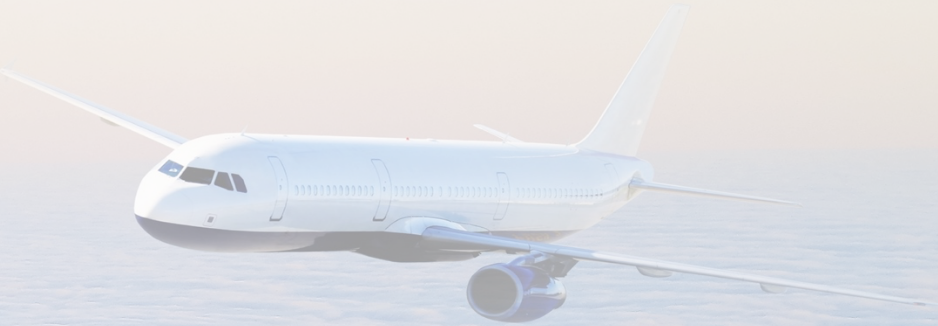
Pioneering Microburst Avoidance with the Terminal Doppler Weather Radar (TDWR)



Lexington Computer and Technology Group (LCTG)

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12 January 2022

LINCOLN LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Aviation Weather Hazards

This brief

Lincoln products improve situational awareness of hazardous aviation weather conditions to enhance system safety & efficiency

Major Accidents Attributed to Microburst Wind Shear

1970 – 1990: Fatal wind shear accidents comparable to fatal air carrier collision accidents

Fatal Accidents	# Accidents	# Fatalities
Accidents Associated with Aircraft Collisions	6	258
Microburst Wind Shear Accidents	4	499

1970 1980 1990 2000

St. Louis
38 fatalities; 6 injured

New York
112 fatalities; 12 injured

Denver
15 injured

Philadelphia
86 injured

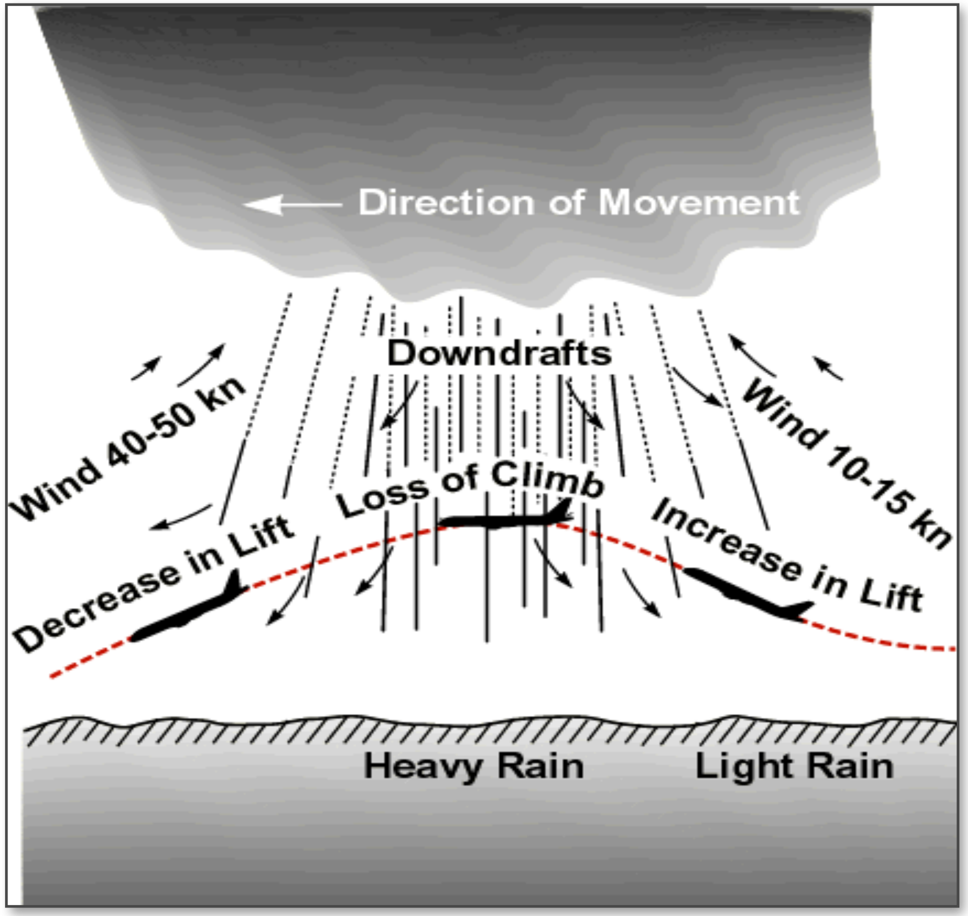
Tucson
0 injured

New Orleans
153 fatalities; 9 injured

Dallas
130 fatalities; 130 injured

Charlotte
37 fatalities; 16 injured

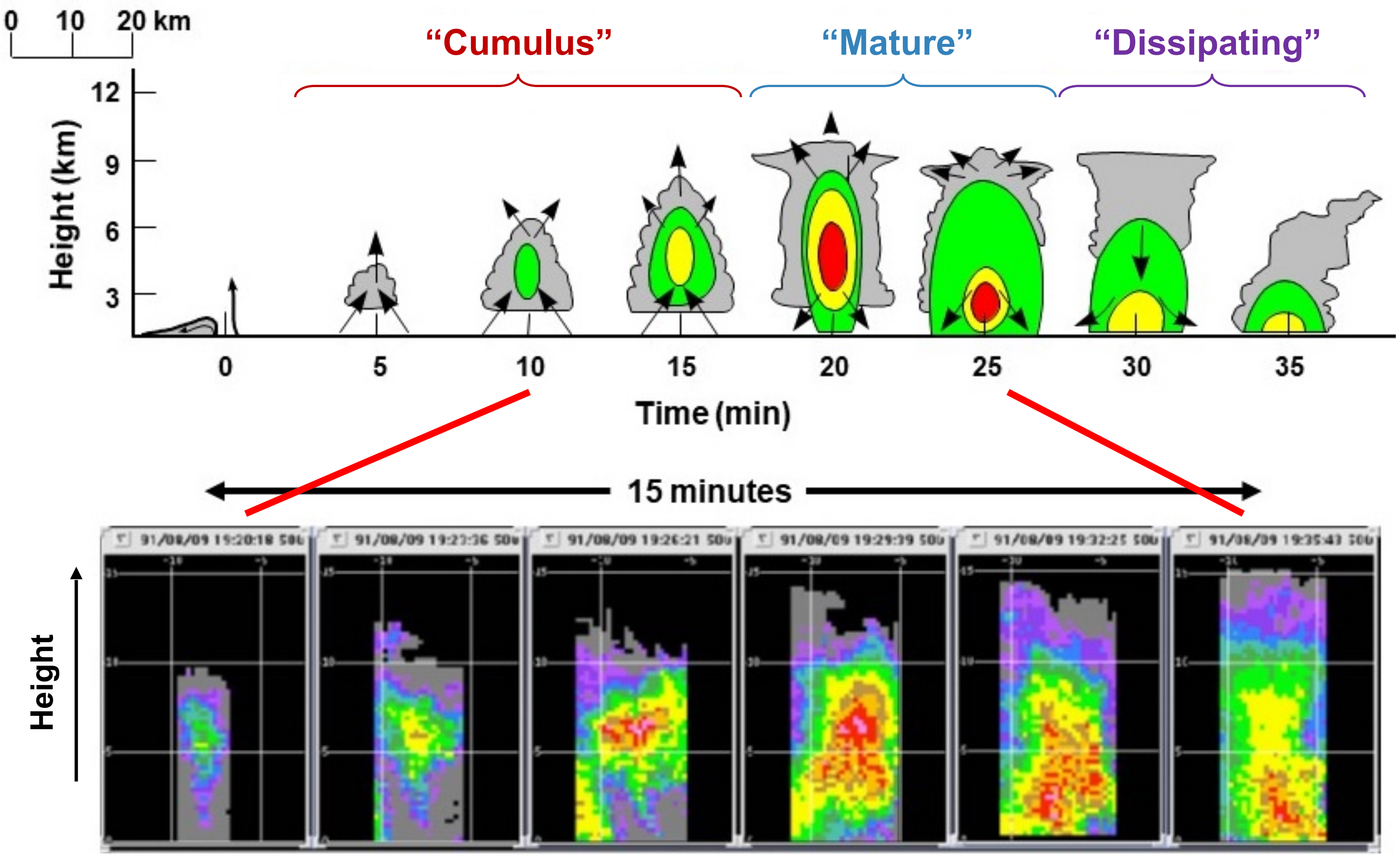
Microburst Hazard to Air Vehicles



Challenges for Pilots

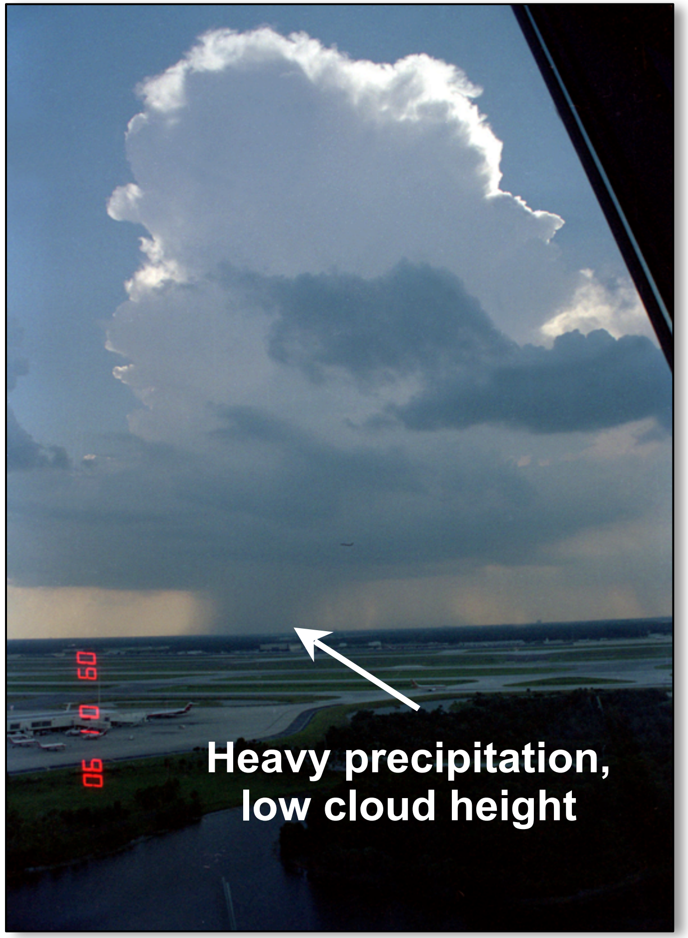
- Recognition is difficult
- Time available for recognition is short (5 to 15 seconds)
- Effective crew coordination is essential
- Pilot training at the time did not emphasize most effective responses
  – Flight path must be controlled with pitch attitude
  – Reduced airspeed may have to be accepted to ensure flight path control
- Operationally significant encounters were infrequent for individual pilots
- Rapid time evolution of phenomena: reports from preceding pilots may understate the hazard

Time Evolution of Microburst-Producing Storms

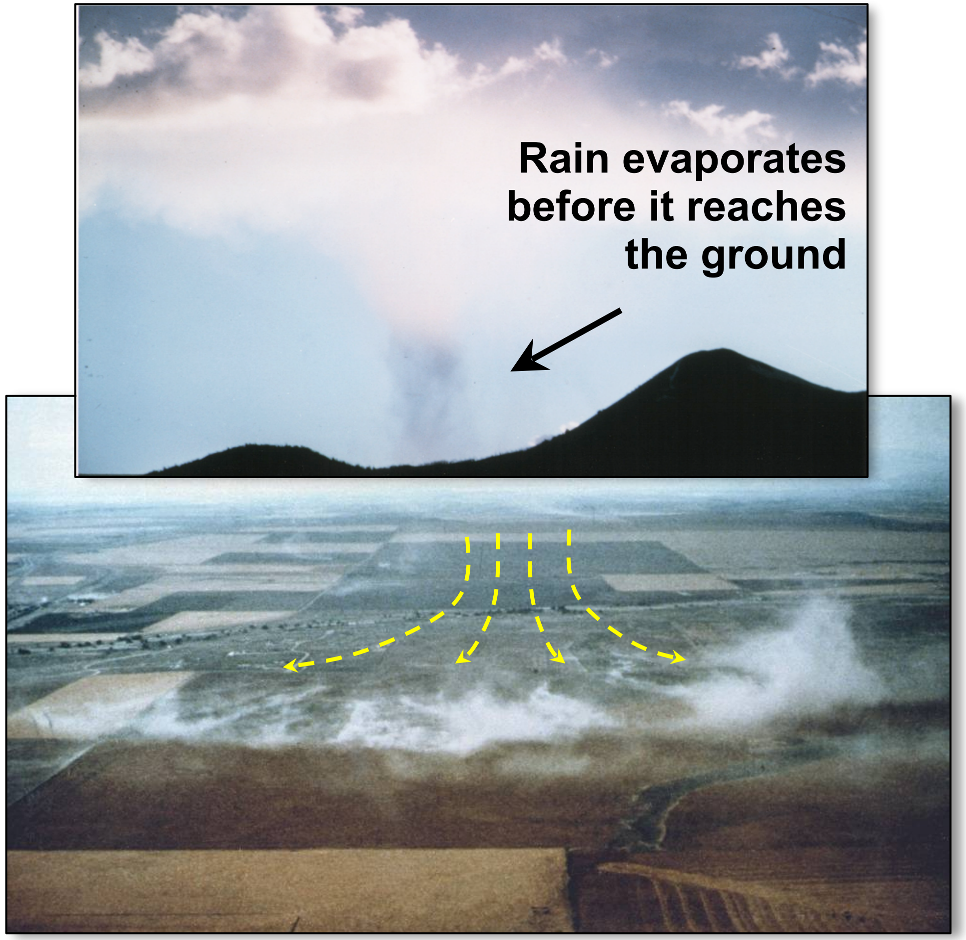


- Storms can rapidly change with time
- Microburst outflow occurs when rain shaft reaches ground
- In dry environments such as Denver, rain may not reach the ground

Visual Depictions of “Wet” and “Dry” Microbursts

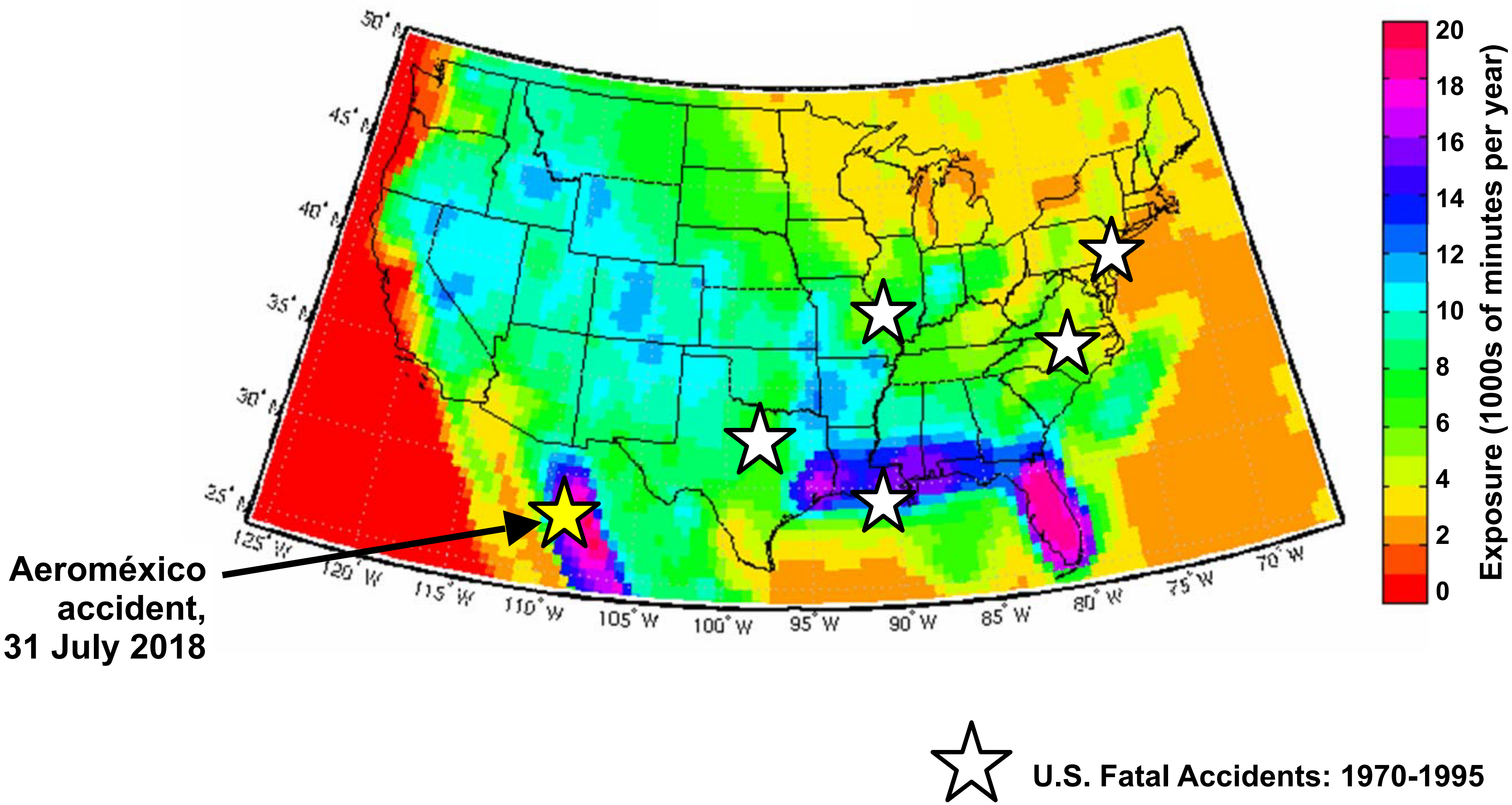


“Wet Microburst”
Easy to detect



“Dry Microburst” (Southwest)
Nearly invisible, just as dangerous

Exposure to Microburst Low Altitude Wind Shear



[Hallowell, R, et, al., Wind-shear System Cost Benefit Analysis Update, Project Report ATC-341, MIT Lincoln Laboratory, Lexington, MA, 2009]

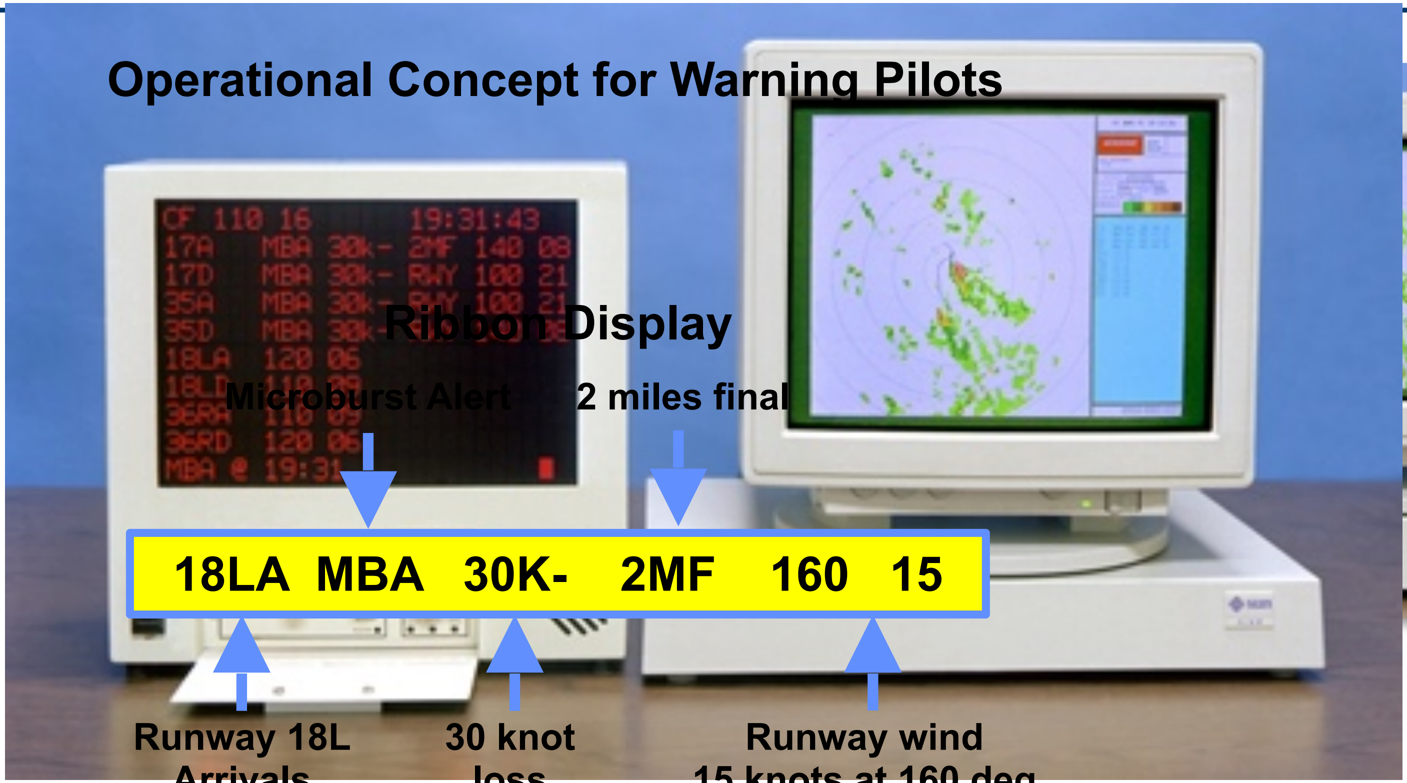
Key Elements of Reducing Fatal Accidents Due to Microbursts

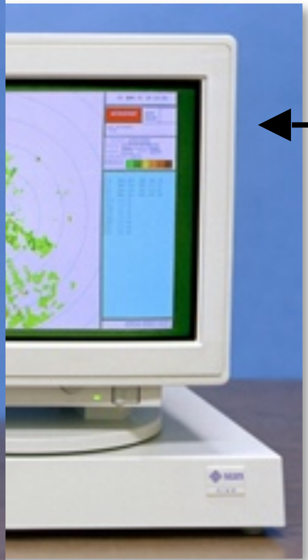
Key Element	How Accomplished
• Reliable automated detection of microbursts and warning generation	• MIT Lincoln Laboratory R & D using Lincoln prototype TDWR
• Procedures for ATC and pilot use of microburst warnings	• NCAR CLAWS real time radar meteorologist detections 1984 • FAA TDWR/LLWAS User Group 1986-1989 • FAA Procedures 1988 • Airline policies for pilots 1988
• Training of pilots to manage microburst encounters	• Windshear Training Aid (Boeing for FAA, 1987) • Airline flight simulators
• Success in acquisition, deployment and operational use of the TDWR	• Collaboration between FAA, Lincoln, Raytheon and various R&D laboratories

Terminal Doppler Weather Radar (TDWR) developed to provide critical microburst detection capability

CLAWS-Classify and Locate Wind Shear
LLWAS-Low Level Wind Shear Alert System
NCAR – National Center for Atmospheric Research

TDWR Operational Concept and Requirements





Plan view display for ATC to minimize the usage of runways and approach/ departure paths that are impacted by microbursts

Airline guidance to pilots: Do not land or take off on a runway with a microburst alert in effect

Technical Performance Requirements

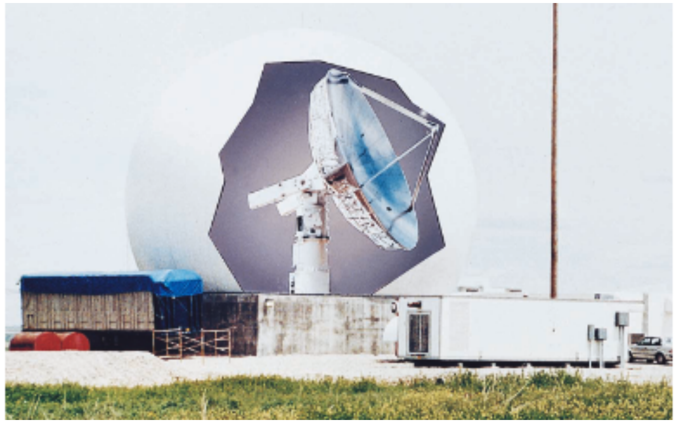
- Probability of detection > 95% for microbursts with a false alarm probability < 5%
- Accuracy of wind shear estimate should be within ± 5 knots or 20% (whichever is greater) for at least 70% of detections

Sensing of Weather vs Point Target Sensing

- Classic radar equation for point targets: received signal power $$P_r = P_t \frac{G^2 \lambda^2 \sigma}{(4\pi)^3 R^4} \propto \frac{\sigma}{R^4}$$
- When sensing weather, $\sigma \approx$ scanned volume x $\sum$ rain drop cross sections so that

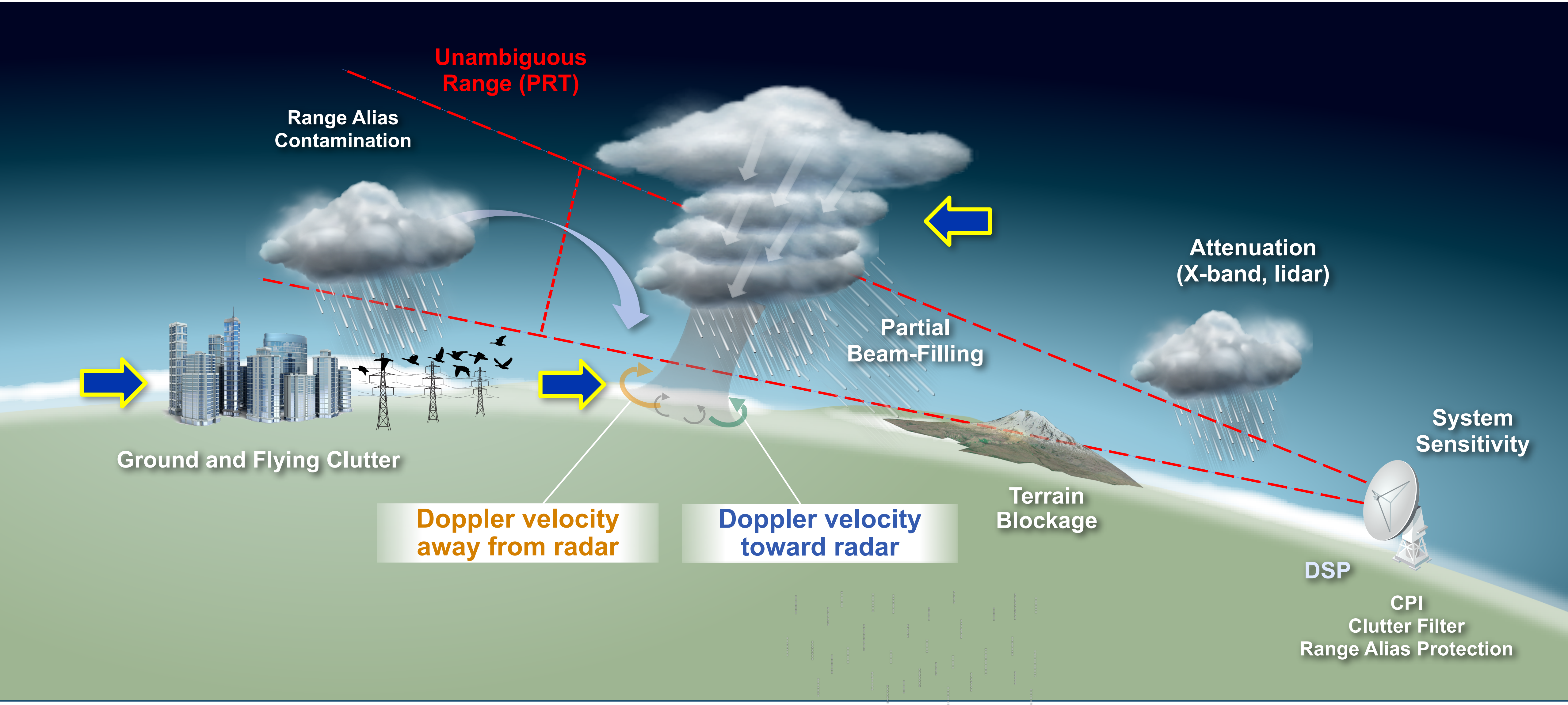
  $\sigma \approx (.5\, cT)\, (R\, \Theta_v)\, (R\, \Theta_h)\, \eta$ so that $P_r \approx \eta\, P_t\, T\, \Theta_v\, \Theta_h\, / R^2$ with η= volume scattering cross section
- Consequences of the nature of the "target" and the resulting range equation
  - Returns are a Gaussian random process whose parameters must be estimated by statistical techniques
  - "Out of trip" returns from weather at long ranges are a significant concern if one is seeking to measure Doppler
  - Ground clutter near radar a challenge if seeking to measure winds near the surface
- Wind shear detection radars are generally straightforward (pencil or fan beam mechanical scanning, S- or C-band, 1 μsec pulses)

Lincoln Laboratory TDWR
at Memphis 1985



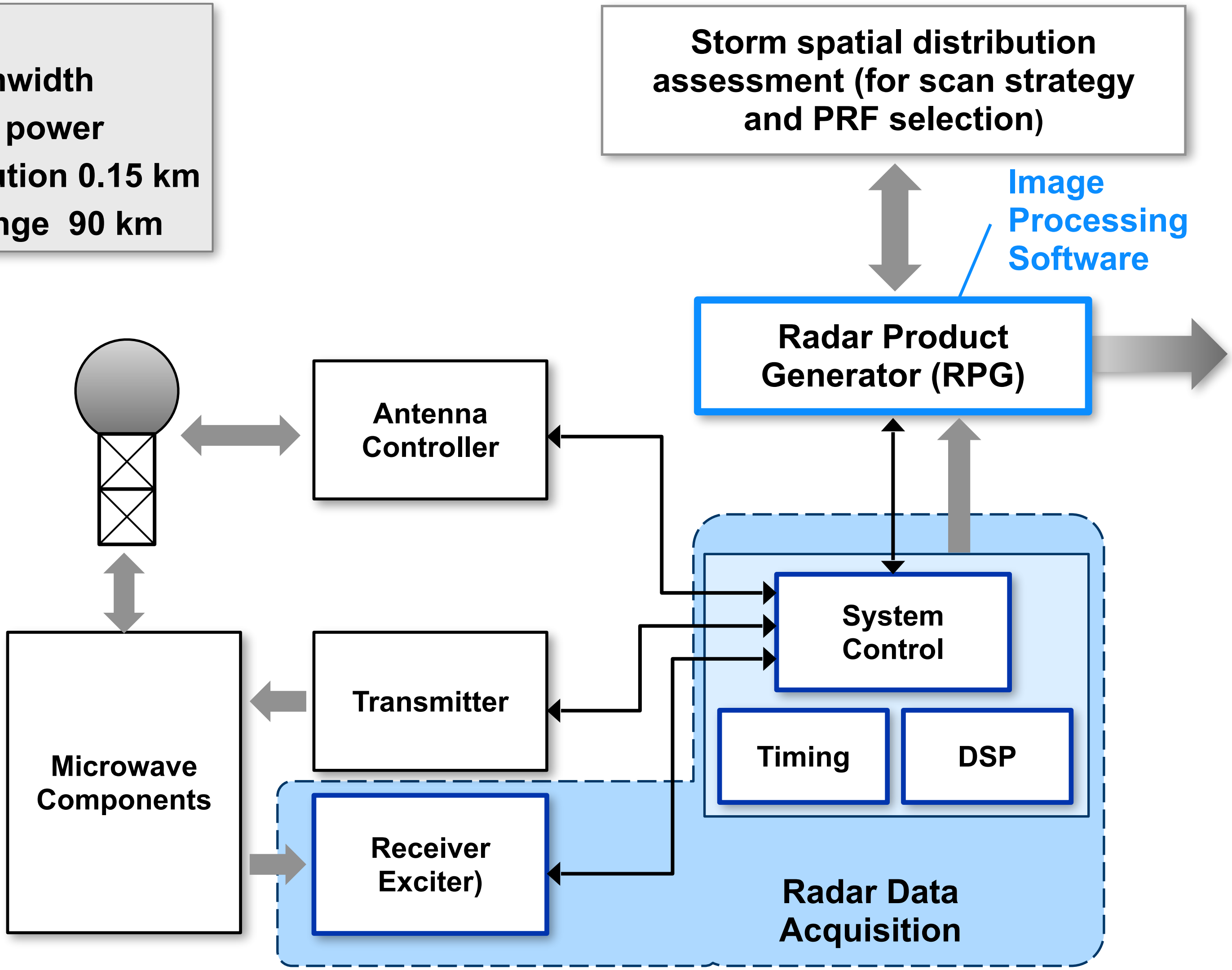
ASR-9
at Austin, TX

Technical Challenges to Wind Shear Detection with Doppler Weather Radar



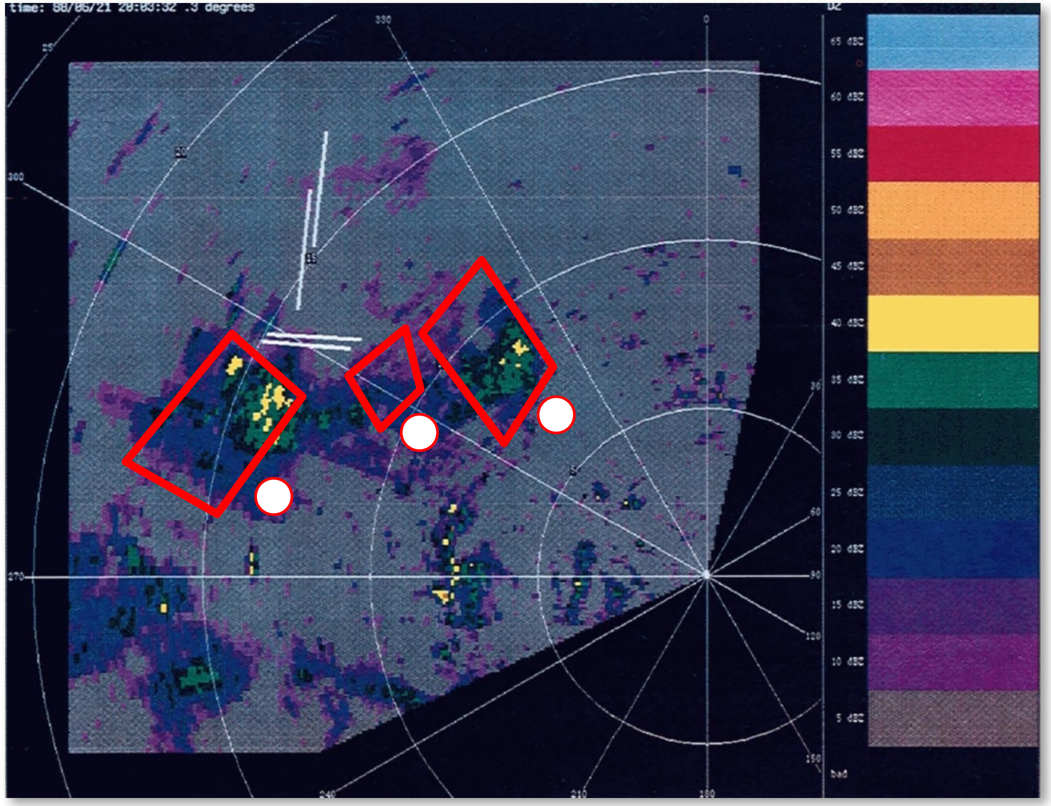
TDWR System Key Features

- C band
- 0.5 deg beamwidth
- 250 kW peak power
- Range resolution 0.15 km
- Maximum range 90 km

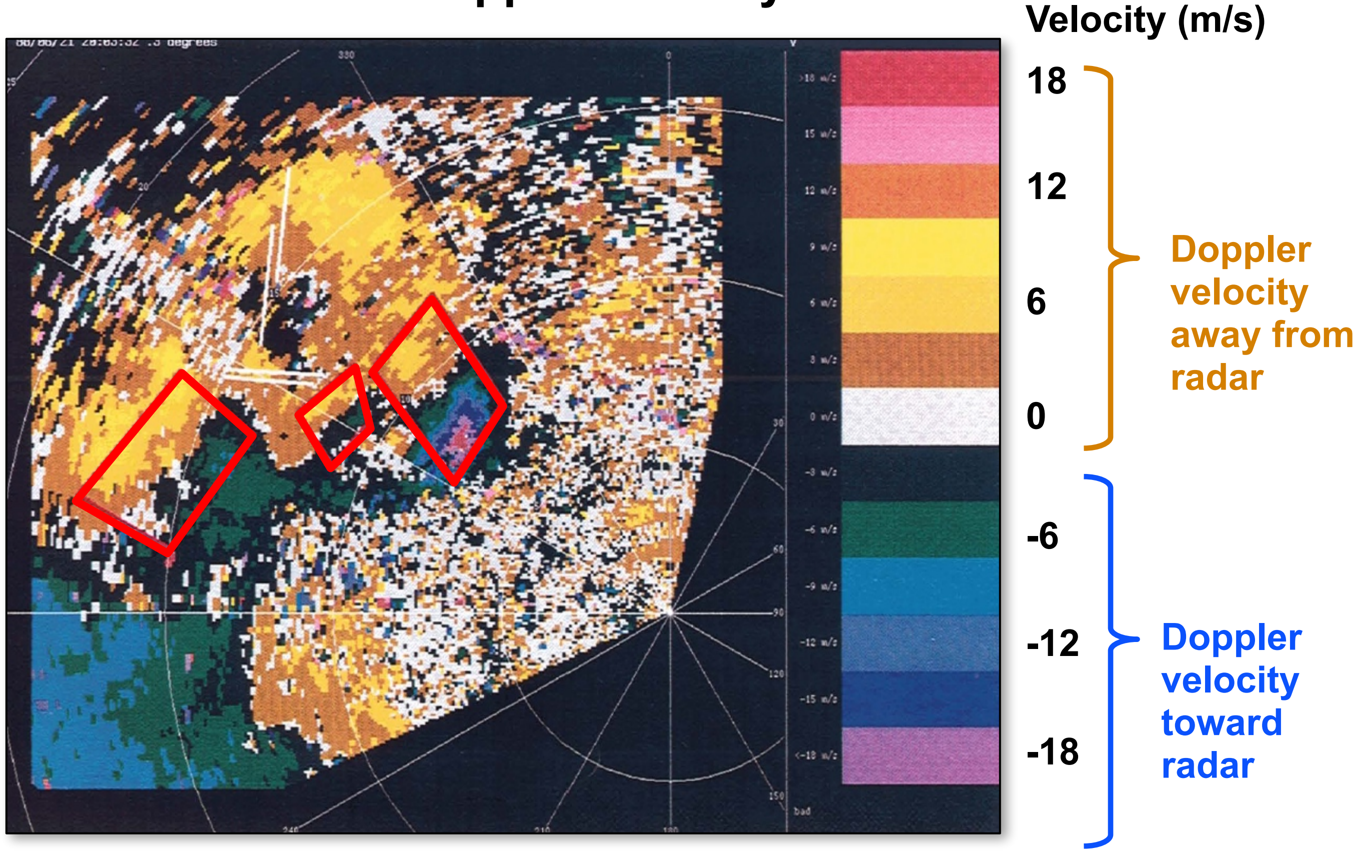


TDWR Surface Reflectivity and Doppler Velocity Images

Surface Reflectivity

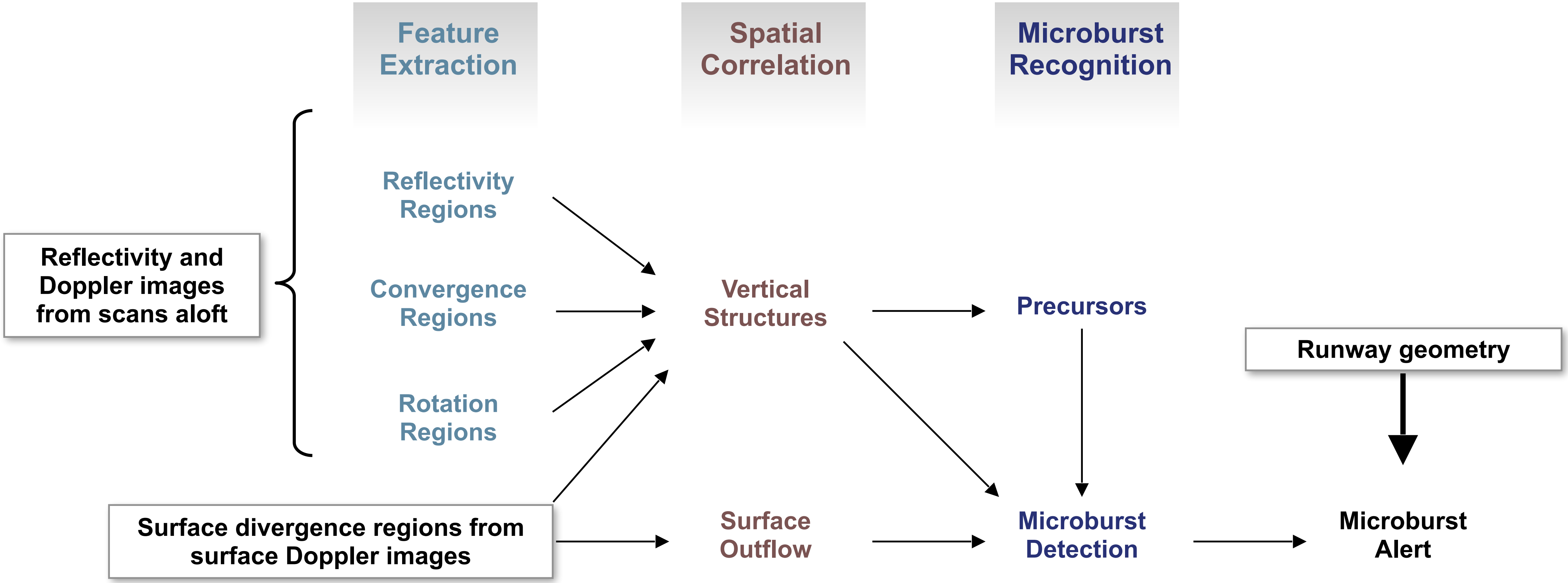


Surface Doppler Velocity



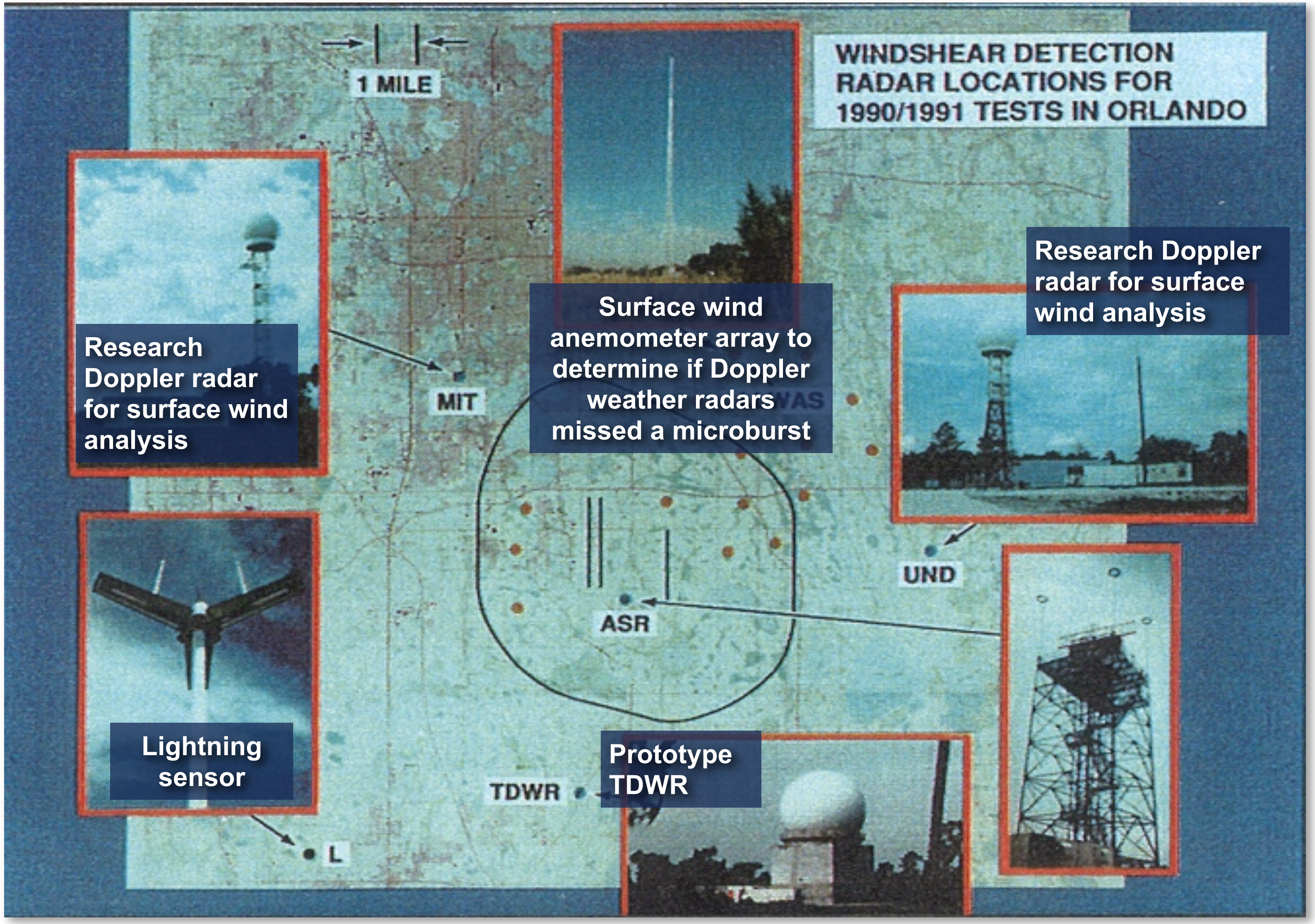
- White lines are runways at Stapleton International Airport
- Event occurred in June 1988
- Red boxes are microburst locations determined by analyst
- Microbursts on approach to runways 26L and 26R

TDWR Microburst Image Processing



Lincoln TDWR Testbed at Orlando 1990-1991

By combining surface Doppler data from the research radars and the prototype, one can determine the 3D wind field



Lincoln TDWR Testbed Time History

Year	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00
Field Experiments TDWR Test Bed	MEM	HSV	DEN	DEN	MKC	MCO	MCO	MCO	MCO							
Integrated Terminal Weather System and Storm Growth/Decay									MCO	MCO MEM	MCO MEM DFW	MCO MEM DFW	MCO MEM DFW	MCO MEM DFW NYC	MCO MEM DFW NYC	MCO MEM DFW NYC

Operational Success in 1988 TDWR Operational Demonstration

- Four aircraft on final approach to Denver's Stapleton airport were given warnings of microbursts with wind changes as high as 70 knots (normal airspeed margin in landing is 20 knots)
- Several of the pilots stated the warnings were a key factor in avoiding an accident ("The day all hell broke loose" FAA video)

- Testbed transmitter transition from S-band to C-band

- Replacement of prototype TDWR by first production TDWR
- Start of ITWS testbed to evaluate enhancements to the baseline TDWR capability

Decision Support Enhancements Developed via the TDWR Prototype

- **Addressing baseline problems**
  - Reduction of false alarms due to birds, insects, strong surface winds with terrain
  - Over-warning due to overly conservative criteria for how close a microburst region had to be to the flight path to warrant issuing an alert
  - Technical performance of gust front detection and tracking
- **Major improvements in decision support beyond the IOC capability**
  - Predictions of intensifying microbursts
  - Providing storm motion/extrapolated positions to manage runway usage
  - Providing microburst information to pilots via data link
  - Integration of TDWR alerts with surface anemometer array alerts

The TDWR Success Arose from Contributions from Many Organizations (especially the FAA, Scientists, Raytheon, and Lincoln)

Ted Fujita
Univ. Chicago

John McCarthy
NCAR

Alan Fraser
Raytheon

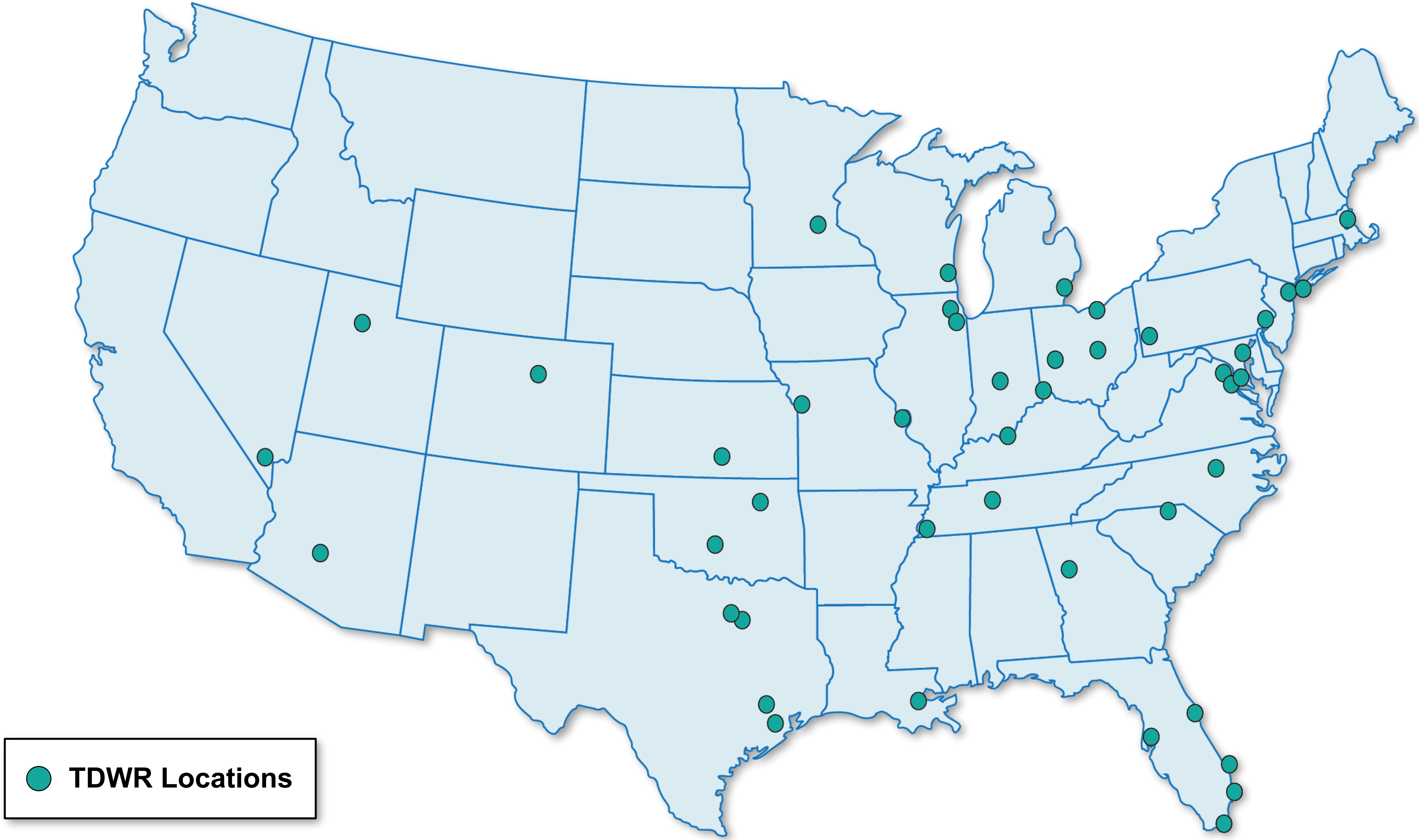
Orlando (MCO) Tower/TRACON staff

Dan Strawbridge
FAA

Lincoln System Development/Prototype Team

FAA Program Support Facility (PSF)

Operational TDWR Locations



Next Steps for TDWR

- **Refurbishment analysis and testing are underway so that TDWR can continue operation at major airports for a number of years**
- **Additional potential uses of TDWR include:**
  - **Use of the existing TDWR derived low altitude winds and wind shear products at 34 major metropolitan areas for:**

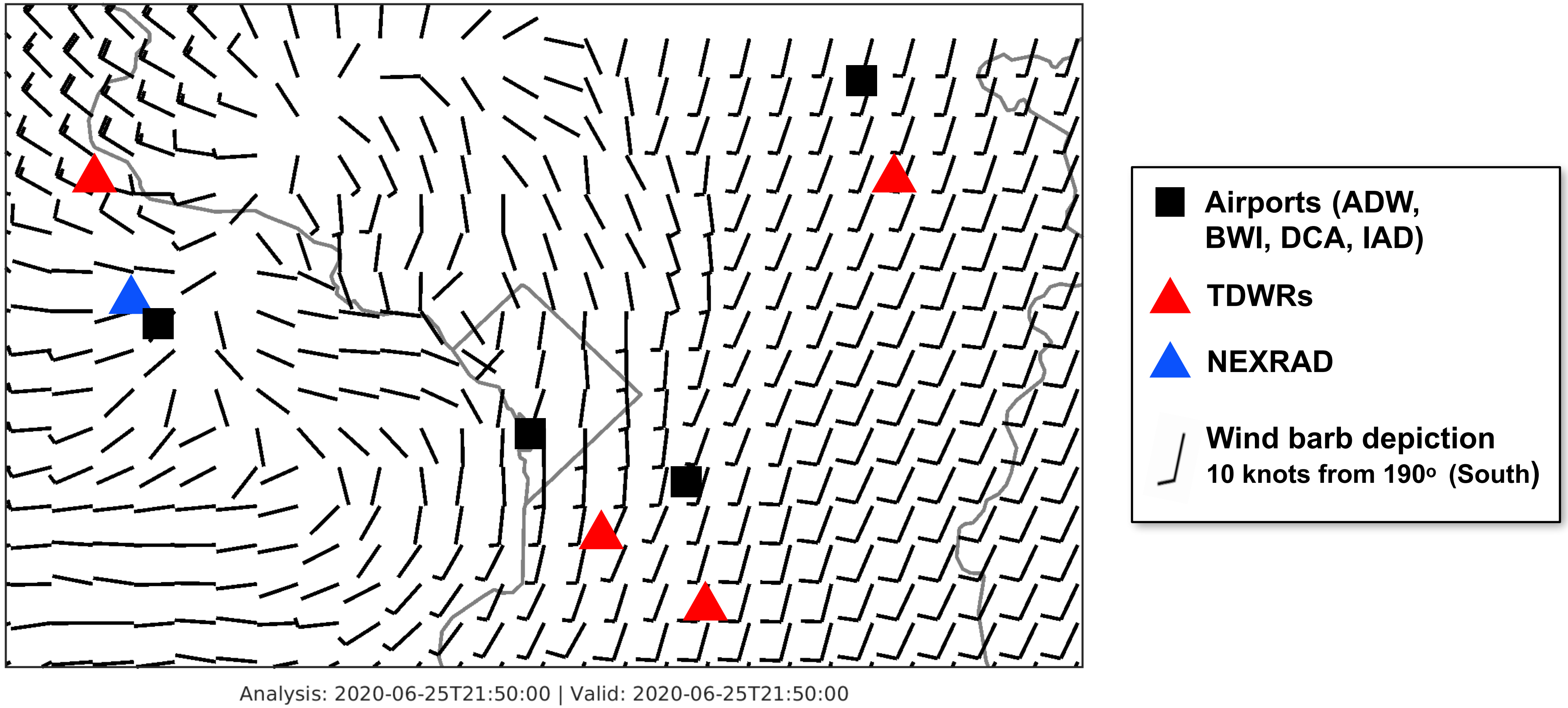
Helicopter Emergency Medical Services (HEMS)

UAS and Urban Air Mobility (UAM)

  - **A "target" channel addition to the TDWR could provide low altitude surveillance of possibly hostile low altitude targets (e.g., UAS) and/or to support UAM operations**

TDWR Role in Real-Time Low-Altitude Wind Information for Major Metropolitan Areas

TDWR / ITWS provides low altitude winds and wind shear detections that could be used to support HEMS, UAS, and Urban Air Mobility (UAM) operations at 34 major metropolitan areas

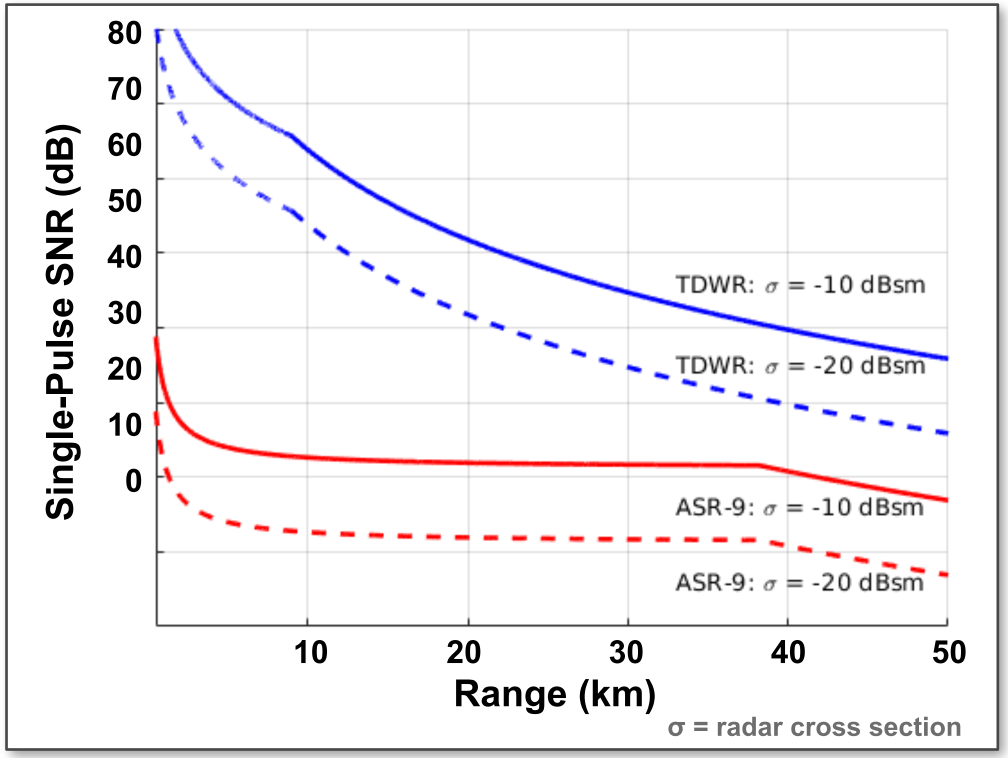


Washington DC gridded surface wind analysis (4 km updated every 5 minutes)

ITWS = Integrated Terminal Weather System

TDWR Surveillance of Low Altitude Discrete Objects

- TDWR scans near surface once per minute
- TDWR sensitivity to low cross section targets is much higher than ASR-9 sensitivity
- Would need to have dual polarization to see discrete targets in precipitation (as is done with the Lincoln-developed ASR-9 Weather Systems Processor (WSP)



Summary

- The TDWR has been very successful in preventing low altitude wind shear accidents and facilitating proactive air traffic management for over 25 years
- Key elements of this success were:
    1. Ongoing prototype testing while procurement was underway
    2. Good working relationship between production contractor (Raytheon) and Lincoln
    3. Signal and image processing technology improvements to address long standing problems such as range/velocity folding and image recognition
- Refurbishment analysis and testing is underway so that TDWR can continue operation at major airports for a number of years
- Additional uses of TDWR that should be considered include:
    1. Use of the existing TDWR/ITWS low altitude winds and wind shear products to support HEMS, UAS, and UAM operations
    2. A “target” channel addition to the TDWR that would provide low altitude surveillance of possibly hostile low altitude targets (e.g., UAS)

Legal Notices

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