The ADS-B VR Turbulence Project

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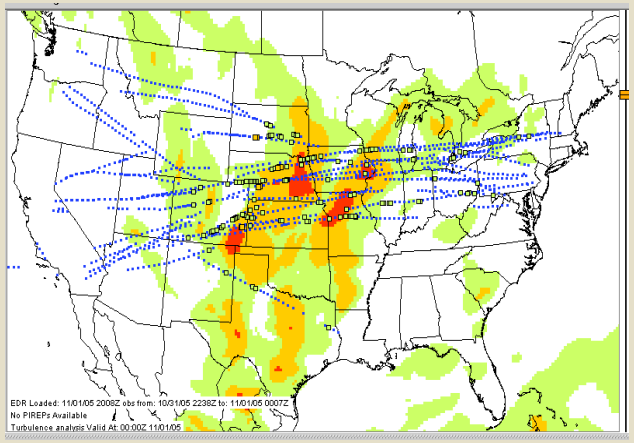
- This research is in response to requirements and funding by the Federal Aviation Administration (FAA).The views expressed are those of the authors and do not necessarily represent the official policy or position of the FAA.
- Part of this research was also sponsored by Aireon.

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

Research sponsored by the FAA's WITC program considering the utility of ADS-B reports for turbulence detection

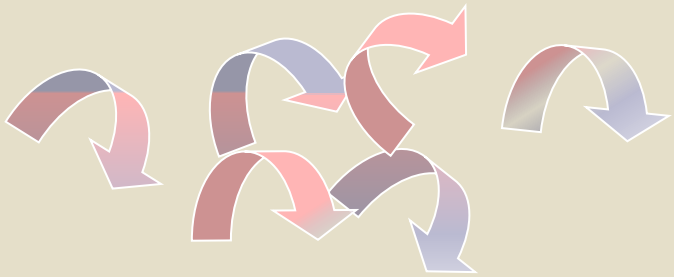
Potential Benefit of ADS-B Turbulence Reports is Significant

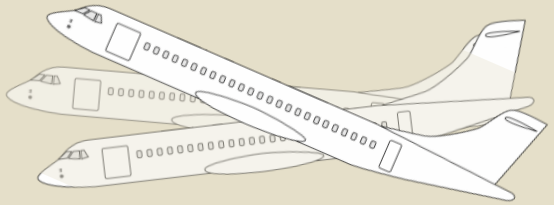
- **Large numbers of a/c**
  - Most a/c in US controlled airspace are now required to have ADS-B Out.
  - ***As of July 1, 2023 there are ~160K US a/c reporting, including ~105K fixed-wing GA a/c.***
  - Compare to ~1700 a/c reporting *in situ* EDR and ~1200 turbulence PIREPS/day (on an active day).
- **Good spatial and temporal accuracy**.
- ***No need to deal with aircraft side of implementation***.

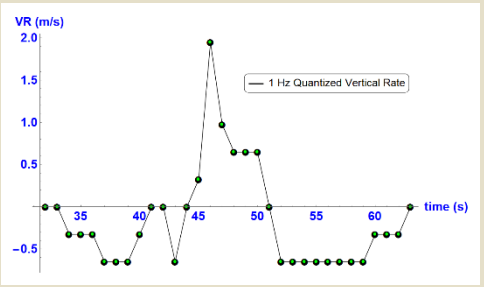
ADS-B VR Key Activities

- ADS-B VR EDR algorithm V1 is complete and undergoing testing/verification.
- Offline demo was performed to investigate the utility of ingesting ADS-B VR EDR into the Graphical Turbulence Guidance Nowcast (GTGN) product. Results were positive.
- Feasibility study regarding utility of space-based ADS-B (SBA) VR is ongoing and showing positive results.
- Preparation for CY24 online demo is underway. This will be a proof-of-concept for operational deployment.

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

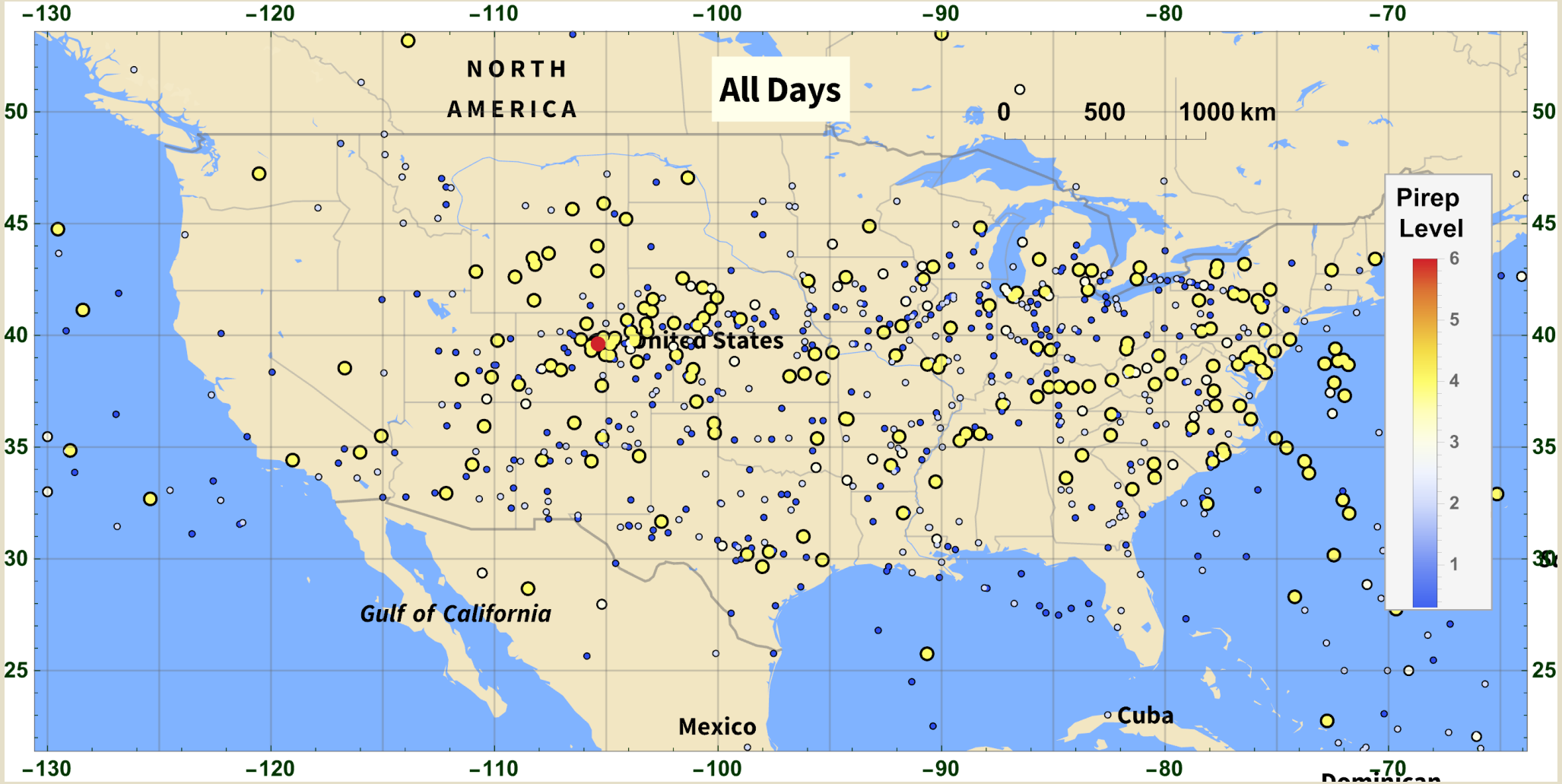
Algorithmic Challenges

- **Extracting accurate turbulence information from the ADS-B vertical rate (VR) requires that we address:**
  - Non-uniform sampling.
  - Low sampling rate (~1-2 Hz).
  - Large quantization (*64 fpm* $\approx 0.325\ m/s$).
  - Maneuver/wave contamination.
  - Scaling for different a/c types and operating conditions.
- The NCAR in situ EDR algorithm, on the other hand, uses 8 Hz estimates of the vertical wind – so these issues are not problematic there.

Algorithmic Challenges, Cont'd

- The low sampling rate means that at times, we'll have a hard time observing the smaller-scale turbulence scales of interest.
- Maneuver and wave contamination means that some sort of mitigation/ filtering is needed.
- Quantization contamination also implies the need for mitigation/filtering. ("step functions" = "bad for derivatives")
- Vertical rate is the response of the aircraft to various inputs (wind, controls), and we're after an aircraft-independent turbulence metric (EDR). Hence, we have to scale aircraft response as a function of a/c type, altitude, airspeed, and weight.

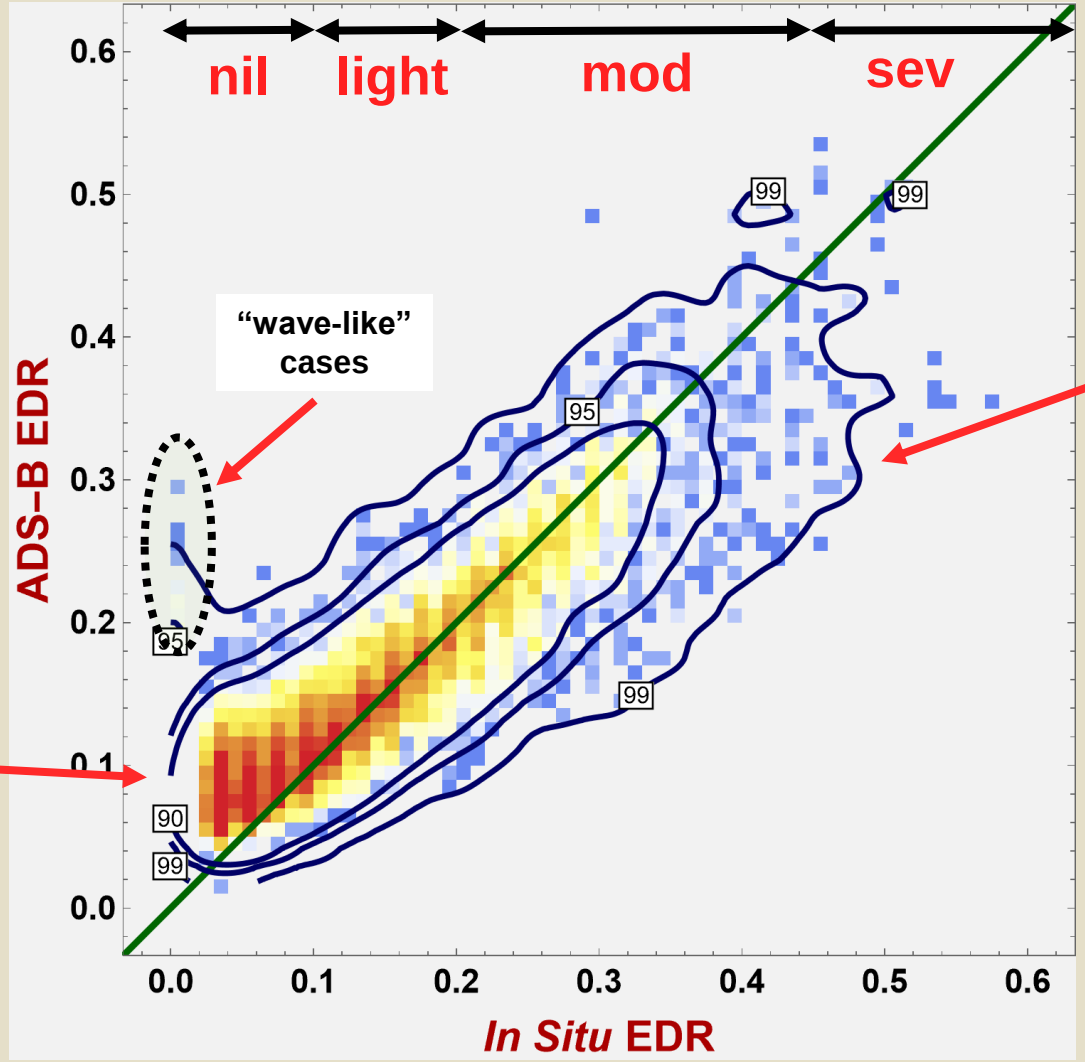
Pireps for Four Case Study Days



Active turbulence days

ADS-B VR Algorithm V1 Verification (~335 flights over 4 days)

Ongoing efforts are focused on addressing over/under-estimates (“outliers”)



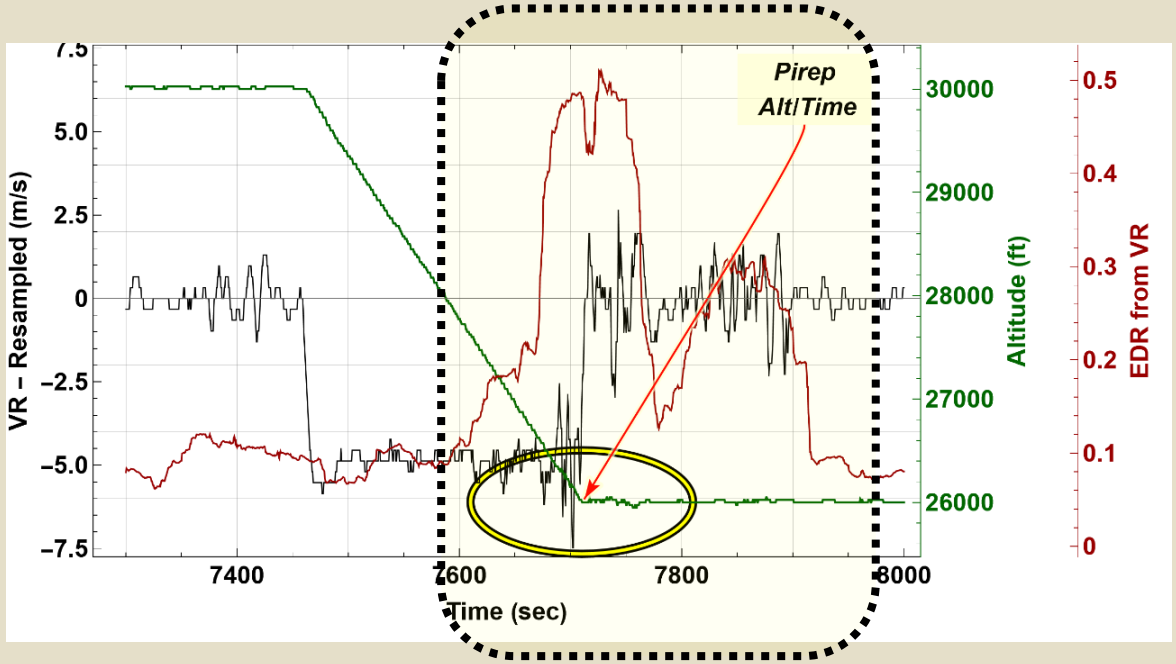
Note: logarithmic scaling

>95% of points are w/in +/- 0.1 of one-to-one line

Pireps vs. ADS-B VR EDR (Ground-Based ADS-B)

Both pireps are “Moderate” – ADS-B VR are also in that range

ADS-B VR Overestimate During Maneuver



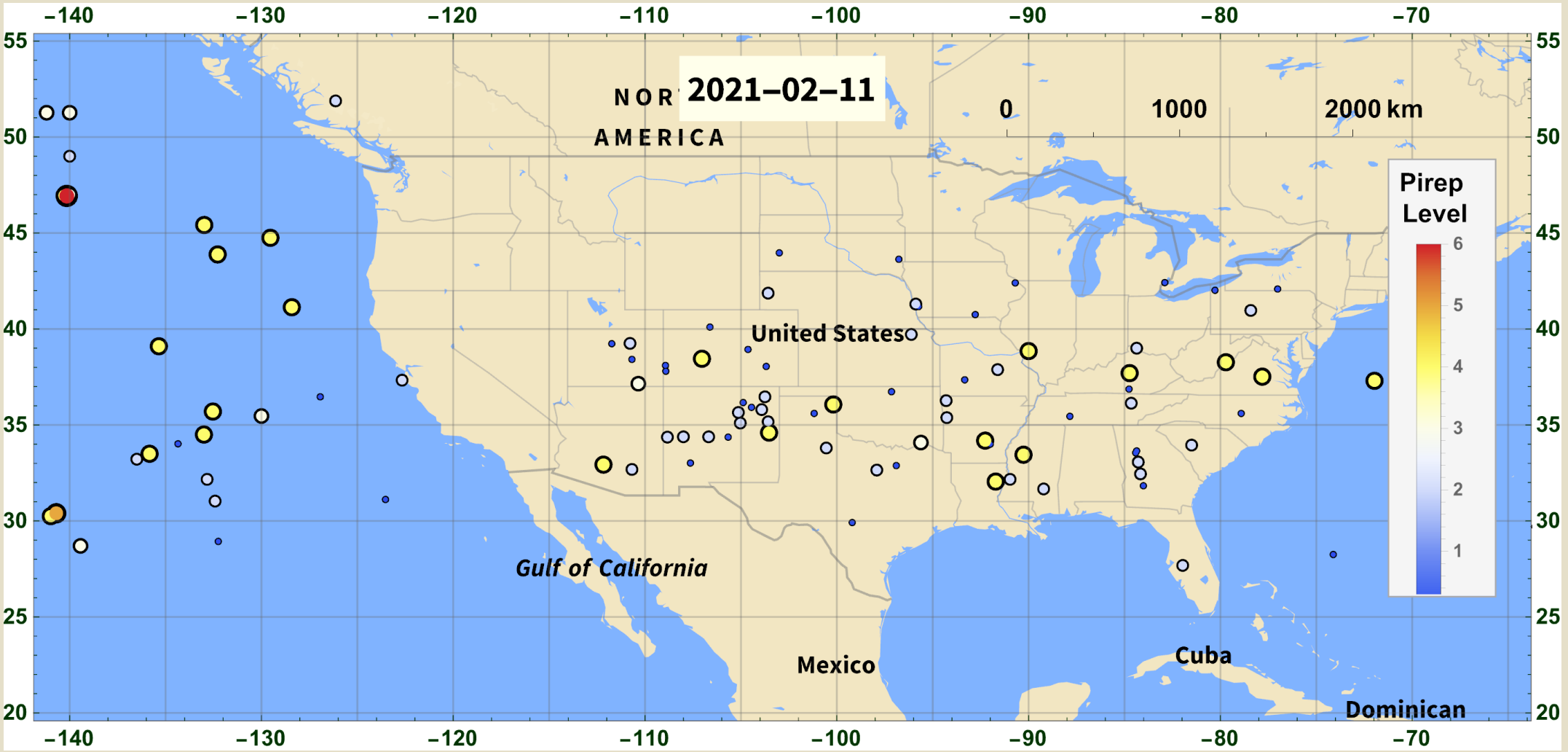
Moderate Pirep vs. severe ADS-B VR estimate

Sharp a/c motions during maneuvers are hard to separate from turbulence

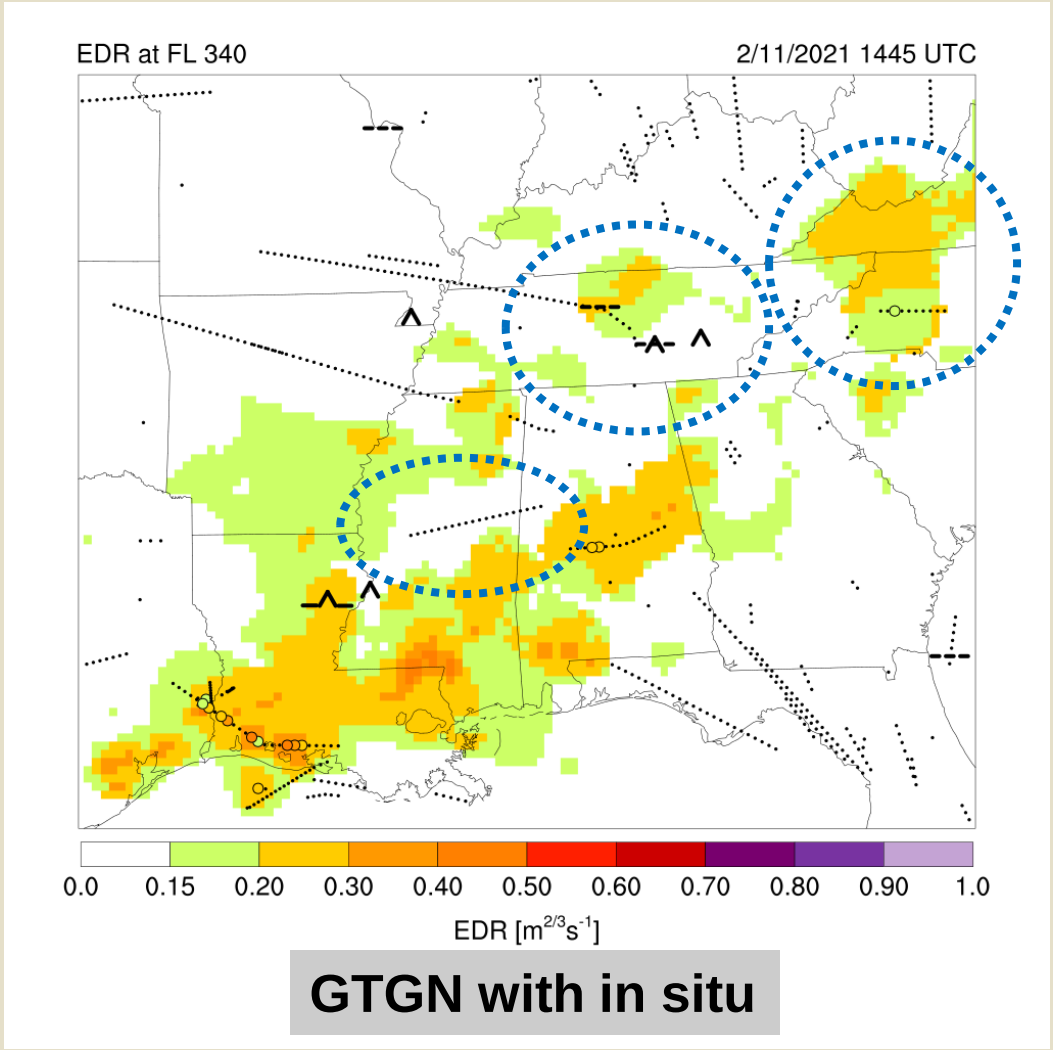
GTGN/ADS-B VR Demo Concept/Efforts

- This demo was a proof-of-concept.
  - One 12 hour active time period was used, consisting of widespread convective and jet stream turbulence.
  - Two scenarios were considered:
    - **Inter-comparison study:** 2189 flights; 737's, where both ADS-B VR and NCAR in situ EDR were available..
    - **Investigated the utility of adding ADS-B VR:** 4637 ADS-B flights, (737's & A32x's w/o NCAR in situ), versus all NCAR in situ EDR.
- Preliminary results have been analyzed and are very encouraging.

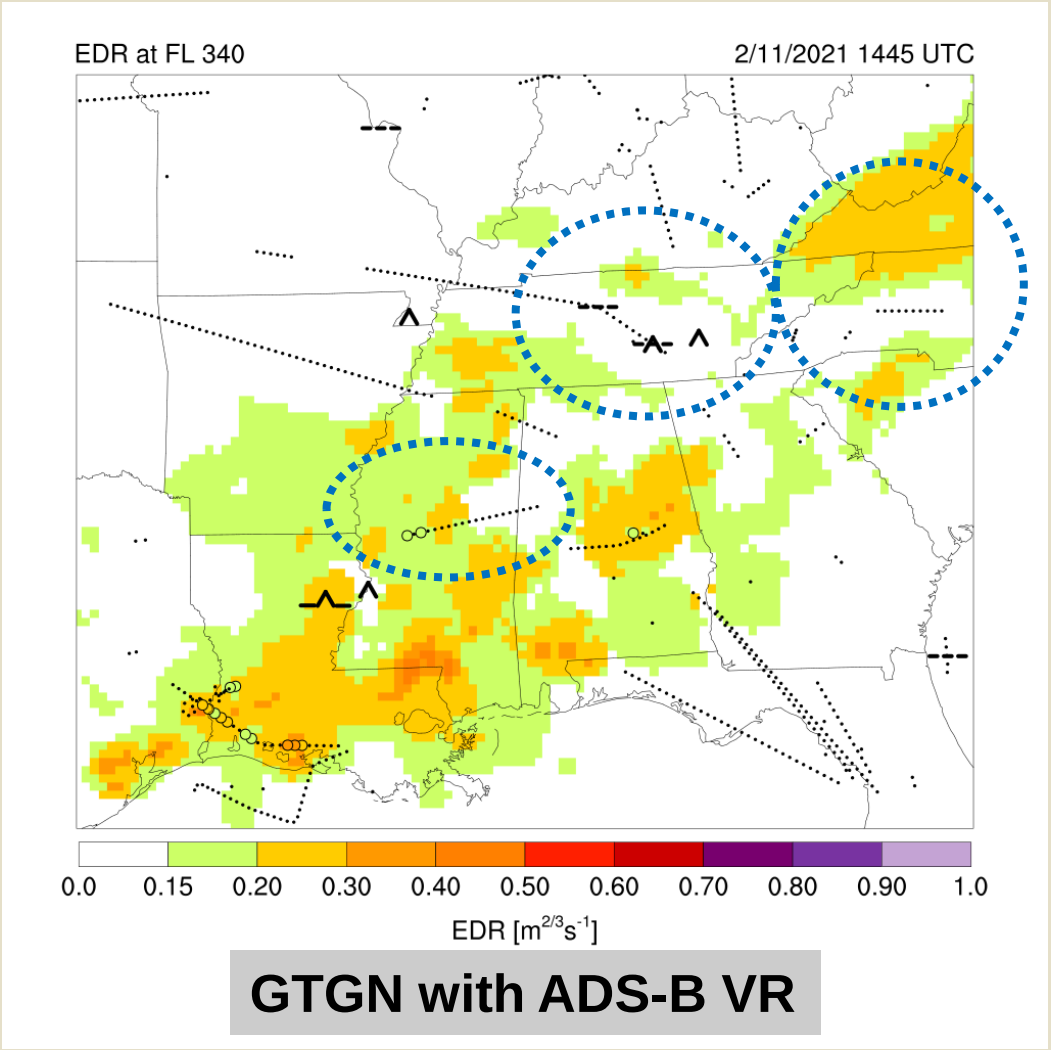
Pireps for GTGN/ADS-B VR Demo



GTGN/ADS-B VR Demo – Example Results (“Scenario 1”)



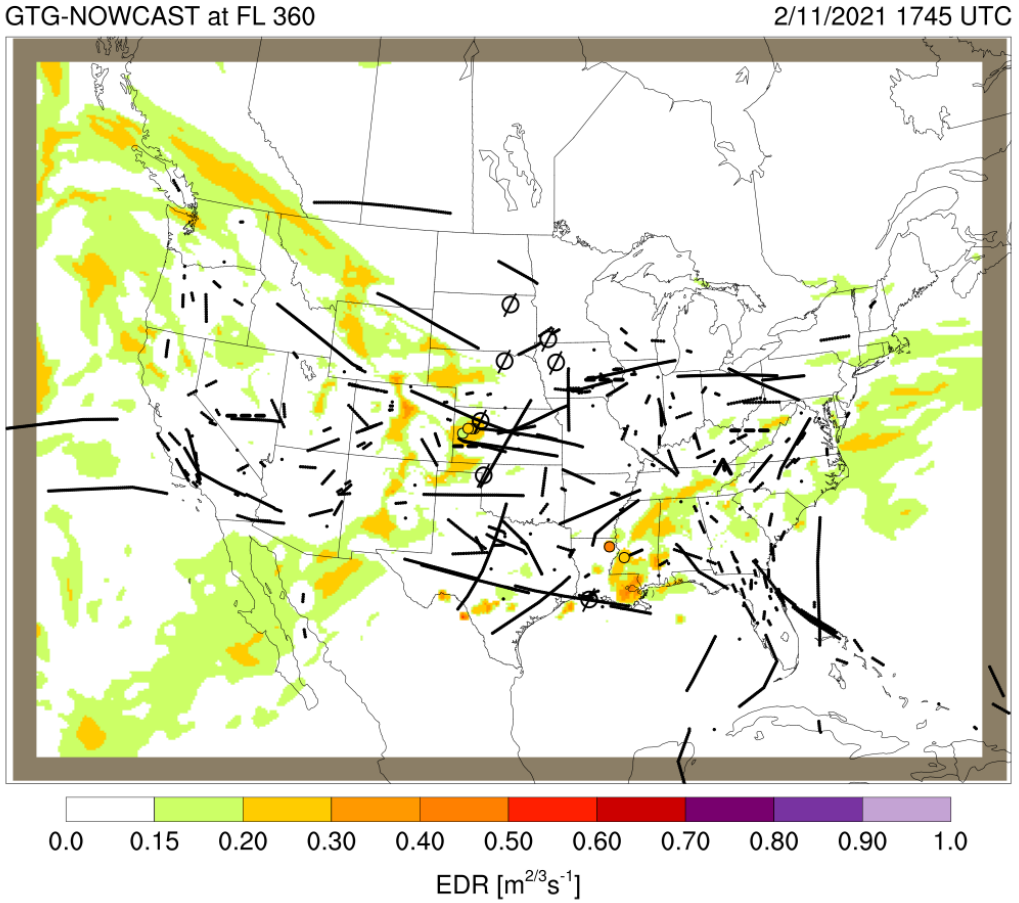
GTGN with in situ



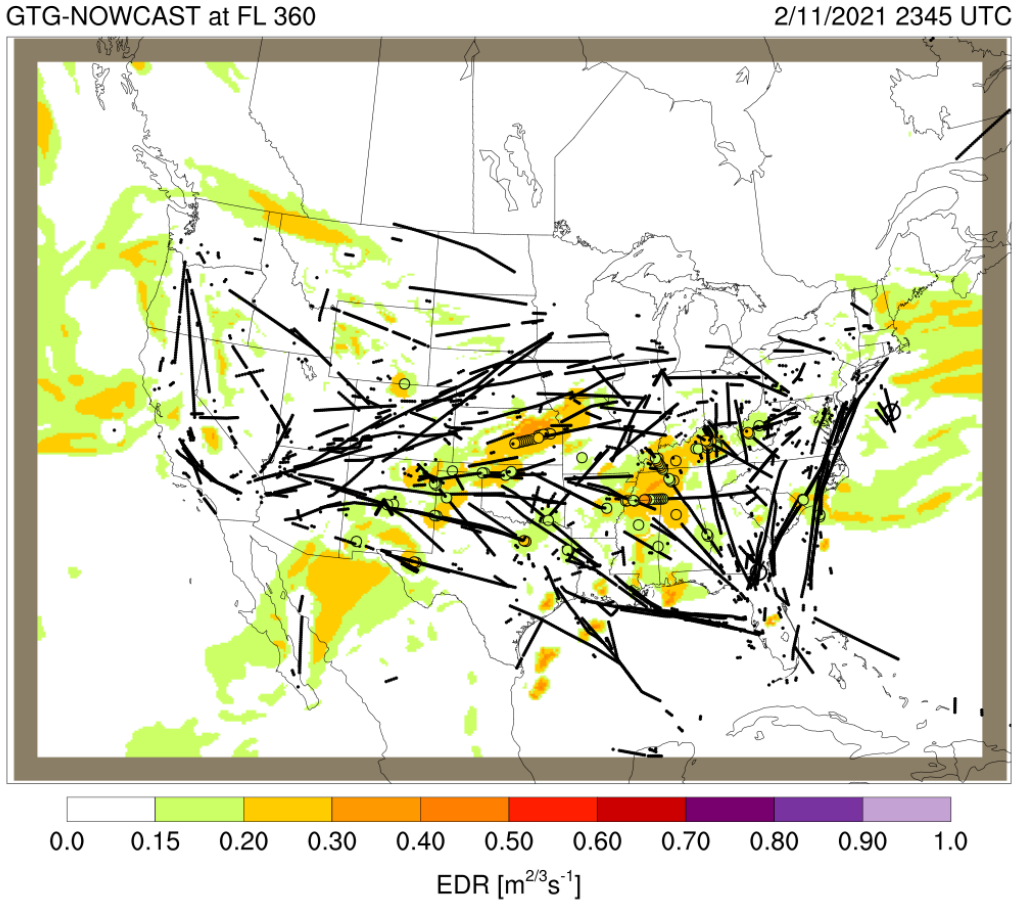
GTGN with ADS-B VR

Very similar results, with minor differences

GTGN/ADS-B VR Demo – Example Results (“Scenario 2”)



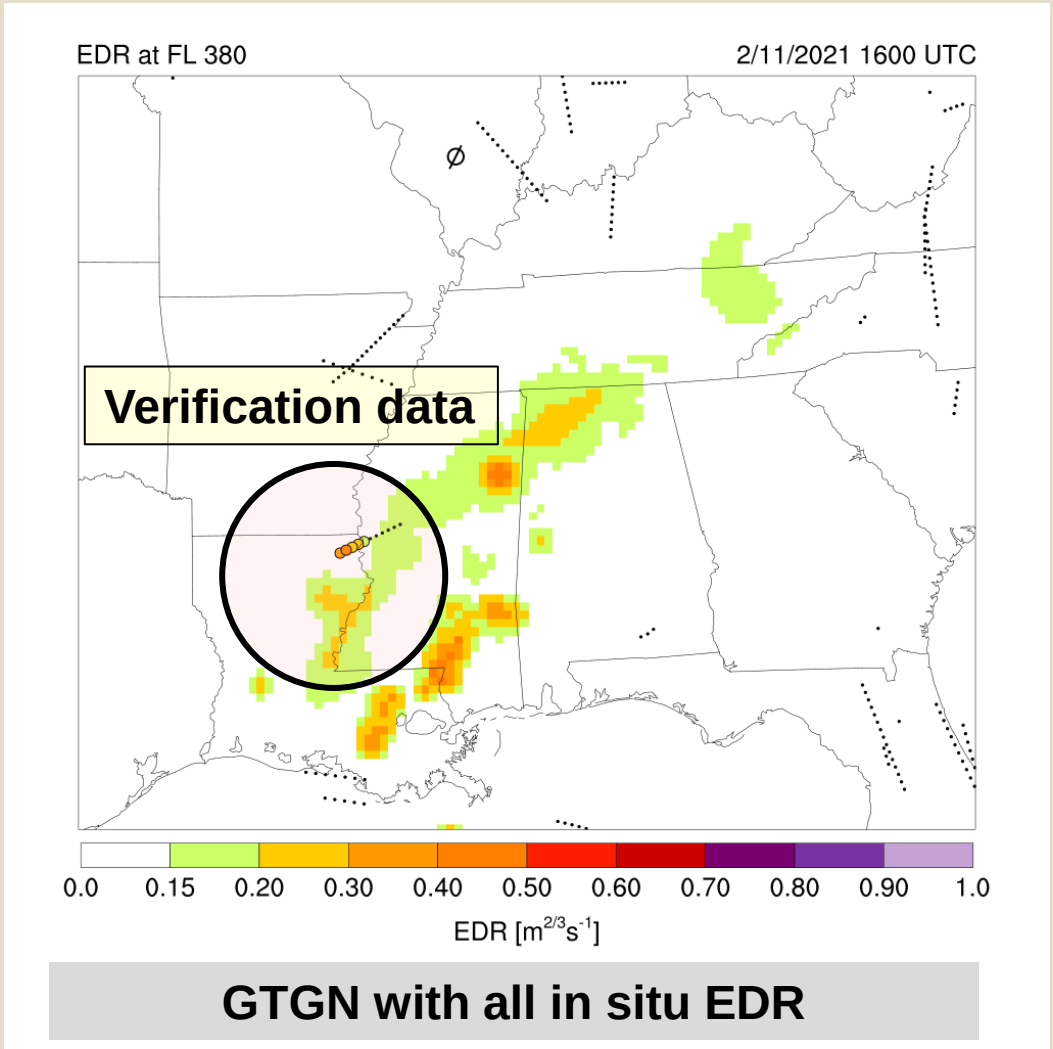
GTGN with all in situ



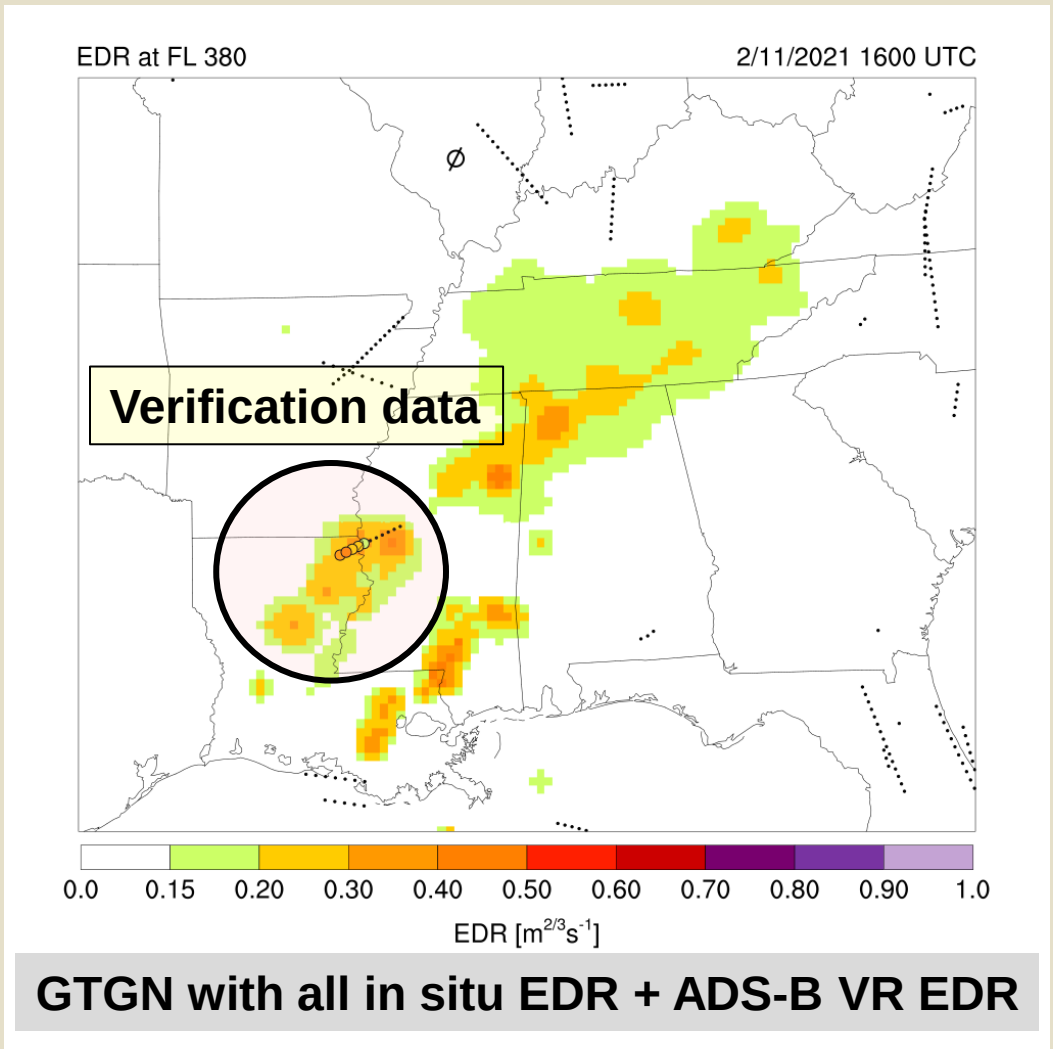
GTGN with ADS-B VR

Doubling the number of reports even with just ADS-B 737s and A32x’s

GTGN/ADS-B Demo: Case Study Showing Benefits of ADSB-VR



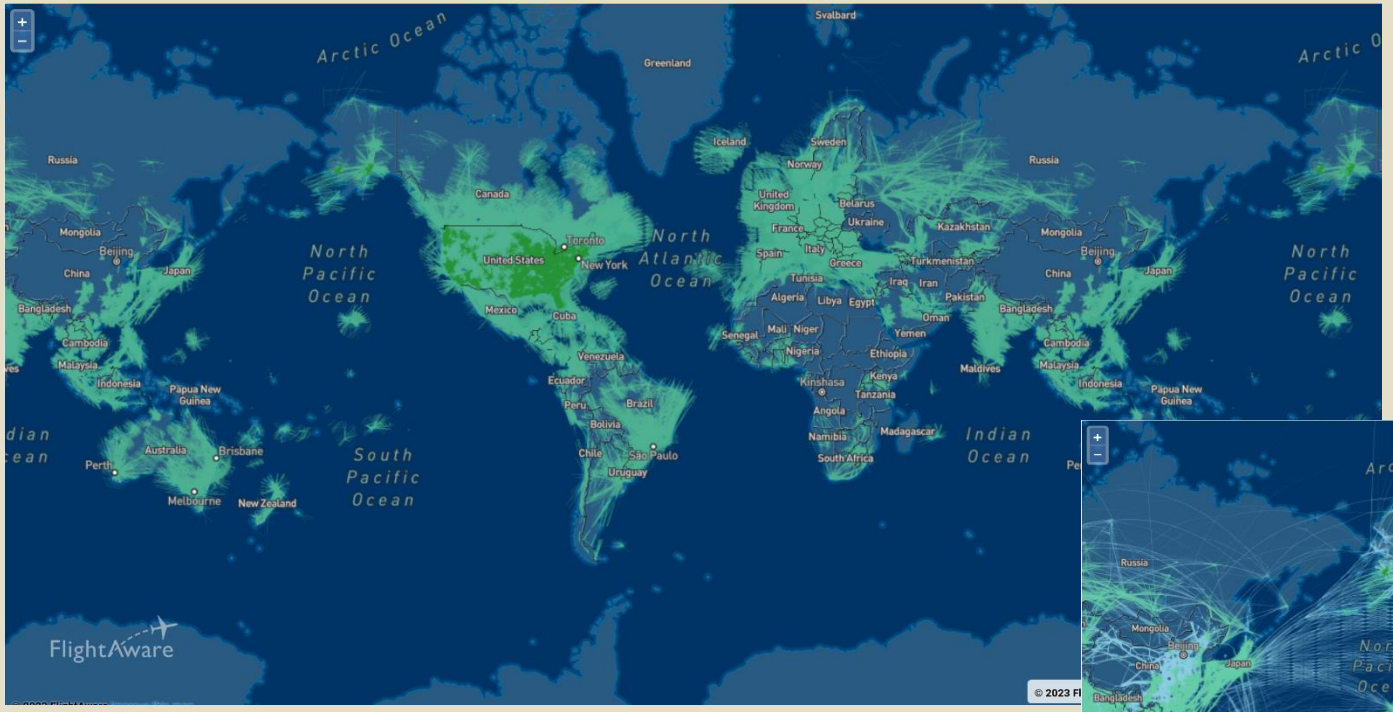
GTGN with all in situ EDR



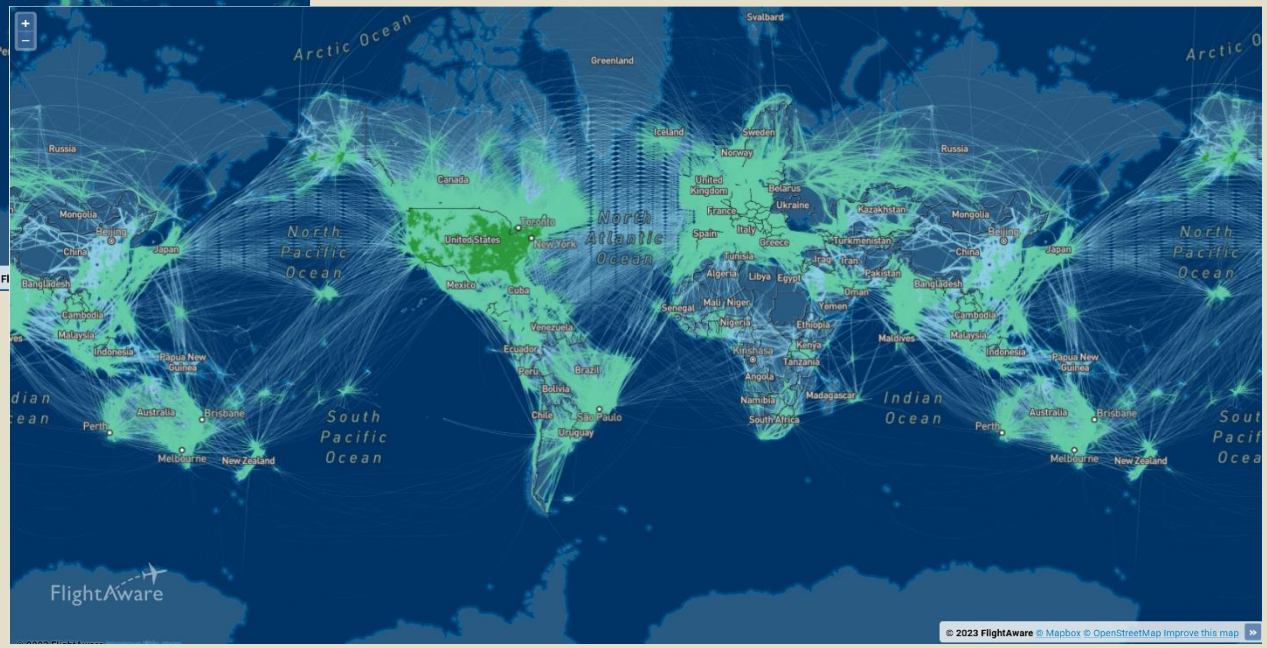
GTGN with all in situ EDR + ADS-B VR EDR

Adding ADS-B VR to GTGN Improves Event Detection

ADS-B Coverage Map (1 week, source: FlightAware/Aireon)



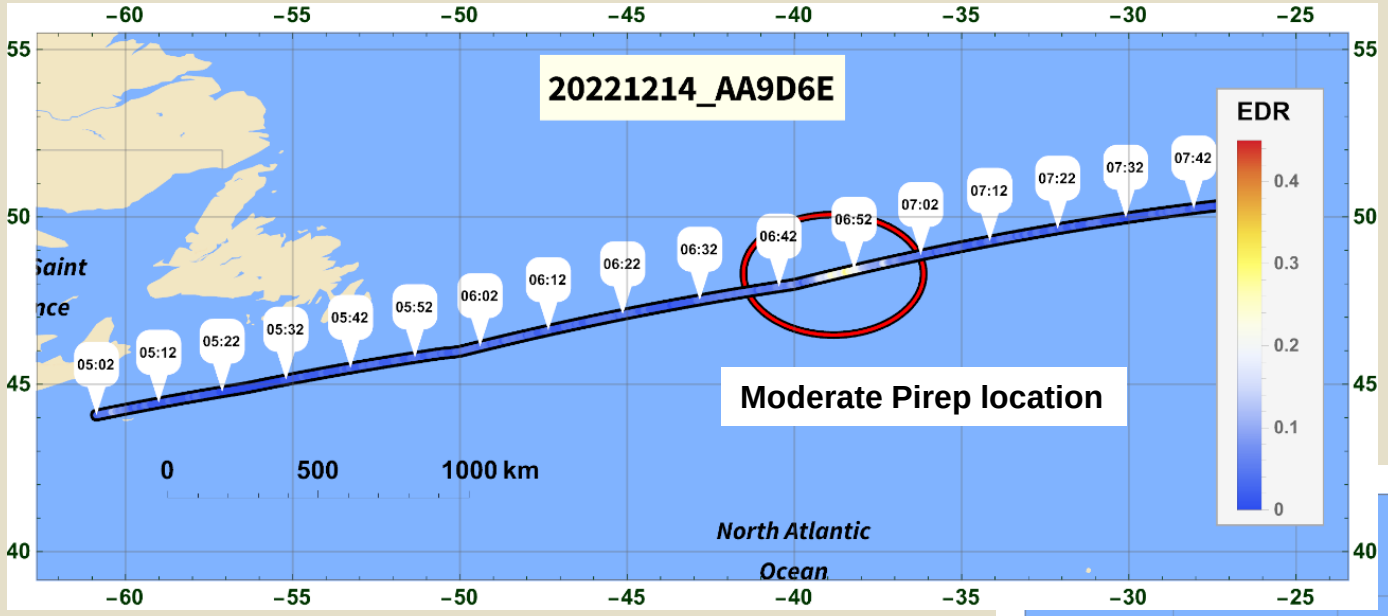
Ground-based



Ground-based + Satellite-based

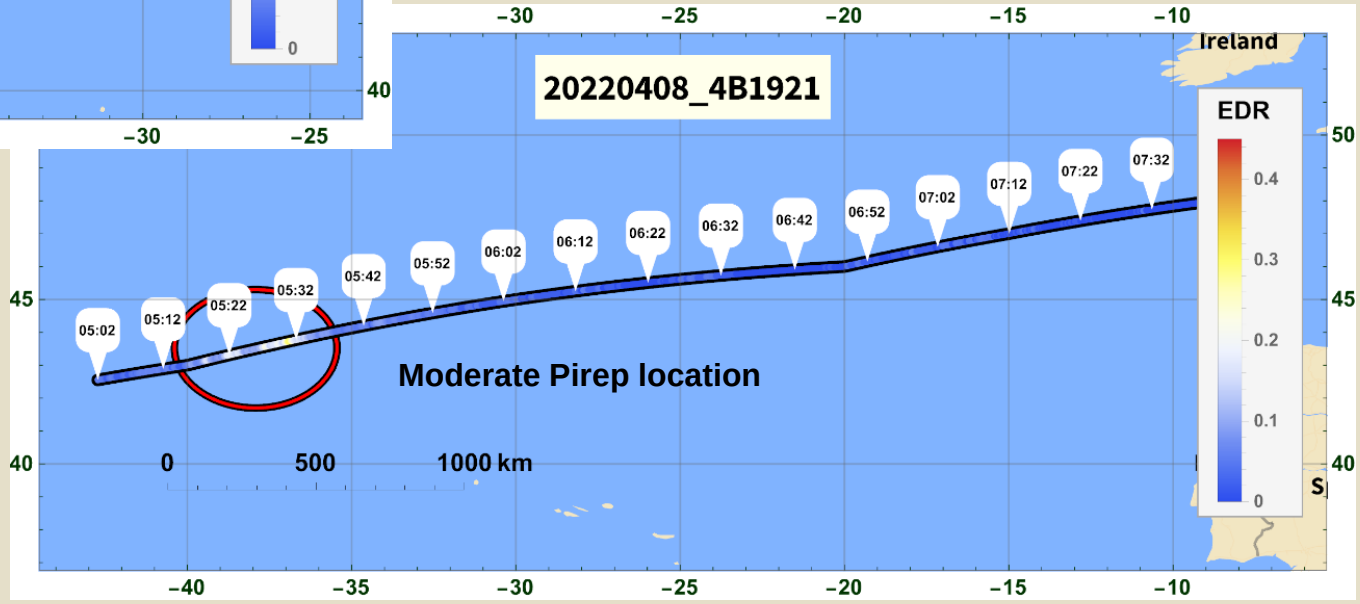
Ground-based + Spaced-based ADS-B provides broad global coverage

Application to Spaced-Based ADS-B (SBA) Data



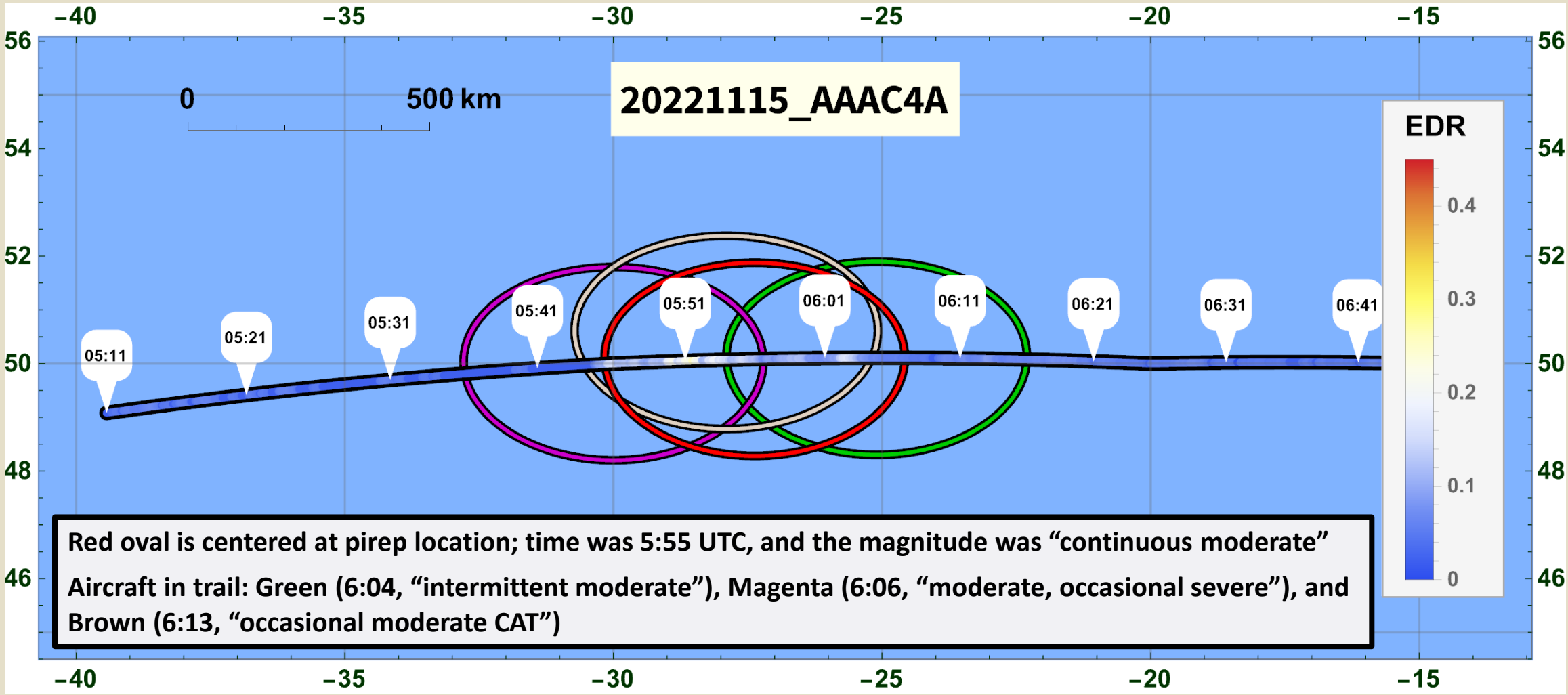
Feasibility study is being funded by Aireon to investigate utility of SBA data for turbulence detection

ADS-B VR algorithm was modified to run on SBA VR data – results have been positive



SBA data allows for enhanced turbulence detection over remote regions

Spaced-Based ADS-B (SBA) Data: Case Study



A “heads up” could have been provided to the a/c in trail…

Follow-on Activities

- Considerations for operational use of the data. NCAR has provided the FAA with plans for moving towards, (1) Limited operational deployment (limiting a/c types and alts), and (2) Final operational deployment.
- Parallel deployment path: Limited operational deployment of ADS-B VR V1 Algorithm, with parallel algorithm improvement and applicability to all a/c types (esp. GA).
- Participate in, and support RTCA standards development.

Ongoing/Future Work

- CY24, “online” CONUS demo: proof of concept regarding operational deployment.
- Follow-on GTGN demos.
- Algorithm improvements:
  - Maneuver/wave detection/mitigation. (focus on overestimates.)
  - Better “adaptation” for filtering and processing windows. (focus on underestimates.)
- Continuation of Aireon spaced-based ADS-B feasibility study.

Planning for CY 24 On-line Demonstration

- Plan is to perform a pseudo-operational demonstration in lab setting at L3-Harris.
- NCAR will provide semi-hardened c code to L3-Harris, who will host and operate.
- QC algorithms will be integrated.
- Focus will be on B737/A32x aircraft, over 18kft (data feed issue).
- This is intended to provide a test-bed for investigating requirements for operational deployment of the algorithm – including needs from the operational provider perspective.