Photo by Herb Stein

Joshua Wurman **jwurman@cswr.org** **www.cswr.org**

What we know
What we don't know

Some warning statistics sound and are good

NOAA forecasts are getting better.

Average lead times are up to about 12 minutes

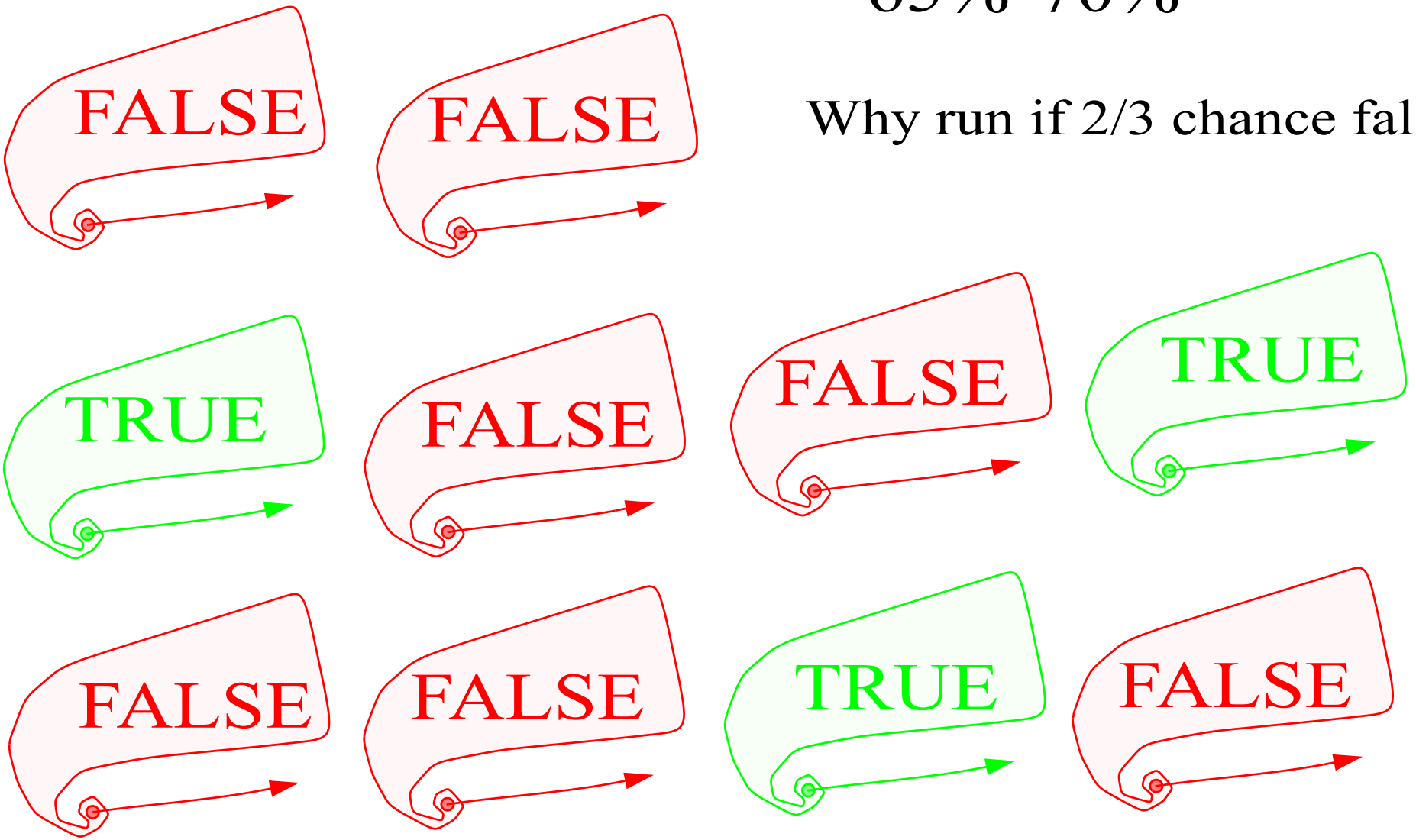
Missed tornadoes are down to 25%

But, the full picture is not so bright

1. Very high false alarm rates
2. No intensity warnings
3. No length of track forecasts
4. 12 minutes is not much time

We don't know When, Where tornadoes form

Warning False Alarm Rate
65%-70%

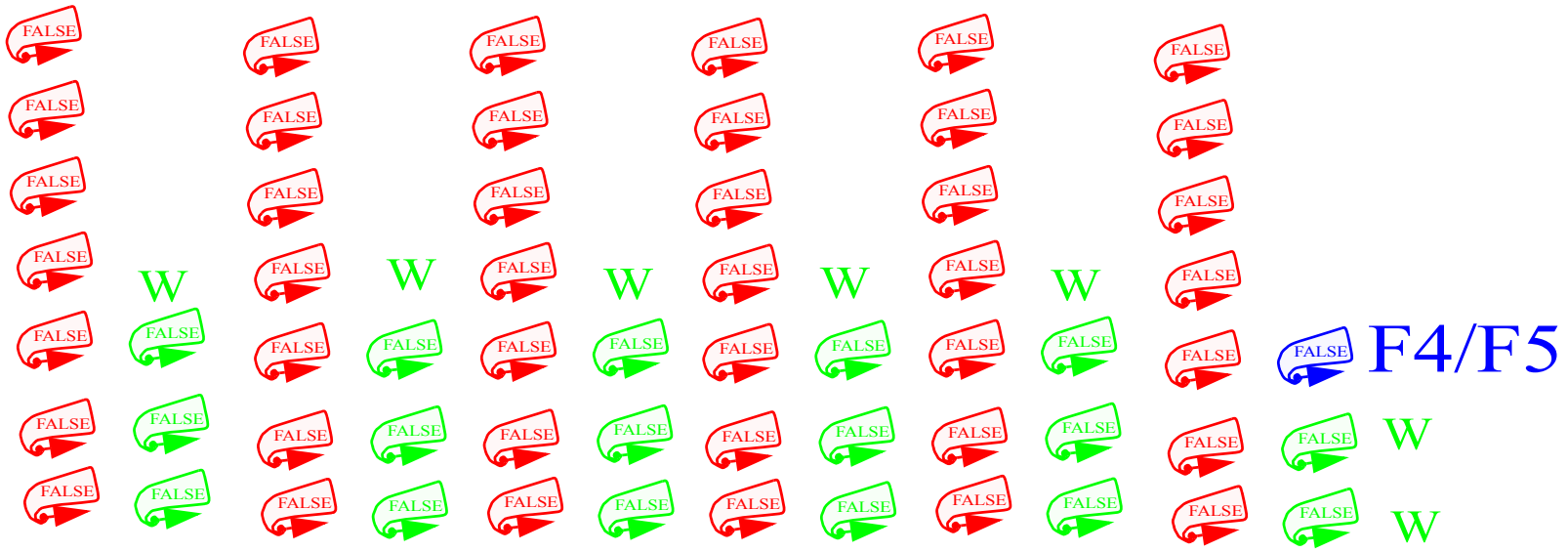


Why run if 2/3 chance false?

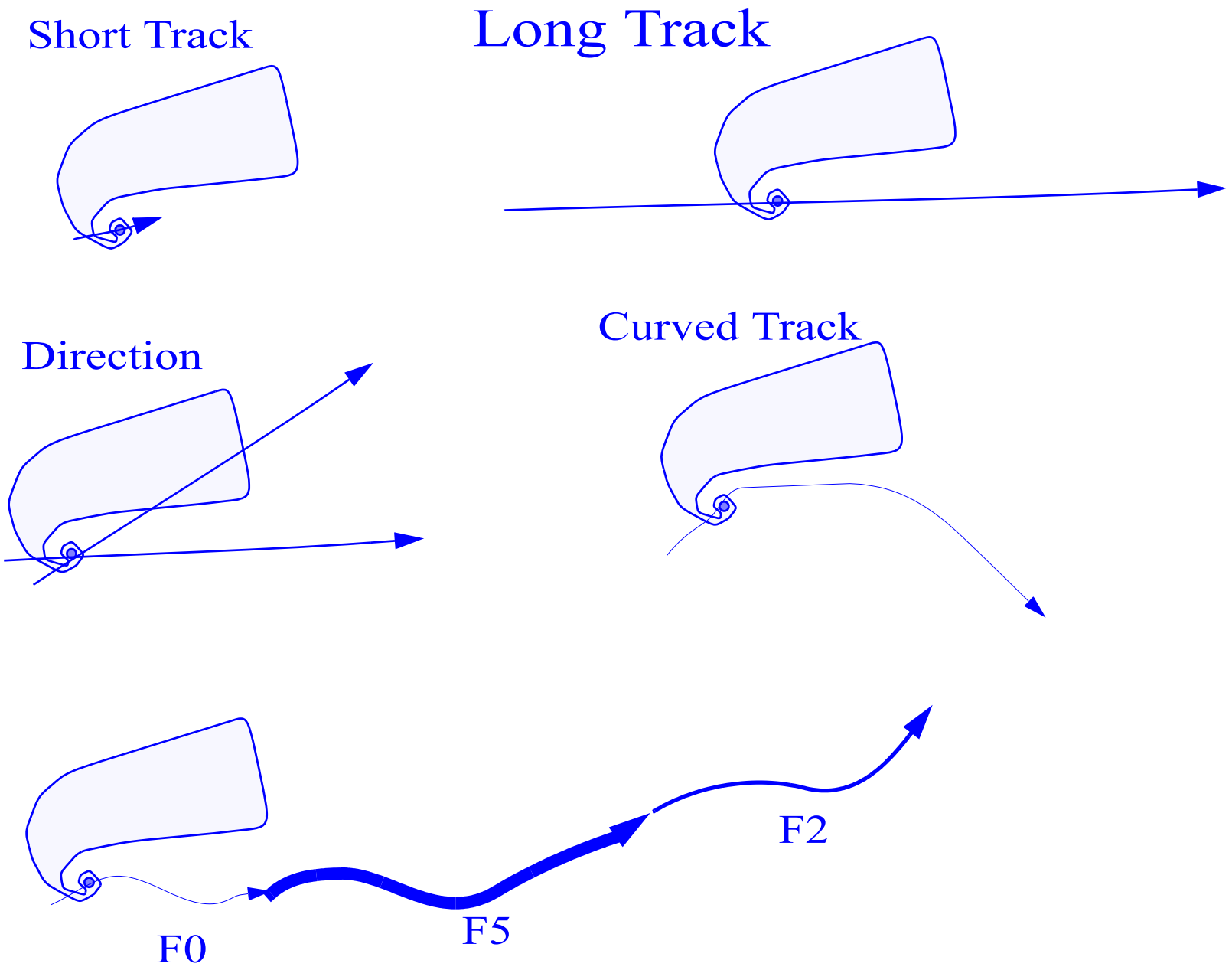
We don't know How strong tornadoes will be

Warnings provide no forecast of intensity

Effective False Alarm Rate for F4/F5 = 98%



We don't know Length, precise path, evolution



Compare this lack of specifics to

Hurricane Warnings:

- **track and probabilities**
- **intensity (Cat 1,2,3,4,5)**
- **timing**

Blizzard Warnings:

- **intensity (6-12 inches)**
- **timing**

The problem is not with forecasters.

NOAA/NWS/SPC are doing the best they can with available knowledge and observations

NWS skill is nearly maxed out

The problem is with the state of:

a. **Scientific knowledge**

b. **Observations**

Scientific questions about tornadoes

How, when, where they'll form
How strong or long lasting they'll be
How they do damage
How big or strong they really are.

Tornadogenesis:

1. Role of downdrafts and downdraft character
2. Sensitivity of genesis to microphysical and thermodynamic fields
3. Role of small-scale vorticity maxima observed along gust fronts
4. Different genesis modes

Near-Ground Winds:

1. Range of observed tornado characteristics: vertical, radial, asymmetries, multiple vortices, and angular momentum budgets, swirl
2. Relationship between damage and peak wind, wind duration, wind direction

Relationship Between Tornadic Storms and Environment:

1. Favorable and unfavorable storm interactions, mergers
2. Effects of environmental heterogeneity

Why don’t scientists know these things?

Good enough observations do not yet exist

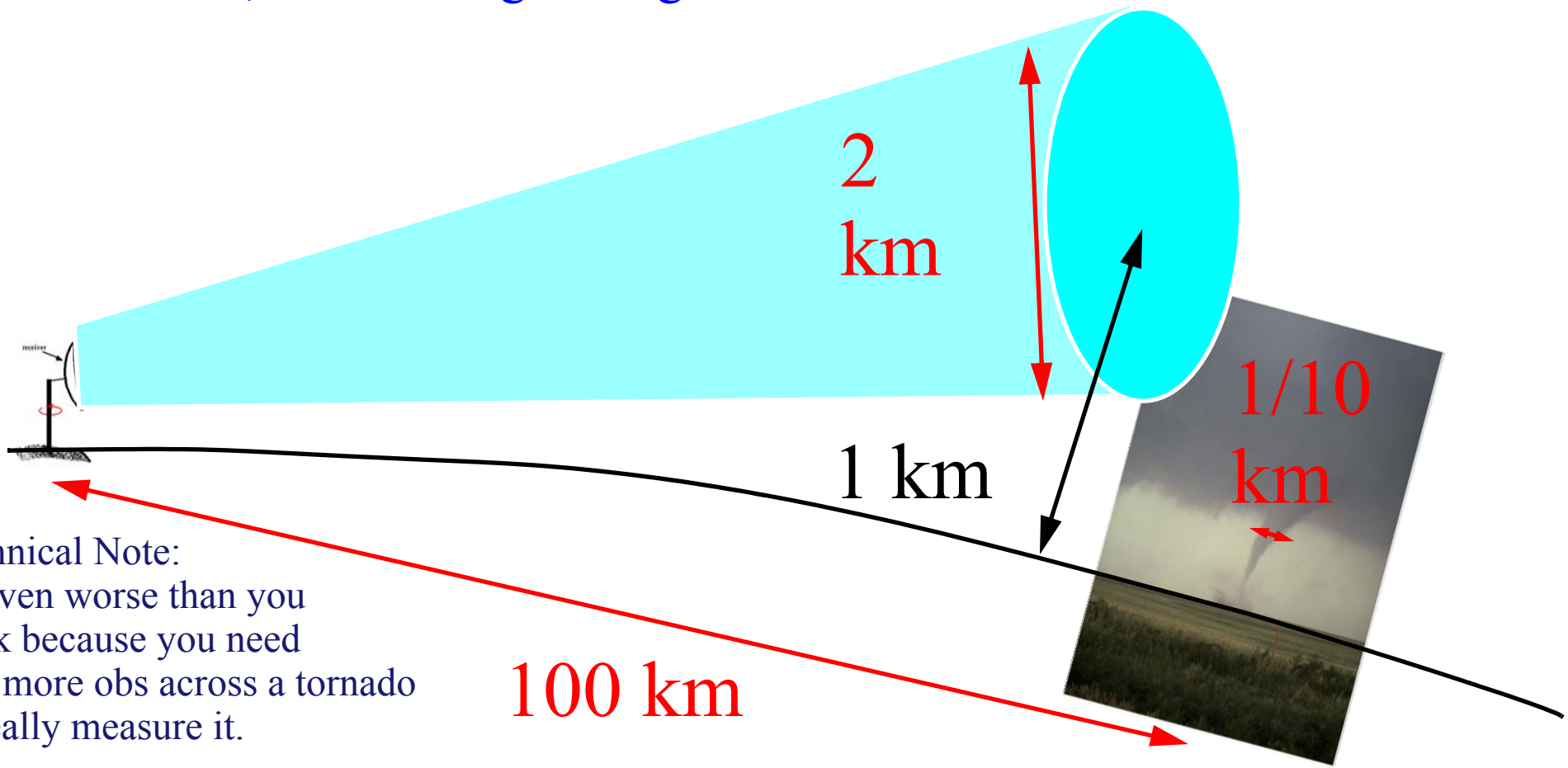
Radars have revolutionized warnings

But...

Normal Radars Can't See Tornadoes

Radar beams spread with distance and are much bigger than tornado

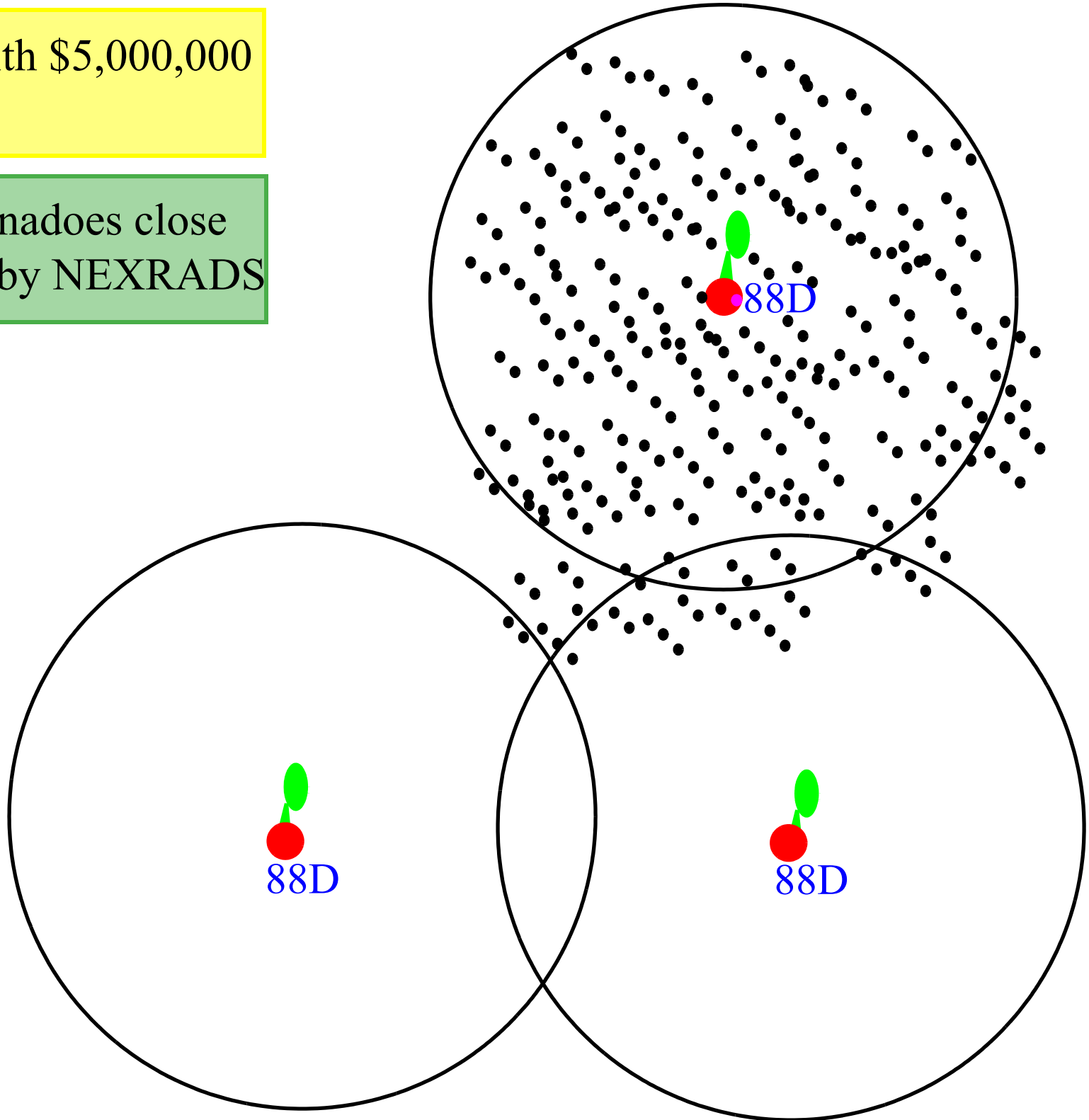
Earth curves, but beams go straight and radar can't see near the surface



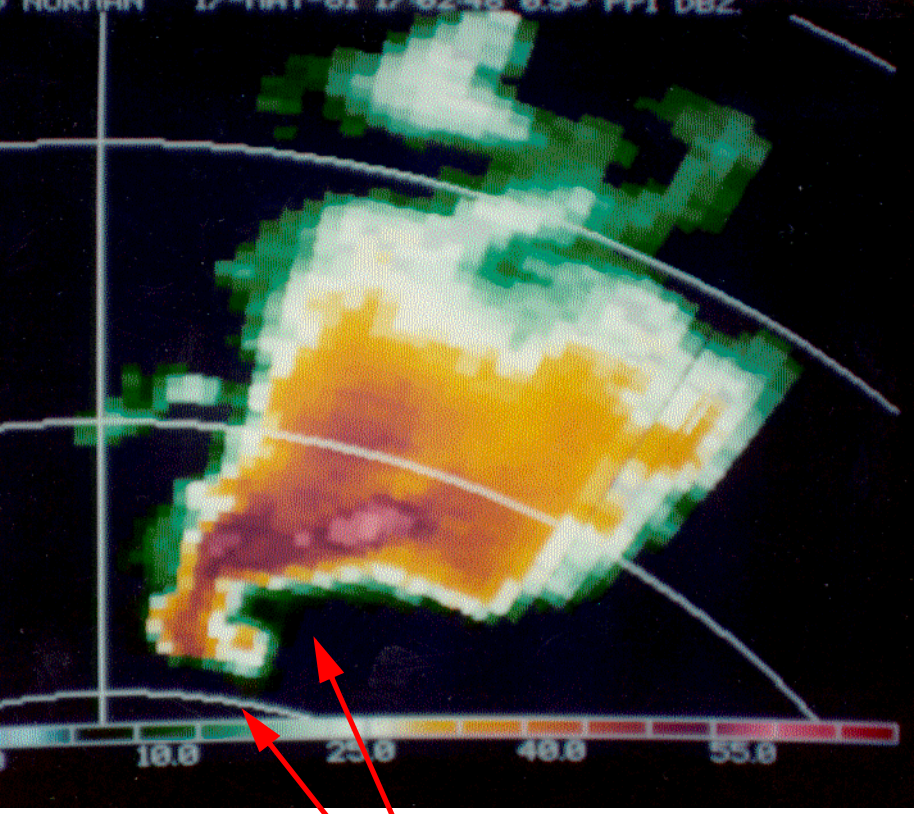
Technical Note:
Its even worse than you think because you need 6 or more obs across a tornado to really measure it.

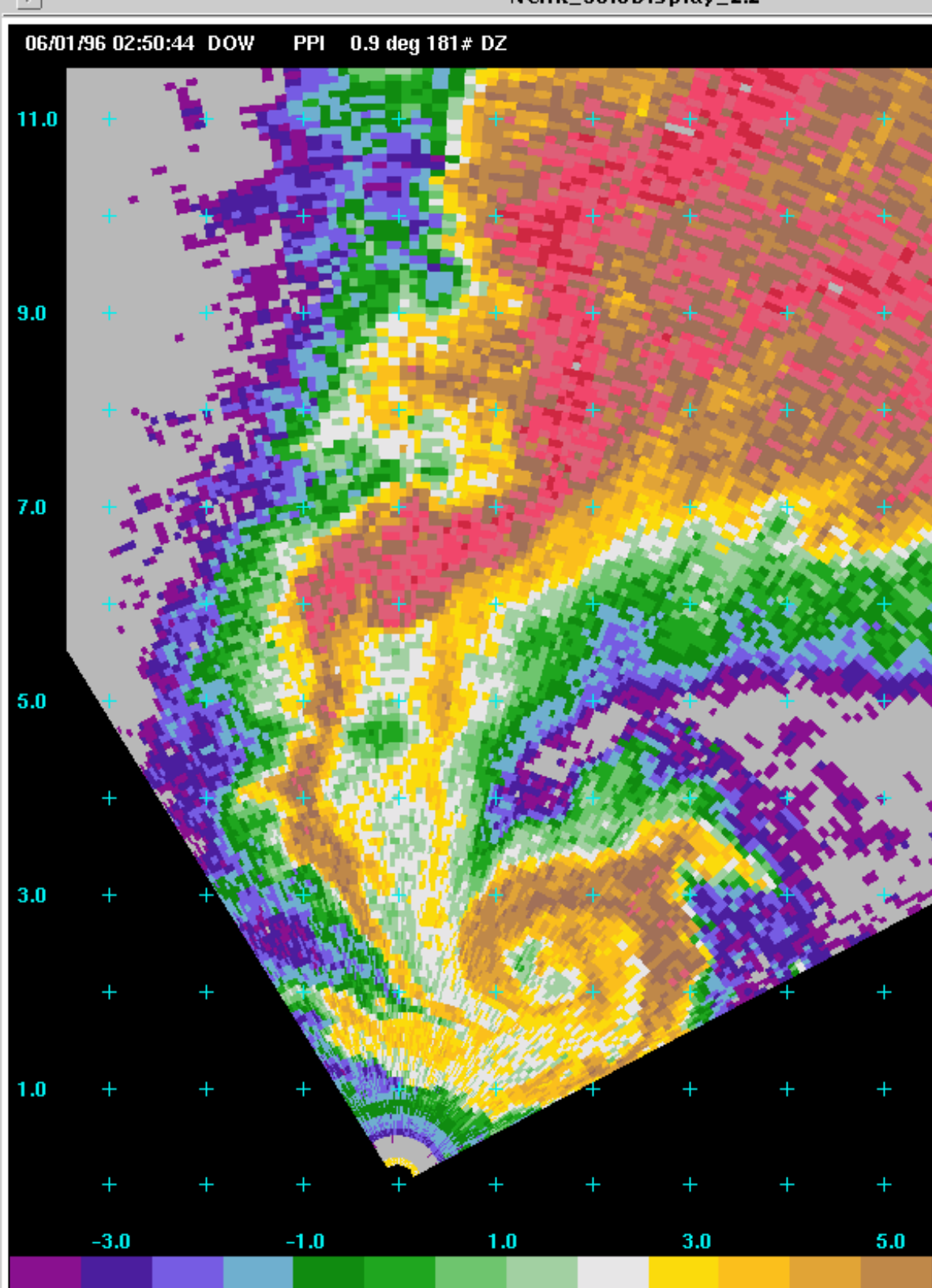
USA is covered with $5,000,000 NEXRADS

Only 1/1000 of tornadoes close enough to be seen by NEXRADS



Solution: Take Radars to the Tornadoes





Get up close

detail: 50x50x20 better

= 50,000x smaller

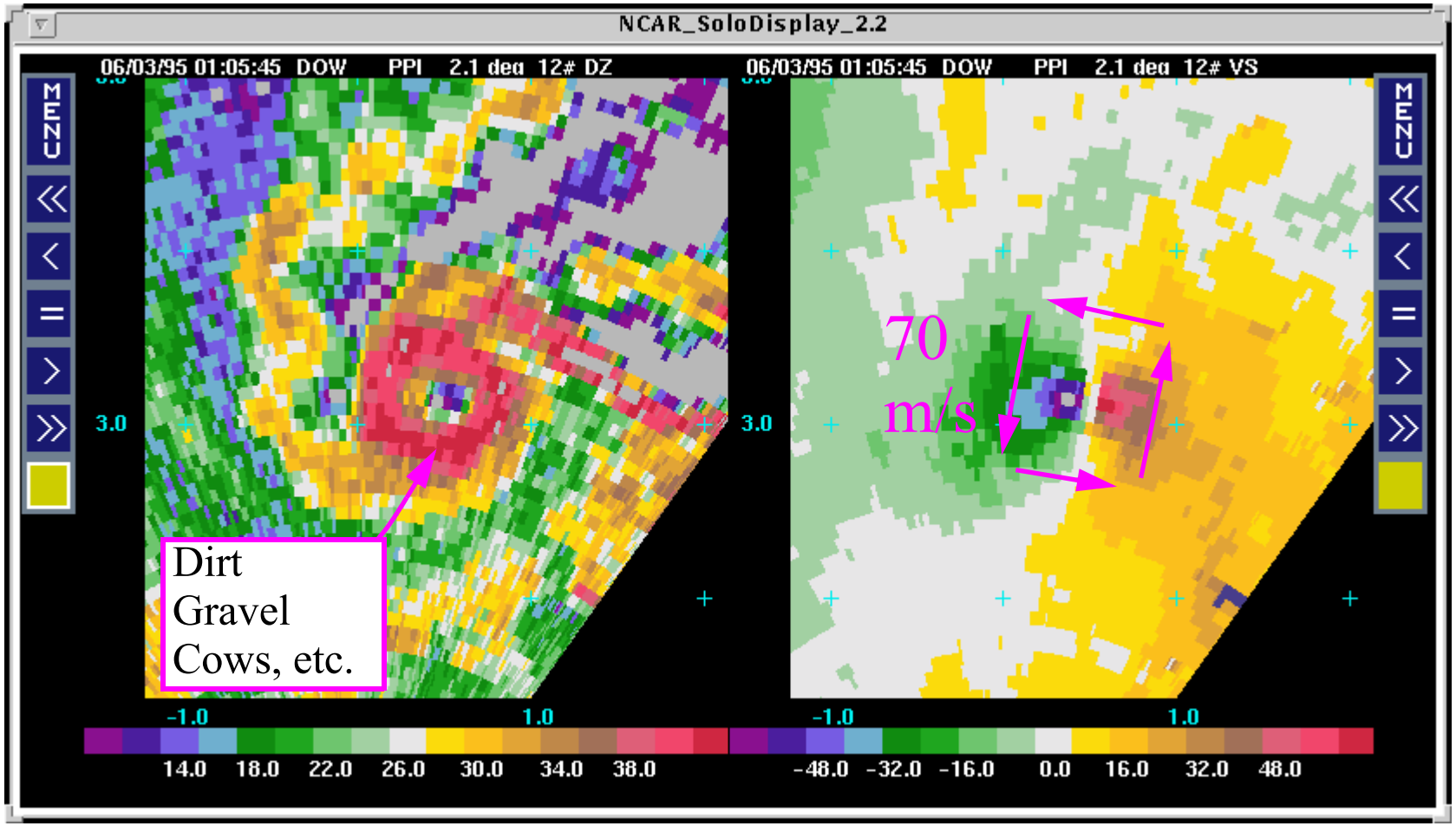
10x50 times faster

Three Observational Pillars to Answer Questions about Tornadoes

Small Scale

Fast Updates

Low to the Ground



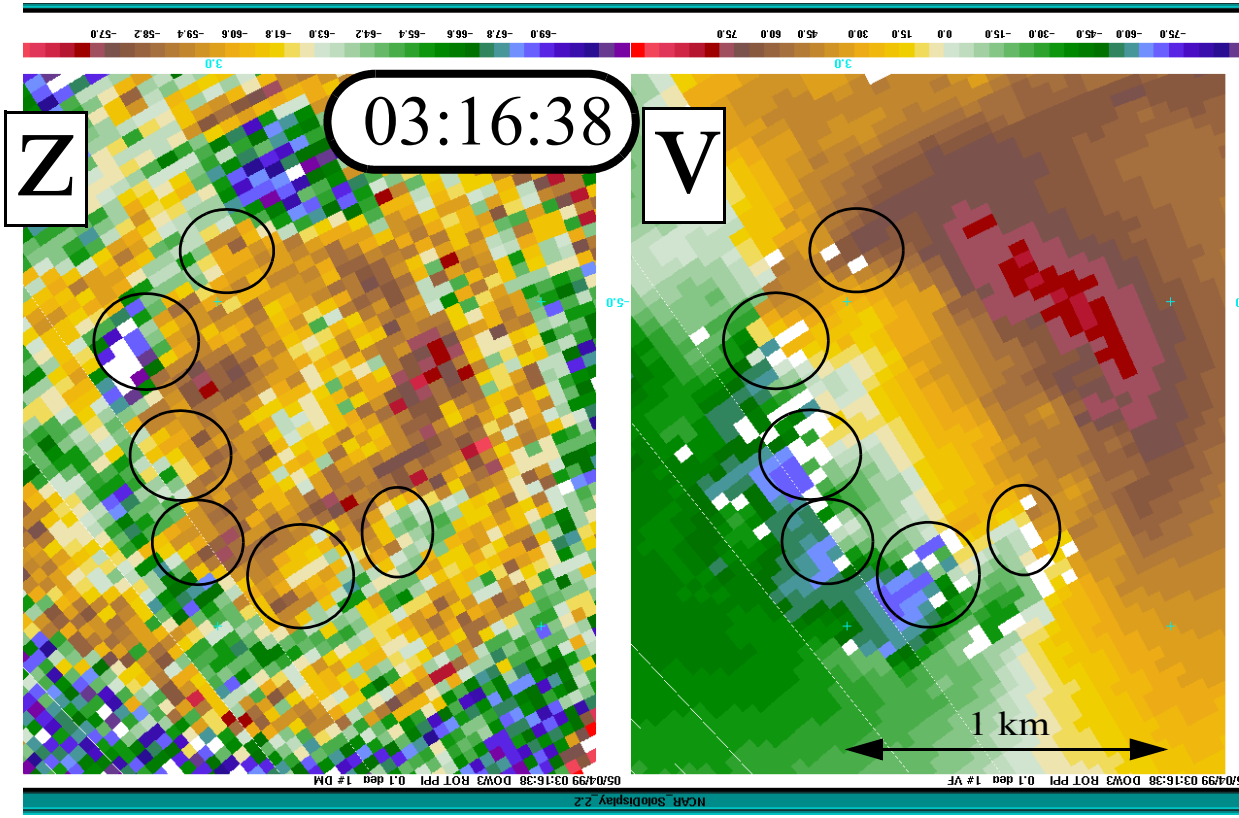
Reflectivity/Power sees debris/rain

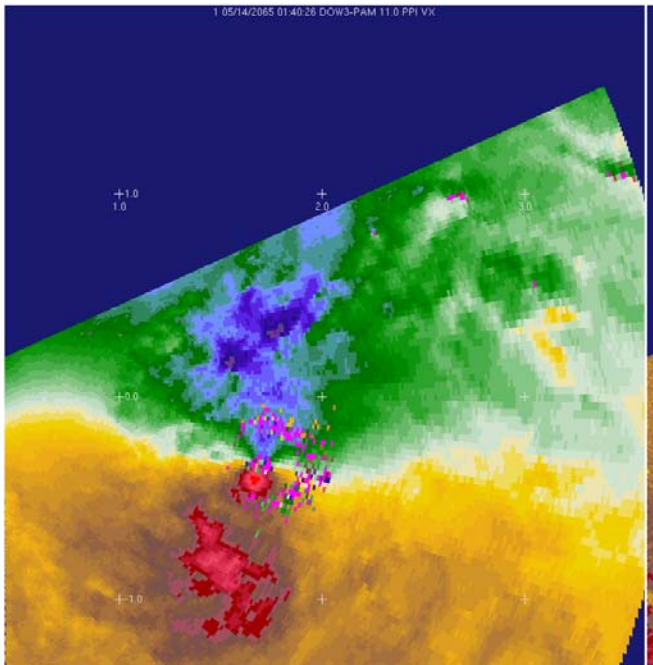
Doppler velocity sees towards/away motion of debris/rain

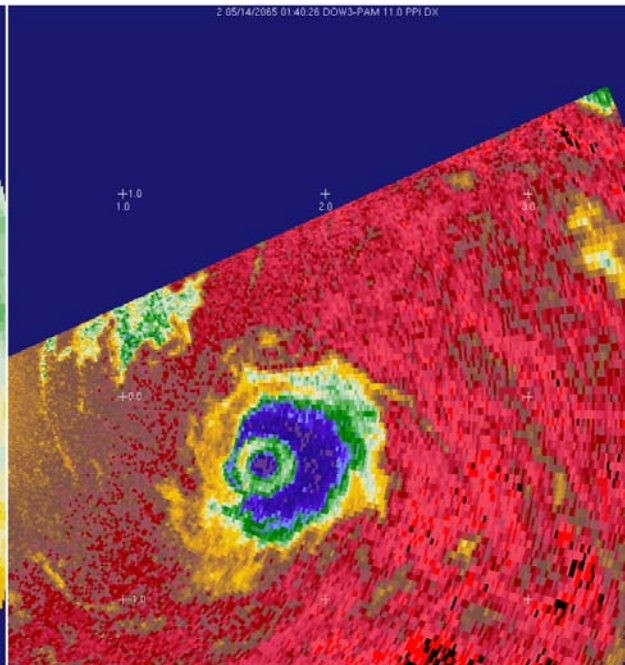
The basics of DOW tornado observations

Multiple Vortices Complex Structure

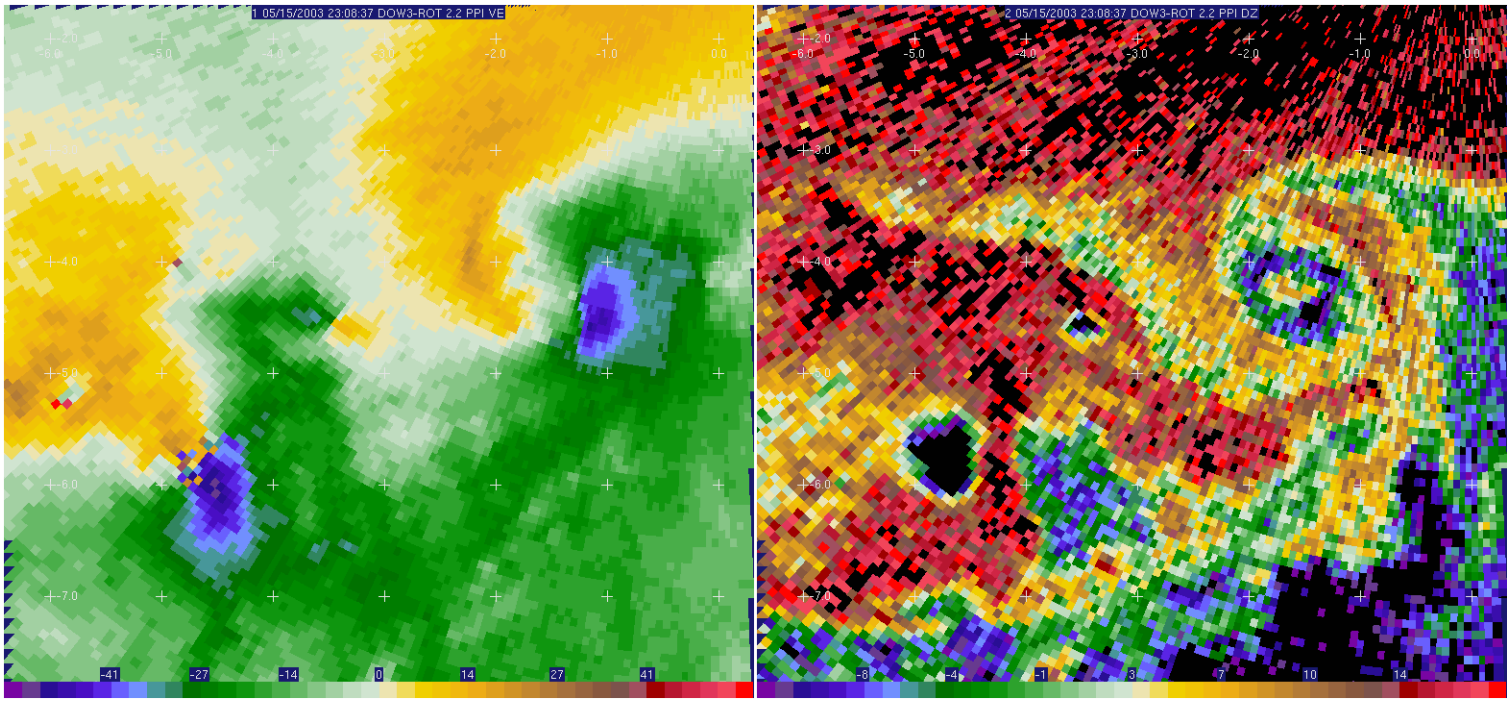
DOWs Observed
100 Tornadoes
1995-2005





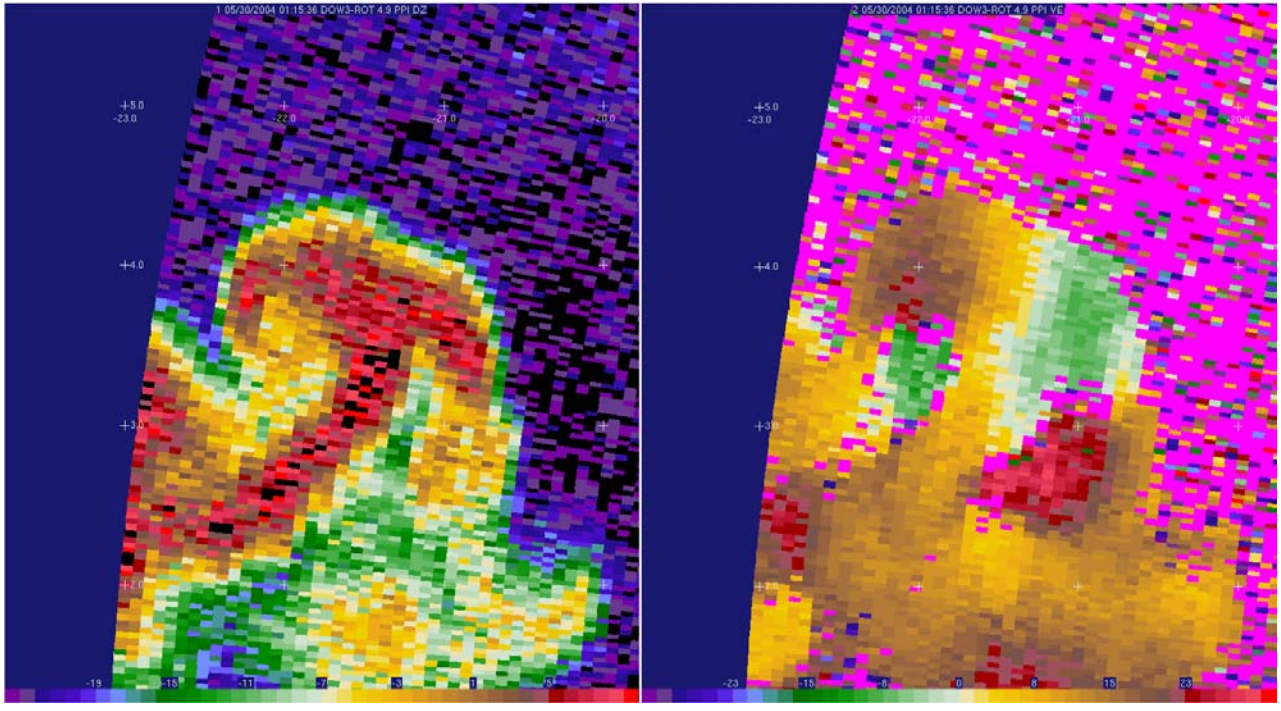


Double Tornadoes



Backwards Tornadoes

(anticyclonic)

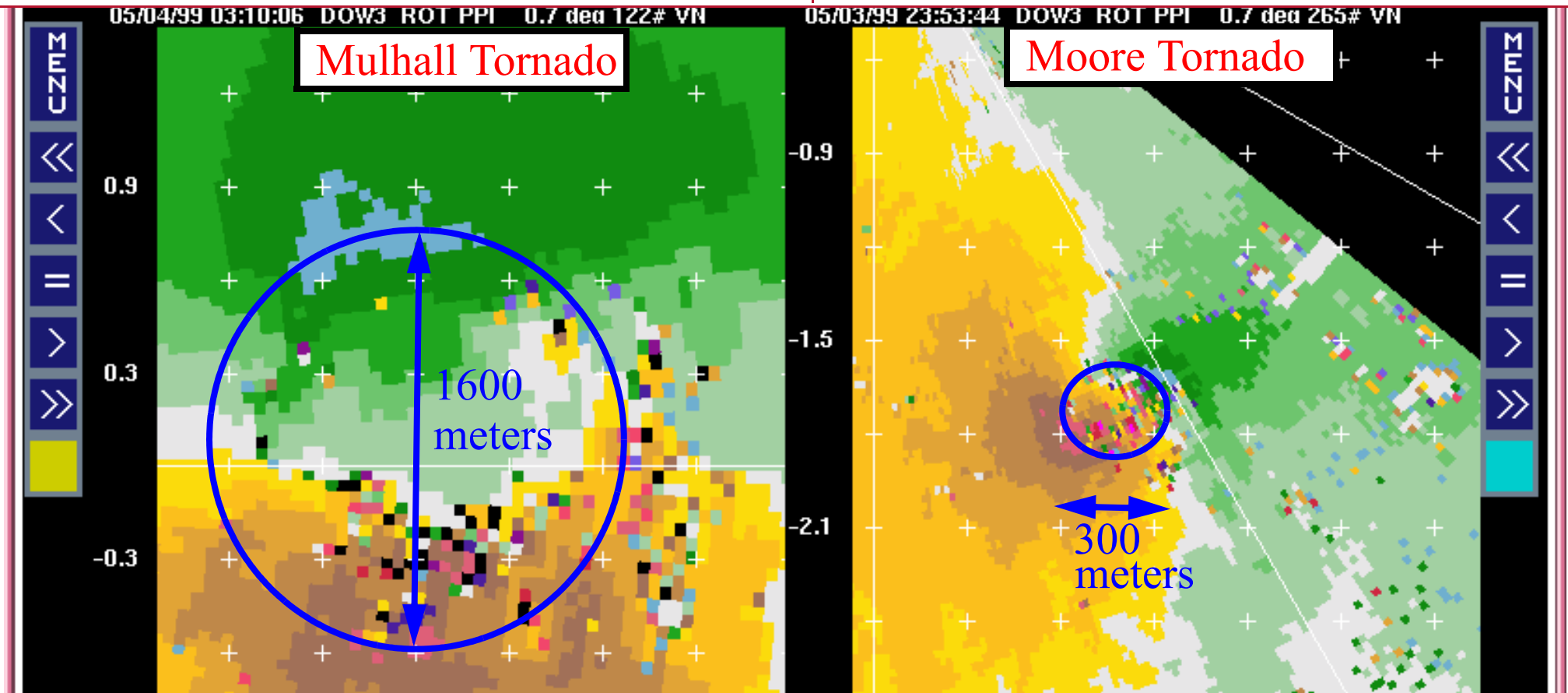


How Big are Tornadoes? (no one really knows)

Unknown Mulhall Tornado...4x larger

What if this had crossed over OKC, ORD, NYC, or DC?

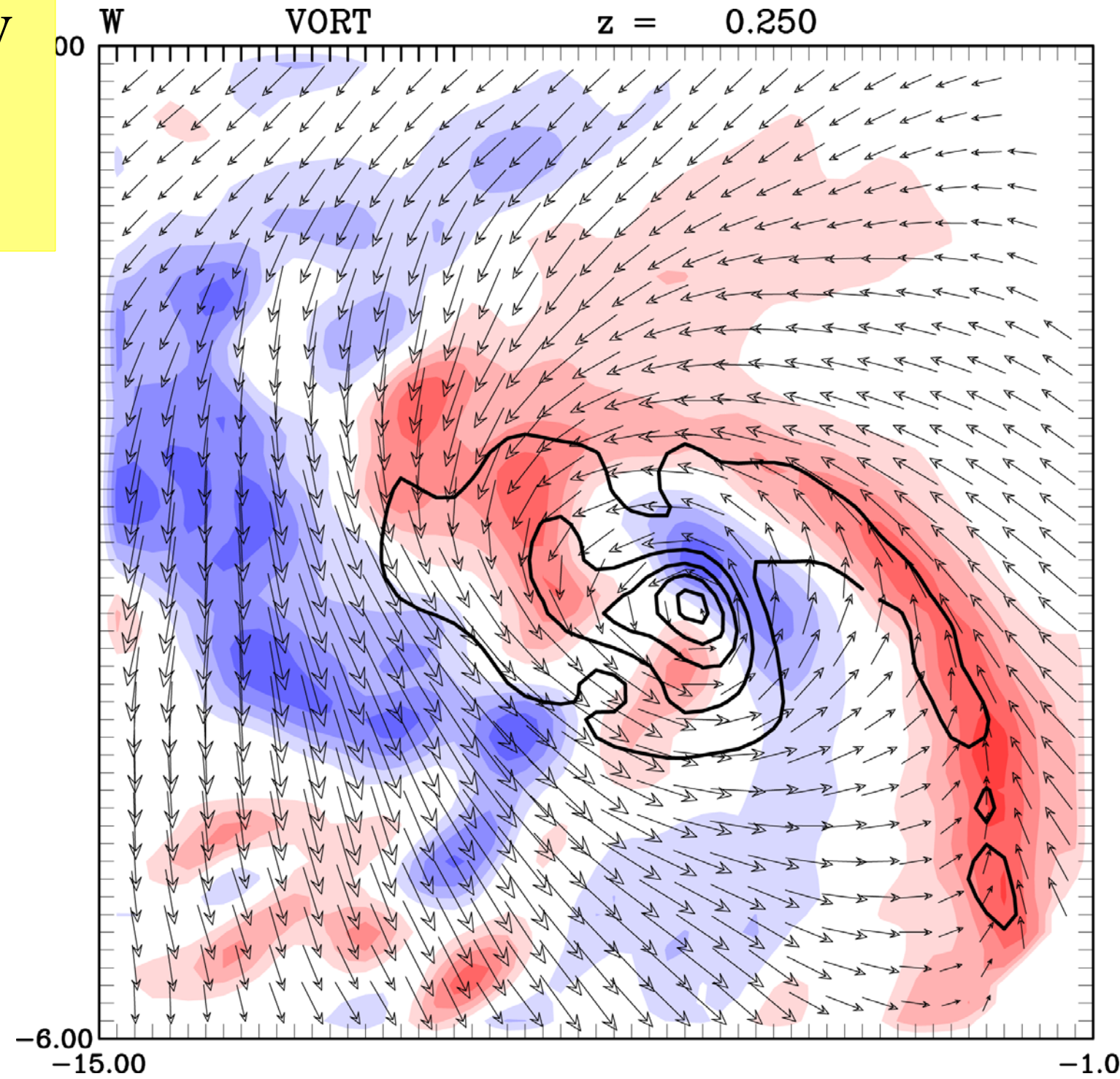
Famous OKC Tornado



How do they form, die, strengthen?

Wind Vectors

Resolve Sources of Rotation



How strong are the winds in tornadoes?

We don't know

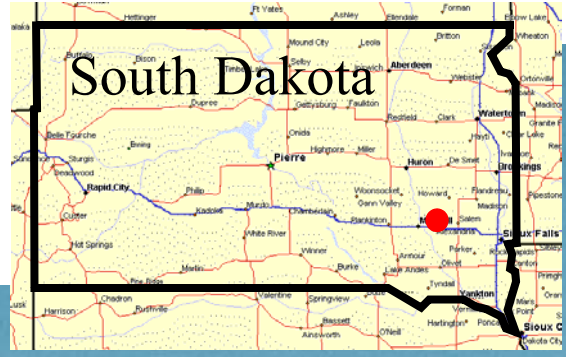
Until DOWs, only method was to look at damage

The Fujita-Scale

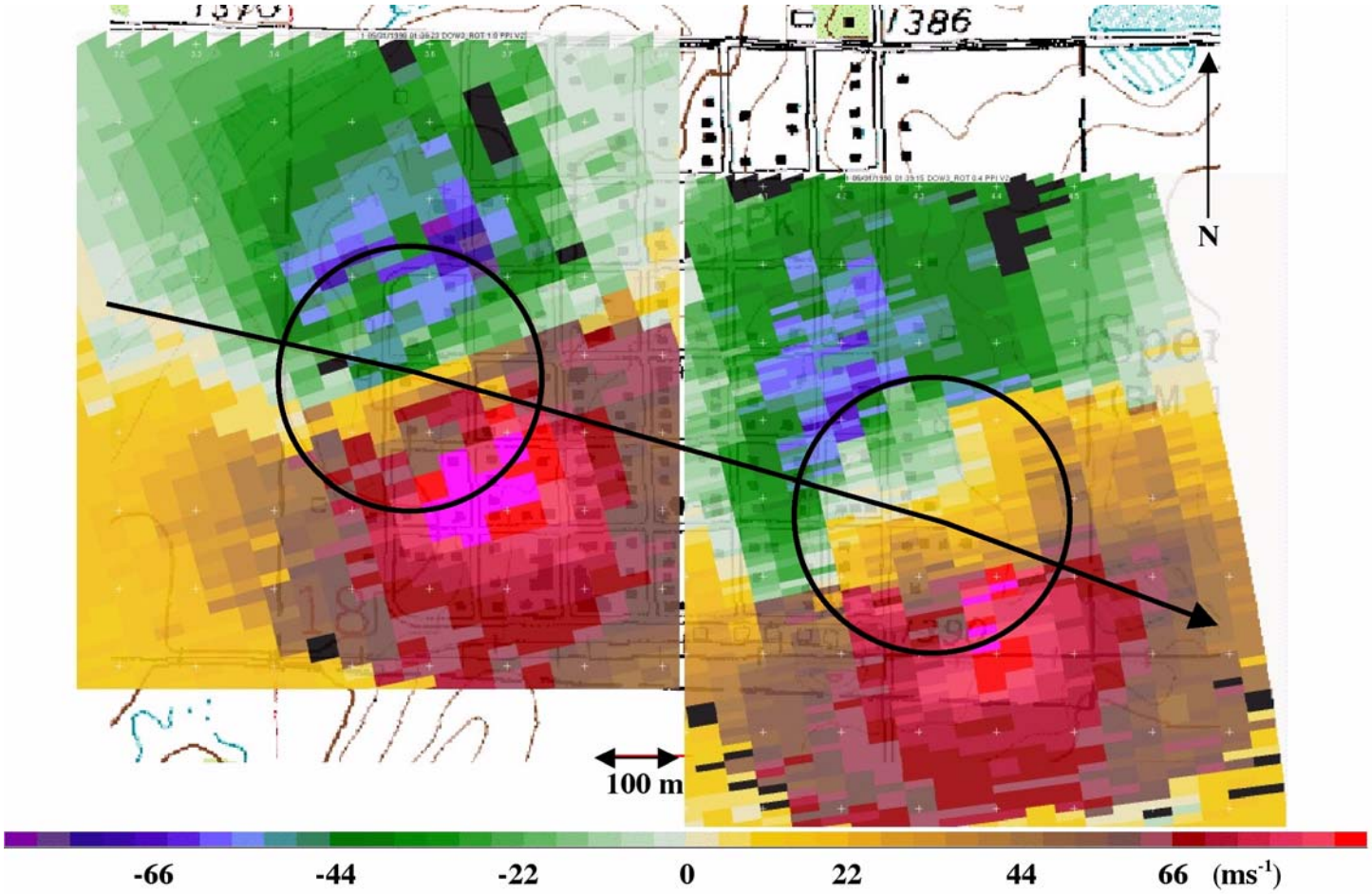
Very approximate

Only works when tornadoes cross towns

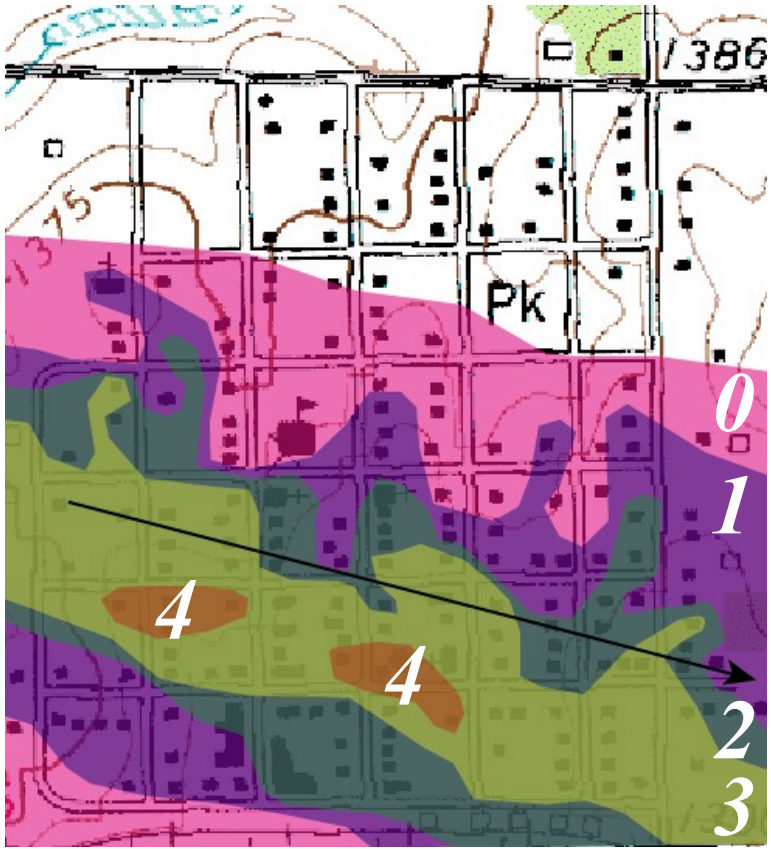
Spencer, South Dakota Tornado, 31 May 1998 Damage and Winds Measured



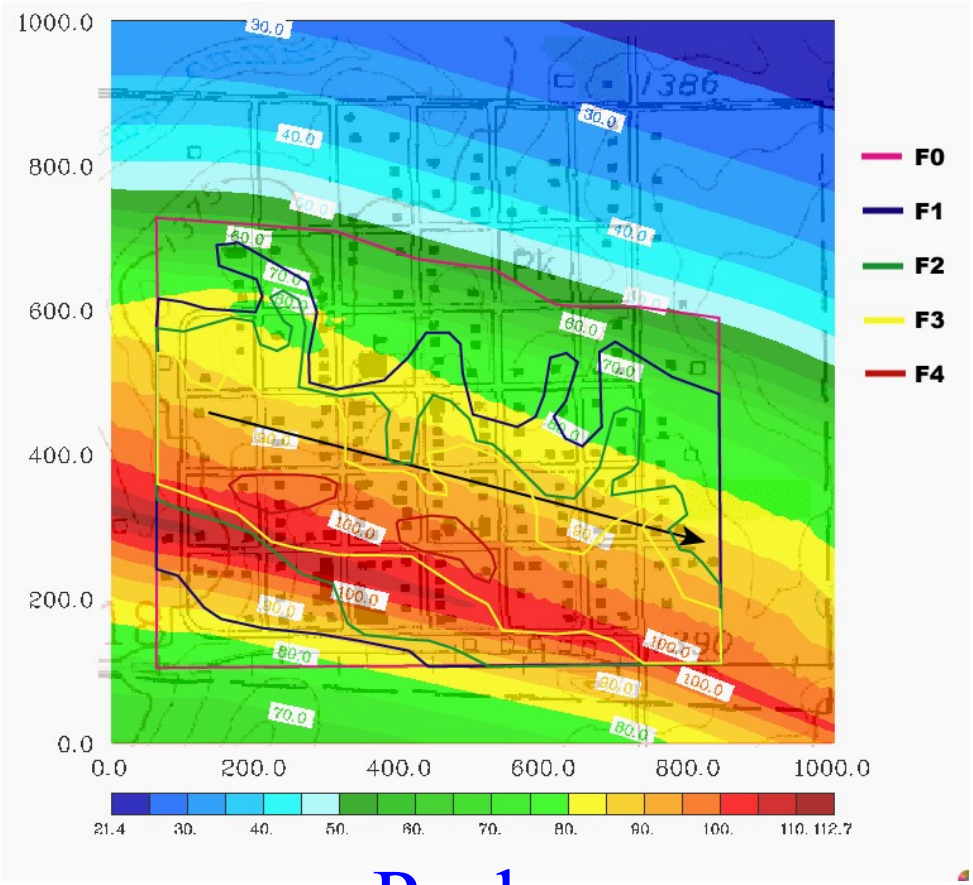
DOW Measured
Winds over ***every*** house



Damage vs Winds



Damage Survey F-scale



Peak
1/4 mile
“F” wind

Three Observational Pillars

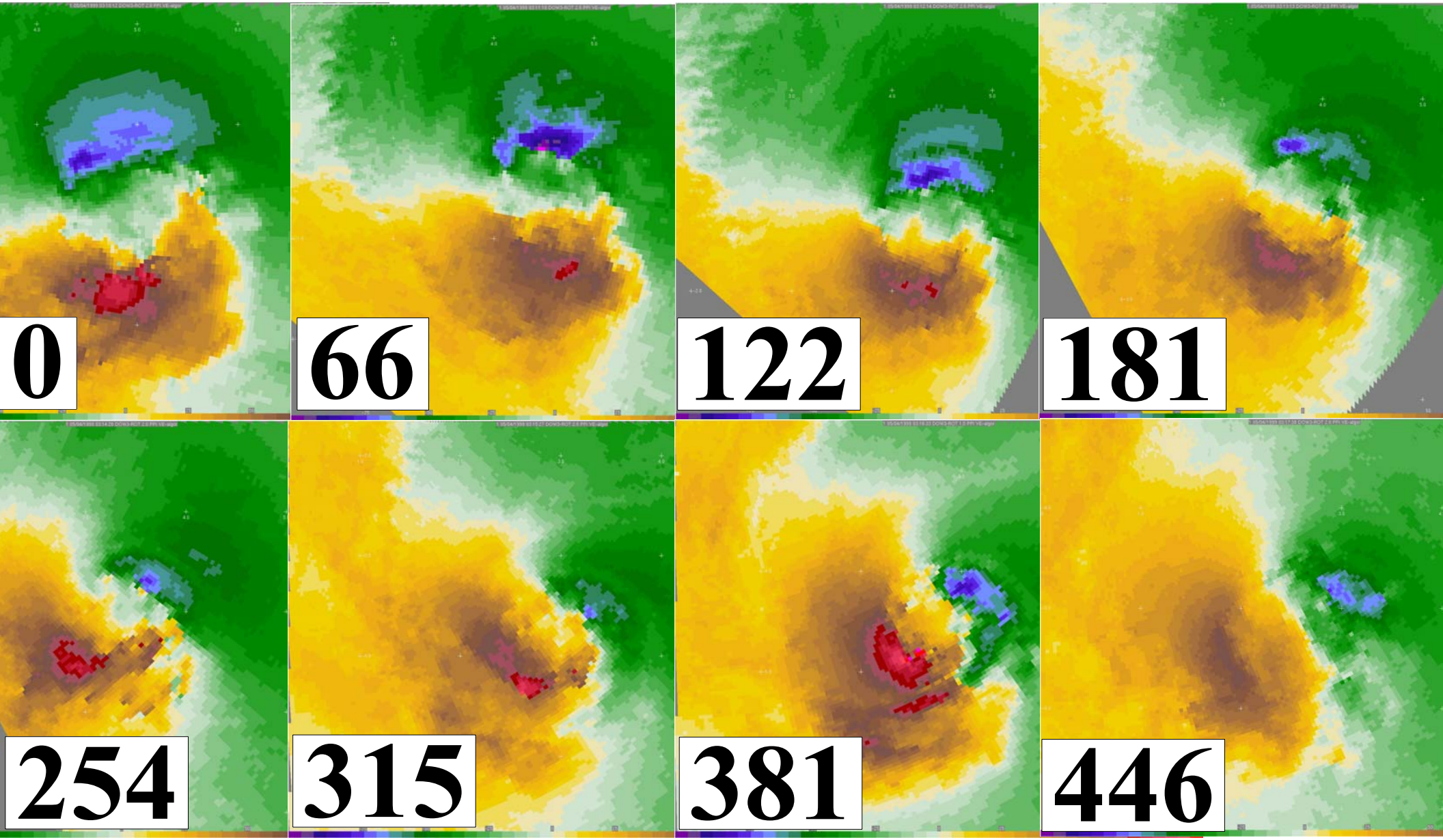
Small Scale

Fast Scanning

Low to the Ground

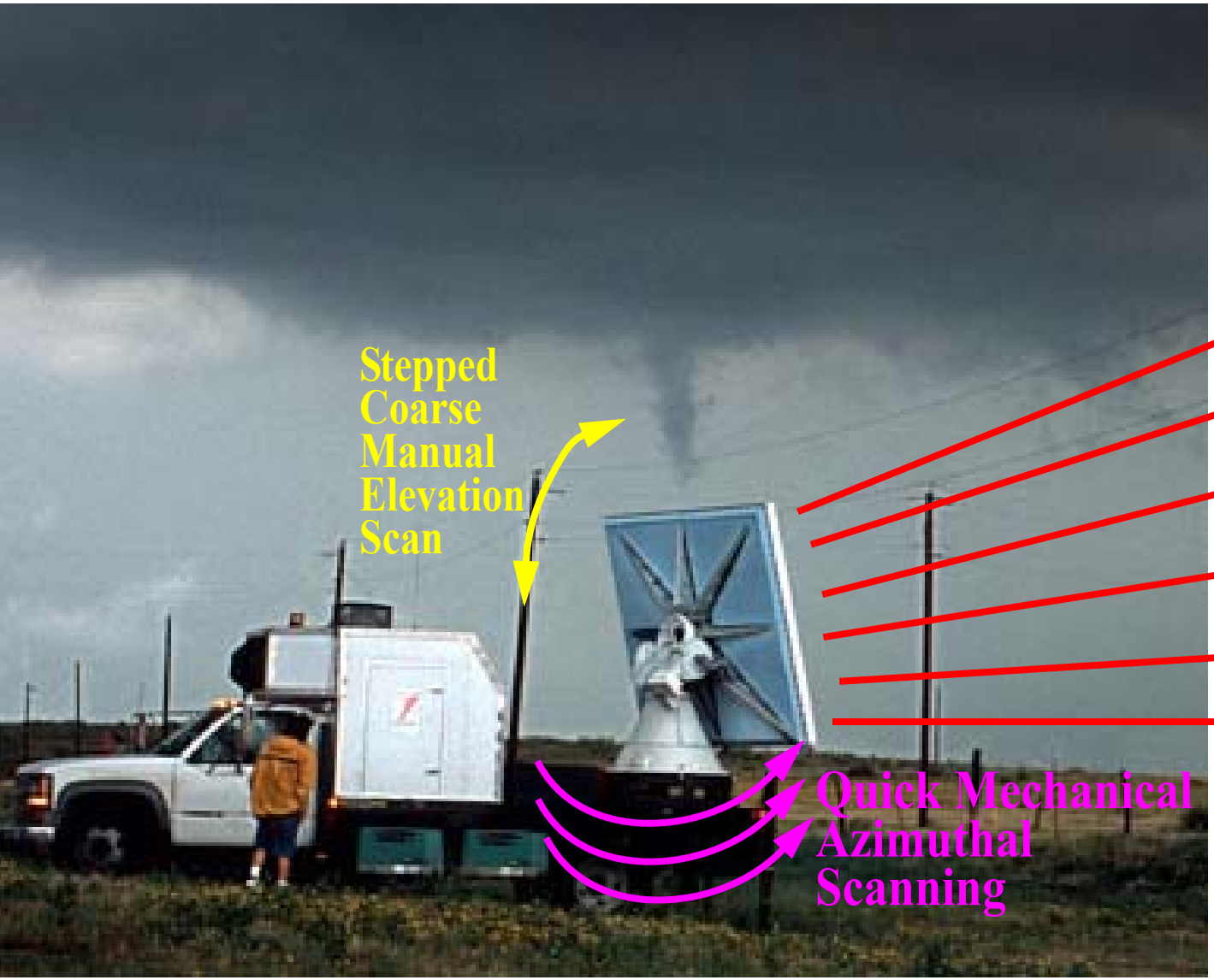
Tornadoes Evolve Very Quickly

Evolution can't be seen with 5 min 88D, 1-2 min CASA, even 50 s DOW



6 Beam Radar just built by CSWR with NSF support

3D volumes in 10 seconds



Current
Low Dispersion
Feed

9680 MHz 5.0°

9604 MHz 4.0°

9528 MHz 3.0°

9452 MHz 2.0°

9376 MHz 1.0°

9300 MHz 0.0°

Azimuthal Scanning up to 60°/s for 6-7 s surveys and 4 s sectors

Three Observational Pillars

Small Scale

Fast Scanning

Low to the Ground

The other
"cone of silence"

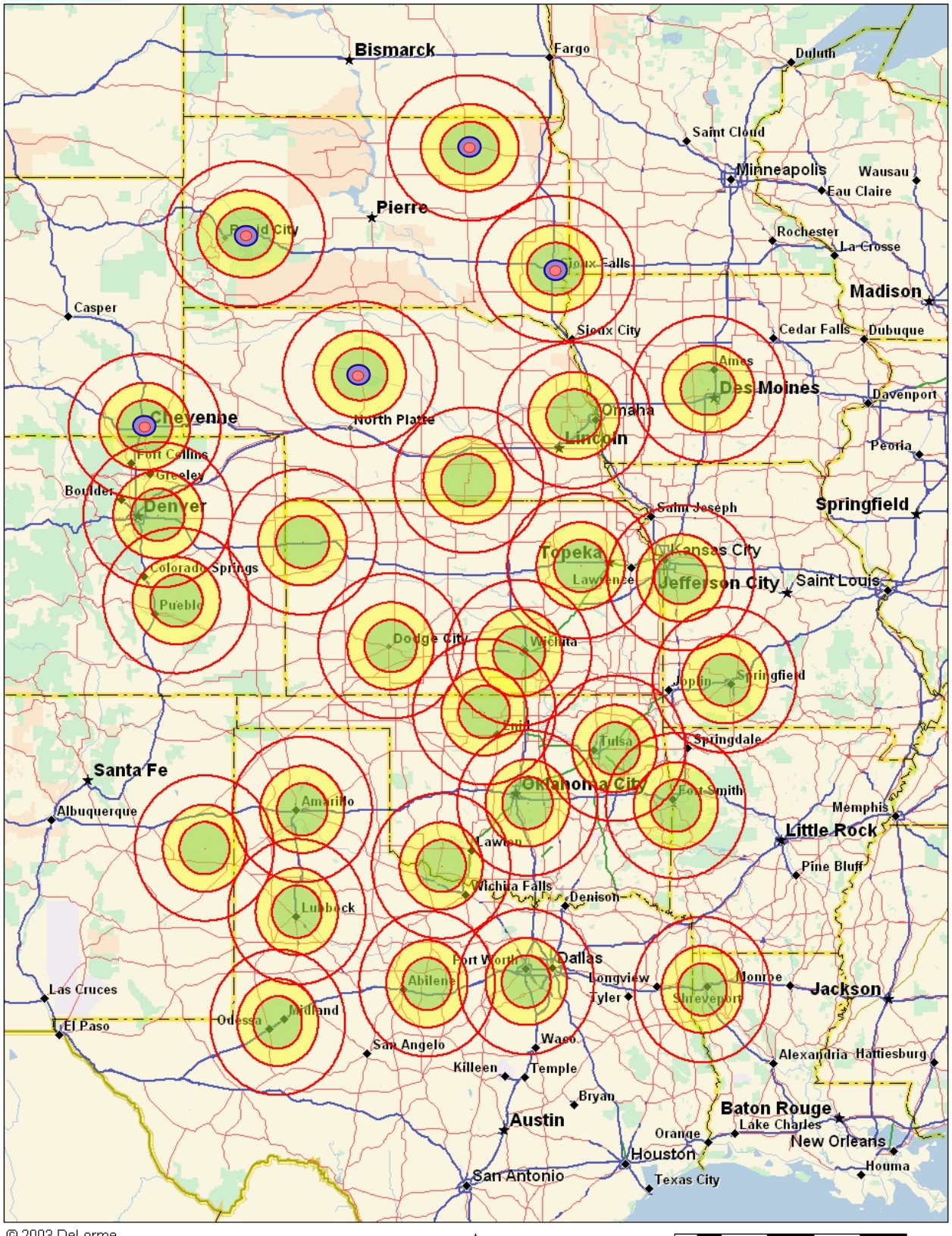
88D Network

65% invisible < 1000 m
88% invisible < 500 m
97% invisible < 250 m
99.5% invisible < 100 m
99.9% invisible < 50 m

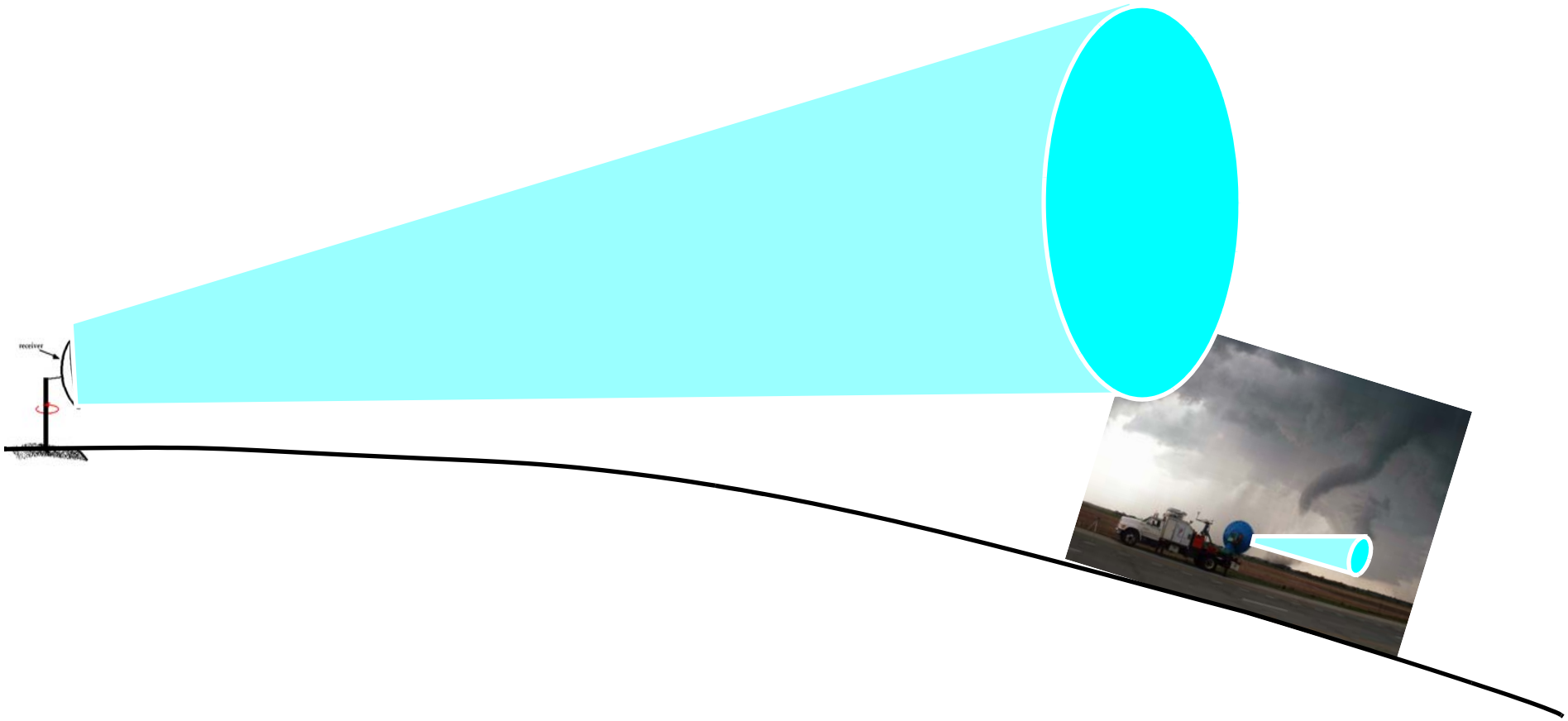
Even with CASA

50% invisible < 240 m
92% invisible < 100 m
98% invisible < 50 m

(assumes 1° elev of
center of CASA beam)



Up Close Radars Can See Low to Ground

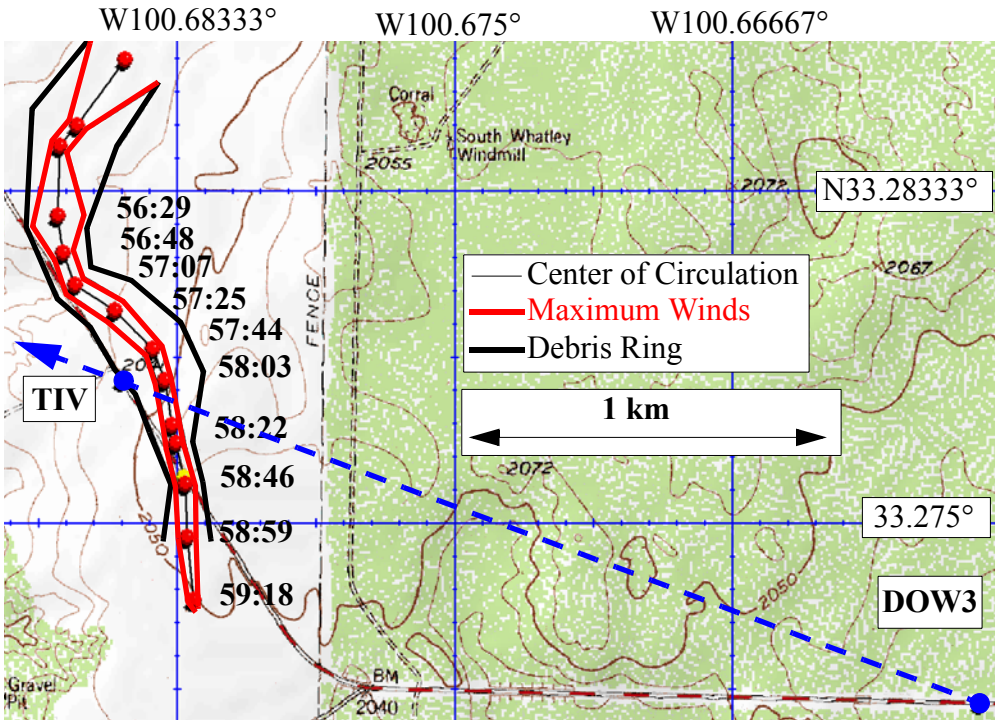


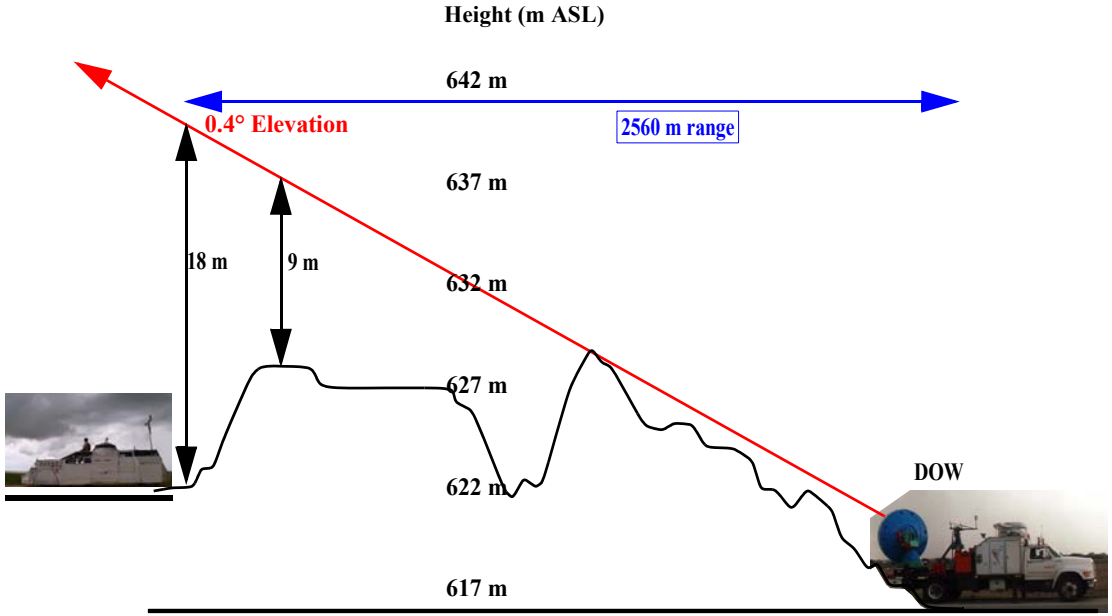
Combine DOW and In-Situ Observations

for Observations Right At Ground

Tornado Passes Over "Tank"

DOW Scans Overhead





Future Technology Alternatives

	Existing WSR-88D	Dense Network CASA	Stationary Phased-Array	DOWs Mbl Balloons Mbl Profilers
Small Scale	No	Fair	No	Yes
Fast Scan	No	Fair	Yes	Yes
Low	No	Fair	No	Yes
# Needed To See All Storms	100	5000	100	100
Cost per	5-10M$	100k$	20M$	200k$
Cost network	exists	500M$	2B$	20M$

A “few” DOWs cannot observe many tornadoes: Research Only

1000 tornadoes per year
20 observed by DOWs each year

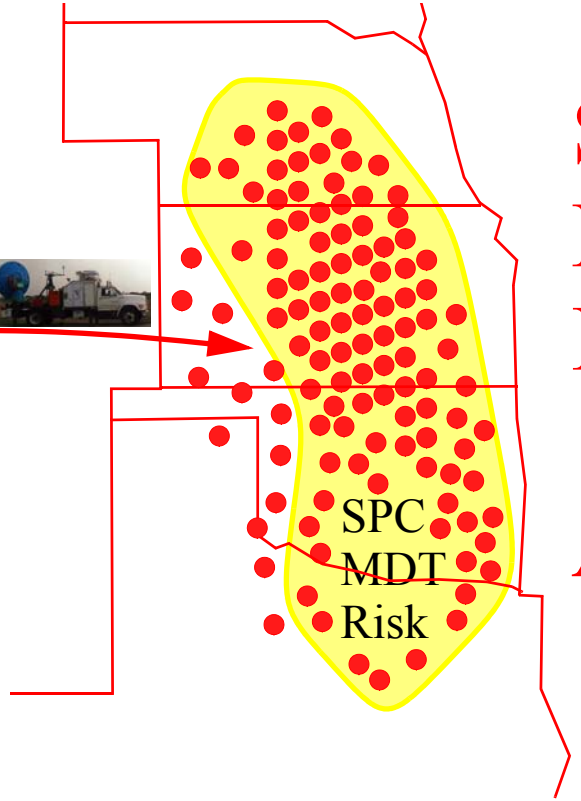
98% not observed by Research DOWs

Targeted Operational Radar Network

Each Day

Dense DOW Array
Pre-Deployed
to SPC Risk Area

+balloons
+profilers



Small
Fast
Low

Affordable

The Future is Adaptable Targeted Observations

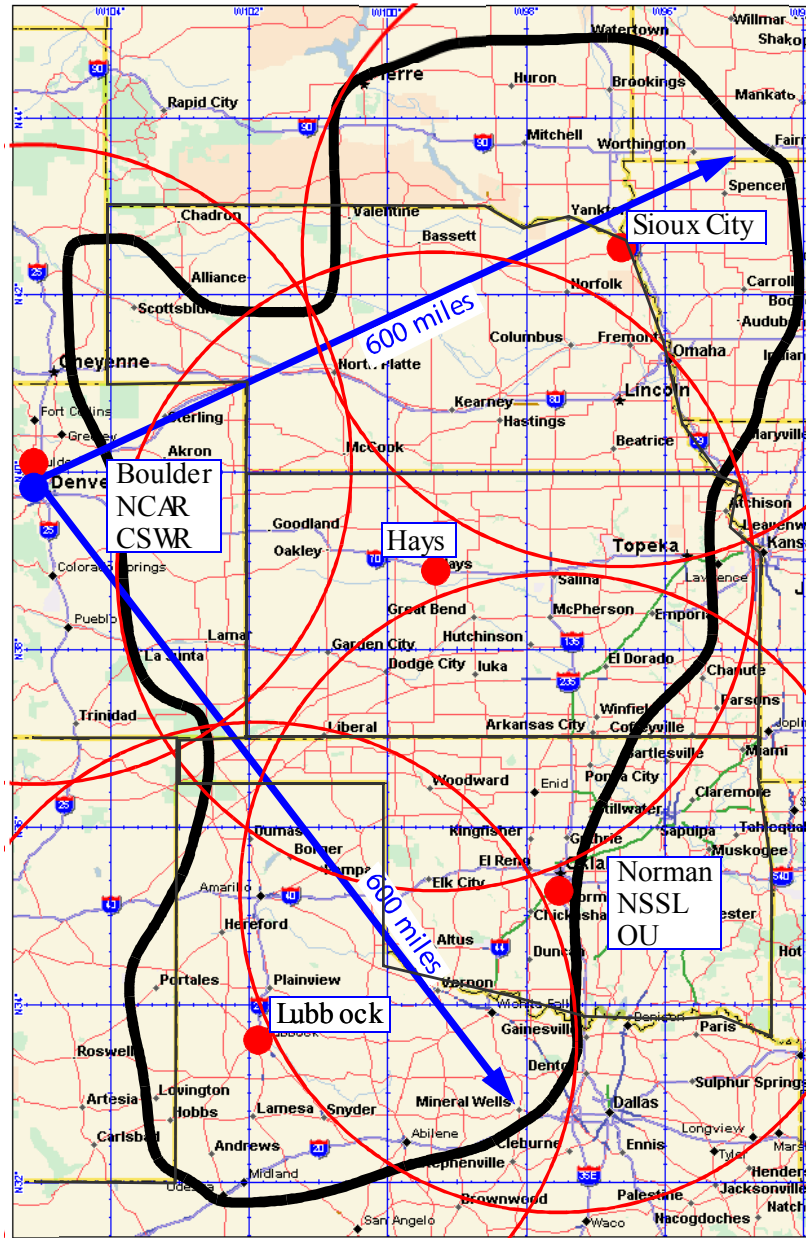
(Hurricane Forecasters Already There)

Adaptable Observation Experiment

VORTEX 2

Currently planned for 2008-9
Decision by NSF expected: June

Aircraft, DOWs, UAV's, cars



Adaptable Observations

Hurricanes Mapping intense winds
+neighborhood variability

Fires Mapping hot spots
Forecasting wind shifts

Italy, Alaska, California, Germany...

Juneau

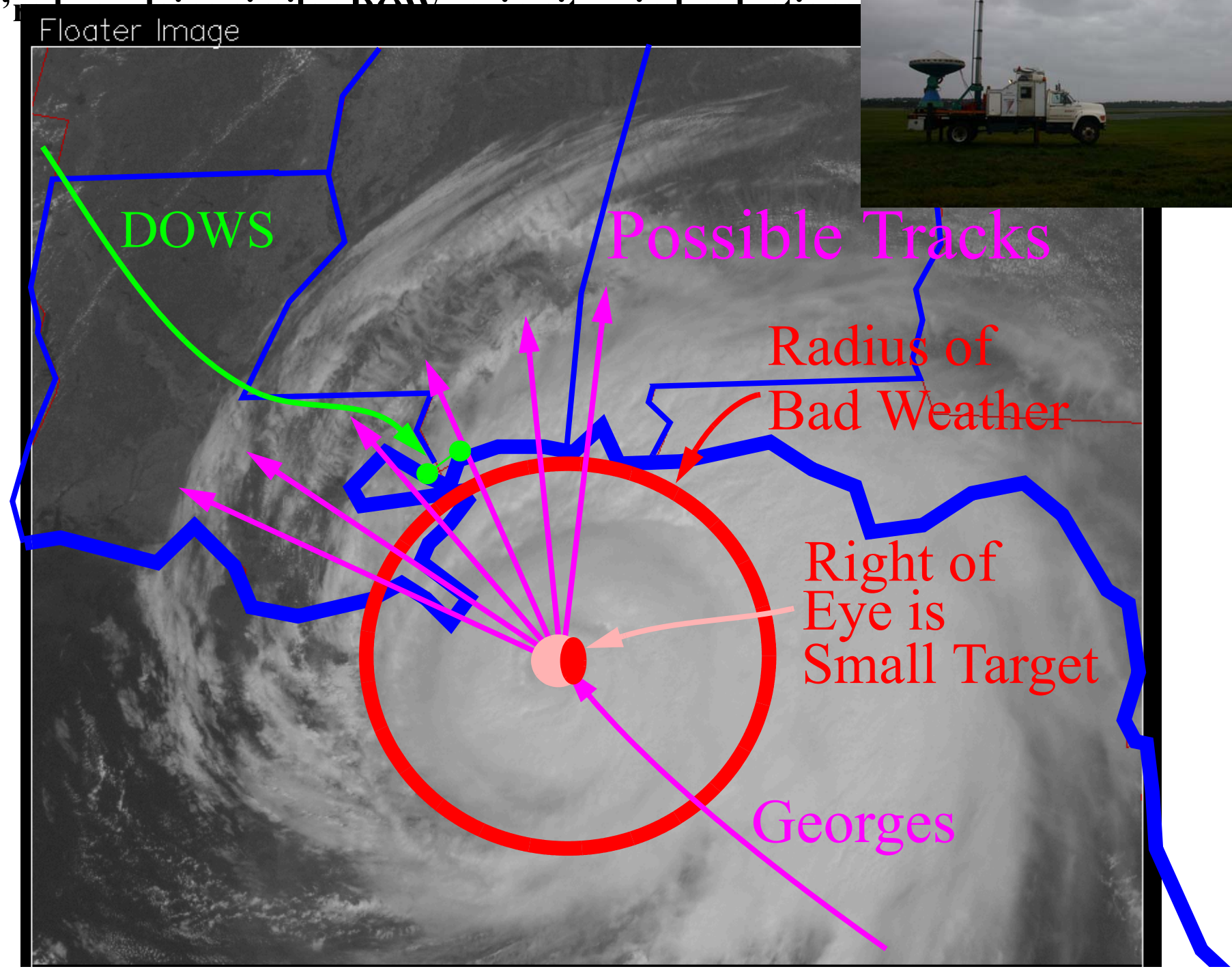
Homeland Security: Particle/Gas Releases

Fire Suppression: Water Drops

Air Traffic Safety: Turbulence

Chico

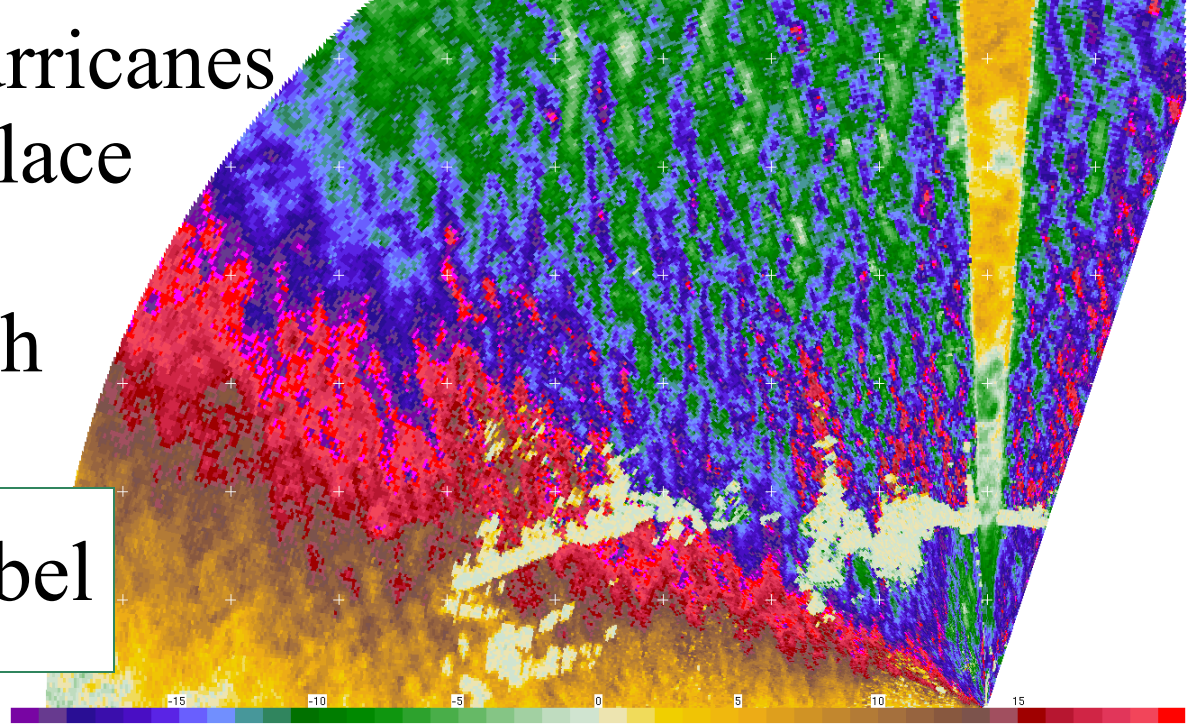
(We'r

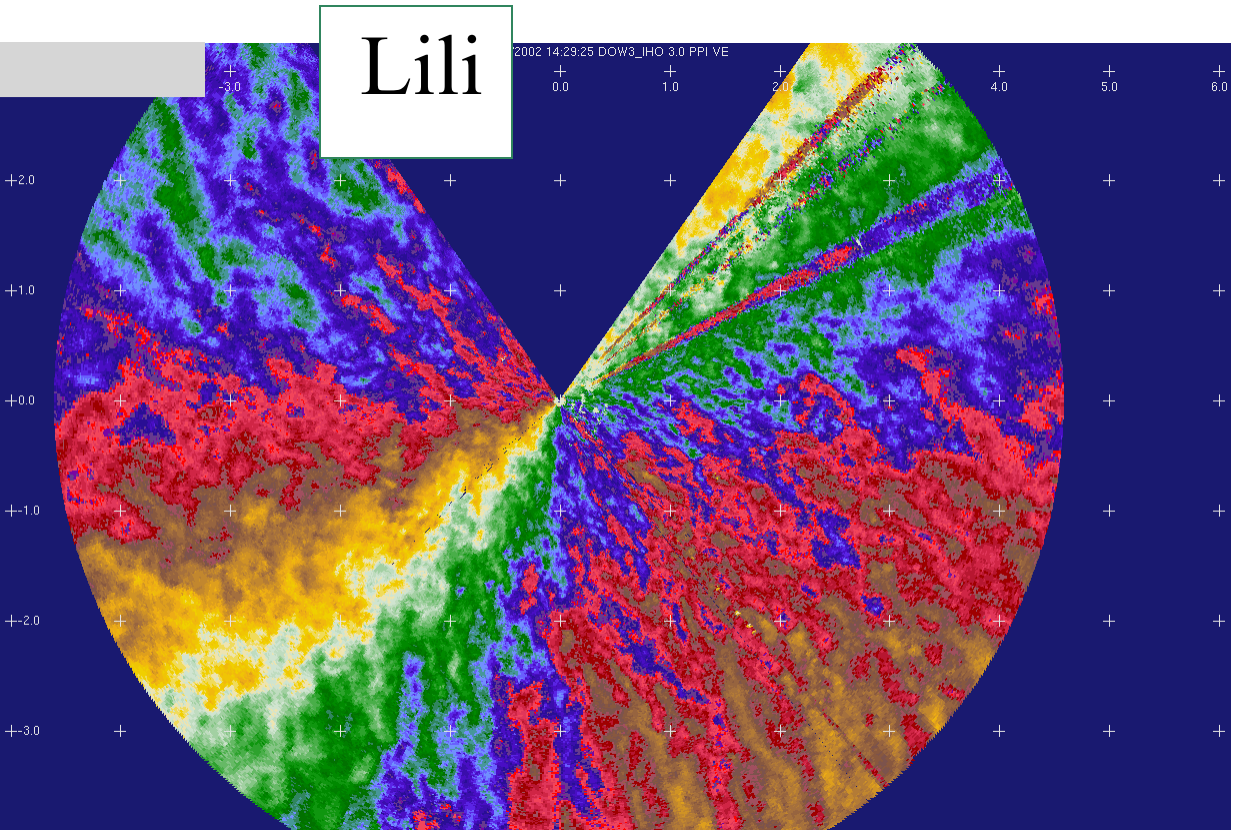


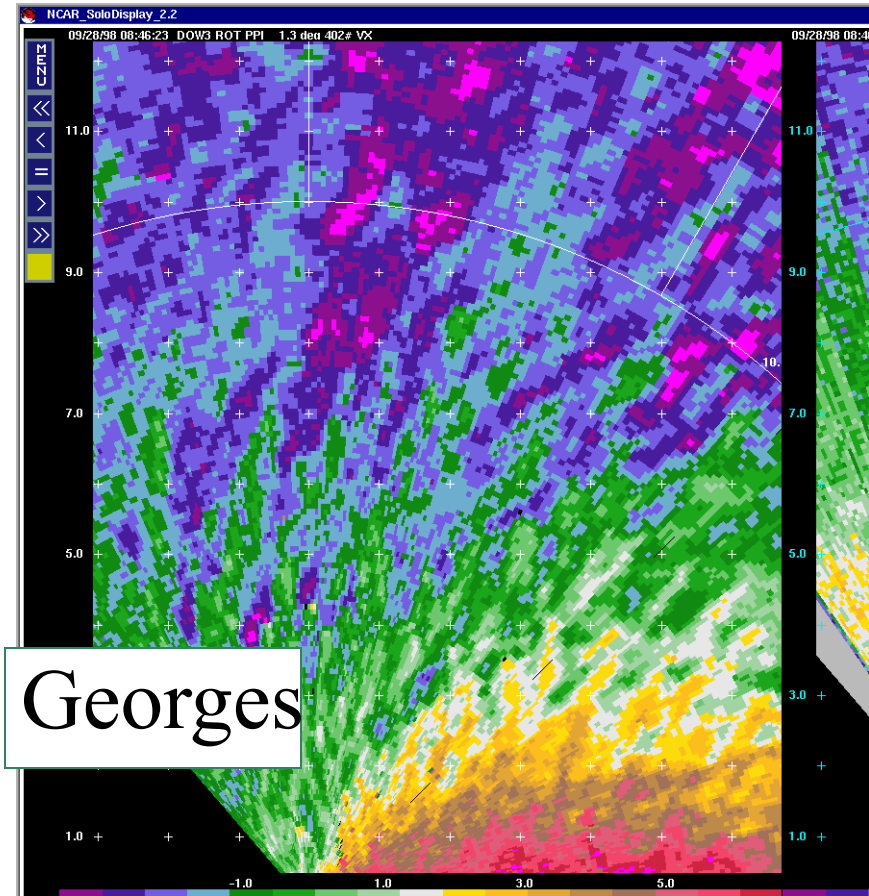
We have to pick our spot before red circle comes onshore

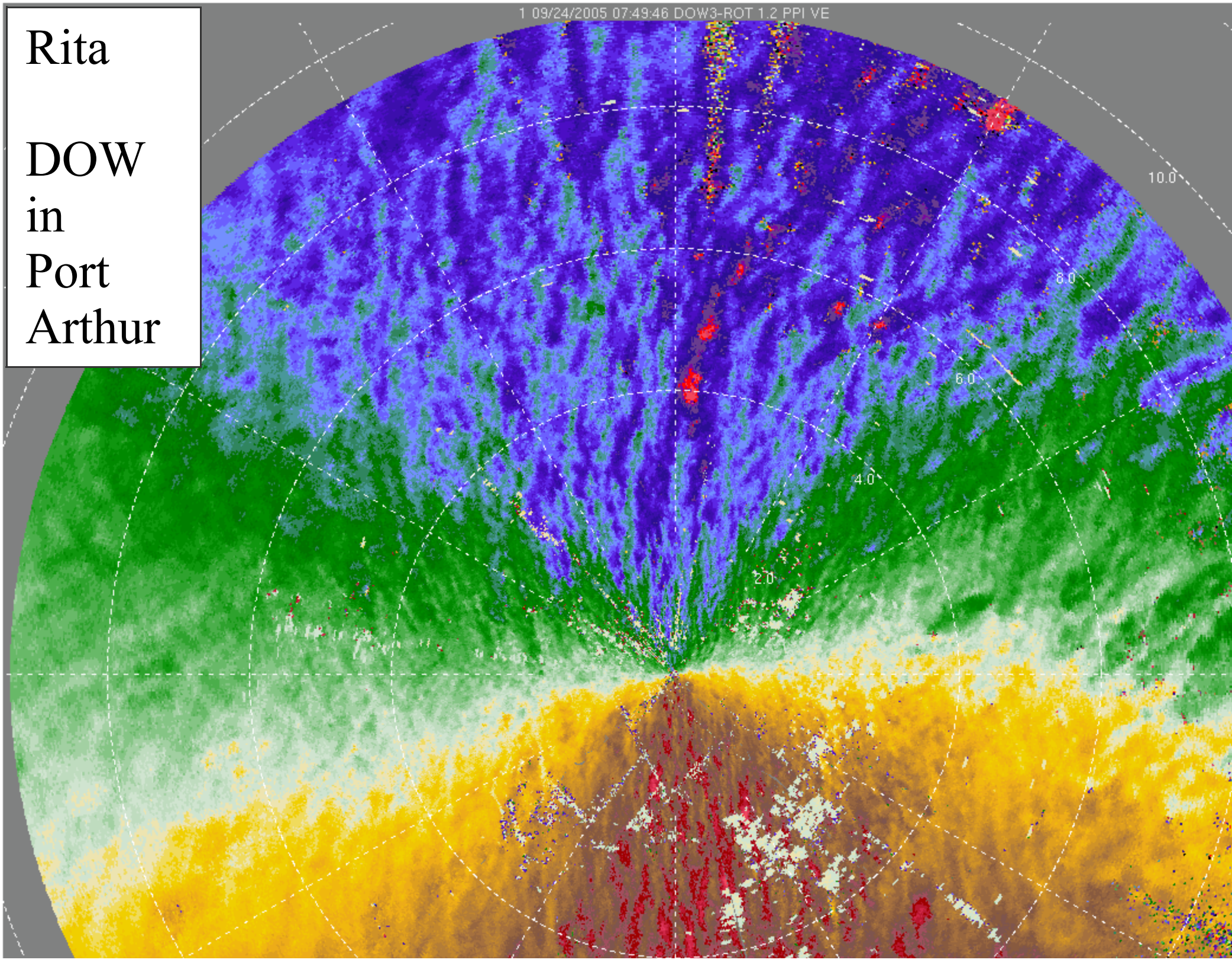
Winds in Landfalling Hurricanes are very different from place to place. Some areas are experiencing 120 mph while others just 80 mph

Only visible close up

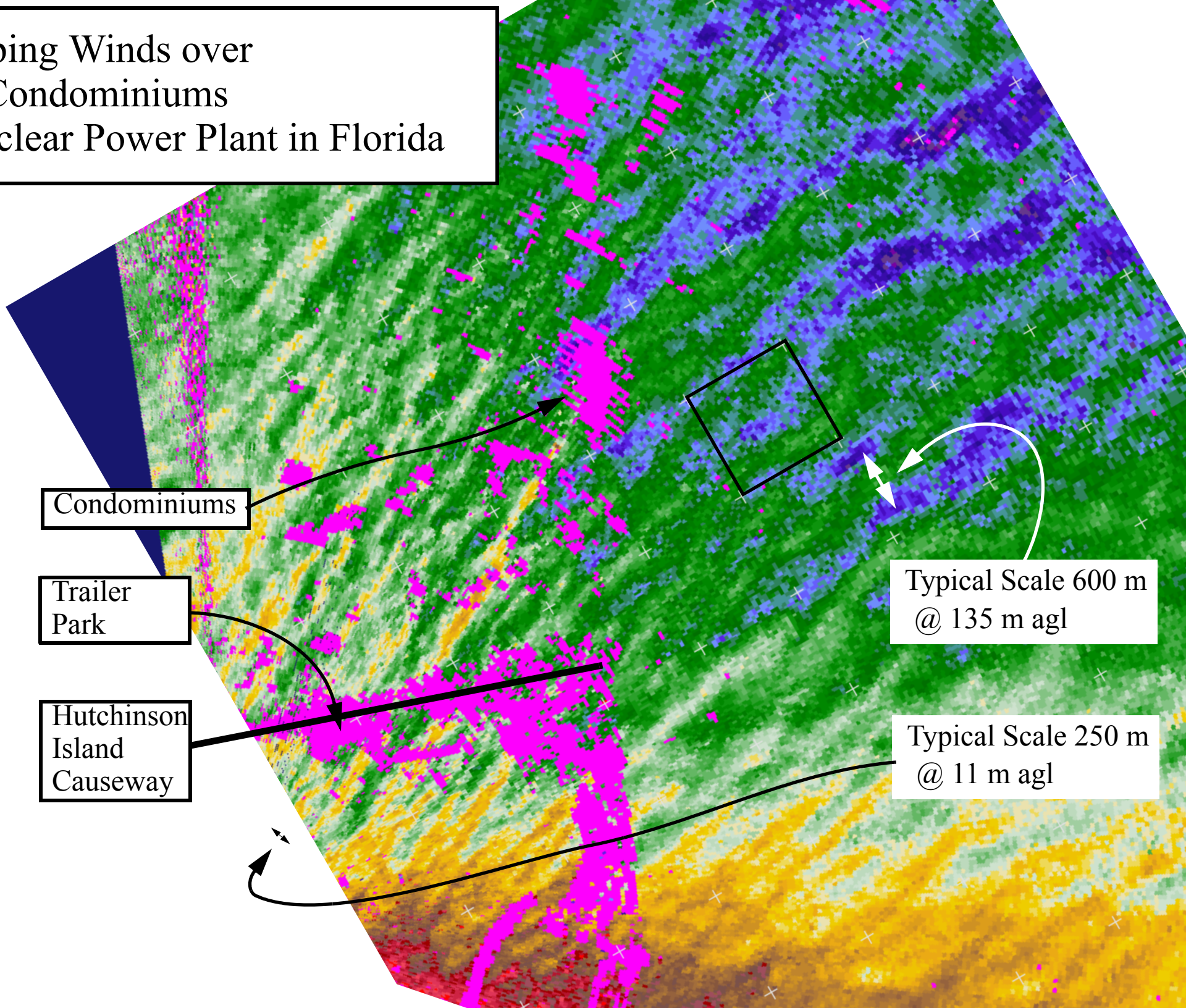







Rita
DOW
in
Port
Arthur
1 09/24/2005 07:49:46 DOW3-ROT 1.2 PPI VE
10.0
8.0
6.0
4.0
2.0

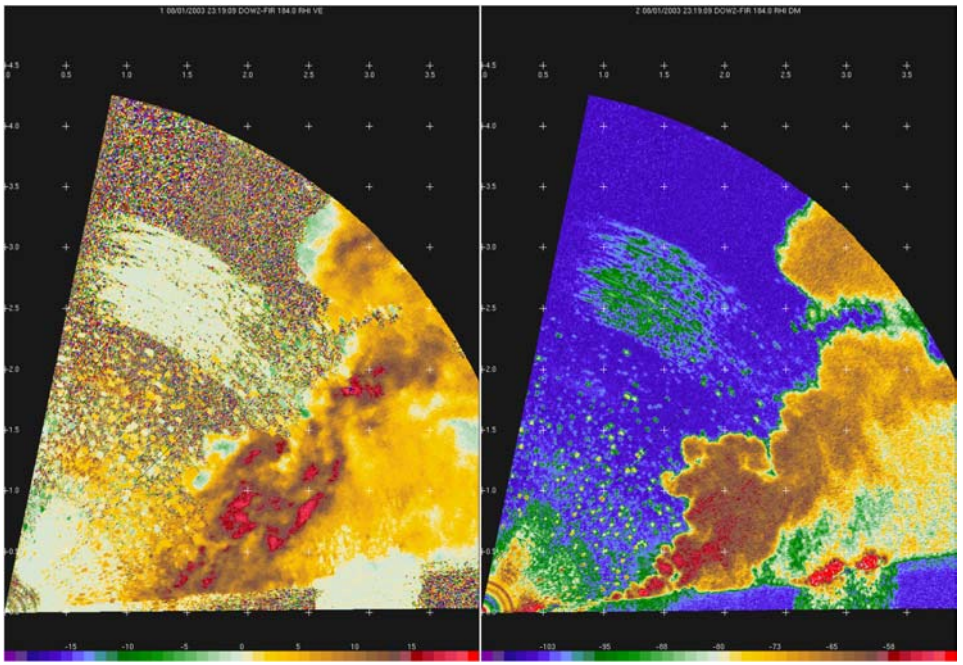
Mapping Winds over Big Condominiums + Nuclear Power Plant in Florida



DOW Near Fire
Mapping Hot Spots
and Strong Fire Winds

Could Save Firefighter Lives

Could guide Firefighting



Potential Urban Impacts of Violent Tornadoes

What if a violent, long-track tornado hit

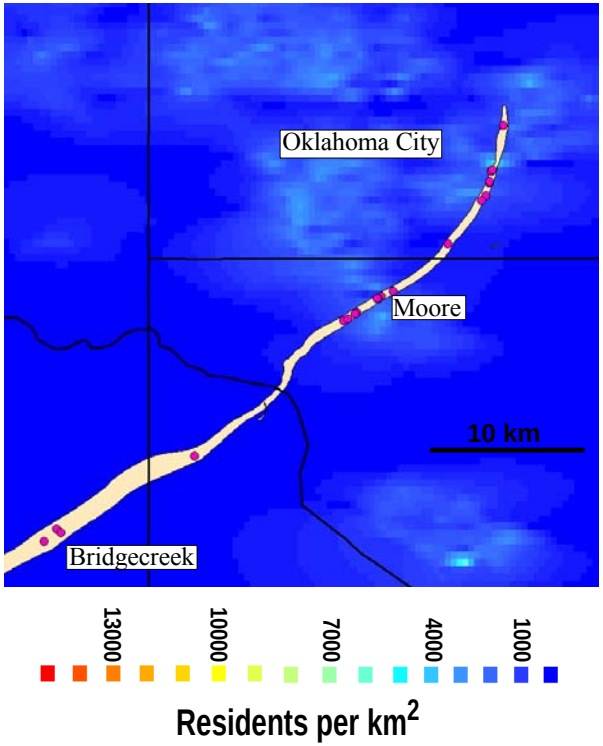
Chicago, or New York, or Atlanta, or Washington?

Impacts could be catastrophic:

Deaths > 10,000

Building Damage > $10 Billion

Strong Nighttime Tornado

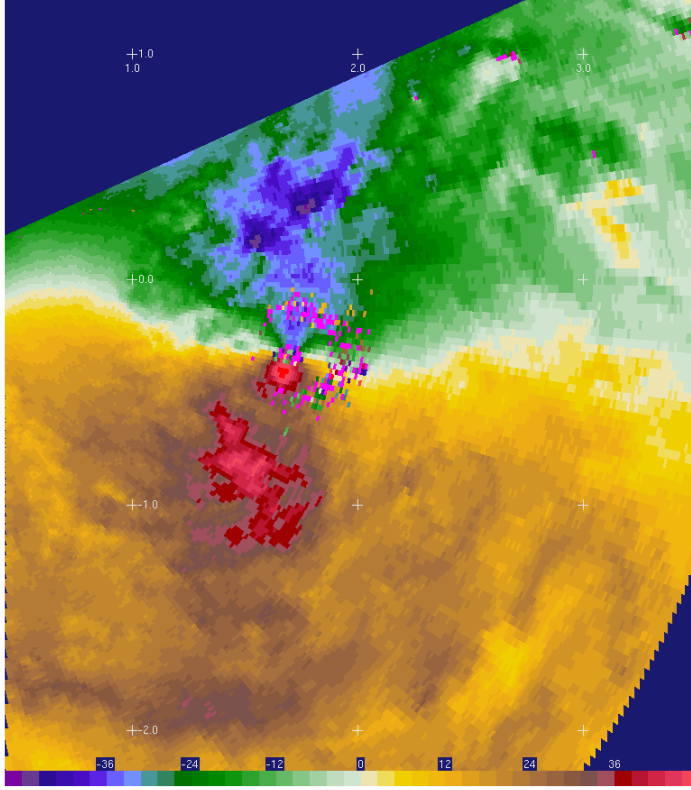


Worst recent urban tornado outbreak was 3 May 1999 in Oklahoma City

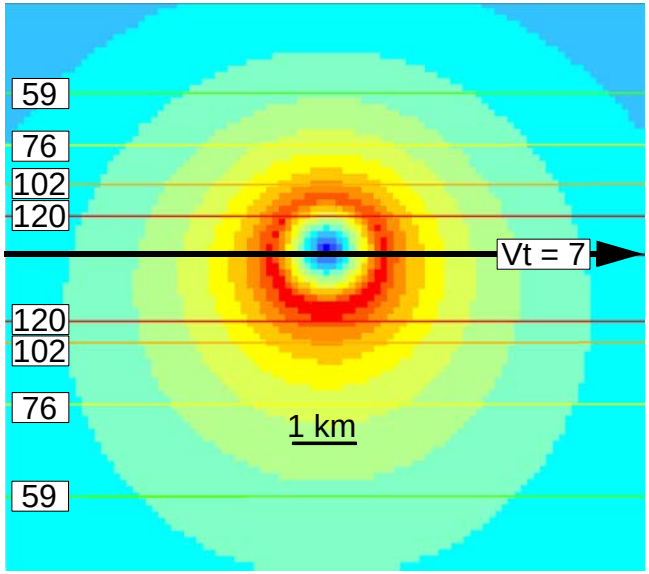
36 dead
$1 Billion in Damage

But, OKC is very low density urban area
And, tornado mostly passed over rural areas

Using Actual DOW Data From Violent Tornadoes and a Constrained Model



Swaths of Winds Expected From Various Violent, Long-Track Tornadoes can be Calculated



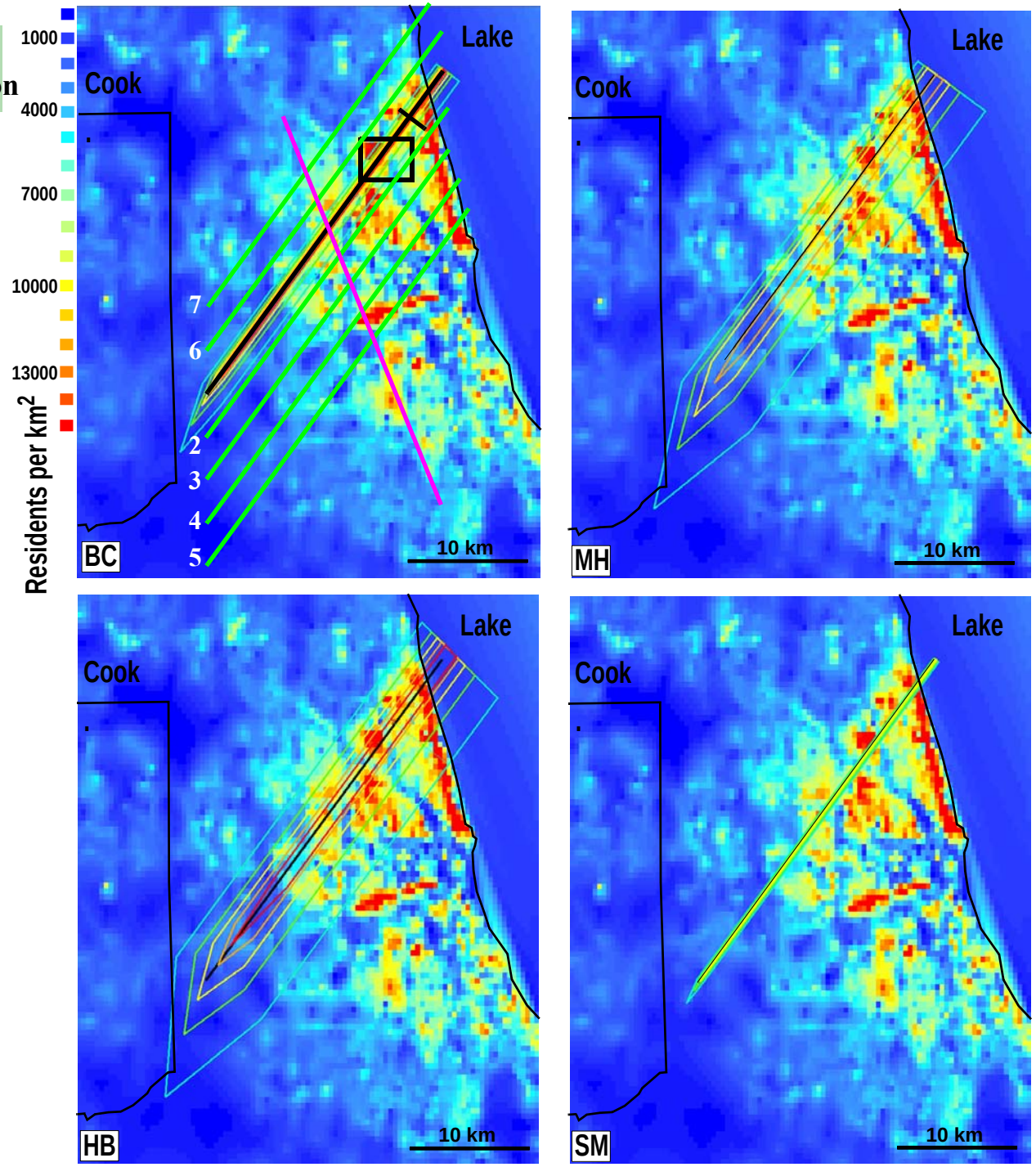
Different tornadoes cause different width swaths

Largest tornadoes, like Mulhall could cause swath 2-5 miles wide of nearly total destruction

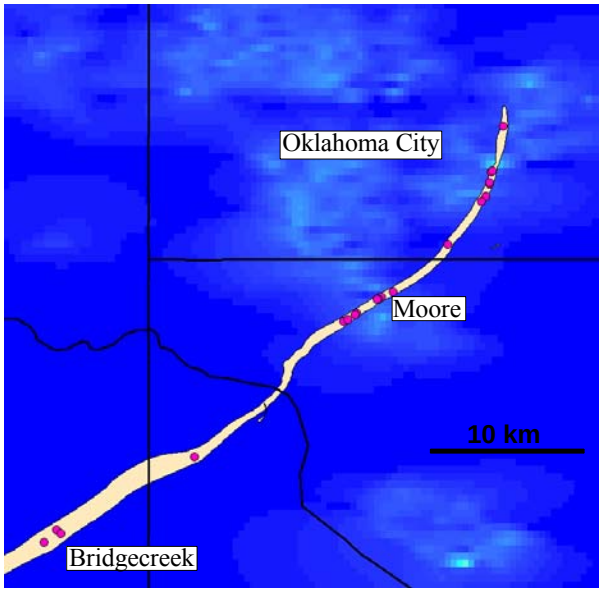
Winds in excess of 170 mph, (yellow lines) destroy all single and dual family homes and two to three story apartments

Much higher building densities in Chicago result in many more people under 170 mph winds

Chicago



Oklahoma City



Older Residential Neighborhoods

Typical of Some Large Cities

Much Higher Population Density

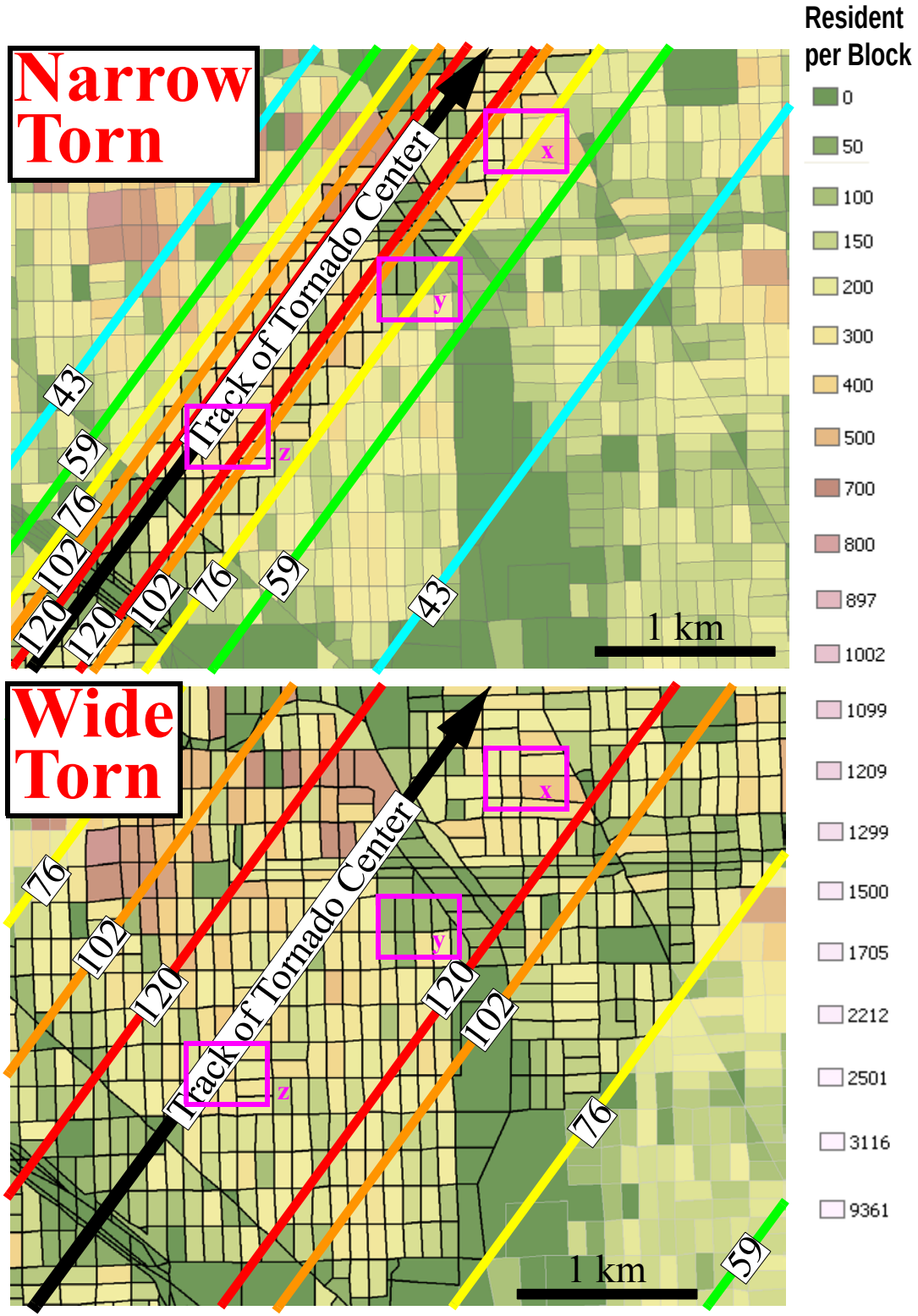
Chicago

Oklahoma City

Count People in US Census Blocks

Who experience

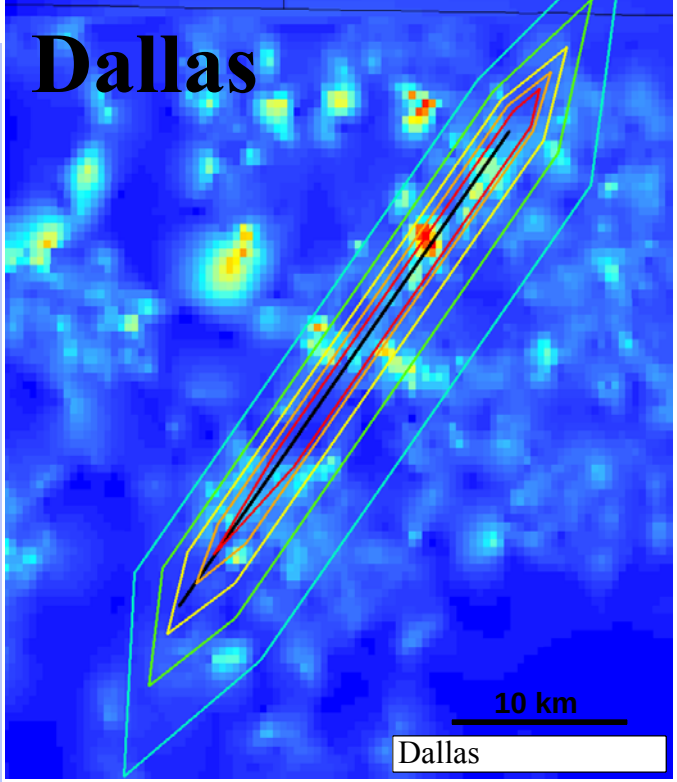
96 mph
132 mph
170 mph
228 mph
268 mph

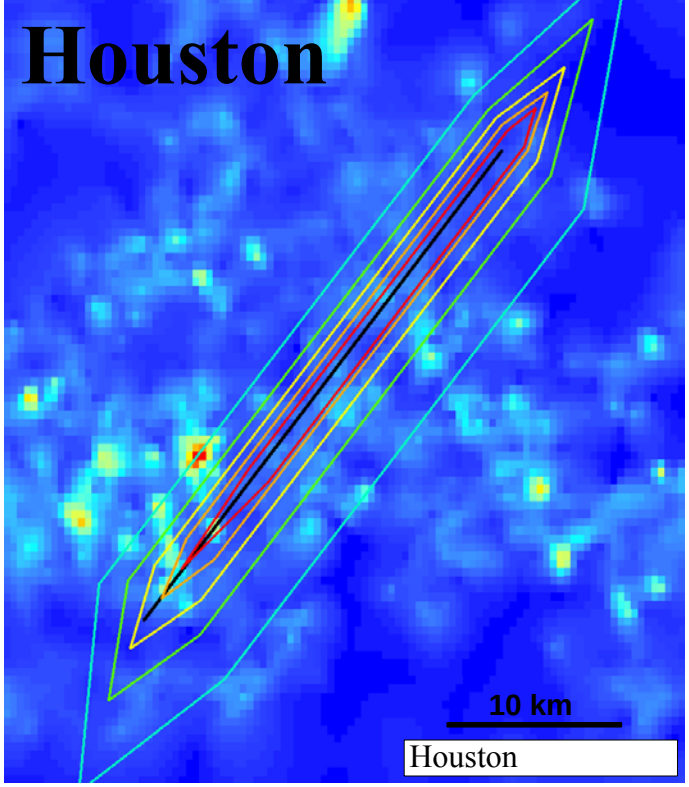


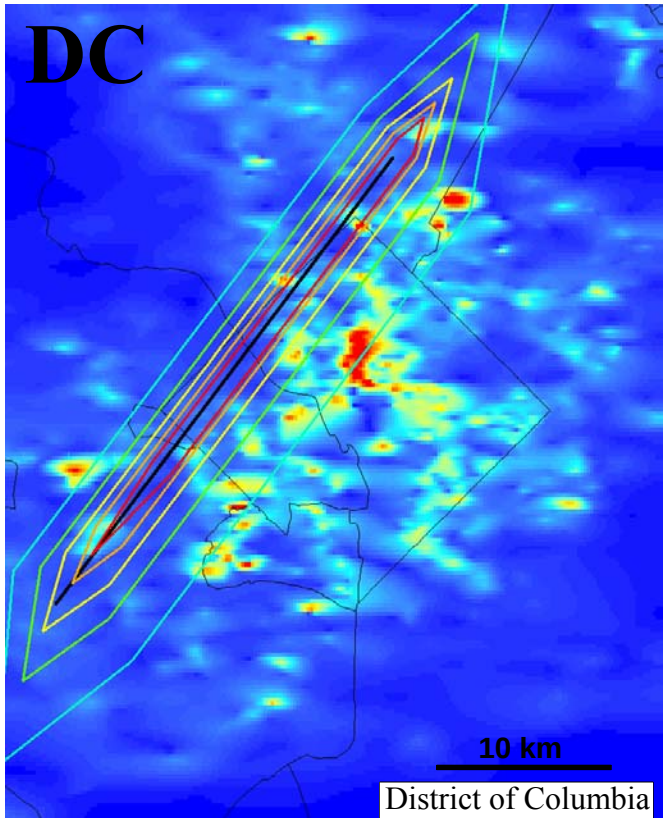
Major Tornadoes have Occured Near

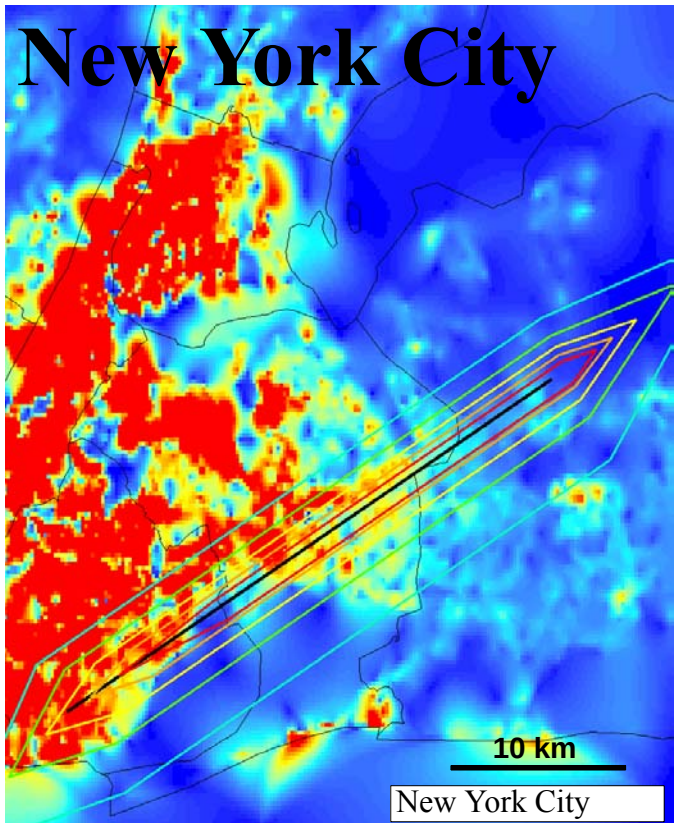
Dallas
Houston
DC
and other cities

Potential Impacts if Violent, Long Tornado over Dense Residential Areas



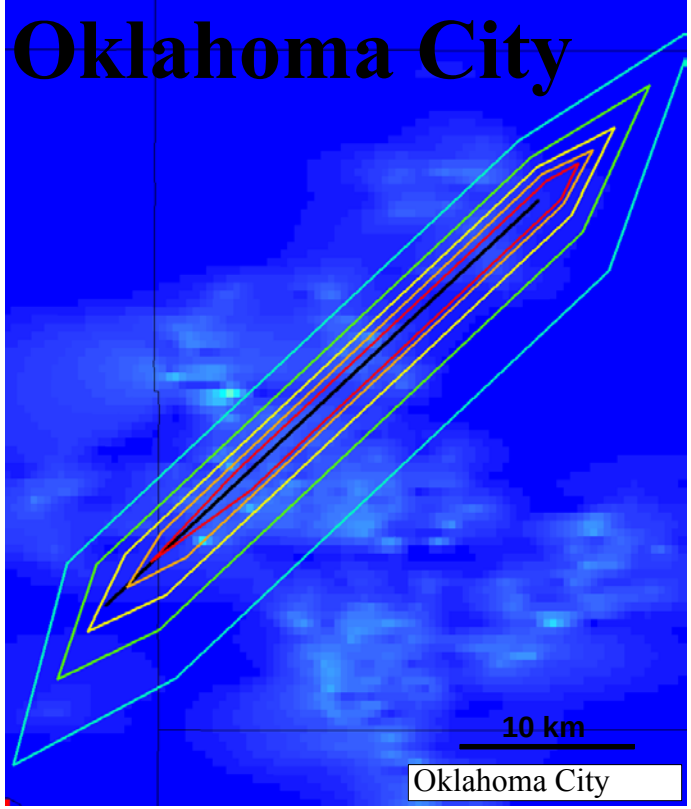


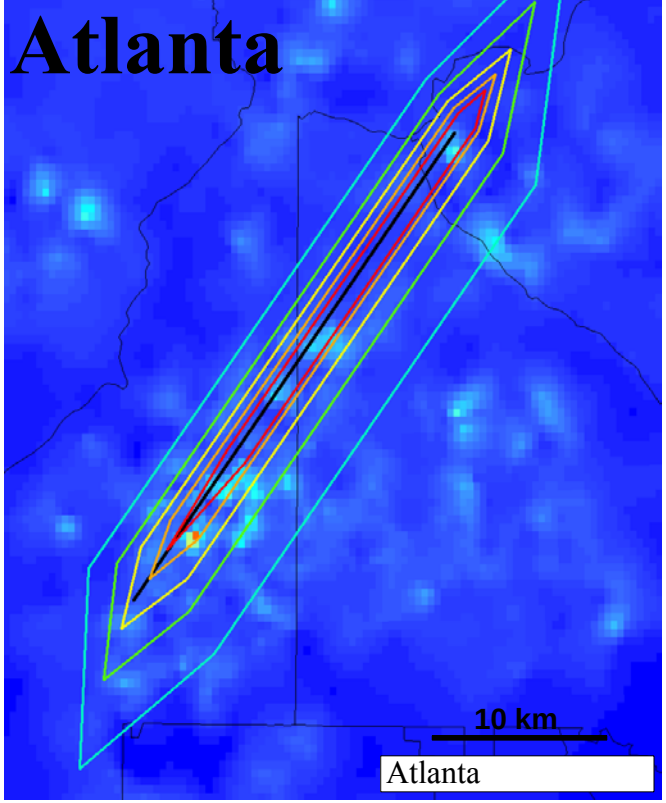


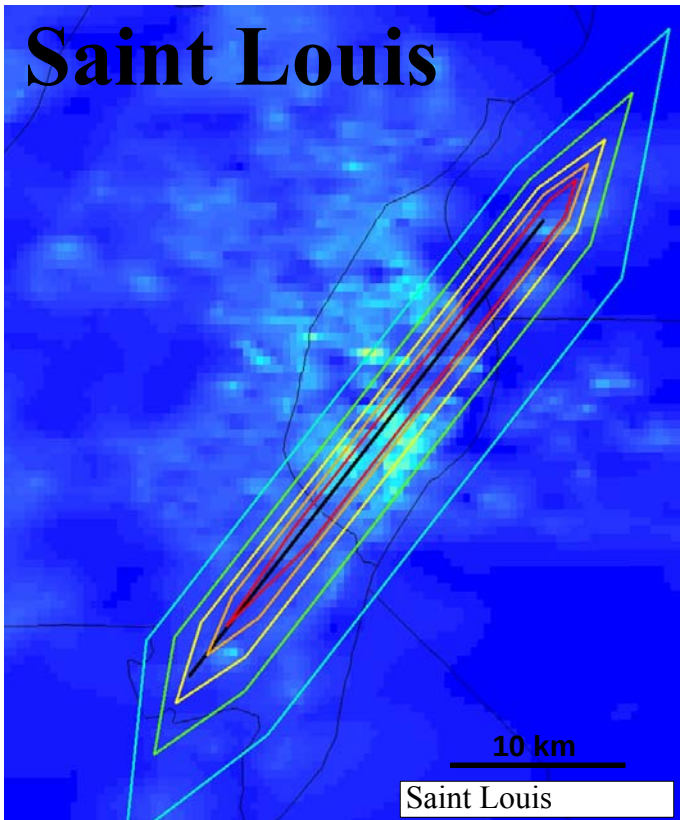


Simulated tornado passes over denser Part of OKC and is Wider

"Rural" parts of STL, ATL are more densely populated than OKC







Impact in Chicago

Inside 170 mph wind swath

Homes Destroyed: **10,000 - 152,000 (depends on torn width)**

Residents in destroyed homes: **30,000 - 450,000**

Deaths: **3,000 - 45,000 (10% fatality rate)**

Hundreds of high rise structures, worth > 10B$ damaged by winds > 260 mph

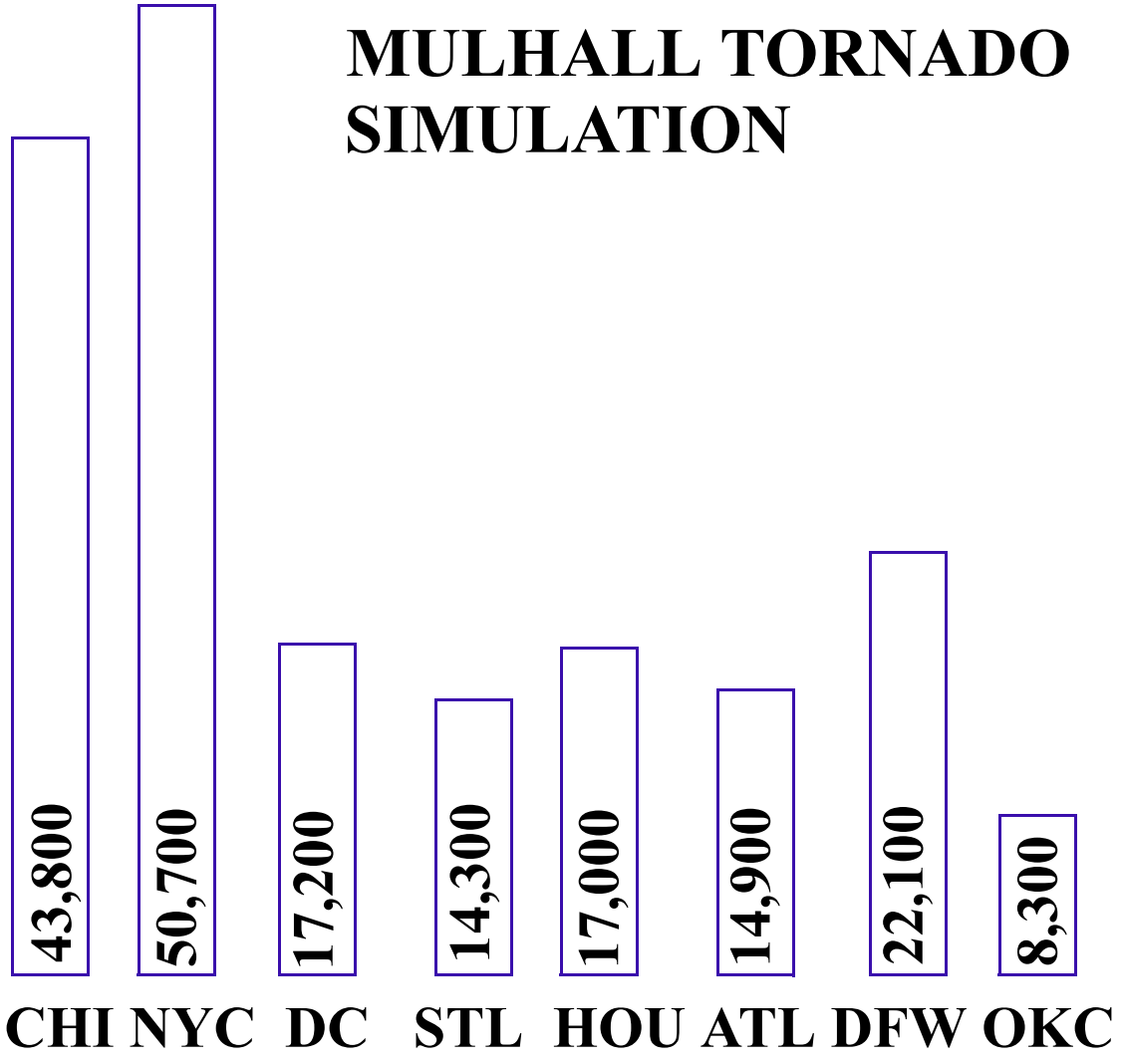
Impacts in Different Cities

High Housing Density in CHI, NYC results in very high impact, but simulated track avoids city core

Potential impacts of violent tornadoes exceed that of worst hurricanes (Galveston 1900, Katrina and earthquakes (San Francisco)

Tornadoes can cause more fatalities than hurricanes because:

1. **Peak winds are much higher 300 mph vs. about 160 mph (over land)**
2. **Swath of total destruction is limited to width of hundreds of yards in hurricane surge, but can be a mile wide in large tornado**
3. **12 minutes versus 24-36 hours warning means evacuation may be impossible**



Longer warning lead times for violent tornadoes would reduce potential deaths by permitting evacuation.

This can only be achieved by better knowledge through better observations, then an adaptable, targetable observation network.

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