InSitu EDR Turbulence Reporting

This research is in response to requirements and funding by the Federal Aviation Administration (FAA). The views expressed are those of the authors and do not necessarily represent the official policy or position of the FAA.

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NCAR – WTIC Industry Meeting - May 24th, 2022

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Aircraft-Based Turbulence Observations

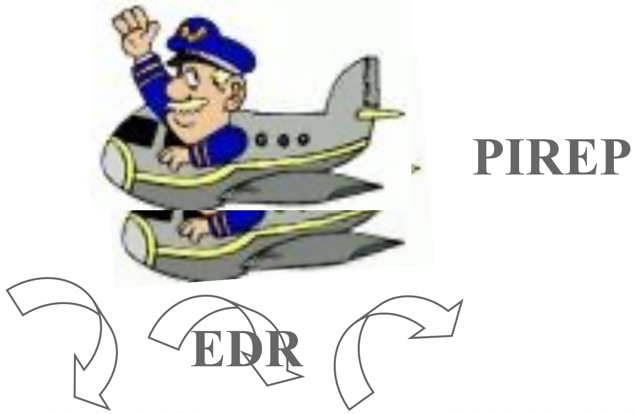
- "Truth" about the turbulence situation are needed for ALL Turbulence Products (Nowcast, Forecast, and Remote Sensing) as well as situational awareness

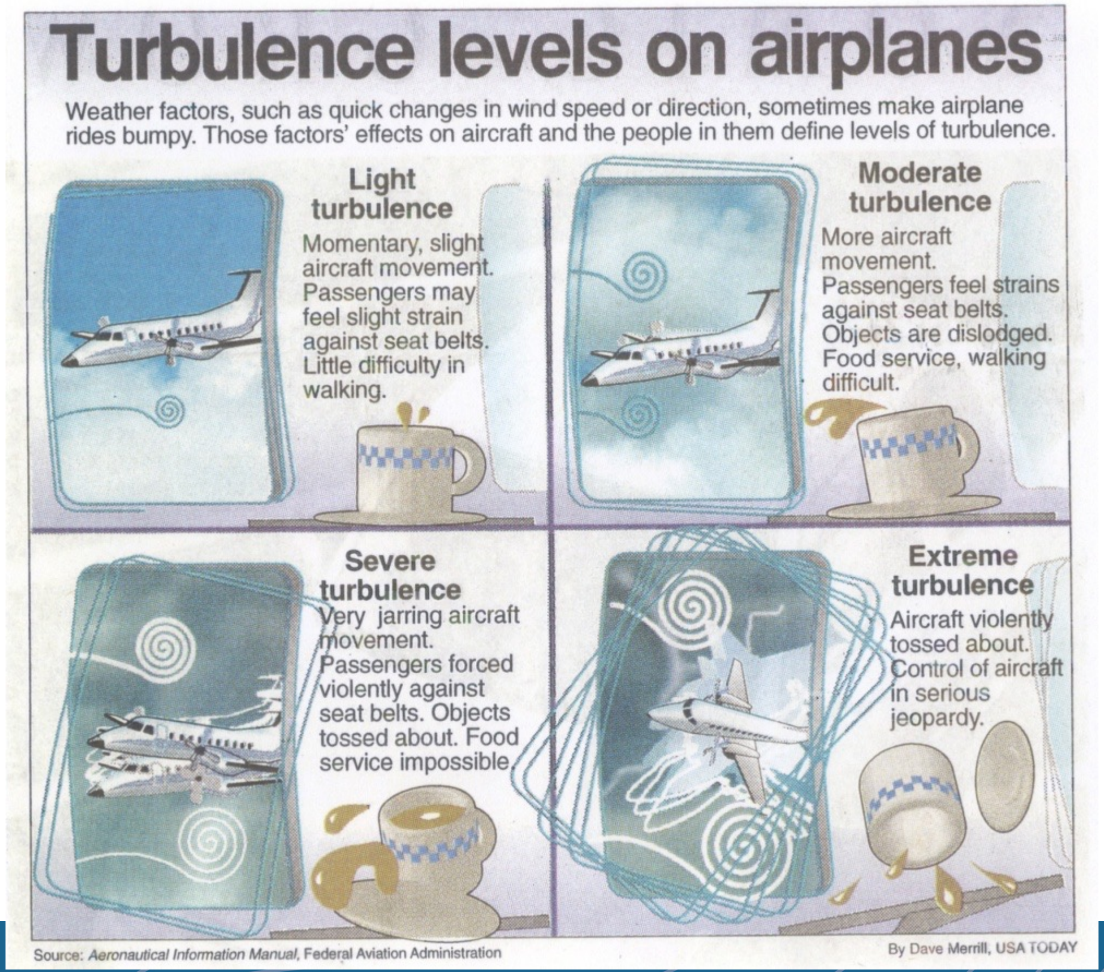
Without aircraft observations, we really have no idea!

PIREP turbulence measurements

- Before *in situ* the only routine observations are pilot reports (PIREPs)
  - Non-uniform reporting in space and time
  - Generally low occurrence
  - Position and time inaccuracies (sometimes quite large)
  - Subjective and categorical (“light”, “moderate”, “severe”, “extreme”)
  - Aircraft dependent – a moderate for a heavy a/c might be a severe for a light a/c, leading to difficulties in translating.

- Better would be an automated atmospheric measure, i.e. aircraft independent





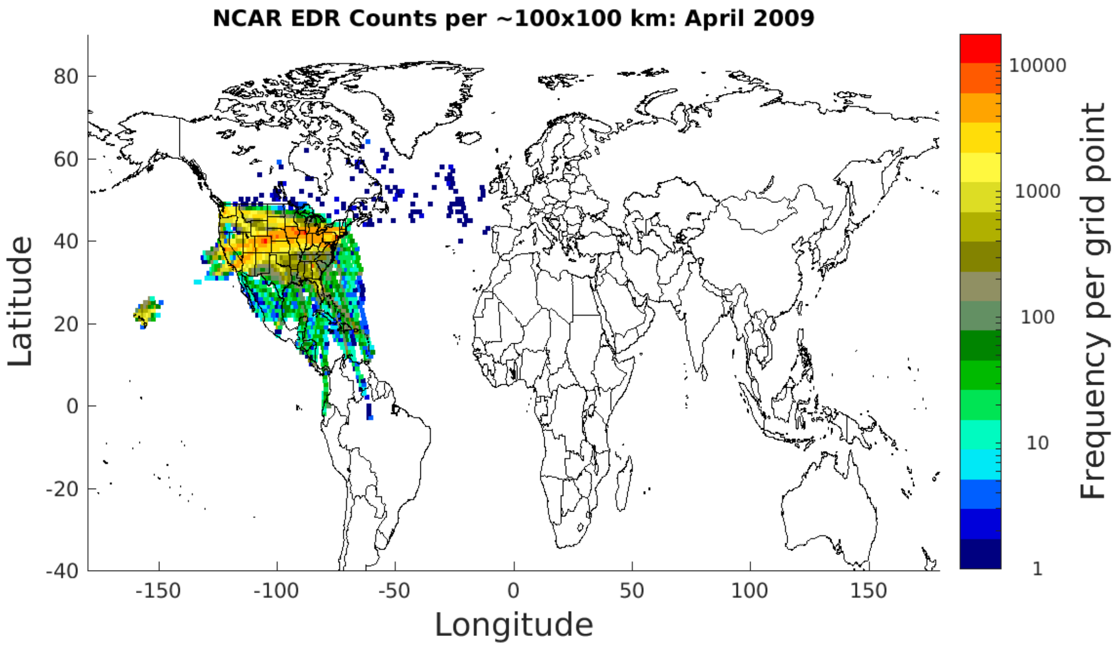
Turbulence and Its Estimation

Eddy (energy) dissipation rate is an <u>atmospheric</u> turbulence intensity metric

- Easier to share and translate to a specific aircraft (just like wave height compared with "calm" and "rough" seas).
- Relevant for scales of turbulence which affect aircraft (very large or very small scales are not "felt" as "turbulence).
- Is sufficient to fully characterize the atmospheric turbulence at these scales (no other parameters are needed).

NCAR *In situ* turbulence Algorithm

- To address the issues related to PIREPS, the FAA has sponsored the *in situ* activities for almost 30 years, through both the AWRP and WTIC programs.
- The output is eddy dissipation rate (EDR) - actually $\varepsilon^{1/3}$ ($m^{2/3}/s$). Typically a number between 0 and 1, which scales proportionally with the winds.
- Current users
  - US: Delta, Southwest, United, American
  - Int'l: Swiss, Aer Lingus, Qantas, Air France, Cathay, Qatar, and many more
- Current Aircraft Types
  - Boeing: 777, 787, 737NG, 737MAX, 767
  - Airbus: 32X, 330, 350
- Systems:
  - ACMS (Honeywell, Teledyne)
  - EFB
  - AID (aircraft interface device)
  - Off-line

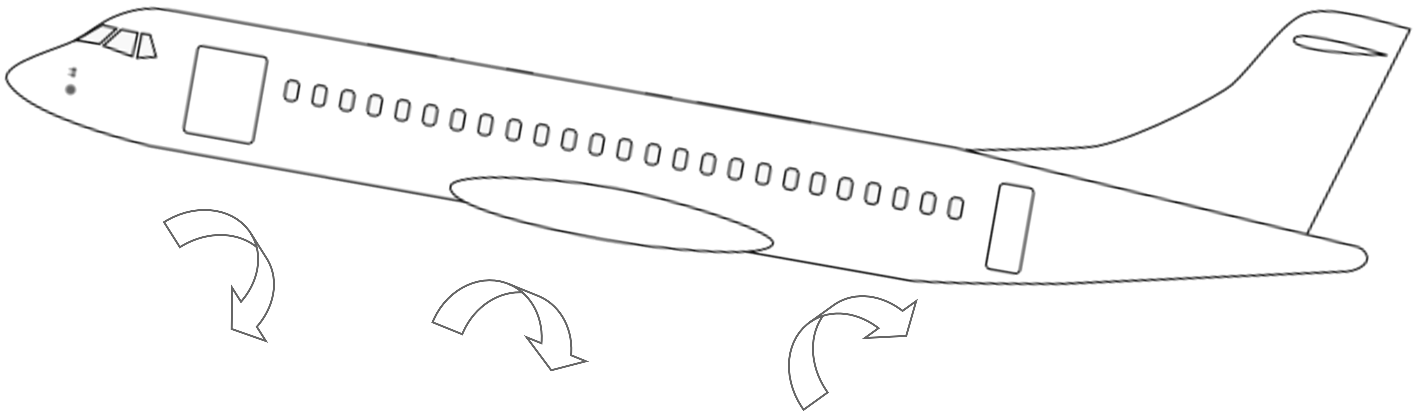


EDR Counts per about 100 x 100 km grid
April of each year from 2009-2022

NCAR *In situ* turbulence Algorithm

- The WTIC program funded the development of the technology transfer package for the *in situ* EDR software, to simplify the integration of the software into operational systems (e.g. ACMS or EFB)
- The open source package includes:
  - On-board software
  - Offline tuning and verification software
  - Ground-based report ingest and QC software
  - Documentation
- Direct users of the package: Teledyne, Boeing, Airbus, Delta, Aer Lingus, and others (most airlines obtain software from these sources)
- Available from NCAR and also IATA (the latter provides additional support and services including an EDR data sharing platform, assistance with building business cases, an EFB viewer)

Wind Algorithm Approach



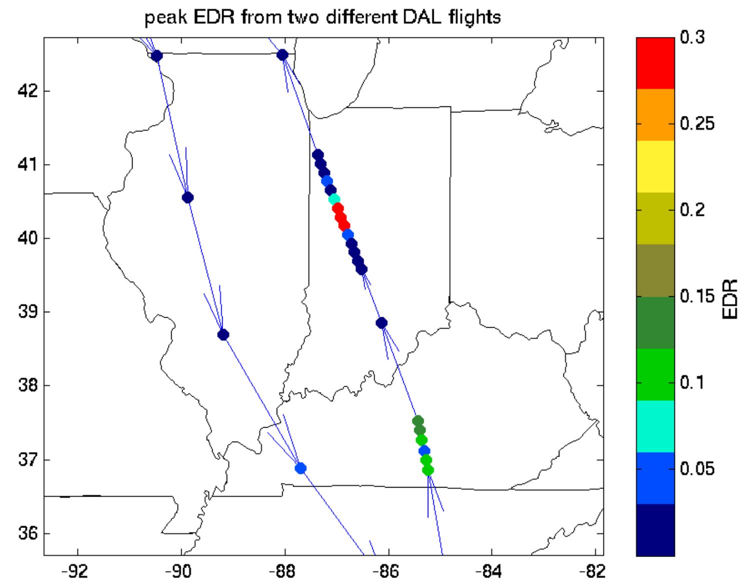
A vertical wind time-series is estimated primarily using TAS and AOA (functionally almost an anemometer). Using this, we can estimate the turbulence in an aircraft-independent way.

Note 1: There are some aircraft-dependent parameters involved to **compute** the EDR, but they relate to the conversion from indicated AOA to body axis AOA, length of the aircraft, and the signal processing applied to the EDR algorithm input up-stream from the algorithm.

Note 2: The response (i.e. accelerations) of the aircraft to the turbulence is not used.

Reporting

- To save on communications costs, it was decided to use event-triggered logic. When an “event” is identified, the logic triggers the downlink of a report.
- Because it is also important to know where the algorithm is working properly and there is *no or light* turbulence, routine reports consisting of 1 measurement are also downlinked at a specific time interval.
  - These routine reports are also downlinked after takeoff and landing.



This plot shows the locations of EDRs for 2 different flights. The color indicates the peak EDR. The blue arrows indicate the aircraft track.

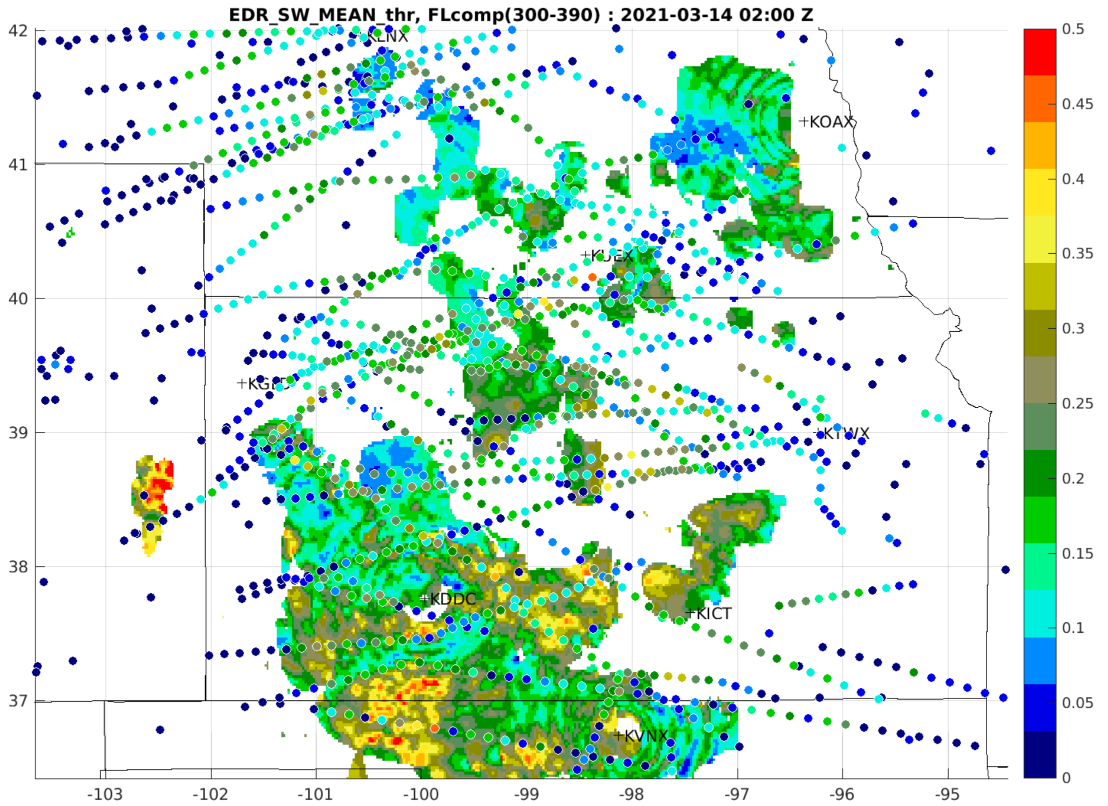
The isolated measurements (usually 15 minute spacing) are from routine reports.

Grouped measurements are from events strong enough to trigger the reporting.

Current Use Cases

- Operations
  - Input into GTGN
  - Displayed directly on EFB apps (e.g. FWV or IATA)
  - Used by Airline Meteorology
  - Aviation Met Offices (e.g. AWC)

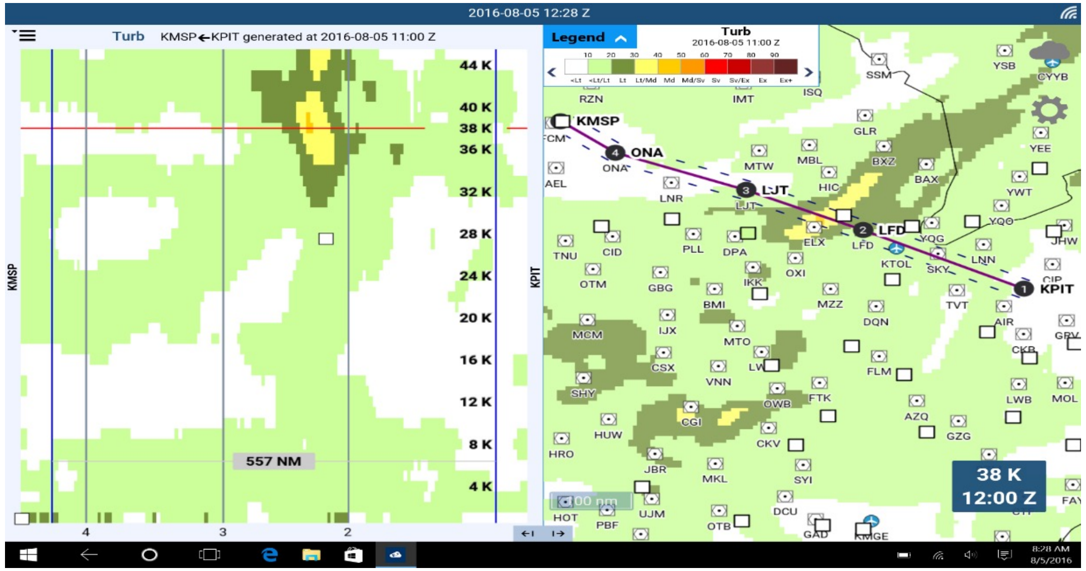
- R&D
  - Development, tuning, and verification of algorithms: GTG, GTGN, Global GTG, NTDA, satellite-based
  - Case studies
  - Climatologies

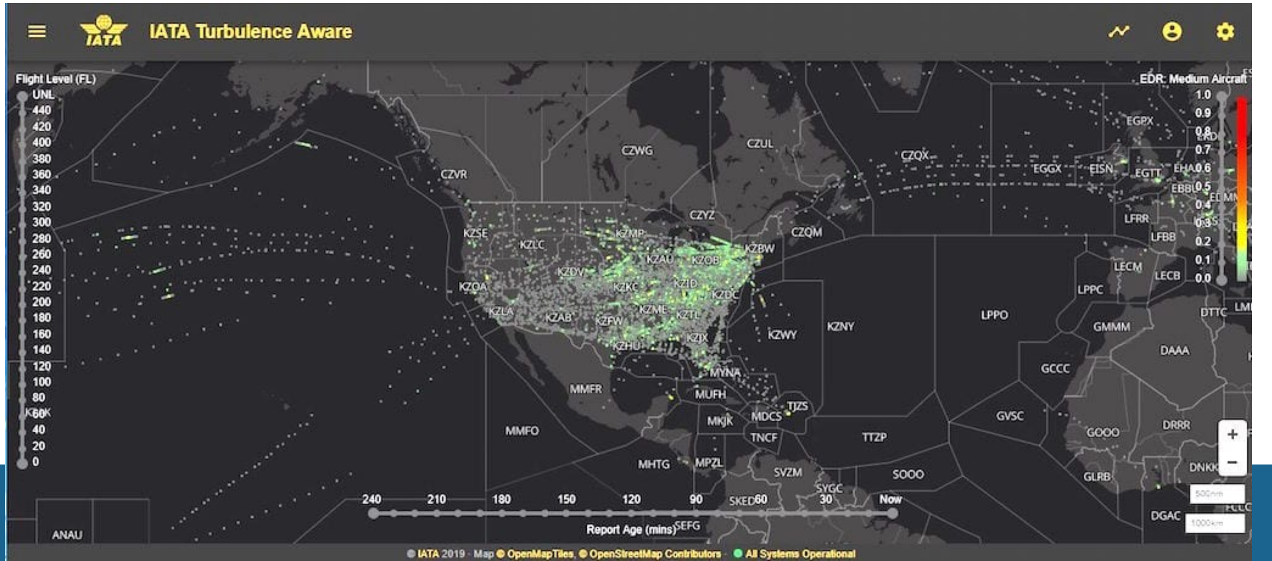


NTDA Case: 3/14/2021 02Z

InSitu EDR Into Operations…

A number of airlines are using *in situ* EDR data operationally using various approaches and display technologies.



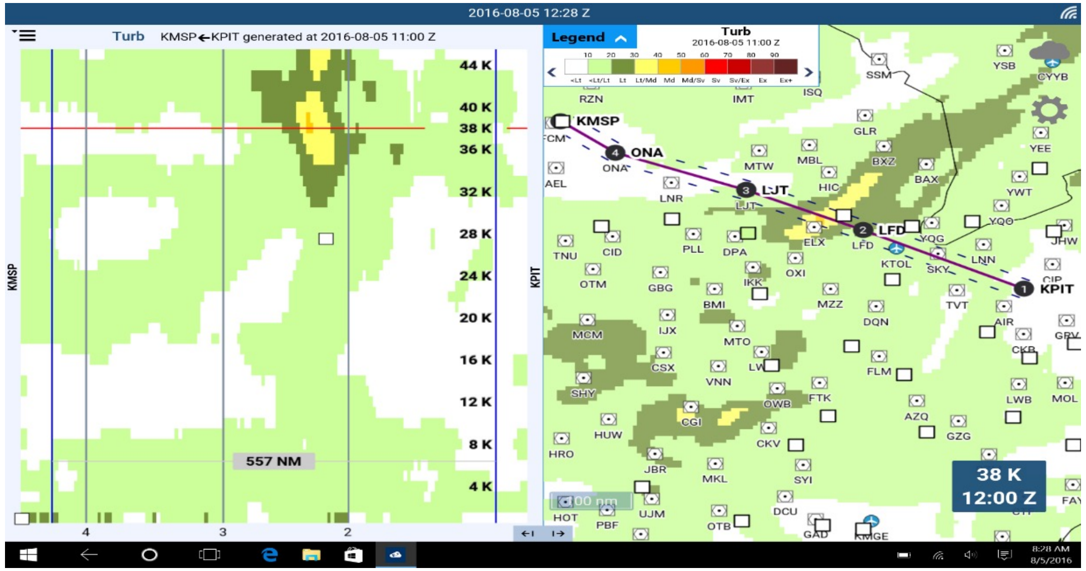


Eddy Dissipation Rate (EDR)
Operational Usage at Delta Air Lines

Late, subjective, and insufficient PIREPs led to poor outcomes in 2 areas:

1. Safety
2. Wild and often unnecessary altitude deviations as pilots seeked better rides using bad information obtained in an ATC "Chat Room". These deviations, in turn, led to an inefficient use of enroute airspace and/or reduction in enroute NAS capacity

- *The impact of these operational inefficiencies in fuel burn/deviation from the most optimal/flight planned altitudes is estimated to be very large*
- *EDR has significant attention from DAL senior management since it can present the NAS with better information so that pilots can make better decisions and potentially reduce these inefficiencies*



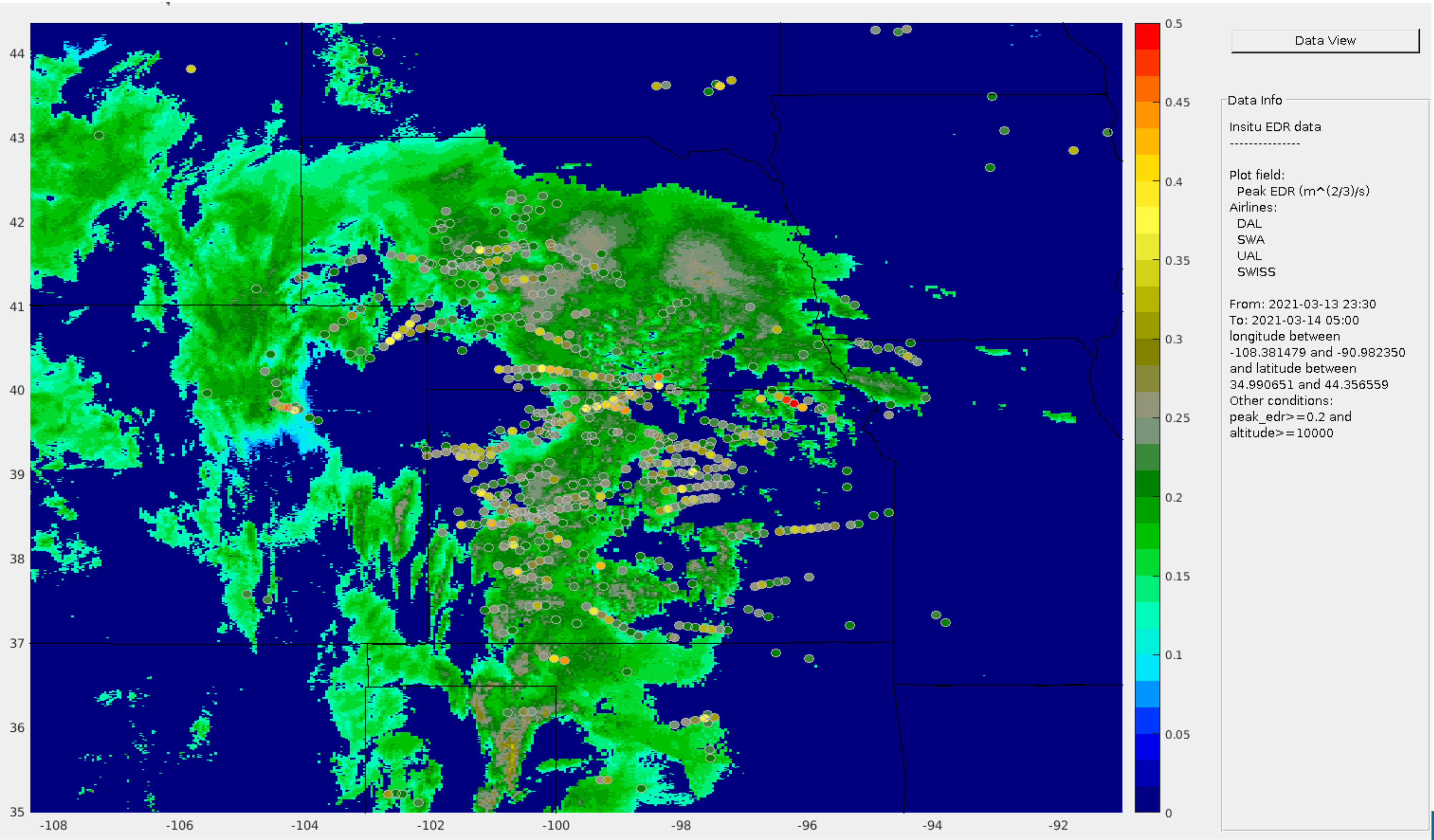
Delta's Flight Weather Viewer

With support of AOC and Flight Ops senior management, Delta created an EFB Flight Weather Viewer app in which GTG and GTGN are shown with insitu EDR reports overlaid with benefits in the areas of safety, capacity and operational efficiencies

Current Focus Areas

- Continue to evaluate the data quality of new and existing EDR data feeds and mitigate, as necessary.
- Continue to promote further deployments of the *in situ* EDR software.
- EDR Standardization (harmonization): ensure operational comparability of different *in situ* EDR algorithms across different fleets (e.g. via RTCA SC-206 and ITSAT).

Questions?



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0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Data View
Data Info
Insitu EDR data

Plot field:
Peak EDR (m^(2/3)/s)
Airlines:
DAL
SWA
UAL
SWISS
From: 2021-03-13 23:30
To: 2021-03-14 05:00
longitude between
-108.381479 and -90.982350
and latitude between
34.990651 and 44.356559
Other conditions:
peak_edr>=0.2 and
altitude>=10000

Turbulence Measurements from ADSB Reports

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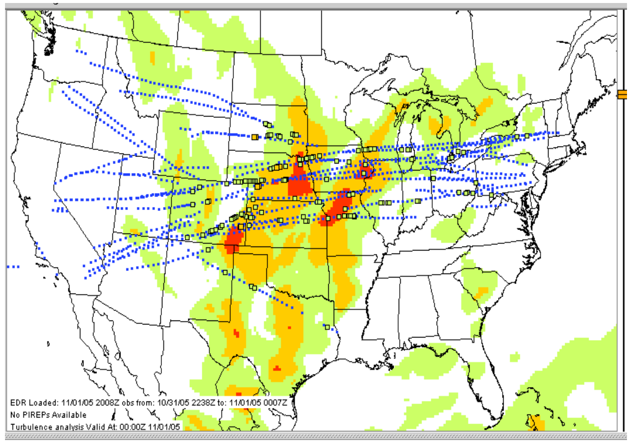
Background

- Turbulence encounters continue to be a significant operational problem.
- Given the spatial and temporal variability of turbulence, large numbers of observations are needed.
- Automatic Dependent Surveillance-Broadcast (ADS-B) is an aircraft position/velocity reporting system that has the potential to augment existing turbulence observations.



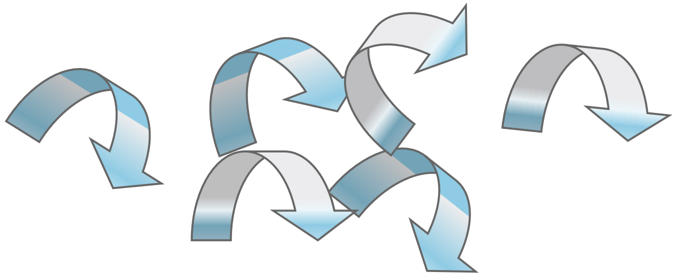
***In situ* EDR reports overlaid on GTG**

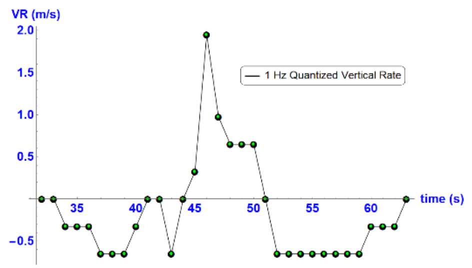
ADS-B Infrastructure

Potential Benefit of ADS-B Turbulence Reports is Significant

- **Large numbers of a/c**
  - Most a/c in US controlled airspace are now required to have ADS-B Out.
  - ***As of Feb 1, 2022 there are 158,055 US a/c reporting, including 108,010 fixed-wing GA a/c.***
  - Compare to ~1600 a/c reporting *in situ* EDR and ~1200 turbulence PIREPS/day (on average).
- **Good spatial and temporal accuracy.**
- **Aircraft side of implementation is already happening.**

Turbulence from ADS-B Reports: High-Level Concept





Input → Atmospheric turbulence → **System** → Aircraft/ Controls Dynamics → **Output** → Sampled/ quantized Vertical Rate (VR)

Desired algorithm goes <u>right to left</u> – meaning that we have to model each backwards step

Note: This project is separate from ADS-B WX in which an on-board <u>*in situ*</u> turbulence obs can be downlinked via ADS-B

Algorithm "Lessons Learned"

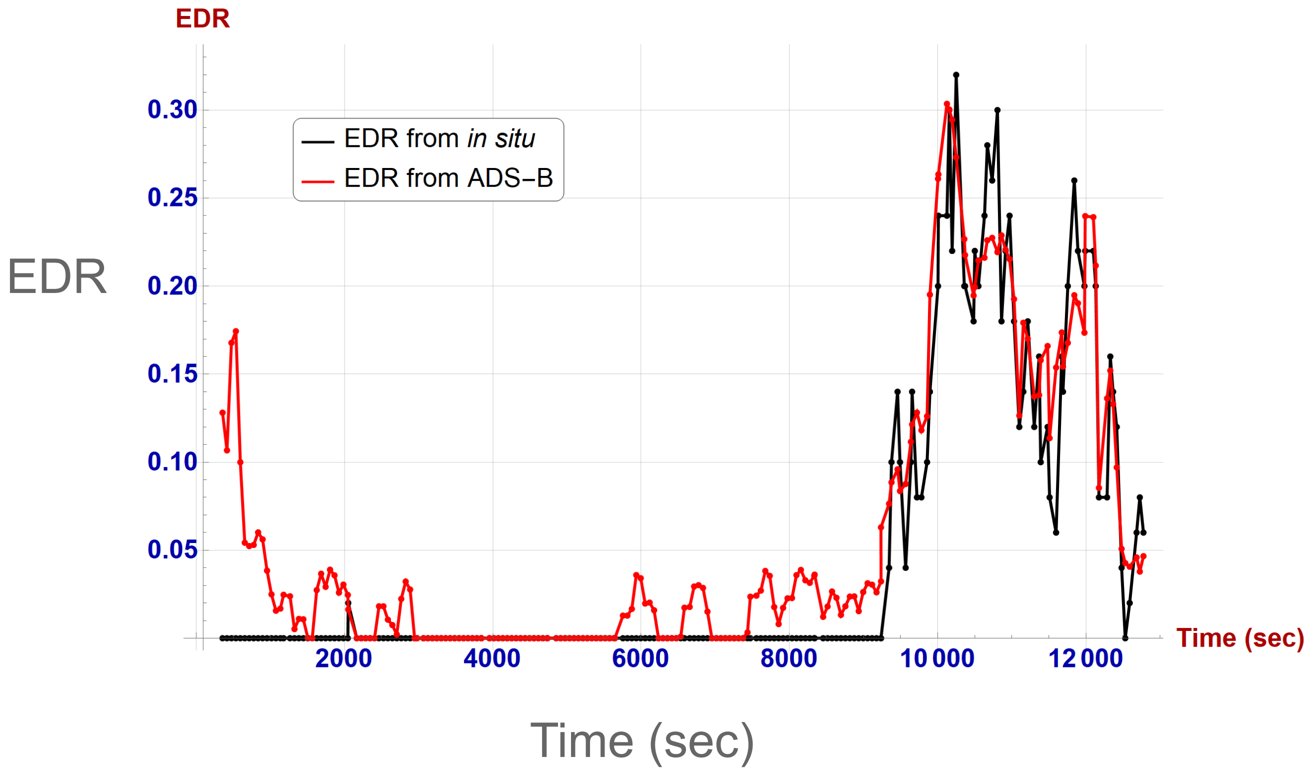
- **Extracting accurate turbulence information from the ADS-B vertical rate (VR) requires that we deal with:**
  - Low sampling rate (~1/sec)
  - Large quantization (*64 fpm* $\approx 0.325\, m/s$)
  - Maneuver and wave contamination
  - Scaling for different a/c types and operating conditions.

Qualitative assessment of real-world ADS-B case studies

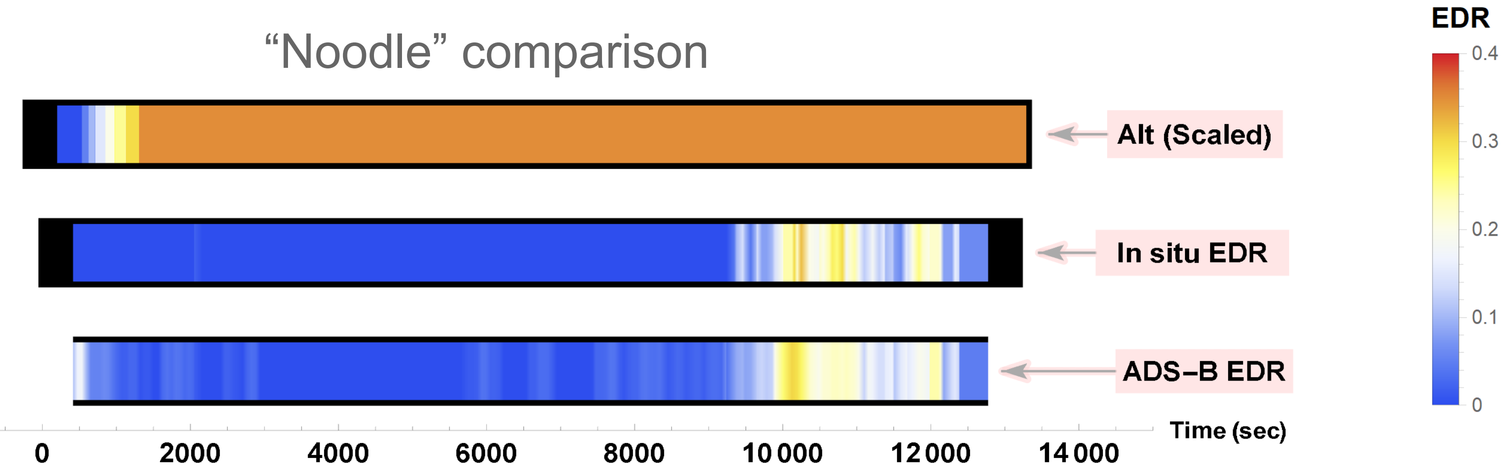
- **Event detection in general is good, in terms of timing and "seeing something."**
- **Overestimates come from:**
  - "Maneuver transitions." (often during climb-out periods)
  - "Short-wave" events
- **Underestimates come from:**
  - Over-filtering
  - Resampling issues
  - Sampling/quantization
  - Scale factors (?)

We think that many of these discrepancies can be mitigated with algorithm improvements

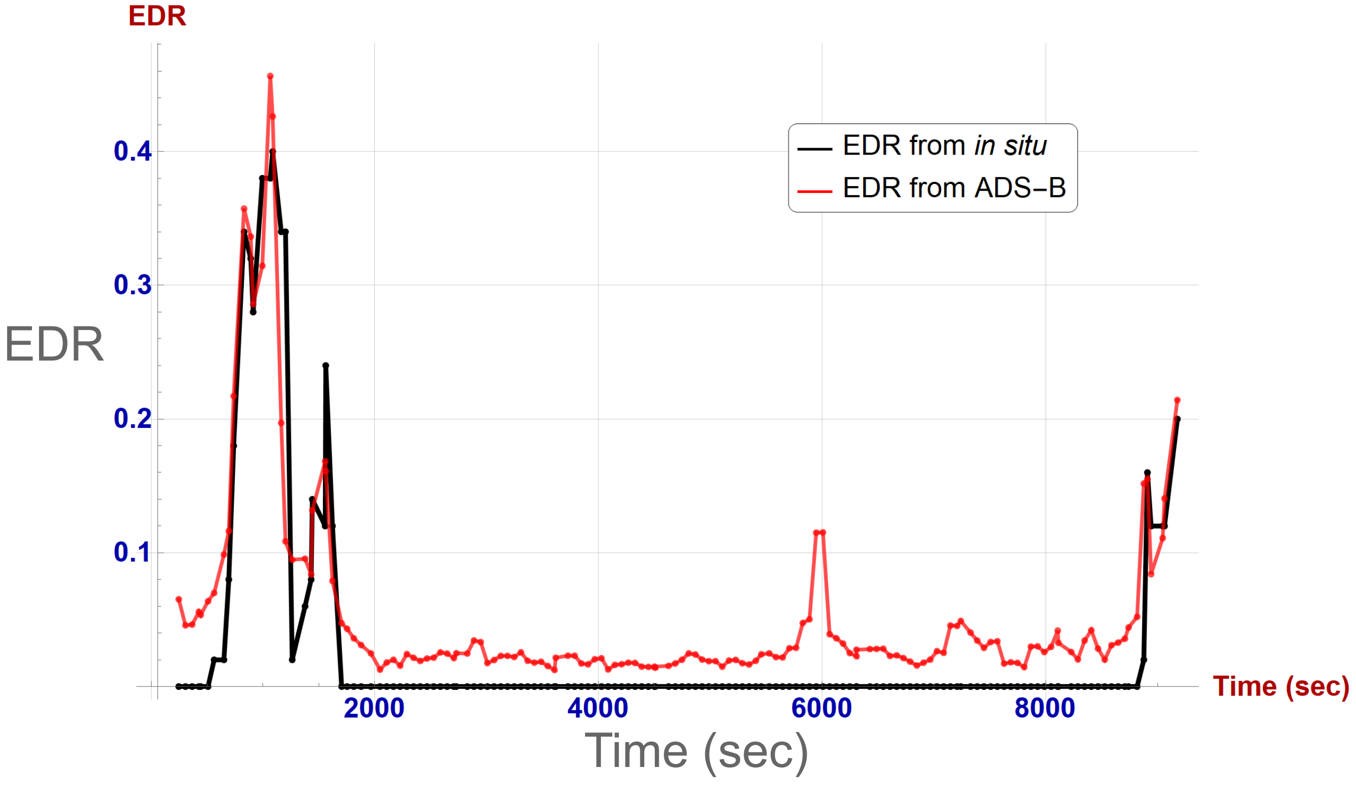
Case Study: "good event match" – Slight over during climb-out

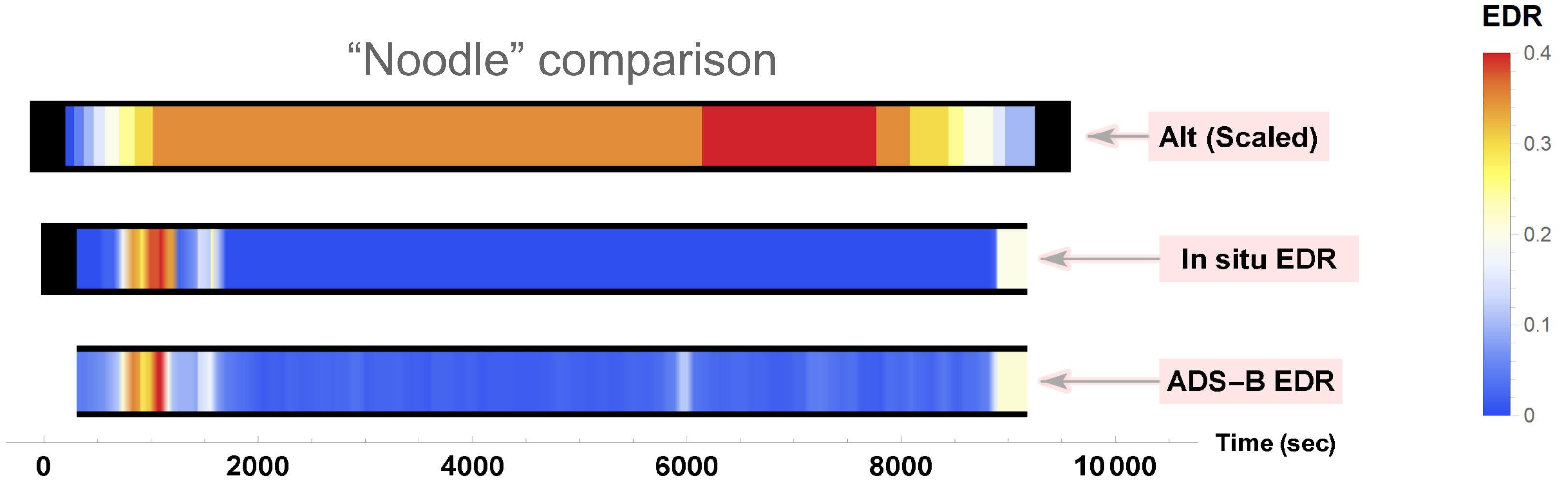


"Noodle" comparison



Case Study: “good event match” – Slight over during maneuver (reporting issue)





Short-term Next Steps…

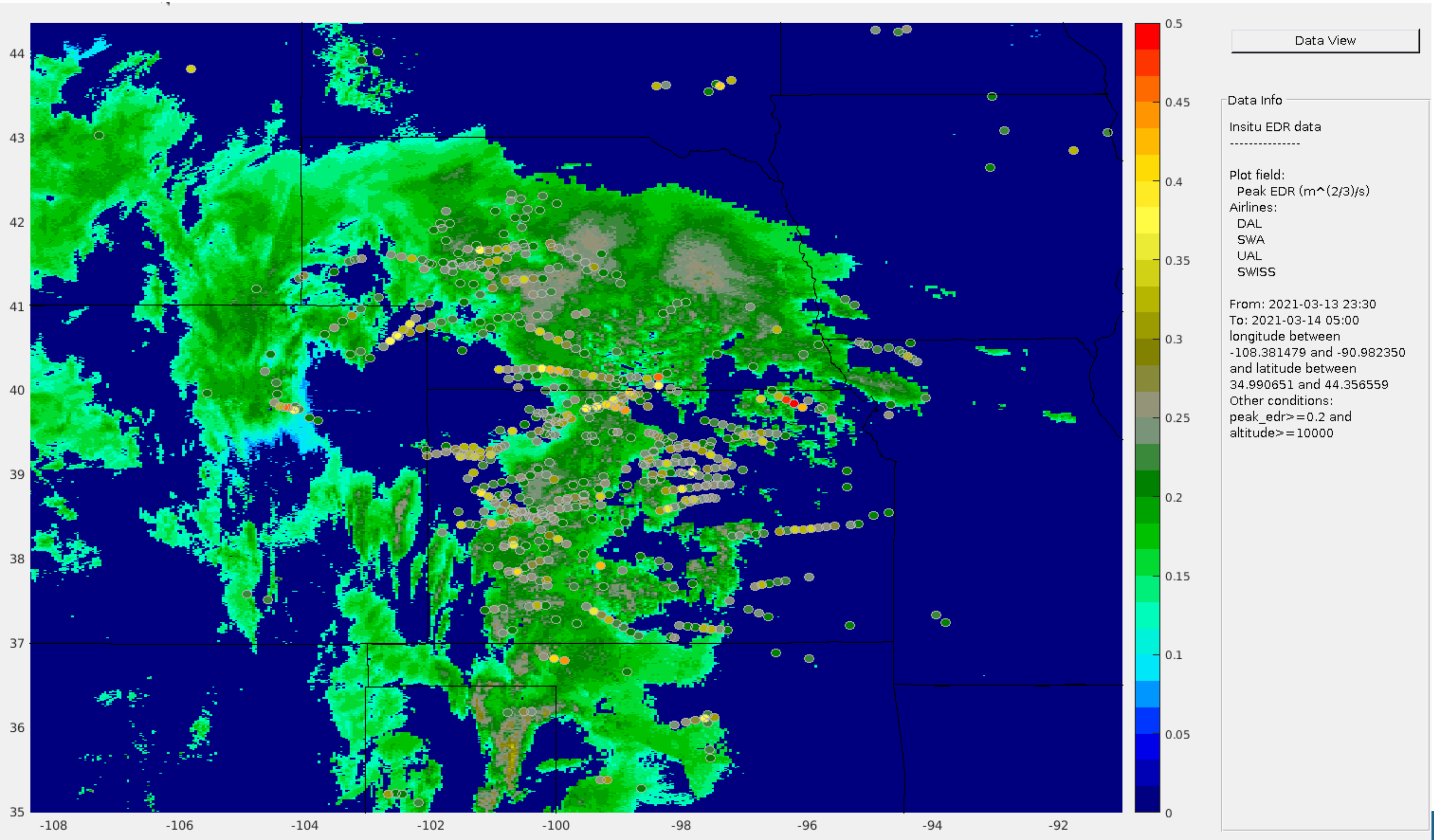
- Criteria needed for "good enough for operational demo…" (see next page.) Who makes this decision?
- What types of demos are appropriate/required?
  - Offline, canned data
  - Online, canned data (?)
  - Online, limited distribution
  - Online, wider distribution
- Who is operating the demos?
- What product is being demo-ed? (e-pireps? GTG-N?)

Longer-Term Issues…

- What are the decision points/criteria in moving forward towards operational deployment?
  - Is a favorable comparison to *in situ* EDR the sole criteria? (what about “wave-like” cases?) If so, how do we quantify, “favorable comparison”?
  - Event-based scoring seems to be appropriate.
  - How do we move forward with other aircraft types where there is no *in situ* EDR for comparison?
- Who will be the operator of the ADS-B turbulence algorithm?
- What are the vehicles for getting these data to users?
  - E-pireps?
  - GTGN?

The idea is to have multiple algorithm releases, steadily improving quality (e.g., waves, overs/unders) and quantity (e.g., more a/c types)

Questions?



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Data View
Data Info
Insitu EDR data

Plot field:
Peak EDR (m^(2/3)/s)
Airlines:
DAL
SWA
UAL
SWISS
From: 2021-03-13 23:30
To: 2021-03-14 05:00
longitude between
-108.381479 and -90.982350
and latitude between
34.990651 and 44.356559
Other conditions:
peak_edr>=0.2 and
altitude>=10000