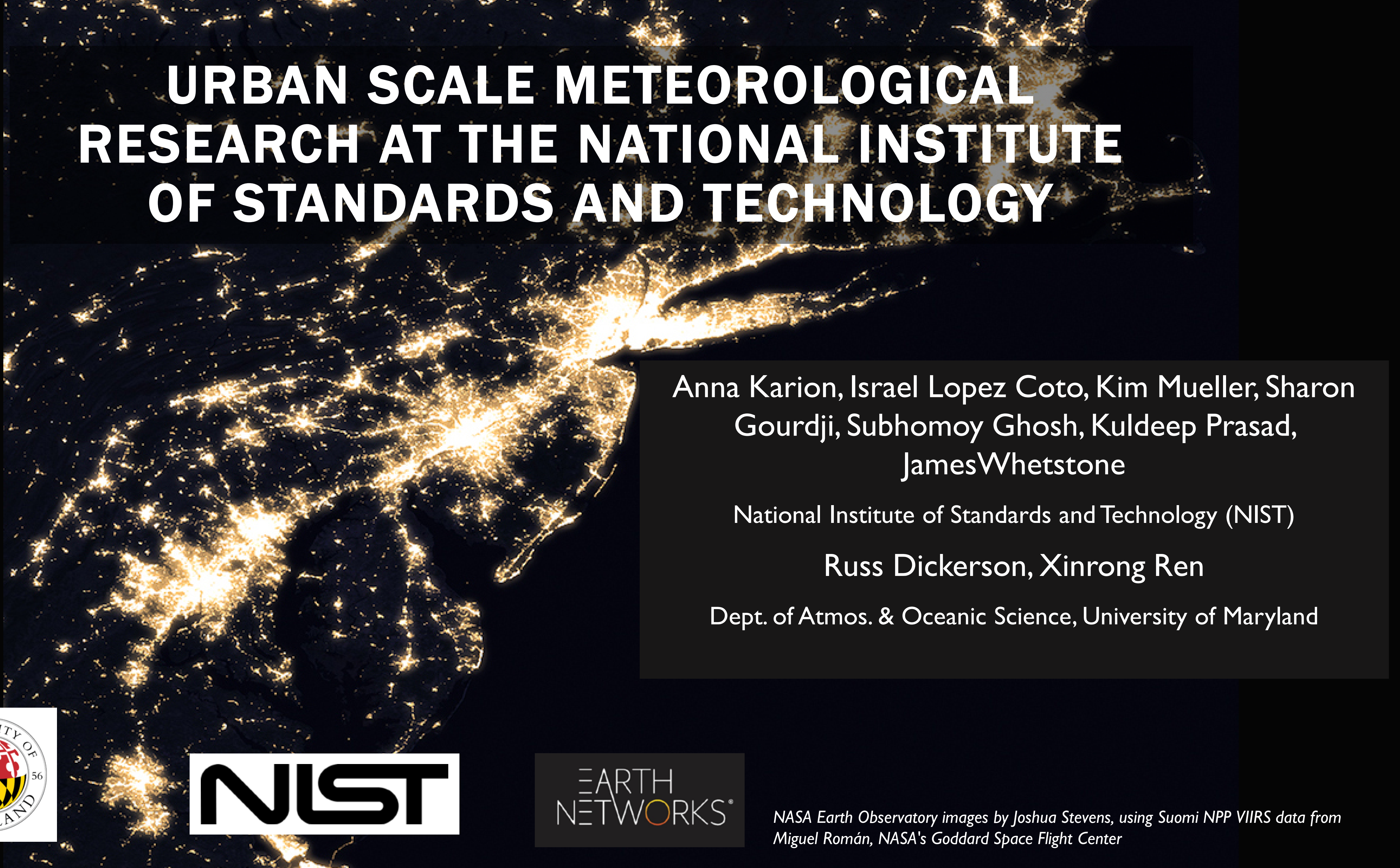

URBAN SCALE METEOROLOGICAL RESEARCH AT THE NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

Anna Karion, Israel Lopez Coto, Kim Mueller, Sharon Gourdji, Subhomoy Ghosh, Kuldeep Prasad, James Whetstone

National Institute of Standards and Technology (NIST)

Russ Dickerson, Xinrong Ren

Dept. of Atmos. & Oceanic Science, University of Maryland

NASA Earth Observatory images by Joshua Stevens, using Suomi NPP VIIRS data from Miguel Román, NASA's Goddard Space Flight Center

OUTLINE

- Background and motivation: urban greenhouse gas (GHG) monitoring
  - NIST urban testbeds
- Dispersion model inter-comparison (Texas 2013)
- Northeast Corridor: Washington DC / Baltimore

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WHY CITIES?

- **Urban populations contribute the most (70%) to anthropogenic GHG emissions.**
- **49% of the 300 most populated cities in CONUS have emission reduction targets.**
- **There is a demand for actionable information to inform policies.**

ADAM ROGERS SCIENCE 09.19.17 06:00 AM

CITIES TURN TO OTHER CITIES FOR HELP FIGHTING CLIMATE CHANGE

Slide: Kim Mueller

INFORMING INVENTORY METHODS

- Countries (Paris Agreement NDC's), States, Municipalities, Cities are interested in reducing GHG emissions and increasing sustainability.
  - Private companies also have a stake in reducing emissions (e.g. methane from livestock, natural gas distribution, landfill capture, etc.).
- Emissions are determined using accounting methods (inventories).
- Inventories can be informed by atmospheric analysis – valuable feedback loop.
  - But only if we understand uncertainties in our estimates!

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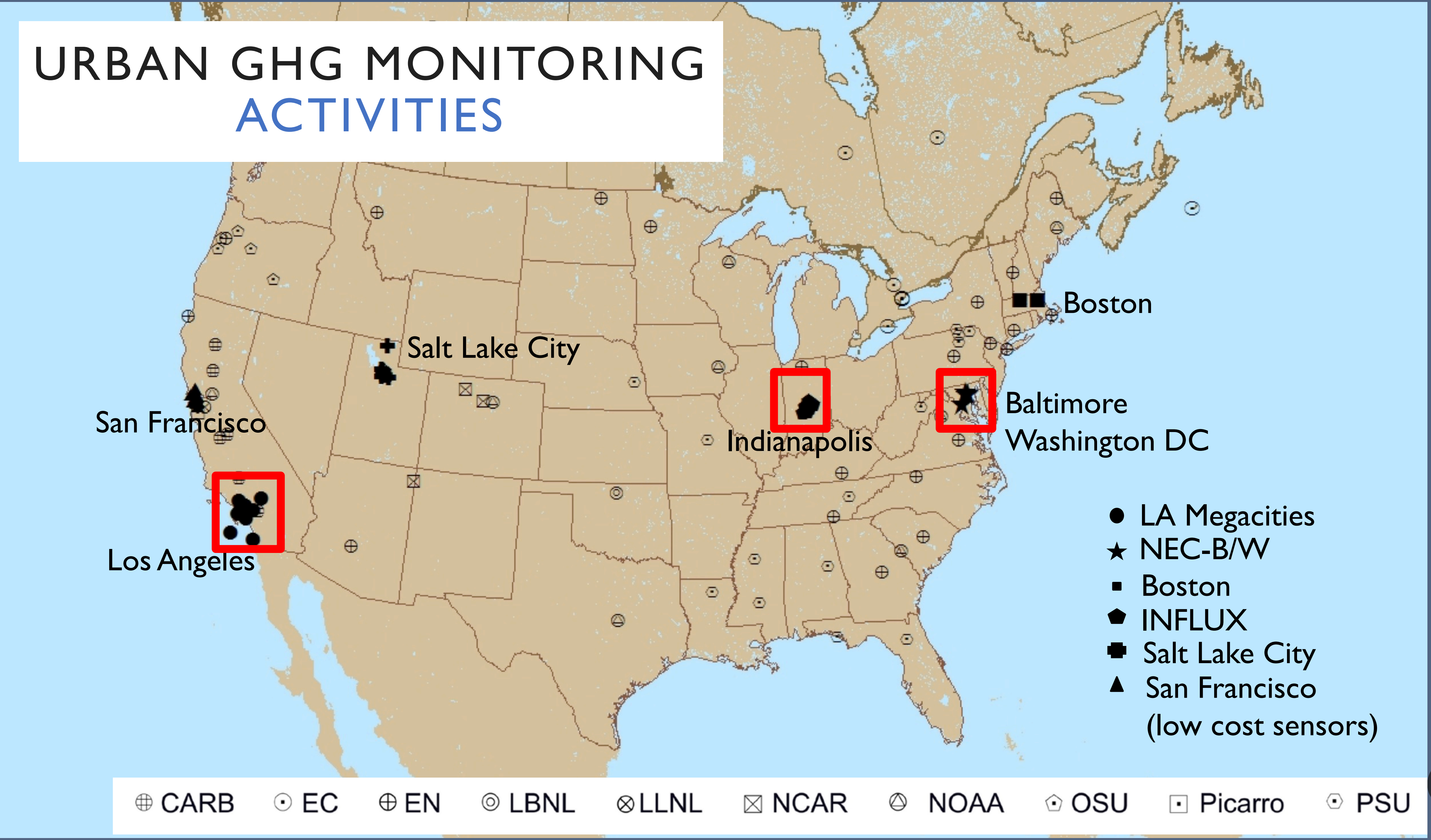
URBAN GHG MONITORING ACTIVITIES

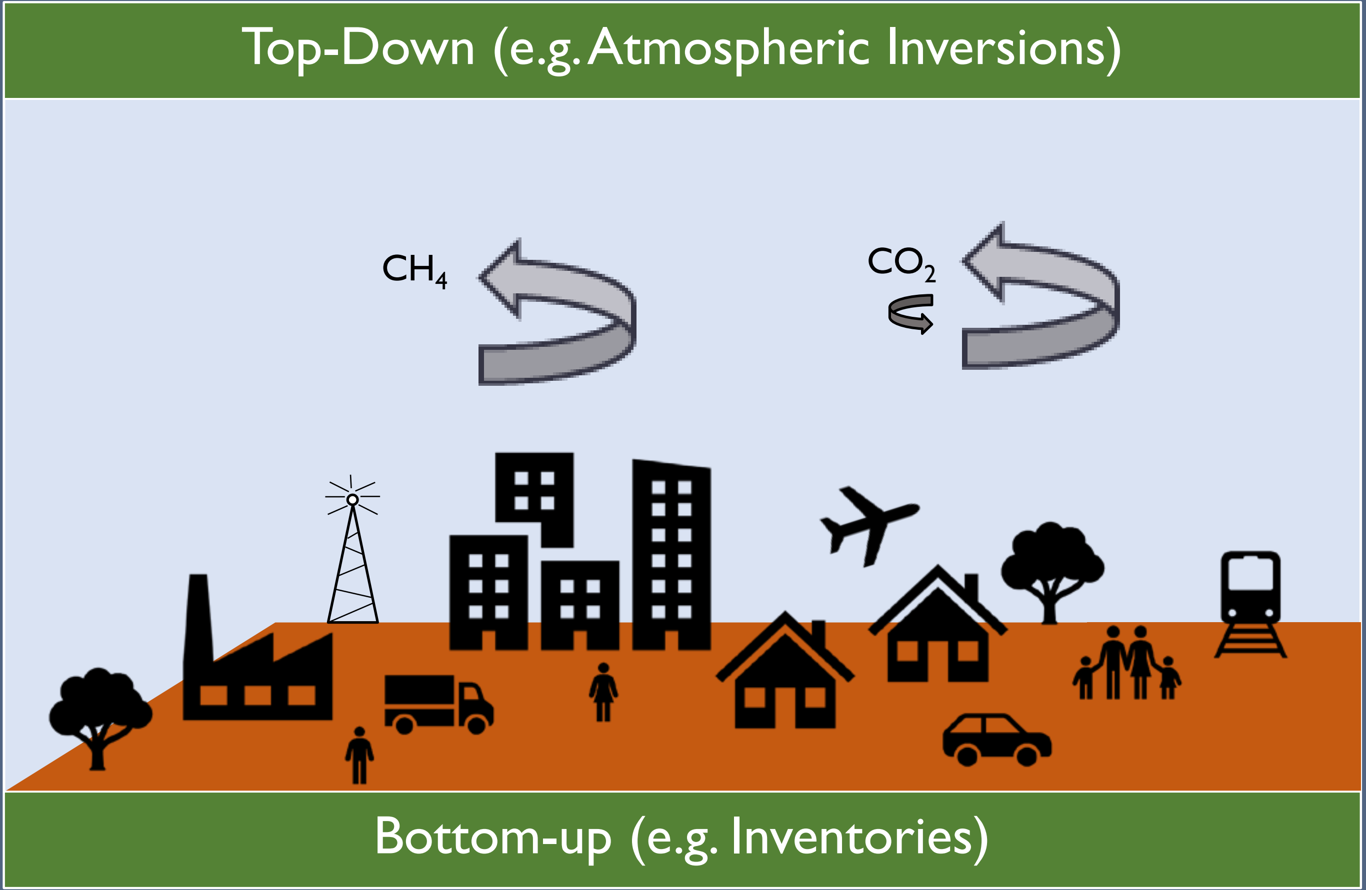


Slide: Kim Mueller

COMPLEMENTARY METHODS FOR EMISSIONS (FLUX) ESTIMATION

Atmospheric observations contain integrated emission signal from a city

Accounting methods use all available information on activities that produce GHG emissions



Slide: Kim Mueller

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BOTTOM-UP METHODS (INVENTORIES)

GHG Emissions = Activity Data x Emission Factors

Activity Data: (e.g. # of building, fuel sales, etc.)

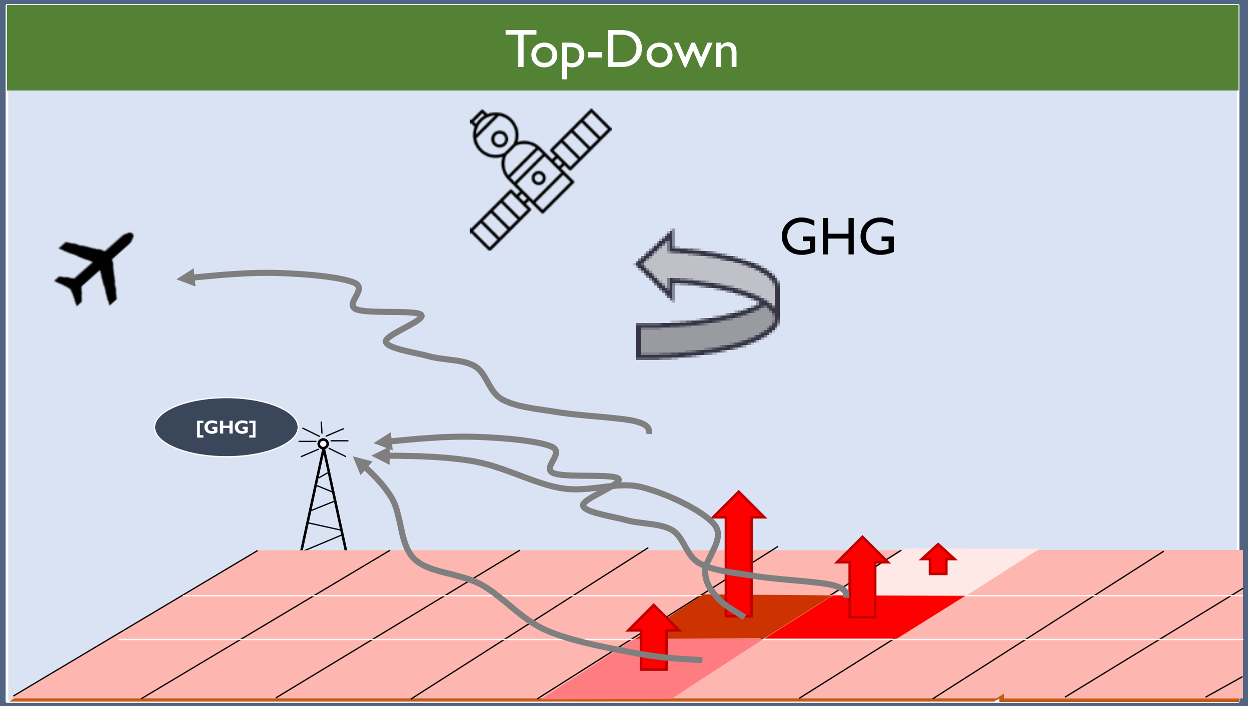
Emission Factors: (parameter that converts to emissions)

Accounting methods use all available information on activities that produce GHG emissions

Slide: Kim Mueller

TOP DOWN
EX. ATMOSPHERIC INVERSIONS OR MASS BALANCE METHODS

- Use relatively dense GHG observation networks.
- Quantification of the transport is needed to interpret GHG concentrations and link to fluxes into and out of the surface.
- Wind transports signal from emissions sources to the measurement location.



Mass Balance

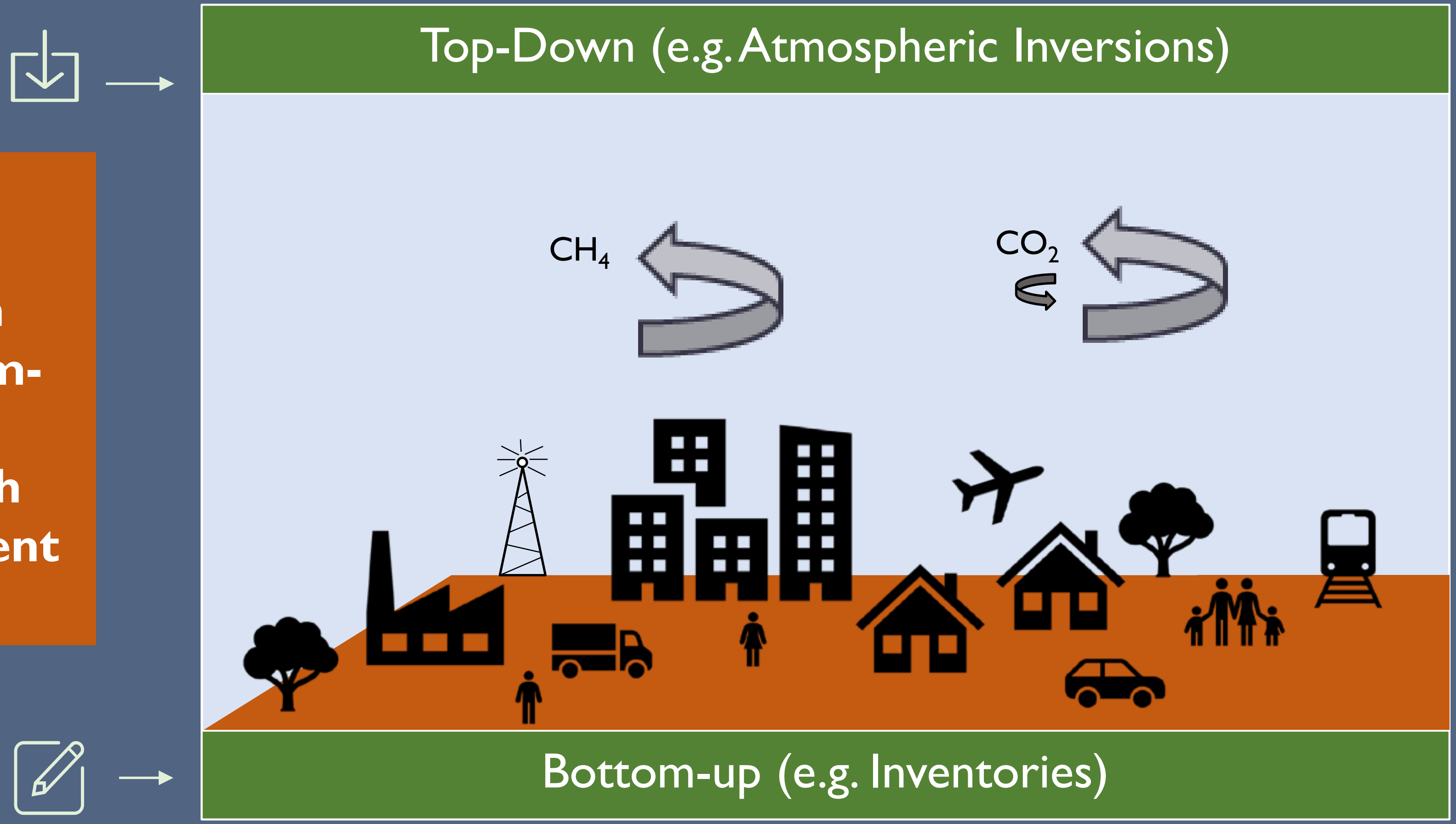
Atmospheric Inversions

Require some understanding of atmospheric transport/dispersion modeling

Slide: Kim Mueller

COMPLEMENTARY METHODS AT URBAN SCALES

NIST goal:
To improve measurements (both top-down and bottom-up) and assess their uncertainties through comparison of different methods.



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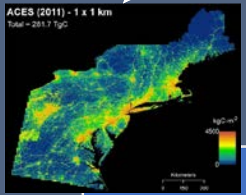
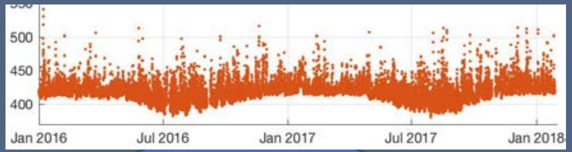
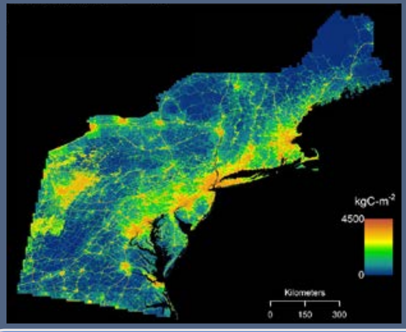
ACES inventory (Gately et al., 2017)



TOP DOWN
ATMOSPHERIC INVERSIONS



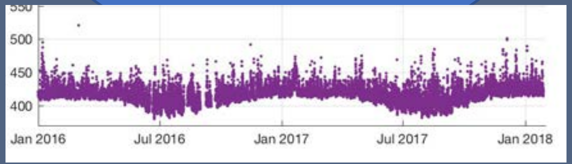


Initial assumed fluxes (e.g. Inventory)

Transport model

Simulated observations

Actual observations



Compare & Optimize

Adjusted (posterior) fluxes

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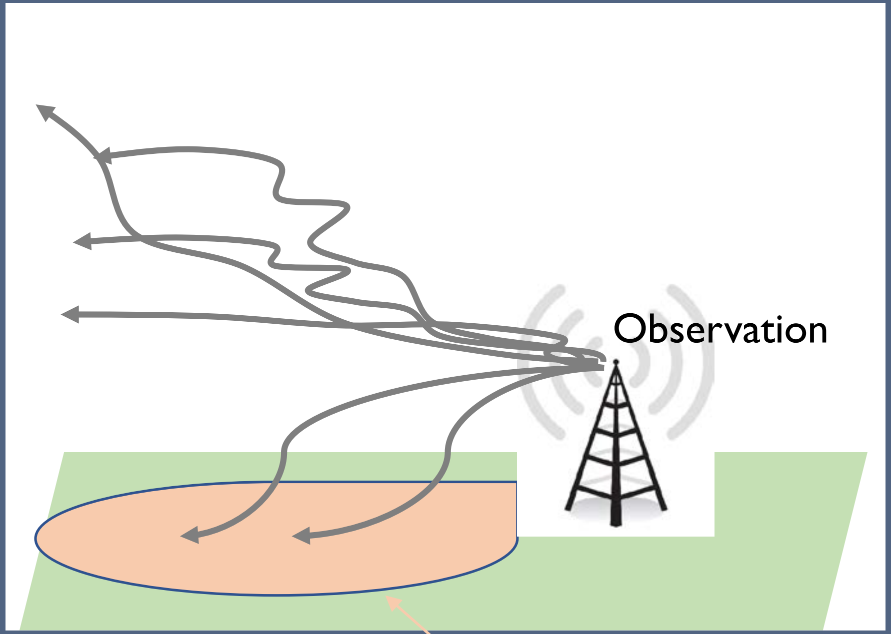
FOOTPRINT CONCEPT

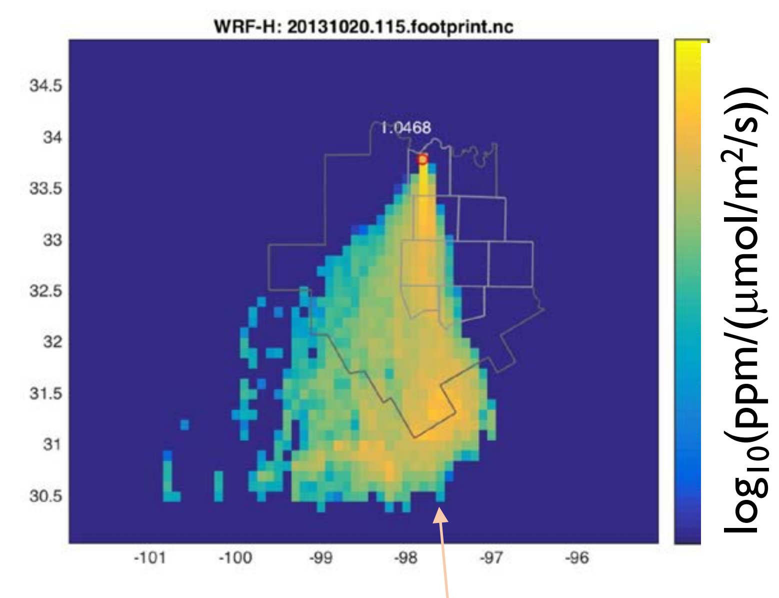


Footprint (surface sensitivity/influence)

- Dispersion model is run **backwards in time** from the observation point (”receptor”).
- Surface influence for observation is calculated (analogous to the surface concentration in a forward run)
  - proportional to residence time of particle over a given pixel and within the PBL
- Surface influence (“footprint”) is convolved with flux (emissions) map:
  - Each pixel’s influence value is multiplied by a surface flux ($\mu mol/m^2/s$)
  - Sum over all pixels equals the predicted concentration (ppm) at the receptor location
- Compare with observed value at that point

NIST

FOOTPRINT CONCEPT



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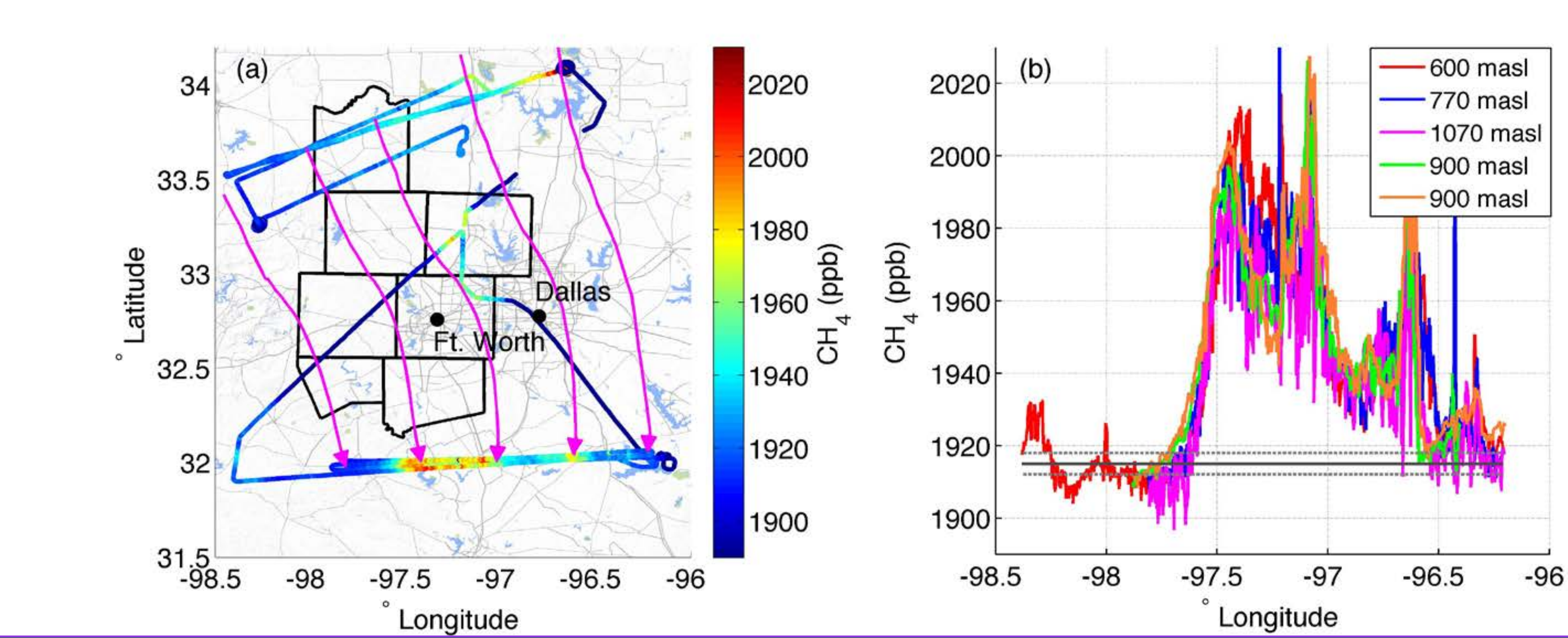
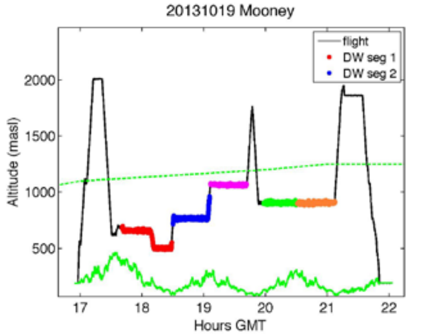
BARNETT SHALE, TEXAS, 2013



Karion et al., ES&T, 2015

Karion et al., in prep.

Contributors: I. Lopez-Coto, S. Gourdji, K. Mueller, J. Whetstone (NIST), T. Lauvaux (PSU), A. Andrews, W. Angevine, C. Sweeney (NOAA/ESRL), A. Stein (NOAA/ARL)



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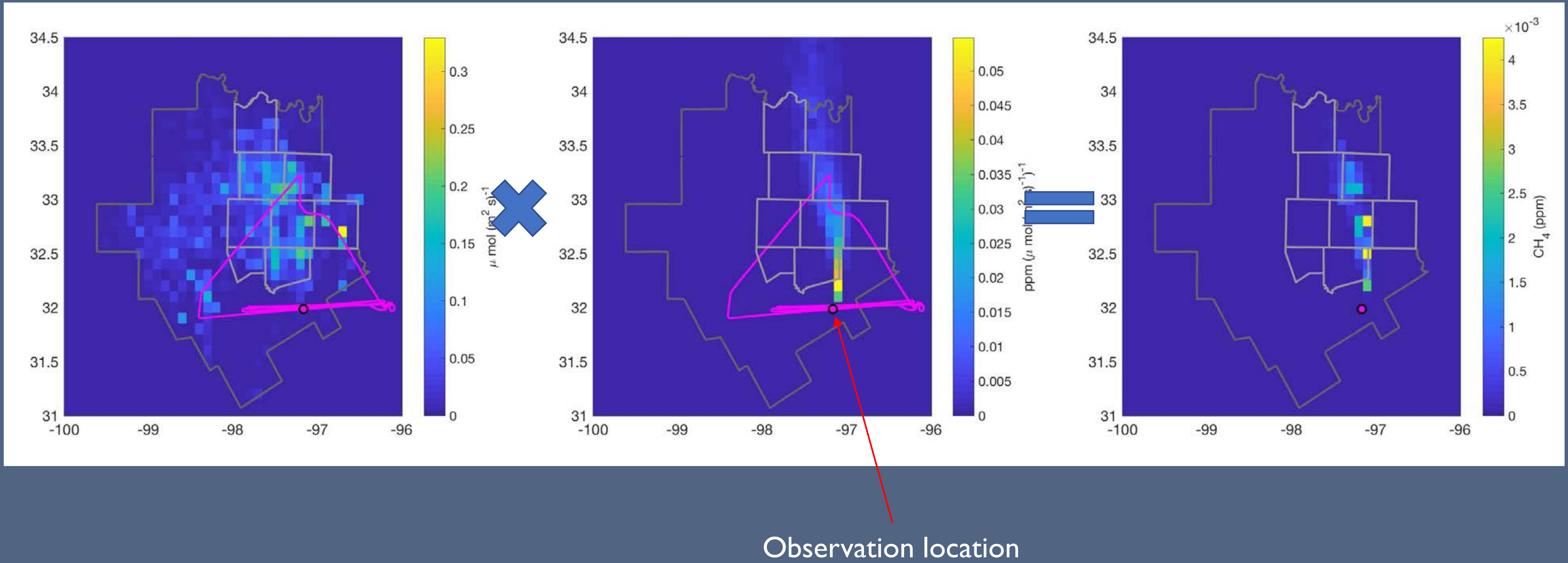
CH_4 Emissions Inventory

Single Observation Footprint

Contribution to observed CH_4



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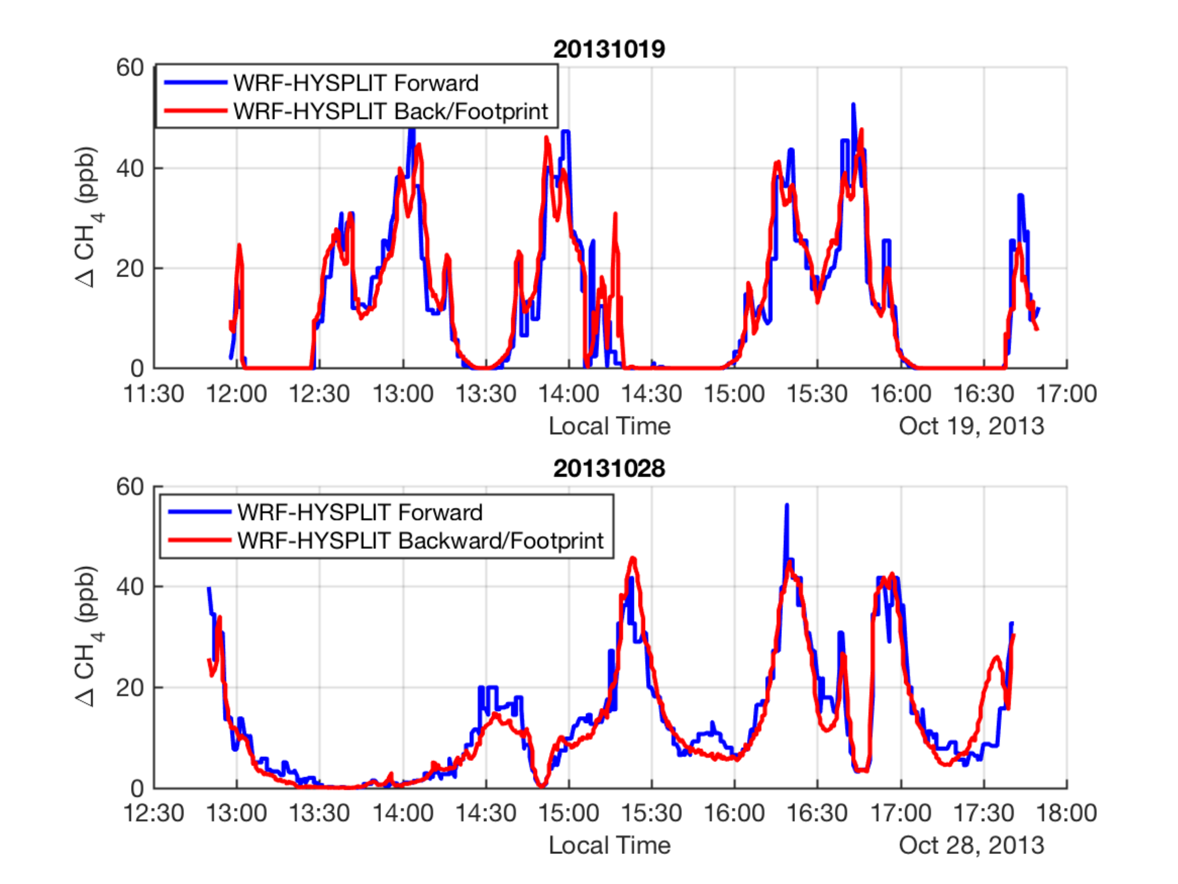
FORWARD-BACKWARD CONSISTENCY



Forward HYSPLIT model is equivalent to the backward/footprint-based model.

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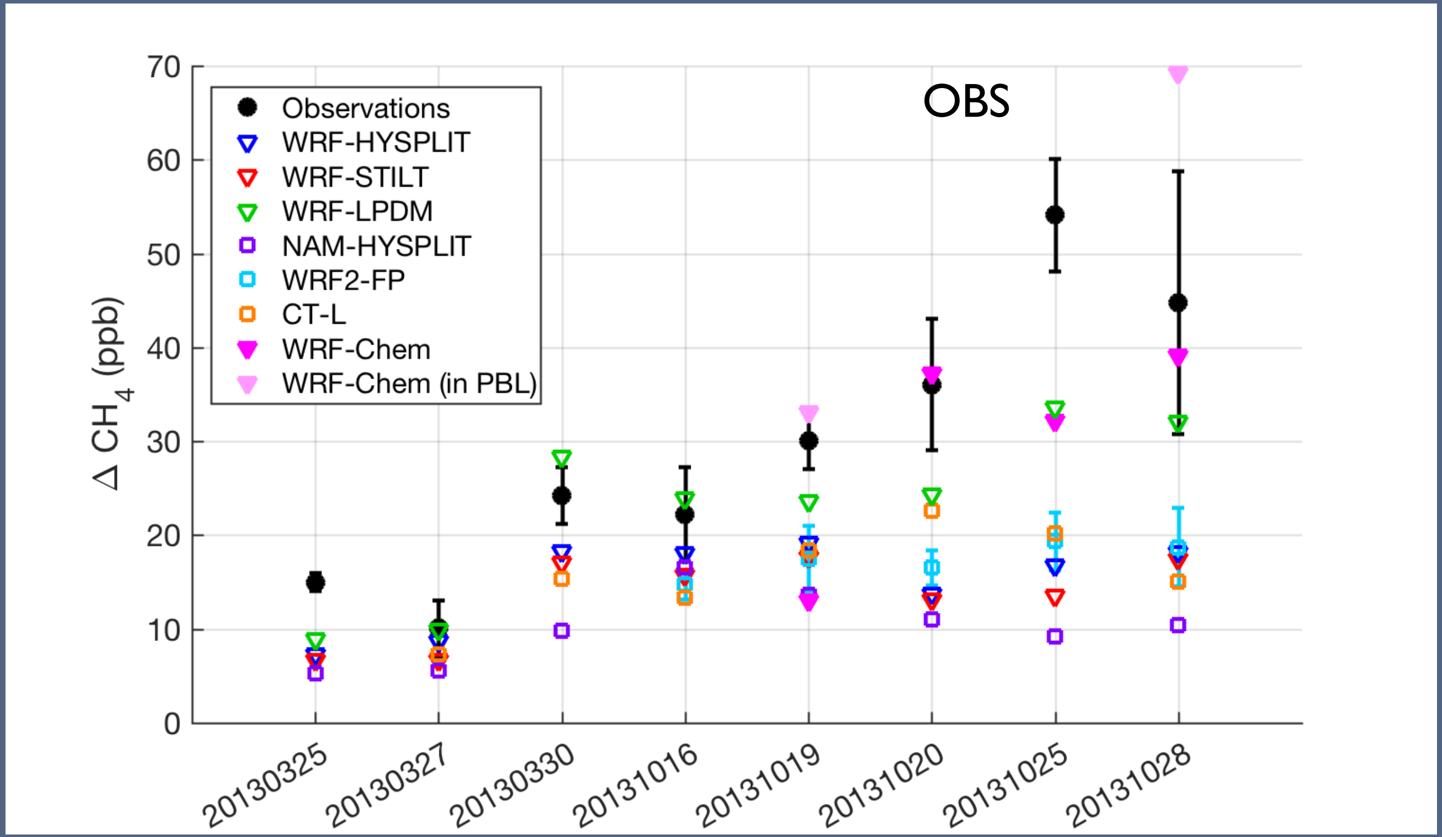
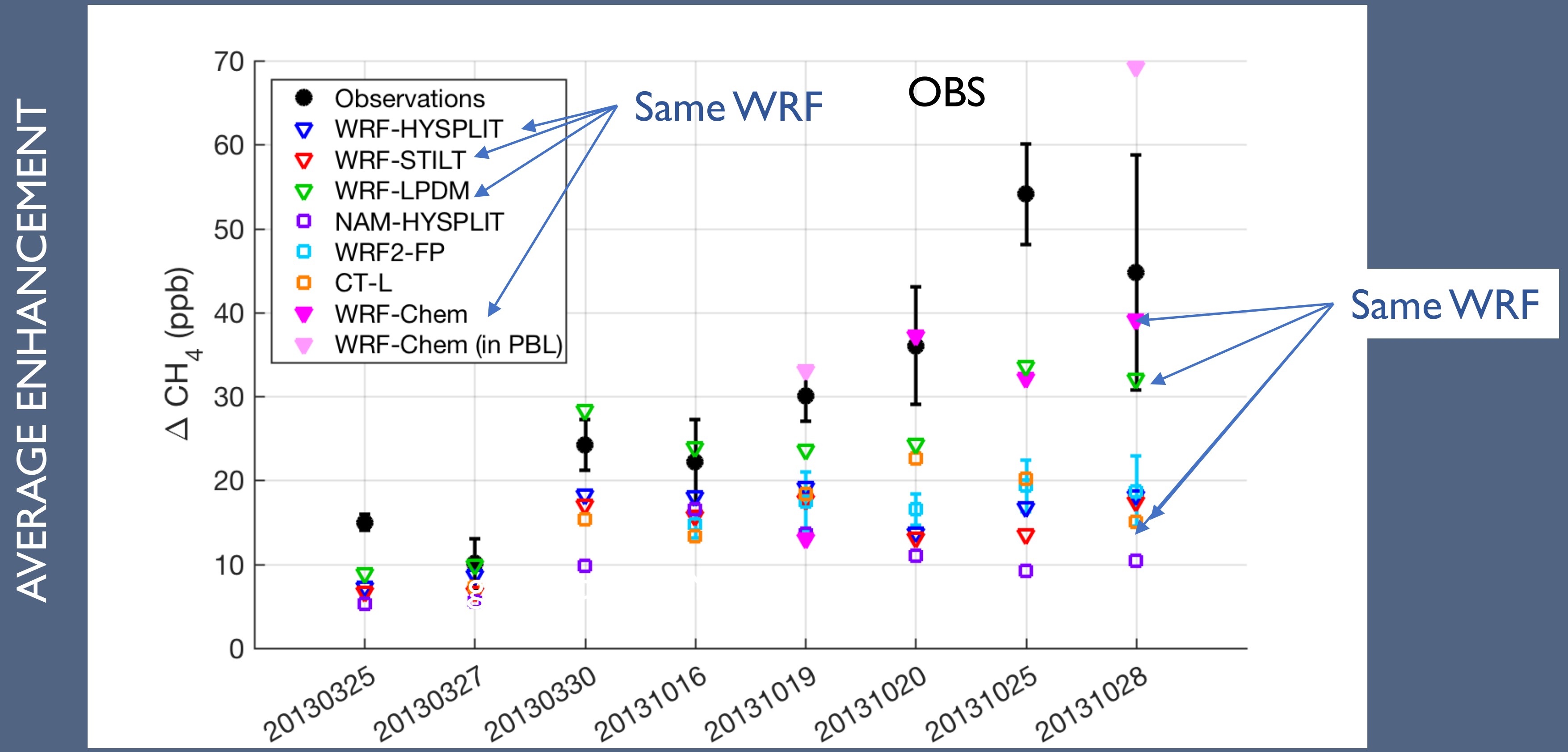
MEAN METHANE ENHANCEMENT
(DOWNWIND TRANSECTS)

AVERAGE ENHANCEMENT



Modeled enhancements = Footprint x inventory convolution.
Background subtracted from observations.

MEAN METHANE ENHANCEMENT
(DOWNWIND TRANSECTS)



Modeled enhancements = Footprint x inventory convolution.
Background subtracted from observations.

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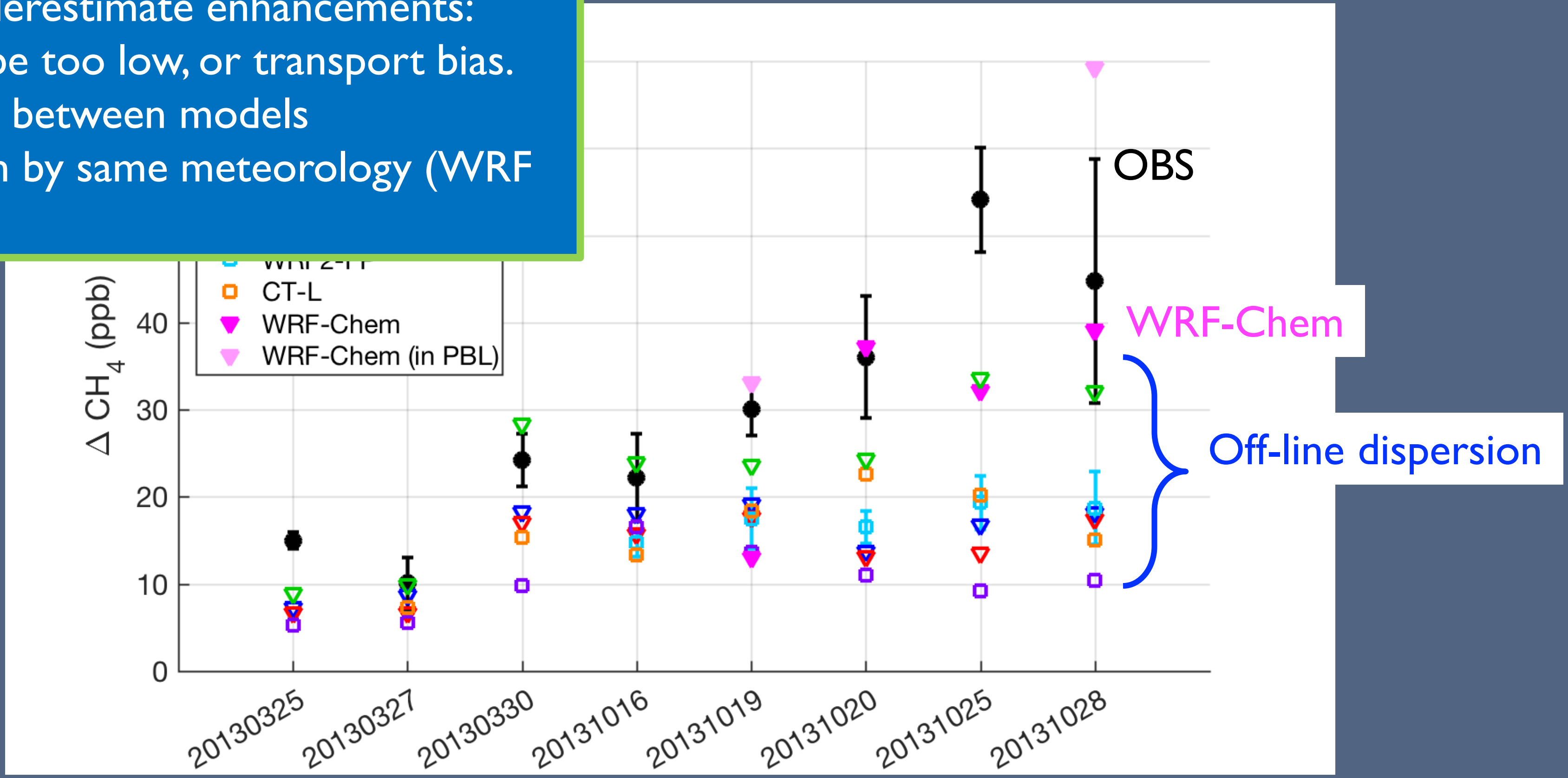
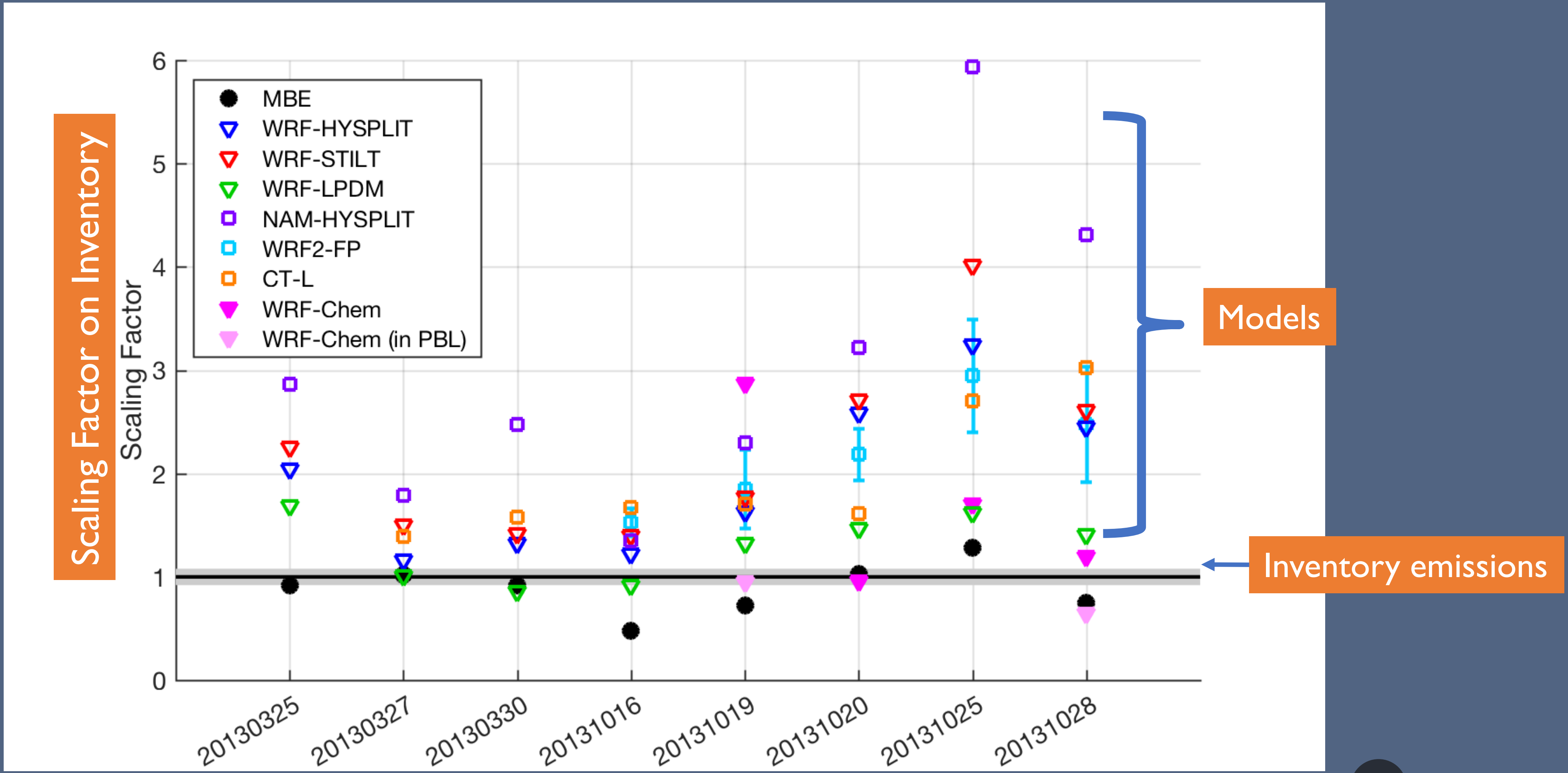
MEAN METHANE ENHANCEMENT
(DOWNWIND TRANSECTS)

- Most models underestimate enhancements: inventory could be too low, or transport bias.
- Significant spread between models
- Even when driven by same meteorology (WRF – triangles)



Modeled enhancements = Footprint x inventory convolution.
Background subtracted from observations.

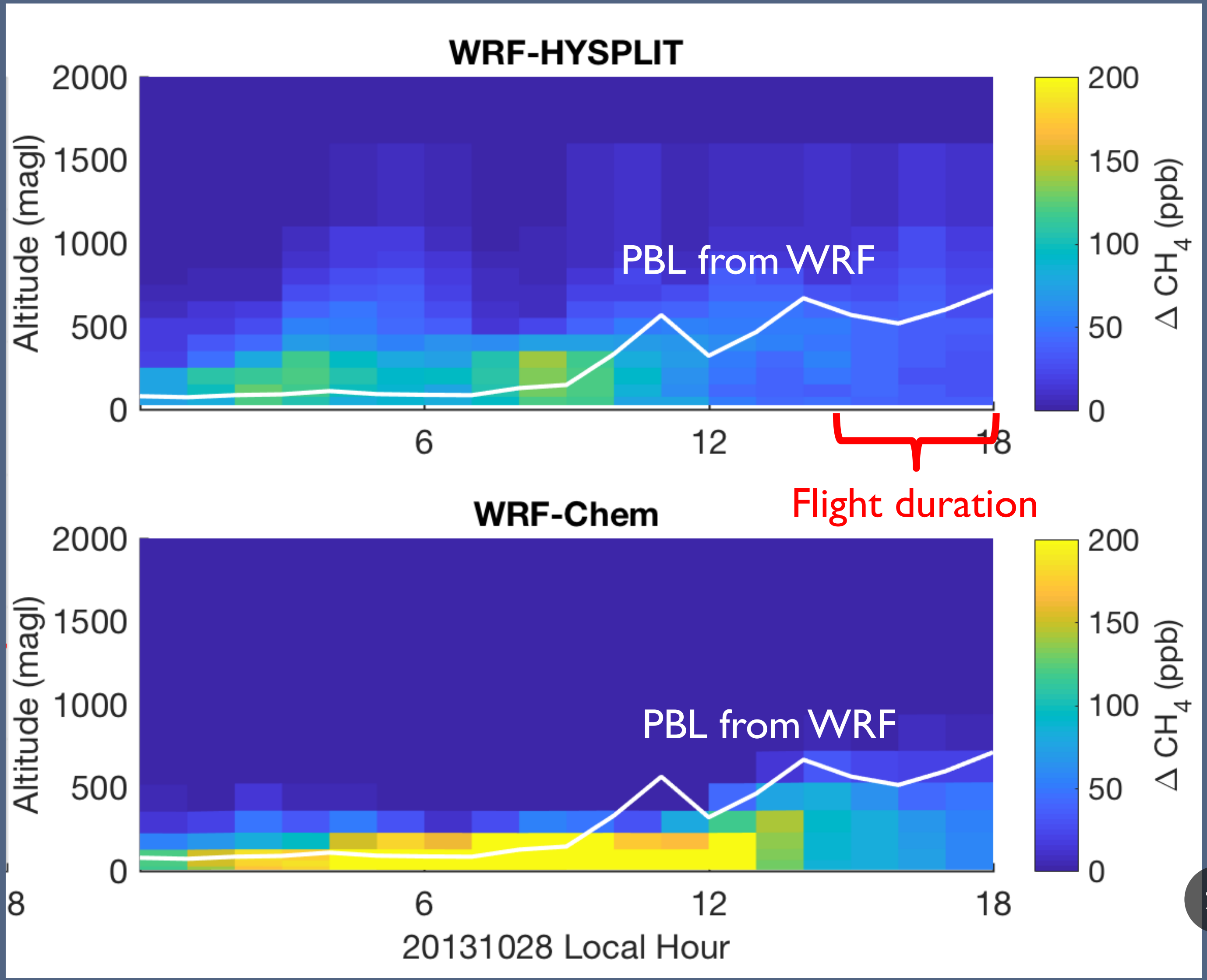
BARNETT SHALE MODEL INTER-COMPARISON



Karion et al, in prep.

FORWARD MODEL COMPARISON: METHANE PROFILE 10/28/2013

CH_4 enhancement at a single location through the day (20131028) shows large differences between the two models at 6-12 UTC (0-6 LST).



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WHAT DID WE LEARN?

1. We see evidence of systematic differences in vertical mixing between different tracer dispersion models, separate from differences in meteorological fields.
2. Meteorological errors at night or early morning can affect mole fractions later in the day due to improper modeling of vertical mixing combined with wind shear.
3. Multiple transport models should be investigated, especially if data set is limited in temporal coverage.
   - Errors may average out if using a year's worth of model data, but on any given day errors are large and not easily diagnosed.

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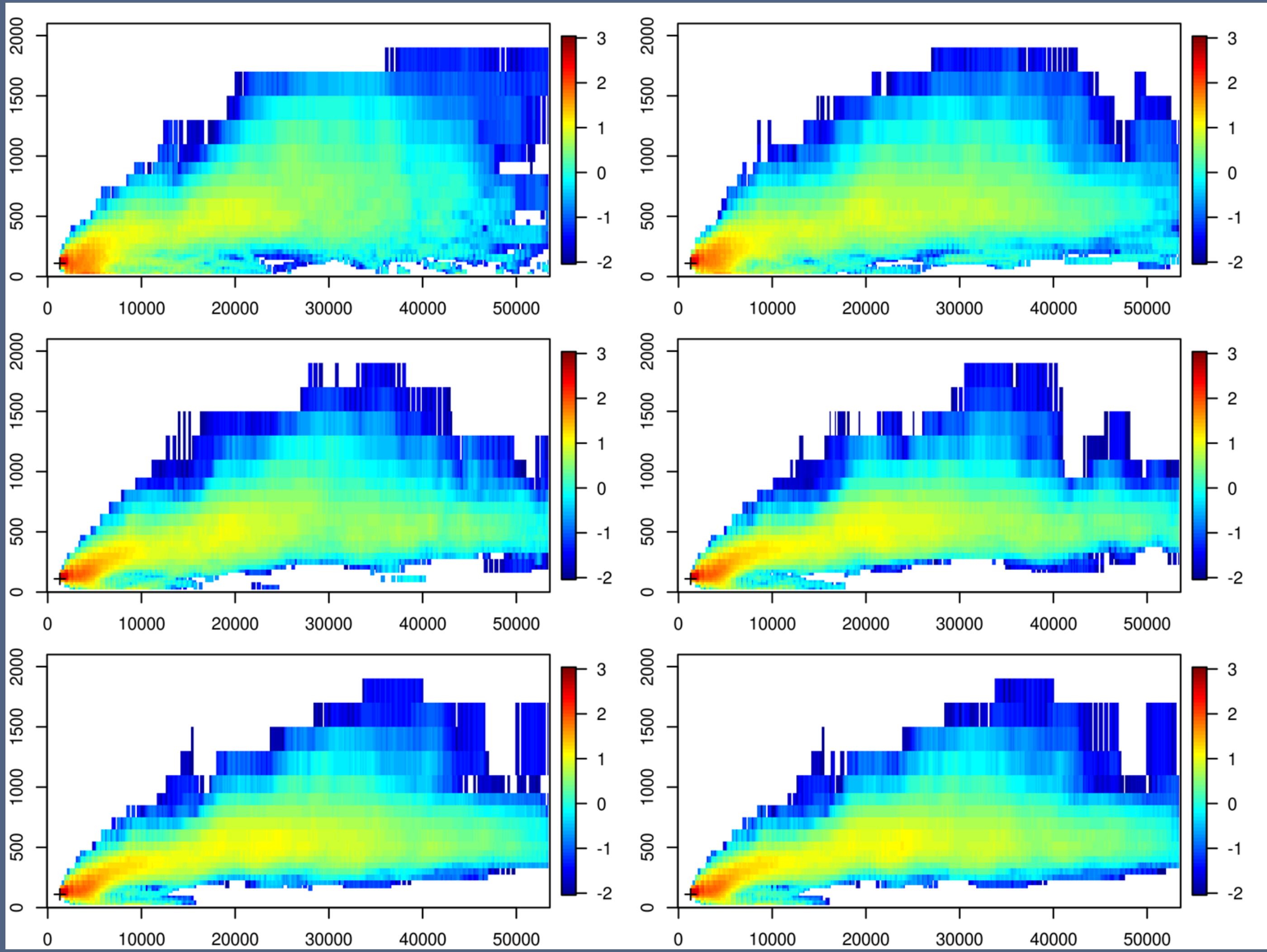
MIXING PARAMETRIZATIONS: FUTURE WORK

4 experimental variants of a new mixing parametrization added to HYSPLIT in collaboration with NOAA-ARL.

Example of test case: Brandon Shore Power Plant.



Each panel corresponds with 2, 3, 5, 6, 7, 8 respectively. The x and y axes are in meters. Colorscale is log10 ppm

NORTHEAST CORRIDOR PROJECT:
MONITORING GHG EMISSIONS FROM WASHINGTON DC AND BALTIMORE

NIST

PROJECT ELEMENTS

Aircraft (FLAGG-MD)

- Mass balance
- Model validation

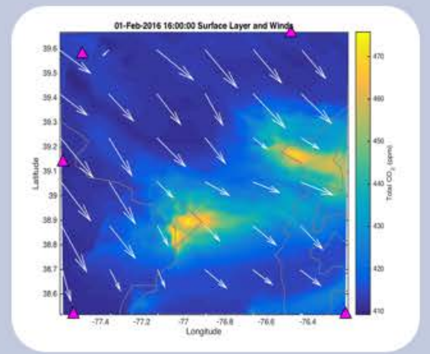
Tower Network

High-accuracy CO_2, CH_4 measurements

Emissions Modeling

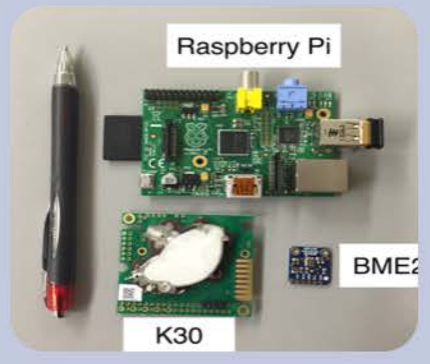
- Hestia

Anthropogenic CO_2 inventory



Modeling

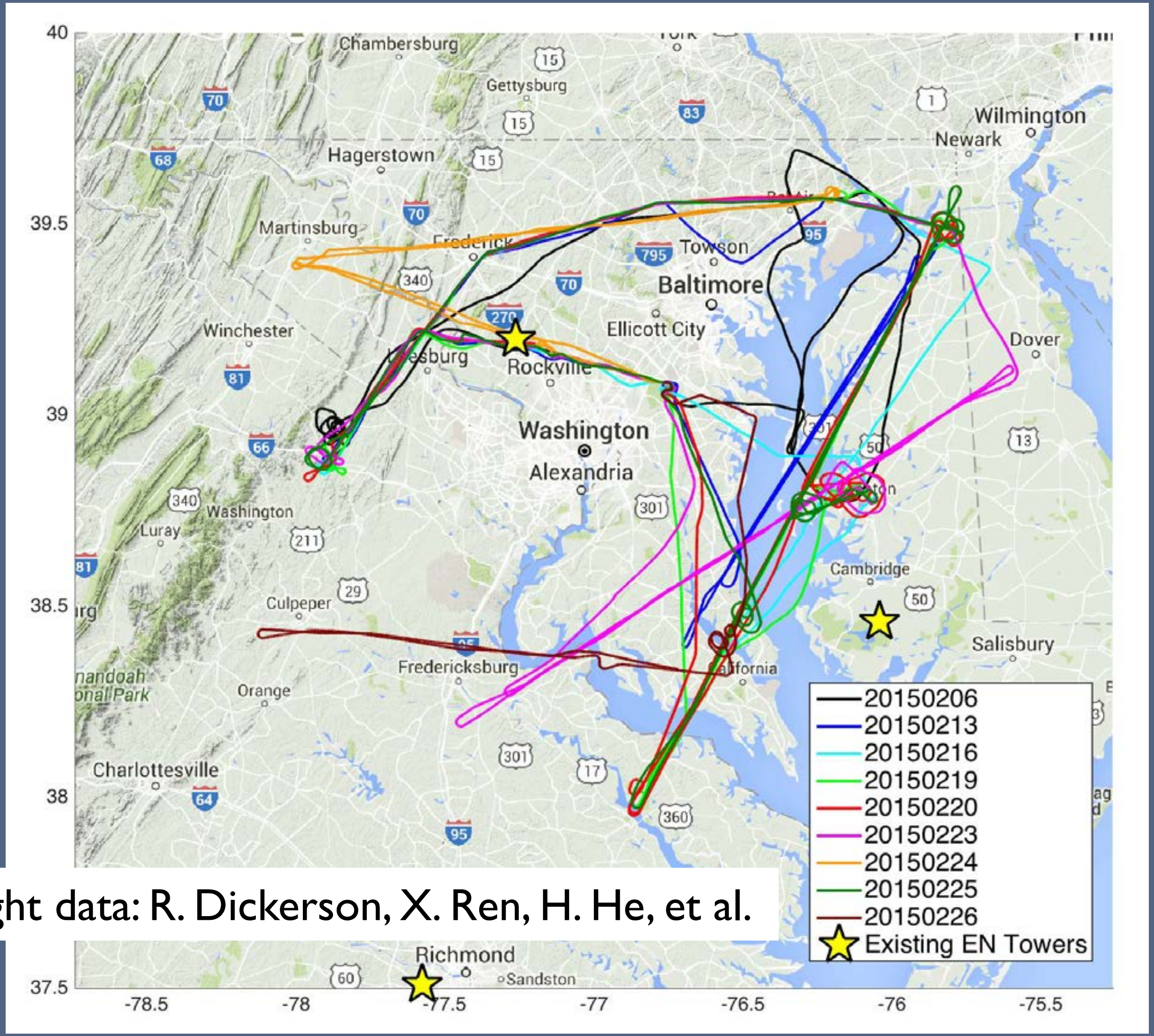
- WRF-Stilt
- WRF-Chem
- Inversions
- LETKF



Also:

- Low-Cost Sensors
- Biogenic fluxes & SIF testbed

FLAGG-MD AIRBORNE CAMPAIGNS



Flight data: R. Dickerson, X. Ren, H. He, et al.

- University of Maryland & Purdue University conducting flight campaigns in the region.
- Flights upwind / downwind of the DC/Baltimore region.
- Measurements of CO_2, CH_4, CO, O_3, NO_2, black carbon.
- Mass balance estimates of total emissions as well as large point sources (landfills, power plants) *(Ahn, in prep; Ren, in prep)*
- Measurements being used with transport model in atmospheric inversion. *(Lopez Coto, in prep.)*

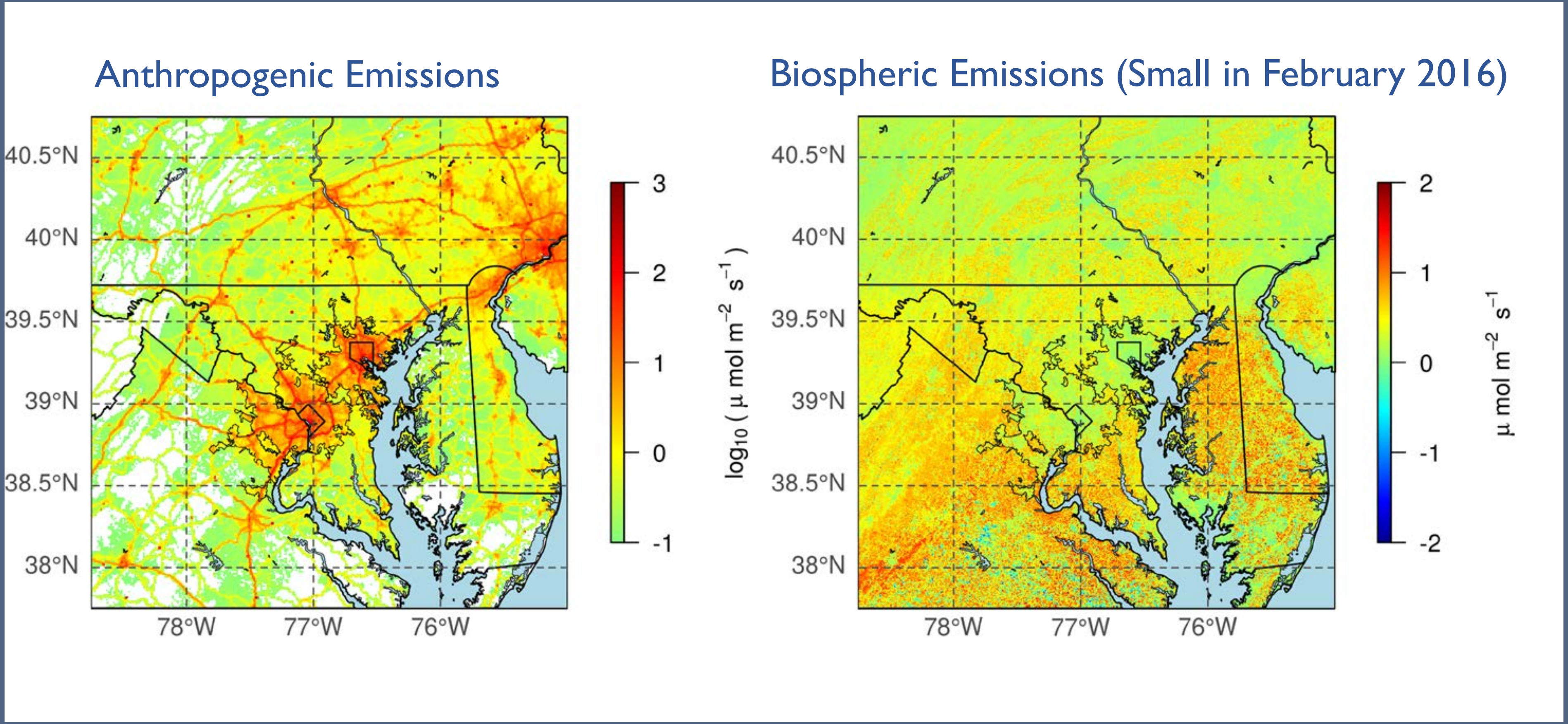
METHODS: TRANSPORT MODELING

- **Meteorological models**
  - HRRR (from NOAA-ARL repository)
  - WRF v3.8 (4 members)
    - 4 PBL schemes (MYNN, YSU, BOUL, QNSE)
    - 1 Urban canopy model
    - IC and BC from HRRR (2) and NARR (2)
    - MP-Thompson, SW (and LW)-RRTMg, LSM-Noah, K-F cumulus scheme (only at 9km)
    - 3 domains (9, 3, 1 km $\rightarrow$ dt $<$ 60 s)
    - 60 vertical levels (30 $<$ 3 km)

- **Dispersion model**
  - HYSPLIT (STILT mode)
  - Receptors every 60 s (48 h back)
  - 500 particles per receptor
  - PBLH and TKE from meteorological model (Kanthar/Clayson when TKE was not available, YSU)
  - 0.03° (lat x lon: 120 x 125)

NIST

METHODS: CO_2 EMISSIONS



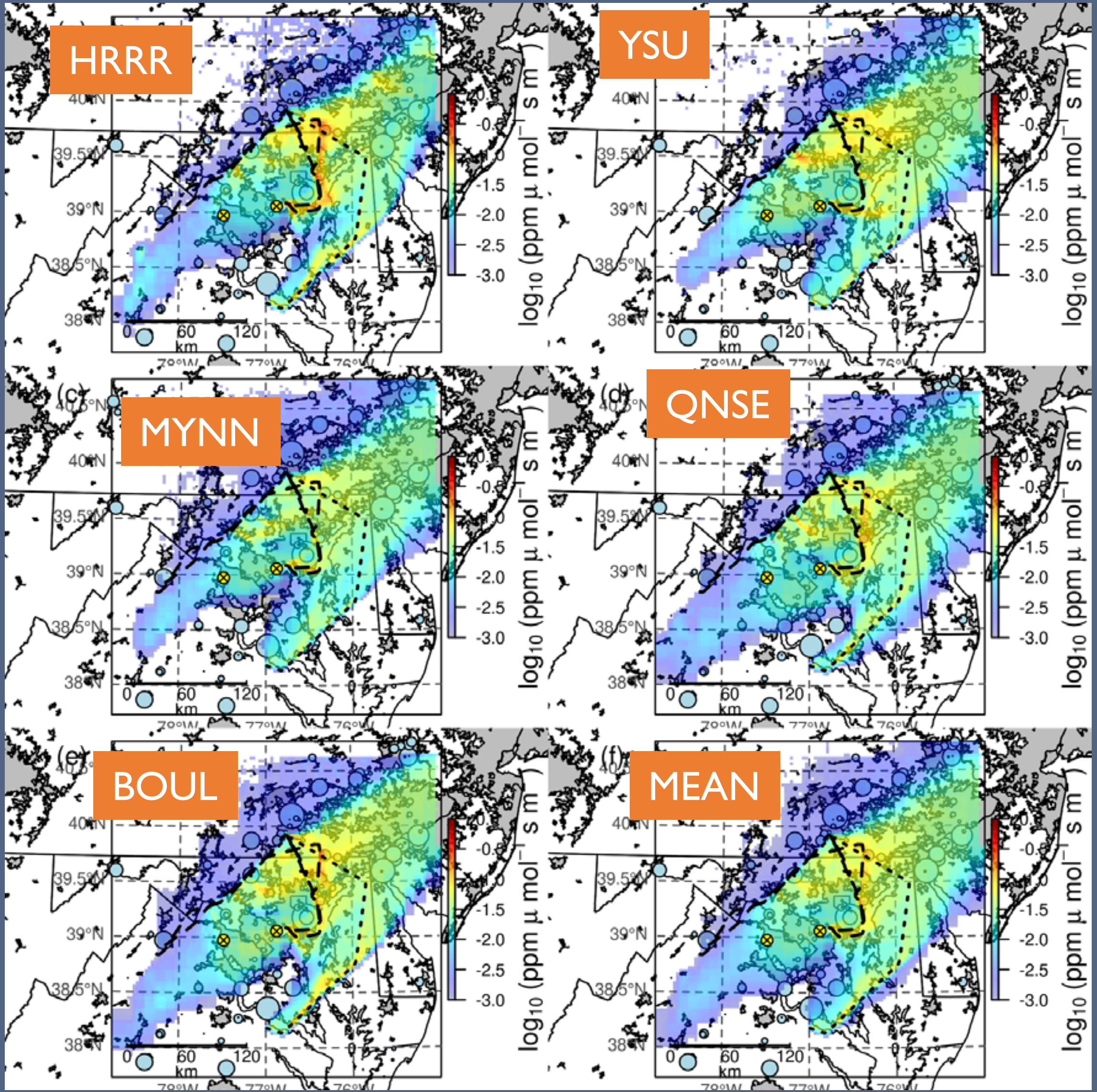
(Lopez Coto, in prep.)

- FFCO2: ACES inventory (Gately et al., 2017)
- 1 km resolution, hourly for 2013 and 2014
- Averaged February during flight time (~ 12-18 EST).

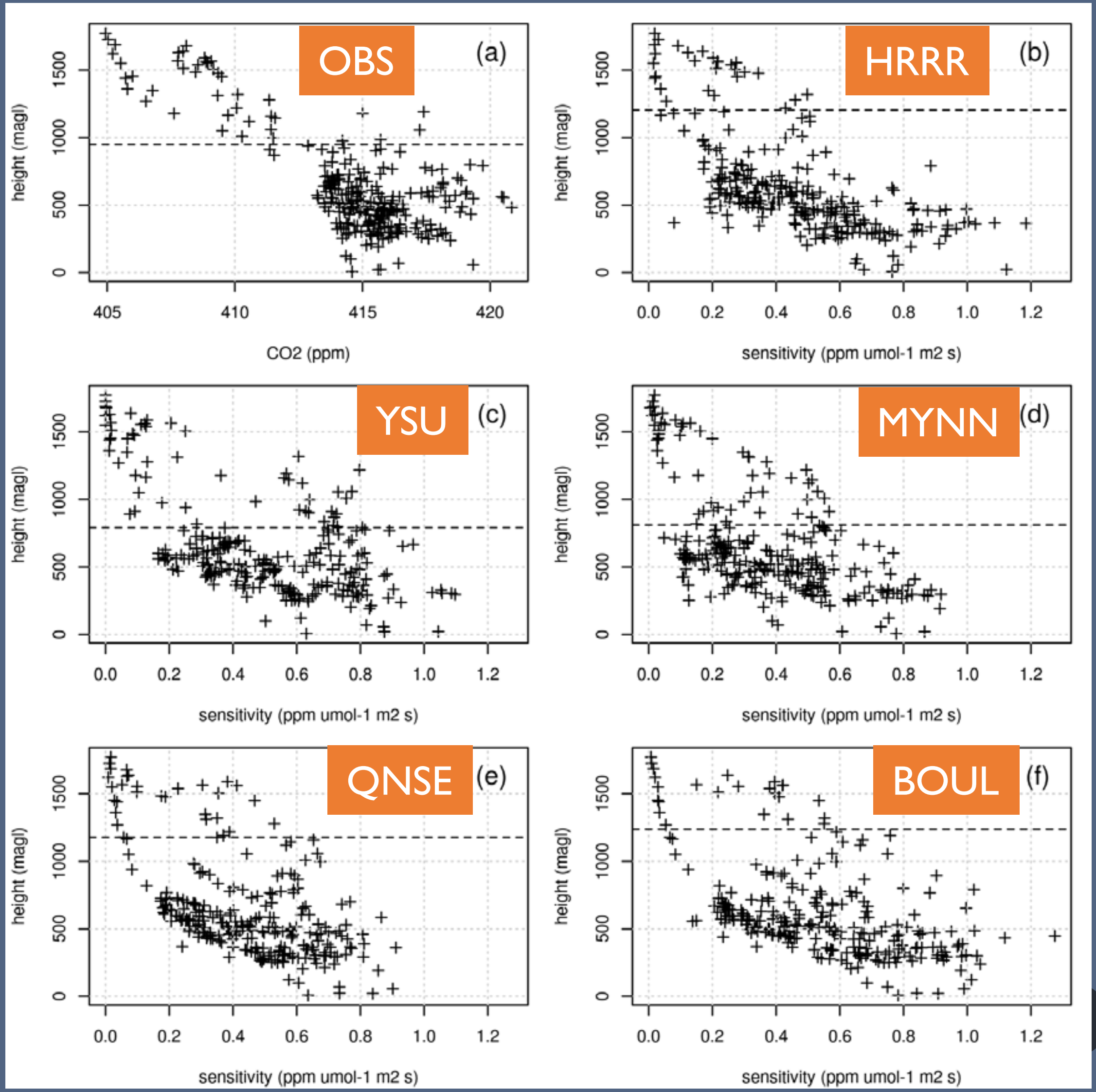
- BIOCO2:VPRM
- 10 vegetation categories
- 250 m resolution, 3 hourly for February 2016

RFI: 02/08/2016

Mean Sensitivity (Footprint)



Sensitivity with altitude



(Lopez Coto, in prep.)

RFI: 02/08/2016

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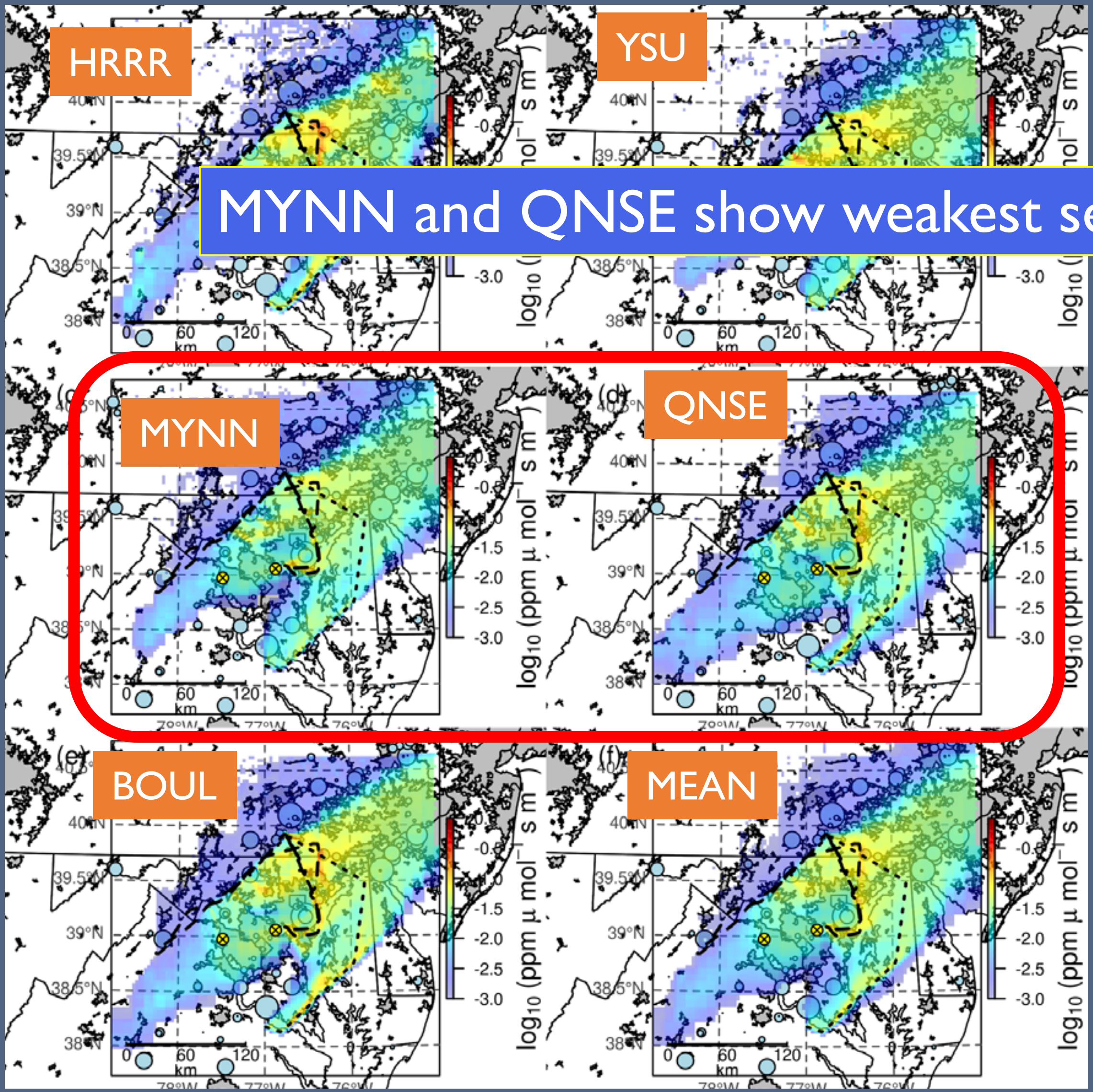
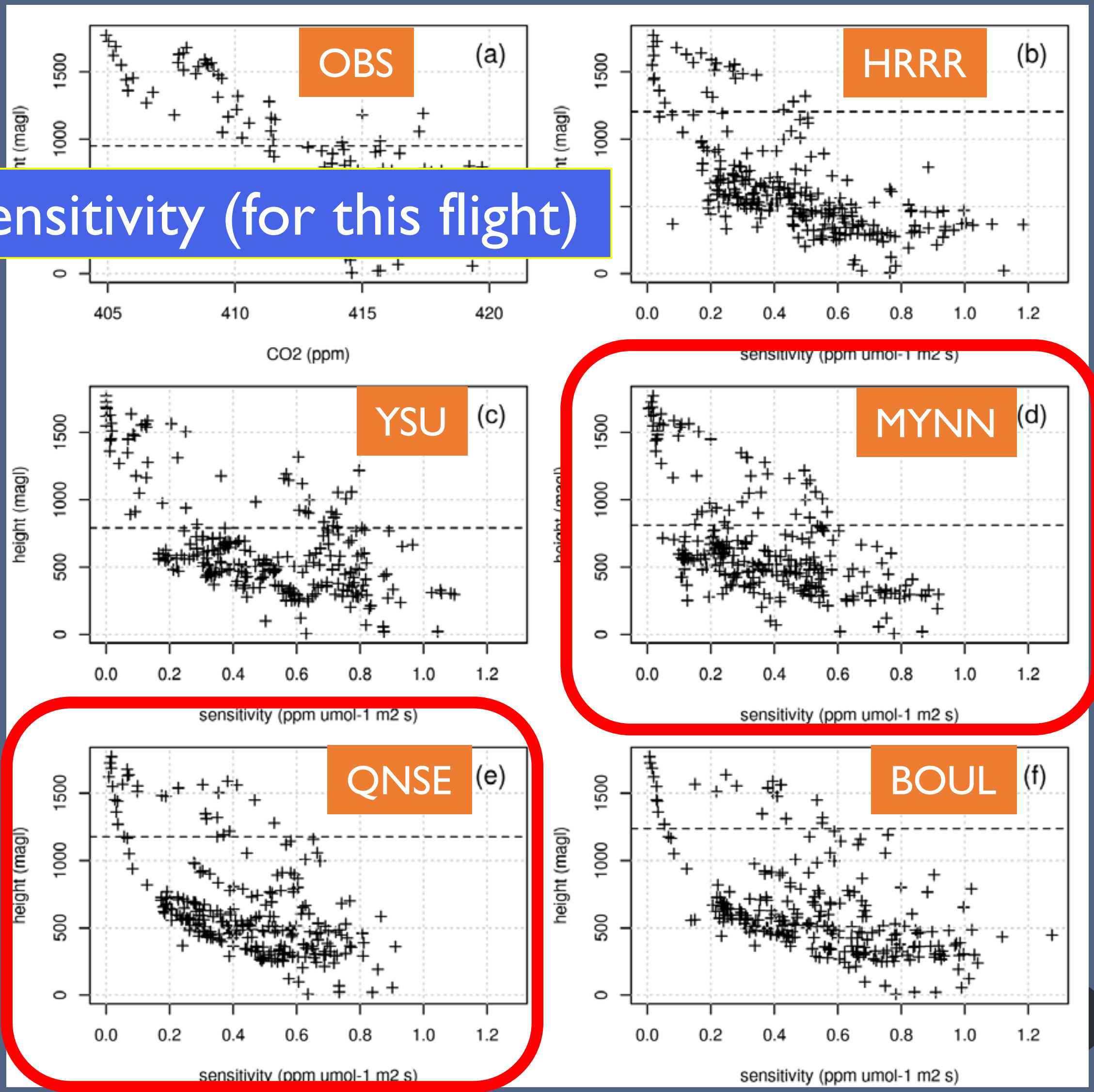


Sensitivity with altitude

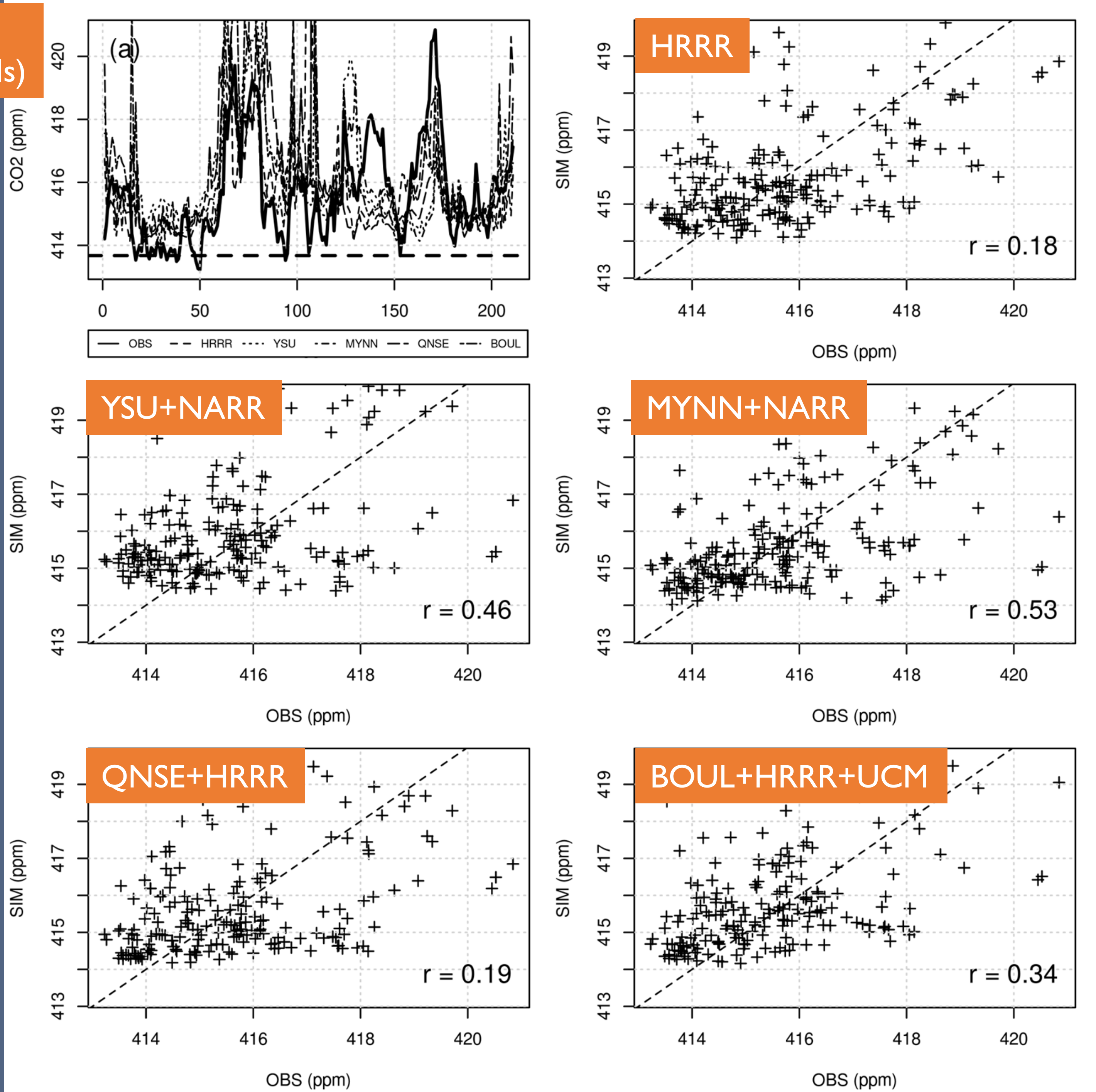


MYNN and QNSE show weakest sensitivity (for this flight)

(Lopez Coto, in prep.)

RF1: 02/08/2016

Time Series (OBS + models)



- CO_2 nearly unbiased
- Better correlation for models driven by NARR (for this flight)

(Lopez Coto, in prep.)

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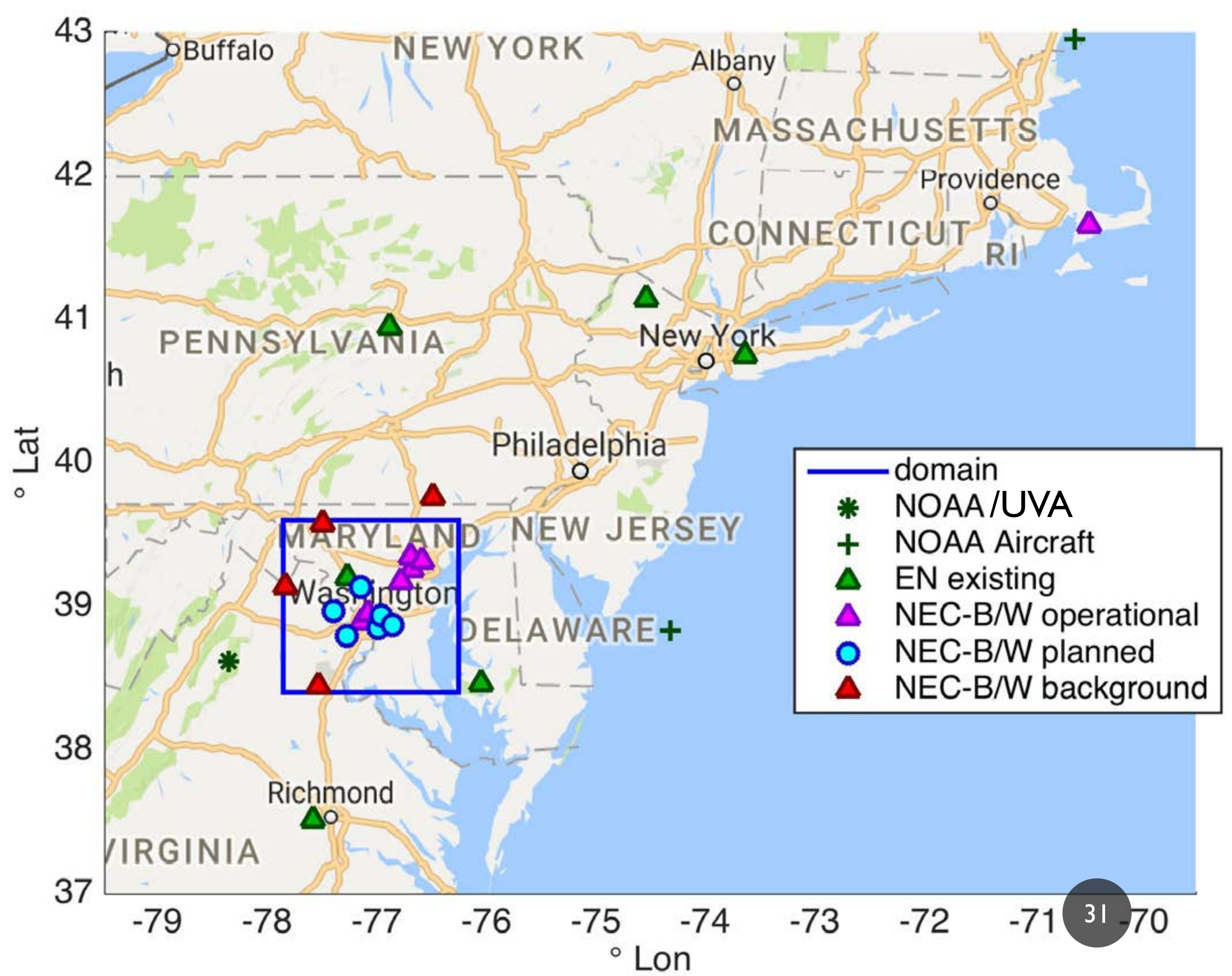
TOWER NETWORK

- Lopez-Coto et al, Advances in Atmospheric Sciences, 2017
- Mueller et al., JGR-A, 2018

- Partnership with Earth Networks
- High-accuracy measurements based on CRDS analyzers
- CO_2 / CH_4 reported on WMO scales
- Communications towers 50m+
- Inlets at 2 heights
- 12 in urban areas
  - 4 near Baltimore
  - 8 near Washington DC
- 4 outside urban area (red)
- Locations identified using network design studies
- Flasks for $^{14}CO_2$ & other gases at 4 sites (1 BG, 3 urban)
- Began in Fall 2015
- 10 of 16 sites operational currently



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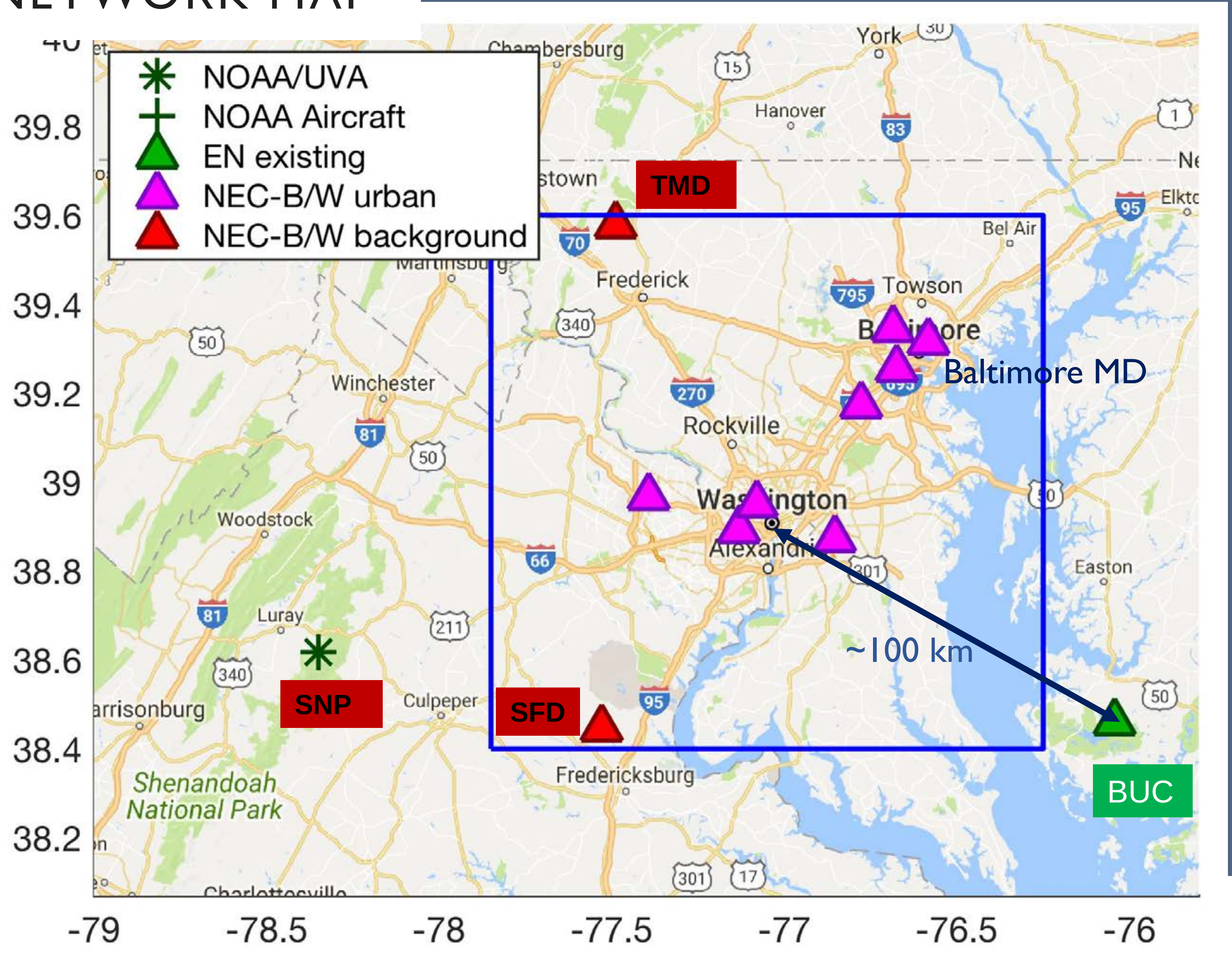
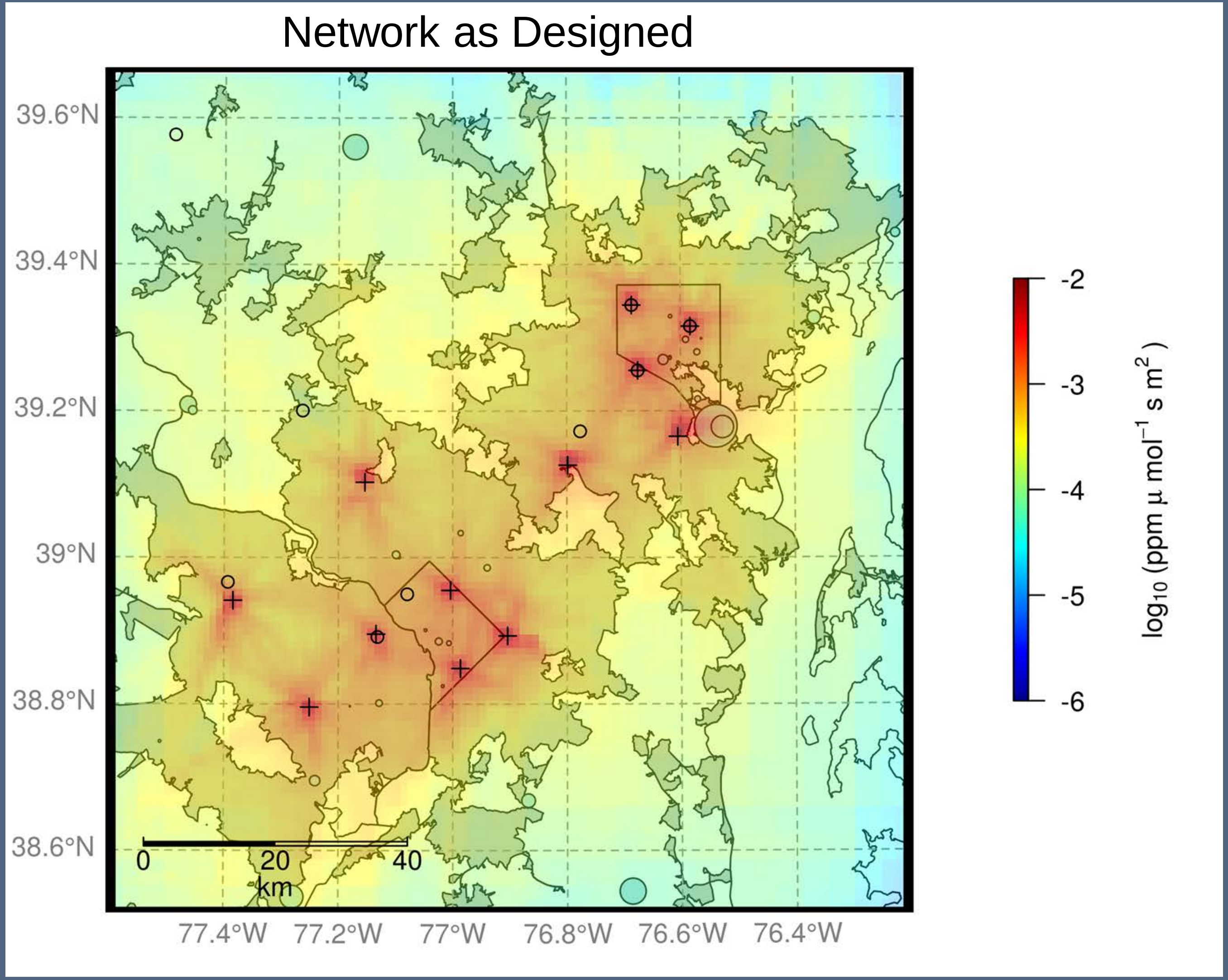
CURRENT NETWORK MAP



map by Google

Movie: Israel Lopez Coto, NIST

NETWORK COVERAGE:
MODEL-BASED REGION OF INFLUENCE FOR EACH LOCATION

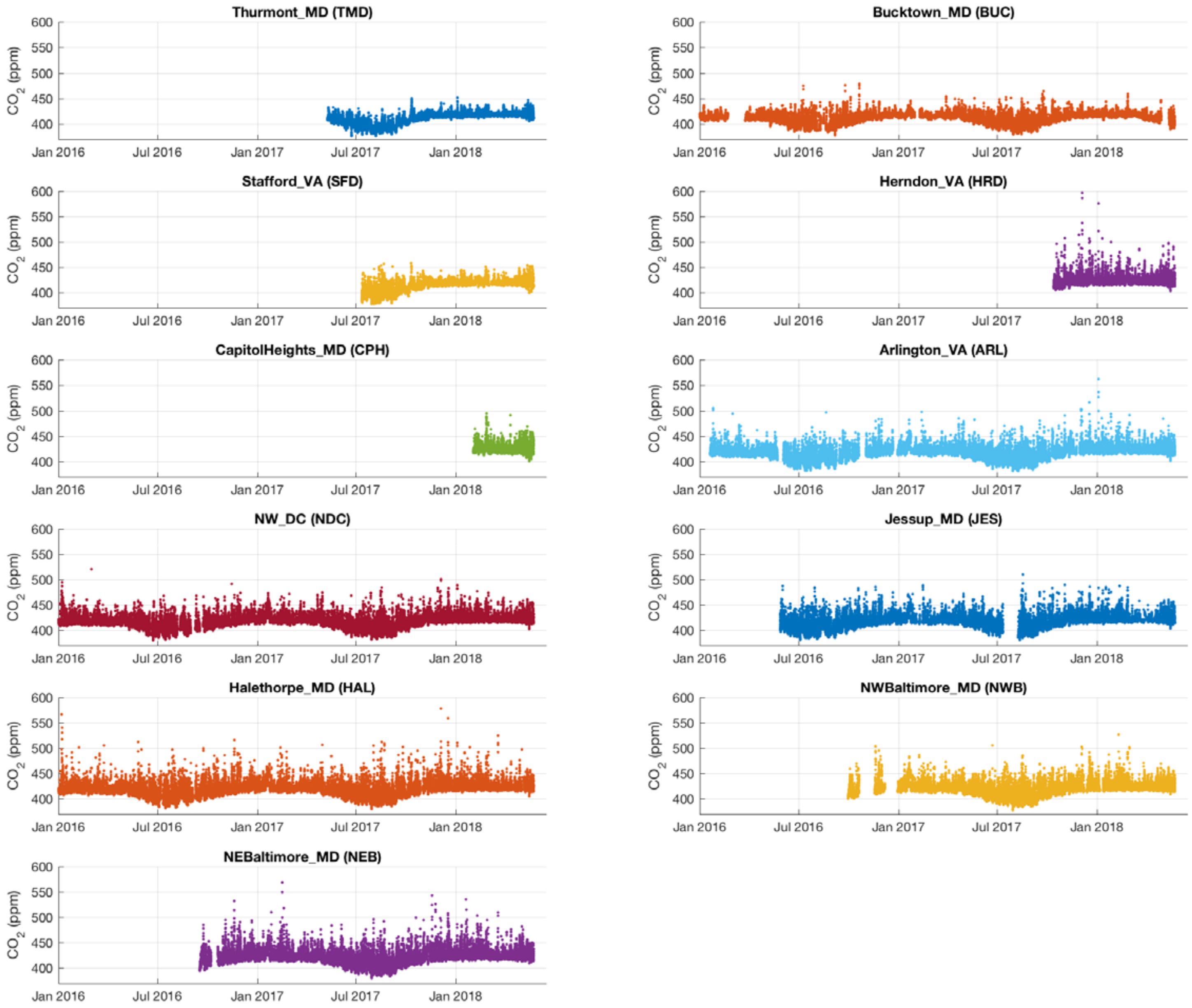


February 2016, Afternoon hours only

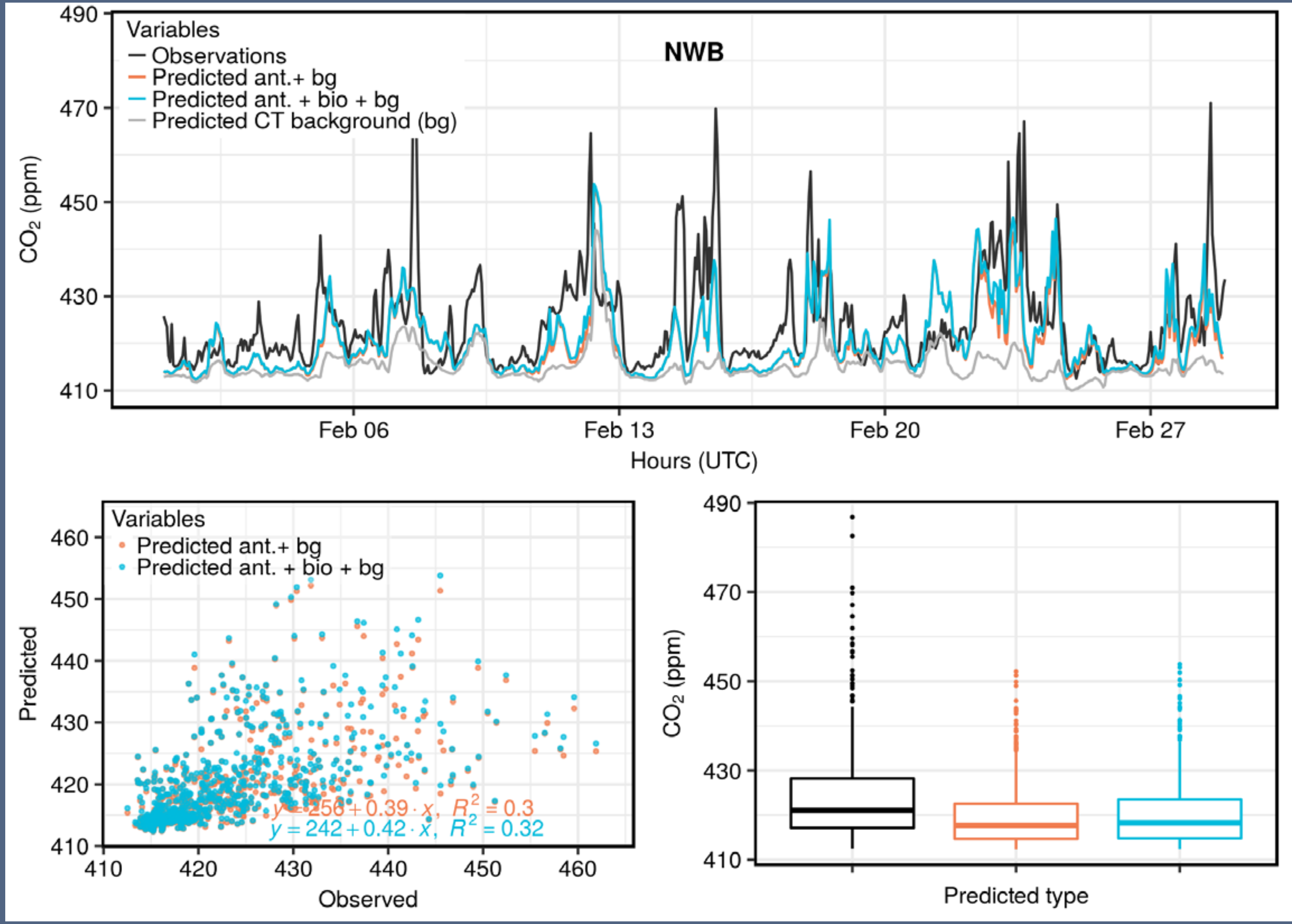
Israel Lopez Coto, NIST

CO_2

Jan 2016 – Apr 2018



LAGRANGIAN DISPERSION / FOOTPRINT MODELING



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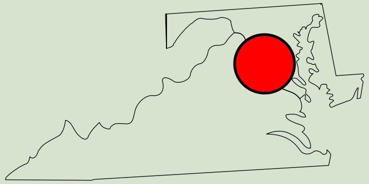
CONCLUSION

- Understanding and modeling transport and dispersion error is key to understanding the uncertainty in top-down emissions estimates!

NORTHEAST CORRIDOR – BALTIMORE/WASHINGTON

NIST	University of Maryland	Earth Networks	…and more
David Allen Subhomoy Ghosh Sharon Gourdji Israel Lopez Coto Kimberly Mueller Kuldeep Prasad Tamae Wong James Whetstone	Russ Dickerson Ross Salawitch Ning Zeng Kayo Ide DaLin Zhang Xinrong Ren Hao He Cory Martin Shaun Howe Doyeon Ahn Courtney Grimes & team	Steve Prinzivalli Clayton Fain Uran Veseshta Bryan Biggs Michael Stock Charlie Draper William Callahan GCWerks: Peter Salameh	Arizona State University: Kevin Gurney & team Boston University: Lucy Hutyra & team Bowdoin College: Barry Logan Purdue University: Paul Shepson NOAA/ESRL: Colm Sweeney, John Miller, Isaac Vimont U. Colorado/GNS Science: Jocelyn Turnbull Scripps & JPL: Kris Verhulst, Jooil Kim, & the LA Megacities team



THANK YOU

https://www.nist.gov/topics/greenhouse-gas-measurements

Anna.Karion@nist.gov