Analysis of the Jack Rabbit II Sonic Anemometer Dataset to Inform Boundary Layer Adjustments in Atmospheric Dispersion Models

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Abstract

Chemical, biological, radiological, or nuclear (CBRN) releases pose significant environmental and human exposure risks, especially in urban areas with high population densities. The complex nature of a cityscape brings substantial challenges when determining pollutant dispersal within the urban canopy because wind profiles become altered and turbulence is generated in street canyons and in wake of buildings. This can affect downwind and ground level concentrations after a hazardous release. To better understand complex flow conditions, the Department of Homeland Security (DHS) and Defense Threat Reduction Agency (DTRA) initiated a series of controlled field studies called Jack Rabbit II (JRII) in 2015 and 2016. Sequences of 10-20-ton releases of chlorine gas were dispersed within an array of CONEX shipping containers to mimic buildings or other roughness elements. Boundary layer wind flow characteristics were also collected using sonic anemometers, but the data have largely not been analyzed. The goal of this study is to present a preliminary analysis of the JRII wind flow dataset to inform urban adjustments in Gaussian dispersion models. Modifications to the local wind profile and turbulence terms could lead to improved boundary layer parameterizations in dispersion models, which are important for efficient and precise emergency preparation and response.

Analysis of the Jack Rabbit II Sonic Anemometer Dataset to Inform Boundary Layer Characterizations in Dispersion Models

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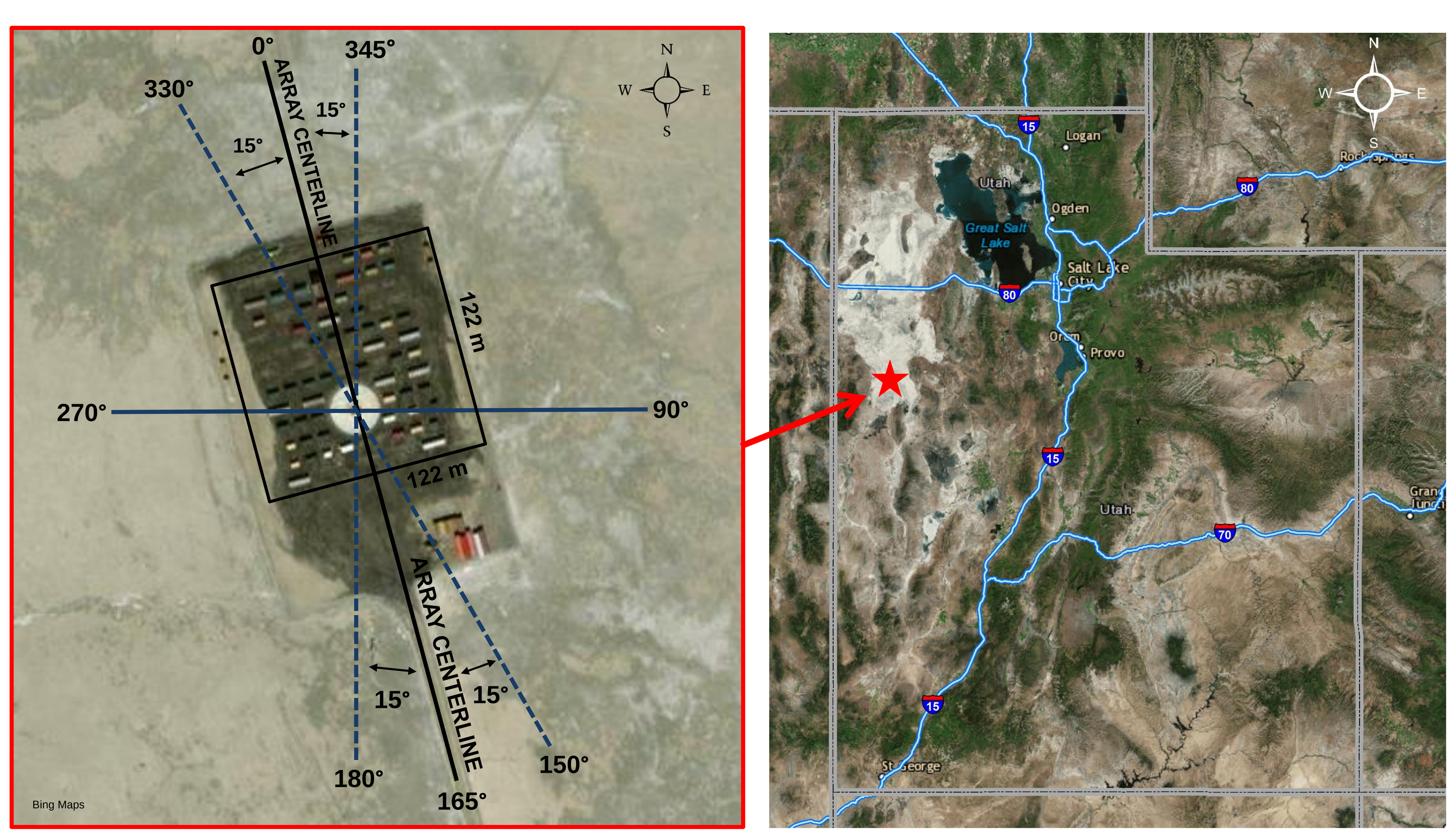
Background and Introduction

- The transport of harmful substances from accidental or intentional chemical, biological, radiological, or nuclear (CBRN) releases poses substantial environmental and human exposure risks, especially in densely populated urban areas.
- Complex urban morphology challenges emergency response operations when determining pollutant dispersal within an urban canopy because planetary boundary layer (PBL) wind profiles become altered and turbulence is generated in street canyons and in the wake of buildings. This can strongly affect downwind and ground level concentrations or depositions after a hazardous release.
- To better understand complex flow conditions, improve chemical hazard dispersion modeling, and more effectively plan and respond to emergency situations, the Department of Homeland Security (DHS) and Defense Threat Reduction Agency (DTRA) initiated a series of controlled field studies called Jack Rabbit II (JRII) in 2015 and 2016.
- Sequences of 5-10-ton chlorine gas releases were dispersed within an array of CONEX shipping containers at Dugway Proving Ground, a US Army testing and training facility, to mimic buildings or other roughness elements.
- After the chlorine trials, 30 sonic anemometers were strategically deployed around a subset of the CONEX array at multiple heights around a stacked tall building structure and a single 40 ft CONEX.
- Wind flow observations were collected continuously for 26 days in March 2017.
- 10 Hz observations were reduced to 30 minute averages of *u*, *v*, and *w* components, eddy and kinematic fluxes, variances, Reynold's stresses, and standard deviations.

Project Objective and Justification

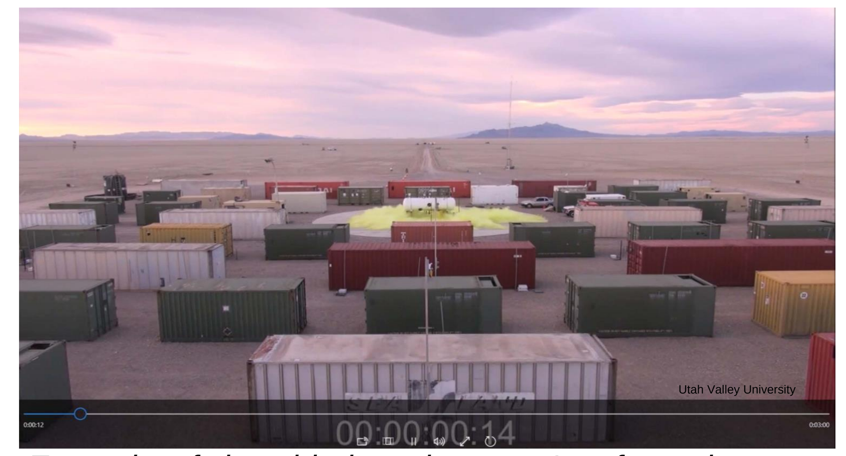
- ***Objective***: Provide an overview of the JRII Special Sonic Study by processing the dataset. Use the analysis of the JRII wind flow dataset to inform urban parameterizations in Gaussian dispersion models and to compliment an upcoming EPA wind tunnel experiment.
- ***Justification:*** Modifications to the local wind profile and turbulence terms could lead to improved urban boundary layer characterizations in dispersion models, which can be used as tools for more efficient and precise emergency preparation and response.

Jack Rabbit II Location at Dugway Proving Ground

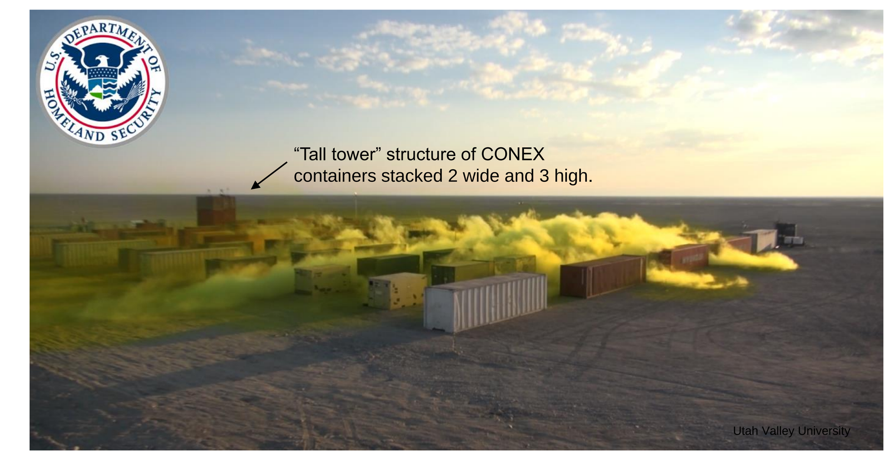


The Jack Rabbit II domain (left) in relation to Dugway Proving Ground, UT (right) overlaid on satellite imagery. The JRII site is identified by the red star. The CONEX array centerline is denoted by the solid black line, and is tilted -15º from true north to account for topographical and mesoscale effects on the desert. The CONEX array was situated in a 400 ft (122 m) square. We rotated the coordinate system 15º counterclockwise to simplify the analysis by making the array centerline 0º.

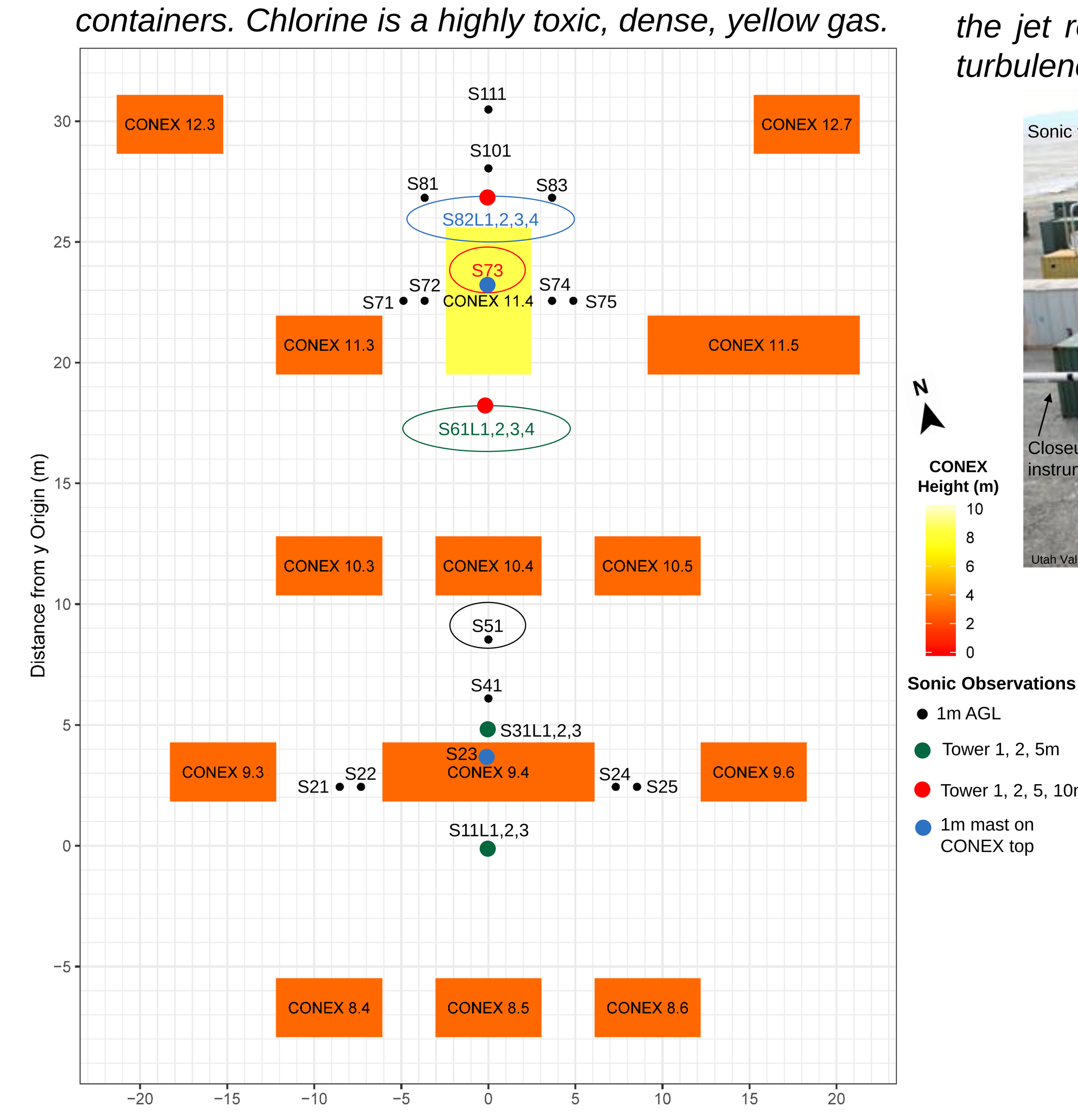
Jack Rabbit II Chlorine Releases and Special Sonic Study



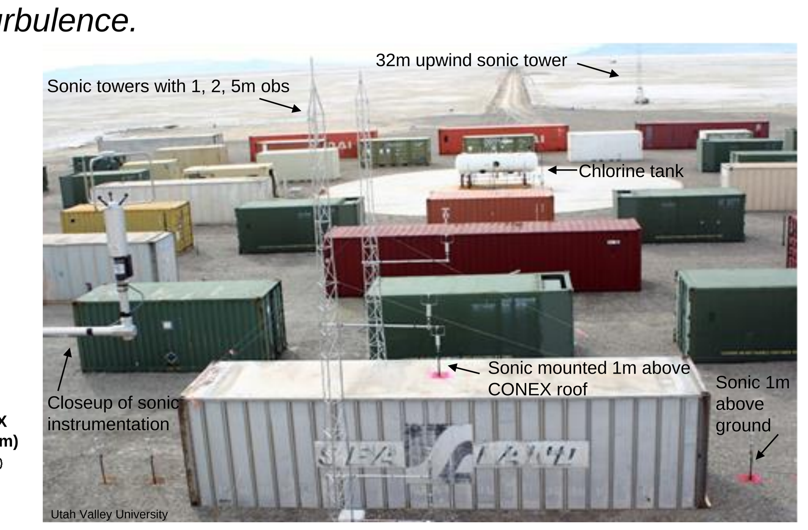
Example of the chlorine plume < 1s after release, as seen looking south from the 8.7m "tall building" structure, which was a 3x2 stack of CONEX shipping containers. Chlorine is a highly toxic, dense, yellow gas.



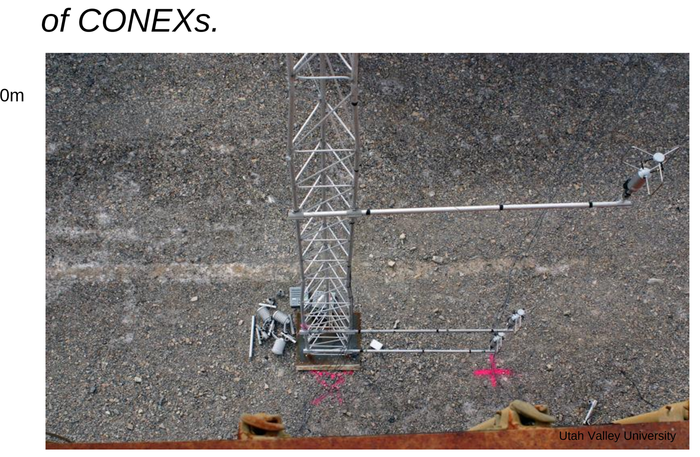
The chlorine gas plume within the CONEX containers sometimes traveled in the opposite direction of the mean wind flow due to the gas's density and force of the jet release, which tended to influence local-scale turbulence.



Subset of the CONEX array with sonic anemometer tower sites identified by various color dots, indicating their observation heights. Circled and colored site names are featured in the wind roses below.

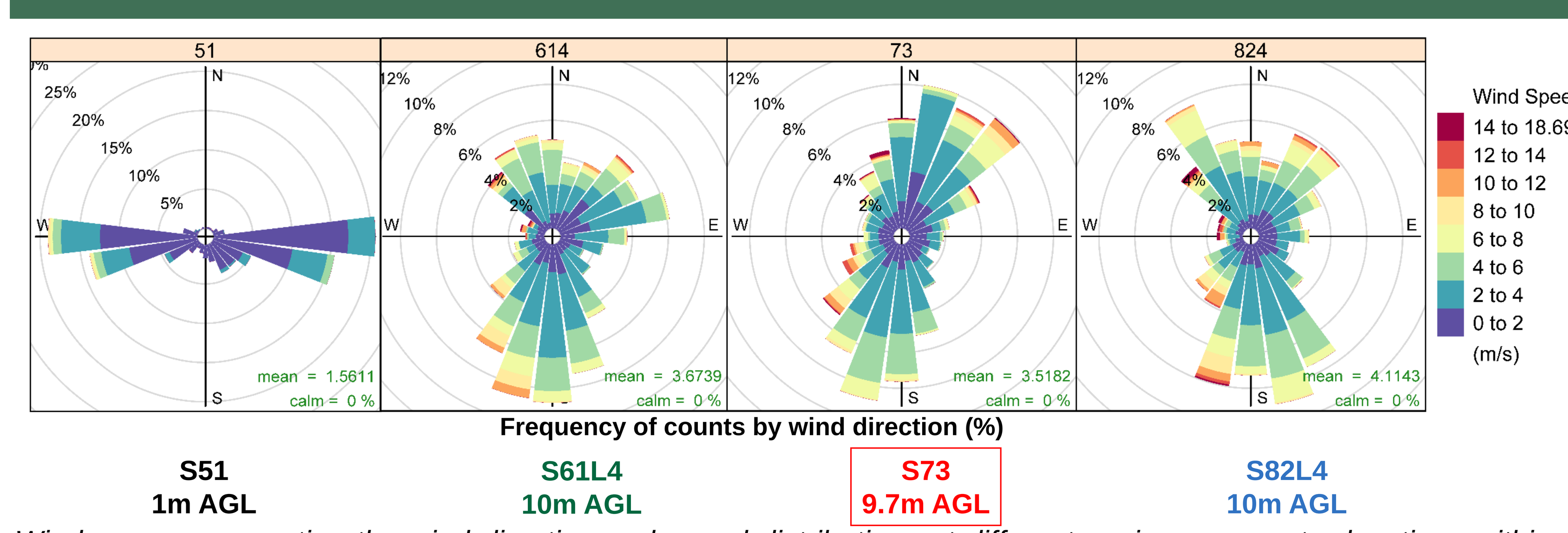


Instrumentation towers from the Special Sonic Anemometer study deployed within the CONEX array, viewed from the tall 2x3 stack of CONEXs.



Sonic anemometer tower with sensors at 1, 2, and 5m above ground level (AGL).

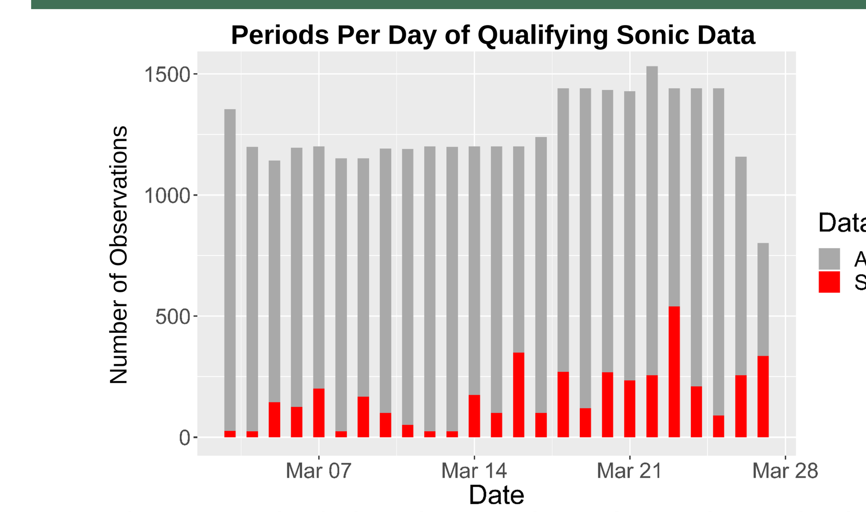
Results and Conclusions



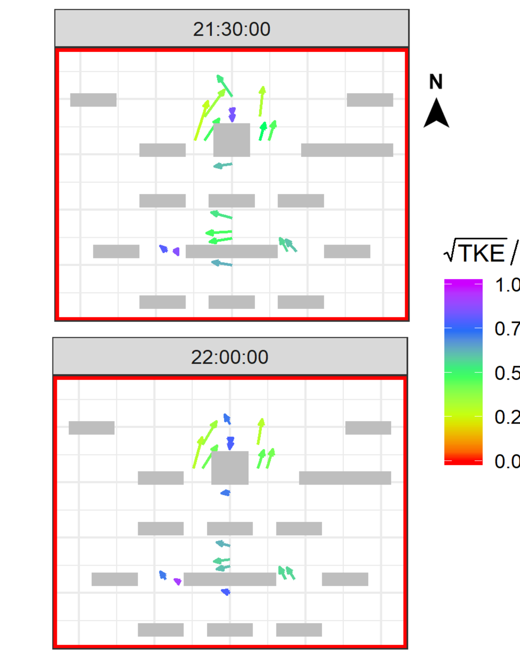
Wind roses representing the wind direction and speed distributions at different sonic anemometer locations within the CONEX array. Considerable differences result, even though sonics were only a few meters from each other. The wind roses are based on 30 minute average observations over a 26 day period. The sites are color coded with circles above. S73 is highlighted in red to show that the dataset was filtered based on data from this sonic site.

- The sonic anemometer data were filtered to periods with somewhat neutral conditions (≥ 2.5 m/s) and winds approximately perpendicular to the long face of the CONEX (±15º from 0º and 180º, rotated). To examine flow fields downwind of obstacles in the recirculation zone, the filtering was based on data from the sonic on the tall building structure, S73.
- Prevailing wind patterns vary considerably at the highest sonics within the array (S61L3, S73, S82L4), indicating that local-scale effects play a large role within the CONEX array, especially near ground level, S51. Unobstructed upwind flow data is therefore needed to more properly assess the approach wind characteristics.

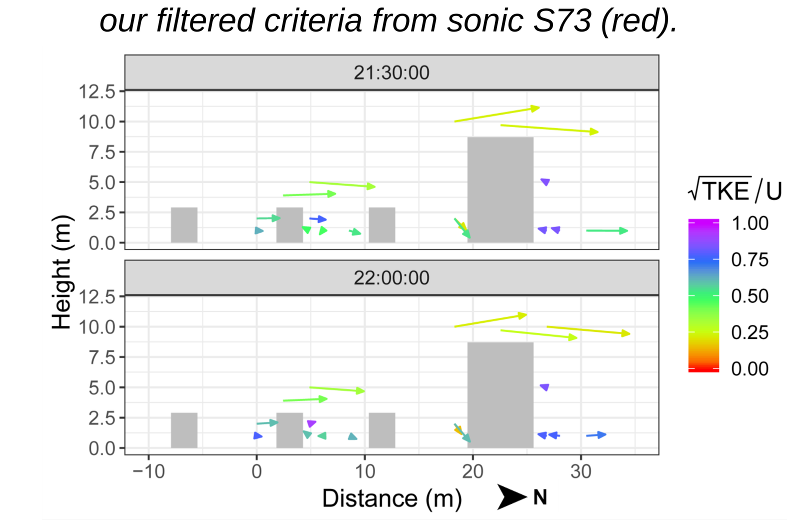
Results and Conclusions (continued)



Histogram depicting the number of 30-min sonic data periods at all sites per day during March 2016 (gray) as well as the reduced dataset of observations fitting our filtered criteria from sonic S73 (red).



Spatial example of 30-min average sonic wind vectors at 1m on March 21, 2016 during a qualifying time period (with mean southerly flow at 10m) shaded by √TKE/U to show near-surface wind interactions within the CONEX array.



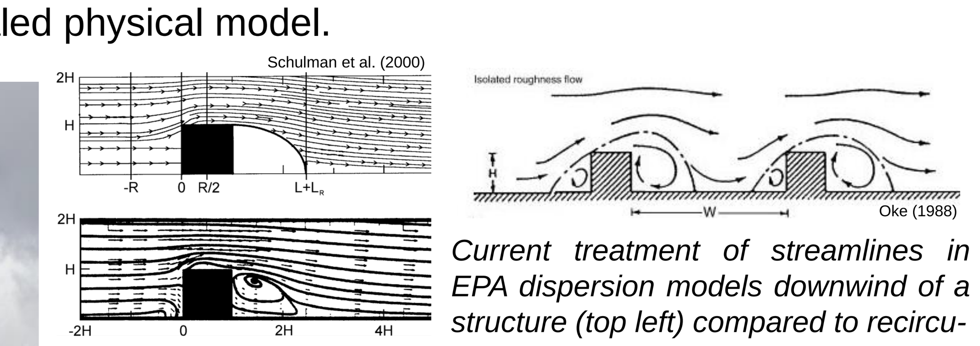
Same as top right, but plot showing vertical profile of wind vectors around CONEXs.

- √TKE/U is a measure of turbulence intensity in the flow.
- High √TKE/U and low wind magnitudes behind and adjacent to obstacles are seen in the figures.

Upcoming Wind Tunnel Project at EPA FMF

- To assess the field data in a more controlled atmospheric state, a laboratory study is being planned at the EPA's Fluid Modeling Facility (FMF) wind tunnel to physically simulate the flow within the scaled JRII array.
- The field study data and upwind PBL flow will be used to establish parameters for the scaled physical model.

32m upwind meteorology tower with sensors at 2, 4, 8, 16, and 32m will provide unobstructed upwind flow which will inform the PBL characteristics in the EPA wind tunnel.



Current treatment of streamlines in EPA dispersion models downwind of a structure (top left) compared to recirculation vortices seen in actual wind tunnel simulations in the FMF (bottom left). Additional buildings create more complex flows (right).

EPA's Meteorological Wind Tunnel in Research Triangle Park, NC

- Turbulence observations will be compared to dispersion model results (such as the flow fields in the QUIC model) and currently established flow "rules of thumb" and urban parameterizations in an effort to suggest improvements to urban capabilities within quick-response dispersion models.
- The physical simulation of JRII in the FMF wind tunnel represents flow and dispersion within a wide-area, complex urban environment. The study results will characterize the fate of harmful contaminants in an urban area and may inform more effective sampling design protocols or waste management initiatives for emergency responders post-release.