Weather Research and Integration for Air Traffic Management

William N. Chan

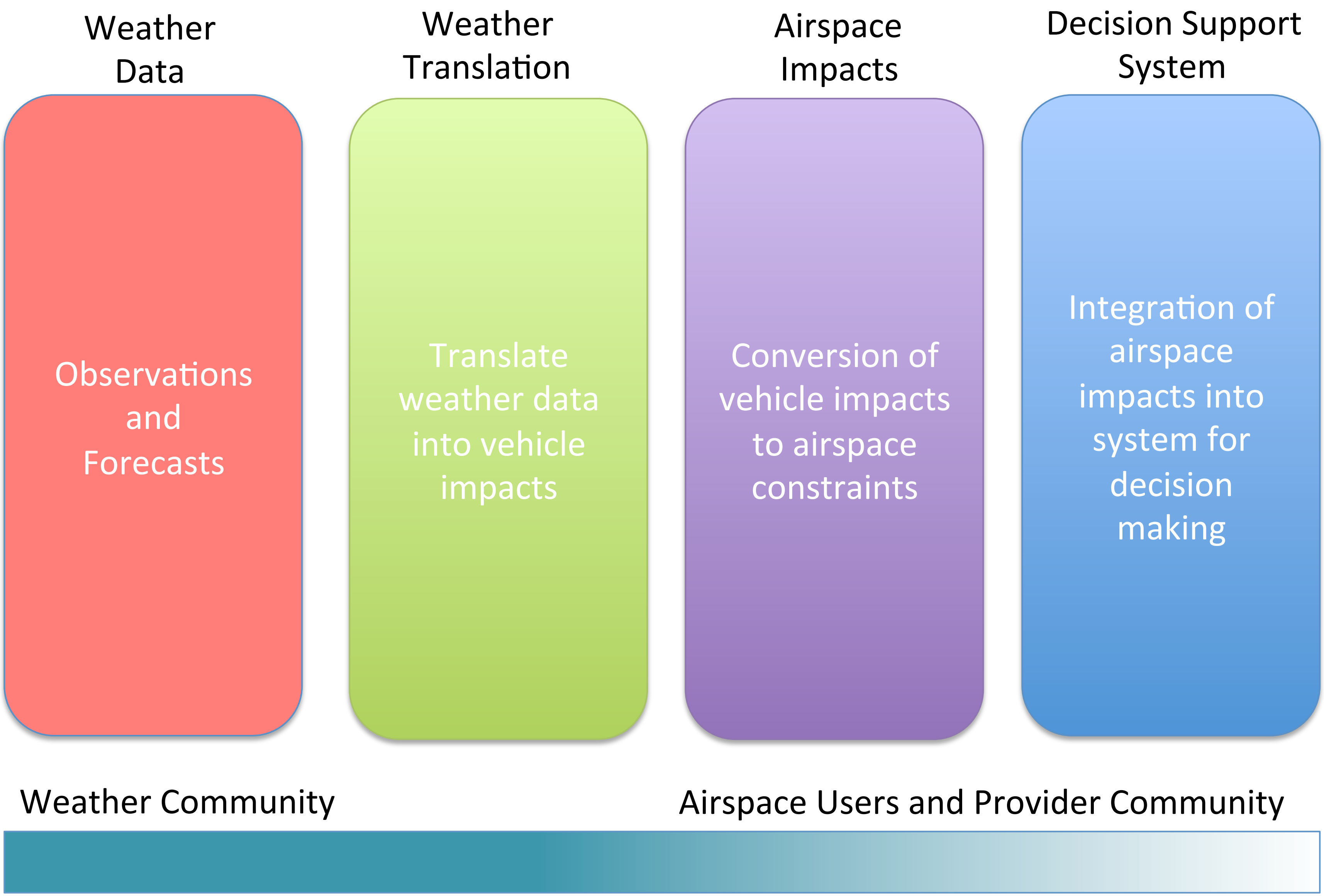
Chief, Systems Modeling and Optimization Branch

NASA Ames Research Center

Moffett Field, CA

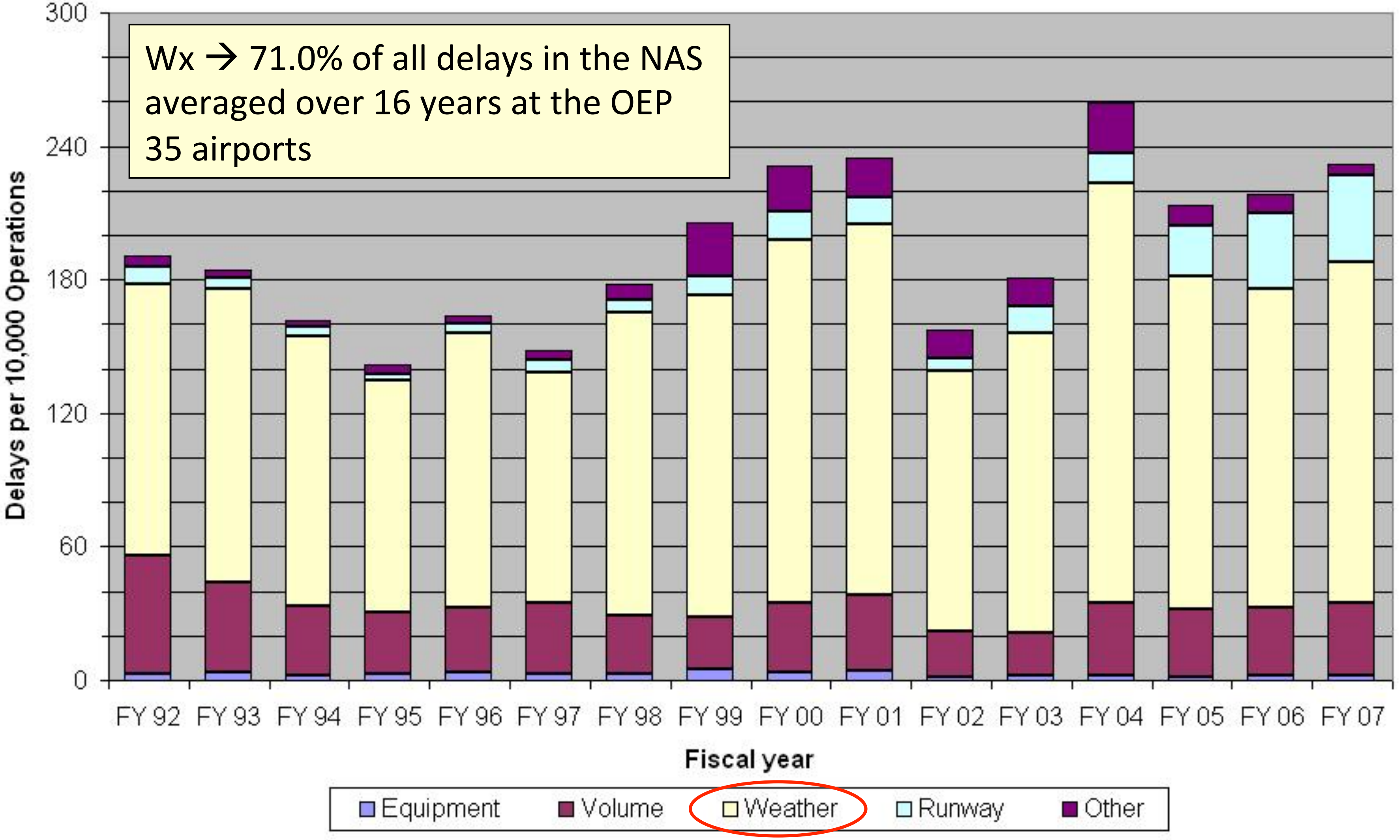
- History of supporting applied weather research for over 15 years
- Integration into air traffic control decision support tools
- Newer area is developing weather products for small Unmanned Aerial Systems within the atmospheric boundary layer (< 400 ft AGL)

- Weather problems
- Turbulence – S. Korea and United States
- Convection
- Wind Optimal Routing
- Low Level Weather for Unmanned Aerial Systems


Weather Data
Weather Translation
Airspace Impacts
Decision Support System
Observations and Forecasts
Translate weather data into vehicle impacts
Conversion of vehicle impacts to airspace constraints
Integration of airspace impacts into system for decision making
Weather Community
Airspace Users and Provider Community

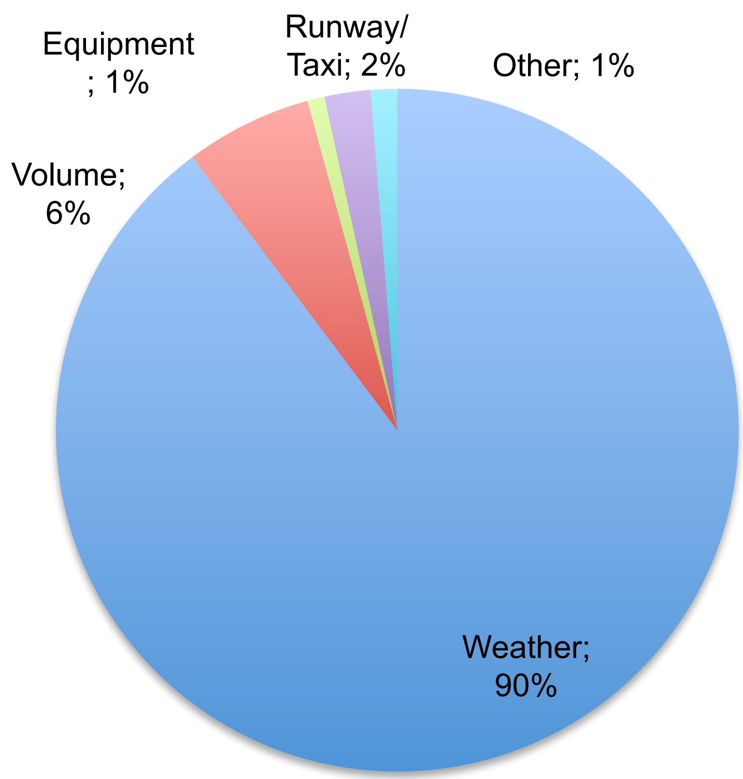
The Weather Problem

US Airspace Weather Related Delays



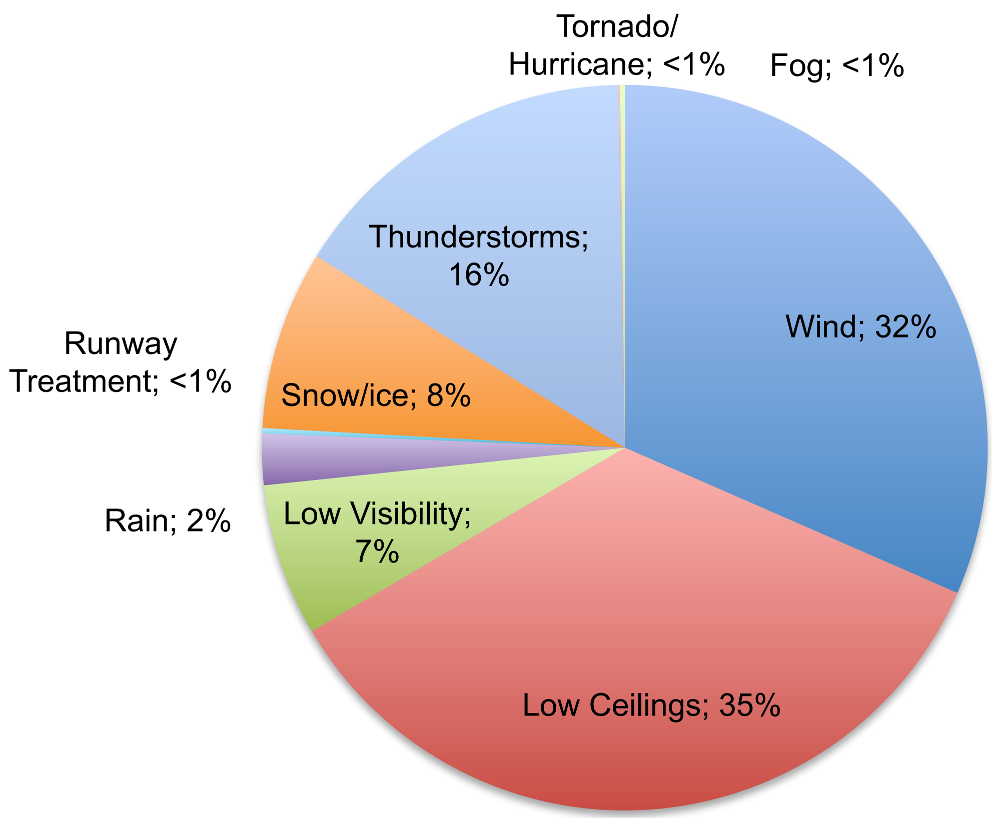
Source: OPSNET Statistics

Causes of Ground Delay 2008



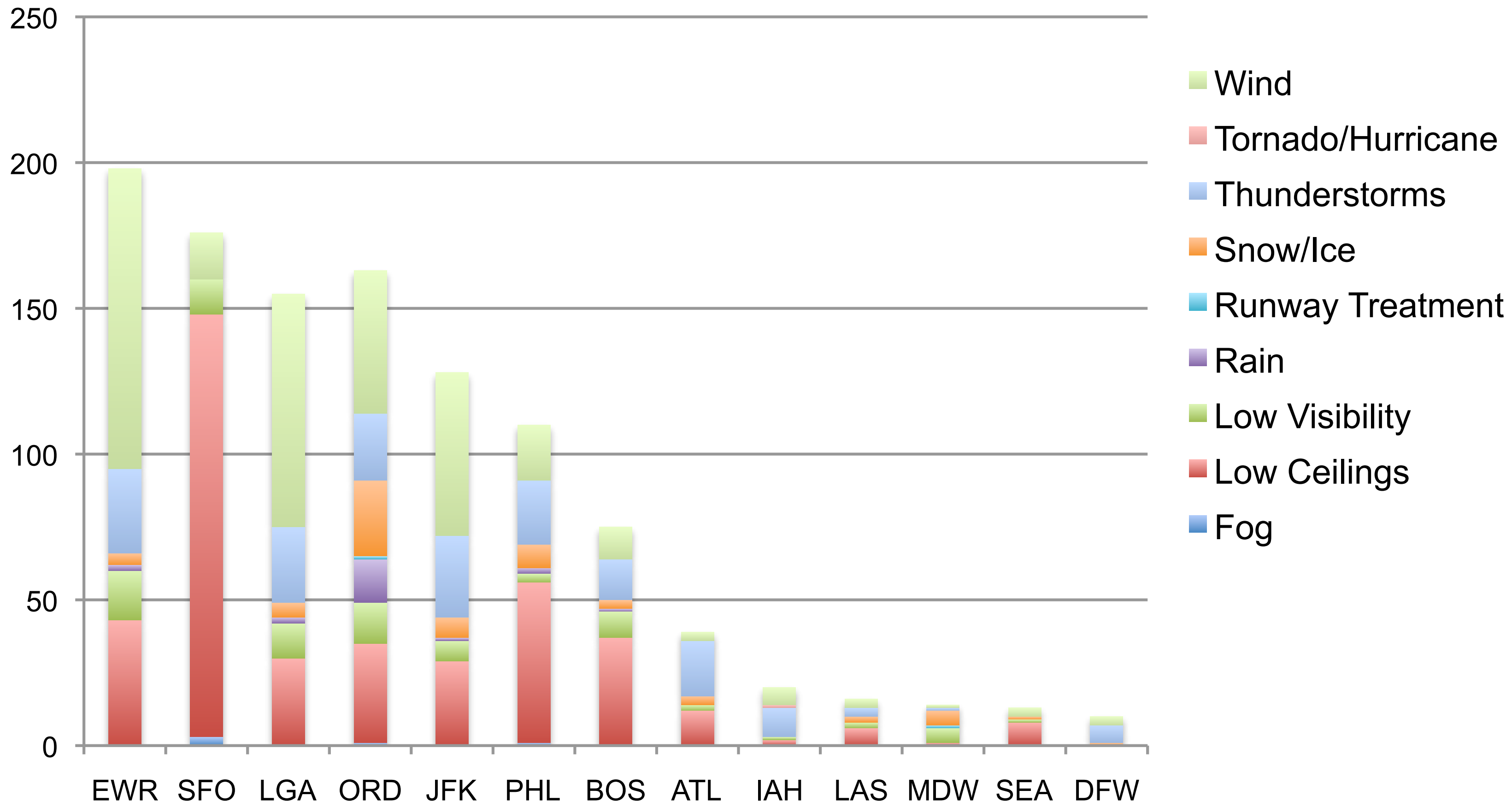
National Traffic Management Log database," Integration of Weather into Air Traffic Management (ATM) Initiative -Recommendation of Enhancement", NASA, Mosaic ATM, MIT/Lincoln Labs

Weather Impacts 2008



National Traffic Management Log database," Integration of Weather into Air Traffic Management (ATM) Initiative -Recommendation of Enhancement", NASA, Mosaic ATM, MIT/Lincoln Labs

Weather Impacts on Airports 2008



Turbulence

Types of Aviation Turbulence

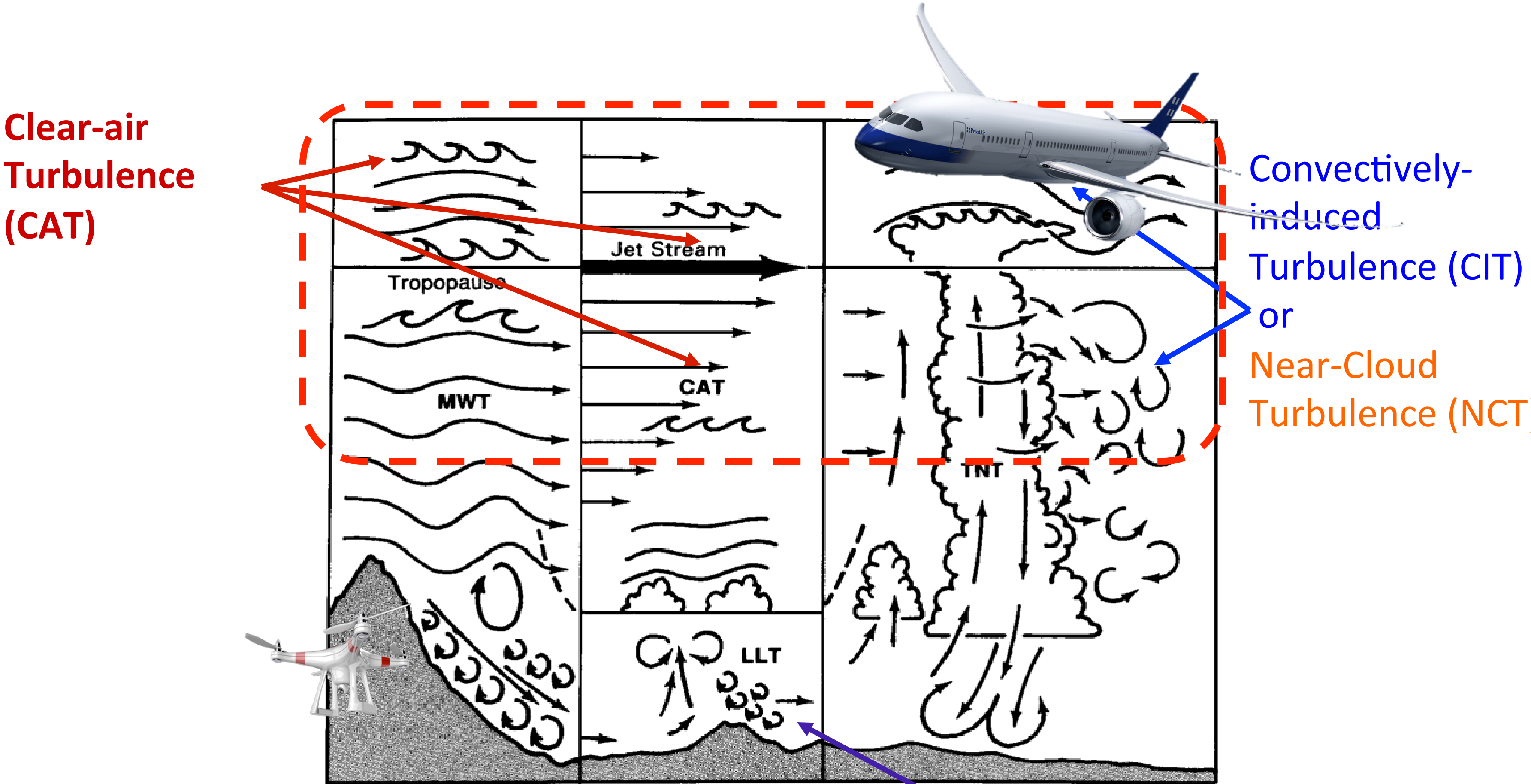
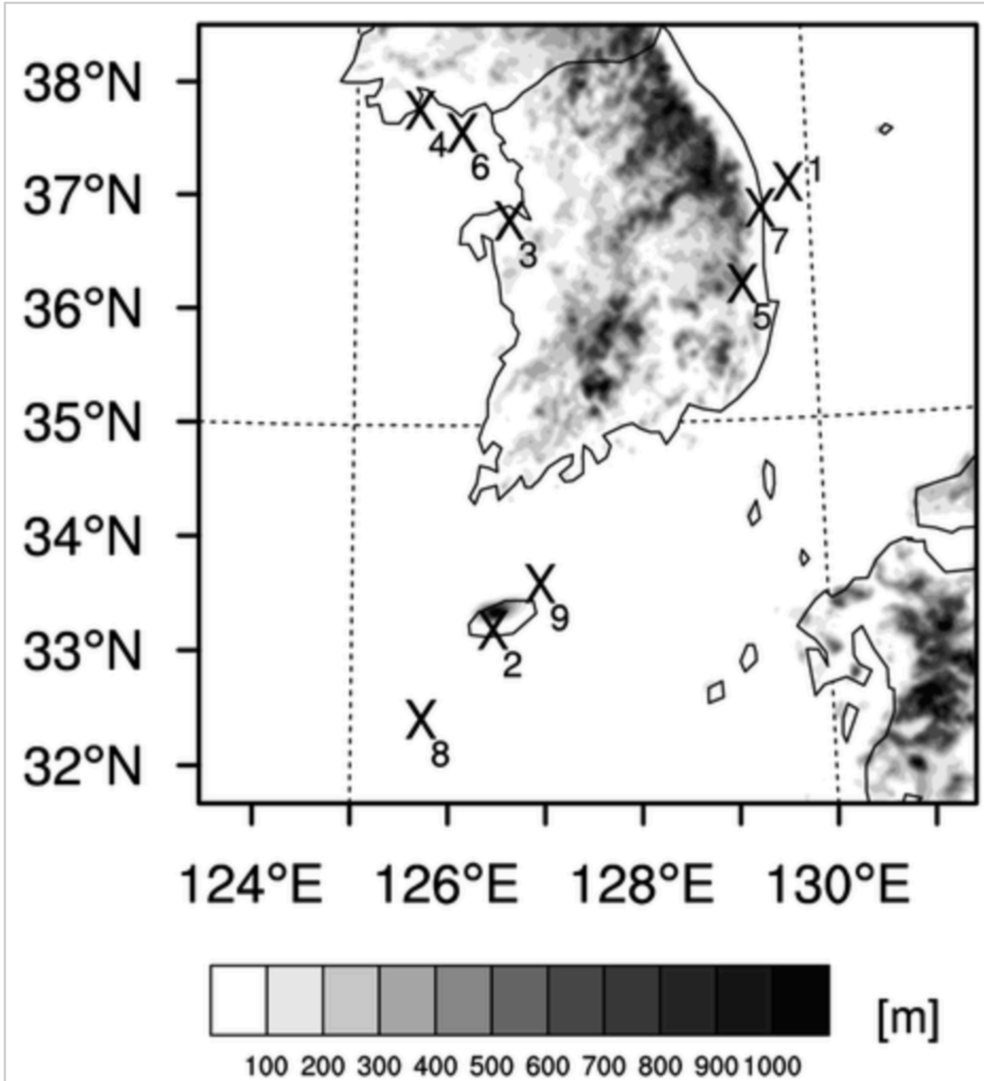


Figure 1-16. Aviation turbulence classifications. This figure is a pictorial summary of the turbulence-producing phenomena that may occur in each turbulence classification.

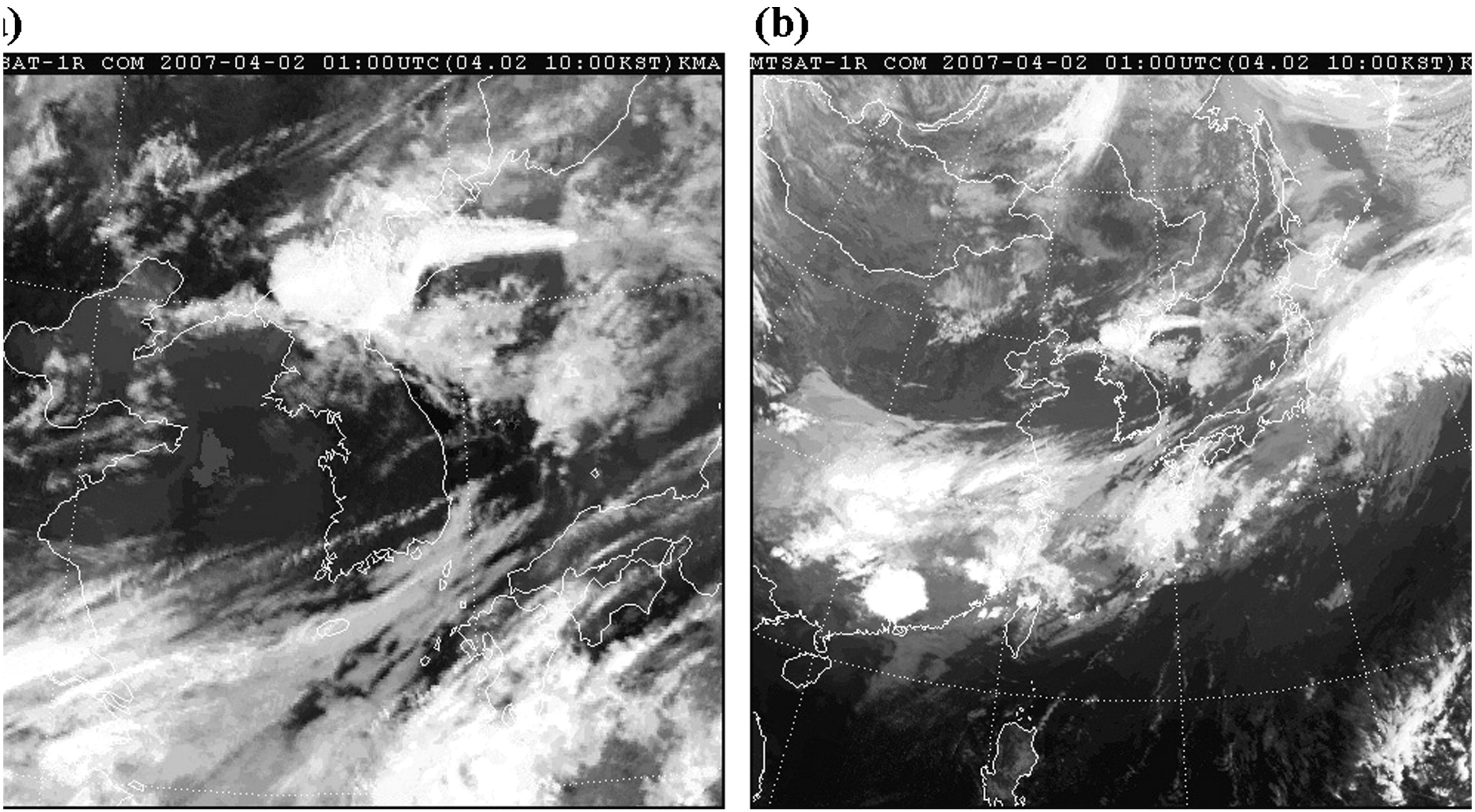
Source: P. Lester, "Turbulence – A new perspective for pilots," Jeppesen, 1994

Korean Turbulence Reports 1998 – 2008
02 Apr 2007



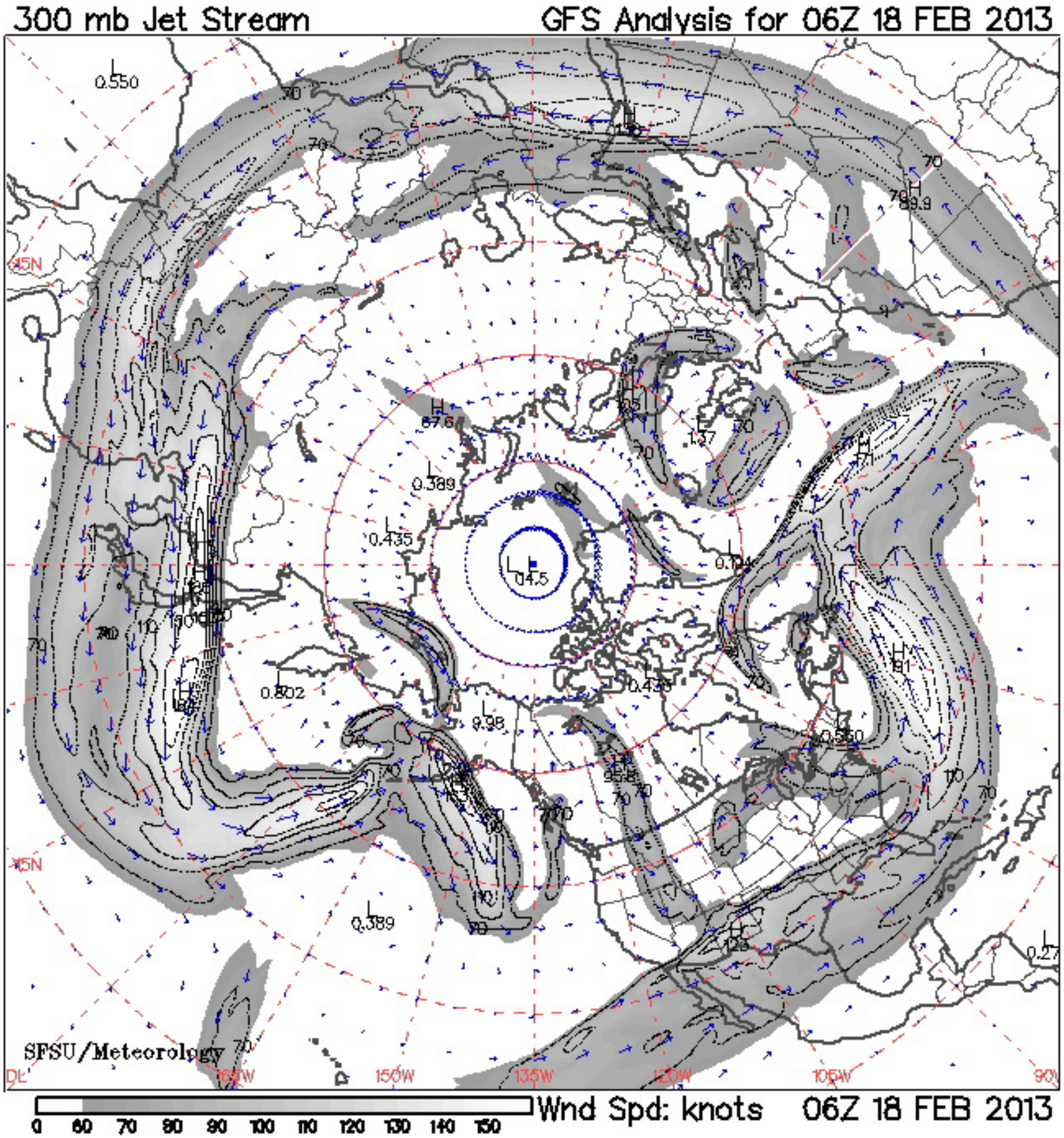
A Numerical Study of Clear-Air Turbulence (CAT) Encounters over South Korea on 2 April 2007, Journal of Applied Met. and Climatology, Kim., J., and Chun, H.

Satellite Image 2 Apr 2007



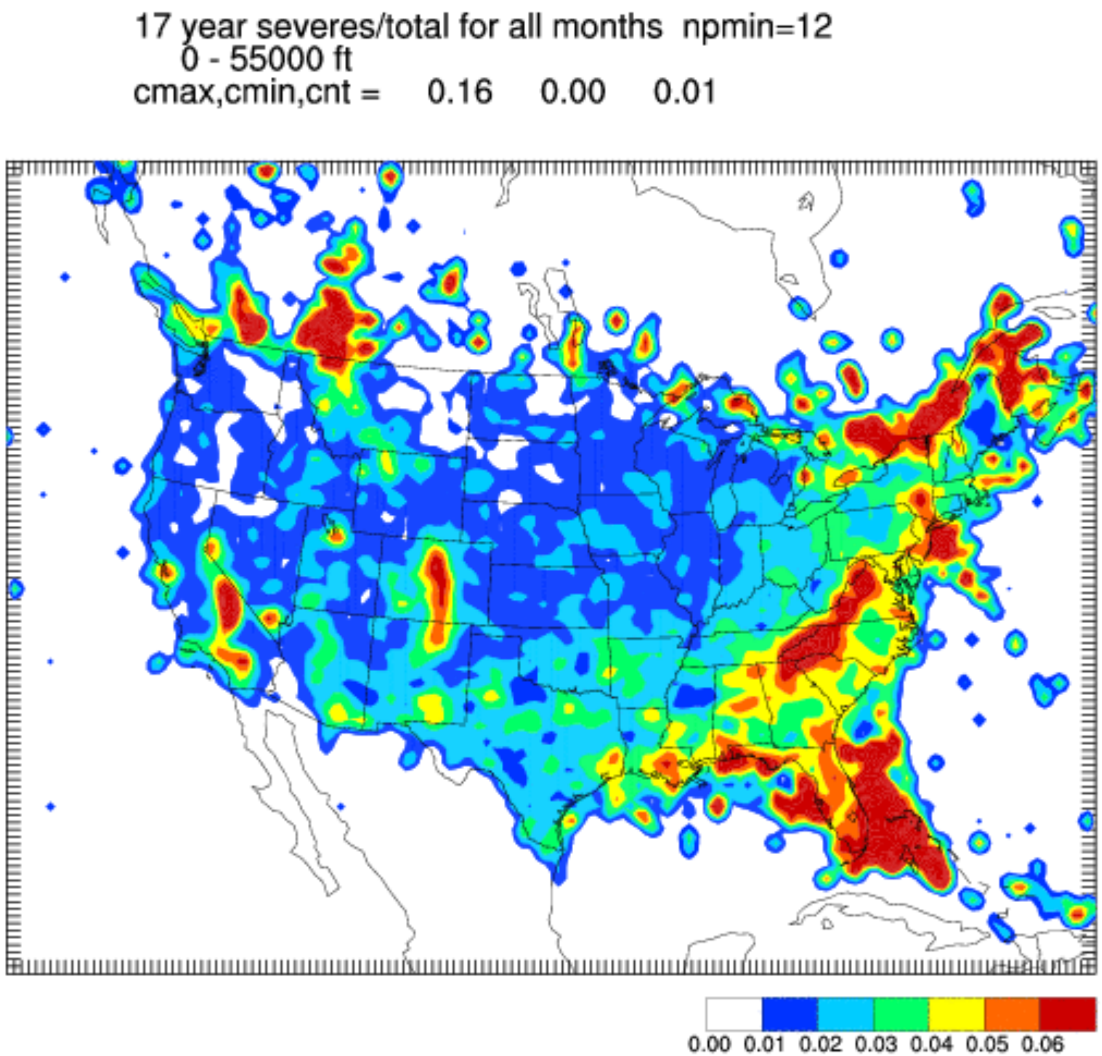
A Numerical Study of Clear-Air Turbulence (CAT) Encounters over South Korea on 2 April 2007, Journal of Applied Met. and Climatology, Kim., J., and Chun, H.

Turbulence Encounter
Feb 18, 2013


300 mb Jet Stream
GFS Analysis for 06Z 18 FEB 2013
SFSU/Meteorology
Wnd Spd: knots
06Z 18 FEB 2013
0 60 70 80 90 100 110 120 130 140 150

17 years of Turbulence PIREPS (1993-2009)

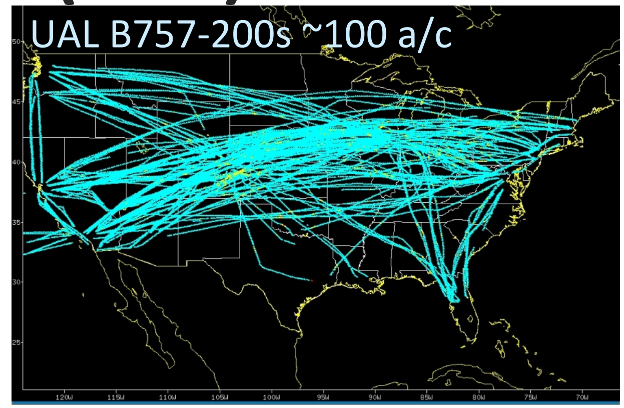
Severe-Or-Greater (SOG)/Total Turbulence PIREPS

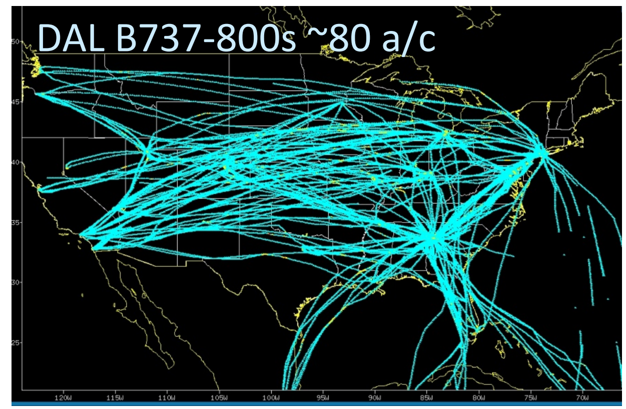


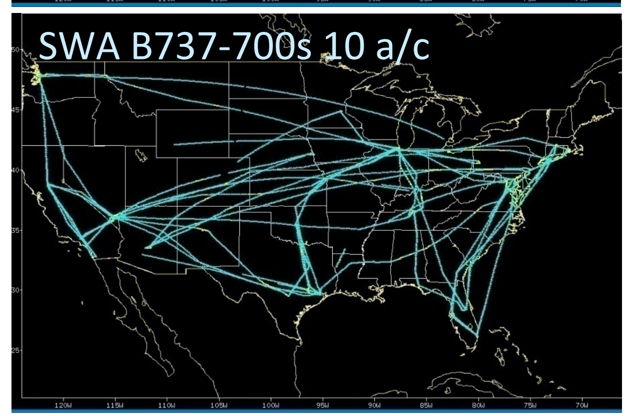
Sharman, R., National Center for Atmospheric Research, 2013

Quantitative Turbulence Metric
Eddy Dissipation Rate (EDR)

- National Center for Atmospheric Research atmospheric turbulence intensity metric: eddy dissipation rate EDR=$\varepsilon^{1/3}$ ($m^{2/3} s^{-1}$) (ICAO standard)
  - < 0.1 ~ smooth
  - 0.1 – 0.3 ~ light turbulence
  - 0.3 – 0.5 ~ moderate
  - > 0.5 ~ severe
- Automatically computes and downloads in situ EDR data during flight using ACARS network
- Accuracy
  - < 1 min
  - < 10 km
- Software: resides within the avionics system on selected commercial aircraft







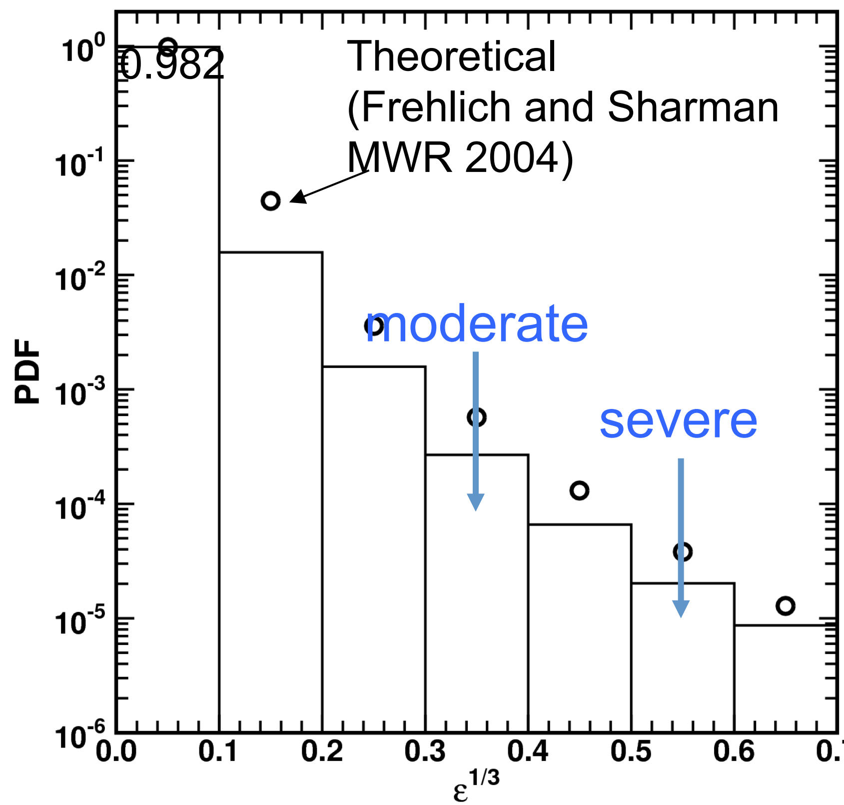
< 03 Jan 2010 >

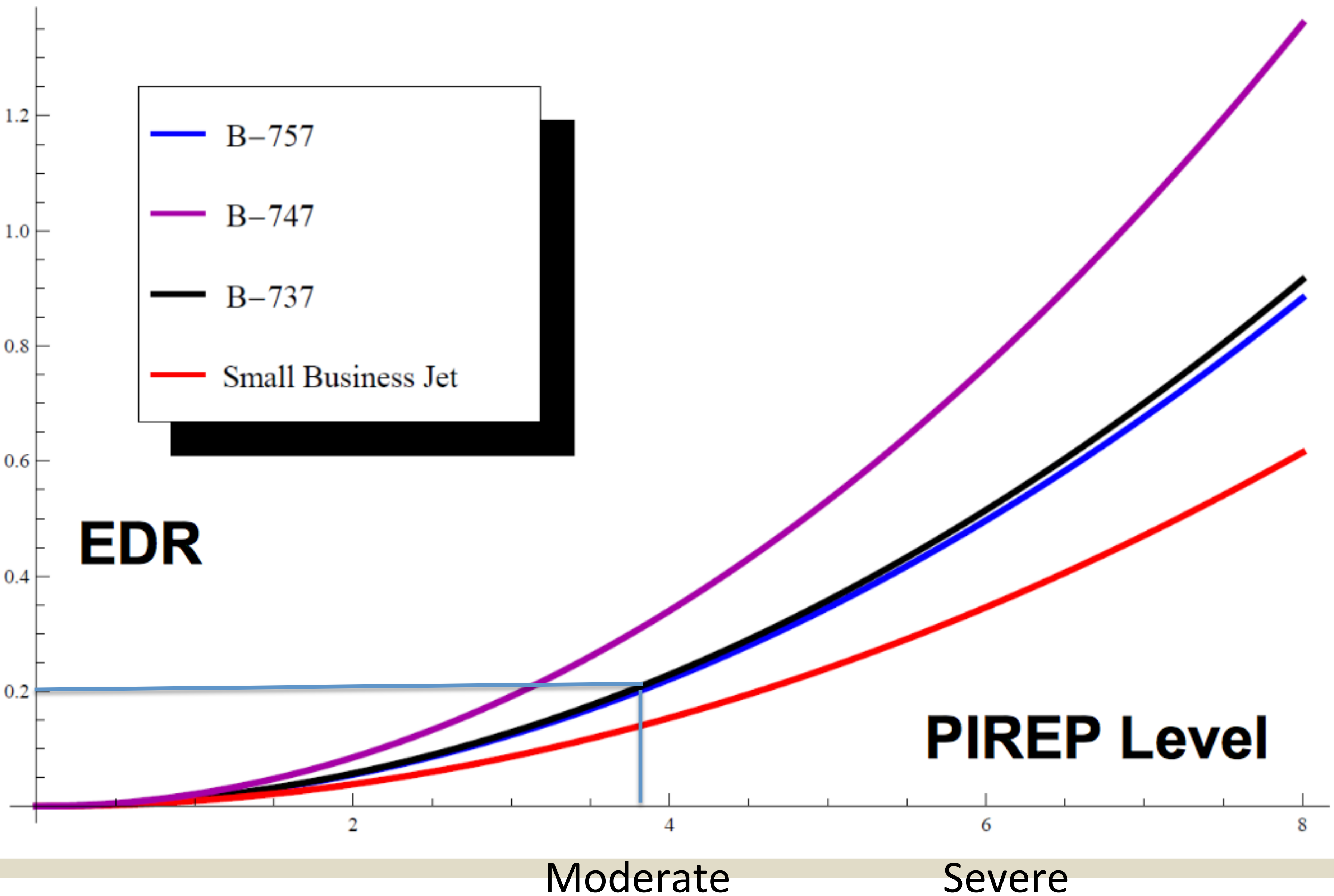
In-Situ Eddy Dissipation Rate Climatology

- ~ 96% - 98% is "smooth"
- Moderate ~ 10^{-3}
- Severe ~ 10^{-4}

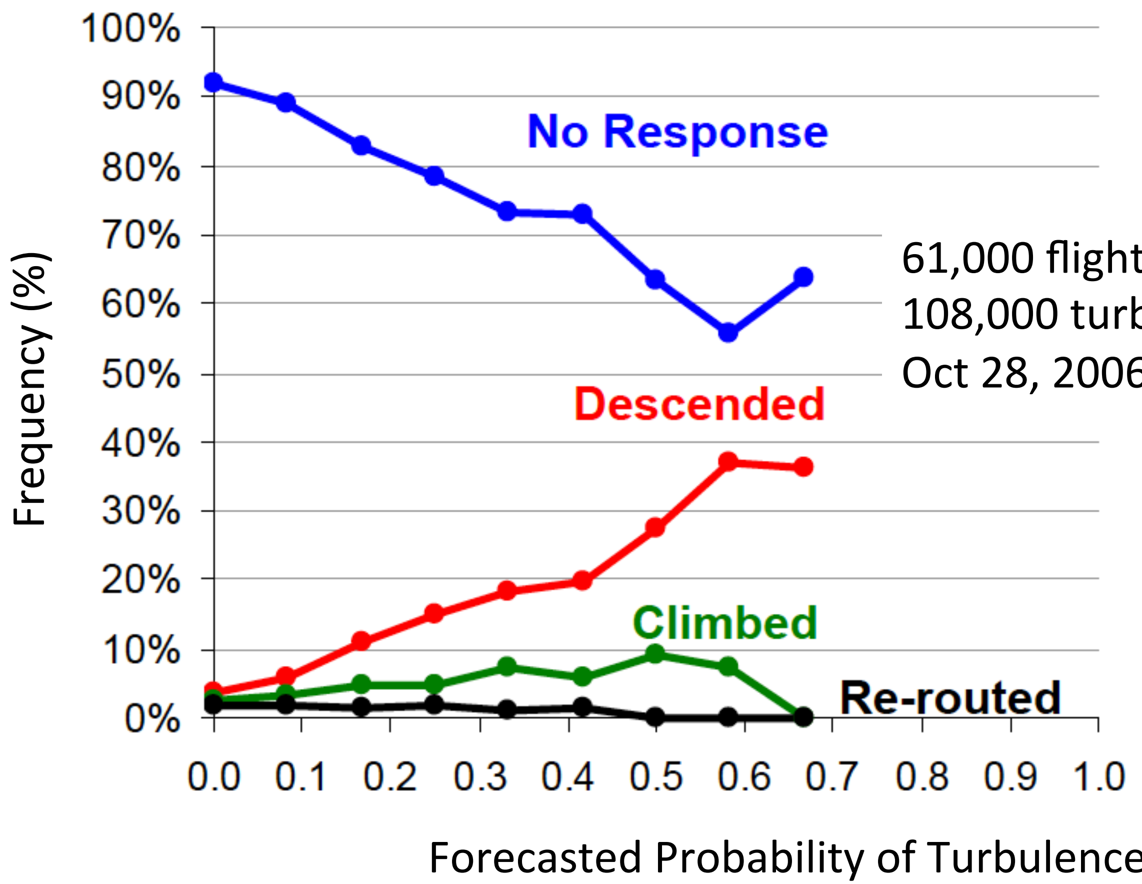
- Moderate-Or-Greater turbulence is a relatively rare event

~ 16M United Airlines Measurements (~1 year) insitu peak EDR measurements




B–757
B–747
B–737
Small Business Jet
EDR
PIREP Level
1.2
1.0
0.8
0.6
0.4
0.2
2
4
6
8
Moderate
Severe

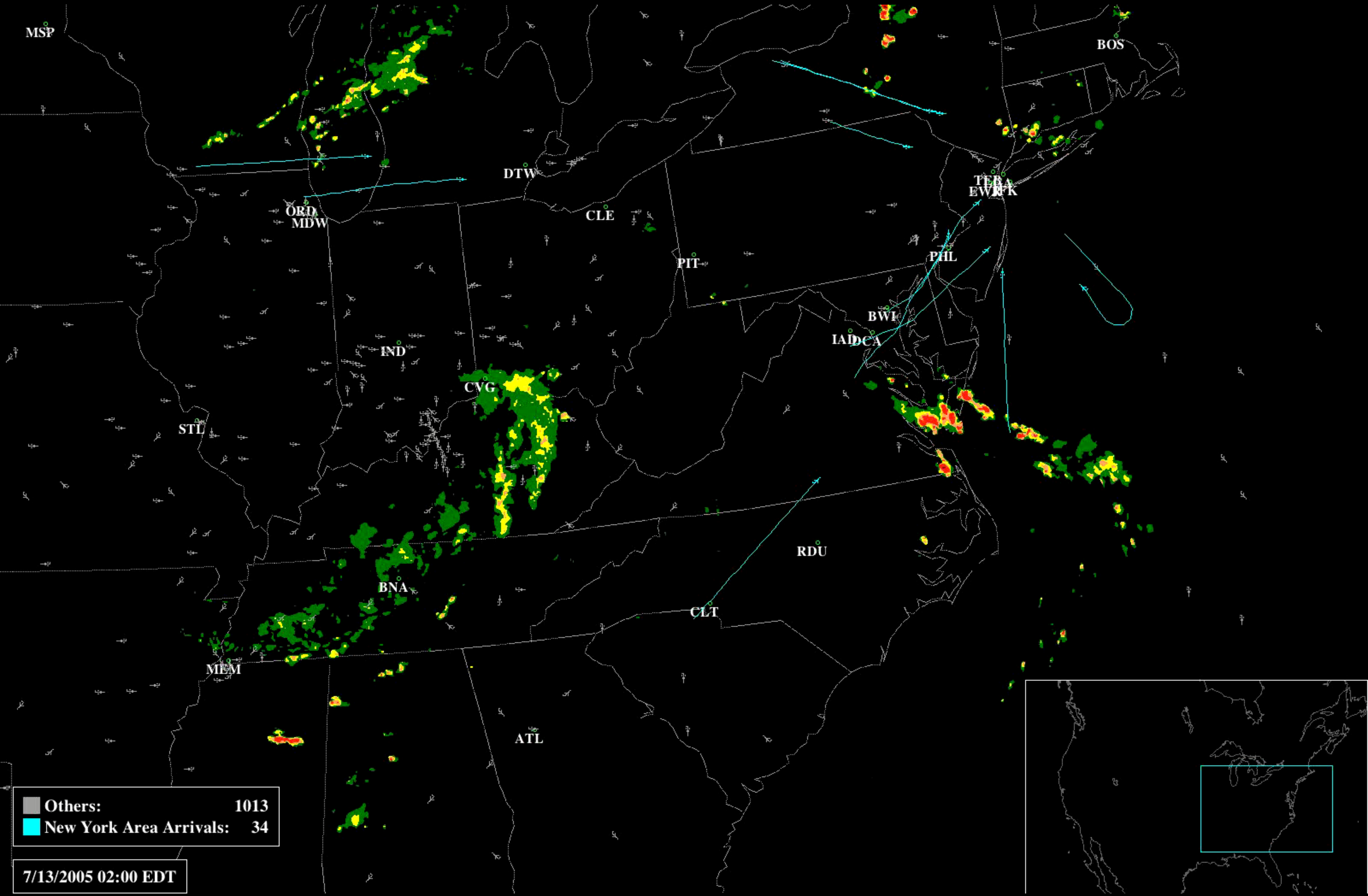
Pilot Turbulence Response



61,000 flights
108,000 turbulence encounters
Oct 28, 2006, Jan 24, 2007, Oct 23, 2007

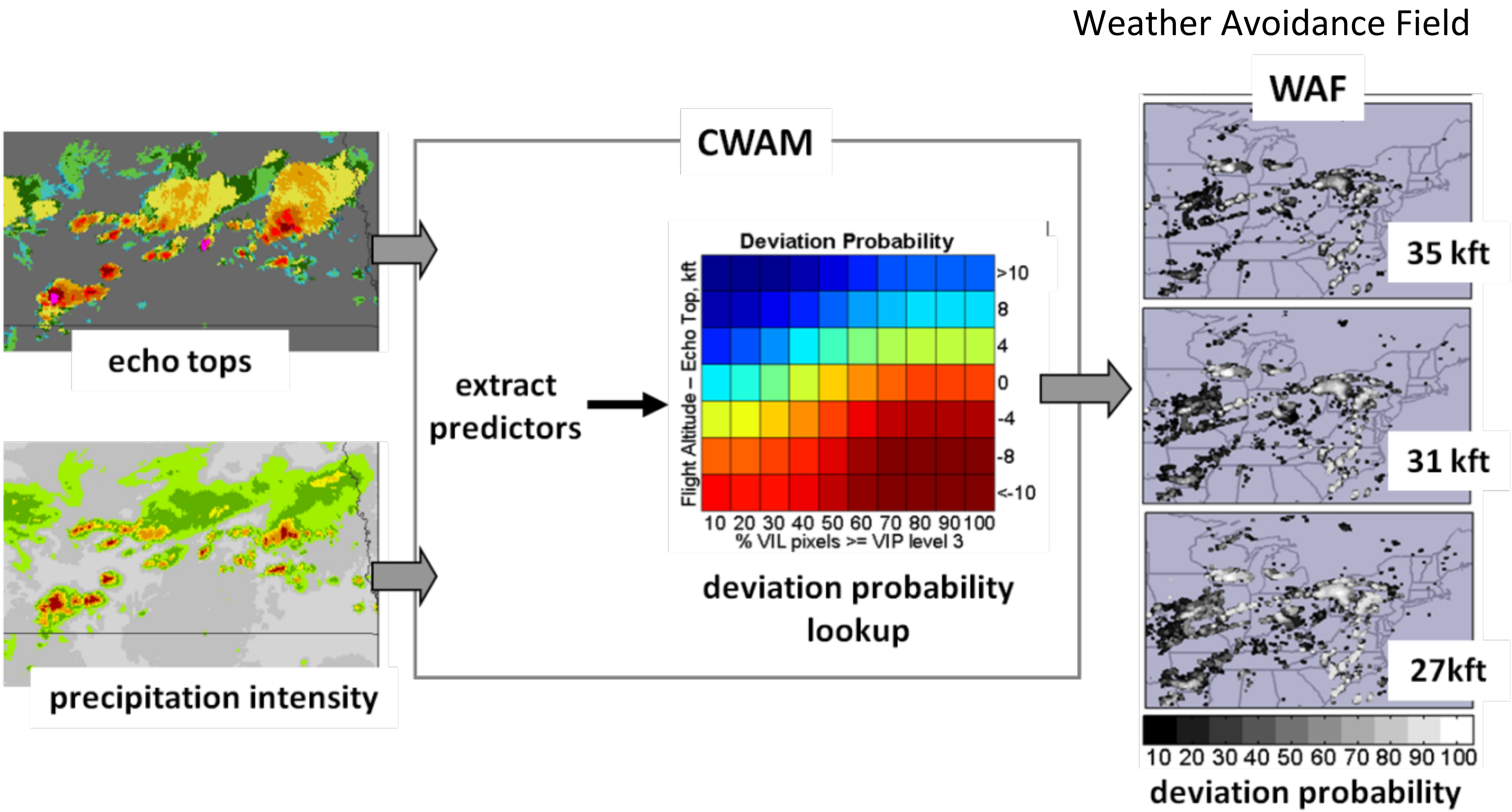
Krozel, J., Klimenko, V., and Sharman, R.D., "Analysis of Clear-Air Turbulence Avoidance Maneuvers", Air Traffic Quarterly, Vol. 19, 2011

Convection



MSP
BOS
DTW
ORD
MDW
CLE
PIT
PHL
BWI
IAD
DCA
IND
CVG
STL
BNA
RDU
CLT
MEM
ATL
Others: 1013
New York Area Arrivals: 34
7/13/2005 02:00 EDT

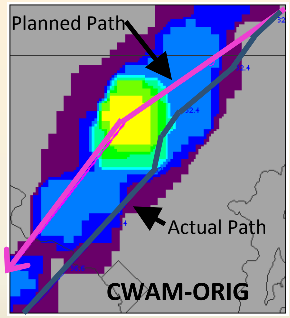
Convective Weather Avoidance Model (CWAM)



Reference: Matthews & DeLaura, "Assessment and interpretation of Weather Avoidance Fields from the Convective Weather Avoidance Model", ATIO 2010

Convective Weather Avoidance Model Accuracy

EXTRACT MAX WAF ALONG FLIGHT PATH



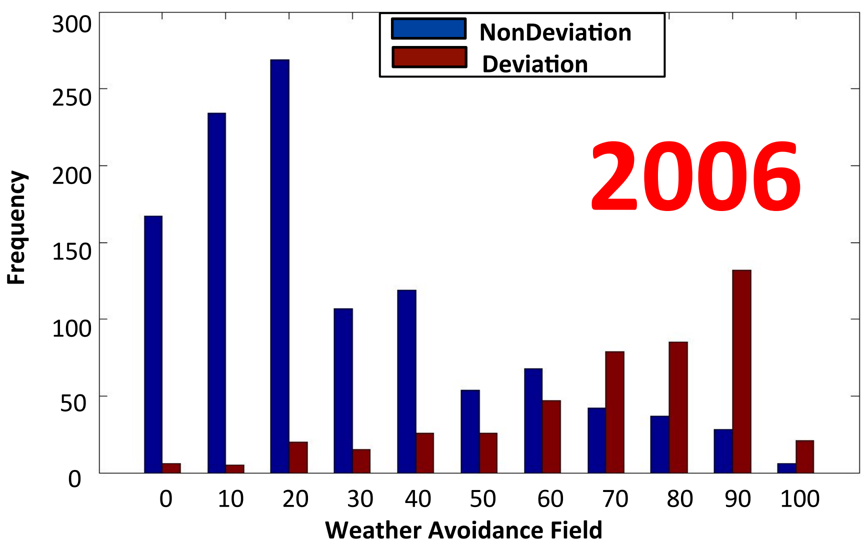
	CWAM-ORIG
Planned Trajectory	80
Actual Trajectory	60

Total Evaluation data set: ~5300 aircraft

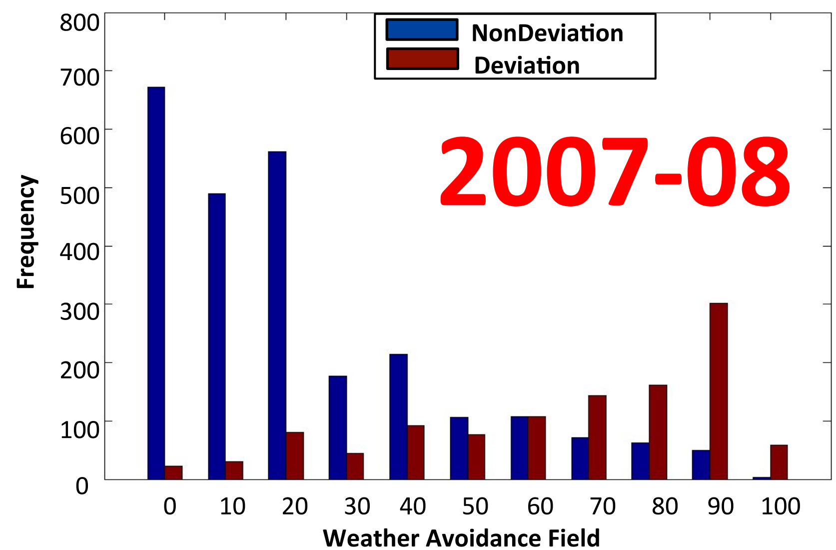
~2000 from 2006

~3300 from 2007 and 2008

ZID

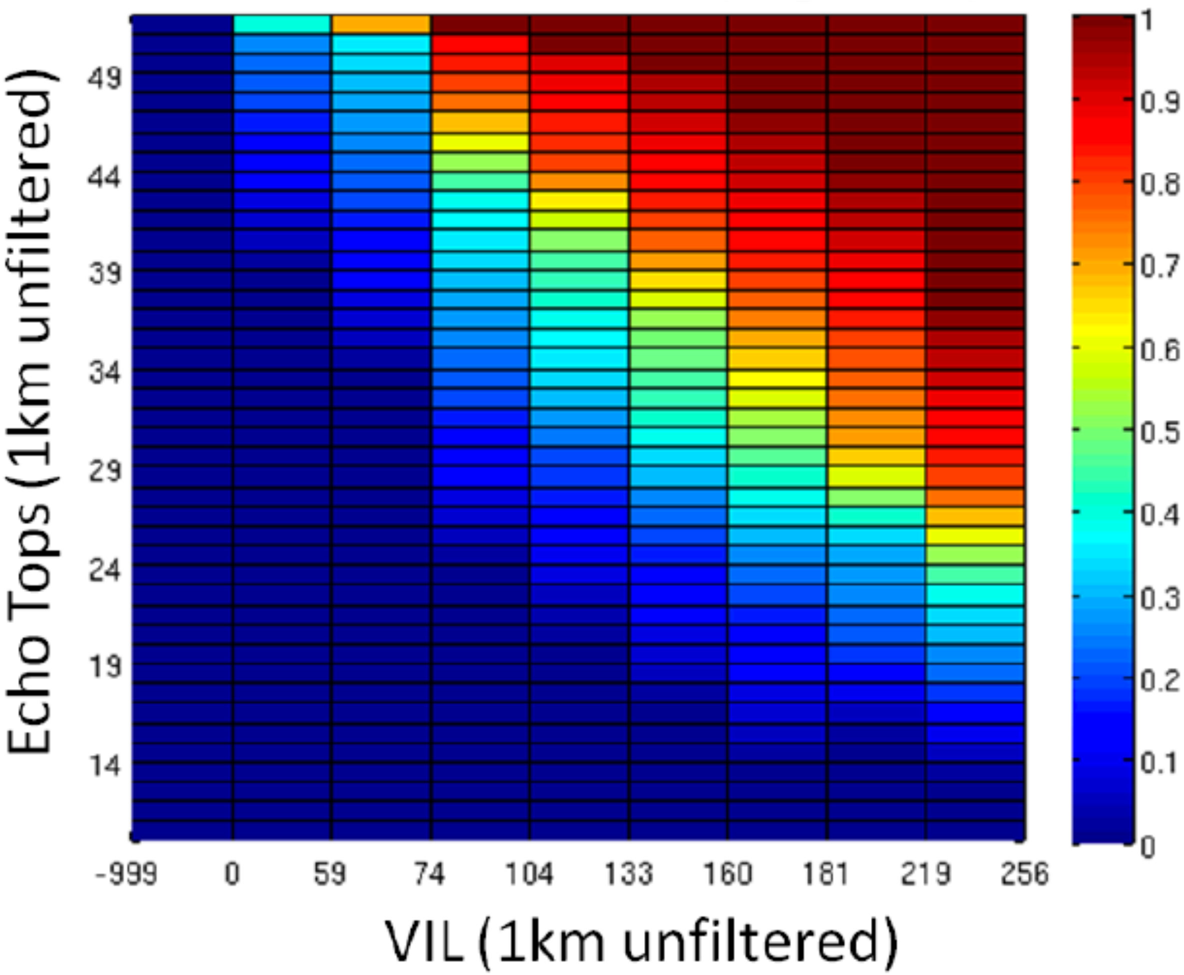


ZDC, ZID, ZOB



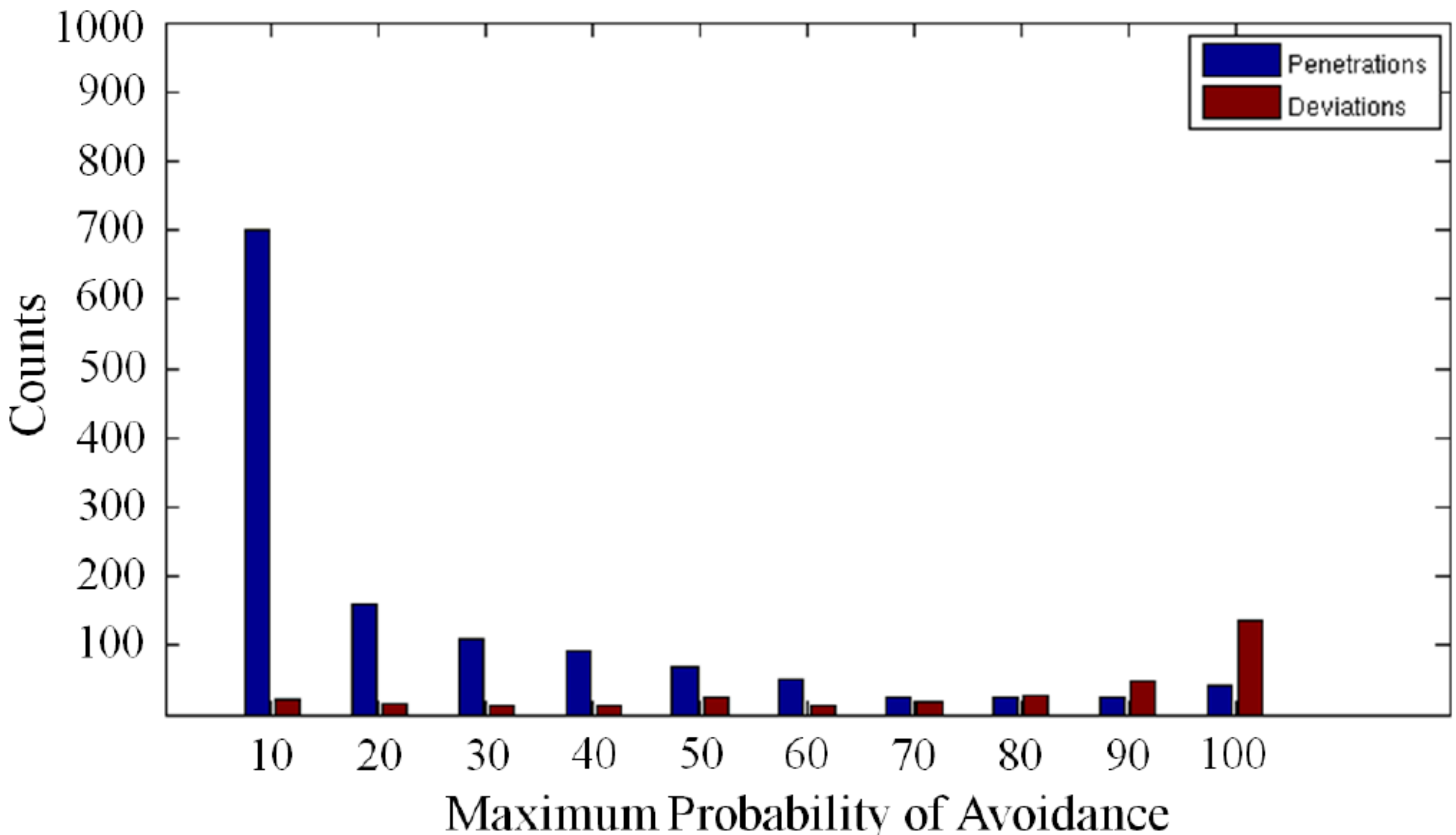
Reference: Matthews & DeLaura, "Assessment and interpretation of Weather Avoidance Fields from the Convective Weather Avoidance Model", ATIO 2010

Terminal Arrival Model

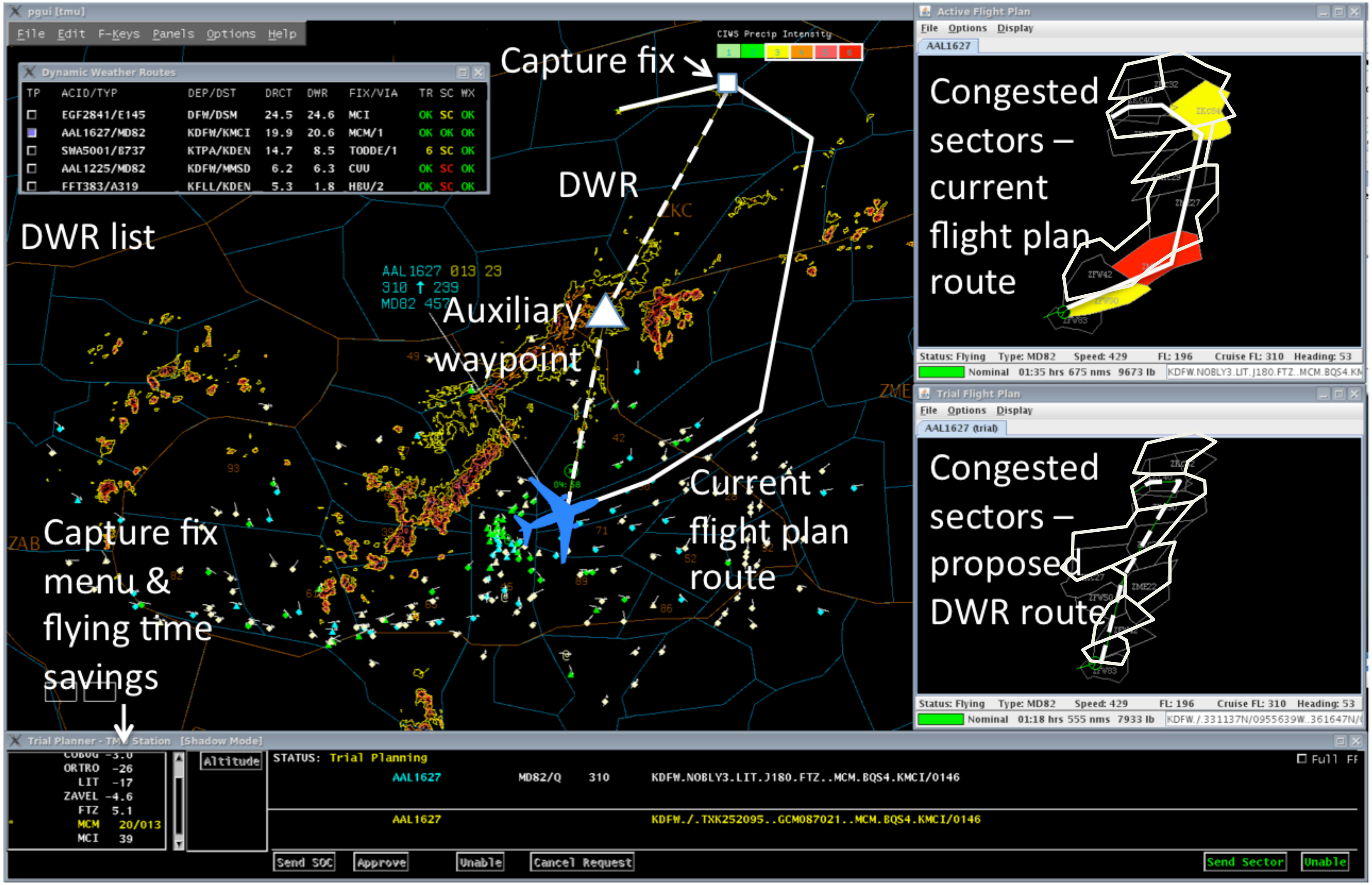


Arrival Weather Avoidance Model Accuracy

11,000 flights
1,900 encounters

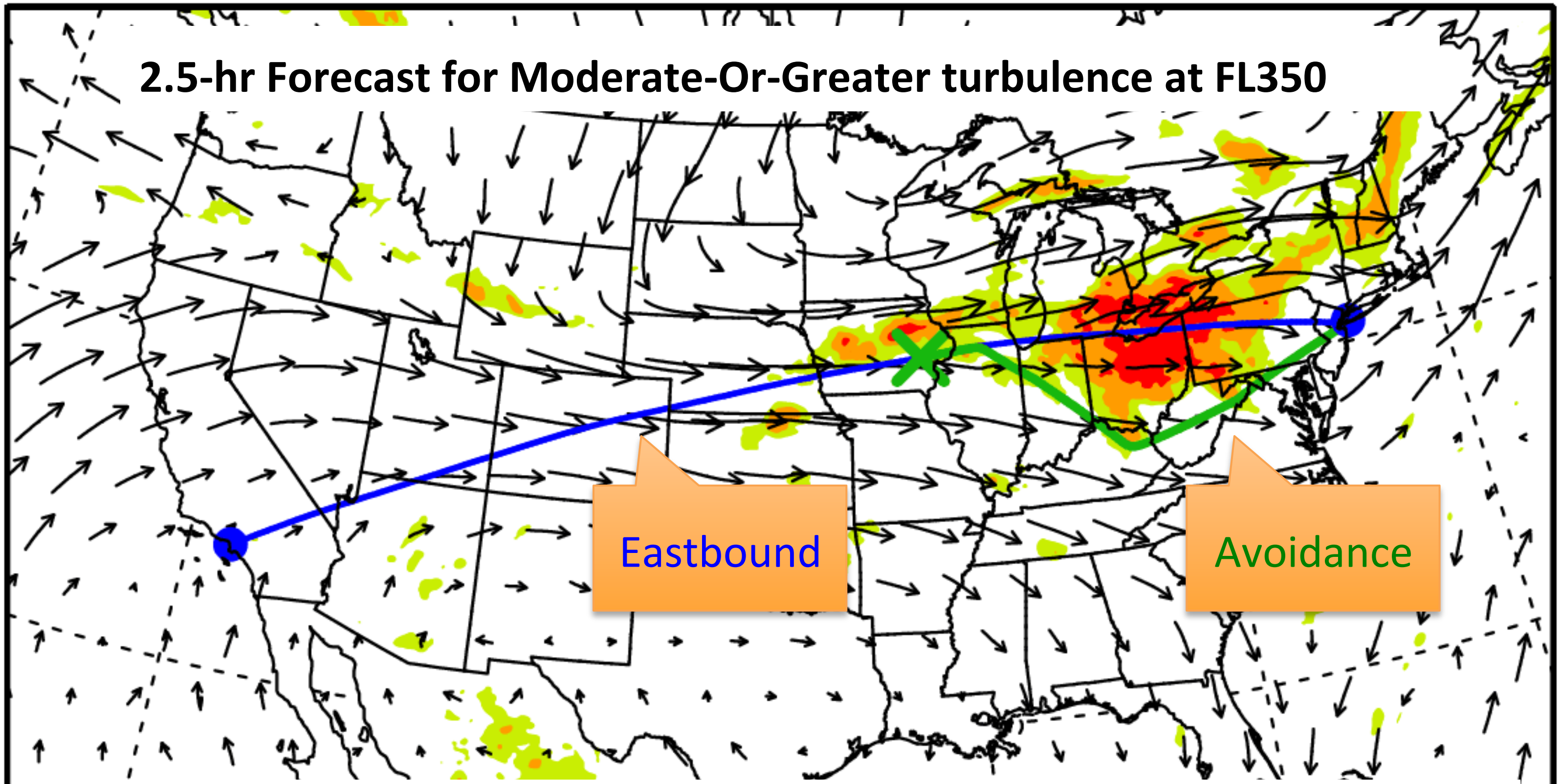


Integration into Dynamic Weather Routes Tool



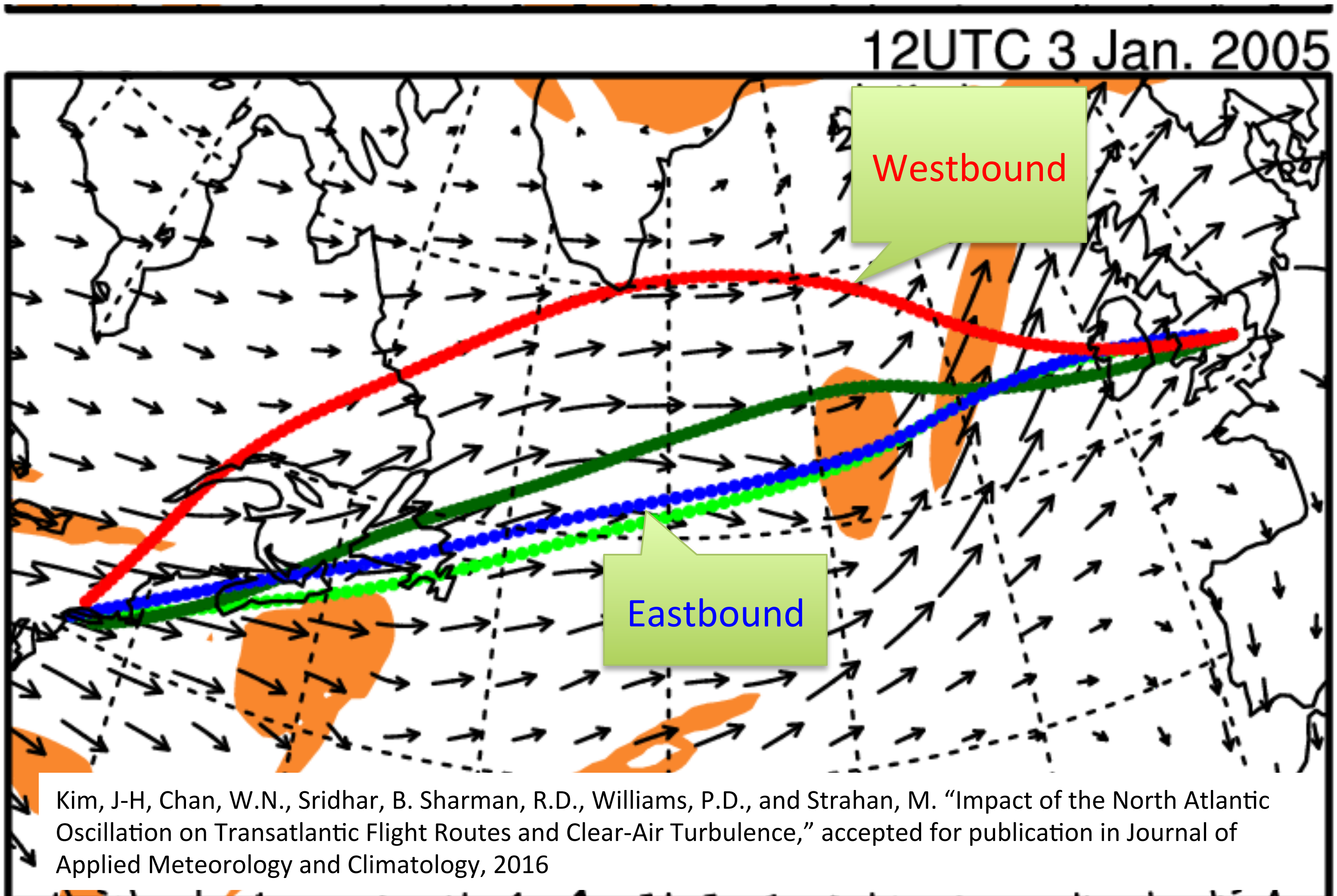
Wind Optimal Routing

Turbulence Aware Wind Optimal Routing



Kim, J.-H., Chan, W.N., Sridhar, B., and Sharman, R.D., "Combined Winds and Turbulence Prediction System for Automated Air-Traffic Management Applications," Journal of Applied Meteorology and Climatology, Volume 54, Issue 4, April 2014

Turbulence Aware Wind Optimal Routing (Atlantic)



Kim, J-H, Chan, W.N., Sridhar, B. Sharman, R.D., Williams, P.D., and Strahan, M. "Impact of the North Atlantic Oscillation on Transatlantic Flight Routes and Clear-Air Turbulence," accepted for publication in Journal of Applied Meteorology and Climatology, 2016

Weather for Unmanned Aerial Systems

Low Level Weather Impacts

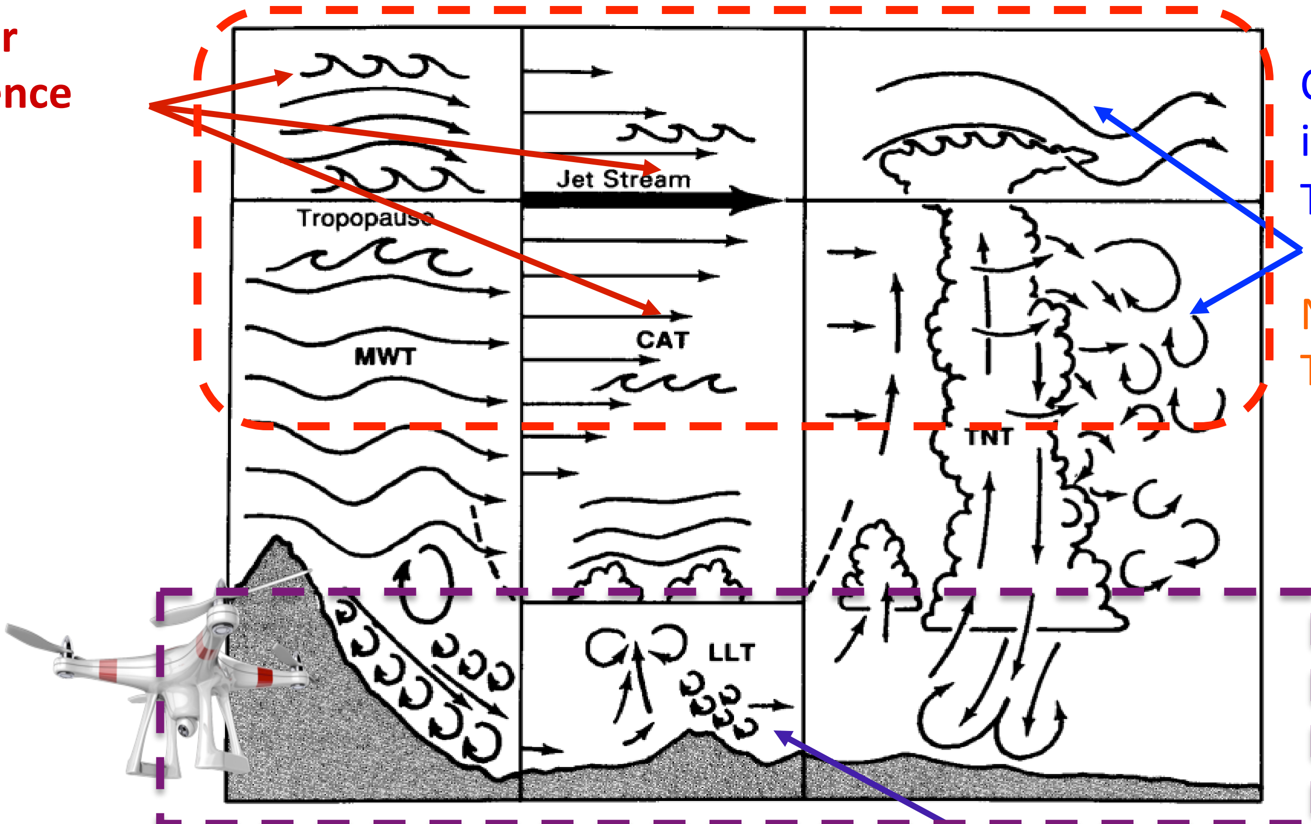


Figure 1-16. Aviation turbulence classifications. This figure is a pictorial summary of the turbulence-producing phenomena that may occur in each turbulence classification.

Source: P. Lester, "Turbulence – A new perspective for pilots," Jeppesen, 1994

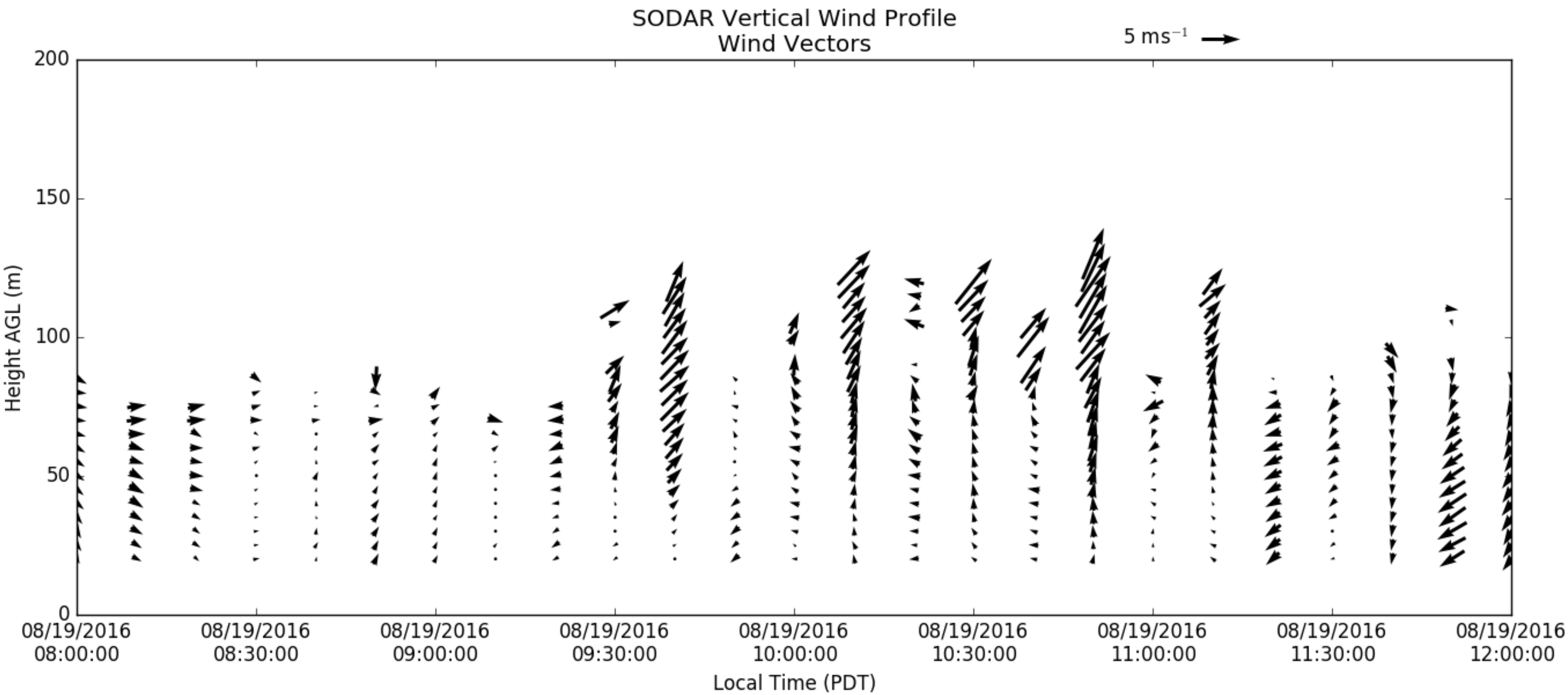

Crows Landing, California
Unmanned Aerial Systems Traffic Management Field Test

Crows Landing Localized Weather Sensors


Reno-Stead Airport
• Dust Devils
• Heat
• Winds
• Dry Convection
• Turbulence

Reno, Nevada - June, 2016

Reno, Nevada Winds August 2016

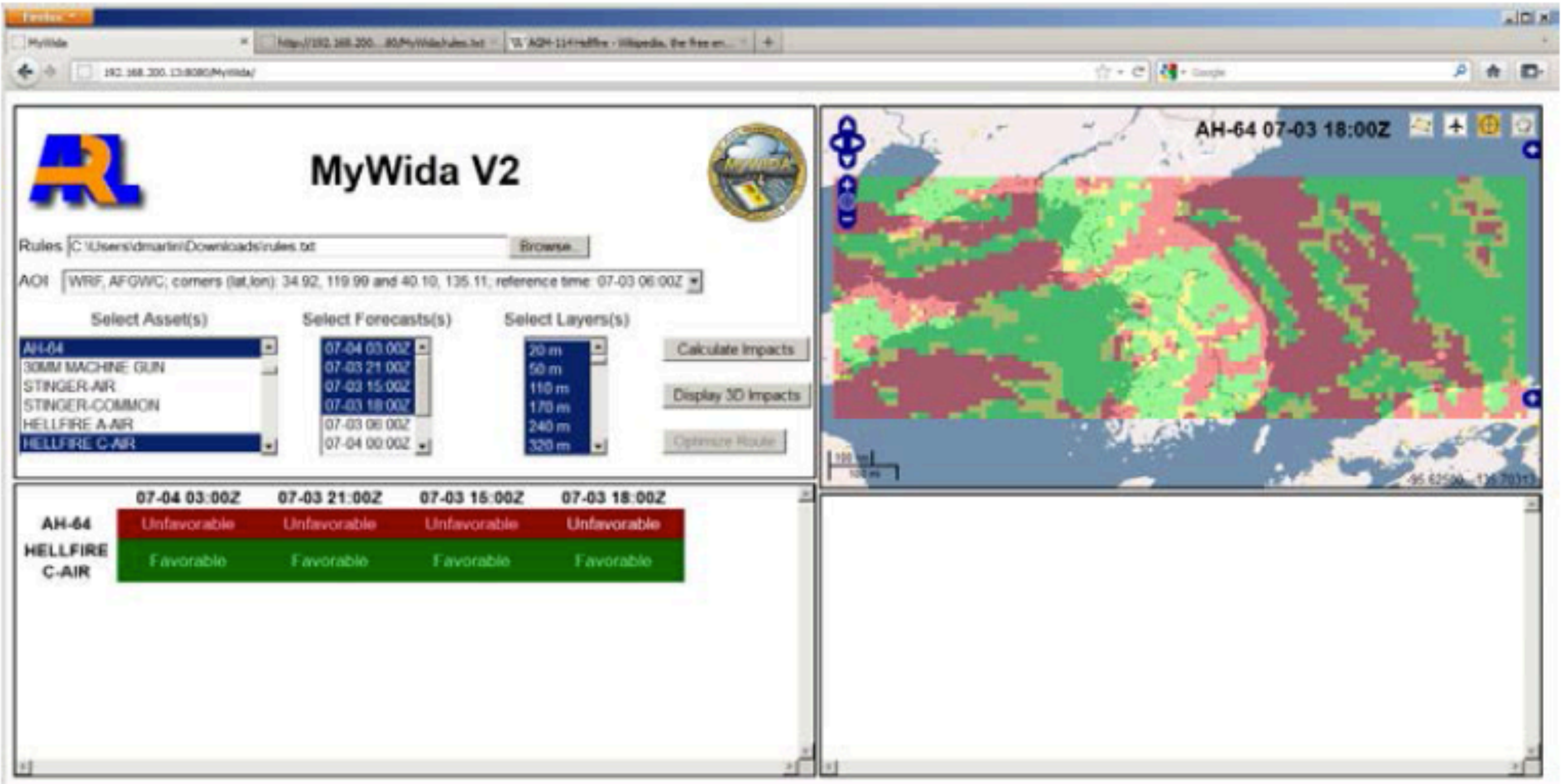


Simple Weather Translation

Max Airspeed Vs. Wind Speed

Issue Warning if Above Predetermined Limits

My Weather Impact Decision Aid (Army Research Lab)



Example Impact Mapping

Table 1. An example of a user-supplied rules (Excel) file for an Army helicopter.

Row No.[a]	Asset Name	Rule ID	Impact Code	Parameter Name	Critical Value	Operator[b]	Units
1	AH-64	1	1	temperatureAir	100	>=	°F
2	AH-64	2	2	thunderstormProbability	50	>	percent
3	AH-64	3	2	weatherRainFlag	2	>	code
4	AH-64	4	1	icingIntensity	2	>	code
5	AH-64	4	1	geopotentialHeight	10,000	<	feet
6	AH-64	5	2	geopotentialHeight	10,000	<	feet
7	AH-64	5	2	icingIntensity	3	>	code
8	AH-64	6	1	turbulenceIntensity	1	>	code
9	AH-64	8	2	windSpeed	45	>=	knots

[a] This column is for illustrative purposes only and is not, nor should it be, included in the Excel file.

[b] For (greater than) or (less than) and equal (≥, ≤), separate contiguous symbols must be used, for example, >= or <=.

- History of supporting applied weather research for over 15 years
- Work with expert groups for weather information
- Wide range of weather phenomena
  - Turbulence
  - Wind Optimal Routing
  - Convection
  - Newer area is developing weather products for small UAS within the atmospheric boundary layer (< 400 ft AGL)