Connecting Ozone exceedances in Houston TX to variability in emissions and meteorology: Implications for federal attainment

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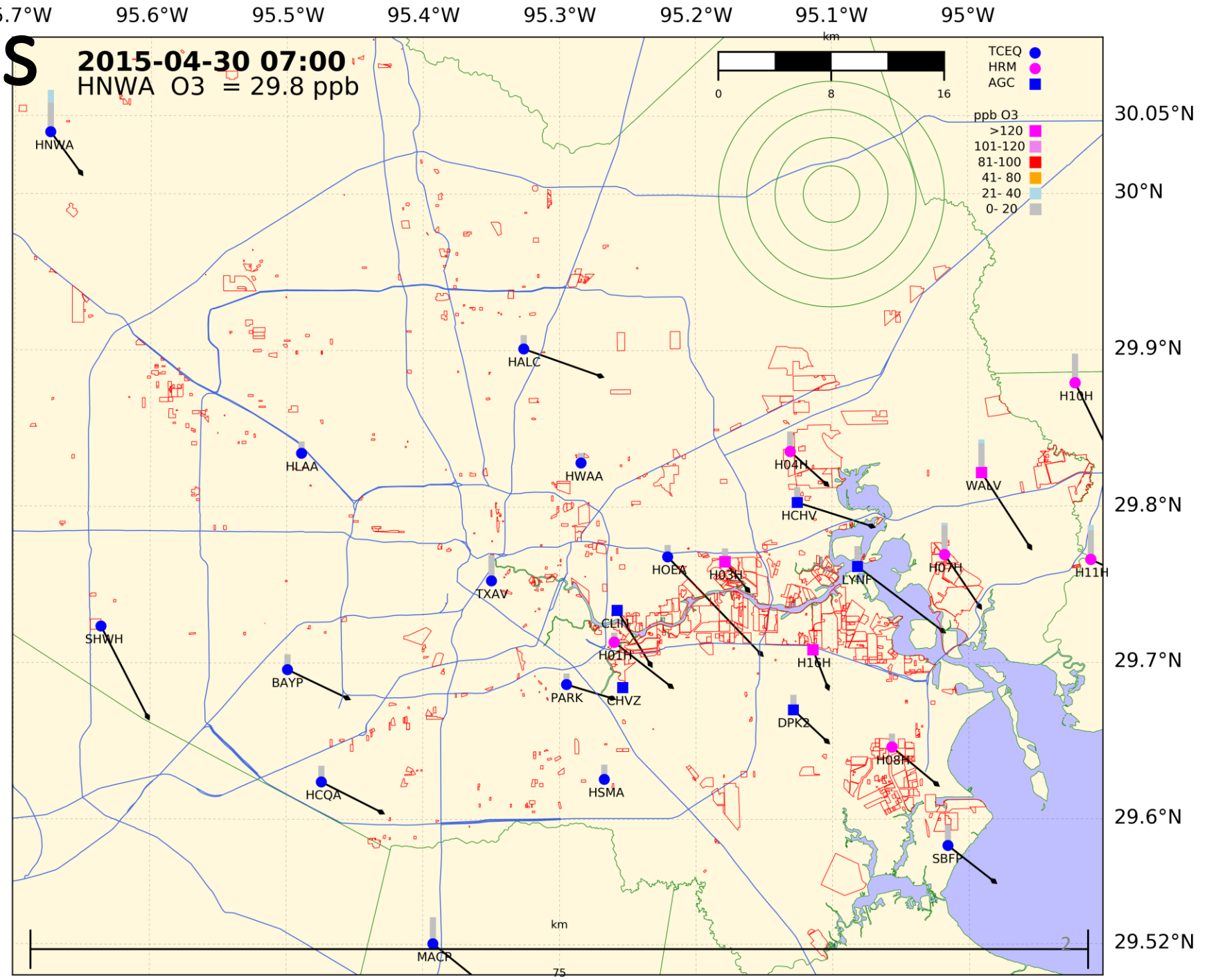
UNC GILLINGS SCHOOL OF GLOBAL PUBLIC HEALTH

Houston, Texas

- 4th Largest City in USA
- Houston Ship Channel
- Coastal Impacts
- 30º Latitude
- Year 2000



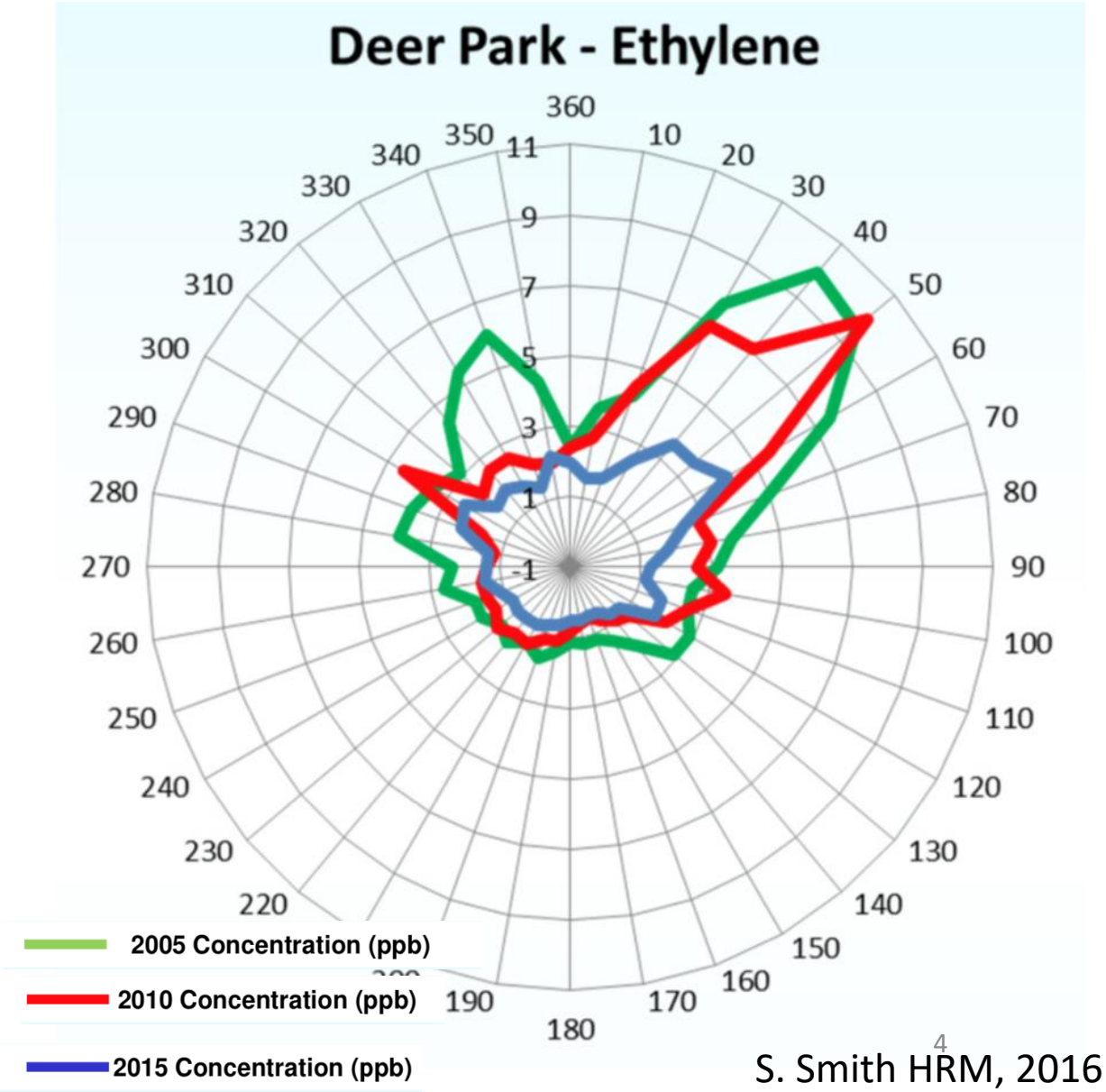
2004 Ozone Conceptual Model

- Ozone formation stems from two types of emissions:
  - Routine associated with an urban core
  - Fluctuations from short-term industrial VOC releases.
- Ozone design values driven by a combination of both types of emissions.
- Routine modeling addresses first type
- Weight of Evidence argument for VOC controls of ethene, propene, butenes, 1,3-butadiene

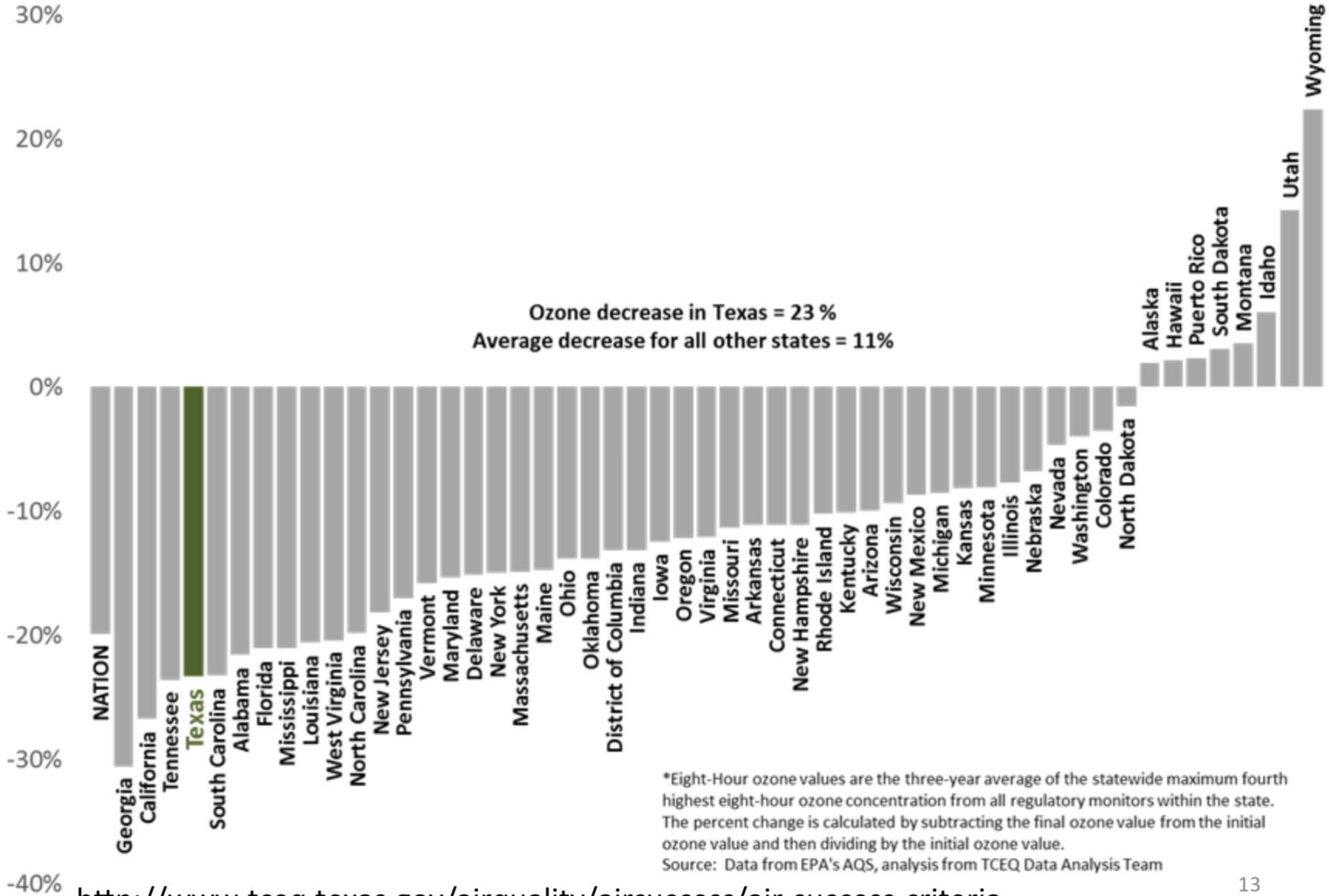
Texas Commission on Environmental Quality
HGB Mid-Course Review SIP
(2004-042-SIP-NR)

Focus On VOCs

- VOC Cap and Trade
- IR Cameras
- Event Emission Reporting (STEERS)
- Monitoring
- Special Emission Inventory

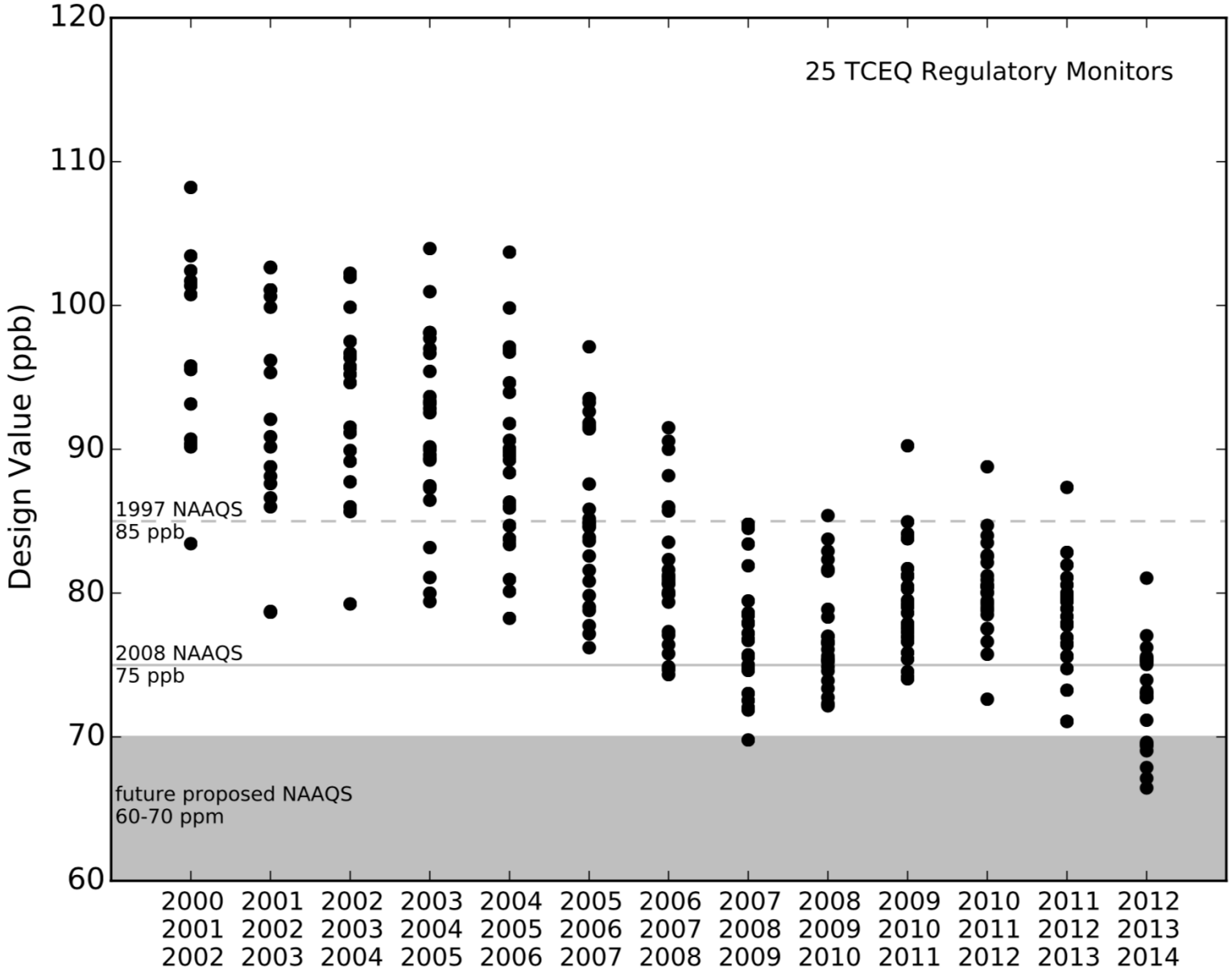


S. Smith HRM, 2016

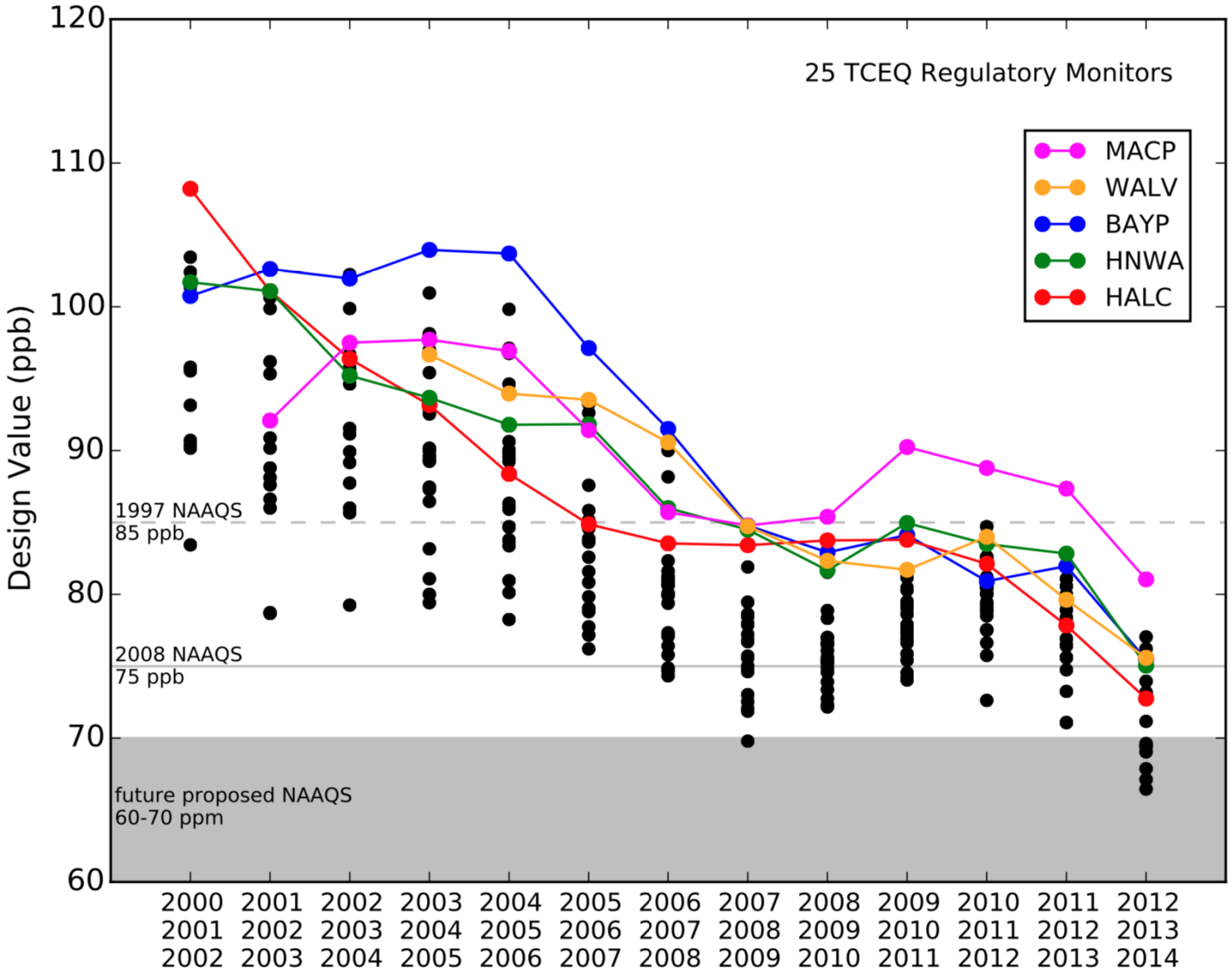


http://www.tceq.texas.gov/airquality/airsuccess/air-success-criteria

Ozone Design Values



Ozone Design Values

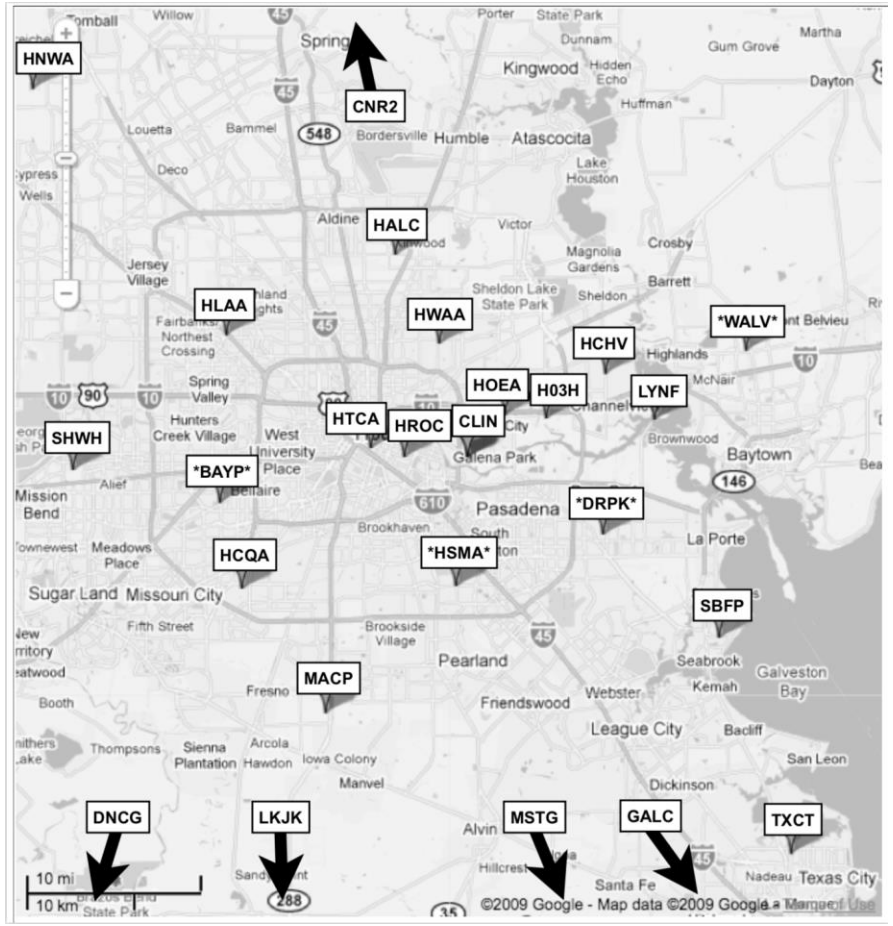


Houston Ozone Attainment

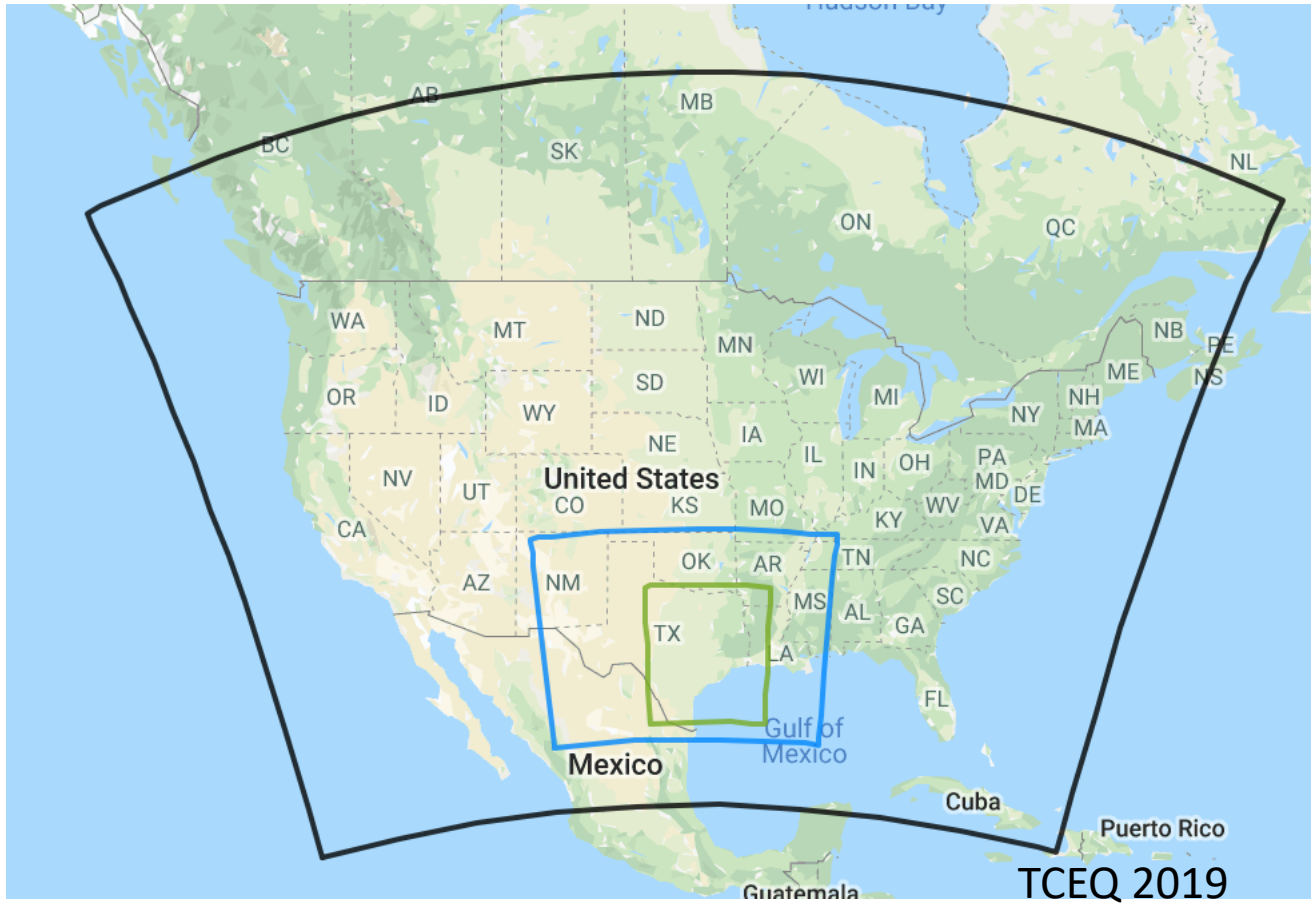
- Is Houston still a two ozone city?
- Are VOCs still relevant?
- Has Meteorological conditions changed?
- Can regulatory model capture observed phenomena?
- Attainment of 70 ppb?

Houston Data

Observations 2000-2015



Regulatory Air Quality Model 2012



- Found ***necessary*** conditions
- Looking for a ***sufficient*** condition

Meteorological Analysis

Necessary Conditions

Presentation at the
TexAQS II Intensive Field Study Meeting
October 11 – 12, 2005

Air Trajectory Tools and Theoretical Analysis of the Houston-Galveston Area Land/Sea Breeze

Daewon W. Byun[1], Seung-Bum Kim[1*] , Fantine Ngan[1]
Soontae Kim[1], and Bonnie Cheng[1]

Institute for Multidimensional Air Quality Studies
University of Houston

*** Present Affiliation: Global Environmental Laboratory,**
Yonsei University

H19 Final Report , Real-Time Trajectory Analysis Operation and Tool Development

Used by permission Dr. Kim 2019

Governing set of layer-mean momentum equations in the mixed layer model

Gutman and Berkofsky (1985); Byun and Arya (1990) →

$$\frac{\partial \mathbf{V}_m}{\partial t} = -\mathbf{ADV}(\mathbf{V}_m) - f\mathbf{k}\times(\mathbf{V}_m - \mathbf{V}_{Gm}) - \left[g'\nabla\bullet\eta - \left(\frac{gh}{2\Theta_0}\right)\nabla\bullet\Theta_m \right] - \frac{C_d}{h}|\mathbf{V}_m|\mathbf{V}_m \quad (1)$$

[1] [2] [3] [4] [5] [6]

[1] Local tendency

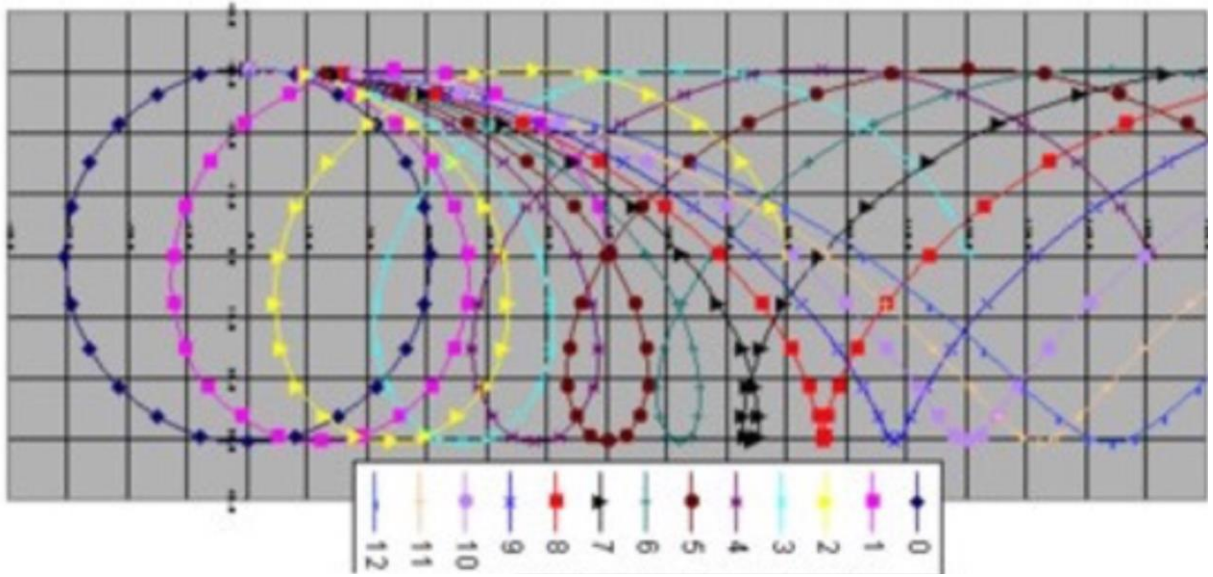
[2] Advection

[3] Coriolis forcing

[4] Large-scale pressure gradient (or geostrophic) forcing

[5] Local thermal forcing

[6] Turbulent drag – Quadratic friction (no entrainment assumption)



Role of friction

Byun and Arya (1990)

$$E_m \equiv C_d |\mathbf{V}_{Gm}| / fh$$

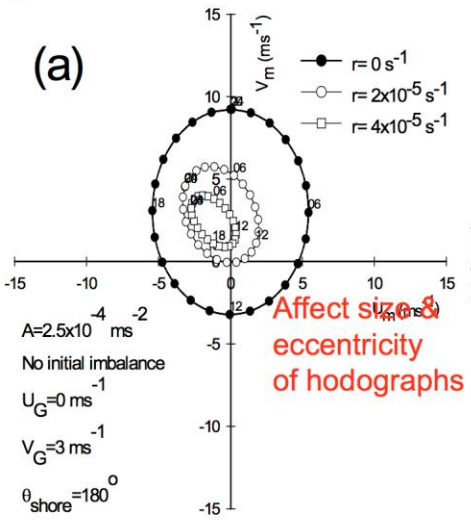
$$r = \frac{f}{\sqrt{2}}\left[-1+(1+4E_m^2)^{1/2}\right]^{1/2}$$

Mixed Layer Ekman Number

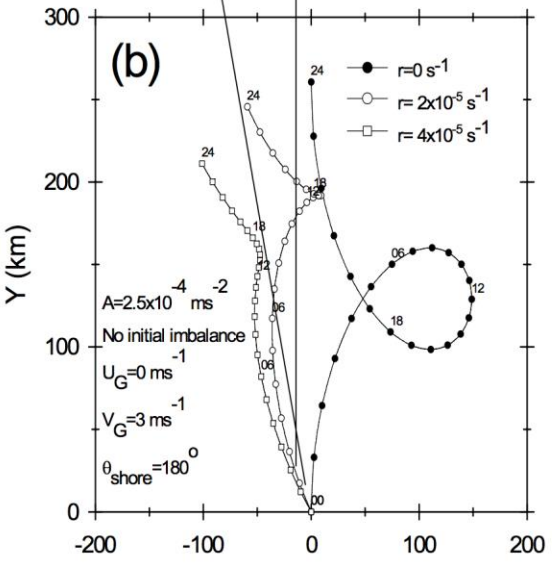
$$\alpha_T = \tan^{-1}\left(\frac{1}{\sqrt{2}}\left[-1+(1+4E_m^2)^{1/2}\right]^{1/2}\right)$$

$r\uparrow \Rightarrow \alpha_T \uparrow$

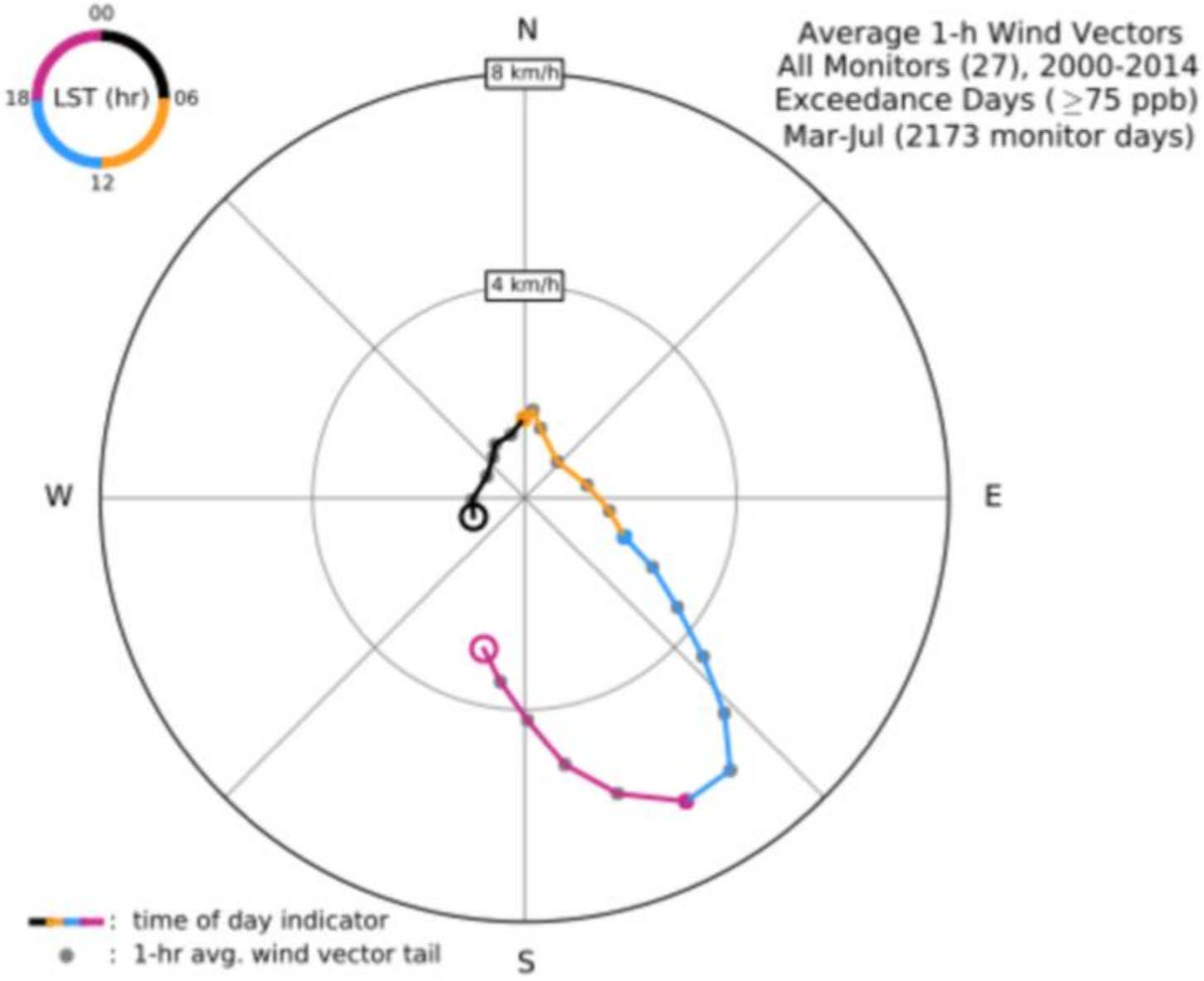
$\alpha_T = \alpha_m$ α_T (cross-isobaric angle of linear stationary flow)



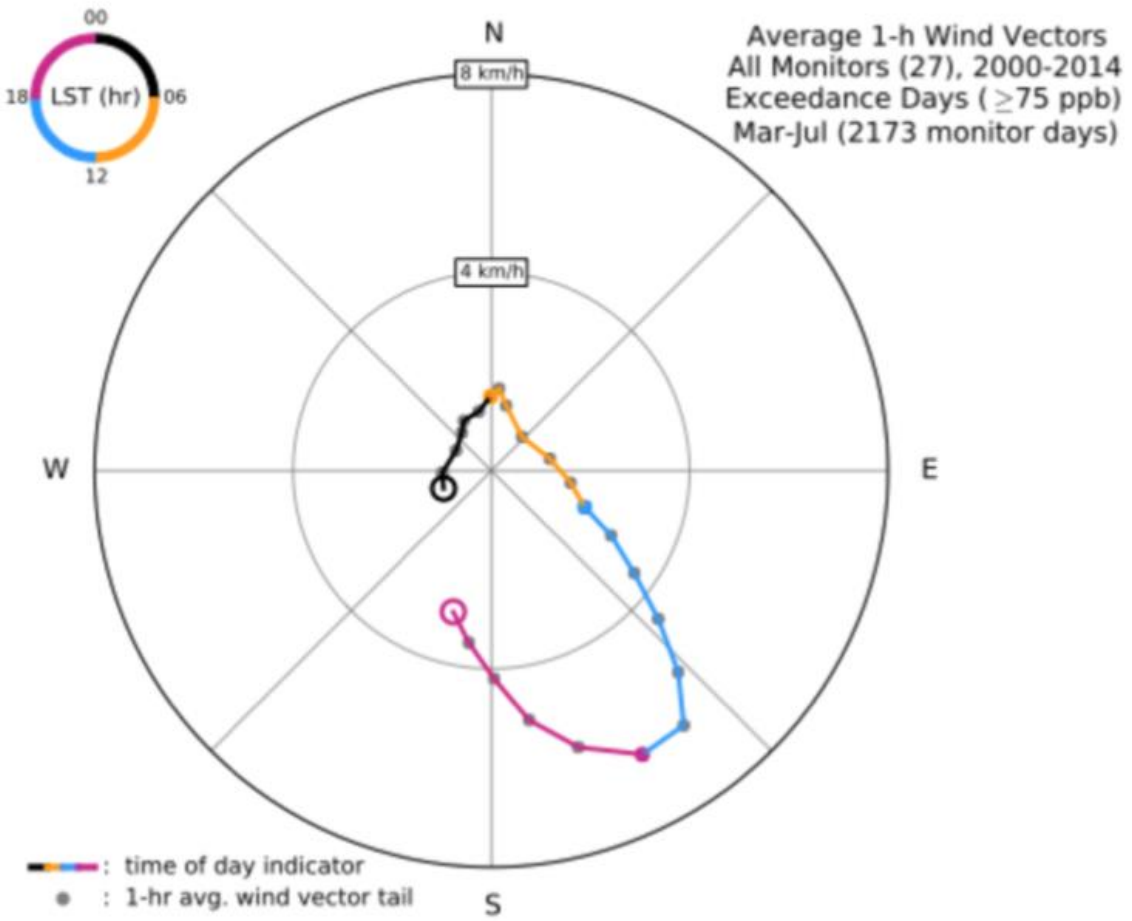
Affect size & eccentricity of hodographs

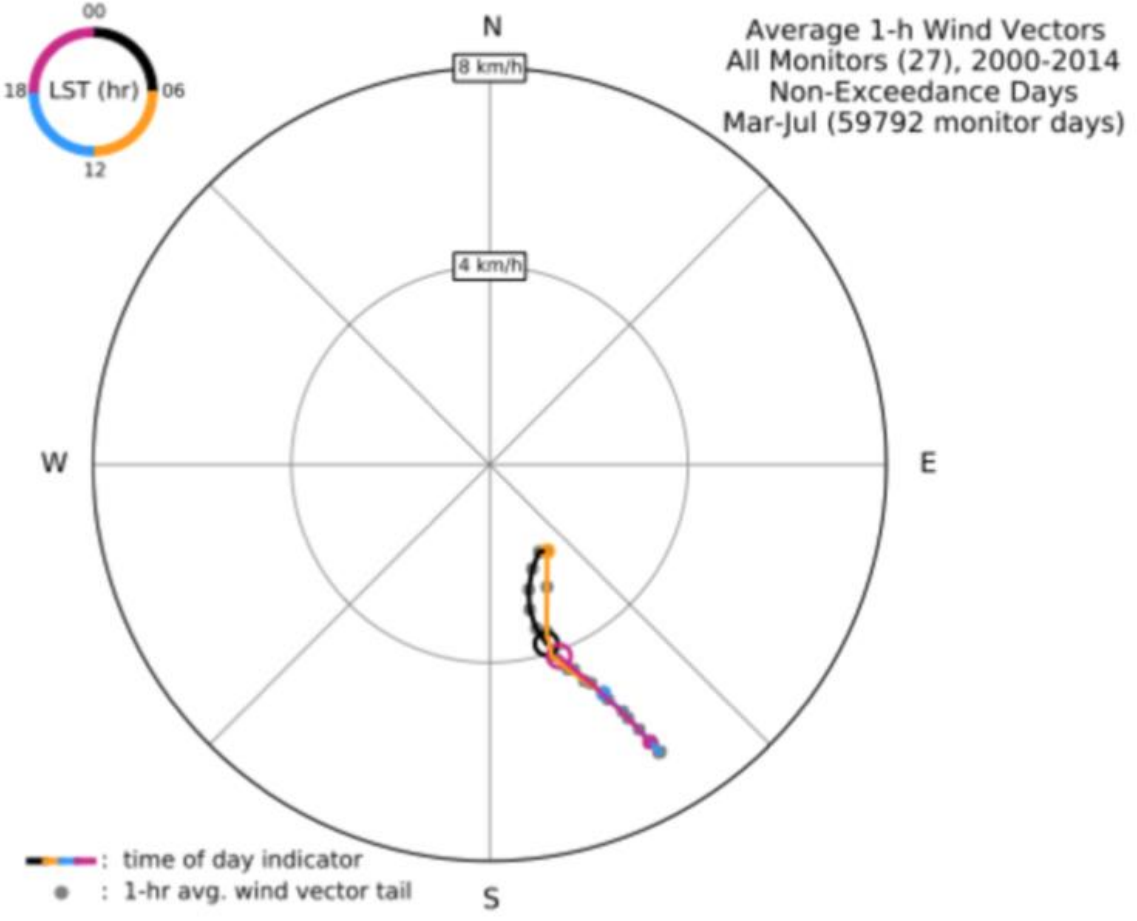


Observed Wind Vectors

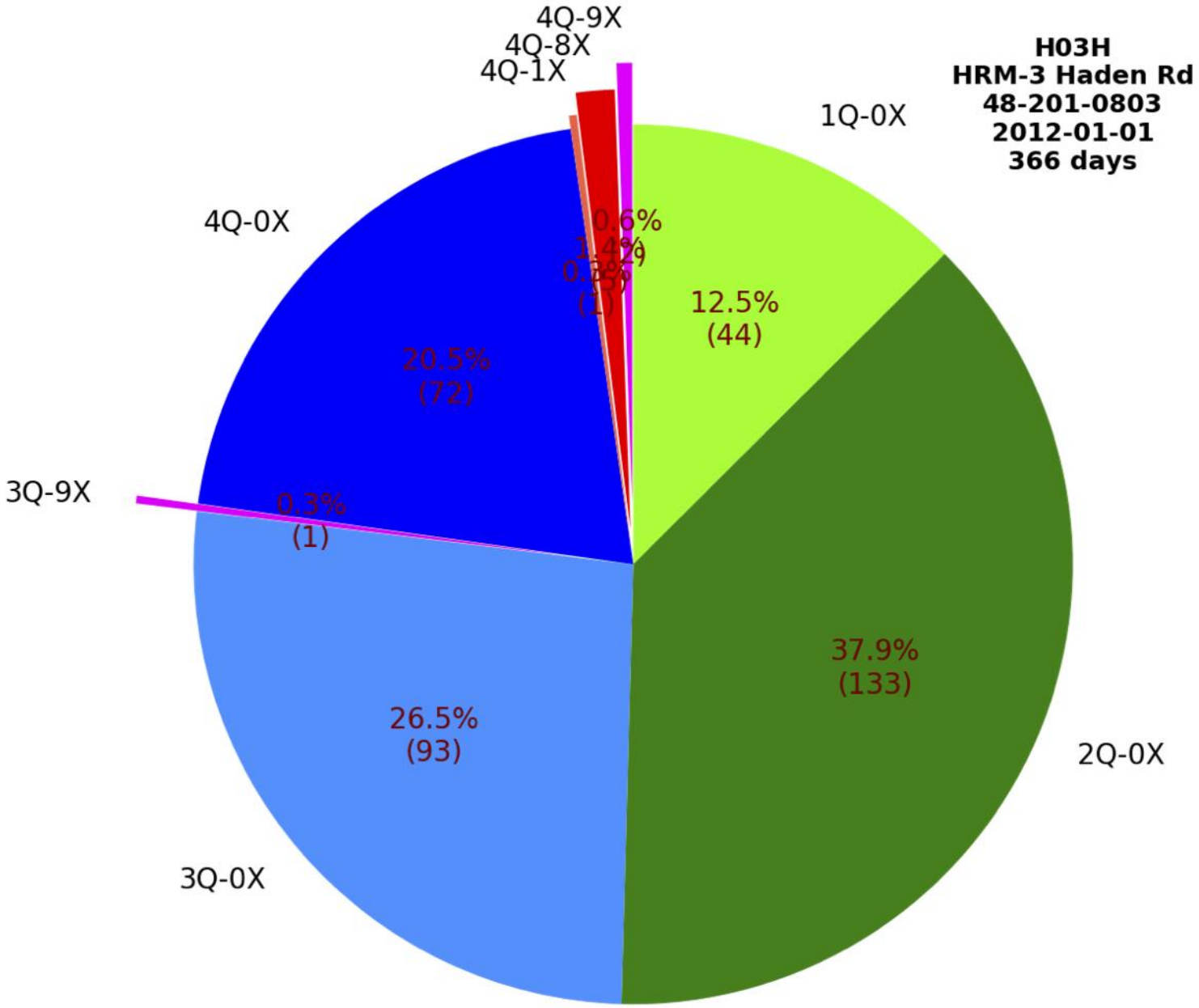


2000 - 2014 Average 1-h Hodograms for Exceedance and Non-exceedance Days at 27 HGA Monitors





Observed Ozone and Wind Quadrants



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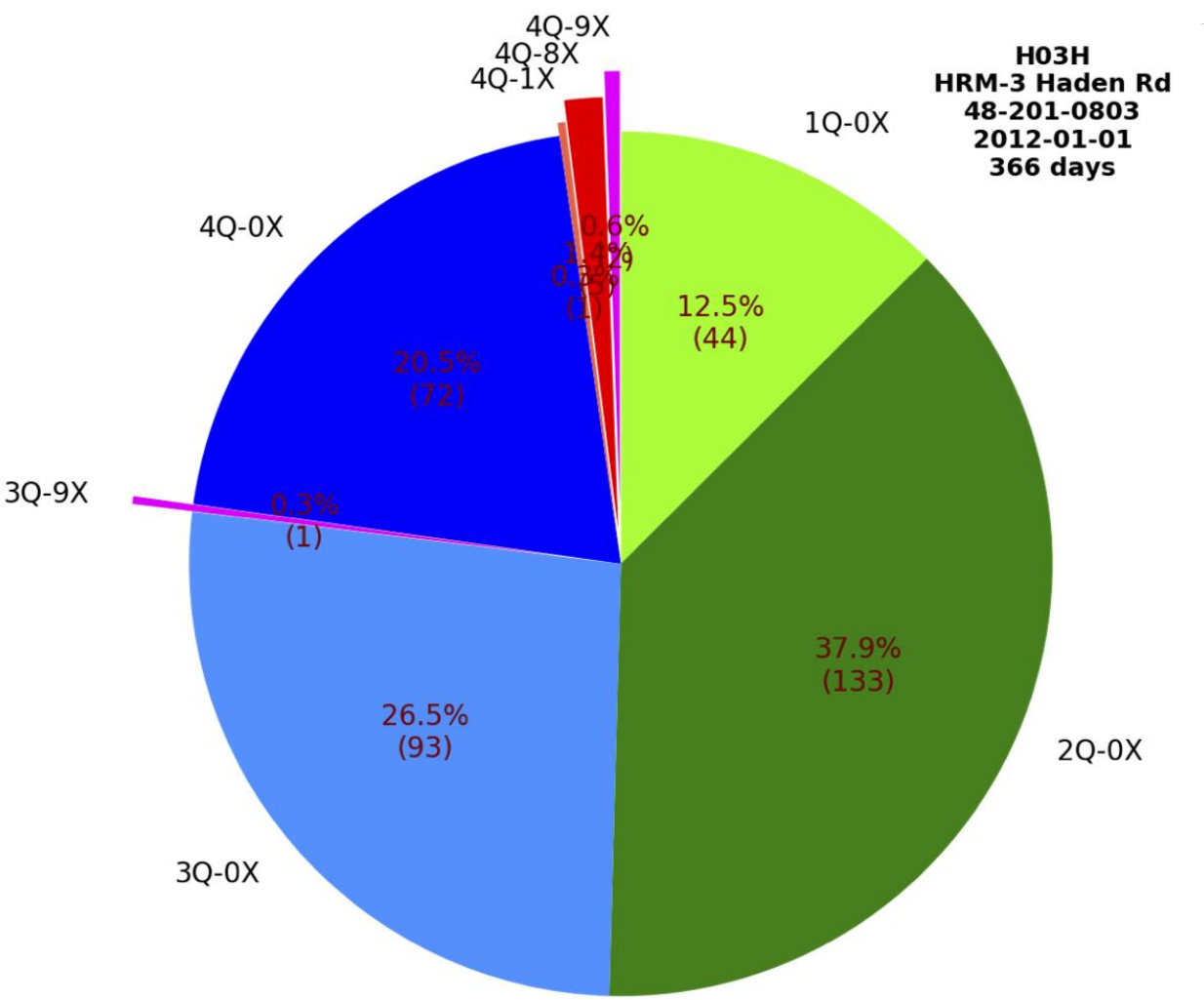

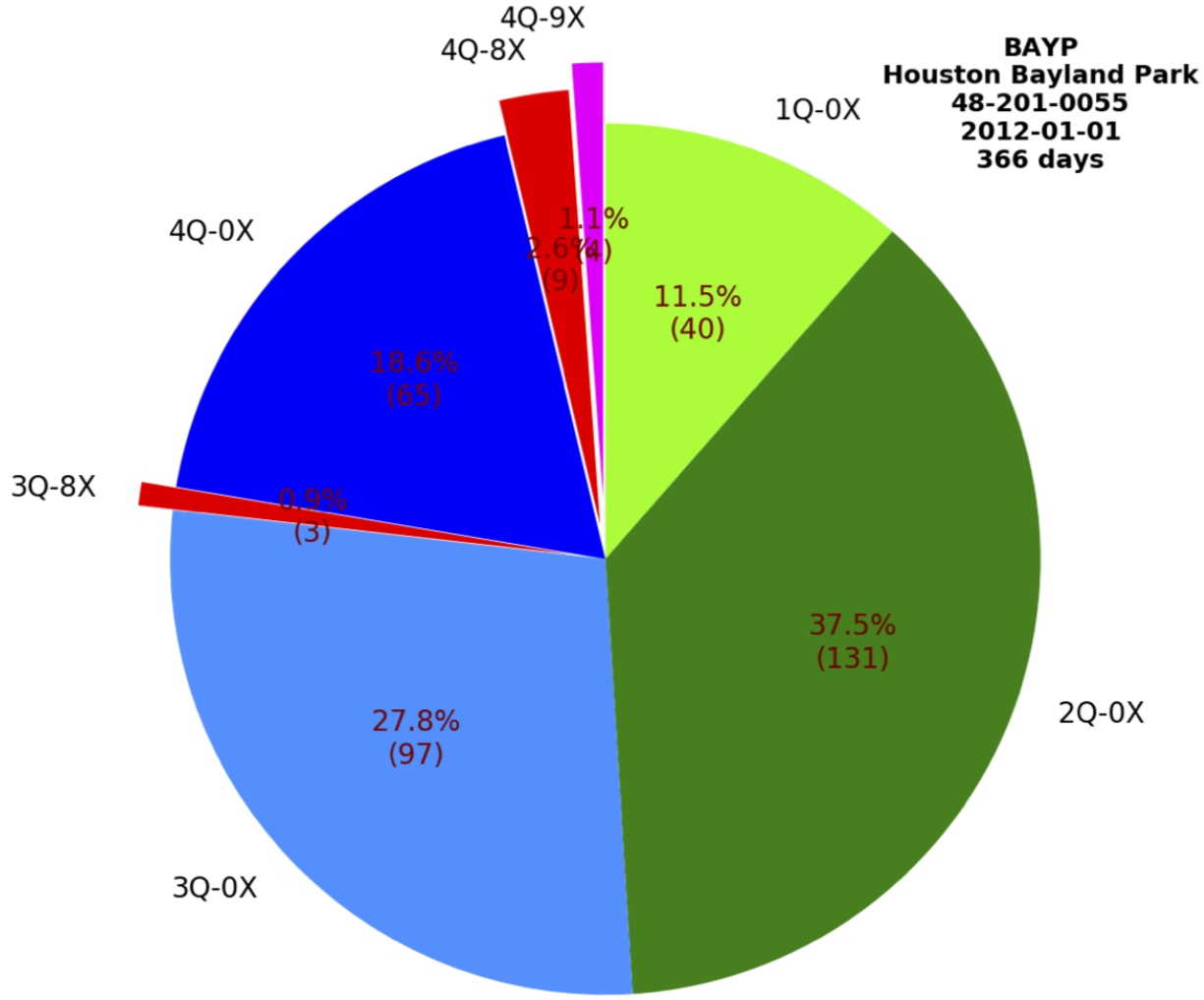

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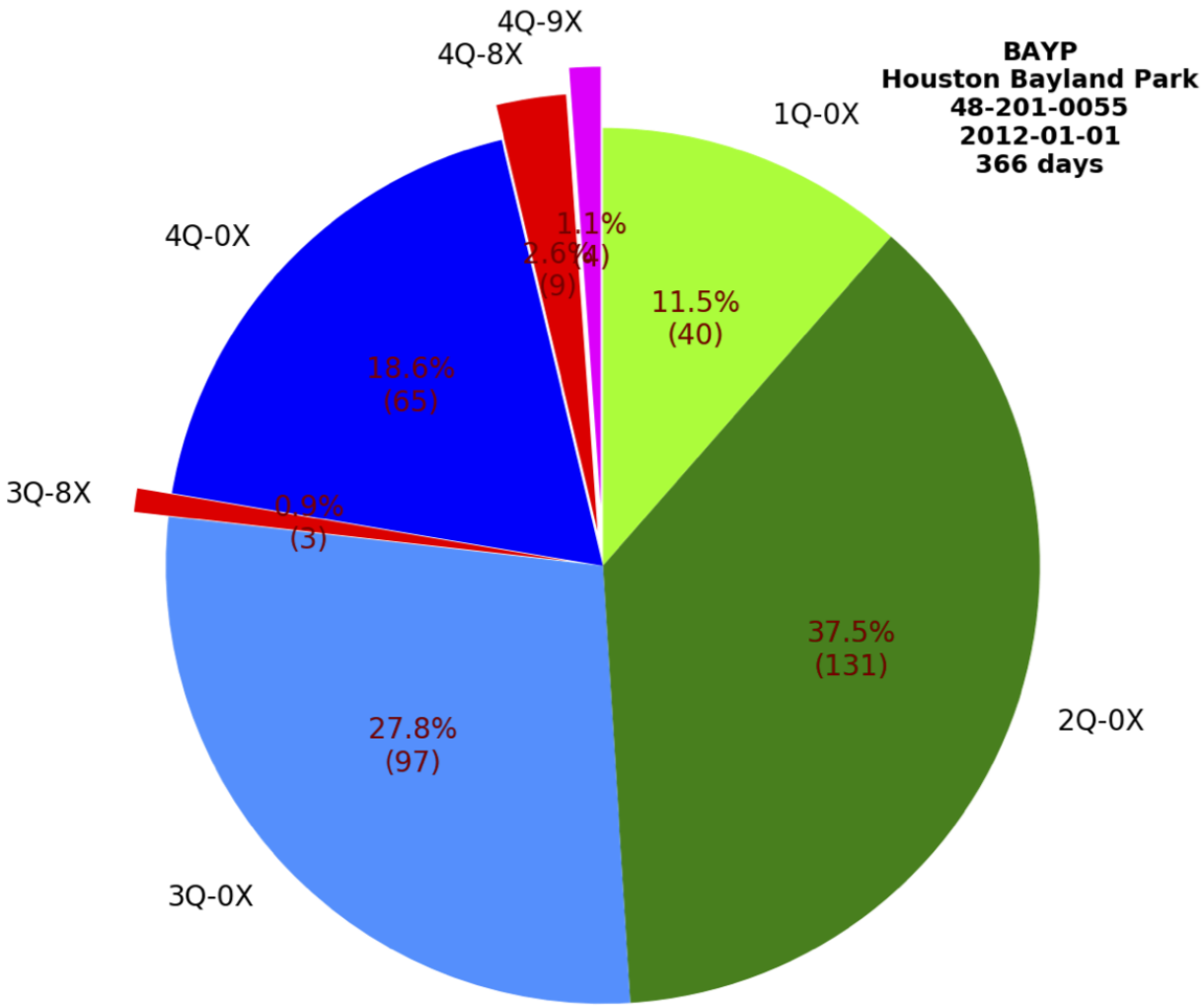
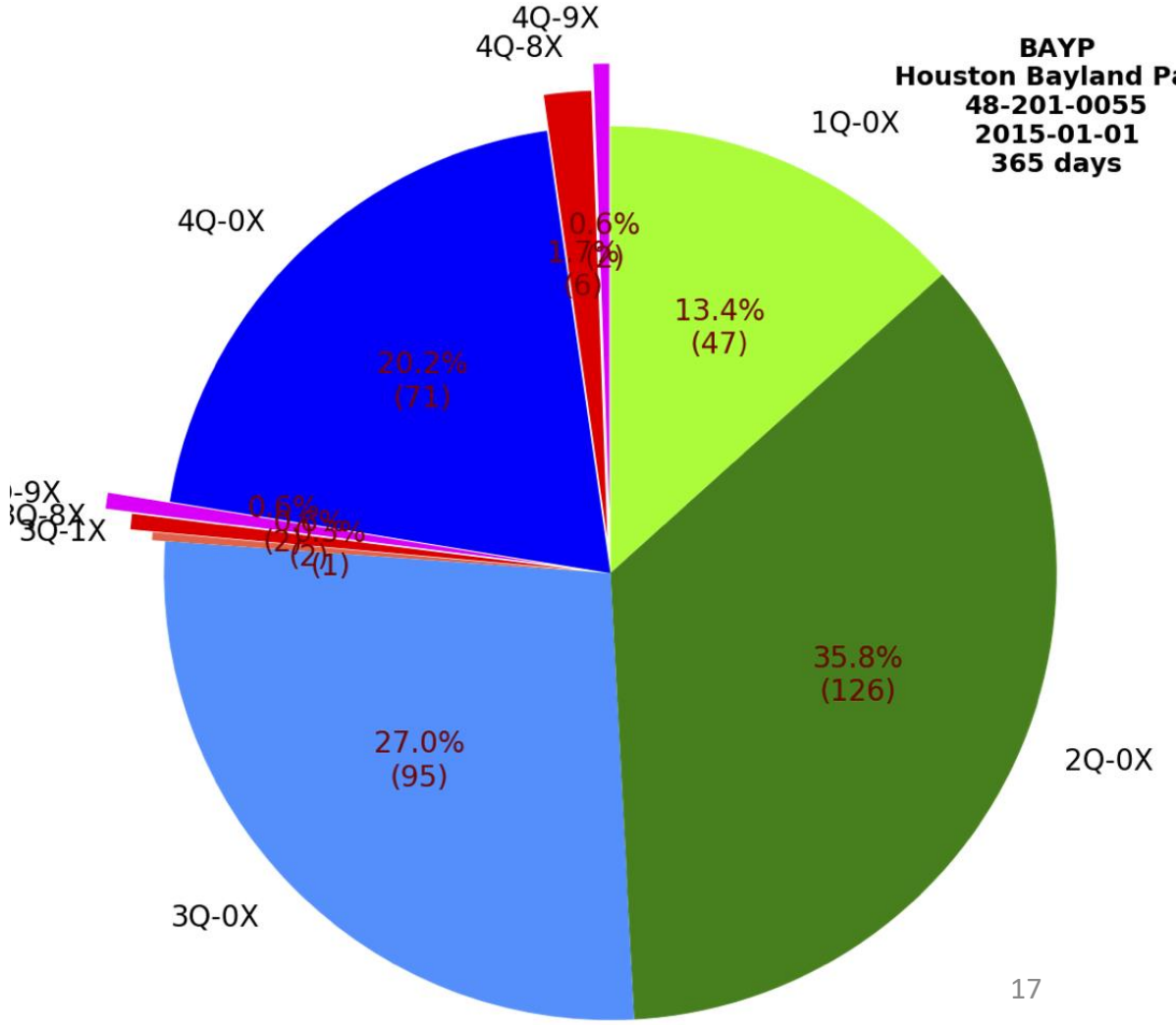
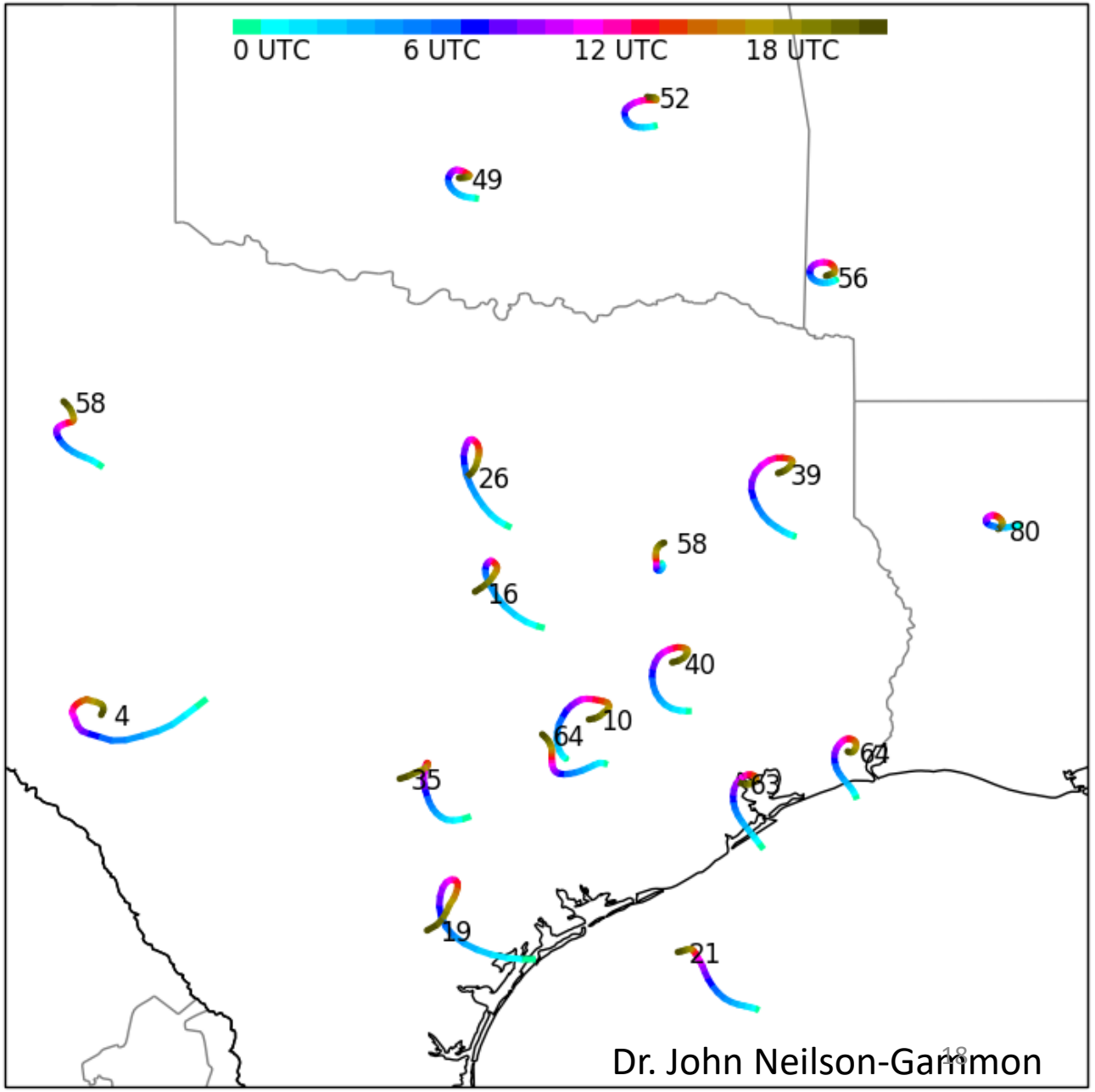


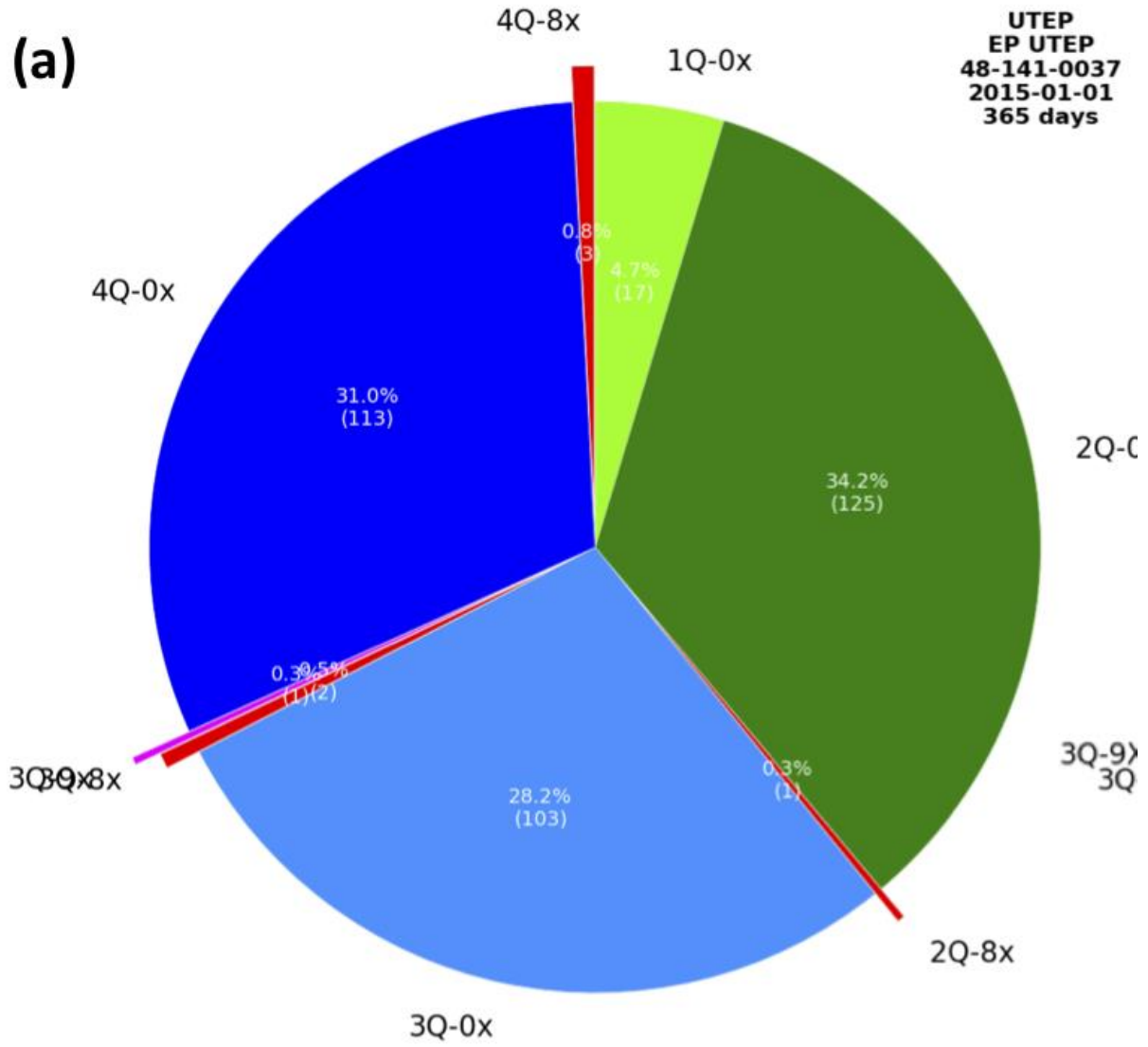


Acoustic Profiler Data

- NOAA Profiler Network
- June 1, 2005 - October 31, 2006
- Composite 500 m AGL trajectories
- Arriving at 0000 UTC (6PM LST) based on winds preceding 24 hours.
- Average of hourly winds during all warm-season (May-October) days in which the vector mean wind speed over the 24-hours <3 m/s (10.8 km/h).



Observed Ozone and Wind Quadrants



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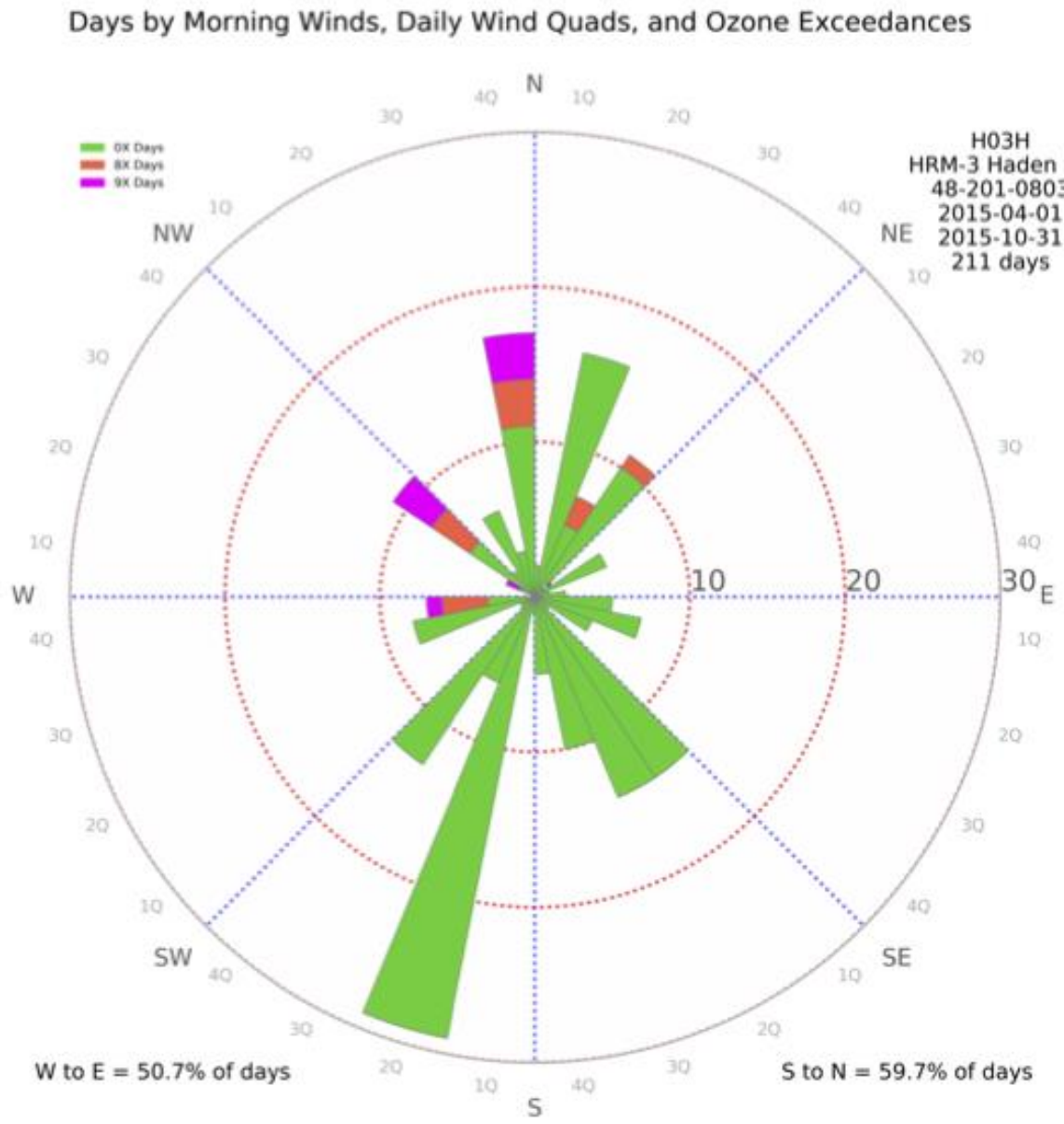
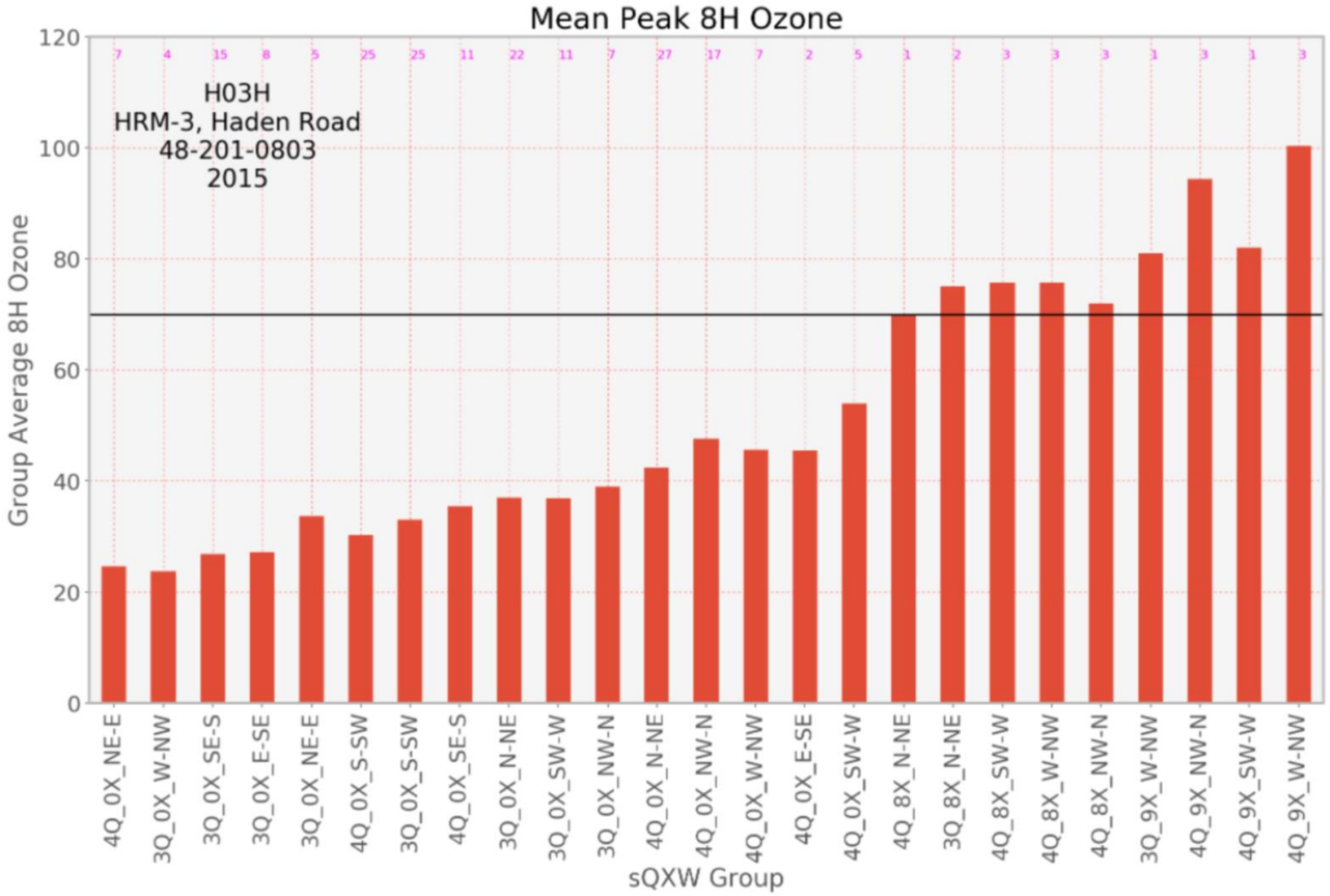
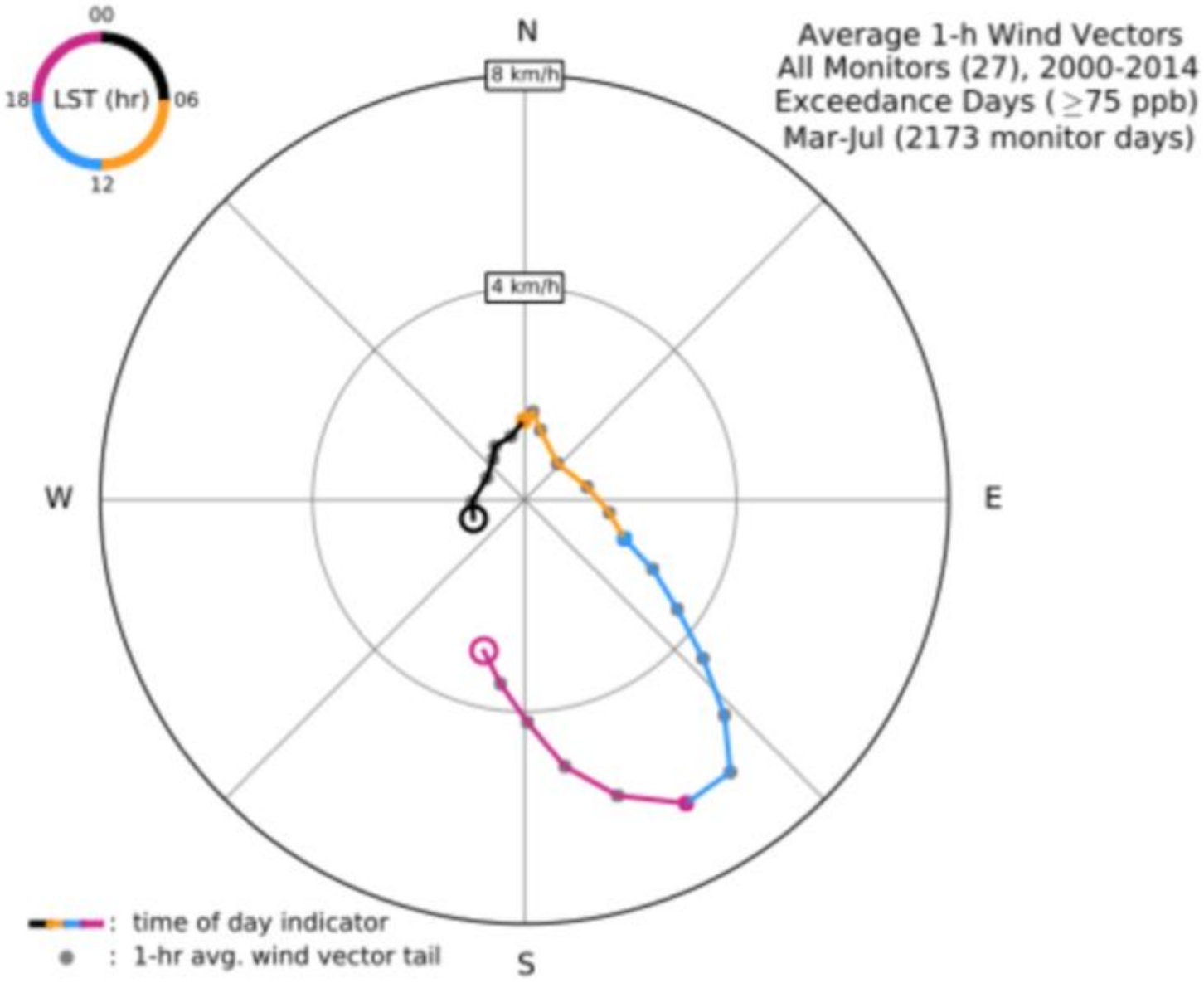


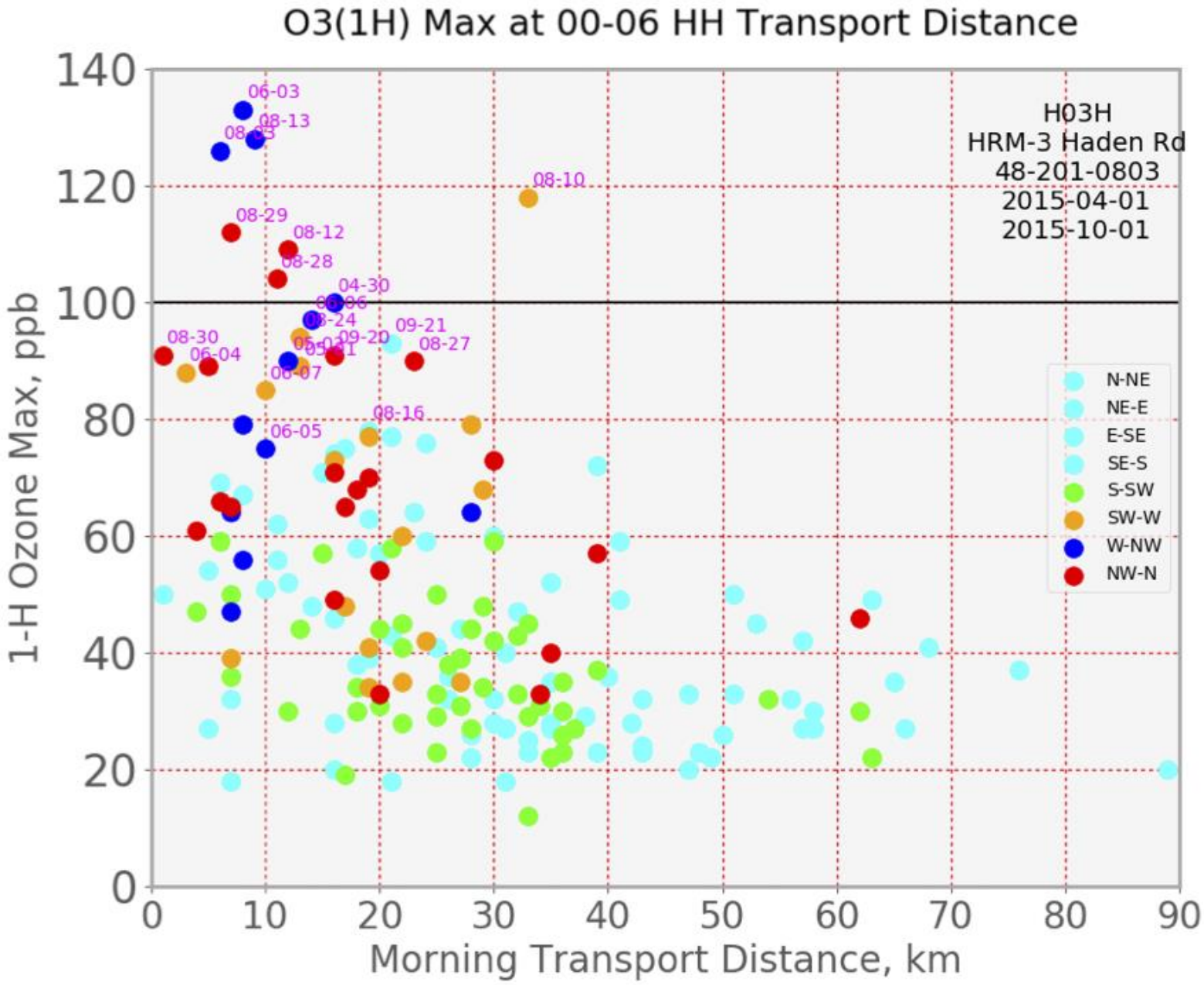
Observed Ozone and Wind Direction



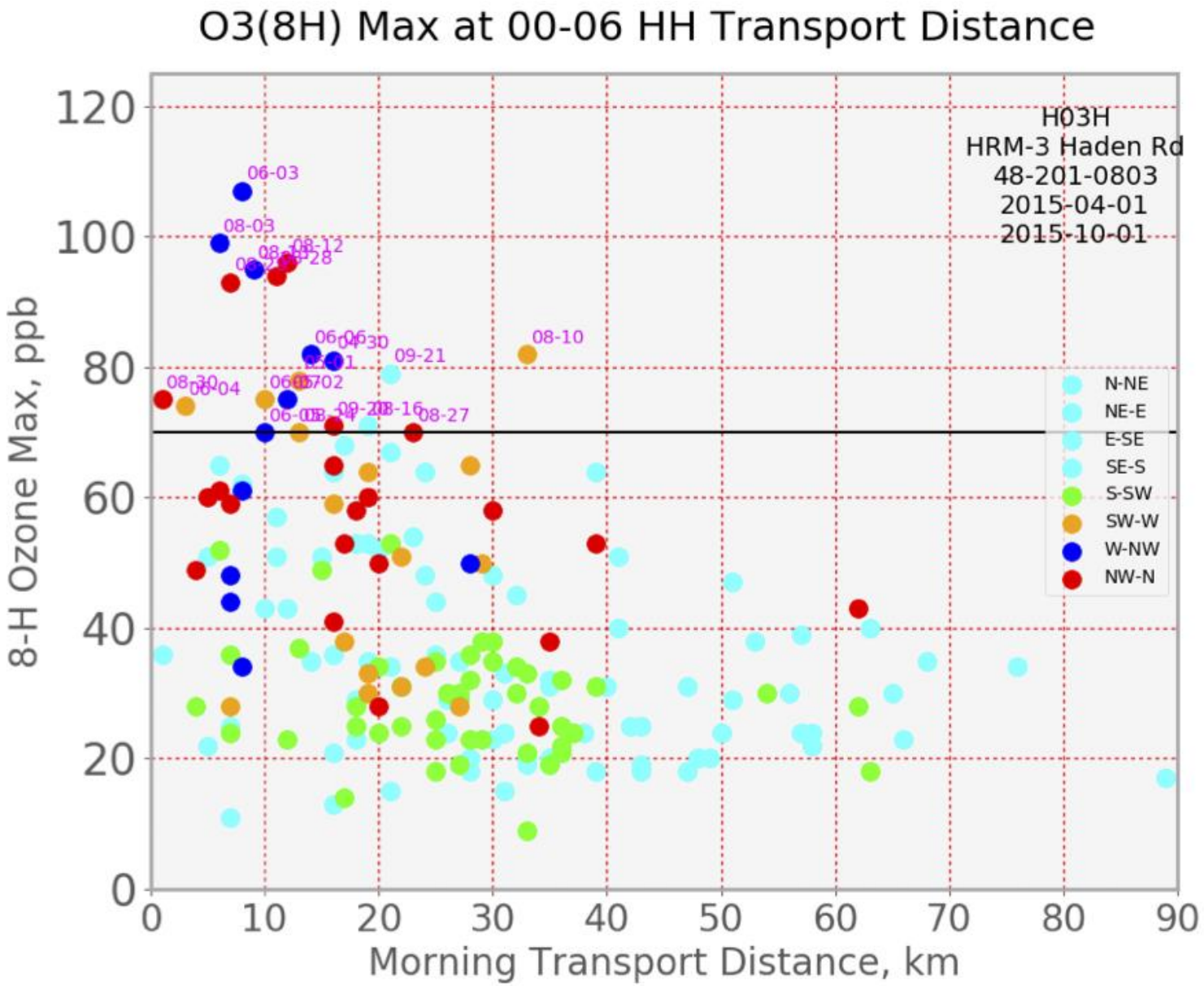
Observed Ozone and Wind Vectors



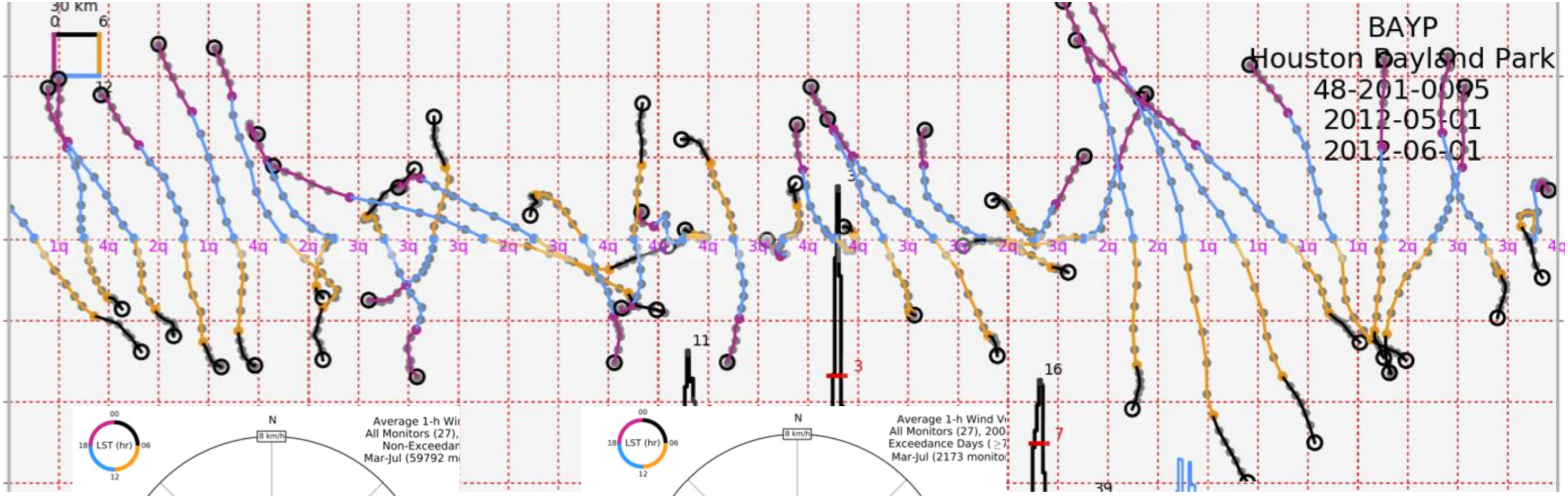
Observed Ozone and Transport Distance

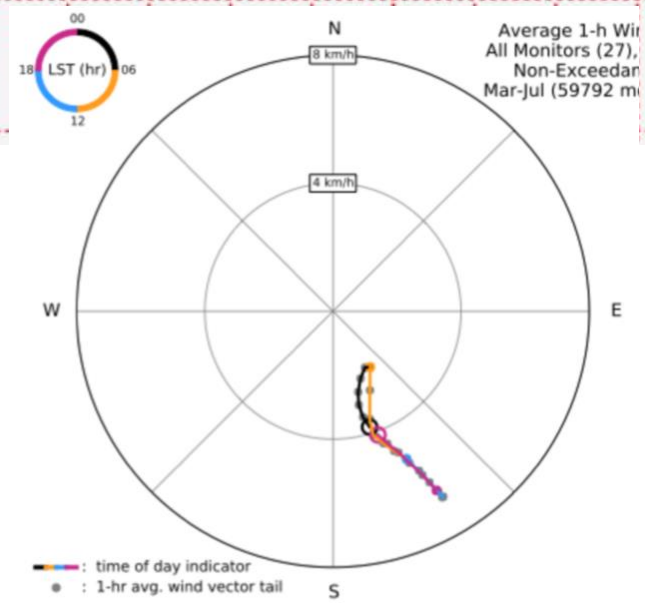


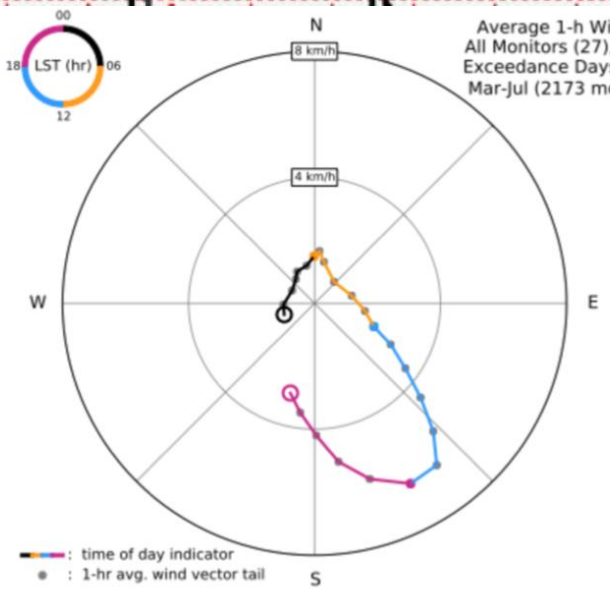
Observed Ozone and Transport Distance

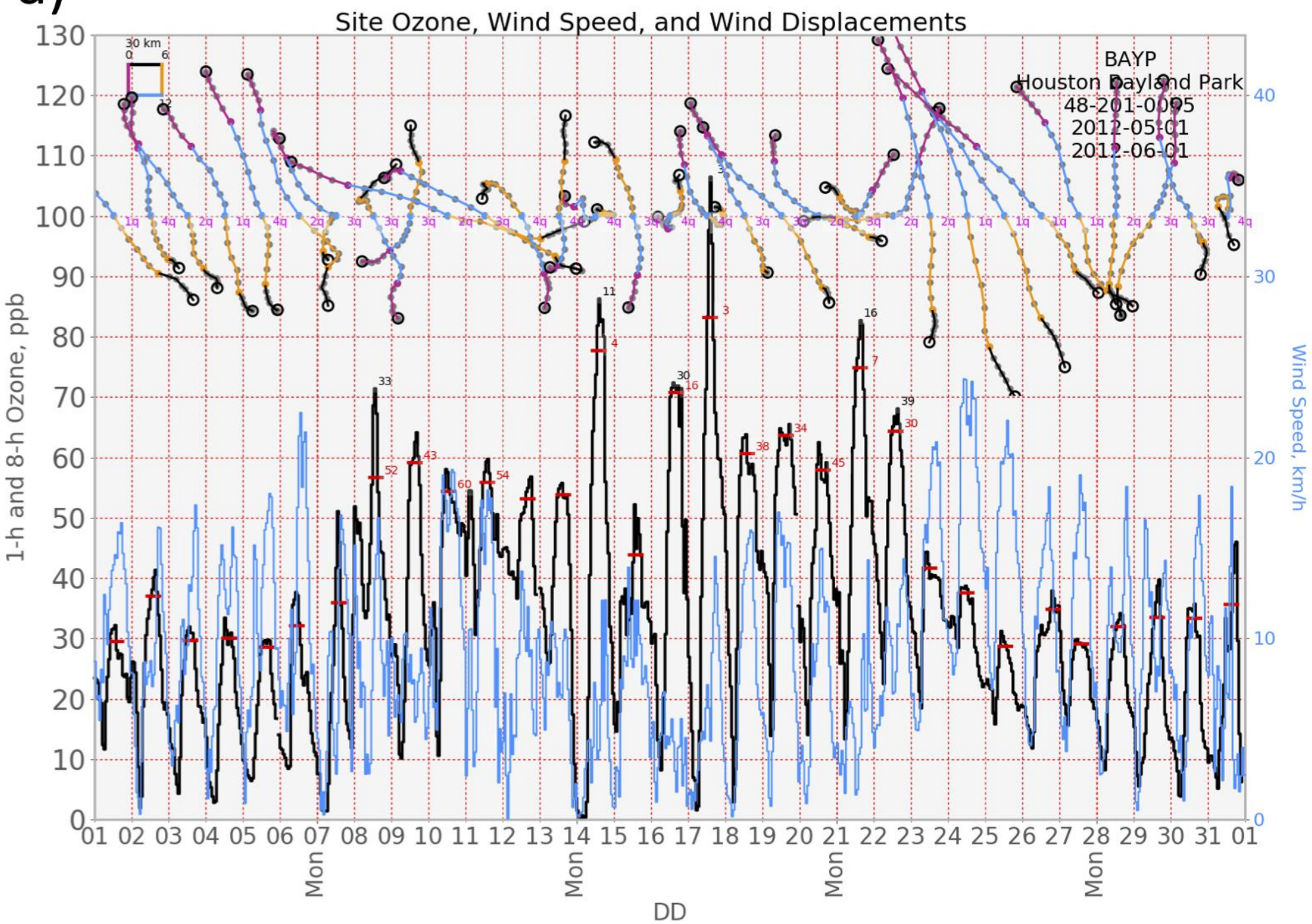


Displacement Distance








a)
Site Ozone, Wind Speed, and Wind Displacements
BAYP
Houston Bayland Park
48-201-0095
2012-05-01
2012-06-01
30 km
0
6
1-h and 8-h Ozone, ppb
Wind Speed, km/h
DD
Mon
Mon
Mon
Mon

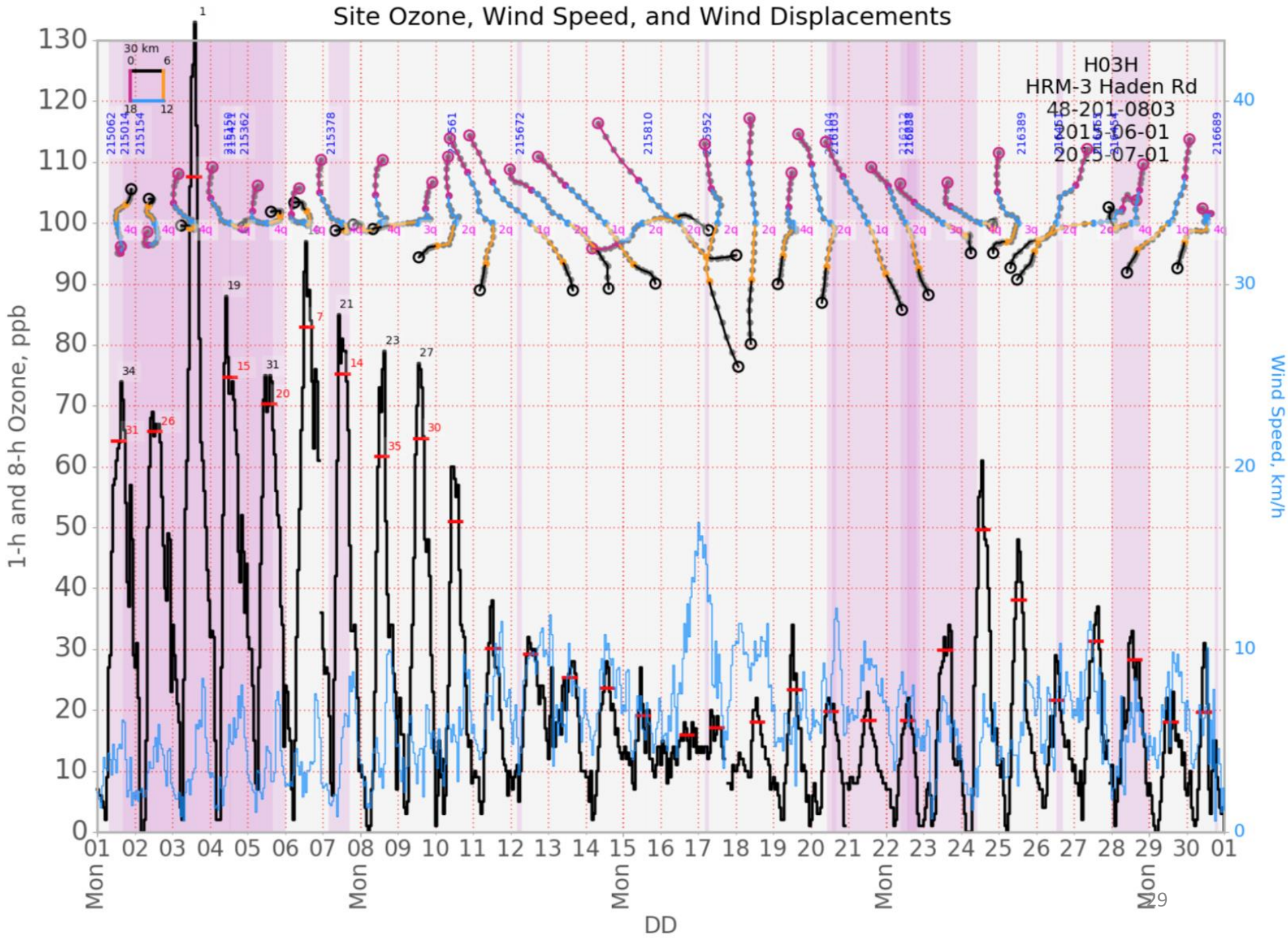
Meteorological Results

- Identified “necessary circulation conditions”
- Highest exceedances <25 km transport distances
- Frequency of 3-4 quadrant days unchanged
- Need “sufficient conditions” to create exceedances.

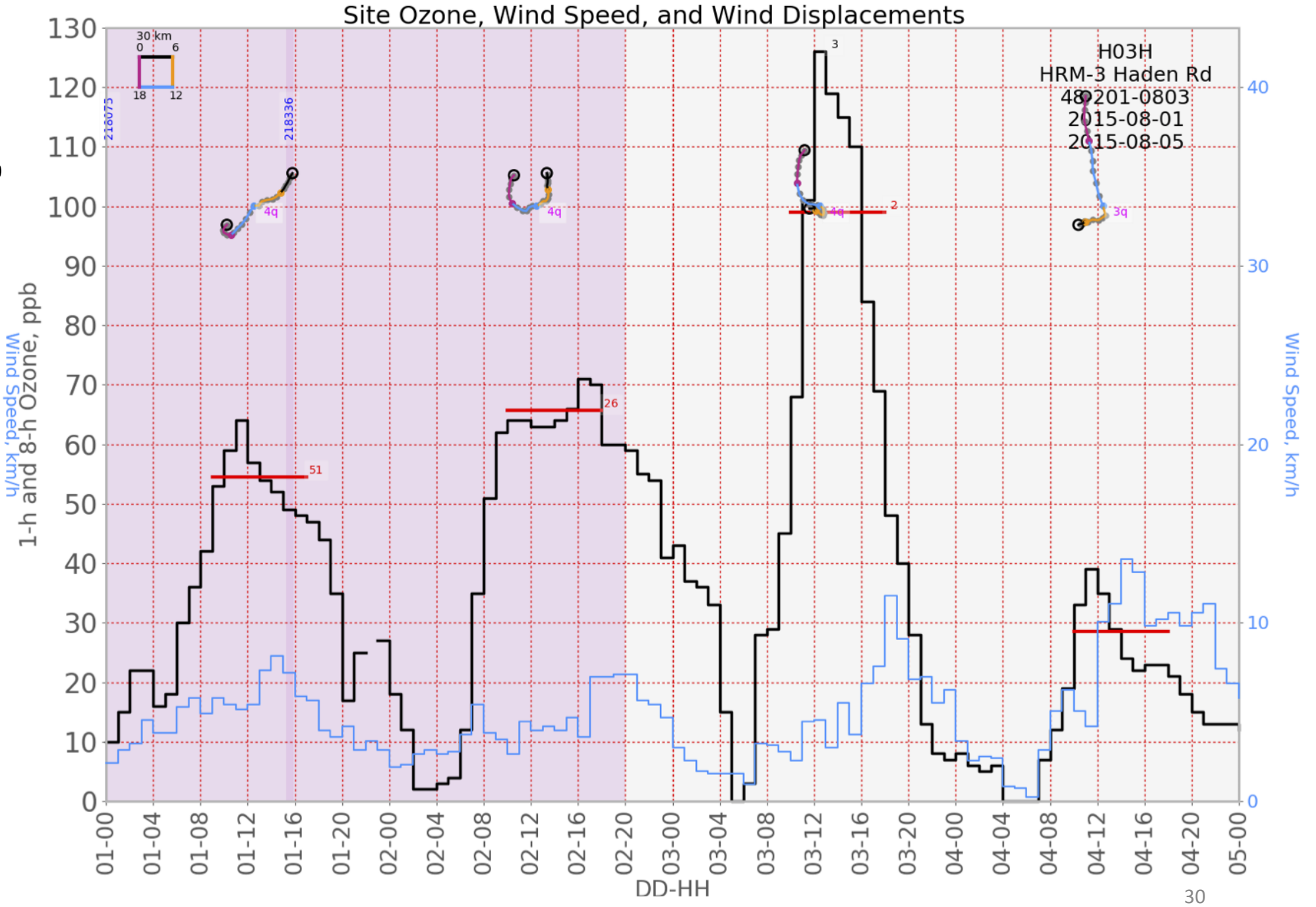
Ozone Analysis

Sufficient Conditions

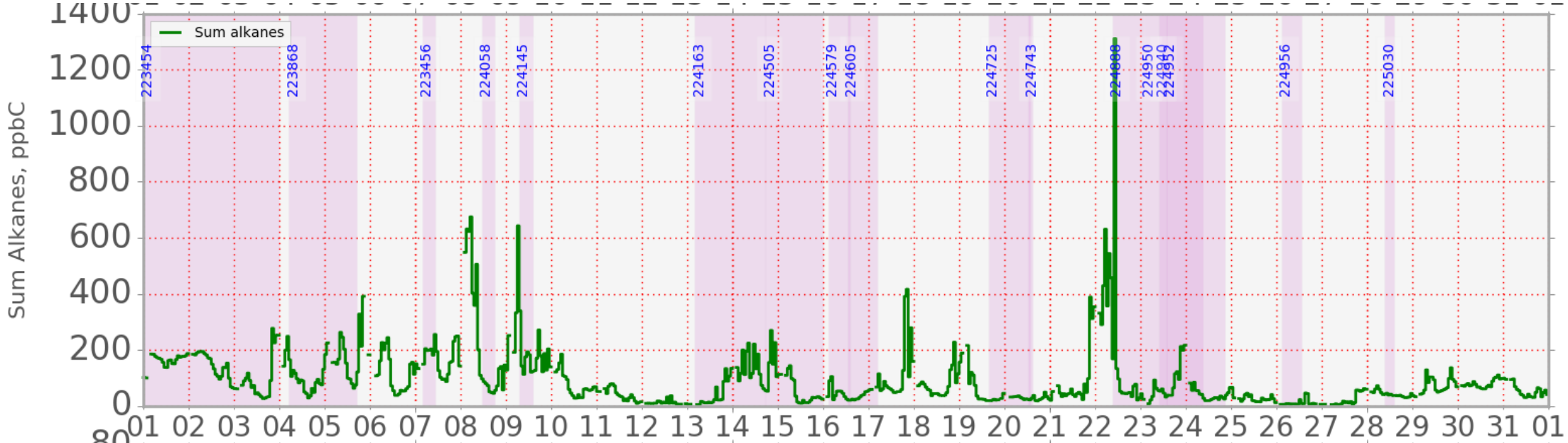
Emission Event Database (STEERS)

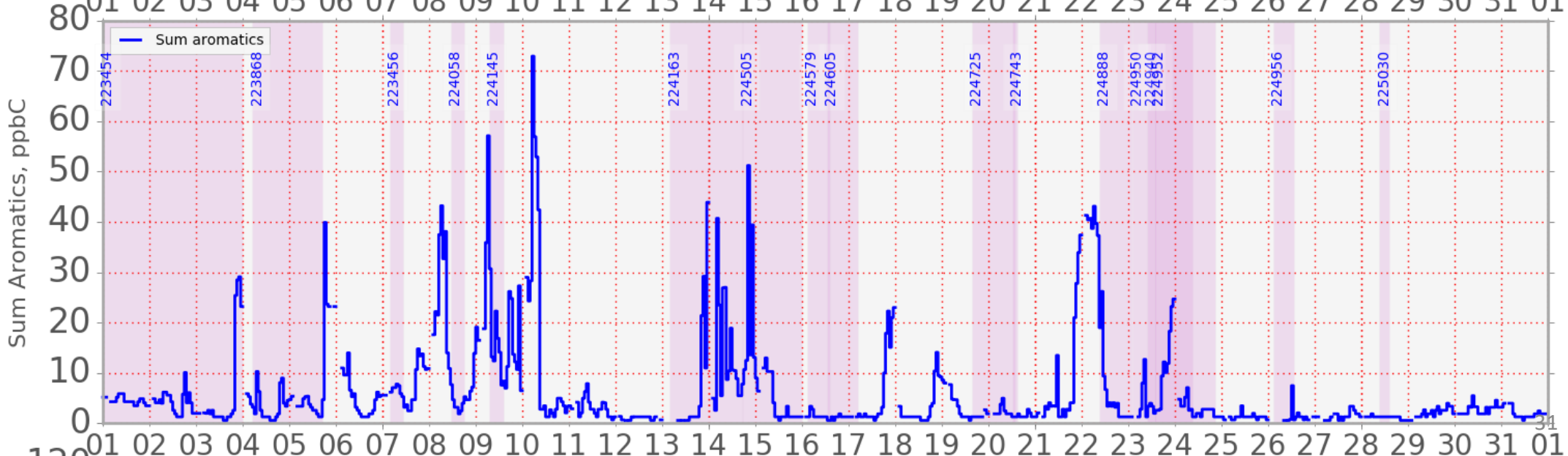


Missing Emissions

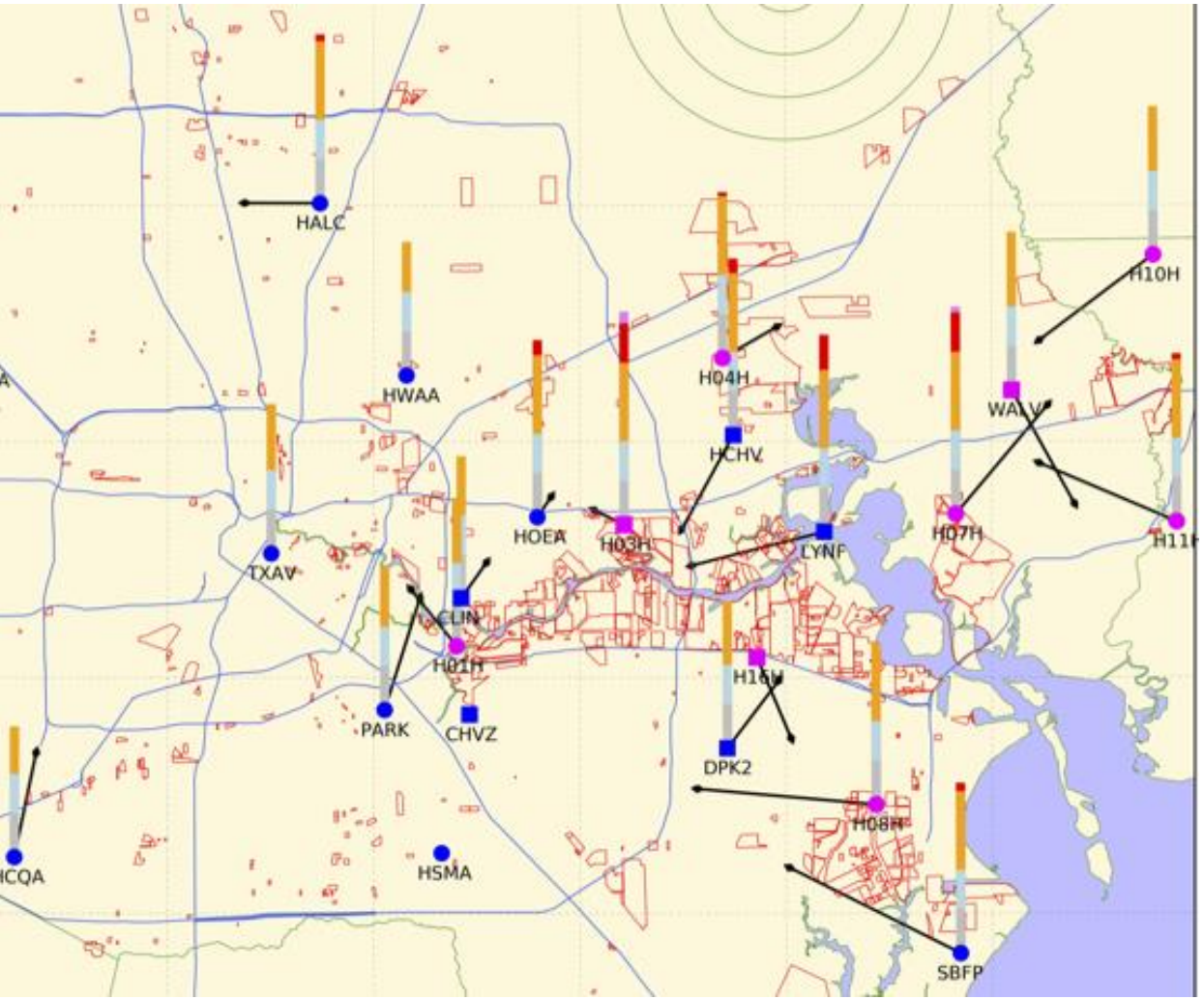


Observed VOC Concentrations

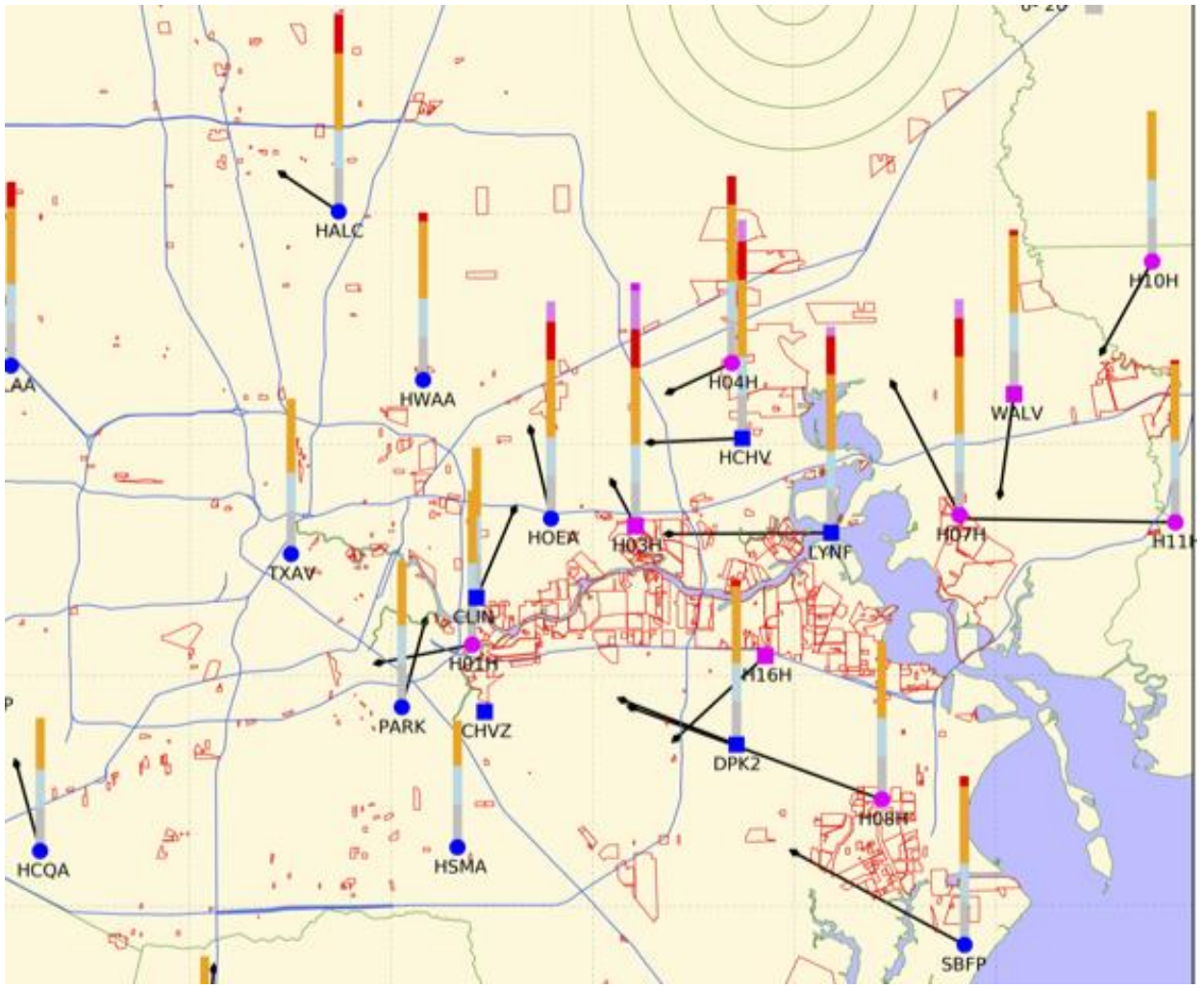




Observed Ozone Plumes



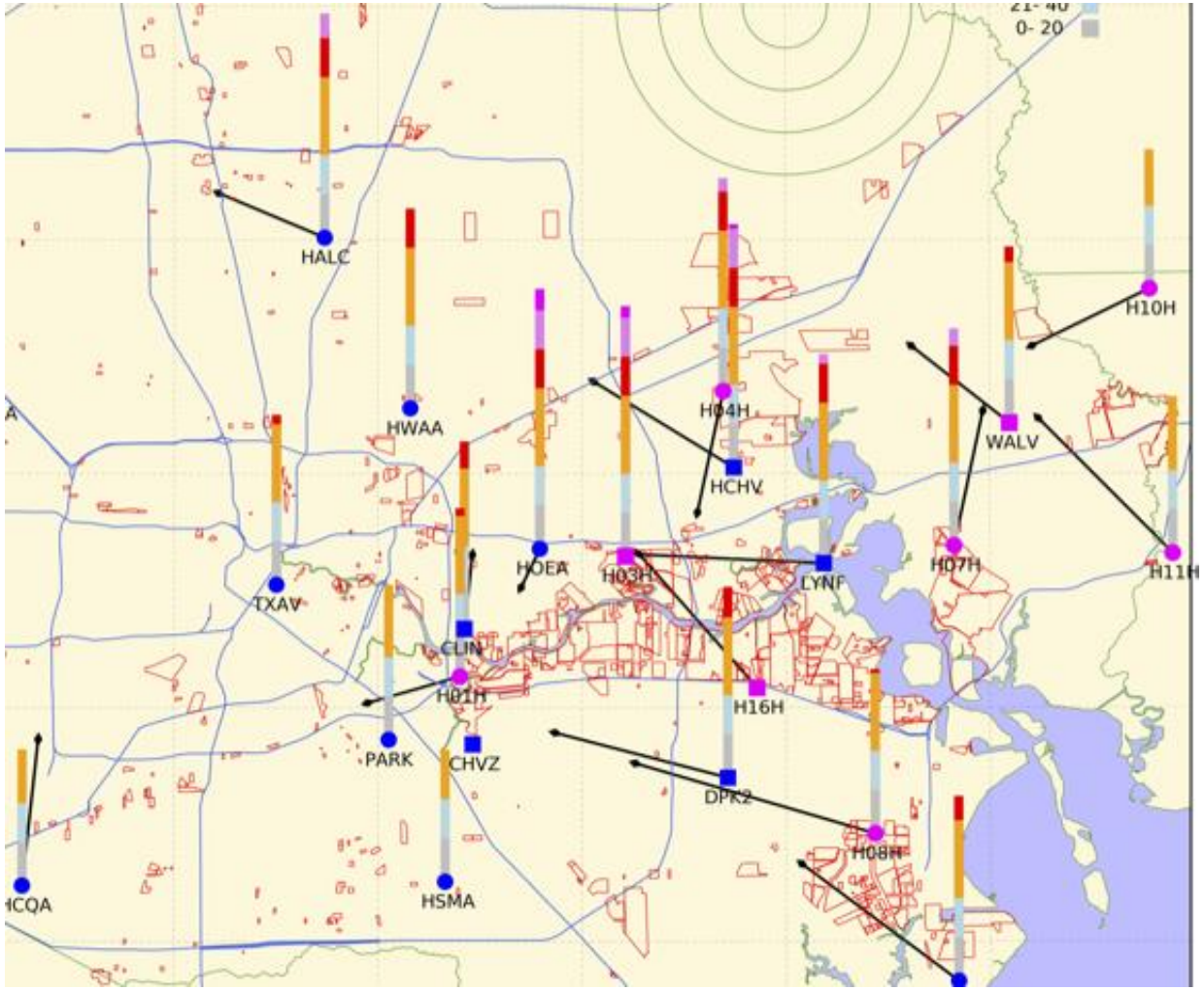
11 am
106 ppb H03H

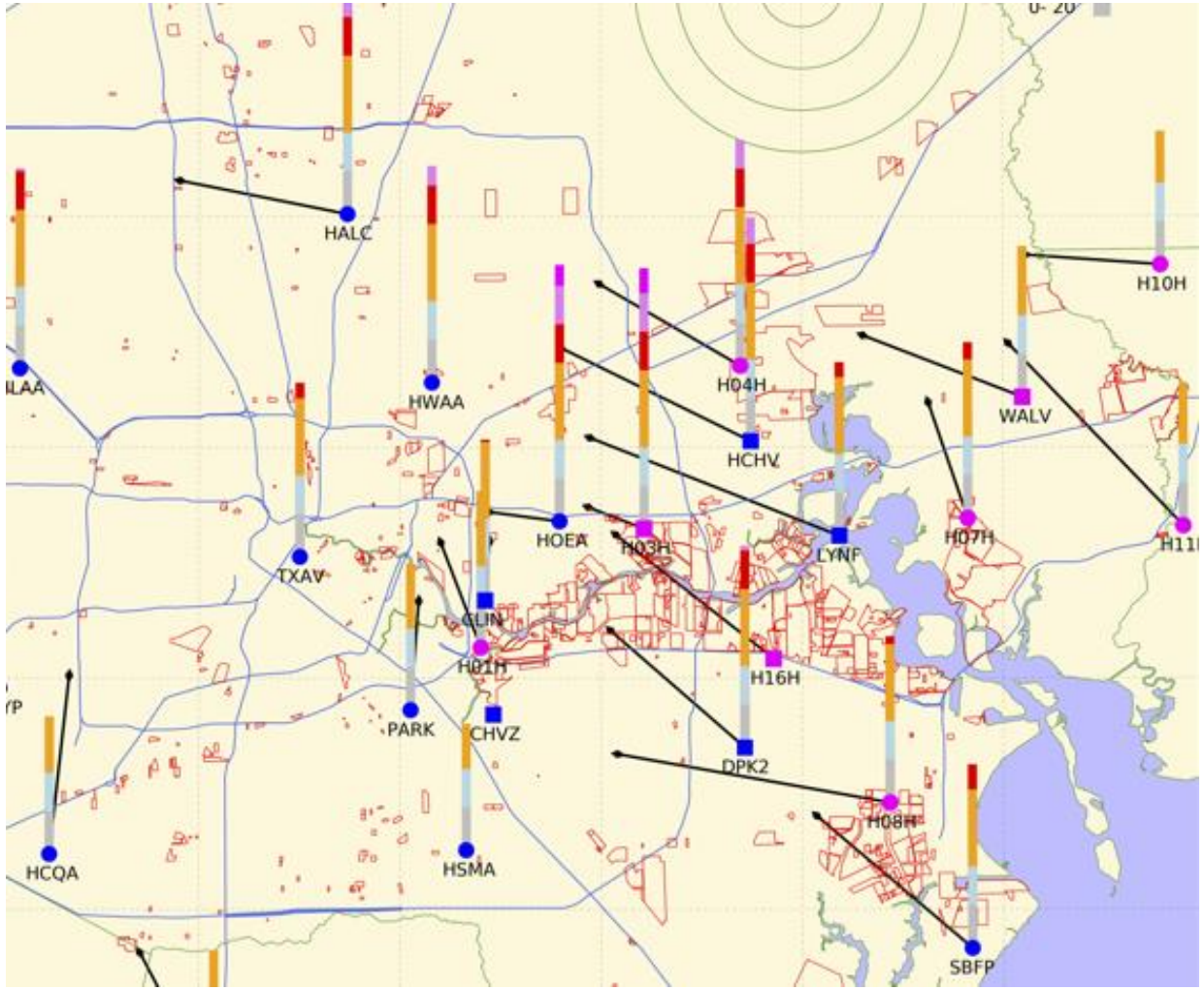


12 pm
124 ppb H03H

June 3, 2015

Observed Ozone Plumes





1 pm
131 ppb H03H

June 3, 2015

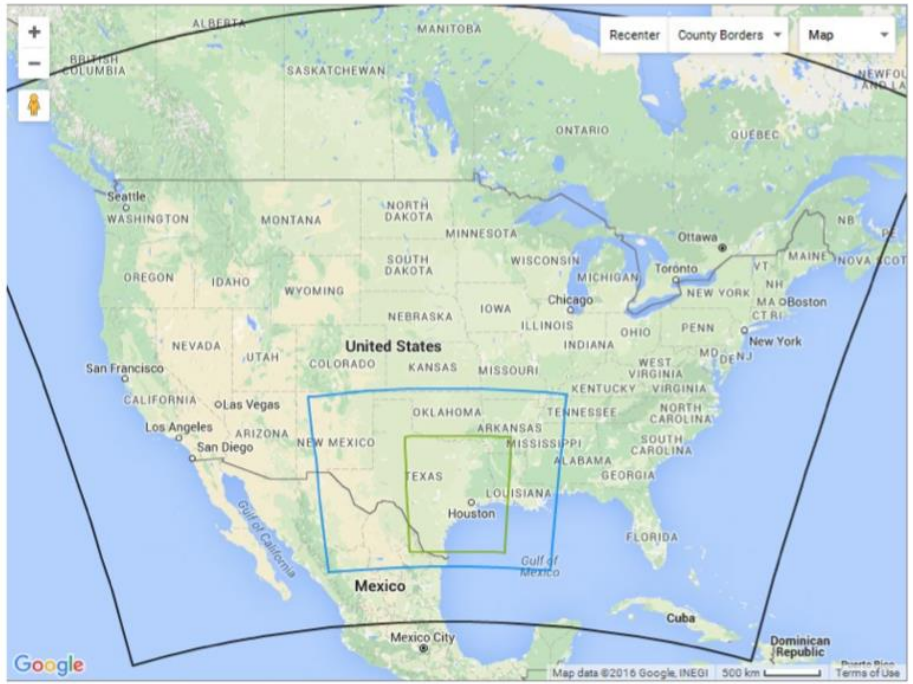
2 pm
133 ppb H03H

Sufficient Conditions

- Ozone produced on these days are very likely the result of local emissions.
- Identified a consistent presence of elevated concentrations of VOCs primarily alkanes and aromatics
- Some alkenes - emission event database.

Ozone Attainment

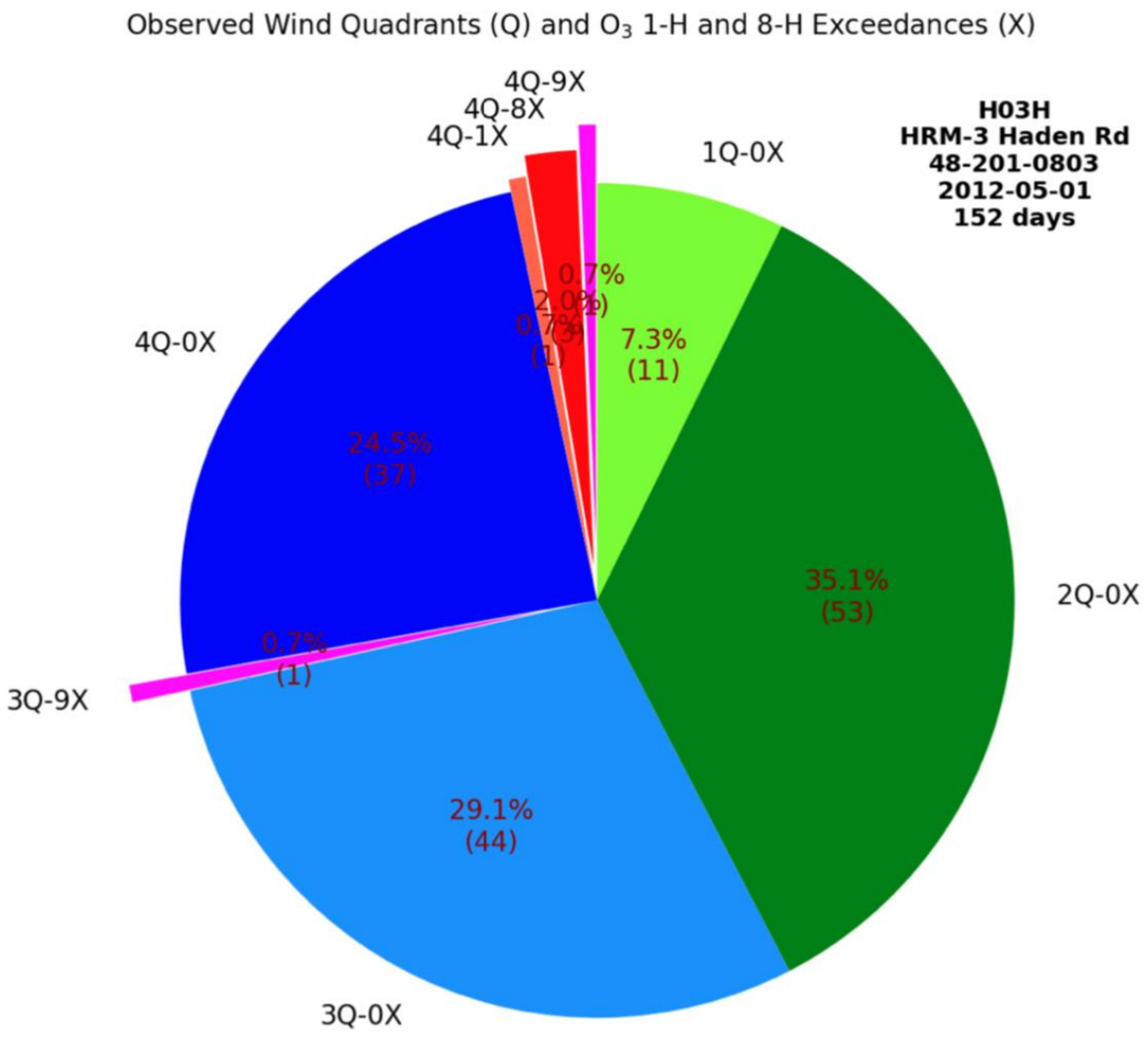
Modeling Episode and Configuration



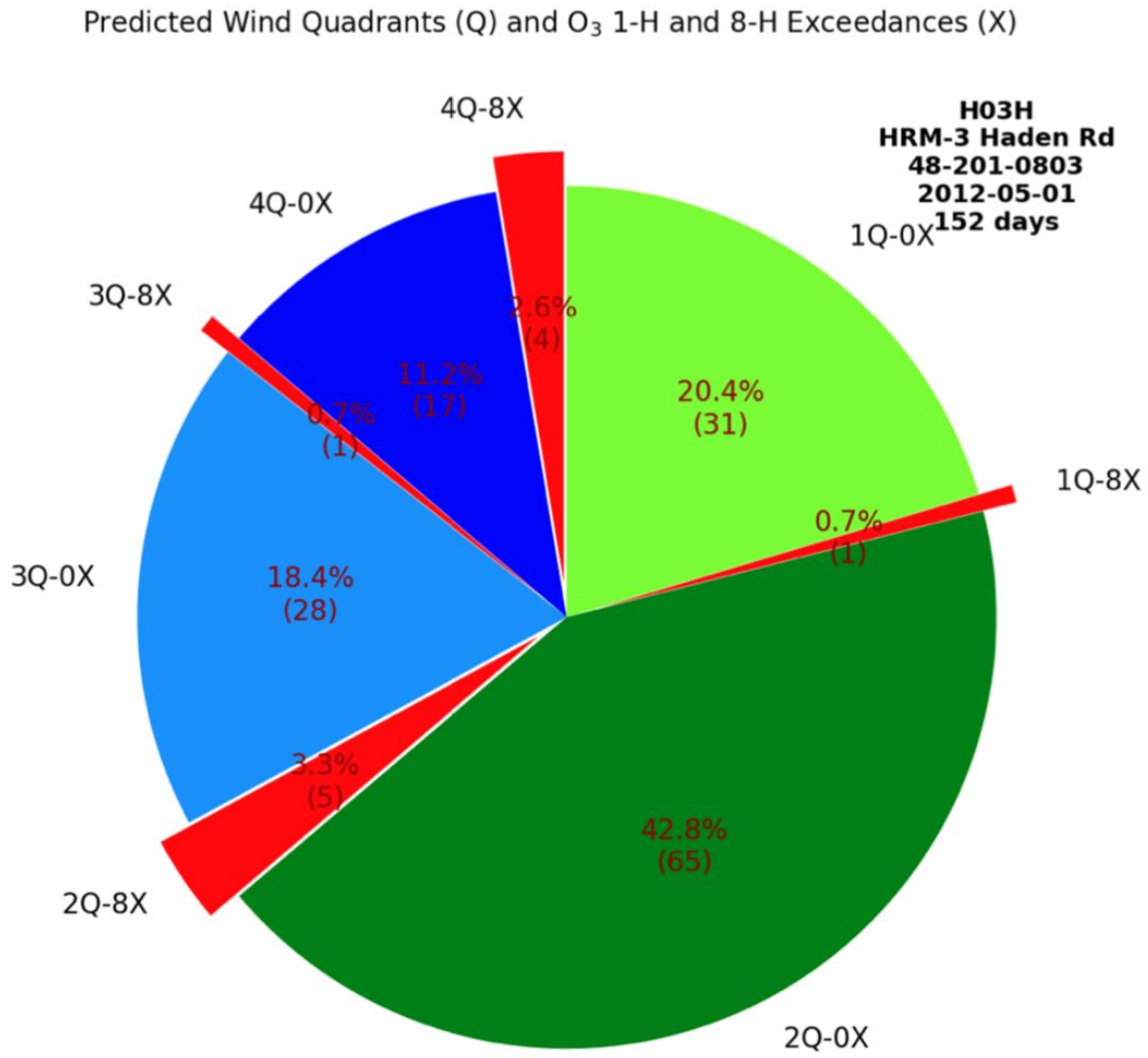
- Episode
  - Base year: May – Sep 2012
  - Future year: 2020
- Domains: 36, 12, 4 kilometers
- CAMx 6.5 with CB6r4h chemical mechanism
  - Update from 6.31
- WRF 3.7.1
  - No change

CAMx = Comprehensive Air Quality Model with extensions; WRF = Weather and Research Forecasting

Model Performance Analysis

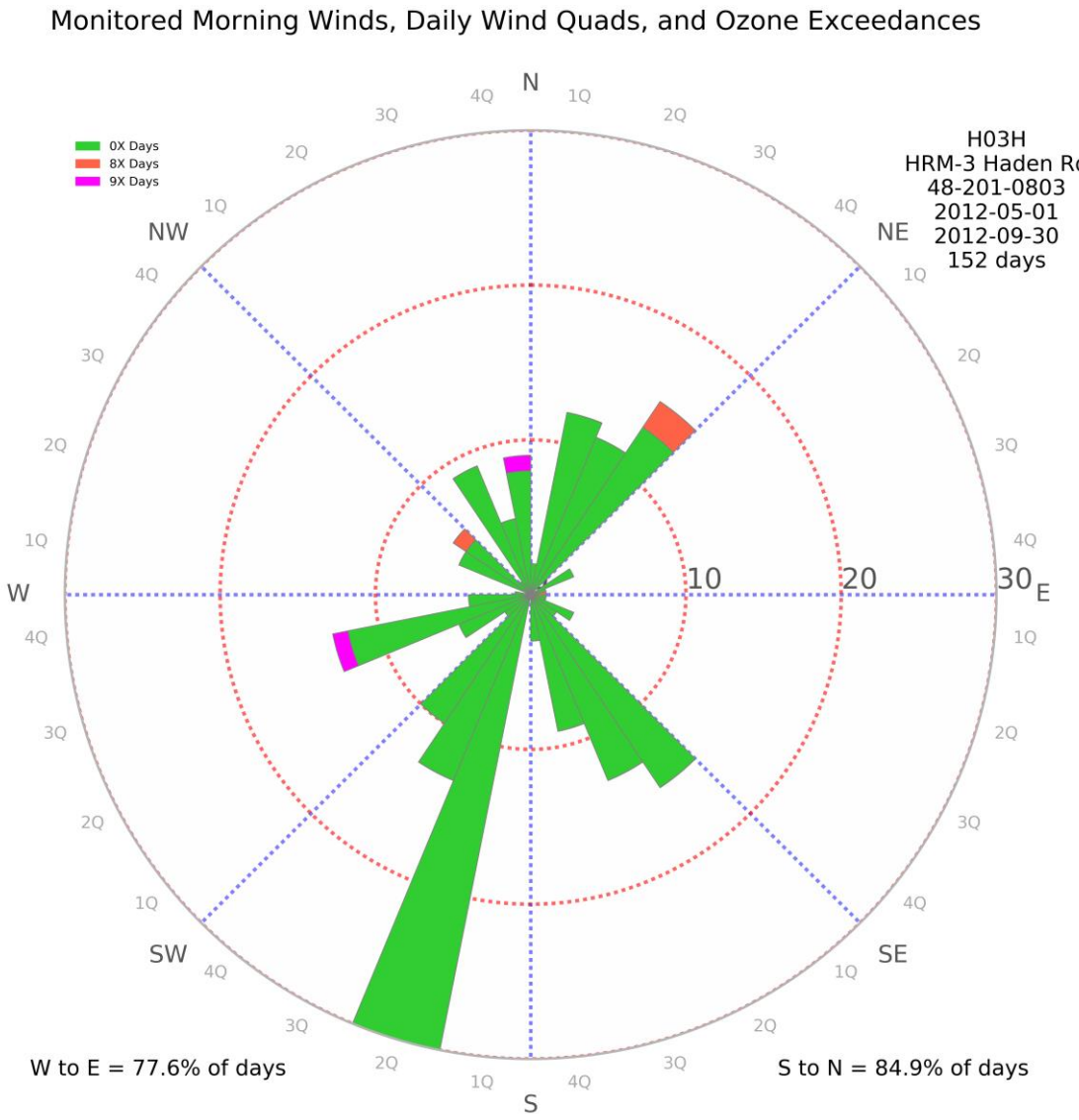


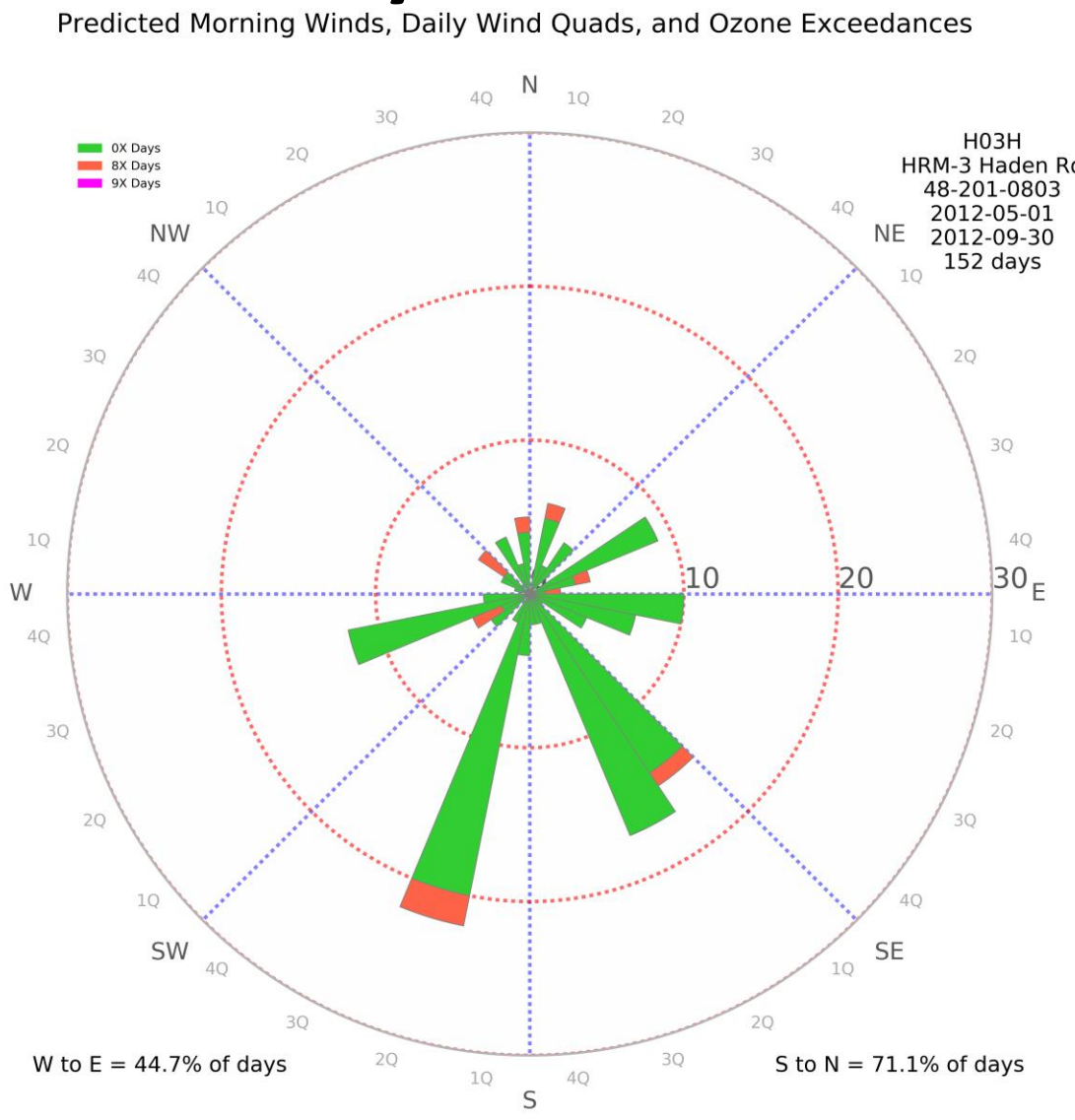
OBSERVATIONS



PREDICTION

Model Performance Analysis

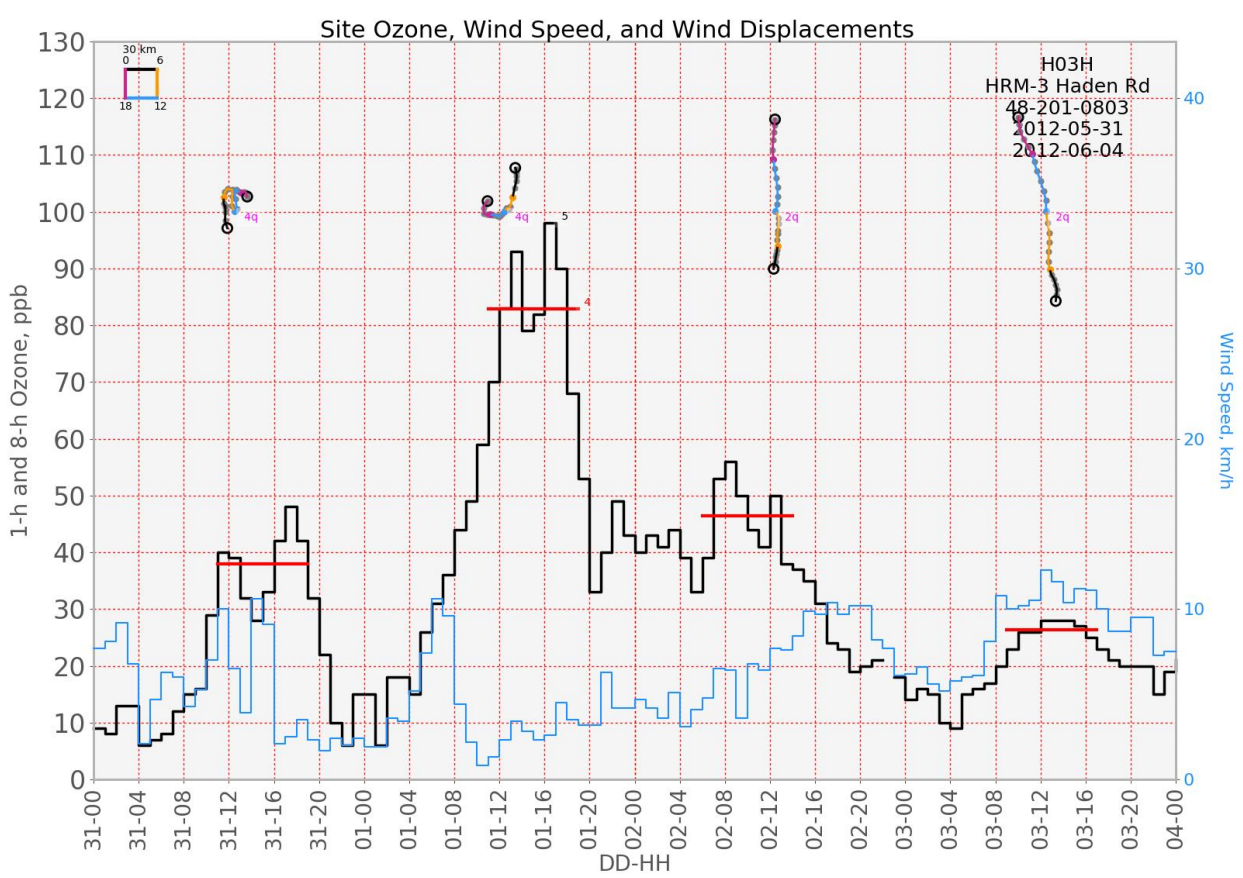


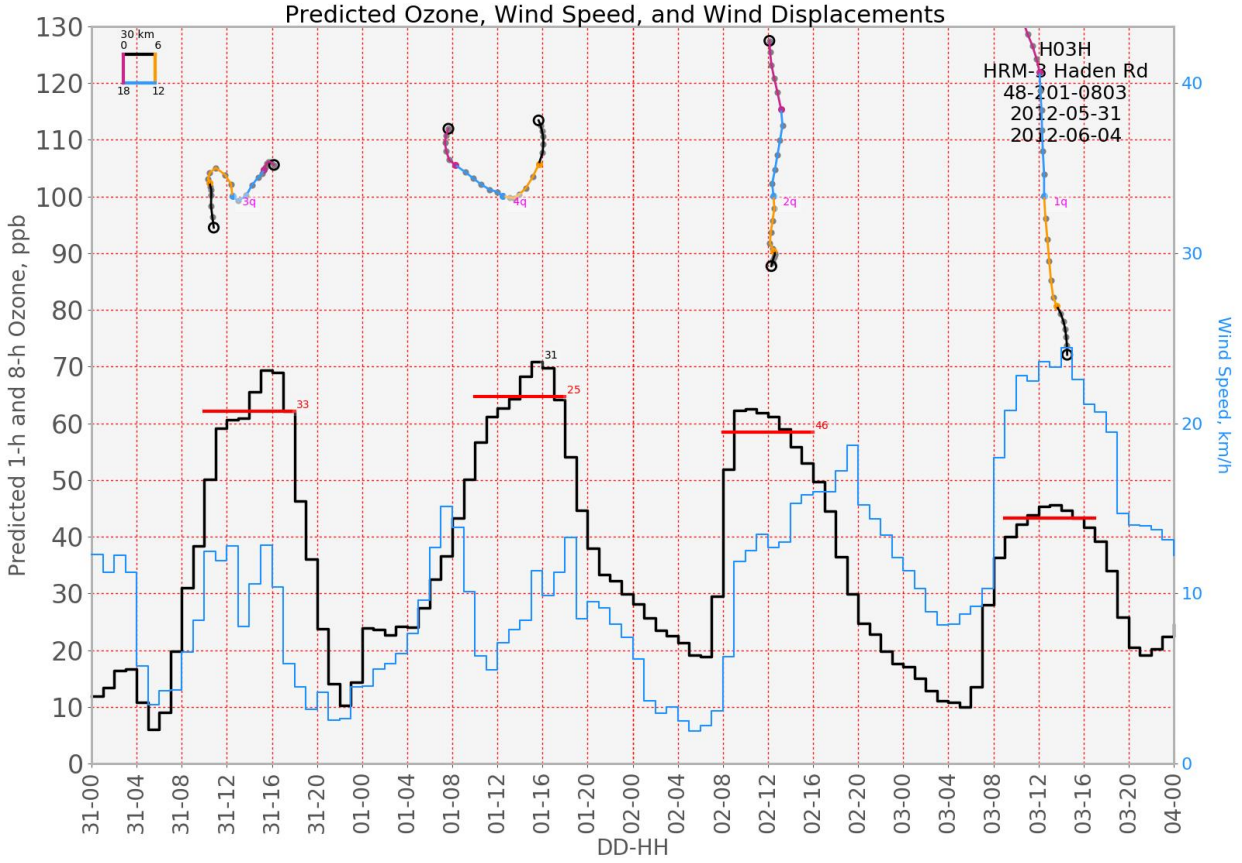


OBSERVATIONS

PREDICTION

Model Performance Analysis

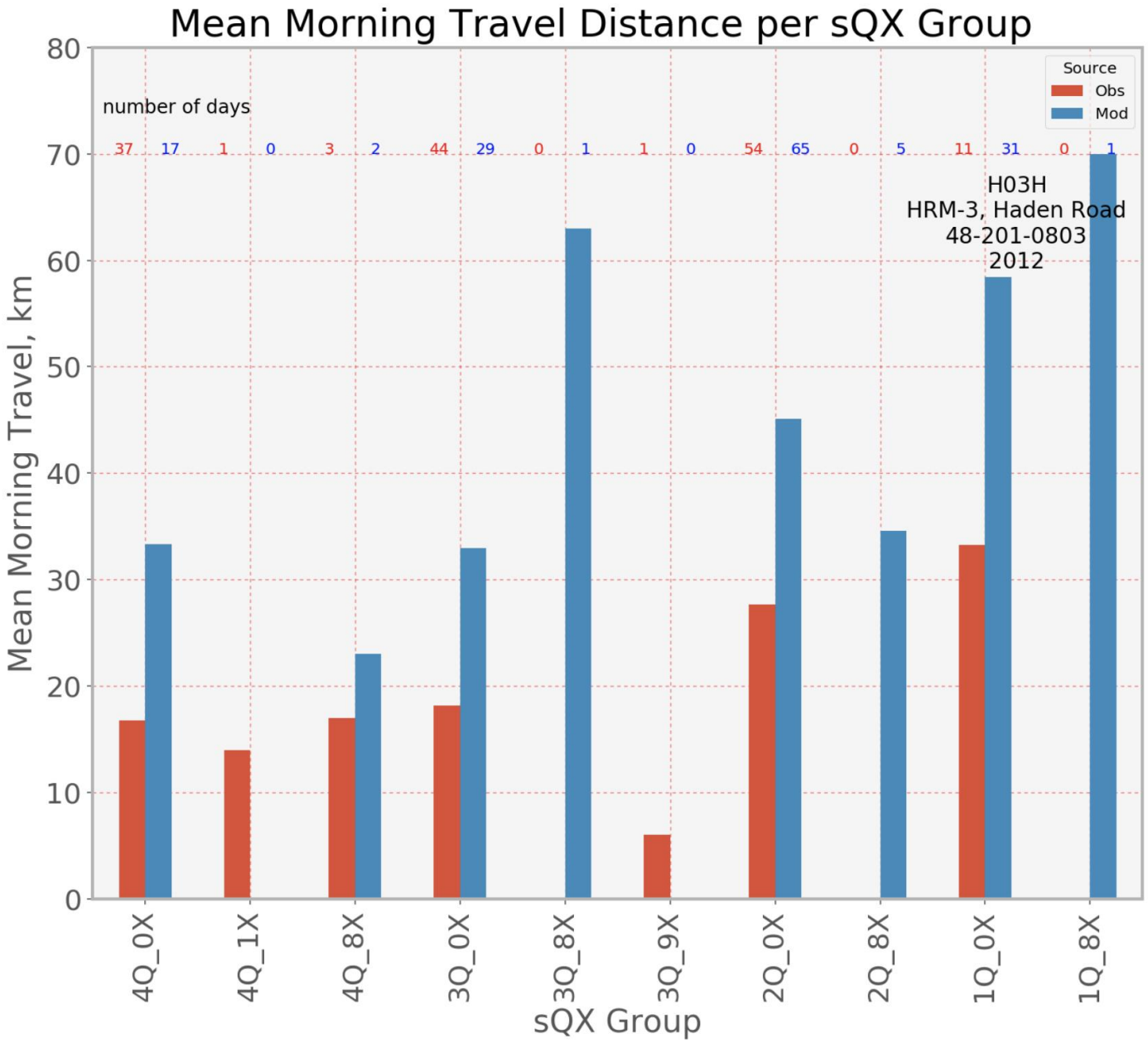




OBSERVATIONS

PREDICTION

Model Performance Analysis



EPA Attainment Methodology

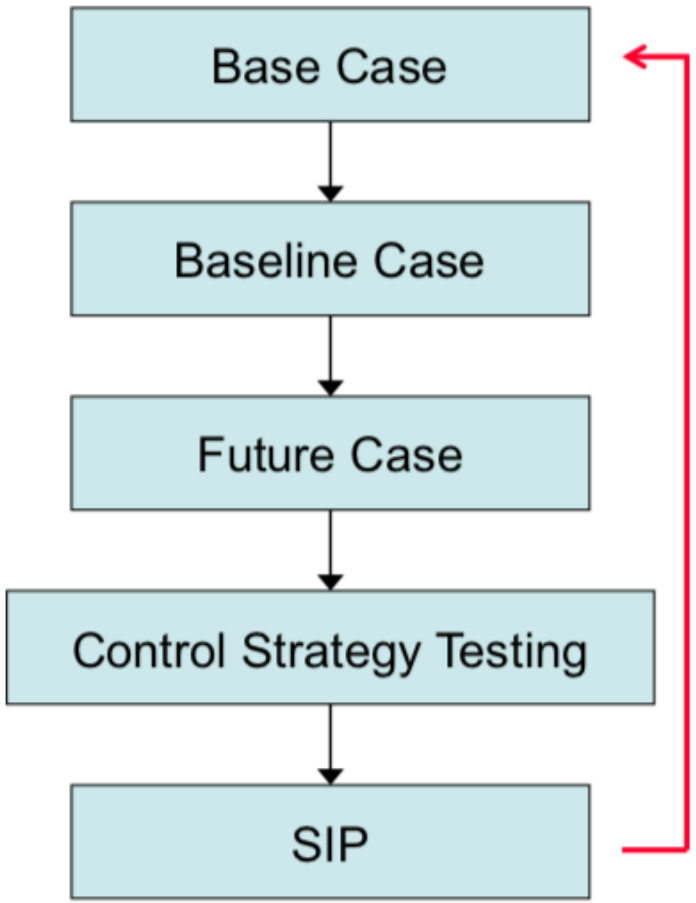
- Modeling Guidance for Demonstrating Air Quality Goals for Ozone, $PM_{2.5}$ and Regional Haze.

- Prior to 2018 fundamental assumption
  - Ozone exceedance variability in Meteorology not emissions.

- 2018 document less emphasis

Ozone Modeling in SIP Development

One Year Typical Development



Day-specific emissions and meteorology; replicate what actually happened

Typical emissions and day-specific met; used in RRF to predict future design values

Apply future growth + on-the-books controls to estimate future ozone precursor emissions

Determine control strategies that will effectively reduce ozone (if applicable)

Document modeling results and procedures

EPA 8-Hr Ozone Attainment Method

EPA's 8-hr attainment test methodology is fundamentally incapable of effectively dealing with certain moderate-to-peak O_3 formation processes in Houston that contribute to DVf's

The model's mean Relative Reduction Factor is calculated at each monitor, m, as

2020 Model

$$RRF_m = \frac{\text{Mean predicted future peak 8-hr daily max "near" monitor}}{\text{Mean predicted baseline peak 8-hr daily max "near" monitor}}$$

2012 Model

Mean Relative Reduction Factor at monitor

$$DV_{F,m} = DV_{B,m} \times RRF_m$$

"weighted" DV based on observed 2004-2008 O_3 data at monitor

"average" estimated future DV
If it is below standard, monitor is in compliance of NAAQS

Houston Ozone Attainment

- Is Houston still a two ozone city?
- Has Meteorological conditions changed?
- Are HRVOCs still relevant?
- Can regulatory model capture observed phenomena?
- Attainment of 70 ppb?

Next Steps

- Alkane Sources?
- Controls?
- How does model make ozone 1Q,2Q?
- How to fix predicted meteorology?
- Can regulatory model capture observed phenomena?

Questions?

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