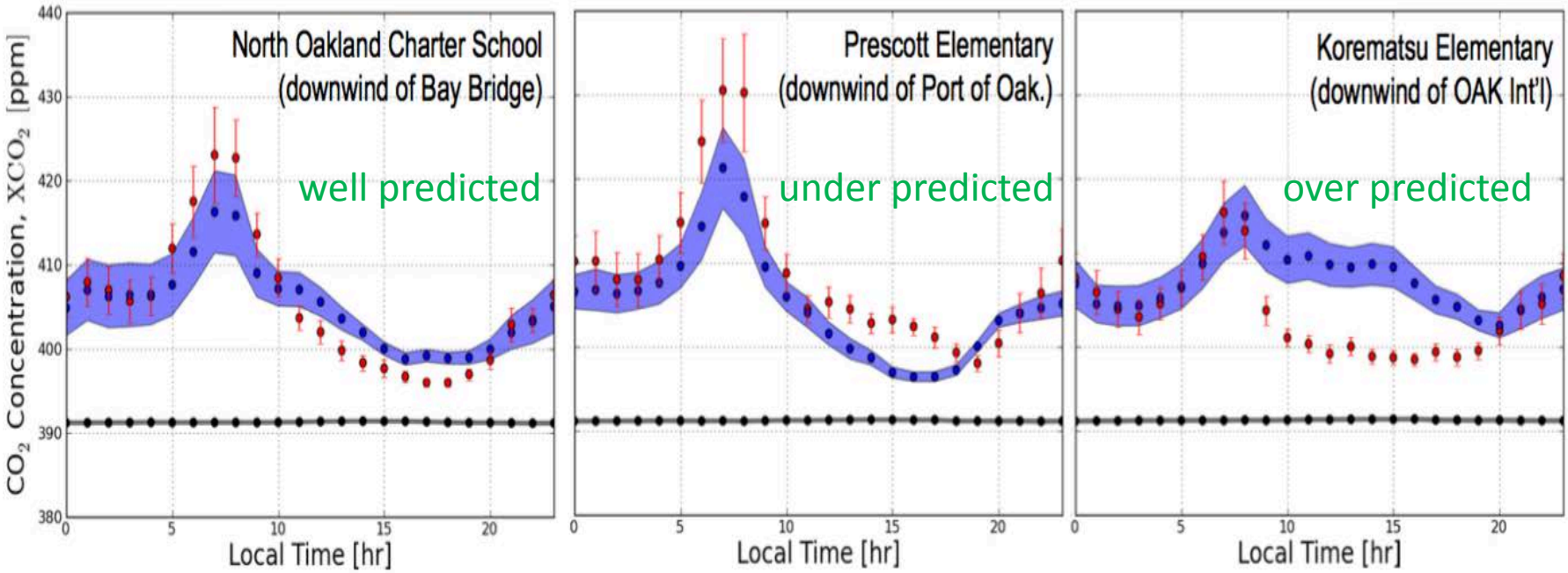
Port Aug/Sept Diurnal Cycle



Port Diurnal Cycle by Ship Movement

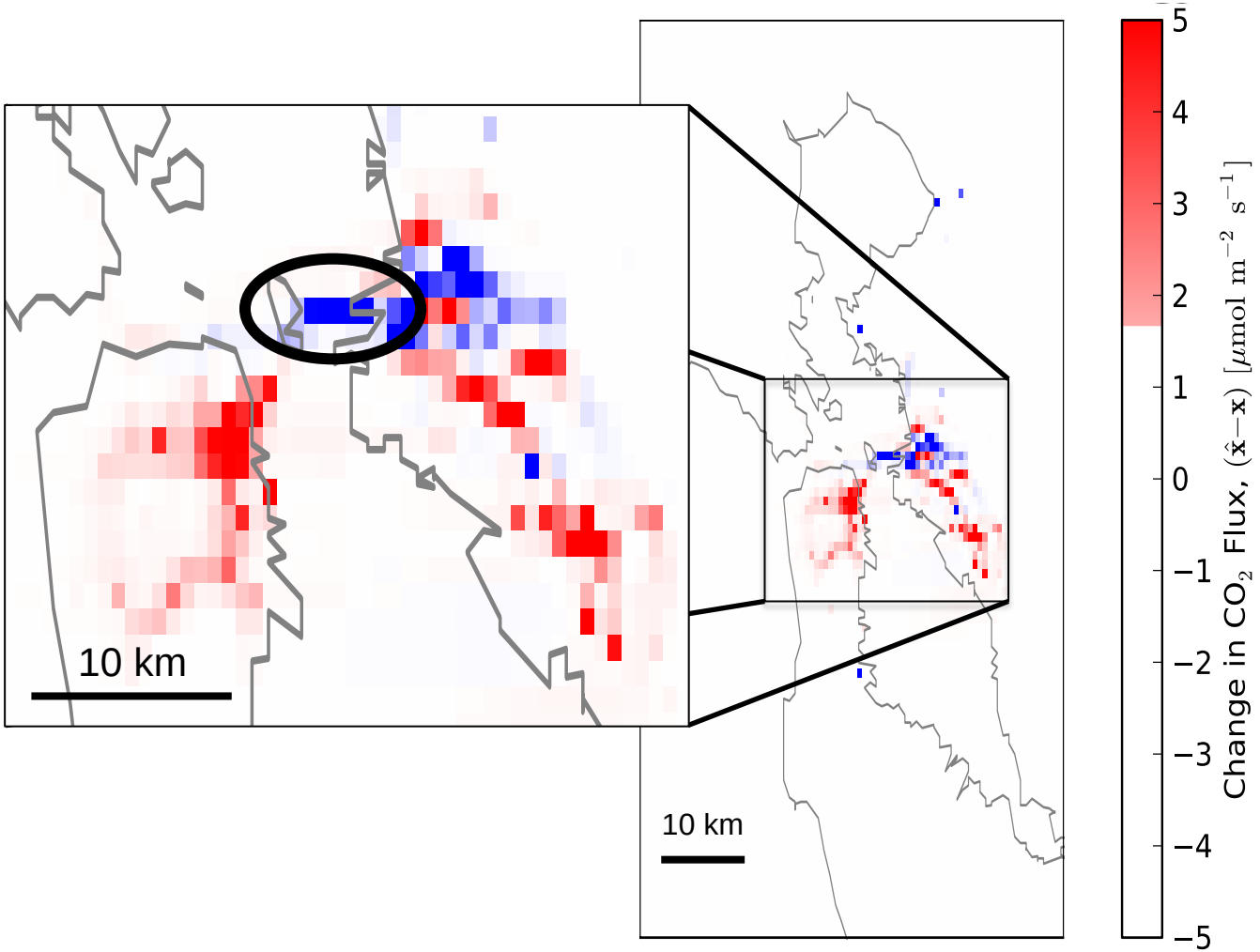


Comparing observations 1 node at a time to a model of emissions and transport with 1 km spatial resolution and sub-hourly time resolution



- BEACO$_2$N observations (September averages)
- WRF forecasts (given 1km bottom-up emissions inventory)

Inverse model using all $BEACO_2N$ nodes as a single instrument



Alex Turner

BEACO$_2$N: A high spatial resolution observing system for GHGs (CO_2) and air quality (CO, O_3, NO, NO_2, particles)

CO_2

A.A. Shusterman, V. Teige, A.J. Turner, C. Newman, J. Kim, and R.C. Cohen: T*he BErkeley Atmospheric CO_2 Observation Network: initial evaluation*, Atmos. Chem. Phys., doi:10.5194/acp-2016-530, 2016.

A.J. Turner, A.A. Shusterman, B.C. McDonald, V. Teige, R.A. Harley and R.C. Cohen, *Network design for quantifying urban CO_2 emissions: Assessing tradeoffs between precision and network density* Atmos. Chem. Phys. Disc., 2016.

AQ gases

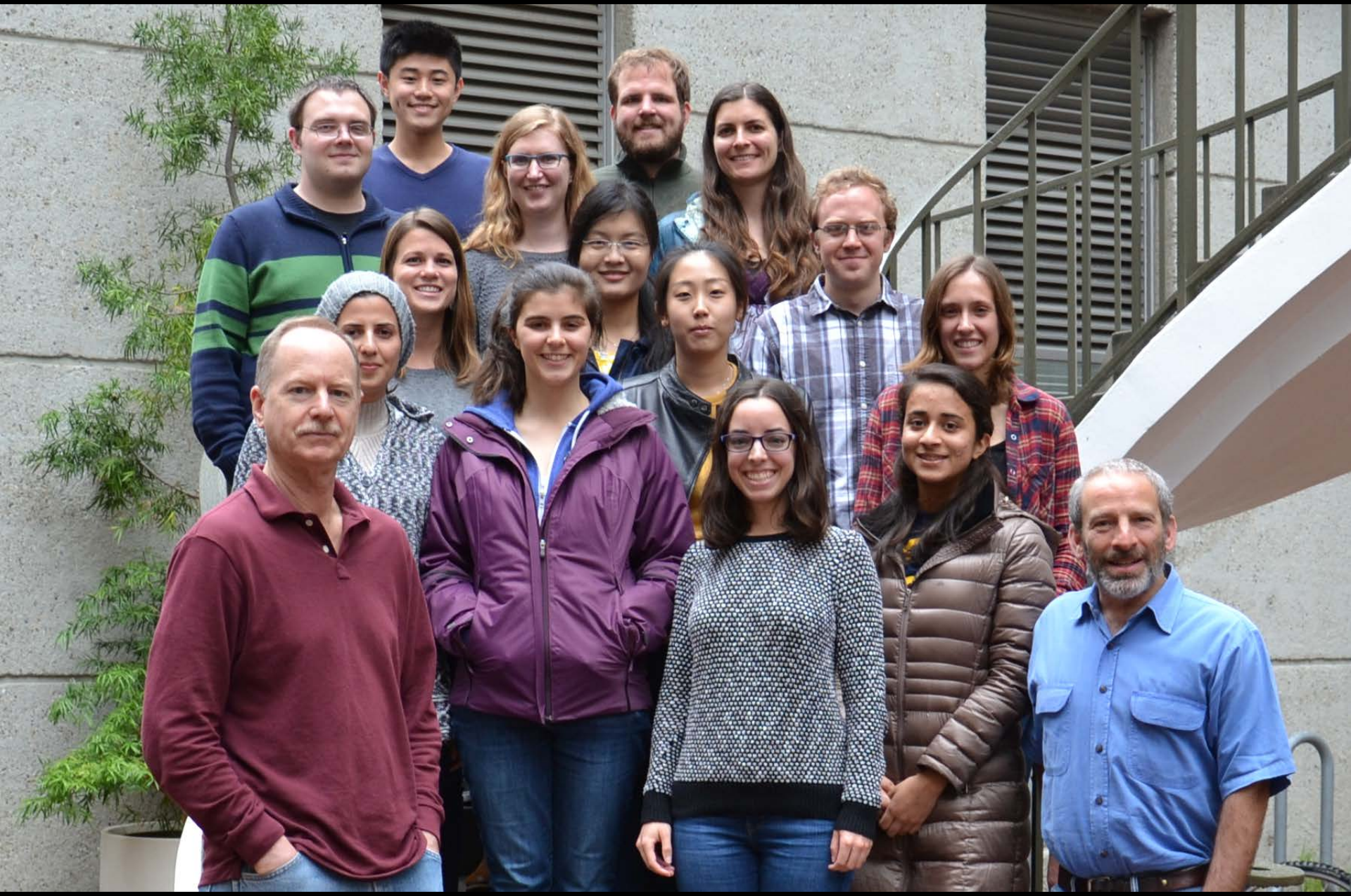
J. Kim, and above team, Network of AQ sensors, in prep

Conclusions

High space and time resolution observations from in situ and space based platforms will offer a new window into mechanisms affecting emissions and chemistry in cities.

Challenges will be:

1) learning to Interpret dense networks as more than the sum of individual instruments.
2) Learning to think about daily variability in ways th at teach us about processes.



Thank you!