United States Environmental Protection Agency

NC STATE

Relating Laboratory-Scale Dispersion Experiments to Full-Scale Data from Jack Rabbit II

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11th EPA International Decontamination Research and Development Conference

EPA's Homeland Security Research

EPA Homeland Security Research Program Mission:

develop research, scientific methods, and technology to improve the capability of responding to and recovering from homeland security incidents.

- **Interest in refining tools and methods to better understand the fate and transport of hazardous airborne releases through all phases of the emergency response process**

Field and Laboratory Data → Dispersion Models

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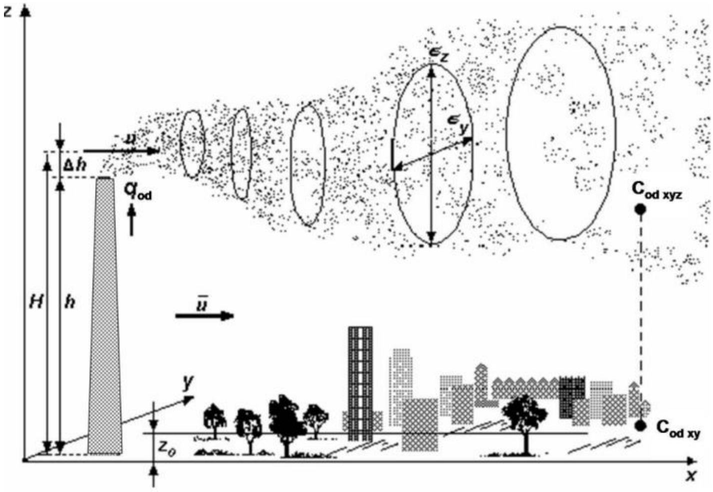
Research Problem & Motivation

Dispersion Model

A mathematical representation of air pollutant transport in the ambient atmosphere that can be used to calculate concentrations at various locations away from a source

[Holmes and Morawska 2006]



$$c_{od,xyz} = \frac{q_{od}}{2\pi \bar{u}\sigma_y\sigma_z}\exp\left[-\frac{y^2}{2\sigma_y^2}\right]\left\{\exp\left[-\frac{(z-H)^2}{2\sigma_z^2}\right]+\exp\left[-\frac{(z+H)^2}{2\sigma_z^2}\right]\right\}$$

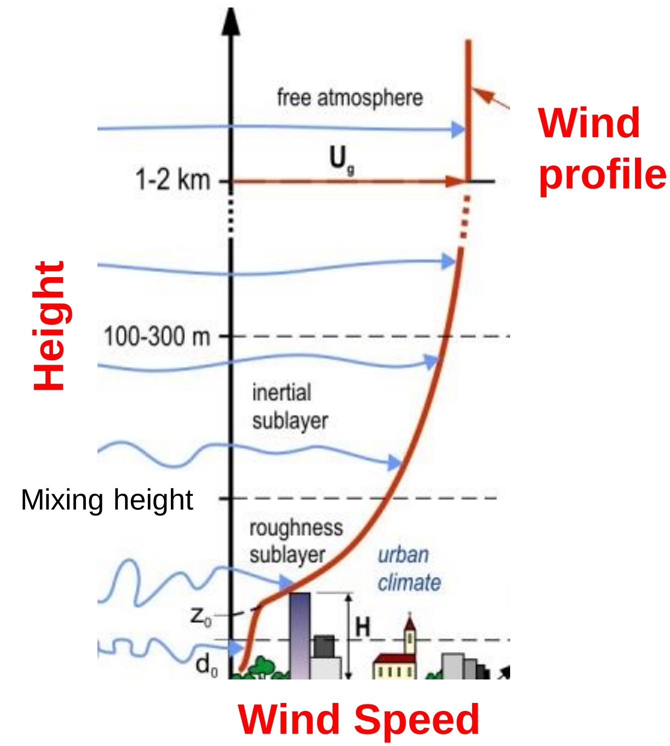
Upon a dangerous atmospheric release emergency response personnel may turn to dispersion models to:

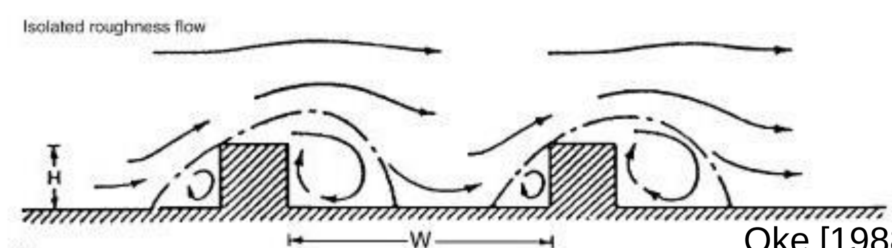
- **Determine the extent of a toxic plume**
- **Inform the following:**
  - Evacuation
  - Sampling
  - Surface decontamination
  - Waste management

Critical tool that offers insight on emergency ***preparation, planning, and response***
[Leitl et al. 2016]

Dispersion Under Complex Scenarios

- **Dispersion is well-understood for homogeneous environments**
- **Additional research needed in urban and complex environments** [Garbero 2008]
  - High population densities and human exposure risks
  - Turbulent flows generated between buildings and streets Belcher et al. [2013]

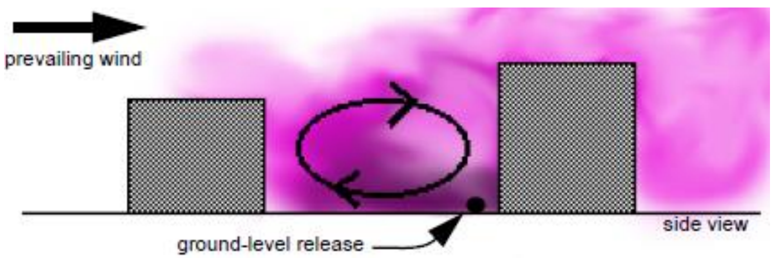


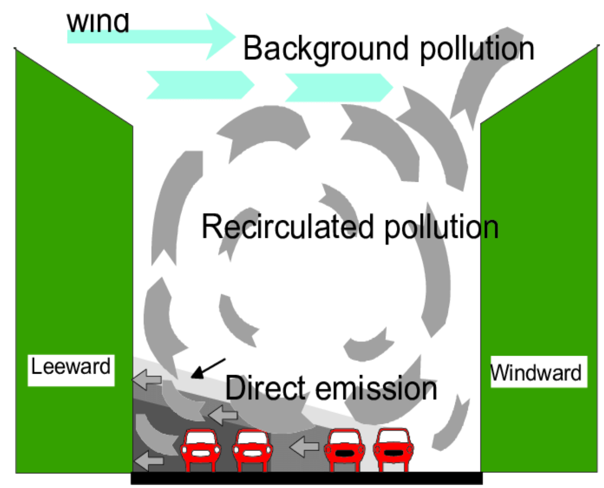


Oke [1988]

Dispersion Under Complex Scenarios

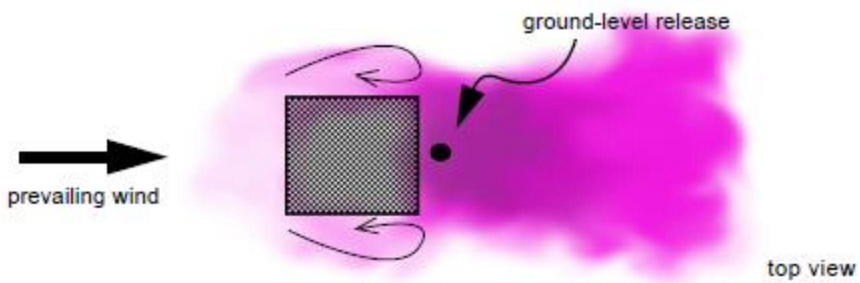
Effluent Trapping in Street Canyon



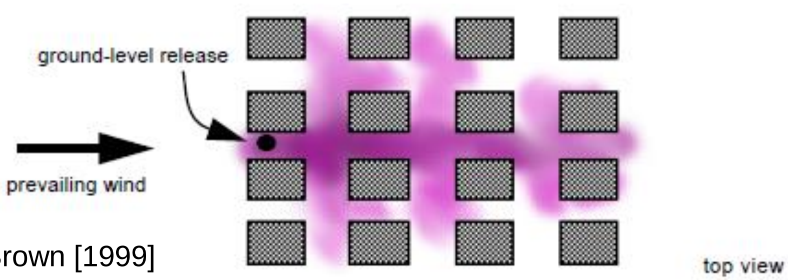


Berkowicz [1998]

Wake Effects



Channeling Effects



Brown [1999]

Research Justification

- **Model performance in urban areas requires further improvement**
- **Controlled field and laboratory tests are often used to simulate hazardous releases**

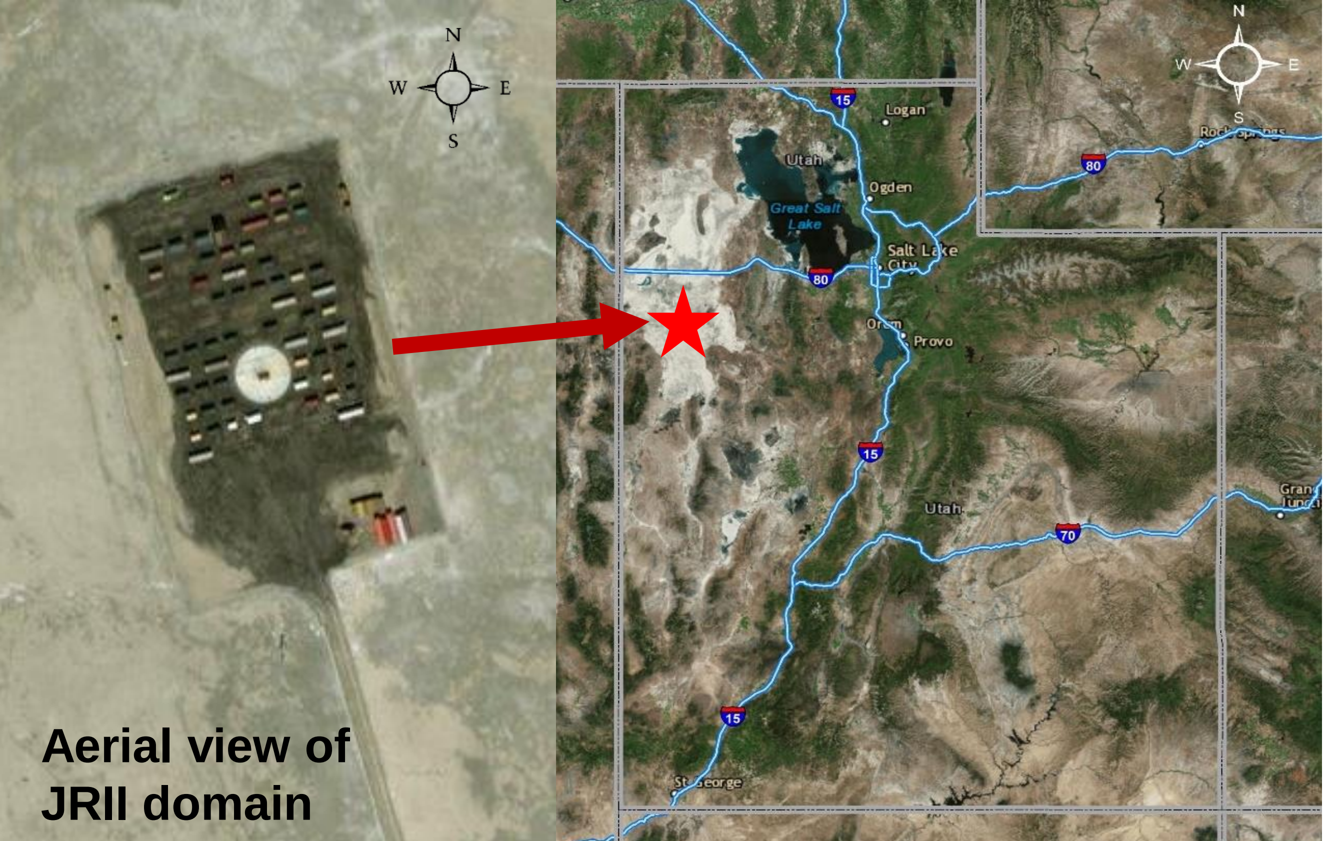
Goal

- Examine flow and turbulence data from the Jack Rabbit II field experiment
- Replicate and expand upon flow and dispersion within a scaled model at EPA's Fluid Modeling Facility (FMF) Wind Tunnel

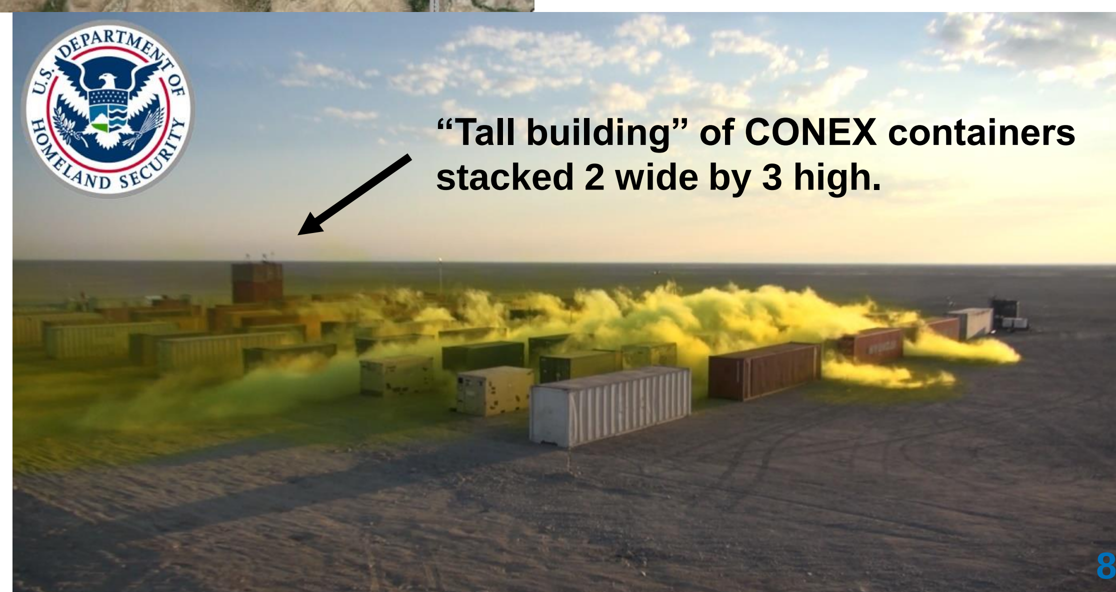
Jack Rabbit II (JRII) Field Study

- **Multi-agency field study at Dugway Proving Ground, UT**
- **Series of chlorine gas releases**
- **Array of 80 CONEX shipping containers positioned to mimic an “urban” release**

Photos: UVU and Steve Hanna



- **Remote, flat, and smooth desert**
- **Ideal conditions for translating field data to models and lab work**

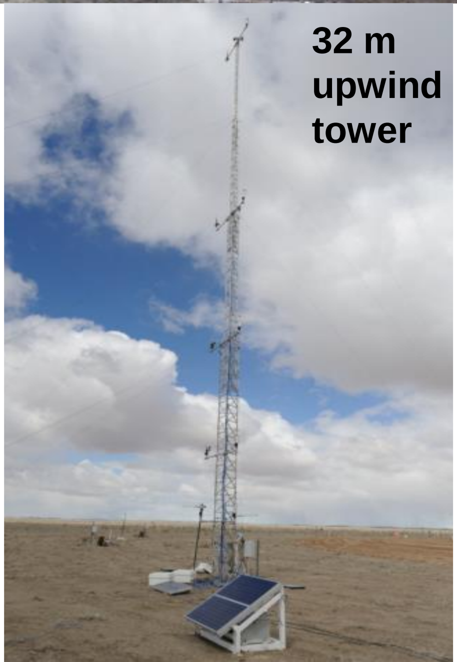


JRII Special Sonic Study

- **March 2016: Special turbulence study to document ONLY the wind flow within the CONEXs**

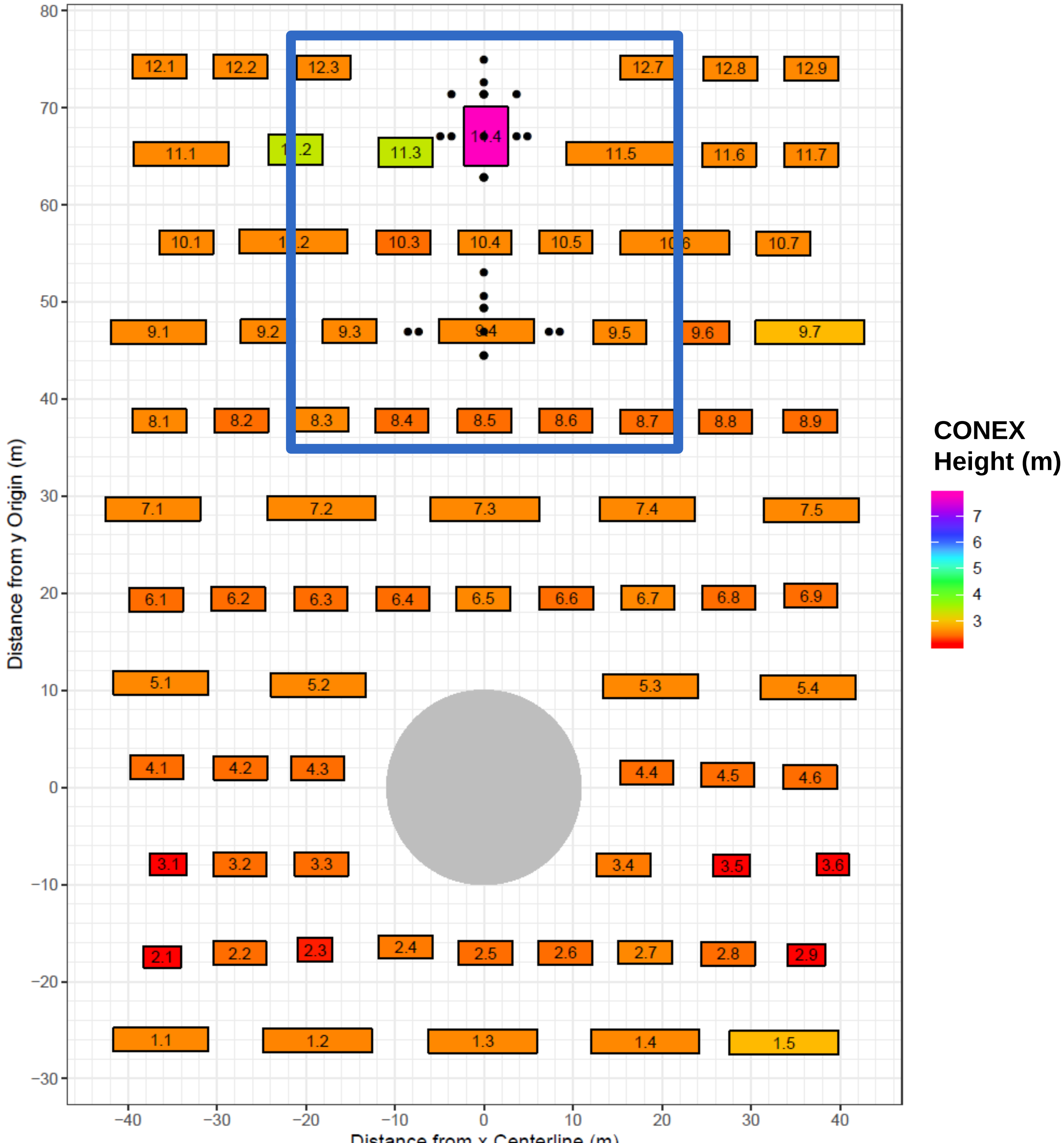
  → *The dense gas creates complex localized flow regimes*

- **Sonic anemometers positioned upwind and at various heights and locations**



JRII Urban Test Domain

80 CONEX structures



EPA Meteorological Wind Tunnel Study

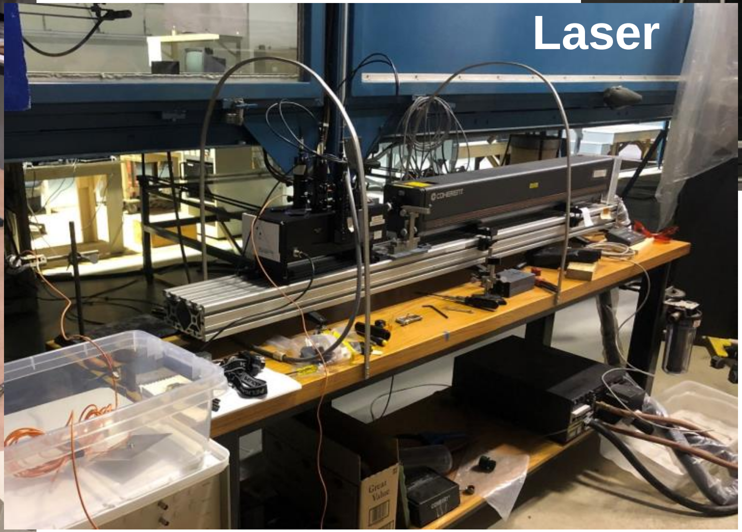
- **Series of laboratory experiments underway in EPA's FMF wind tunnel to complement JRII study in controlled atmospheric conditions**
- **Fully characterize the flow, turbulence, and dispersion within the CONEX 'building' array**

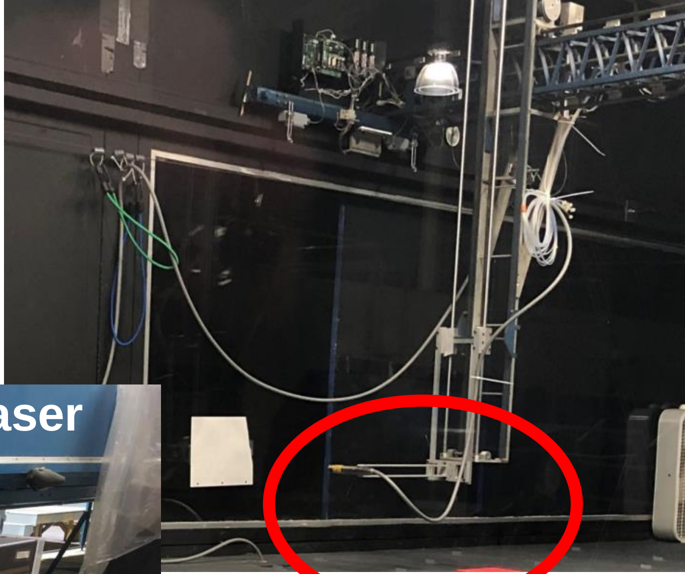
Specs:	**3.6m (12 ft) wide**
	2.1m (7 ft) high
	18m (60 ft) long test section
	Up to 8m/s (18mph) wind velocity

EPA's Meteorological Wind Tunnel

Model Construction and Instrumentation

1:50-scale polyisocyanurate foam building structures





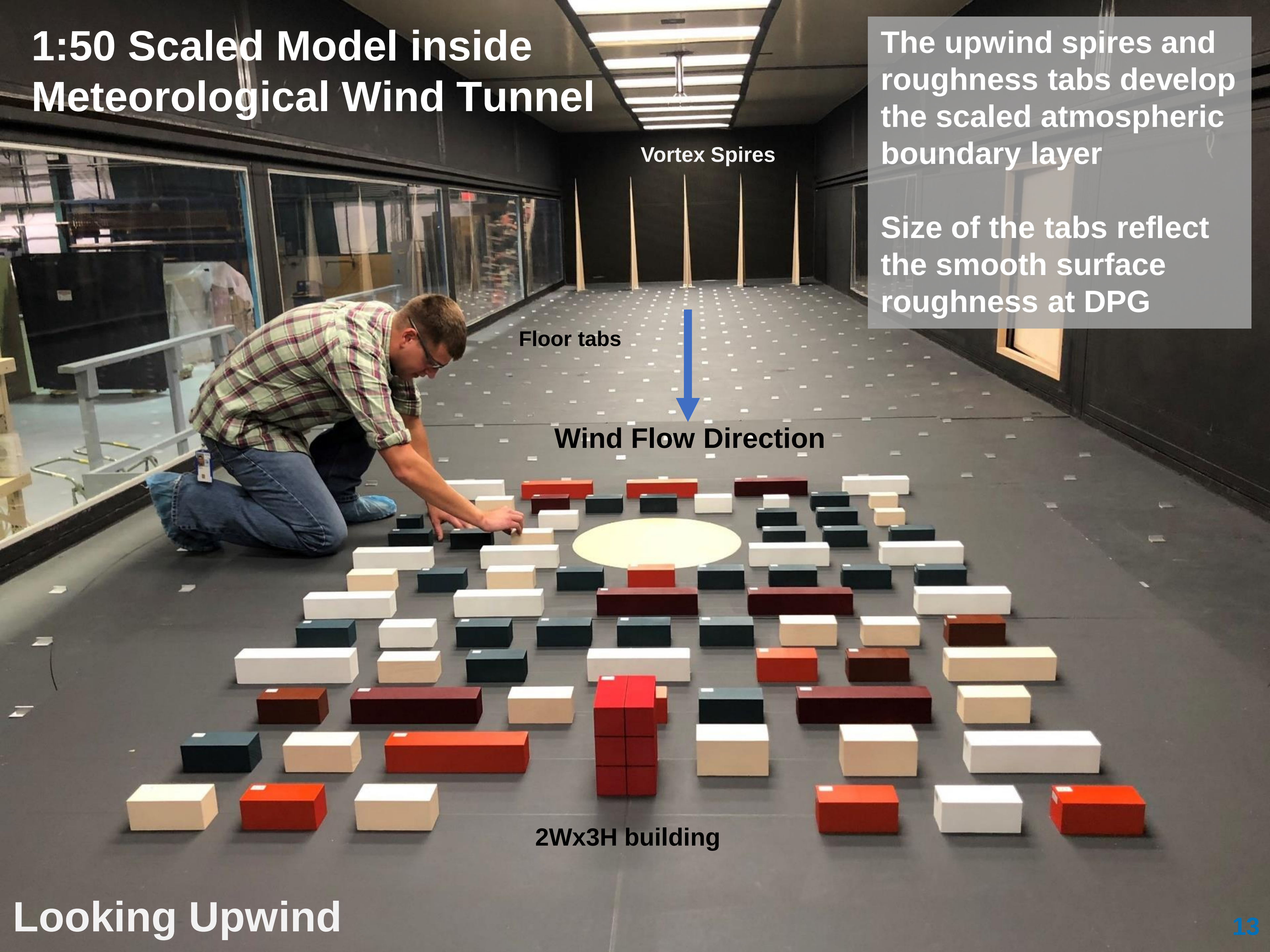
Laser Probe

- **Laser Doppler Velocimetry (LDV) for velocity flow measurements**
- **Neutrally buoyant hydrocarbon tracer (ethane) gas emission releases**
- **Flame Ionizing Detectors (FID) for concentrations**

1:50 Scaled Model inside Meteorological Wind Tunnel

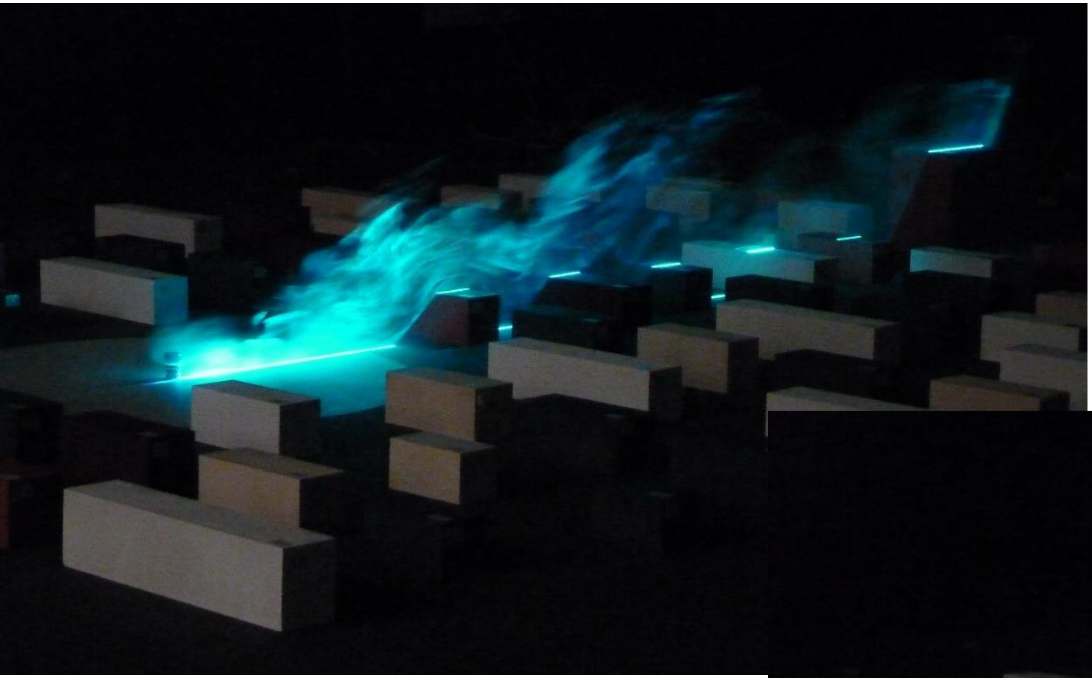
The upwind spires and roughness tabs develop the scaled atmospheric boundary layer

Size of the tabs reflect the smooth surface roughness at DPG



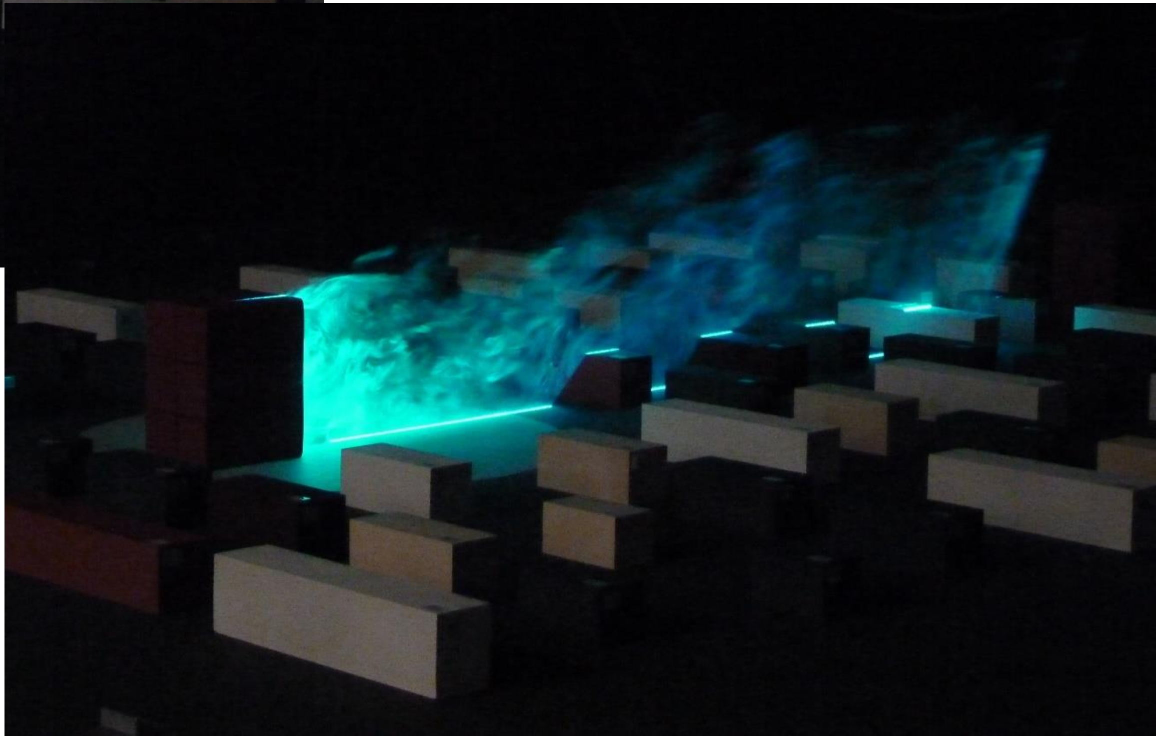
Looking Upwind

Wind Tunnel Flow Visualization



Illumination: Laser light sheet
Effluent: Theatrical smoke release

Neutrally buoyant ground level source



Same release
Tall building upwind of source creates greater plume thickness

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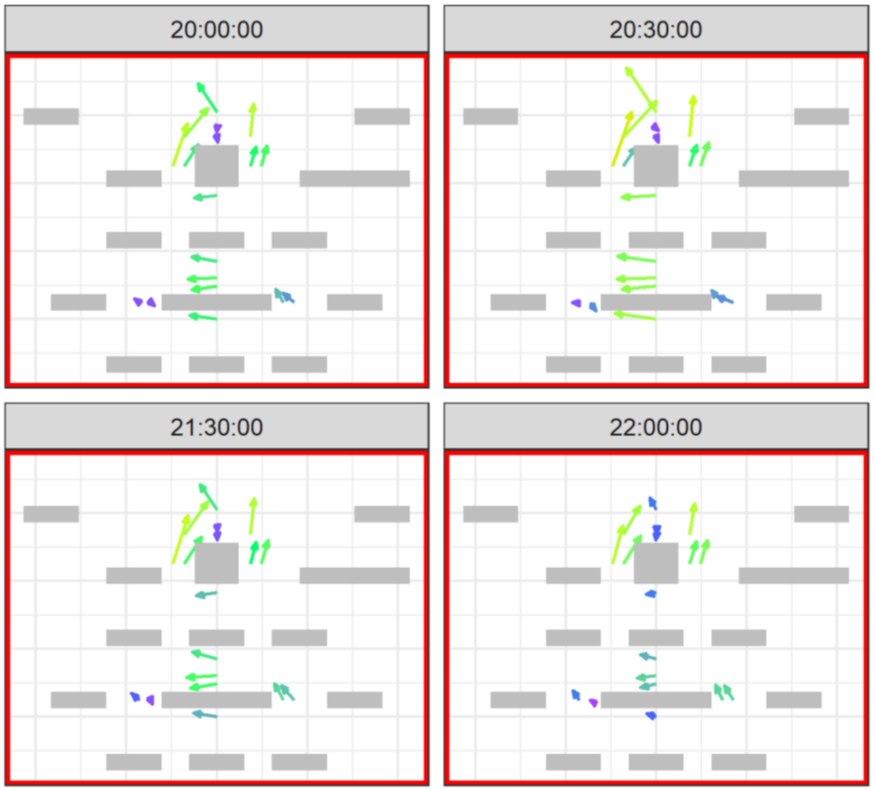
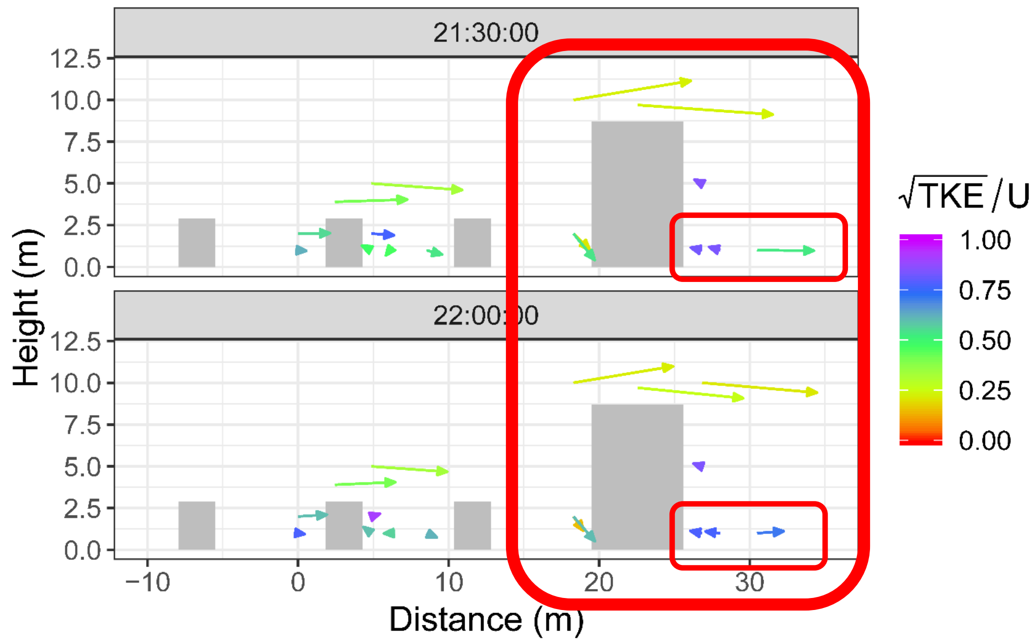
Flow Within the CONEX Array

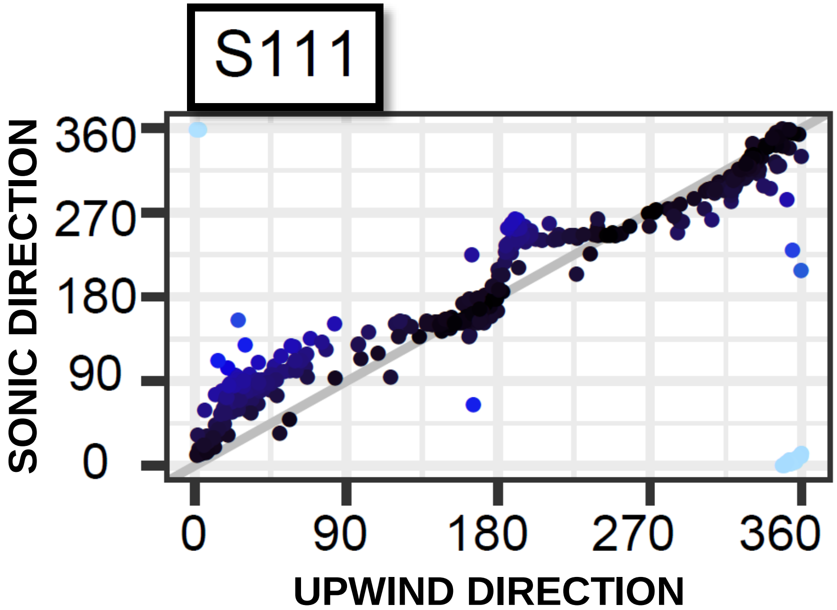
- **Sonic wind vectors from select 30 minute periods**
  - » *March 21, 2016*

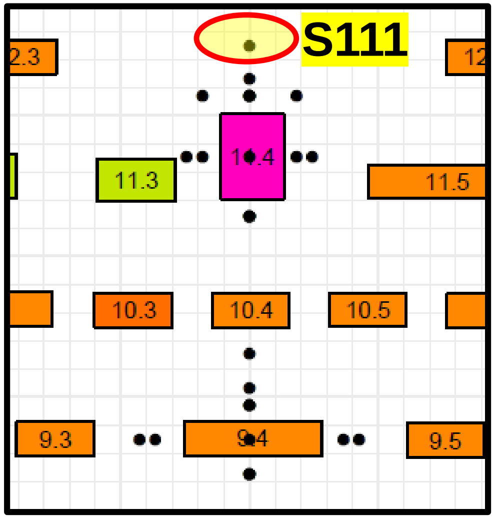




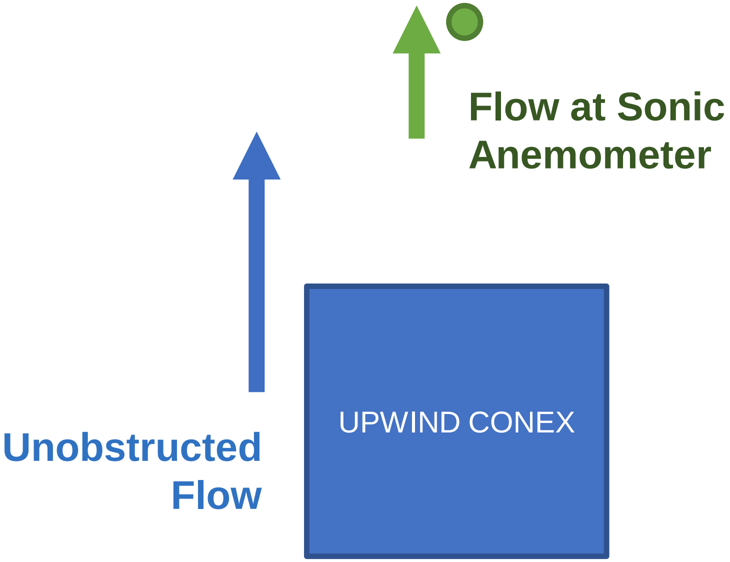
– **High TKE and low wind behind and adjacent to obstacles depicts higher turbulence intensity**

Localized Flow Patterns

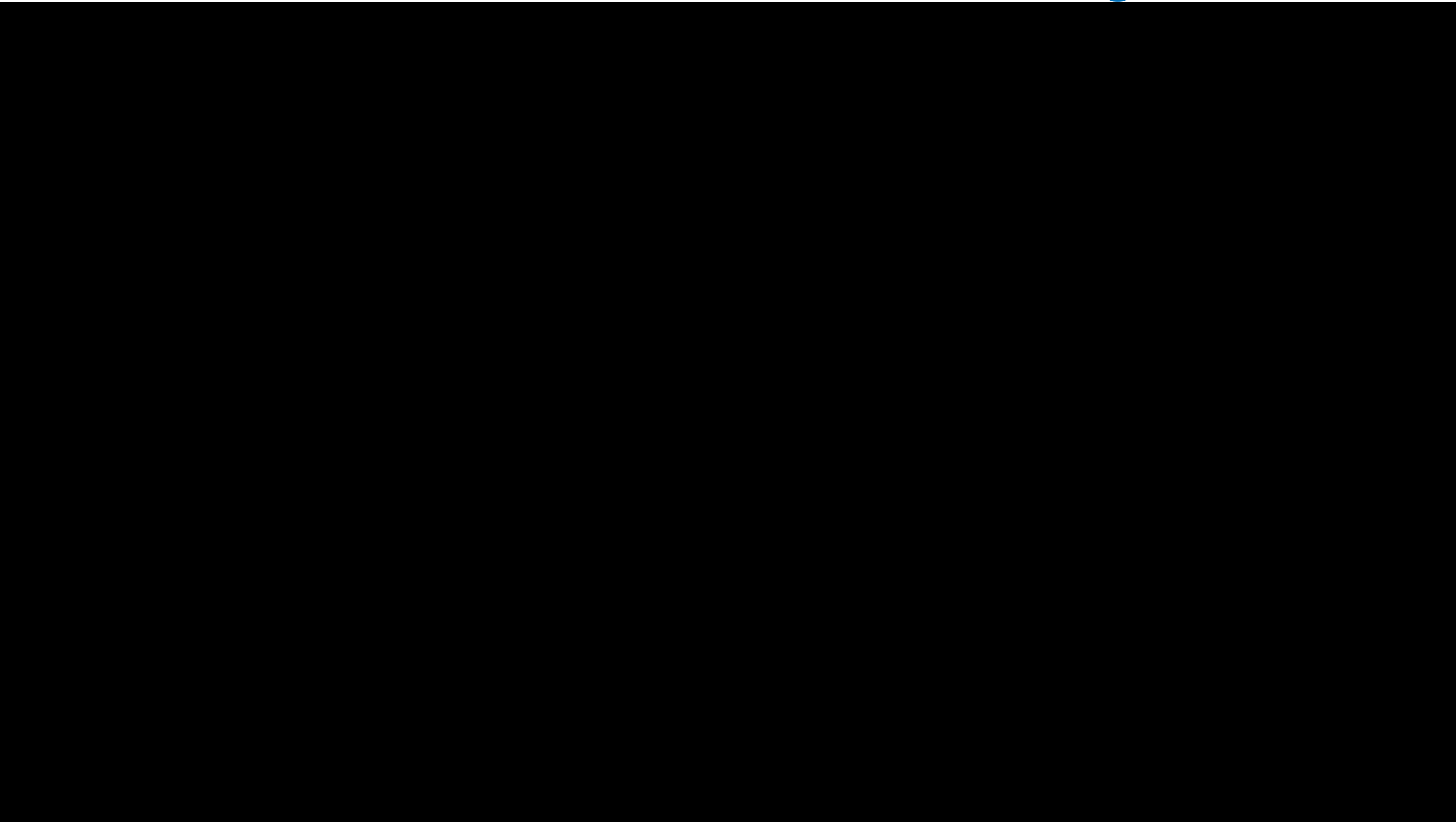




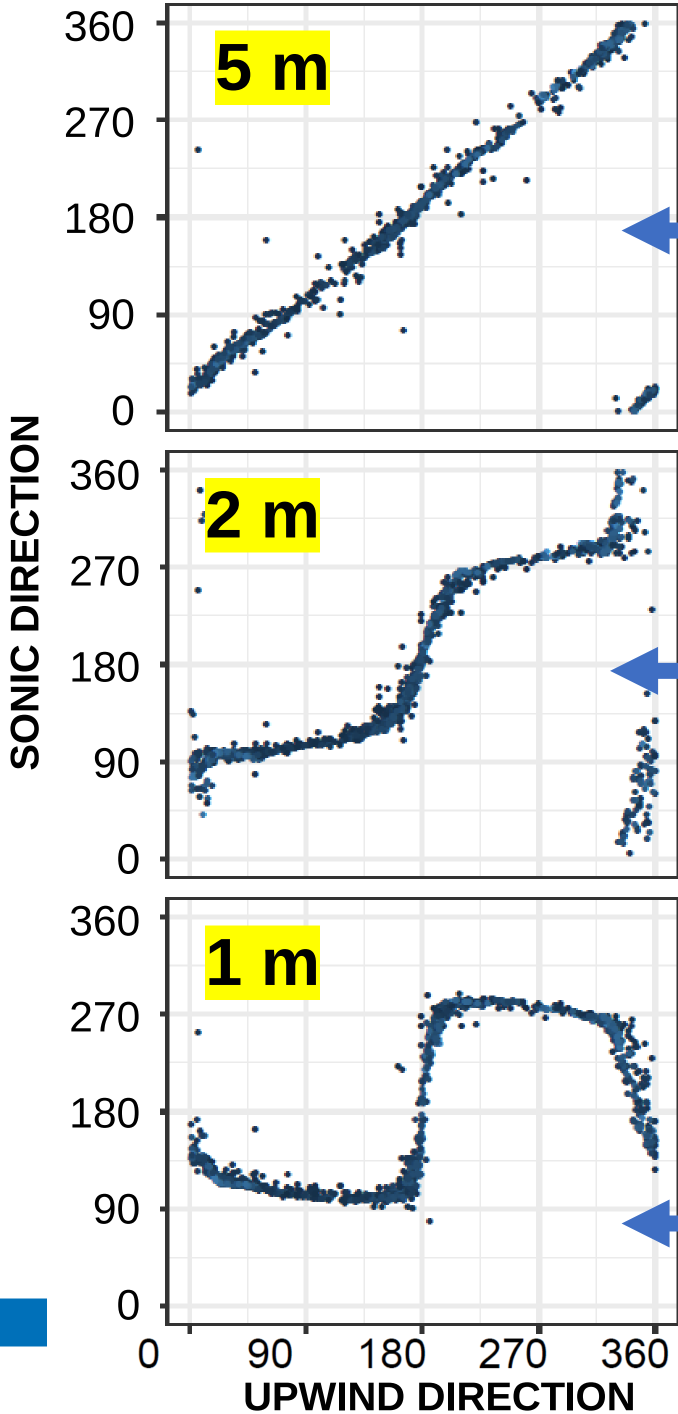
- **5m downwind of tall building**
- **Far enough from building to limit changes to the overall local wind flow**



Ground Level Source, Downwind of Tall Building



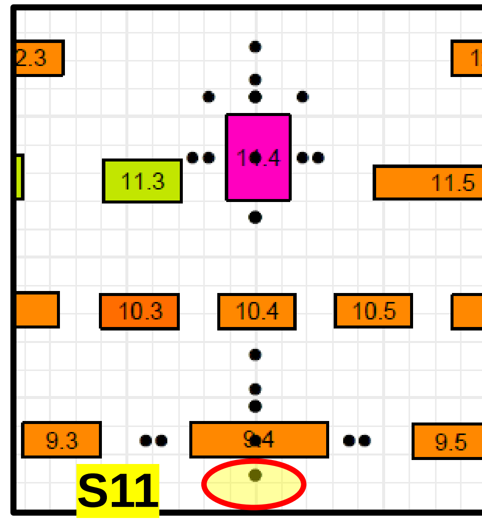
Localized Flow Patterns



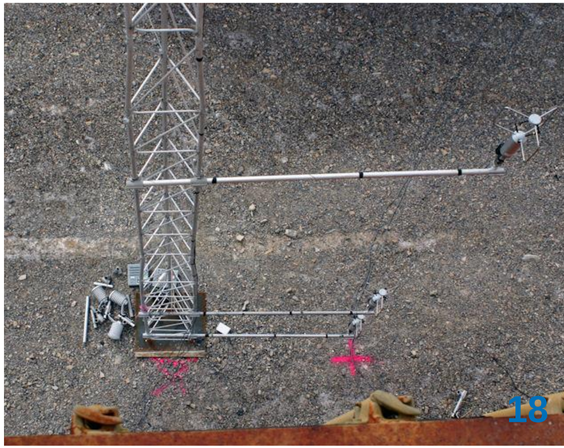
1:1 Upwind vs. Sonic wind direction relationship indicates mostly prevailing flow

More wind variation closer to CONEX roof

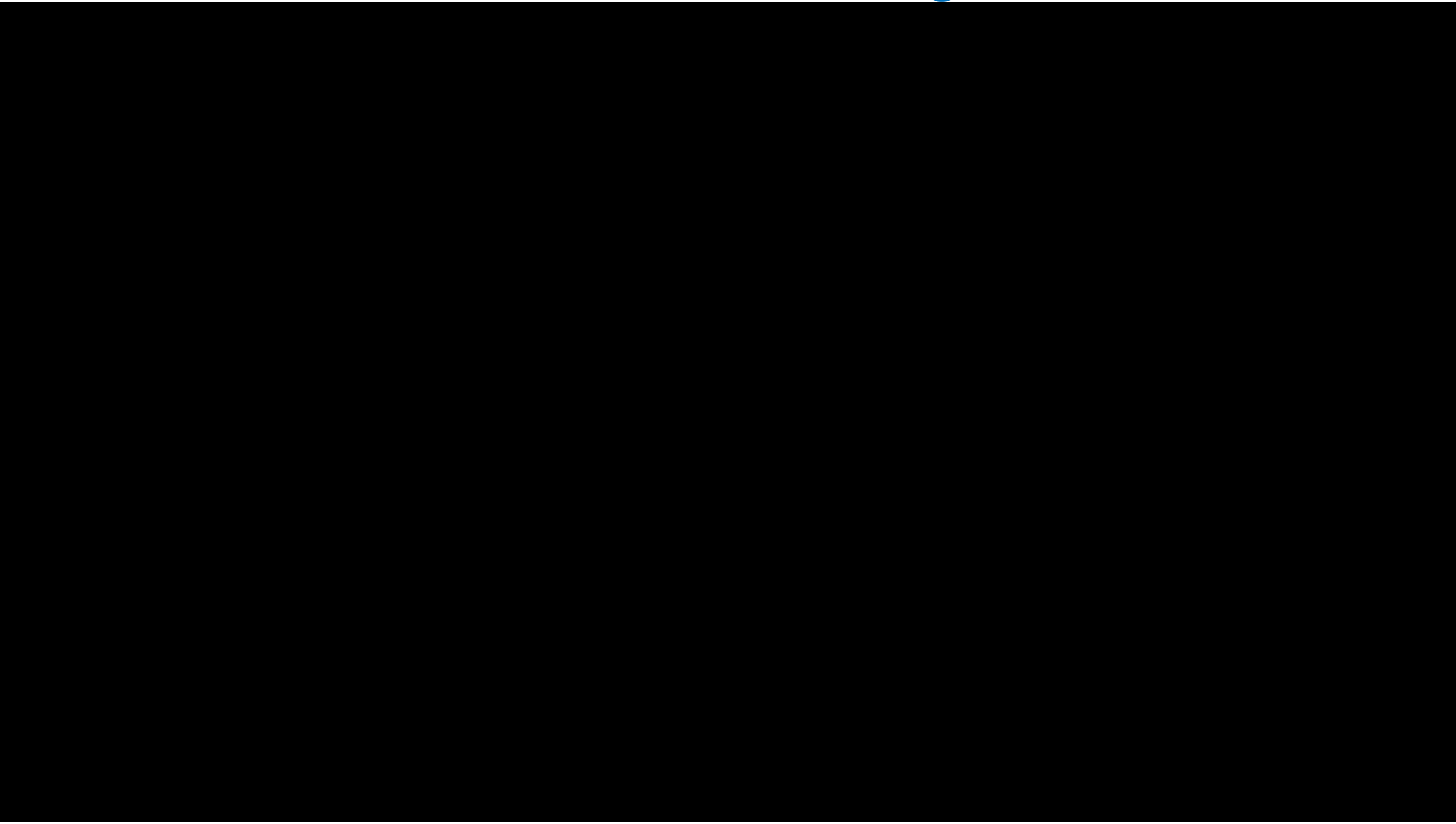
Wind within street canyon forced mainly easterly or westerly



- **S11 Tower: sonics at 1, 2, 5m above ground level**
- **2m upwind of building**
- **CONEX 9.4 was 2.6m tall**



Source Upwind of Tall Building: Various Source Heights



Concluding Remarks

- **Small fluctuations in wind can cause large changes in effluent dispersion**
- **The sonic anemometer data can help us approximate:**
  - Proximity to the building where a wake will significantly affect the flow
  - Locations to study velocity and tracer concentrations in the wind tunnel experiments
- **The laboratory data can help test and evaluate urban parameter modifications in Gaussian dispersion models**

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THANK YOU

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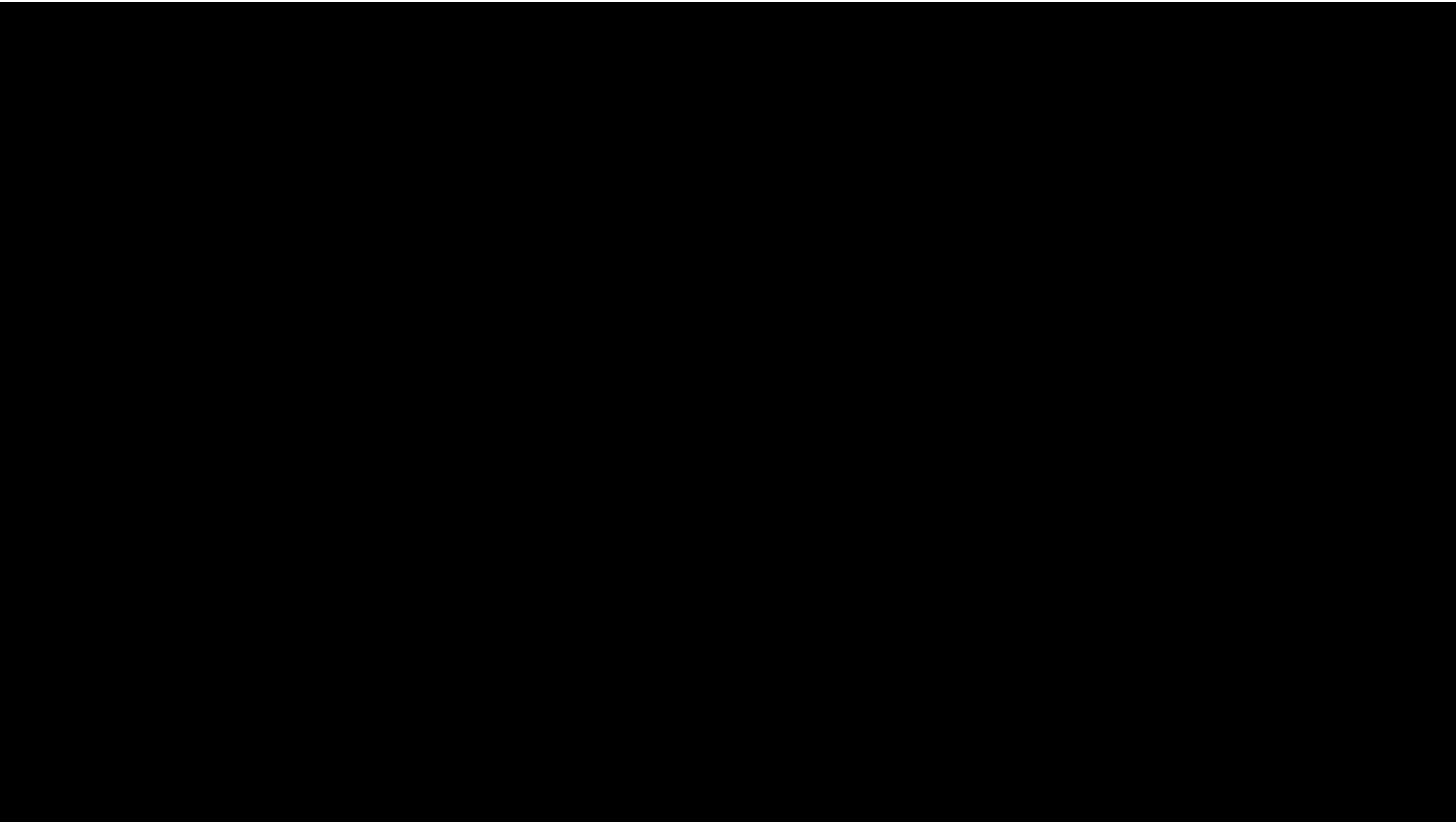
Extra Slides

Source Upwind of Tall Building: Horizontal Laser Sheet

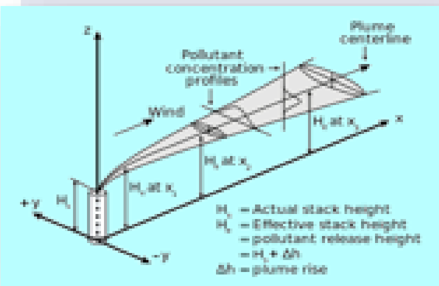


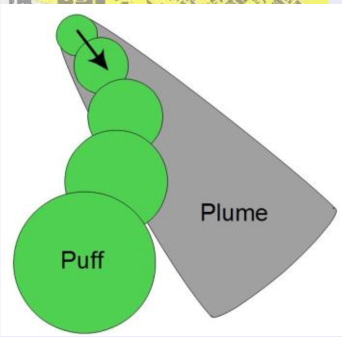
Ground Level Source, Downwind of Tall Building

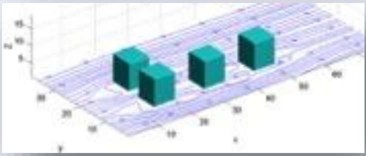
Source Upwind of Tall Building: Various Source Heights

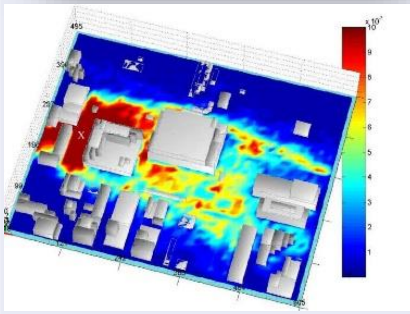
Source Upwind of Tall Building: Horizontal Laser Sheet

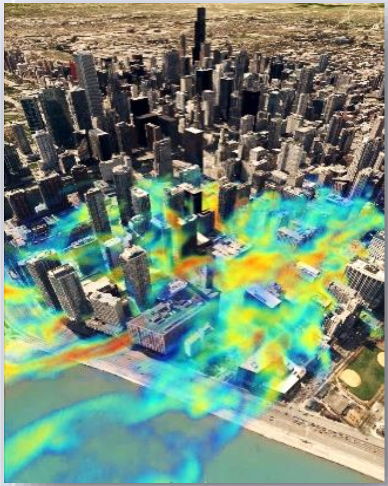
Gaussian Plume Models	Gaussian Puff Models	Lagrangian Dispersion Models	Computational Fluid Dynamics (CFD) Models
Typical Computational Time			
Seconds	**Minutes**	**Minutes to Hour**	**Hours**
• Very fast estimate with minimal calculations and simplified parameterizations	• Fast estimate resulting in concentrations through a sequence of puffs	• Tracks individual particles downwind with more resolved urban features	• High resolution simulation following fluid dynamics







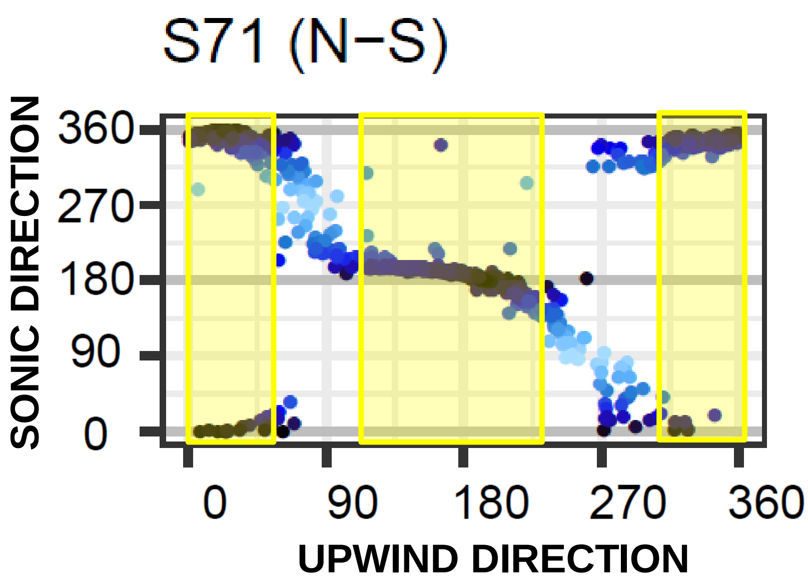




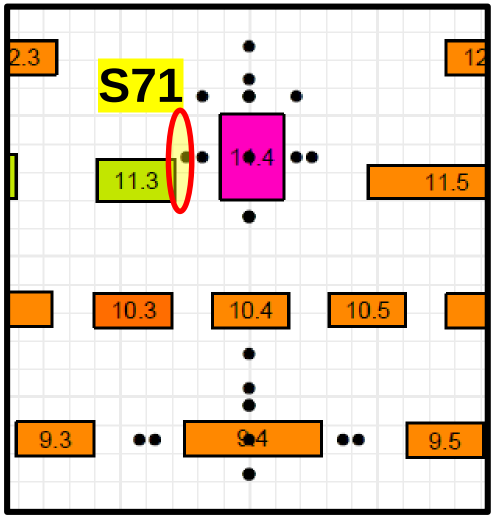
Increased model complexity, accuracy, and computational requirements

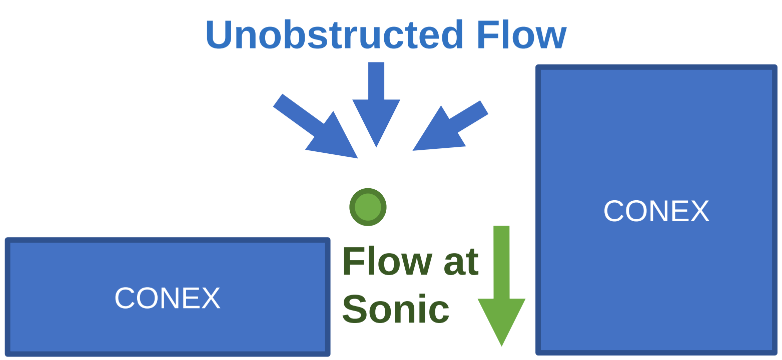
Based on material from A. Gowardhan [2018]

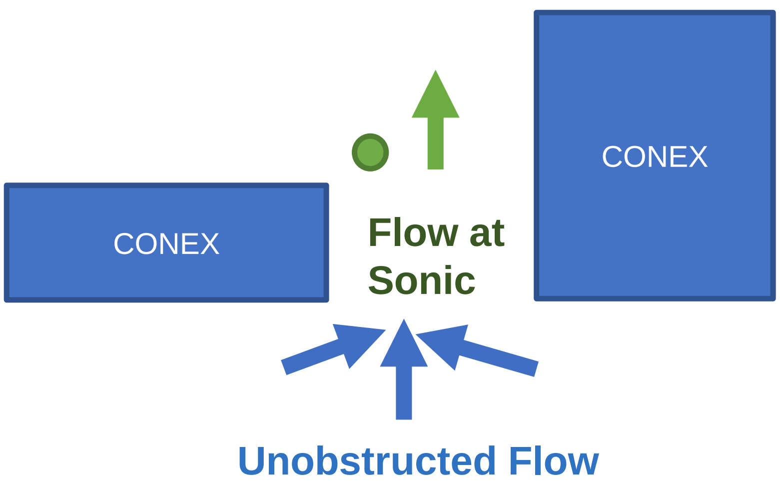
Localized Flow Patterns



Flow channeled predominantly northerly or southerly due to street canyon

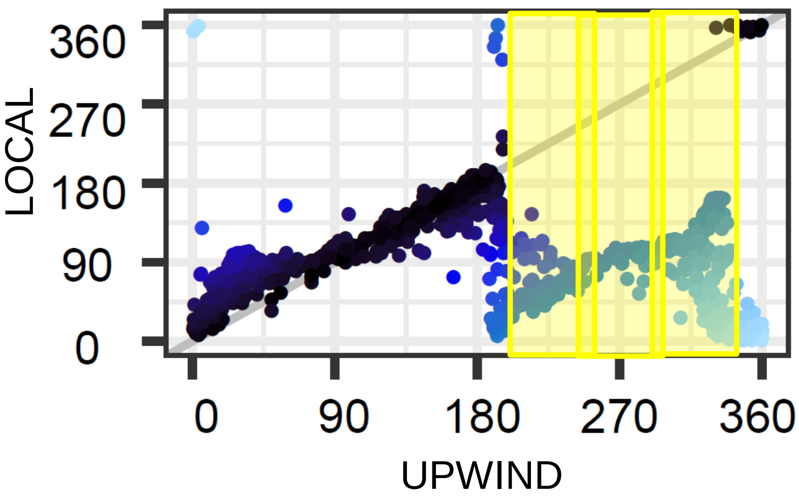




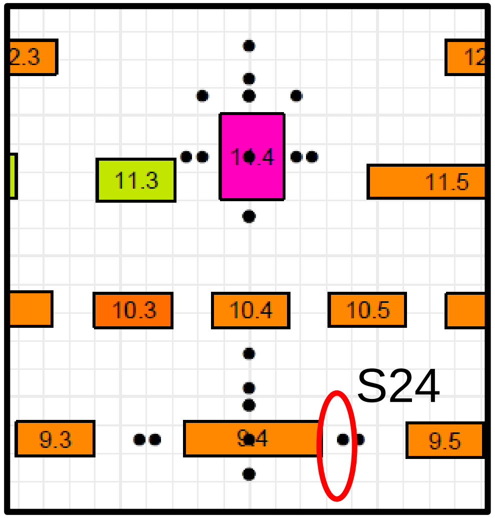


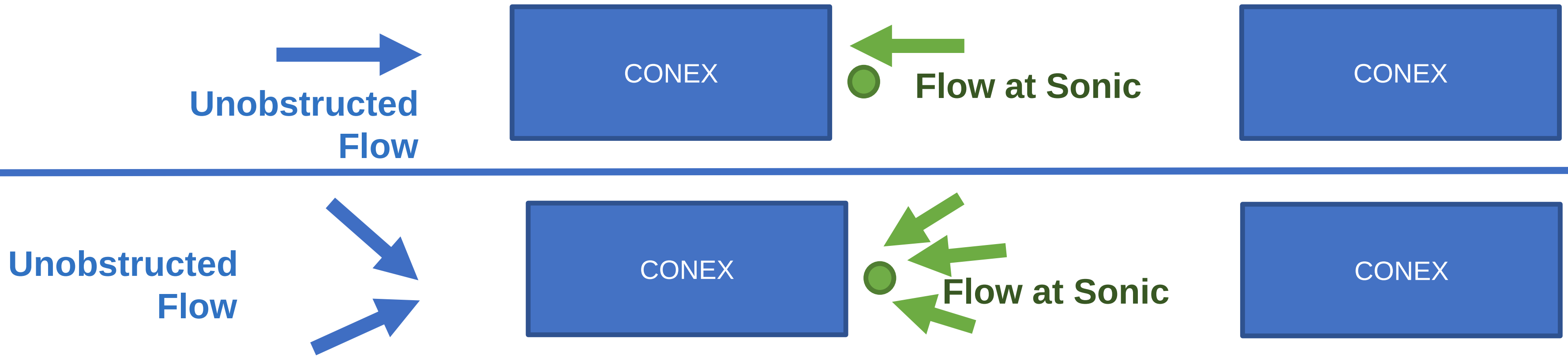
Localized Flow Patterns

S24 (Prevailing)

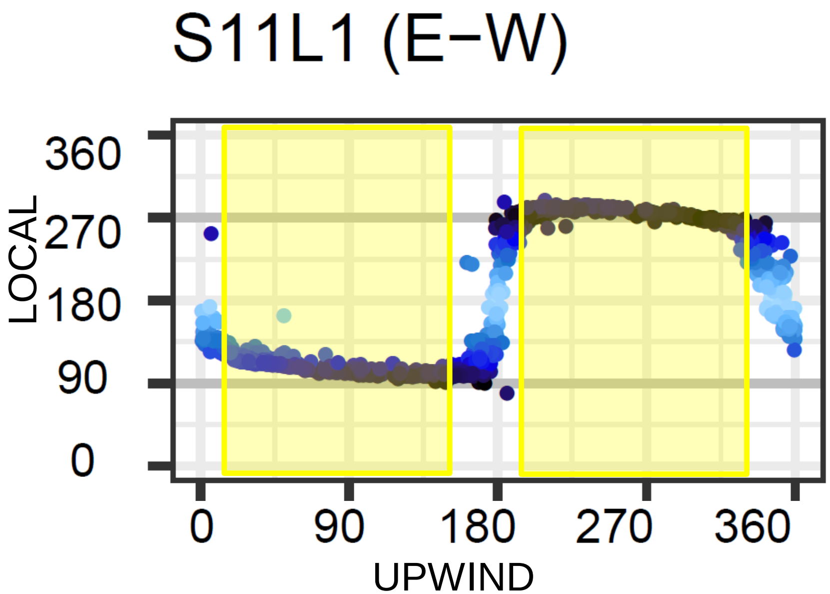


- ~1m to the east of a building
- Flow is prevailing when wind comes from N – E – S
- From S – W – N, flow is forced more opposite





Localized Flow Patterns



- ~2m upwind of building and ~6m downwind of another
- N-W-S flow forced westerly at sonic
- Opposite = easterly
- Direct N or S flow, wake effects