

# Reducing vulnerability to non-synoptic winds. The WindEEE Dome

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## SUMMARY

 WindEEE Research Institute  
Engineering, Energy & Environment



- Minimizing Vulnerability
- WindEEE
- Tornadoes
- Downbursts
- Further work

# VULNERABILITY

Pielke Jr. (1997):

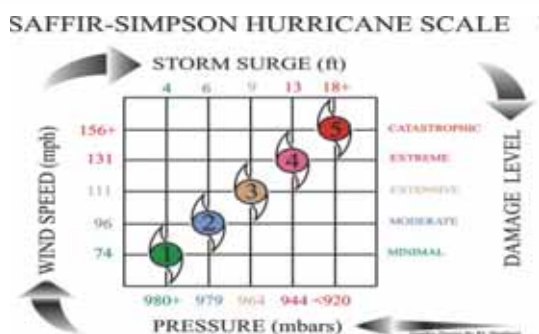
minimize **Vulnerability** = f (**Incidence**, **Exposure**)

**Incidence** = f (Intensity, Occurrence, Frequency)

**Exposure** = f (Population, Property, Preparedness)

## Wind Incidence: Intensity

### HURRICANES



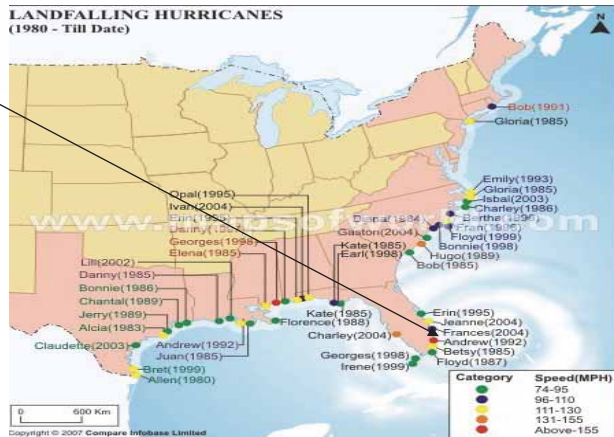
$$V = 14.1 (F+2)^{1.5}$$

### TORNADOS

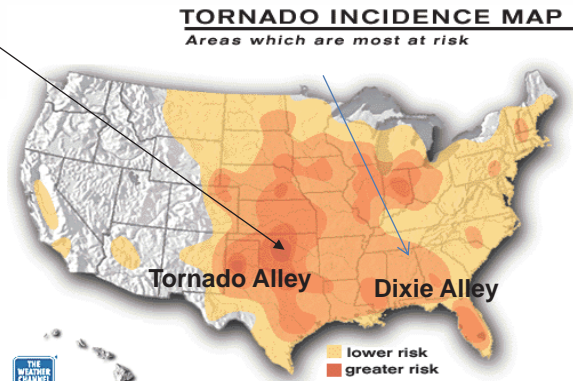
ORIGINAL FUJITA SCALE		ENHANCED FUJITA SCALE	
F5	261-318 mph	EF5	+200 mph
F4	207-260 mph	EF4	166-200 mph
F3	158-206 mph	EF3	136-165 mph
F2	113-157 mph	EF2	111-135 mph
F1	73-112 mph	EF1	86-110 mph
F0	<73 mph	EF0	65-85 mph

$$BF12 = M1$$

# Wind Incidence: Occurrence



HURRICANES



Source: "The Thunderstorm in Human Affairs" 2nd Edition, Edwin Kessler, Editor University of Oklahoma Press, Norman, OK, 1983

TORNADOES

# Wind Incidence: Frequency



Figure 10: Return period for F2 or greater tornadoes in thousands of years from Monte Carlo simulation. Note that contours follow progression 1, 2, 5, 10, etc.



Figure 11: Same as Fig. 10, except for F4 or greater tornadoes in tens of thousands of years.

>F2

- Monte Carlo Simulations for 30,000 years
- Minimum Return Period = 4,000 years/sq.km
- Maximum in Oklahoma, Minimum in Nevada

>F4

- Monte Carlo Simulations for 18 million years
- Minimum Return Period = 16,700/sq.km

95% F0, F1 and F2; Only 0.1% F5

$$F5 = 0.1 * F4 = 0.02 * F3 = 0.006 * F2$$

1921-1995 Data base by Grazulis (1993), Monte Carlo Simulations by Meyer et al. (2005)

# WindEEE: Milestones



Funded : April 2009

Design : December 2010

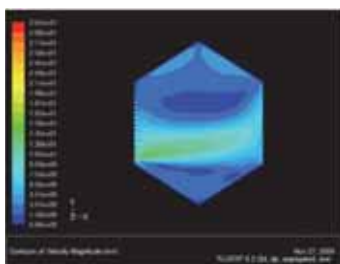
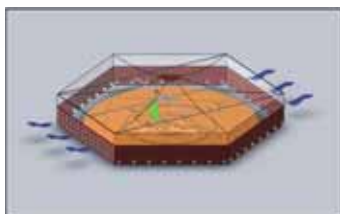
WindEEE RI : July 2011

Construction : September 2013

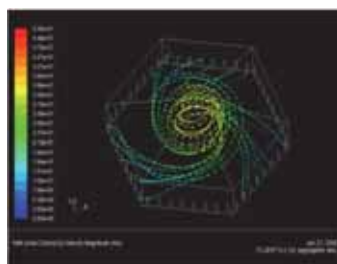
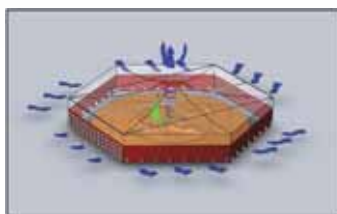
Commissioned: September 2014

# WindEEE: Preliminary Design

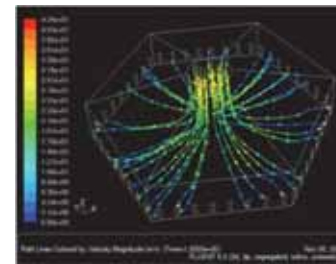
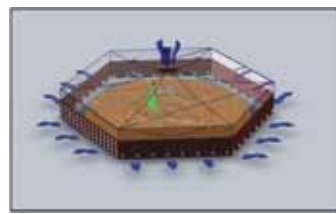
straight/sheared flow



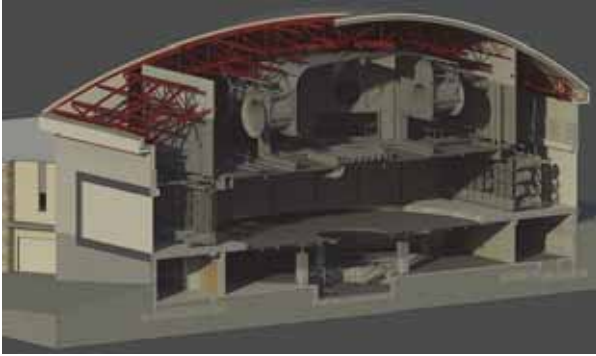
tornado flow



downburst flow

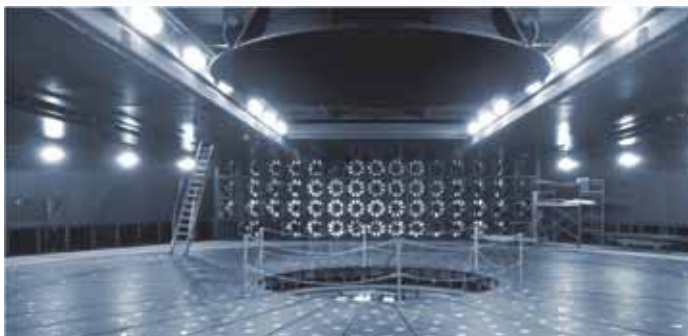


## WindEEE: Engineering Design



- Active topographic terrain
- 1.5 MW of fan power
- 5 m lift and turntable
- 106 individually controlled fans
- 1600 floor roughness elements
- 5 m diameter storm systems
- 2 m/s wind storm translation

## WindEEE: Research Ready



### Six Initial Design Specifications:

- Straight Mode Uniform
- Straight Mode Boundary Layer
- Straight Mode Shear
- Tornado
- Downburst
- Reversed Flow Mode

+ HH 7 😊

## WindEEE Research Institute: Outcomes



Publications: 50–55 /year

Conferences / seminars : 55-60/year

Research Grants: \$2 M (excluding operational funds)

Graduate Fellows: 25-30 core group

## TORNADOES



Elie, Manitoba tornado 2007

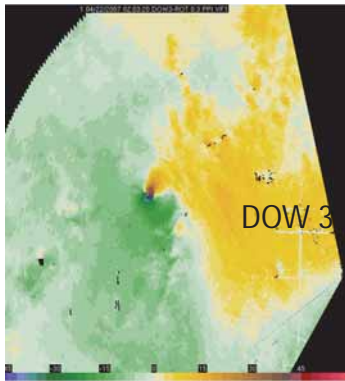


Bennington Kansas EF-4 Tornado 2013

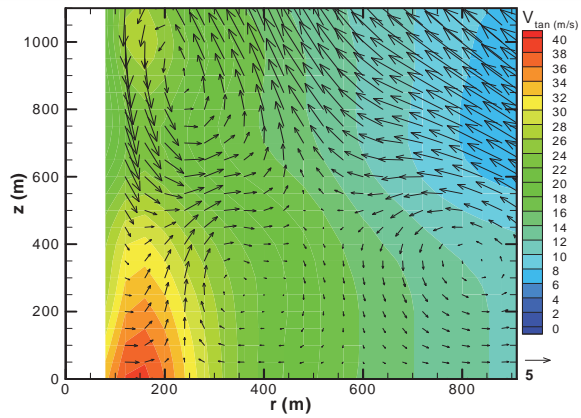


# Tornadoes: Full scale ROTATE campaign

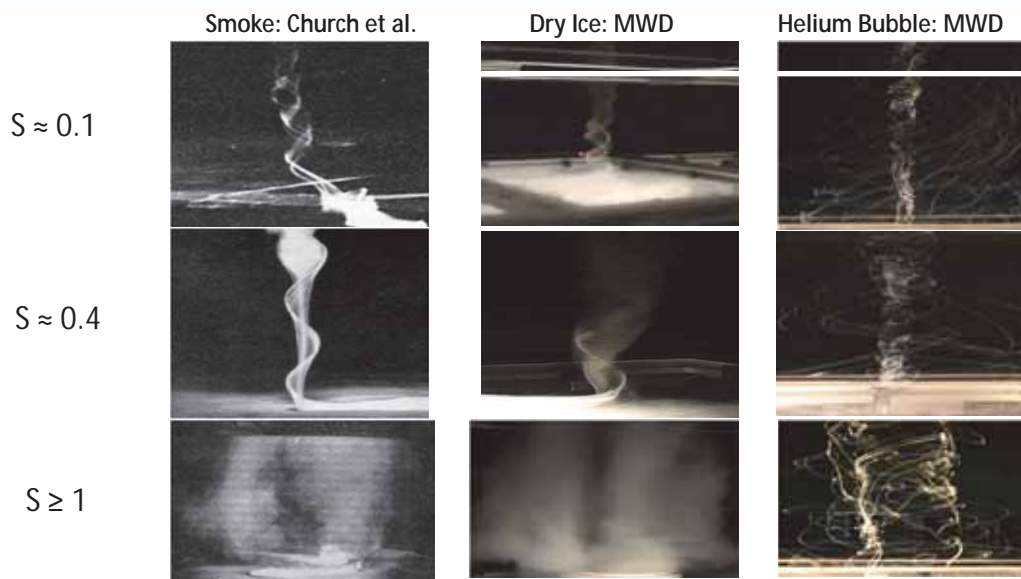
Data from CSWR Colorado: 9 tornado volumes from EF0 to EF3



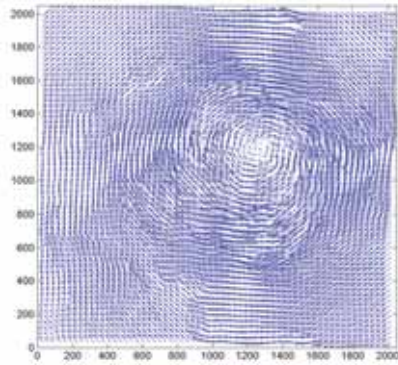
Doppler velocity (m/s) contour map of the Happy, TX 2007 tornado at 0203:20 UTC and at 0.3° radar beam angle



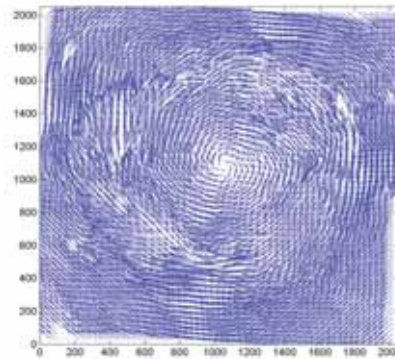
# Tornadoes: Laboratory Flow Visualizations



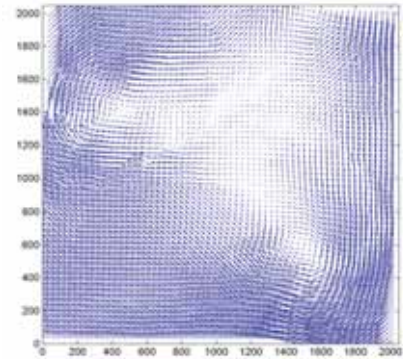
# Tornadoes: Laboratory PIV



$S \approx 0.25$



$S \approx 0.57$



$S \geq 1$

# Tornadoes: Scaling

- The overall maximum tangential velocity

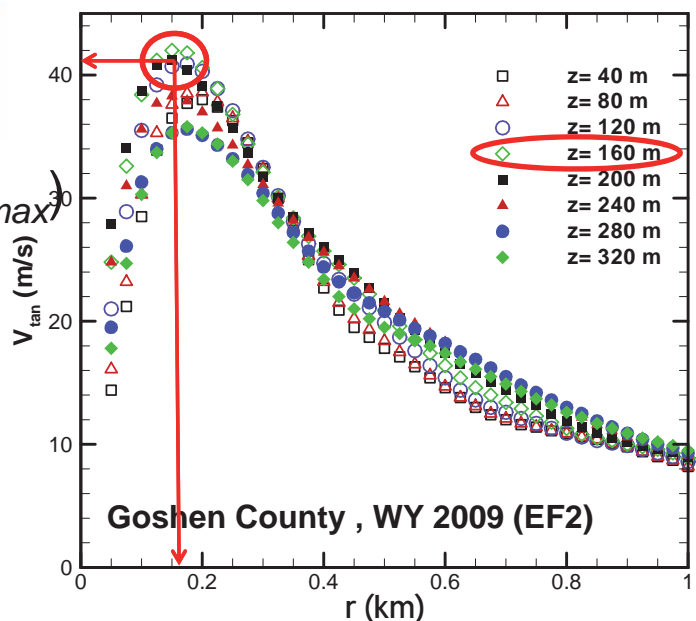
$$V_{tan,max} = V_{tan}(r_{c,max}, z_{max})$$

- Velocity scale

$$\lambda_v = V_{tan,max,D} / V_{tan,max,S}$$

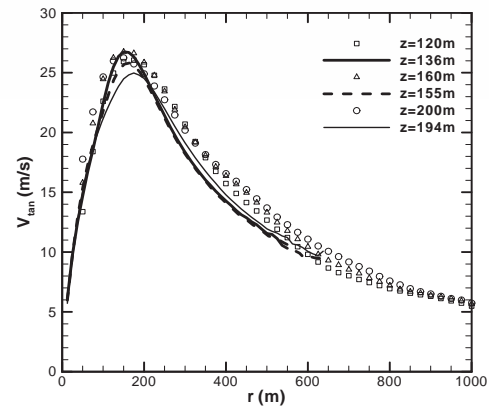
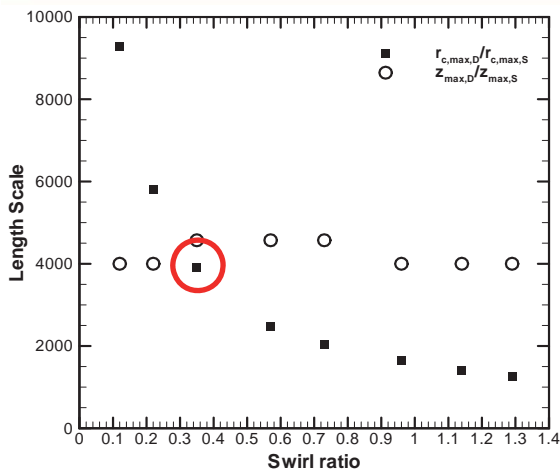
- Length scale

$$\lambda_l = \begin{cases} r_{c,max,D} / r_{c,max,S} \\ z_{max,D} / z_{max,S} \end{cases}$$





# Tornadoes: Scaling



GC v2

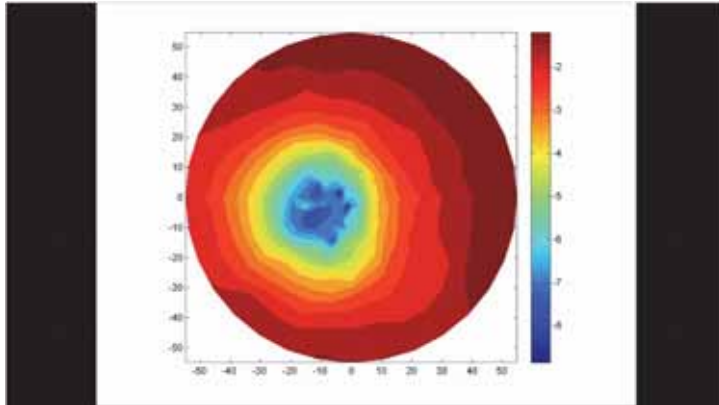
- Intersection of the two scaling ratios -> Swirl Ratio
- Matching radial profiles of tangential velocity at every height

# Tornadoes: Flow visualizations in WindEEE



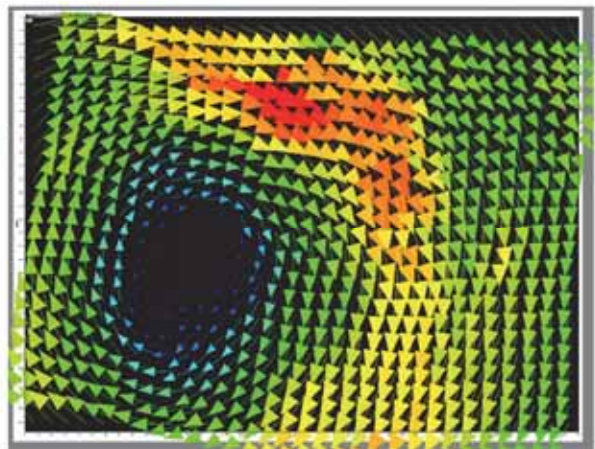
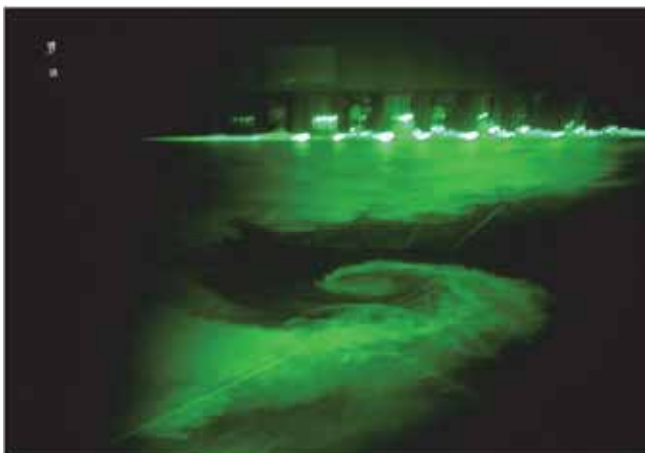
- Simulate EF1, EF2, EF3 and EF4 tornadoes
- Demonstrate flow structure vs. Real tornadoes

## Tornadoes: Base pressures in WindEEE



- Simulate EF1, EF2, EF3 and EF4 tornadoes
- Demonstrate flow structure vs. Real tornadoes

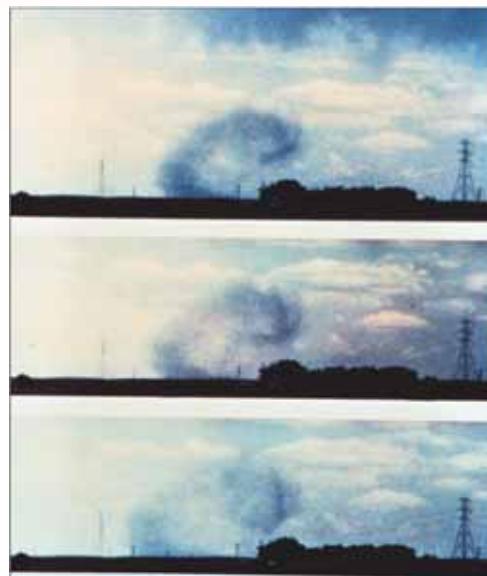
## Tornadoes: Large Scale PIV in WindEEE



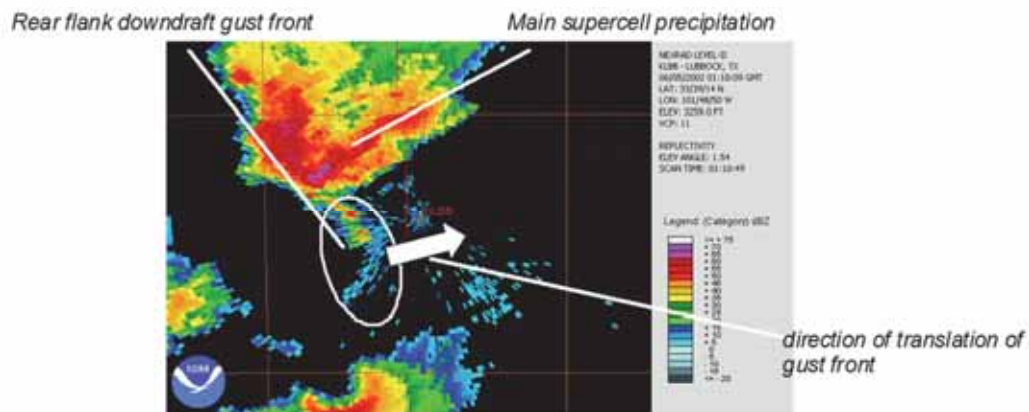
# Tornadoes: Translation



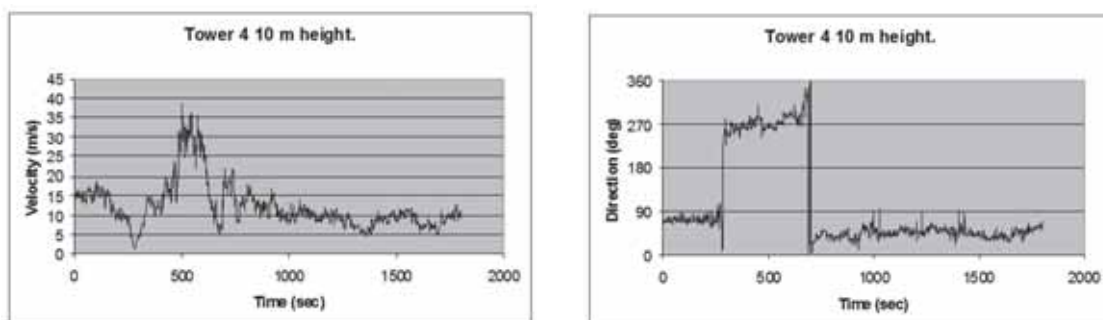
# DOWNBURSTS



# Downbursts: Full Scale Data



# Downbursts: Full Scale Data



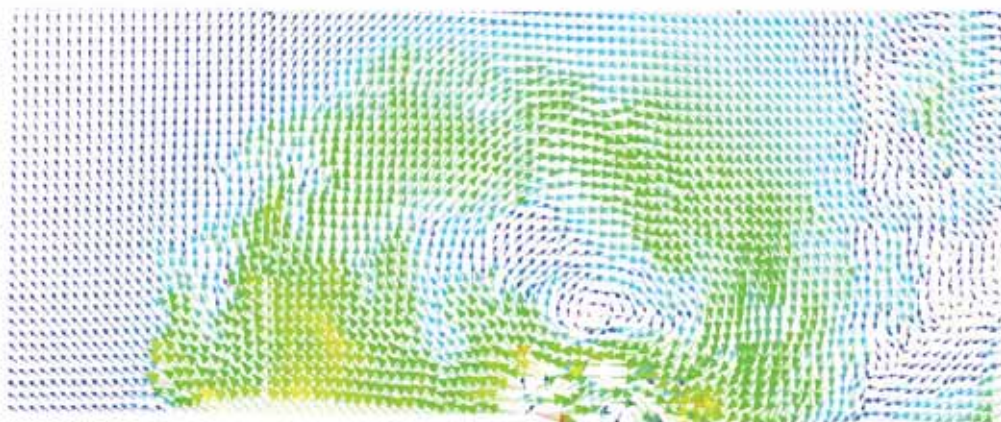
Moving average ? Coherent behaviour? POD/Wavelet/PR/Dynamic PCA/ICA?

Holmes et al. (2008)

# Downbursts: Flow Visualizations in WindEEE



# Downbursts: PIV in WindEEE





## Work to do

- Statistics of non-synoptic winds:
  - Under development
- Simulation of Flow Fields
  - Full Scale Data under development
  - Mean and First Order Statistics only
- Interaction with Structures
  - Differences in loading between ABL and non-ABL winds
  - Time analysis (what type?) vs. Spectral analysis

## Damage

- Damage Path
- Engineering retrofit and new solutions

**Thank you !**

[www.windeee.ca](http://www.windeee.ca)

