



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 Community

Weather Translation



Airspace Impacts



Airspace Users and Provider Community

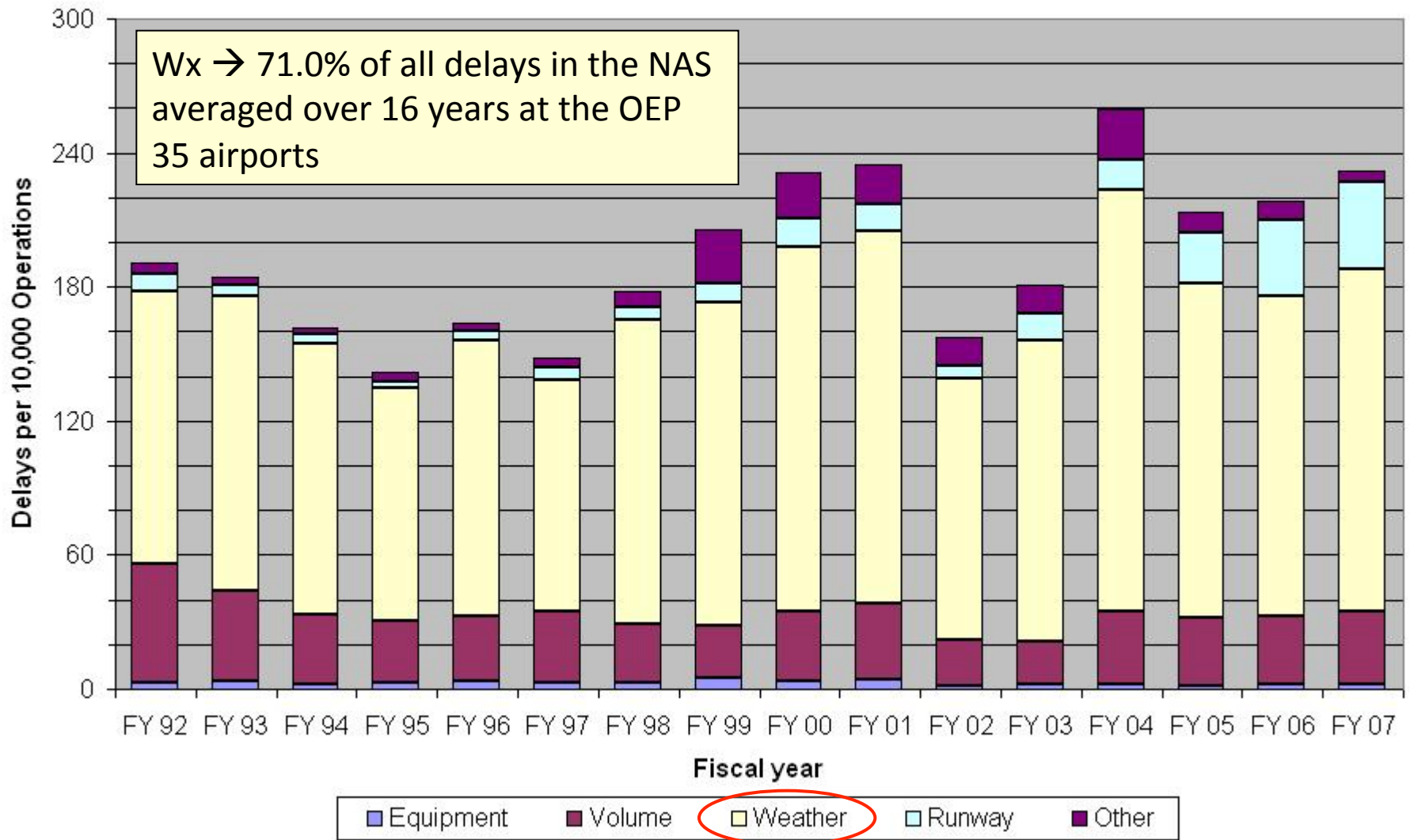
Decision Support System



The Weather Problem

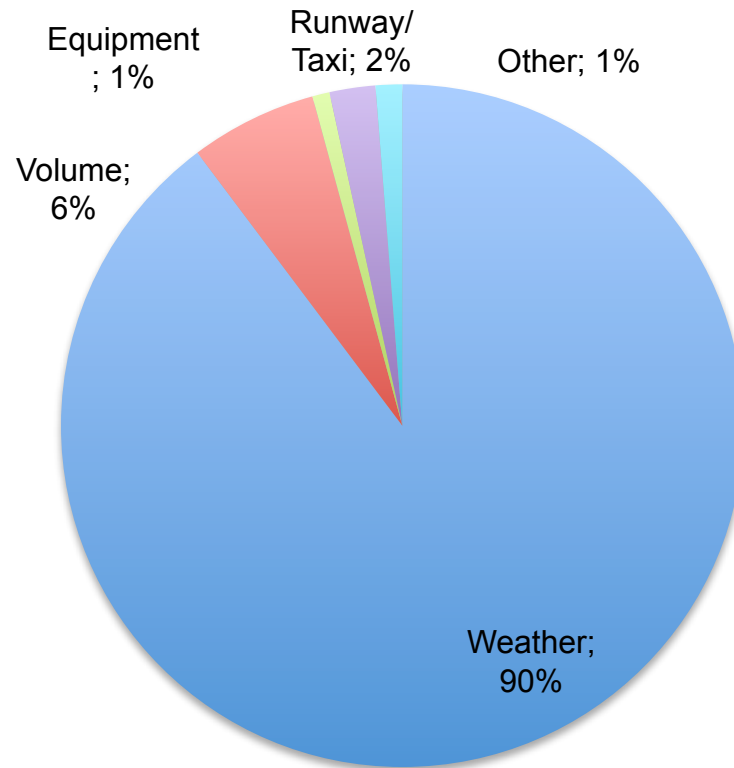


US Airspace Weather Related Delays

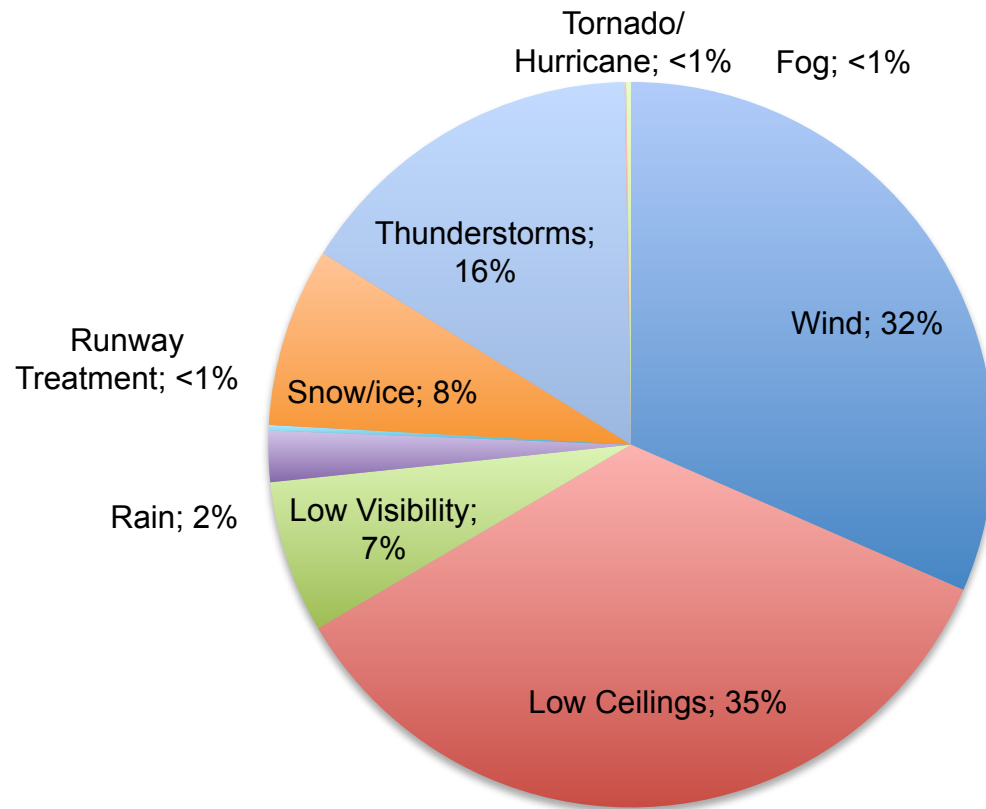


Source: OPSNET Statistics

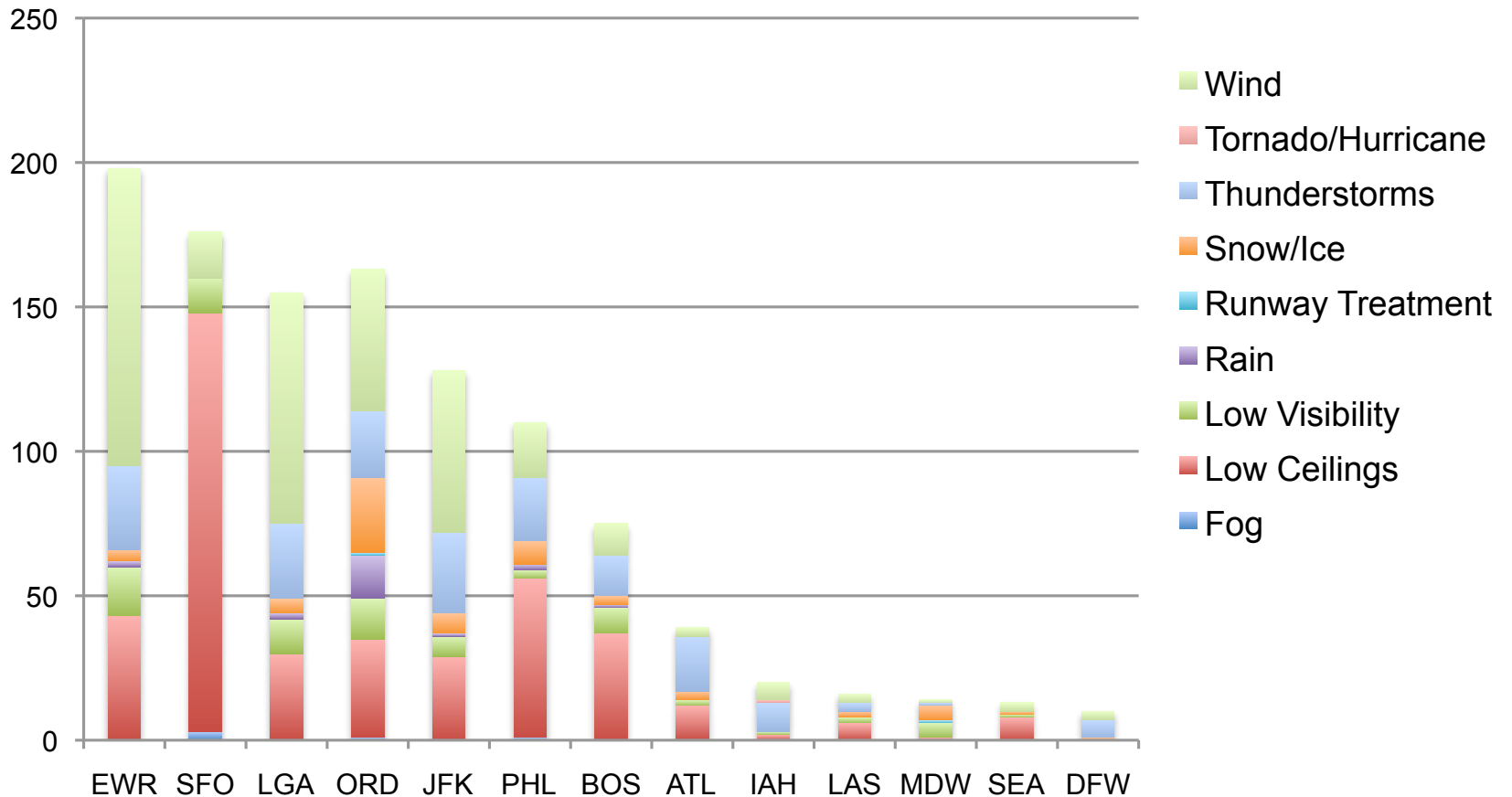
Causes of Ground Delay 2008



Weather Impacts 2008



Weather Impacts on Airports 2008

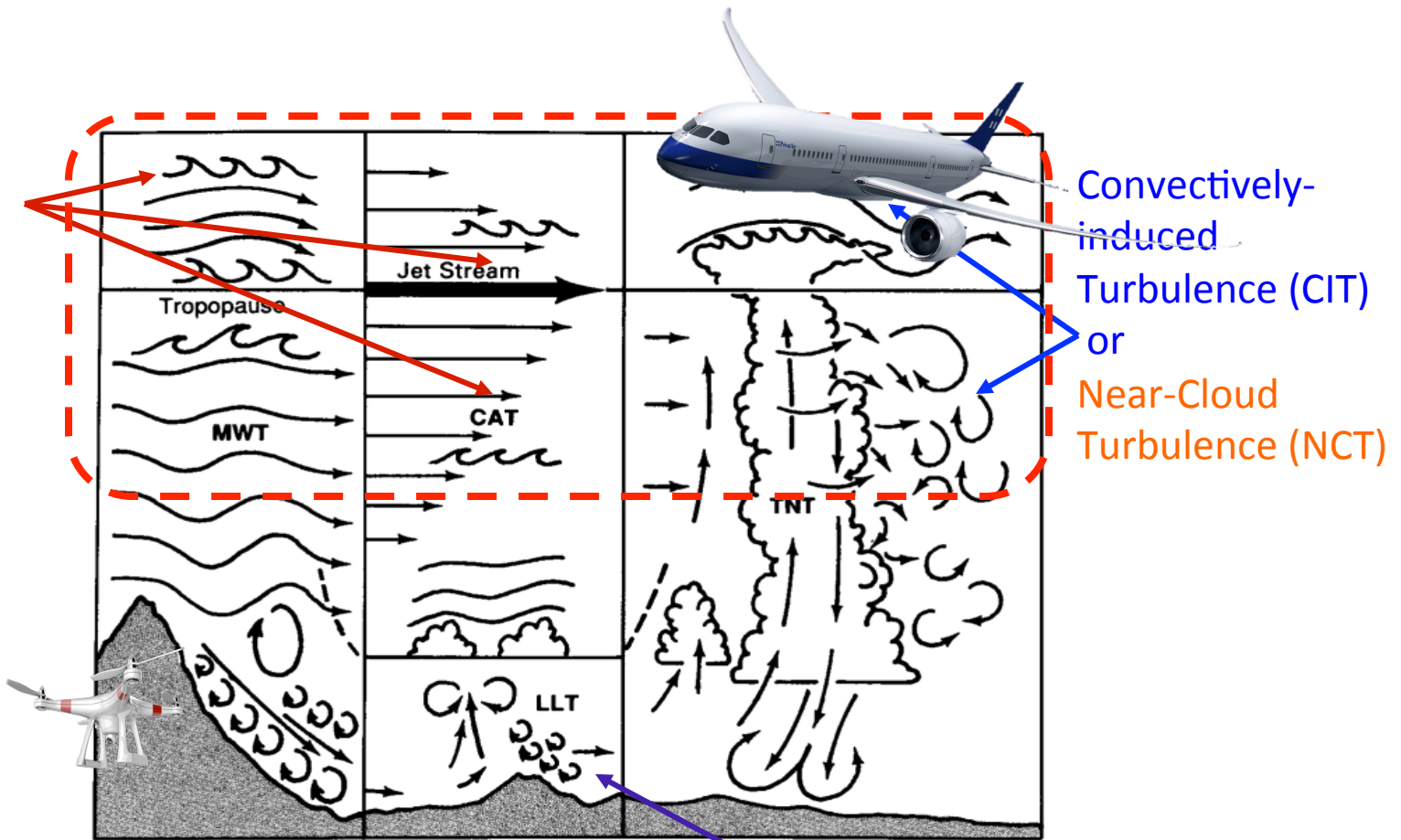


Turbulence



Types of Aviation Turbulence

Clear-air
Turbulence
(CAT)



Convectively-
induced
Turbulence (CIT)
or
Near-Cloud
Turbulence (NCT)

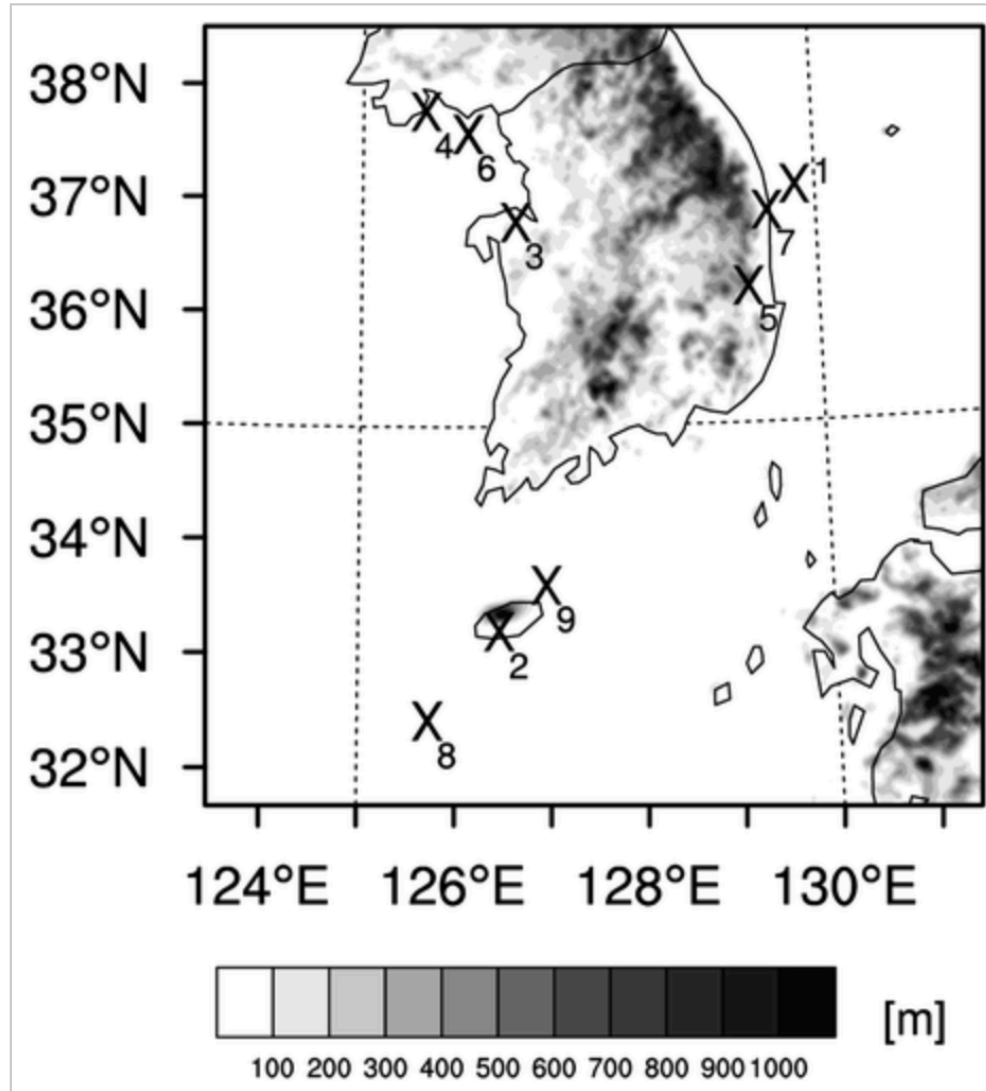
Figure 1-16. Aviation turbulence classifications. This figure is a pictorial summary of the turbulence-producing phenomena that may occur in each turbulence classification.

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

Convective boundary
Layer turbulence

Korean Turbulence Reports 1998 – 2008

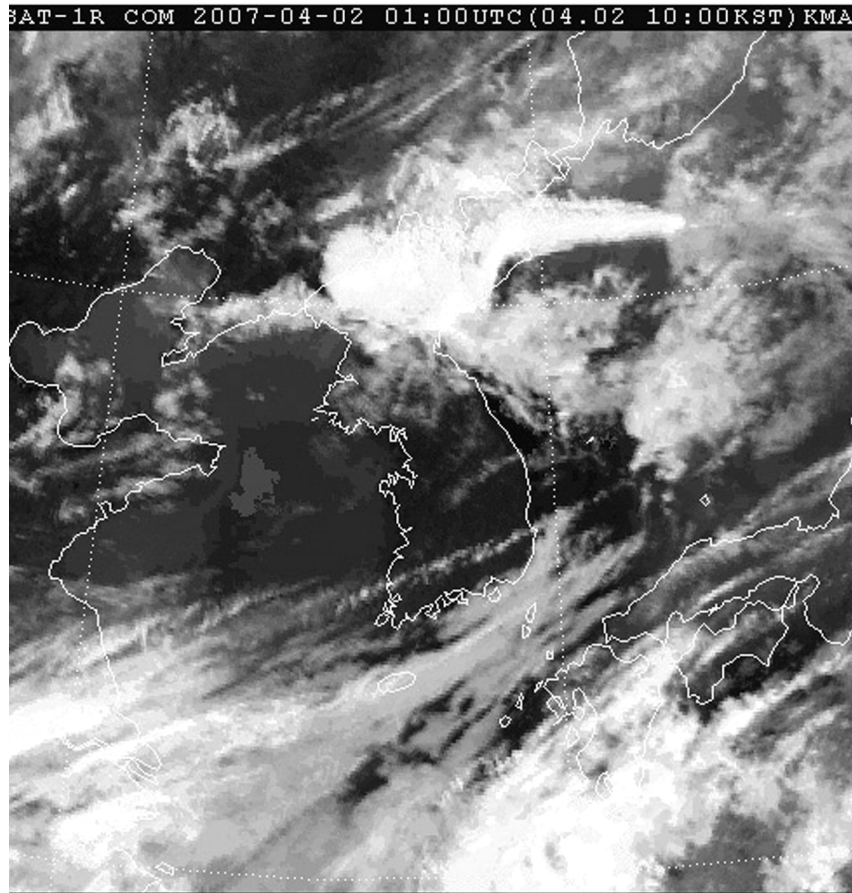
02 Apr 2007



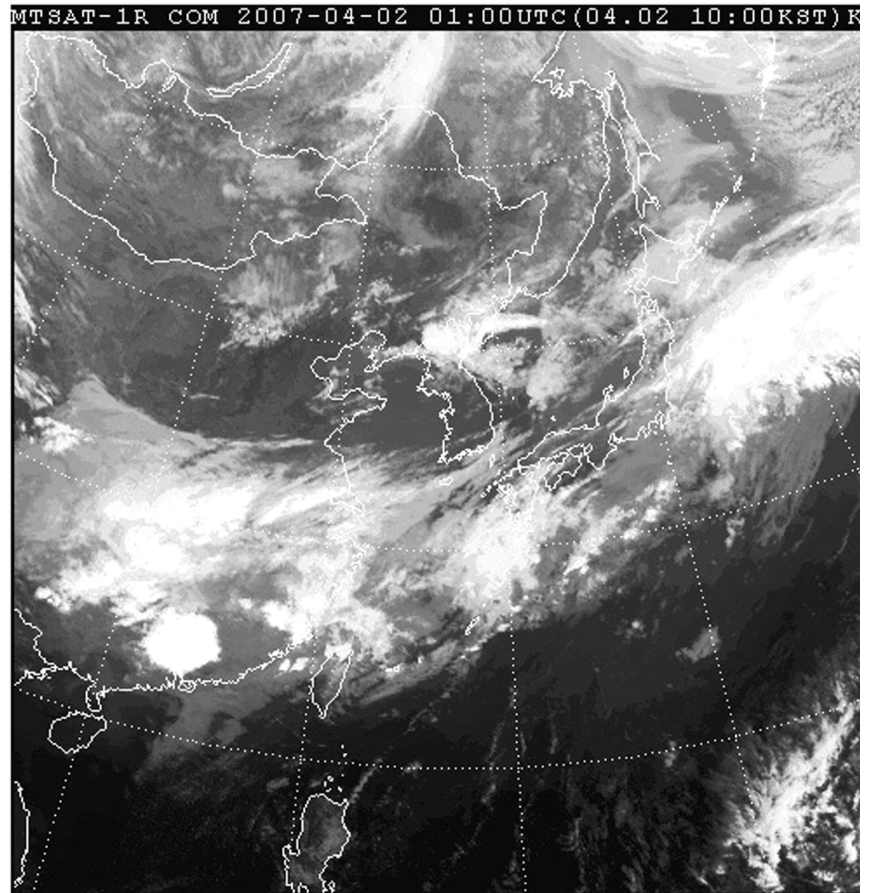
A Numerical Study of Clear-Air Turbulence (CAT) Encounters over South Korea on 2 April 2007, Journal of Applied Met. and Climatology, Kim, J., and Chun, H.

Satellite Image 2 Apr 2007

(a)



(b)



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

Tokyo
8:13 PM

CNN

BREAKING OVERNIGHT

NEW
DAY



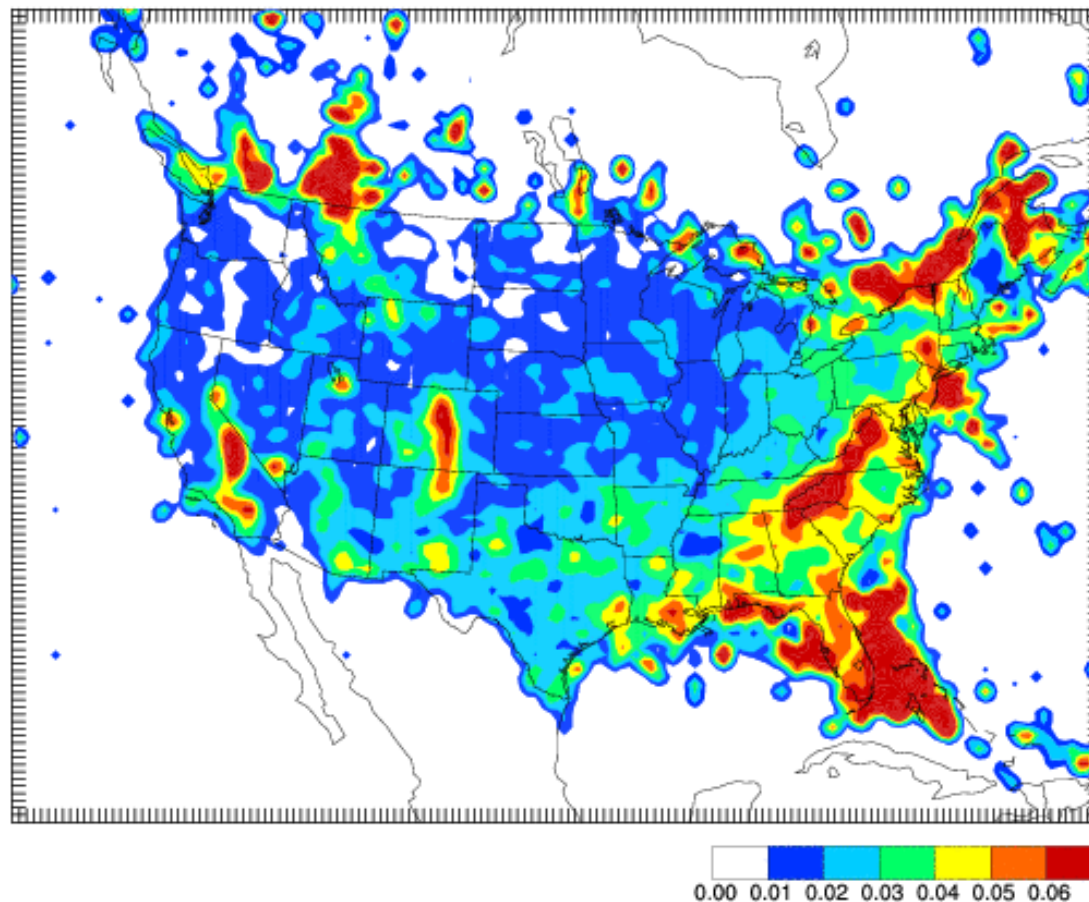
VLADIMIR DUTHIERS
CNN INTERNATIONAL CORRESPONDENT

LIVE
CNN

17 years of Turbulence PIREPS (1993-2009)

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

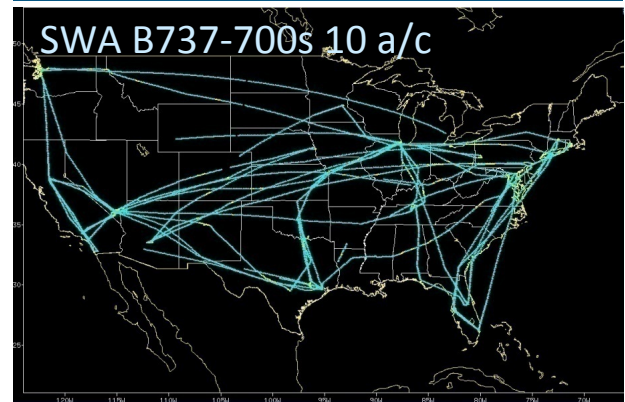
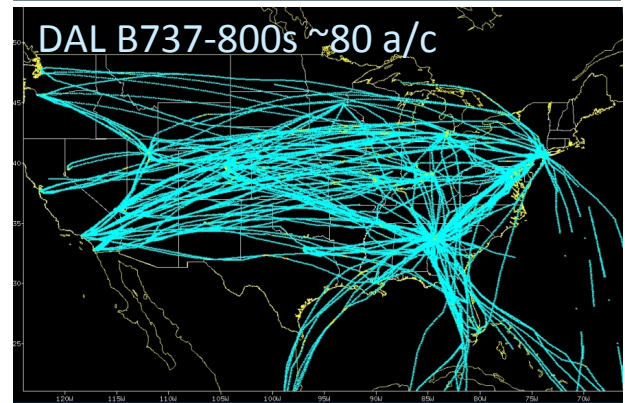
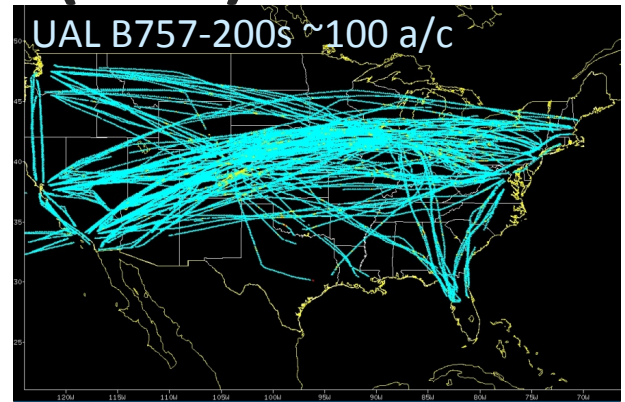
17 year severes/total for all months npmin=12
0 - 55000 ft
cmax,cmin,cnt = 0.16 0.00 0.01



Quantitative Turbulence Metric

Eddy Dissipation Rate (EDR)

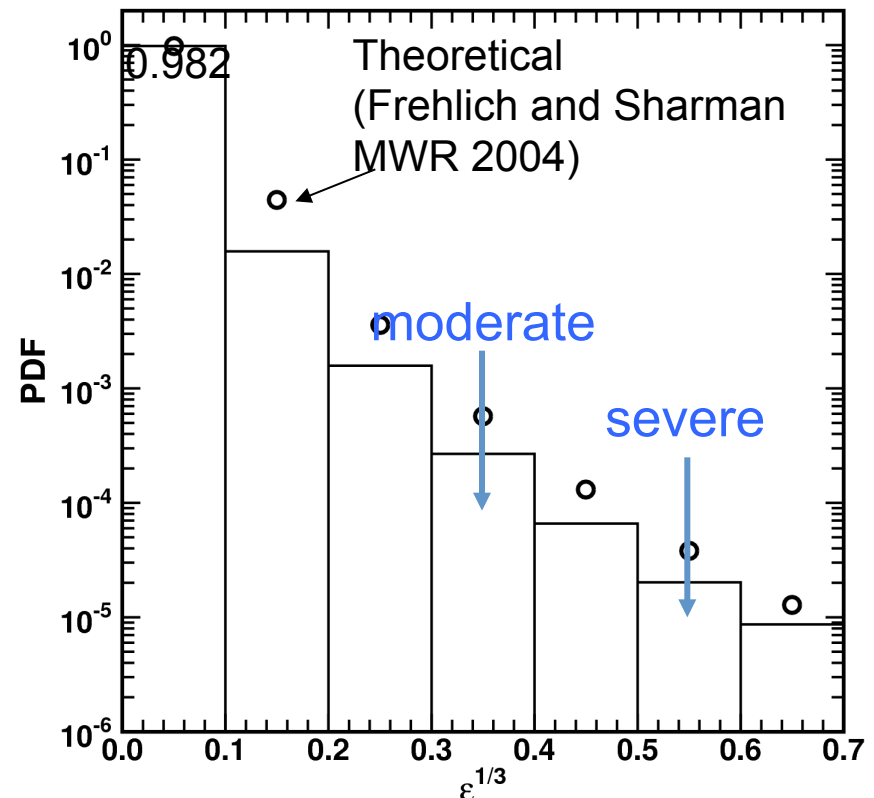
- National Center for Atmospheric Research atmospheric turbulence intensity metric: eddy dissipation rate $EDR = \epsilon^{1/3}$ ($m^{2/3} s^{-1}$) (ICAO standard)
 - < 0.1 ~ smooth
 - $0.1 - 0.3$ ~ light turbulence
 - $0.3 - 0.5$ ~ moderate
 - > 0.5 ~ severe
- Automatically computes and downloads in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

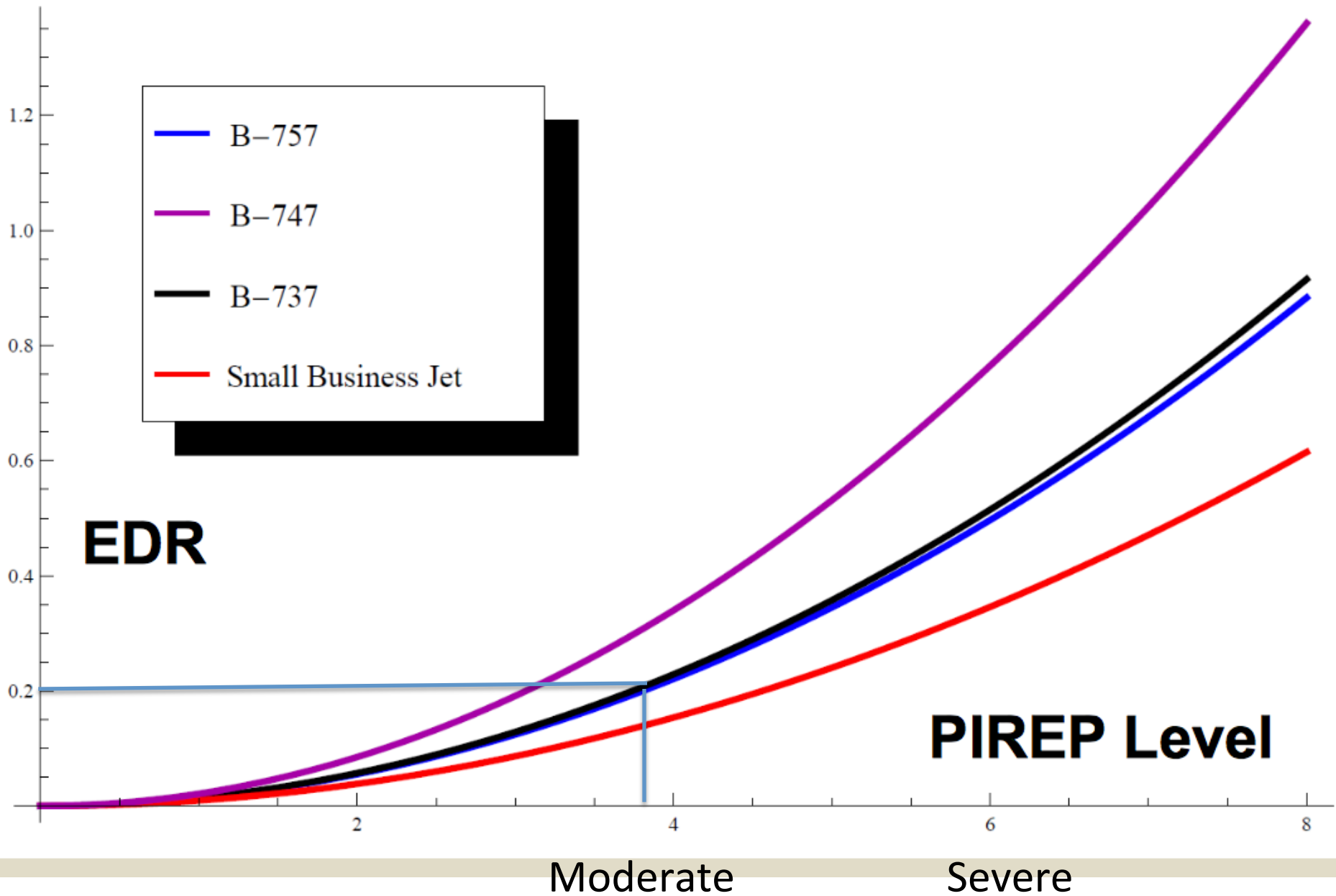


In-Situ Eddy Dissipation Rate Climatology

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

- ~ 96% - 98% is “smooth”
- Moderate $\sim 10^{-3}$
- Severe $\sim 10^{-4}$
- Moderate-Or-Greater turbulence is a relatively rare event





- B-757
- B-747
- B-737
- Small Business Jet

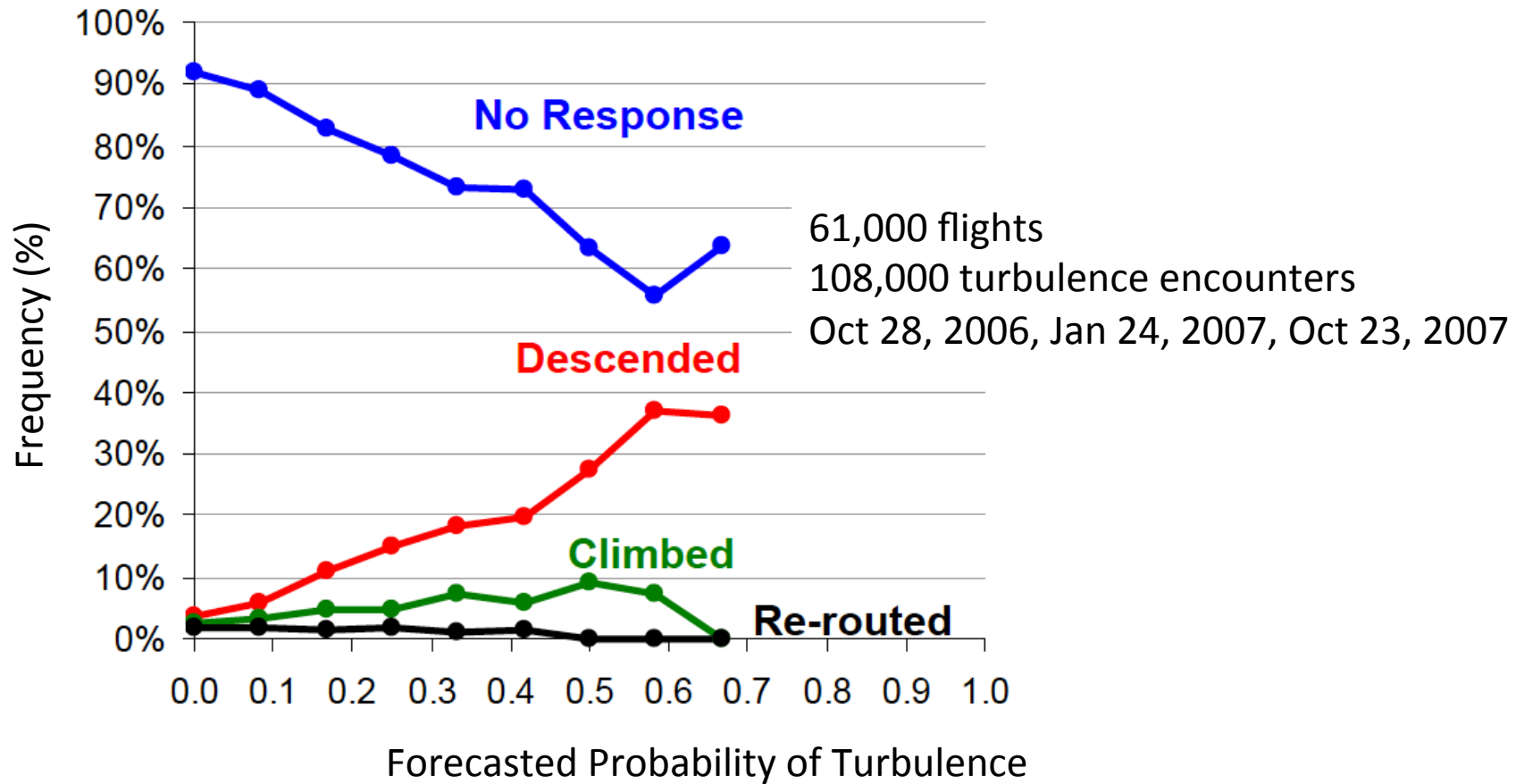
EDR

PIREP Level

Moderate

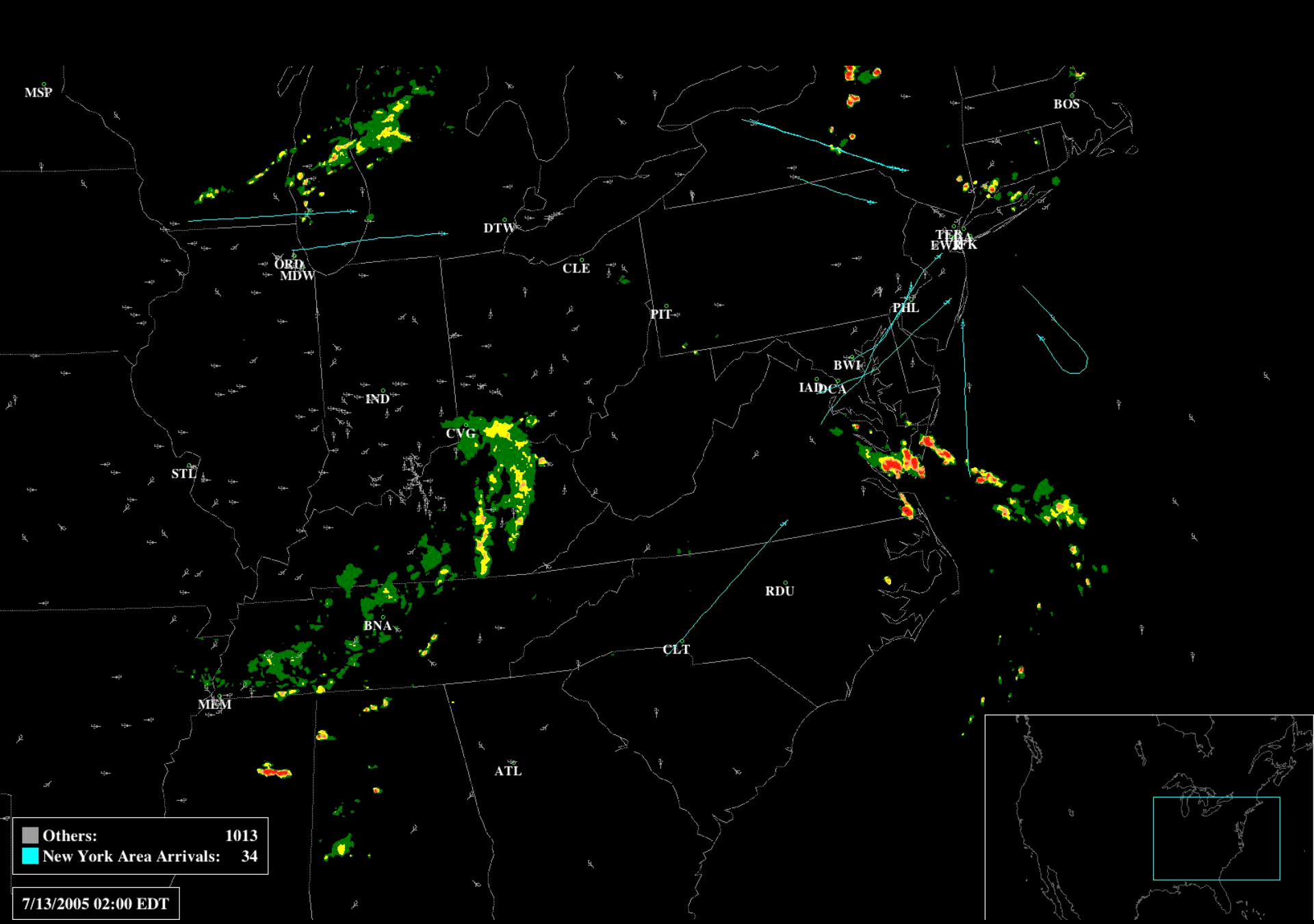
Severe

Pilot Turbulence Response

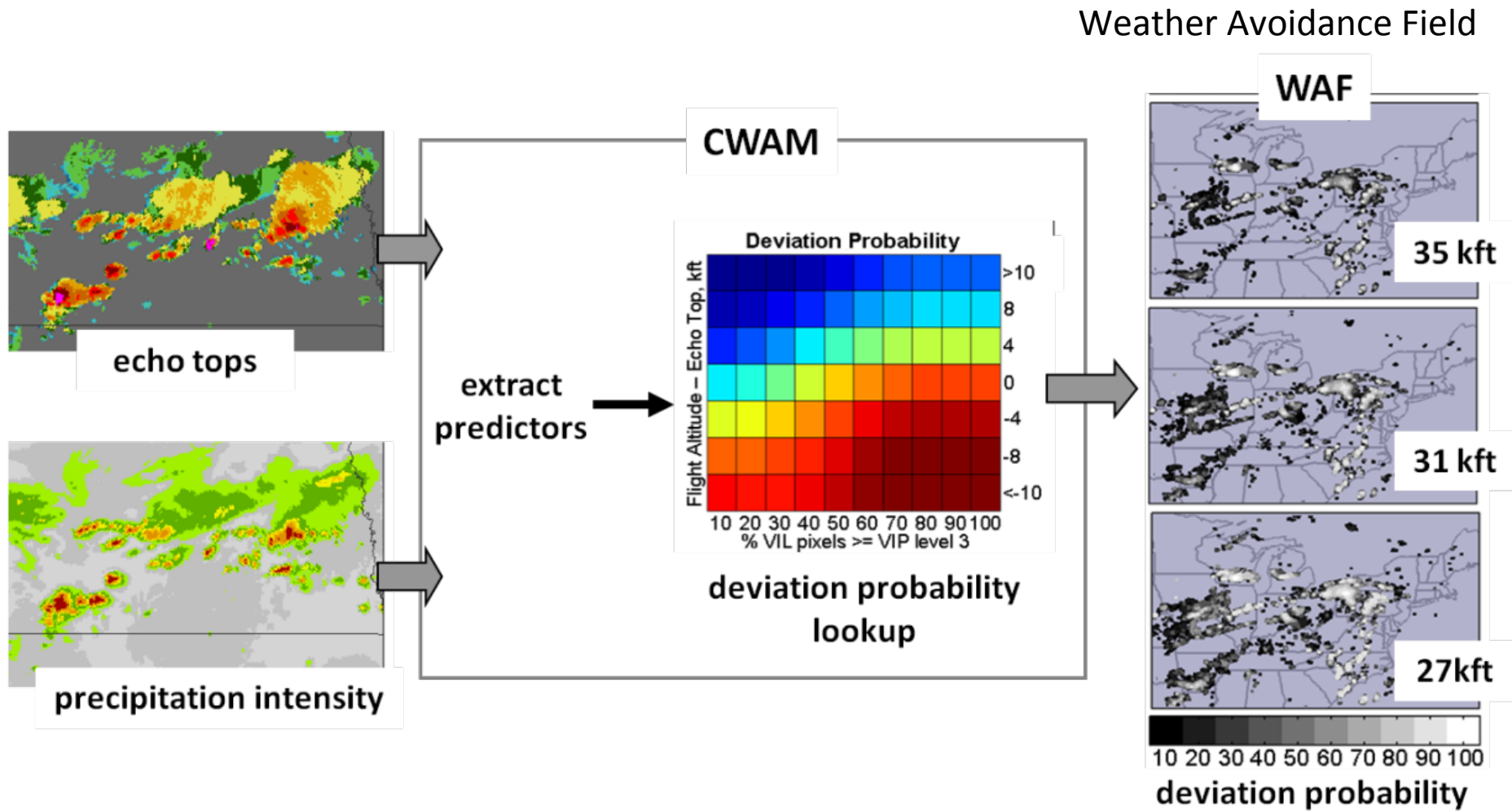




Convection

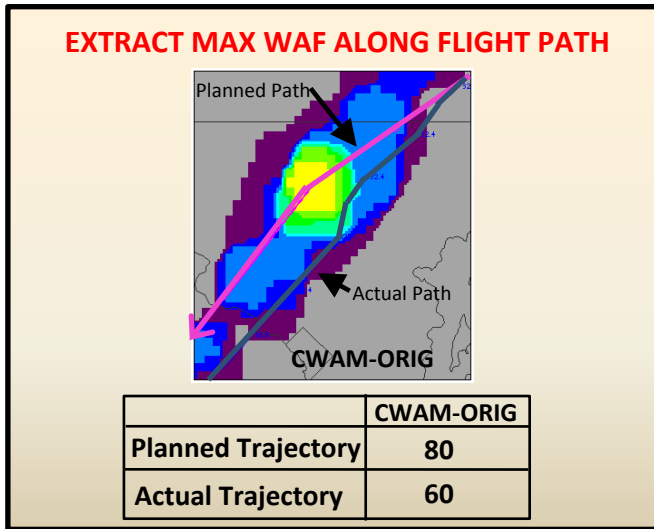


Convective Weather Avoidance Model (CWAM)



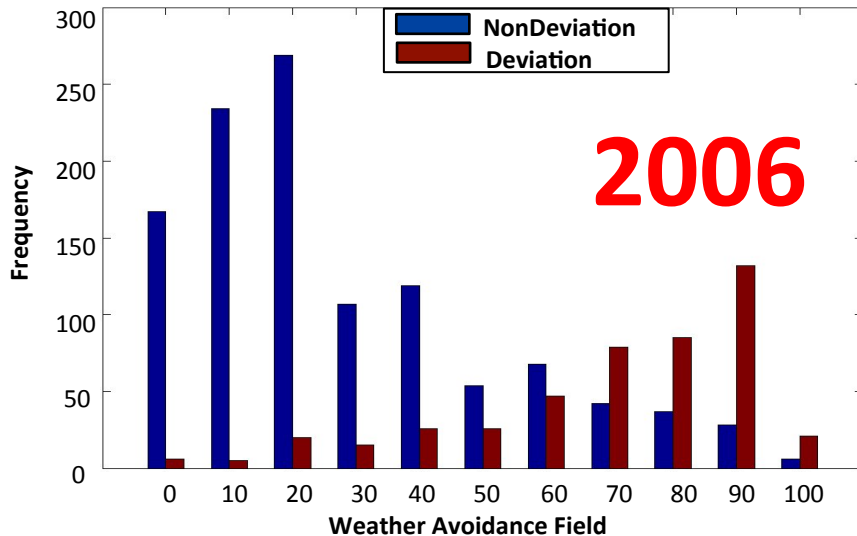
Reference: Matthews & DeLaura, "Assessment and interpretation of Weather Avoidance Fields from the Convective Weather Avoidance Model", ATIO 2010

Convective Weather Avoidance Model Accuracy

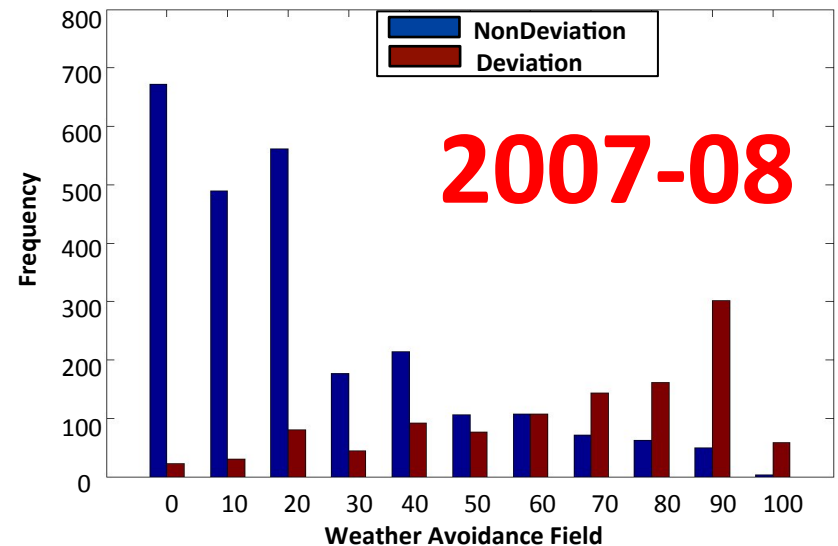


Total Evaluation data set: ~5300 aircraft
 ~2000 from 2006
 ~3300 from 2007 and 2008

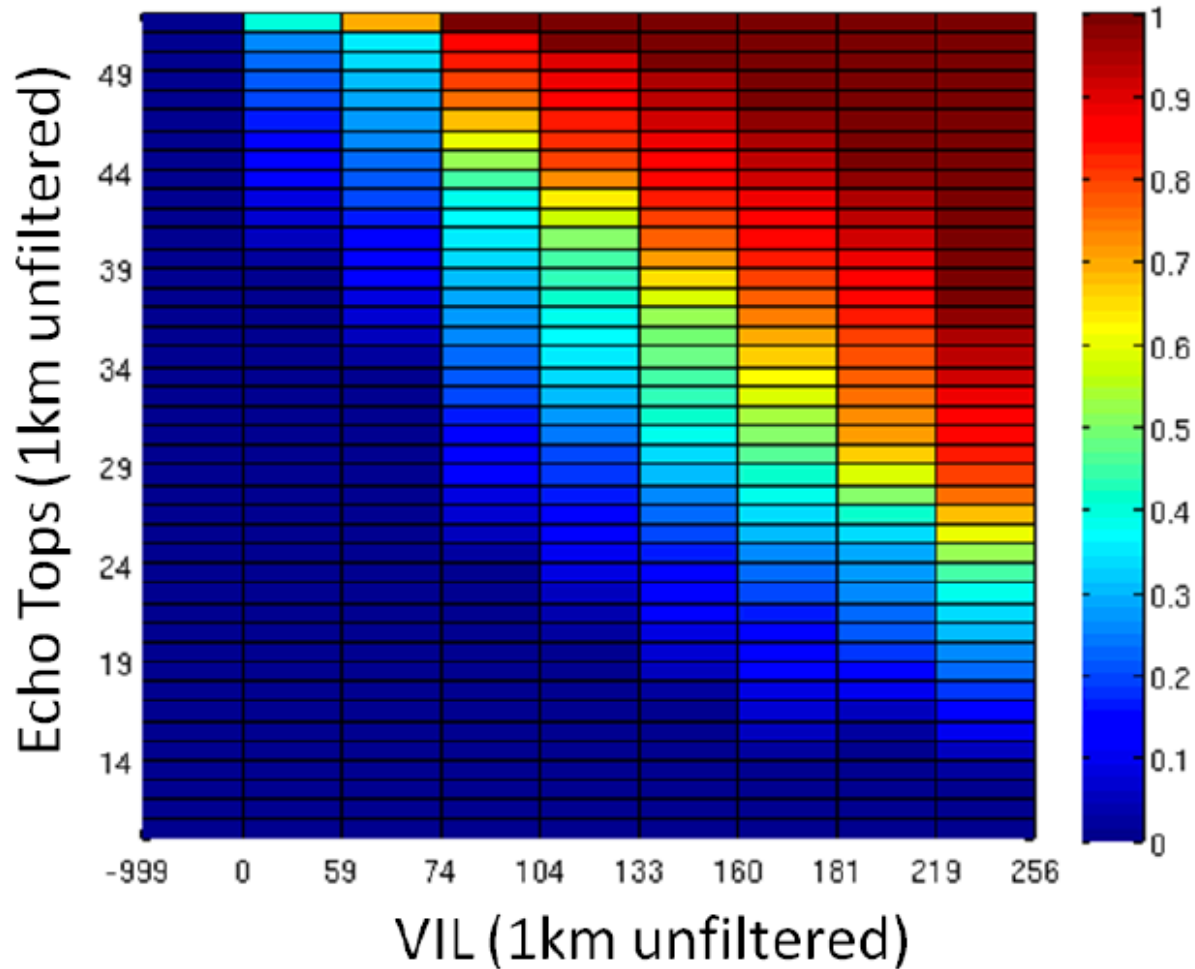
ZID



ZDC, ZID, ZOB

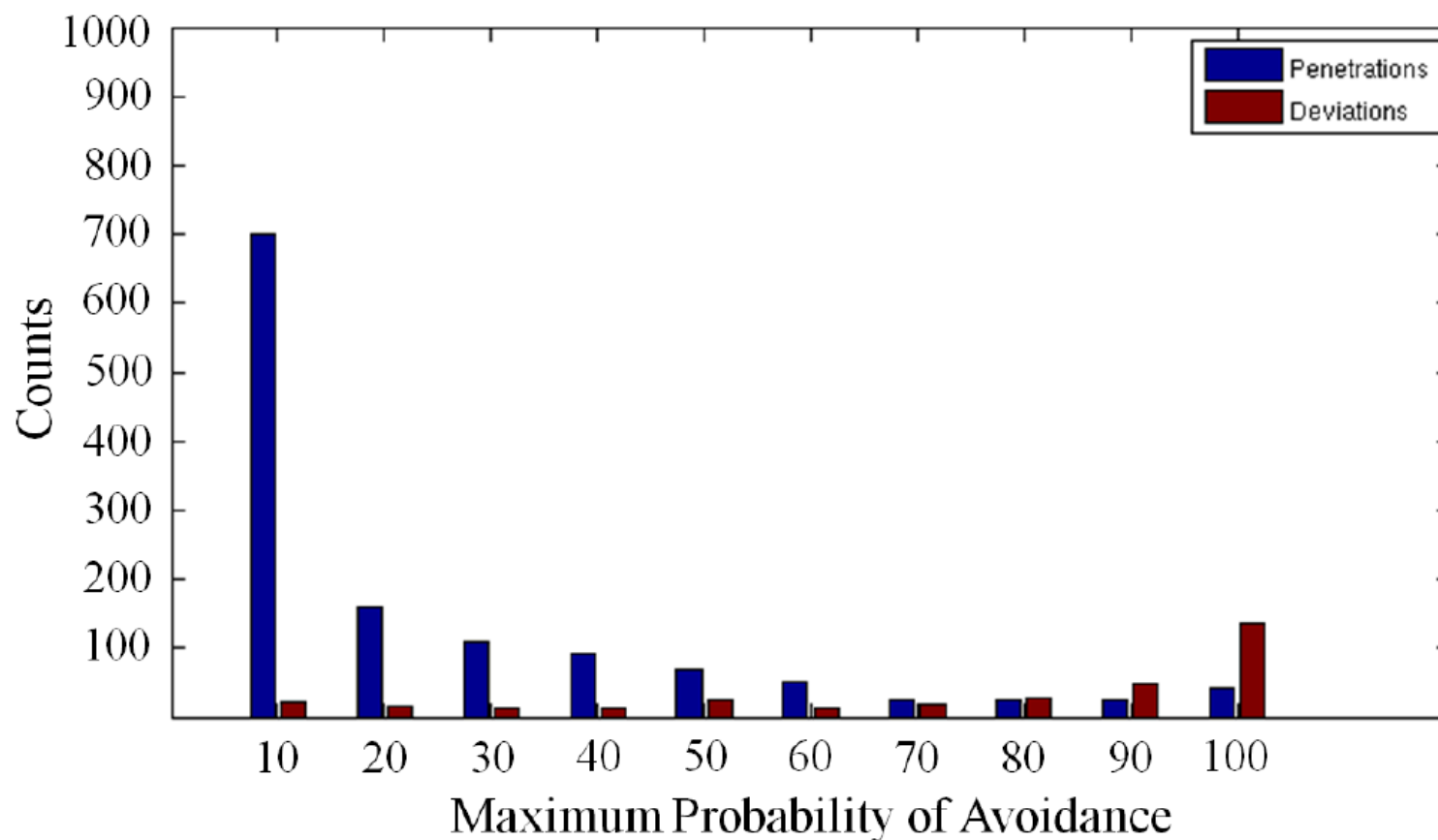


Terminal Arrival Model



Arrival Weather Avoidance Model Accuracy

11,000 flights
1,900 encounters



Integration into Dynamic Weather Routes Tool

The screenshot displays the 'Dynamic Weather Routes' tool interface. The main window shows a map with a flight plan route and weather data. A 'Capture fix' menu is visible, and a 'DWR list' table is shown in the top left. The map includes a 'Current flight plan route' and a 'DWR' (Dynamic Weather Route) that deviates from the current route to avoid congested sectors. A 'Capture fix menu & flying time savings' is indicated by an arrow pointing to a menu item. The 'Active Flight Plan' and 'Trial Flight Plan' windows on the right show the current and proposed routes, respectively, with status and performance metrics.

Dynamic Weather Routes Table:

TP	ACID/TYP	DEP/DST	DRCT	DWR	FIX/VIA	TR	SC	WX
<input type="checkbox"/>	EGF2841/E145	DFW/DSM	24.5	24.6	MCI	OK	SC	OK
<input checked="" type="checkbox"/>	AAL1627/MD82	KDFW/KMCI	19.9	20.6	MCM/1	OK	OK	OK
<input type="checkbox"/>	SMA5001/B737	KTPA/KDEN	14.7	8.5	TODDE/1	6	SC	OK
<input type="checkbox"/>	AAL1225/MD82	KDFW/MMSD	6.2	6.3	CUU	OK	SC	OK
<input type="checkbox"/>	FFT383/A319	KFLL/KDEN	5.3	1.8	HBU/2	OK	SC	OK

Map Labels:

- Capture fix
- DWR
- Auxiliary waypoint
- Current flight plan route
- Congested sectors - current flight plan route
- Congested sectors - proposed DWR route
- Capture fix menu & flying time savings

Active Flight Plan (Top Right):

AAL1627

Status: Flying Type: MD82 Speed: 429 FL: 196 Cruise FL: 310 Heading: 53
 Nominal 01:35 hrs 675 nms 9673 lb KDFW.NOBLY3.LIT.J180.FTZ.MCM.BQS4.KMCI

Trial Flight Plan (Bottom Right):

AAL1627 (trial)

Status: Flying Type: MD82 Speed: 429 FL: 196 Cruise FL: 310 Heading: 53
 Nominal 01:18 hrs 555 nms 7933 lb KDFW./331137N/0955639W.361647N/4

Trial Planner - Trial Station (Bottom Left):

Altitude: STATUS: Trial Planning

AAL1627 MD82/Q 310 KDFW.NOBLY3.LIT.J180.FTZ.MCM.BQS4.KMCI/0146

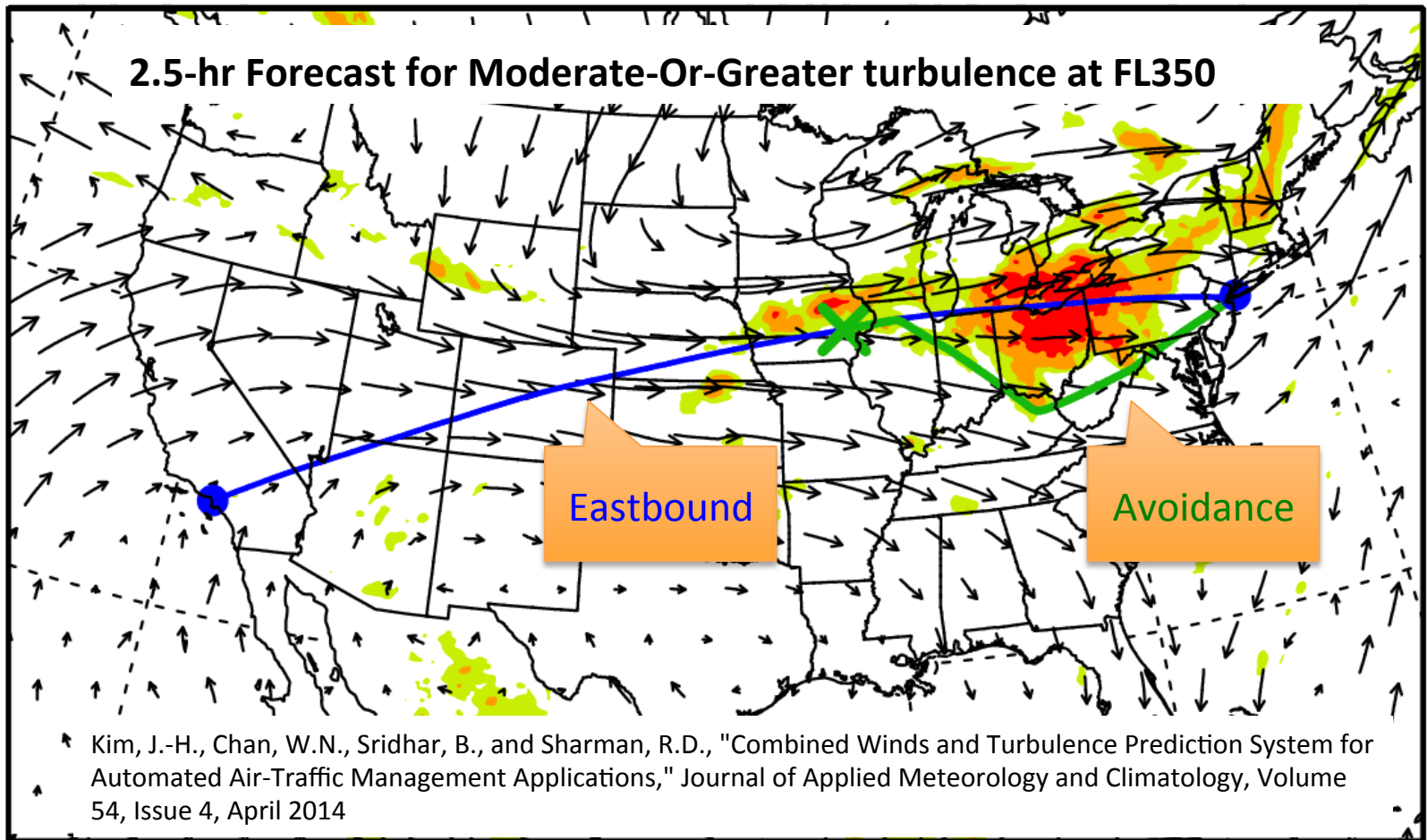
AAL1627 KDFW./331137N/0955639W.361647N/4

Buttons: Send SOC, Approve, Unable, Cancel Request, Send Sector, Unable

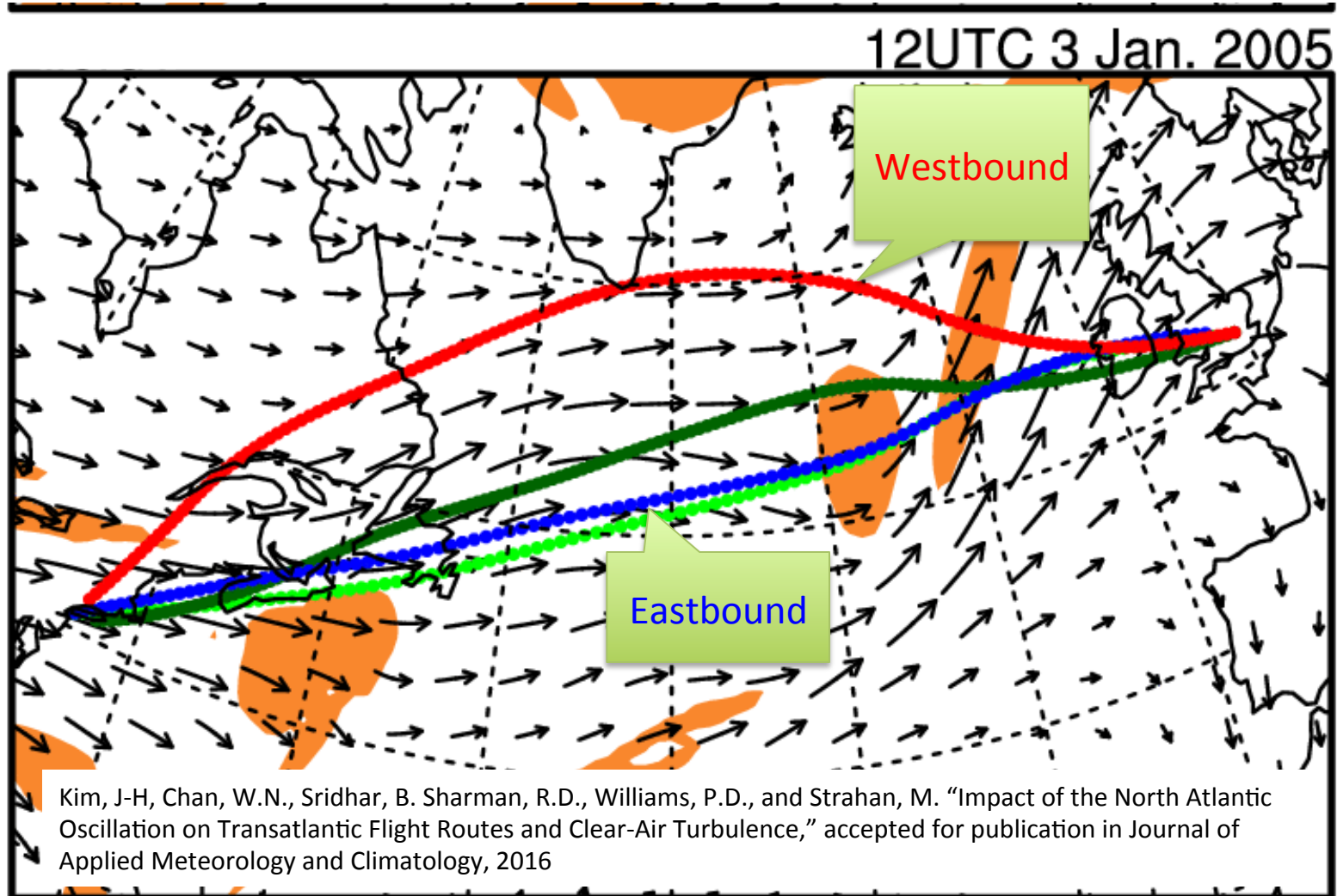
Wind Optimal Routing



Turbulence Aware Wind Optimal Routing



Turbulence Aware Wind Optimal Routing (Atlantic)

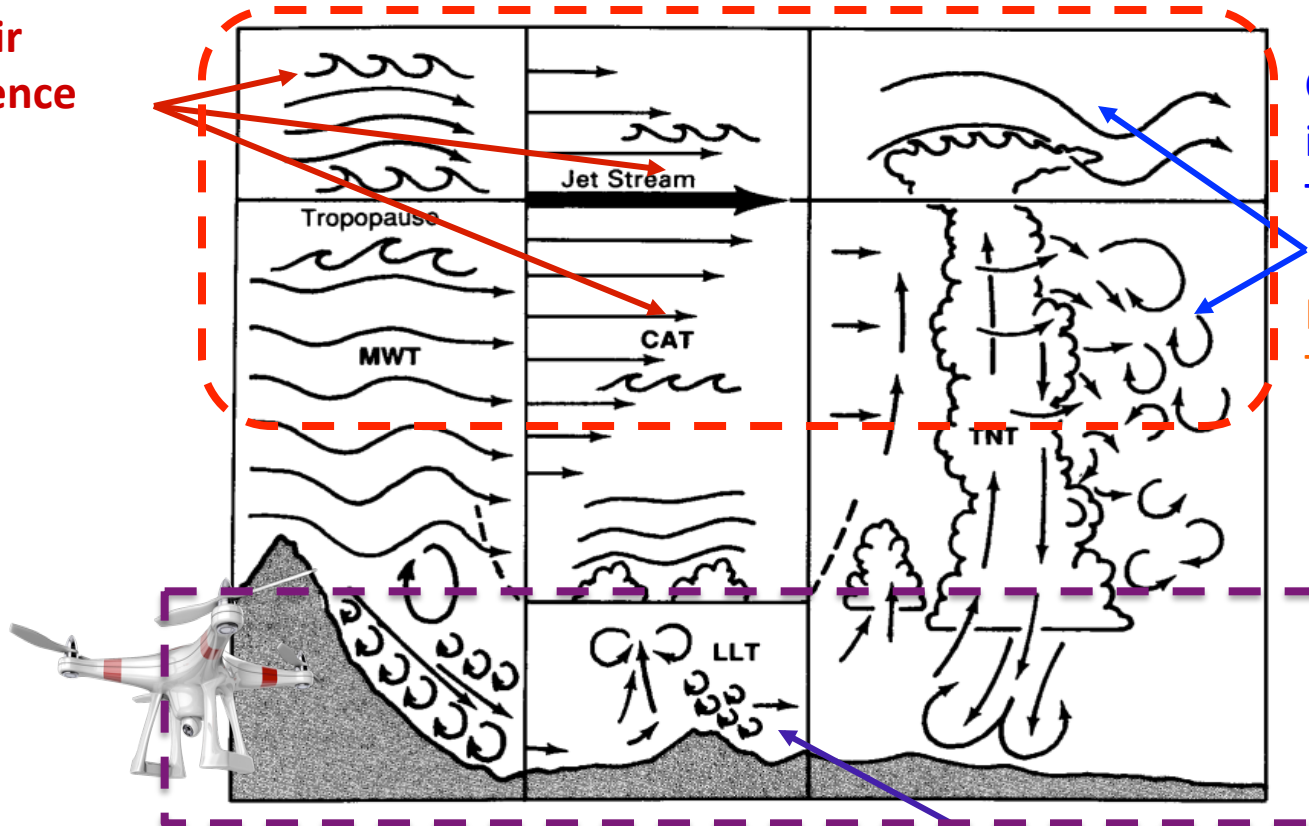


Weather for Unmanned Aerial Systems



Low Level Weather Impacts

Clear-air
Turbulence
(CAT)



Convectively-
induced
Turbulence (CIT)
or
Near-Cloud
Turbulence (NCT)

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

Convective boundary
Layer turbulence

Crows Landing, California

Unmanned Aerial Systems Traffic Management Field Test



Crows Landing Localized Weather Sensors



Reno-Stead Airport

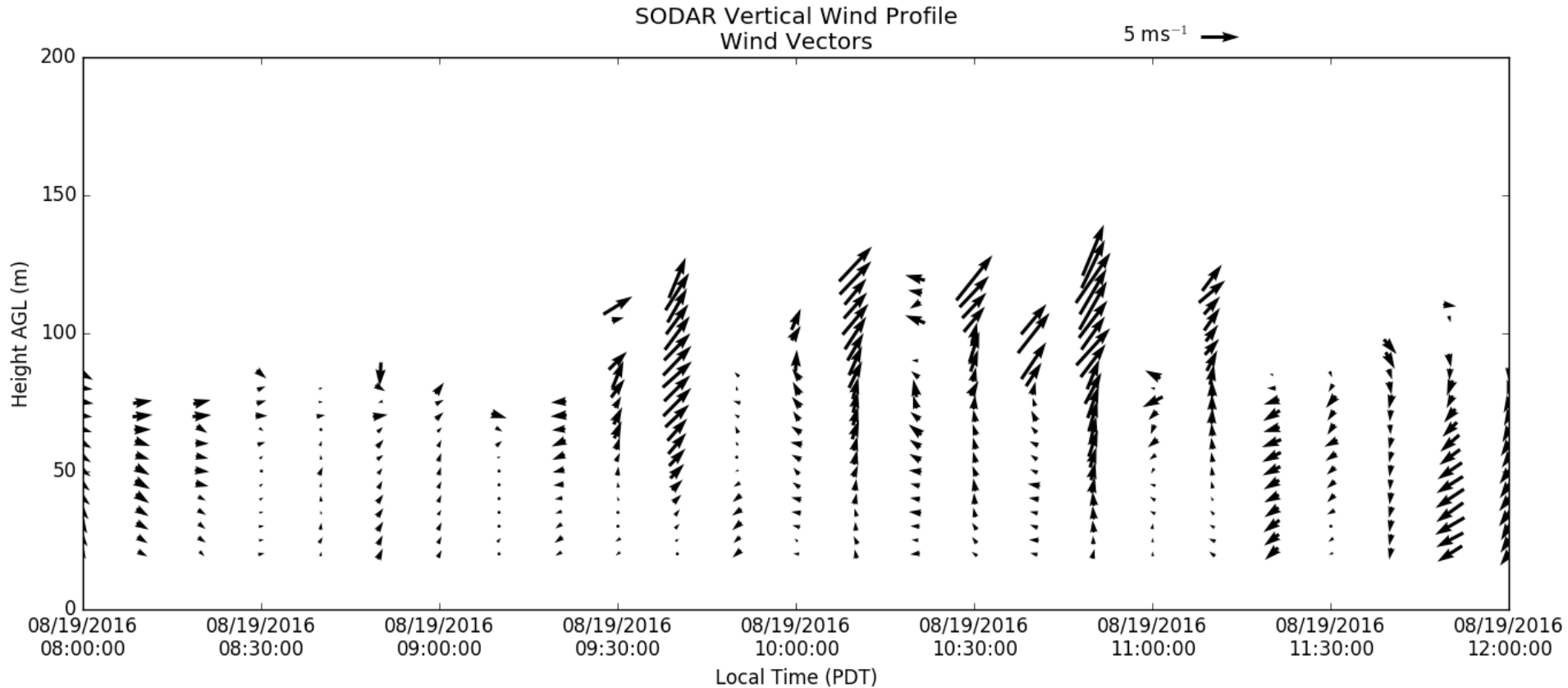
An aerial photograph of Reno-Stead Airport, showing the runway, taxiway, and surrounding airfield. The airport is situated in a valley with mountains in the background. The sky is blue with scattered white clouds. The foreground shows the airport's infrastructure, including parking lots, hangars, and other buildings.

- 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)

The screenshot shows the MyWida V2 web application. The browser window at the top displays the URL <http://192.168.200.10/MyWida/rules.txt>. The application header features the AR logo and the title "MyWida V2".

The control panel on the left includes the following fields:

- Rules: C:\Users\dmarini\Downloads\rules.txt
- AOI: WRF, AFGWC, corners (lat,lon): 34.92, 119.99 and 40.10, 135.11, reference time: 07-03 06:00Z
- Select Asset(s): AH-64, 30MM MACHINE GUN, STINGER-AIR, STINGER-COMMON, HELLFIRE A-AIR, HELLFIRE C-AIR
- Select Forecasts(s): 07-04 03:00Z, 07-03 21:00Z, 07-03 15:00Z, 07-03 18:00Z, 07-03 06:00Z, 07-04 00:00Z
- Select Layers(s): 20 m, 50 m, 110 m, 170 m, 240 m, 320 m

Buttons for "Calculate Impacts", "Display 3D Impacts", and "Optimize Route" are visible.

The 3D impact map on the right shows a color-coded area over a geographic region, with the title "AH-64 07-03 18:00Z".

The summary table at the bottom provides the following data:

	07-04 03:00Z	07-03 21:00Z	07-03 15:00Z	07-03 18:00Z
AH-64	Unfavorable	Unfavorable	Unfavorable	Unfavorable
HELLFIRE C-AIR	Favorable	Favorable	Favorable	Favorable

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 (\geq , \leq), separate contiguous symbols must be used, for example, \geq or \leq .

- 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)