Progress in Aircraft Weather & Turbulence Observations
Flight Safety Foundation: Safety Forum 2024, Aviation Weather Resilience

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Abstract

The Boeing Company provides airline customers with cross-model (777, 787, 737 MAX, 777X) **real-time weather and turbulence observations** as well as integration of this information into pilot and dispatcher applications and services. Customers benefit from such information in areas of cabin management, better flight routing decisions, reduced fuel burn and emissions, improved passenger and crew comfort, and reduced crew fatigue. Additionally, the data being created is used for ongoing research within aviation and the scientific communities.

Over the last few years, our industry has collaboratively created data link weather standards satisfying the **International Civil Aviation Organization's (ICAO) Annex 3** regarding near-real-time turbulence reporting, as well as published literature and guidance documents from the RTCA and EUROCAE for an aircraft-type-independent metric for **turbulence, known as Eddy Dissipation Rate (EDR).**

Status and some ongoing analyses for the extensive global coverage of these comprehensive meteorological observations will be presented. Progress towards furthering comprehensive meteorological observations beyond EDR will also be discussed as well as the need for more aircraft types and market segments to contribute globally to the available data.

Continued direction: Use of airplane as a comprehensive atmospheric sensing platform

Atmospheric Parameters:
- ☑ Winds
- ☑ Temperature
- ☑ Icing
- ☑ **Turbulence**
- ❑ Water vapor (restarting!)
- ❑ Greenhouse Gases
    - ❑ (CO_2, CH_4, N_2O, O_3 ,...)
- ❑ Cloud and Ash
- ❑ Onboard weather radar downlink
- ❑ Other aerosols
- ❑ Space weather
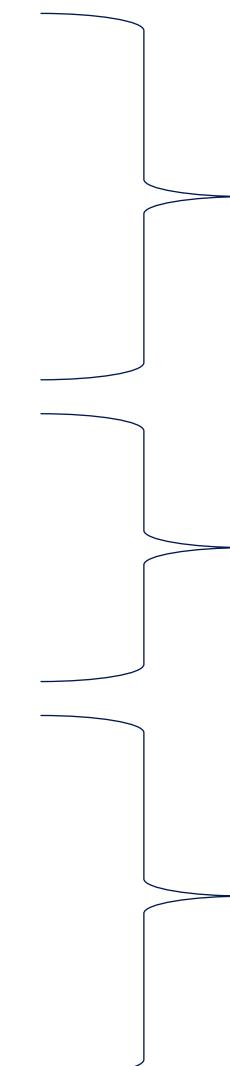
Mature & evolving

Starting work

Research needed

Motivations – Turbulence a leading cause of air carrier accidents

Part 121 Air Carrier Weather-Related Accidents: 2008-2022

Low CIG & VIS 1%
LLWS 1%
Precipitation 2%
Icing 1%
Adverse Winds 4%
TSTMS 2%
General 15%
Turbulence 74%

Weather Factors
- Turbulence
- TSTMS
- Adverse Winds
- Icing
- Precipitation
- LLWS
- Low CIG & VIS
- General

431 Accidents

WX-Related 39%
Non-WX-Related 61%

NTSB

Content courtesy of Don Eick (US NTSB)
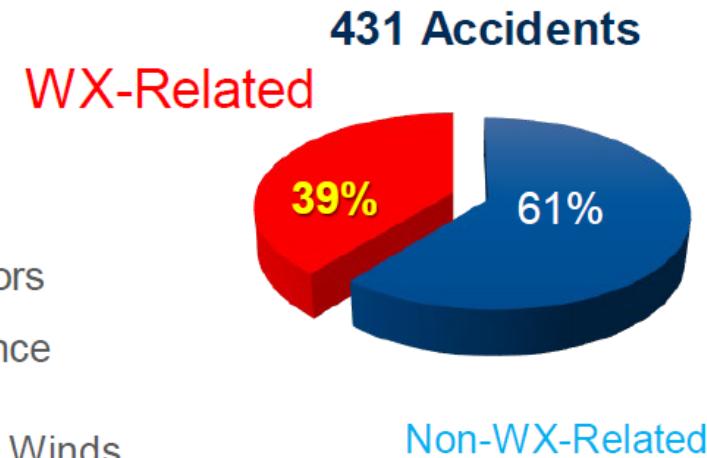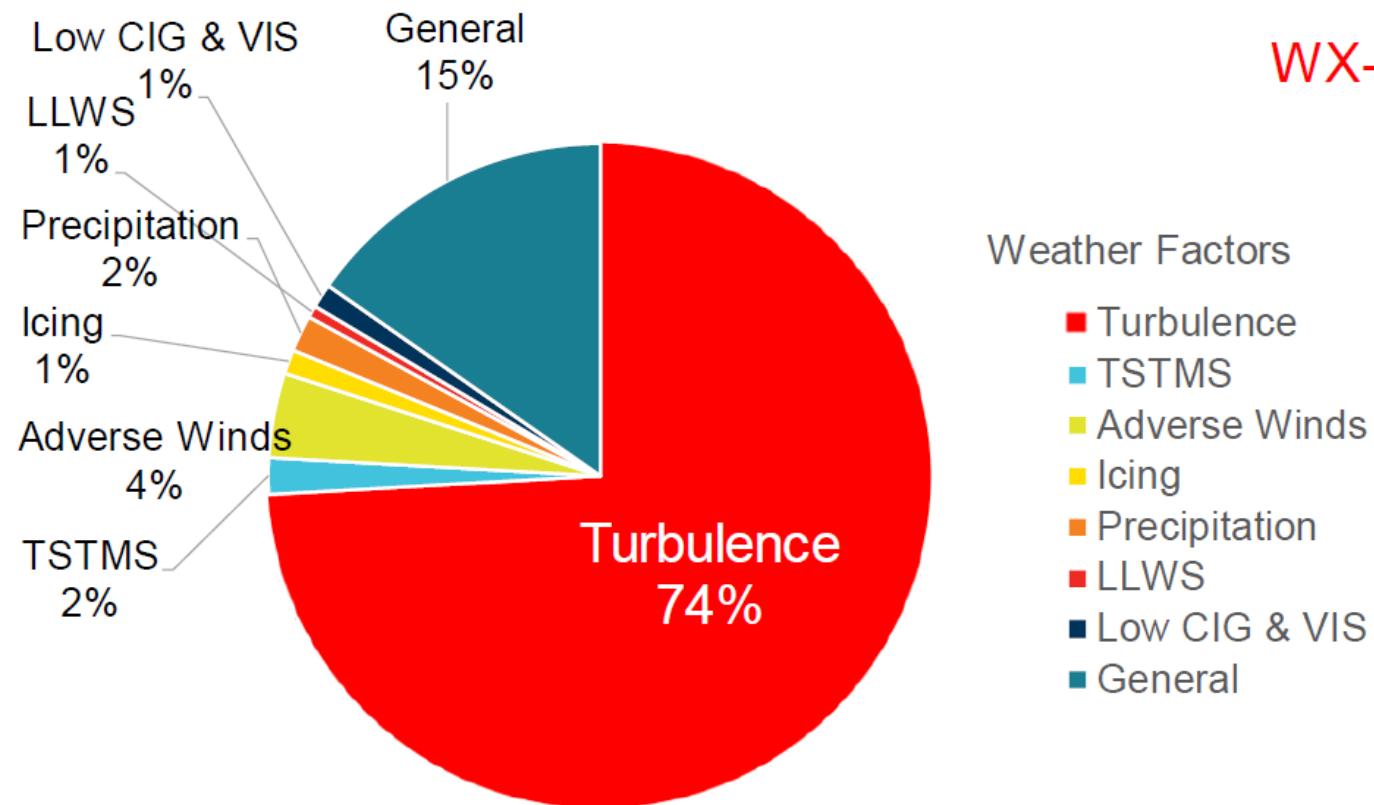
How does it work?

Generate meteorological data to support airline world-wide operations

Aircraft

Weather & turbulence reports

Pilot apps

12/16/2014 13:31

Meteorological Observations

Service Providers

Airline & Industry Sharing

- Aggregate observations
- Parse
- Format
- API to deliver needed information

Better information of weather & turbulence

Dispatch & Flight Planning Applications

Other Users

- **Weather Services**
- **Researchers**
- **Regulators/ANSPs**
- **Other service providers**

Monthly 777, 787, and 737 MAX Weather & Turbulence Observations

Monthly Observations til 5/01/2024
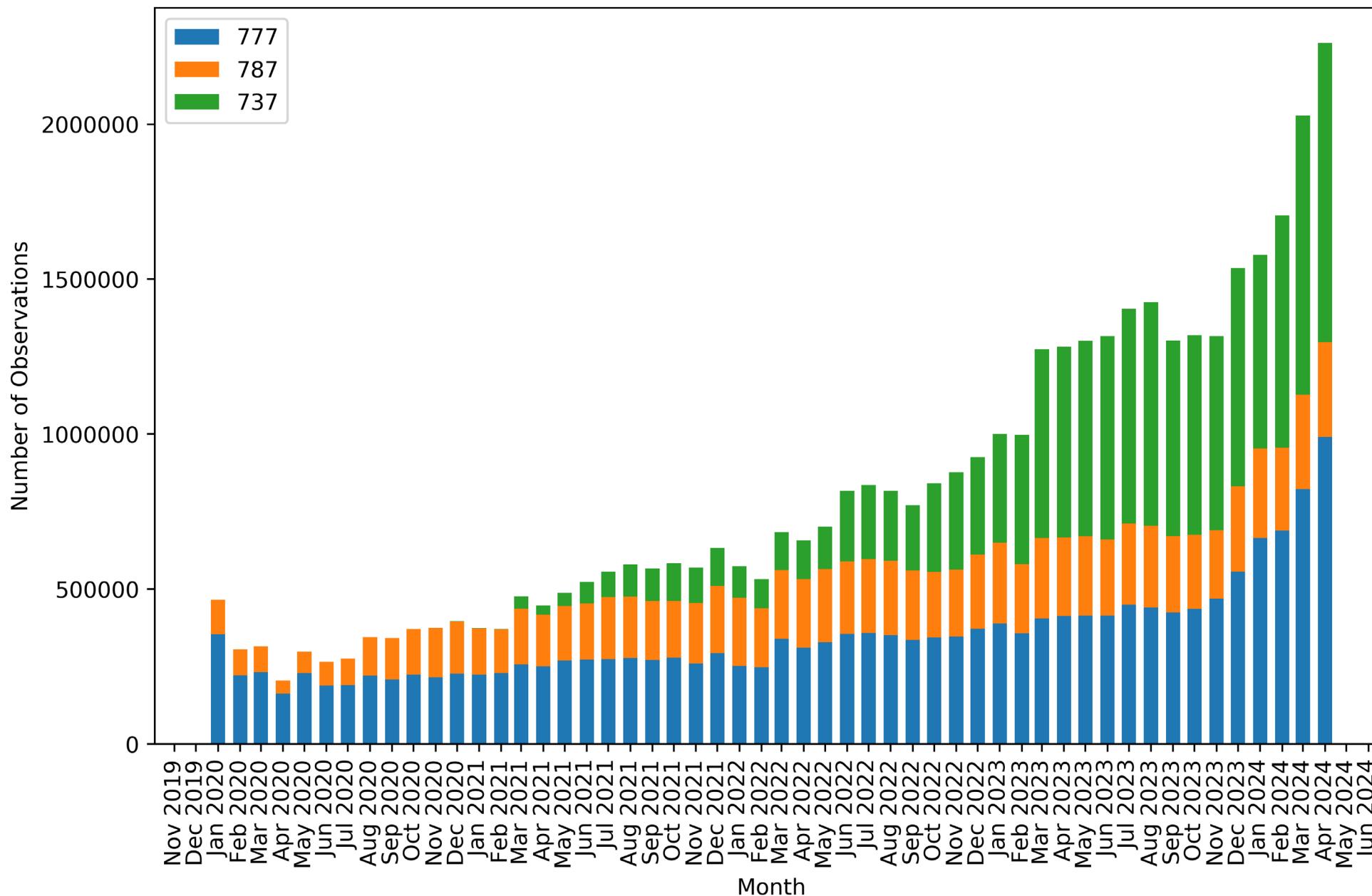
Boeing Airplane Program Contributions

777, 787 & 737 MAX EDR Periodic Turbulence Observations April 2024

Legend
- 777
- 787
- 737
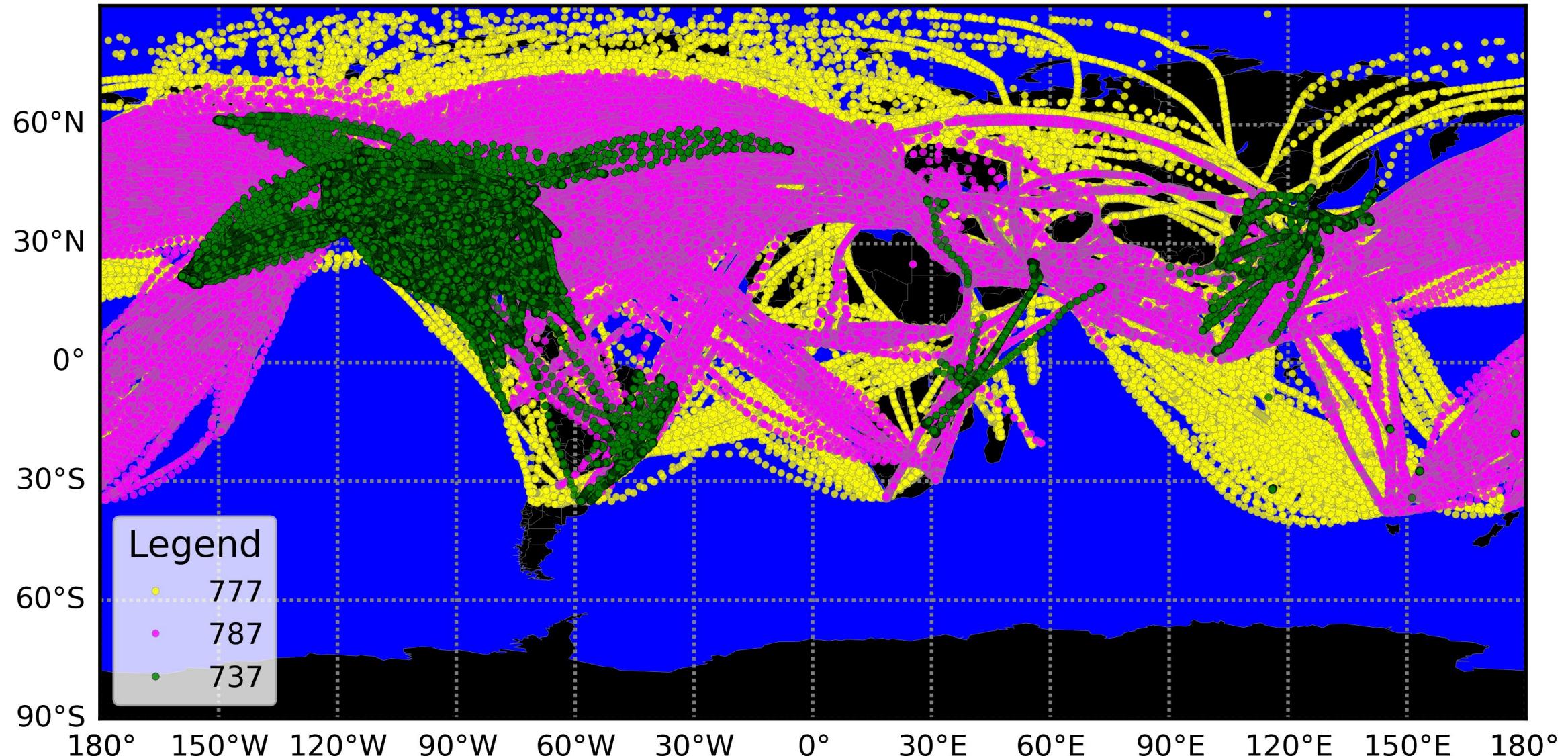
Boeing Airplane Program Contributions

Counts of 777, 787, 737 MAX EDR Observations in April 2024

Counts in 5° x 5° box

Boeing Airplane Program Contributions

All reports from 777, 787, 737 MAX during April 2024
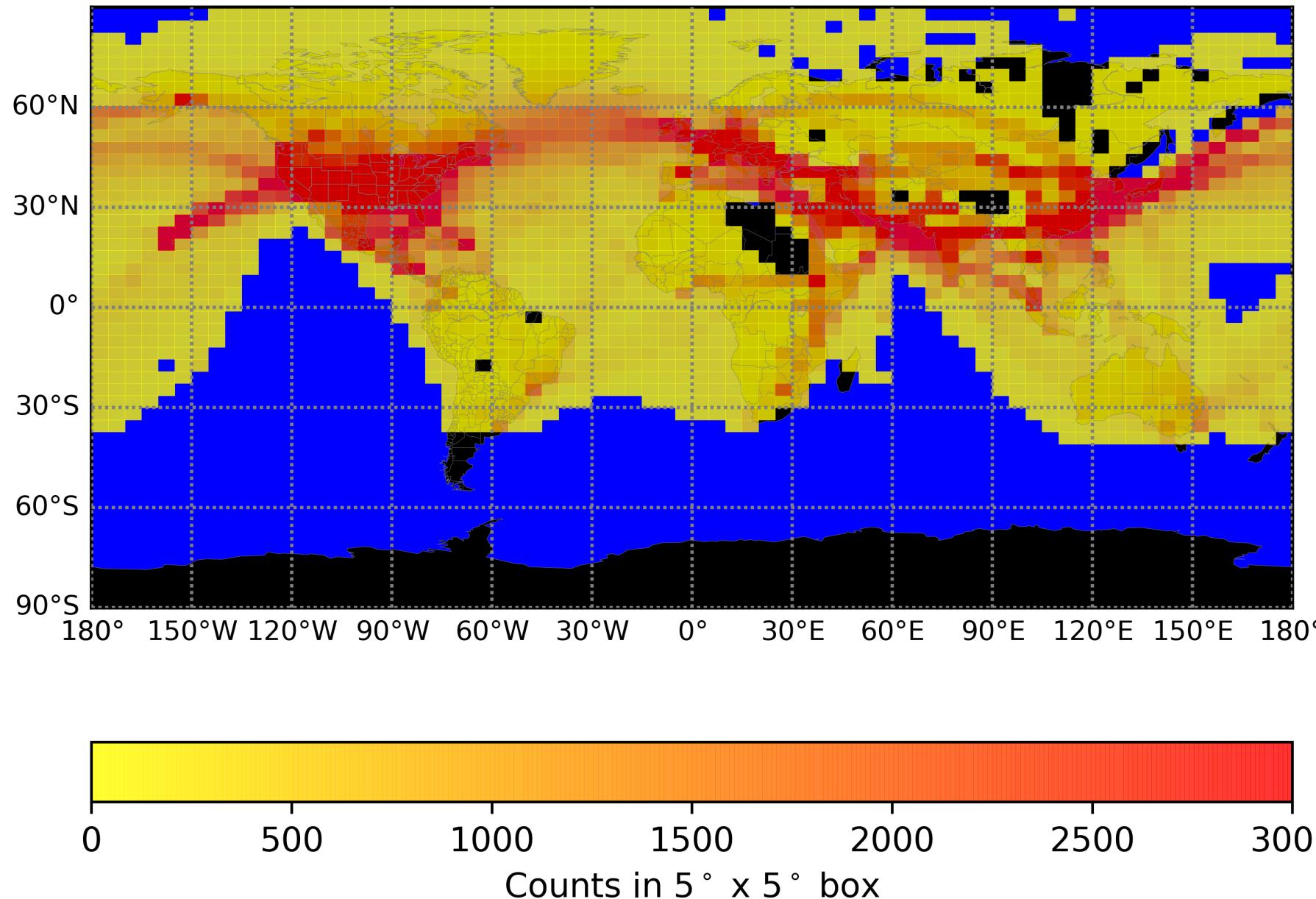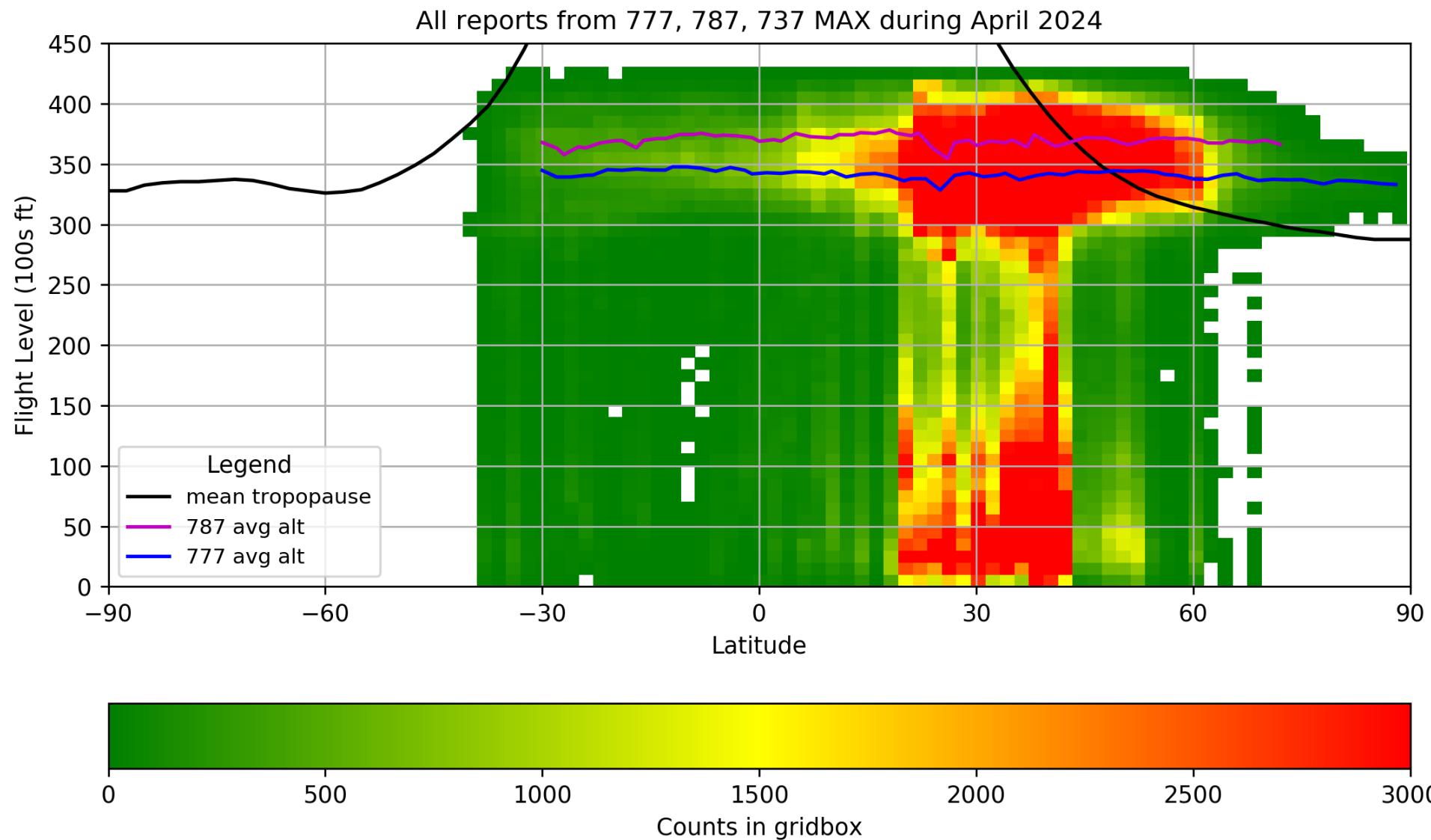
Increase data and include other market segments
RTCA & EUROCAE EDR calculation systems under evaluation

New, emerging technologies are shown in BLUE

Aircraft Air Data Systems
(winds or airspeed based)
- AOA
- pitch
- pitch Rate
- airspeed
- altitude
- *includes optical air data, Tropospheric Airborne Meteorological Data Relay (TAMDAR)*

Aircraft accelerometer-based
- Temporarily mounted portable electronic devices that are stable

ADS-B / Mode-S
- vertical rate, air speed, altitude
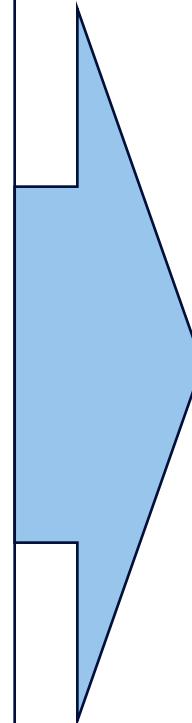
## EDR Calculation

Aircraft
- Includes Quality Control

Ground
- Includes Quality Control
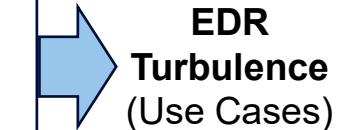
EDR Turbulence (Use Cases)

We welcome others to participate in this standards development activity!

Some recent developments in applications & services

❑ **Jeppesen FliteDeck Pro layers for IATA & SkyPath aircraft observations**

❑ **ForeFlight Sentry now includes turbulence reporting (GA, BusAv)**

❑ **Several other service providers integrating data!**
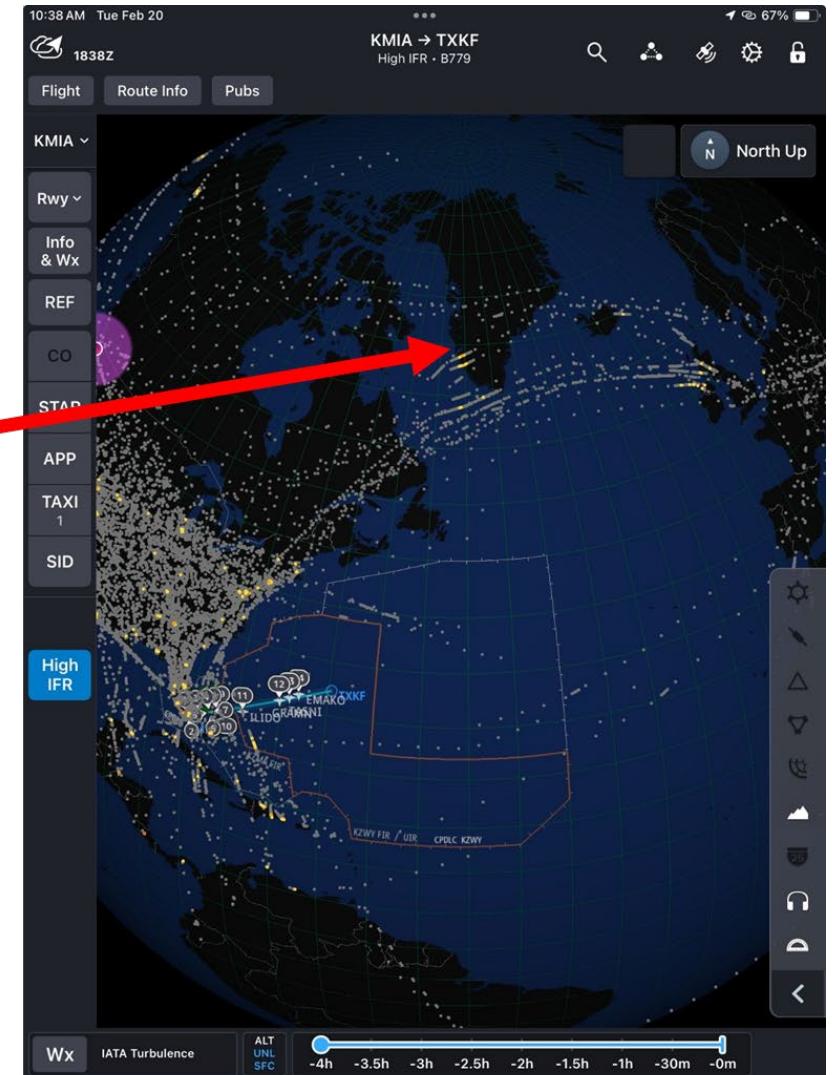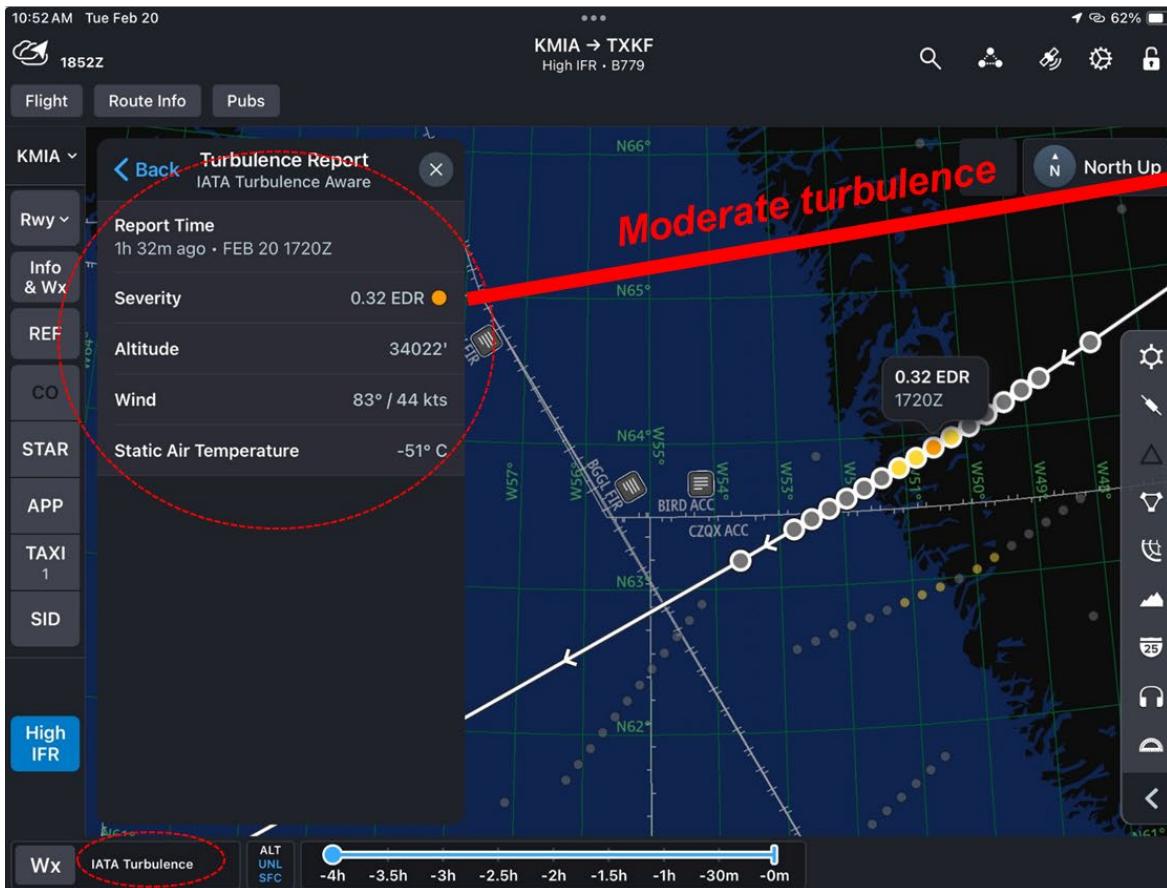
Moderate turbulence

AI: UW-CIMSS Turbulence Model
Use satellites to predict moderate-or-greater (MOG) turbulence

North Atlantic area of 25% Probability of MOG turbulence

Legend
- EDR<=0.1
- 0.1<EDR<=0.2
- 0.2<EDR<=0.3
- 0.3<EDR<=0.4
- 0.4<EDR<=0.5
- 0.5<EDR<=0.6
- 0.6<EDR<=0.7
- EDR>0.7

Good Results!

64 x 64 image pixels
1. WV (ch 8)
2. IR (ch 13)
3. Surface elevation
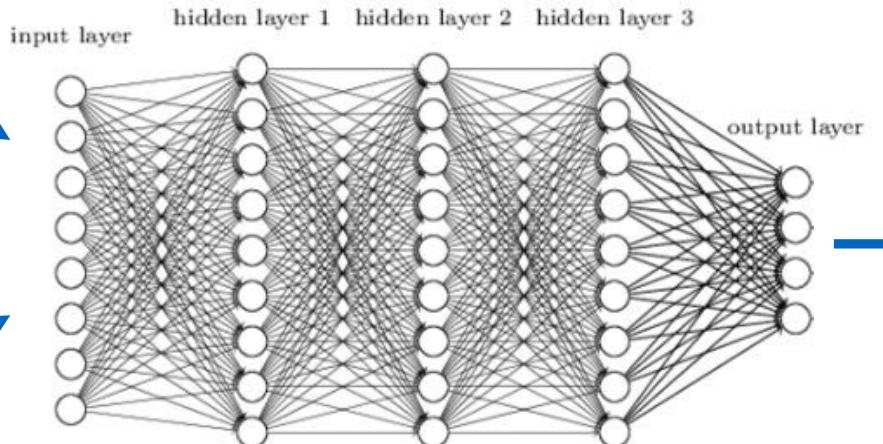
Context from the NWP model

Deep neural network

input layer   hidden layer 1   hidden layer 2   hidden layer 3

output layer

- Prob. of MOG @ 40-41 kft
- Prob. of MOG @ 38-39 kft
- Prob. of MOG @ 36-37 kft
- Prob. of MOG @ 34-35 kft
- Prob. of MOG @ 32-33 kft
- Prob. of MOG @ 30-31 kft

❑ For every 4x4 pixel spot on the satellite image
❑ Trained on ~30,000 aircraft EDR obs from 4 years
❑ Generates probability of MOG *over a 10-minute segment*
❑ Takes 34 seconds to calculate a full-disk product

Content courtesy of Dr. Tony Wimmers (U. Wisconsin)

Advantage: Satellites are always observing & cover large regions!

Conclusion/Next Steps

- ❑ Boeing aircraft weather & turbulence reporting: Airlines determine if they will participate in this program, considering datalink costs and the benefits

- ❑ Continued data sharing is key to getting full value from these observations, as it helps create the "full solution" for customer use

- ❑ Continued growth outside US needed

- ❑ Standards: Within RTCA & EUROCAE, we are working towards determination of EDR (ICAO Annex 3) from other data inputs

- ❑ As an industry, we need more aircraft types and from other segments to contribute to the available data

- ❑ Encourage other methods such as satellite-inferred turbulence (AI)

- ❑ Mature our plans for meteorological parameters beyond turbulence