Automatic Dependent Surveillance-Broadcast (ADS-B) Derived Turbulence

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Background

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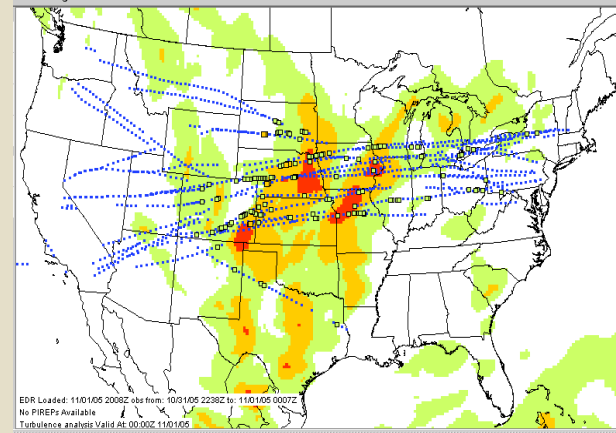
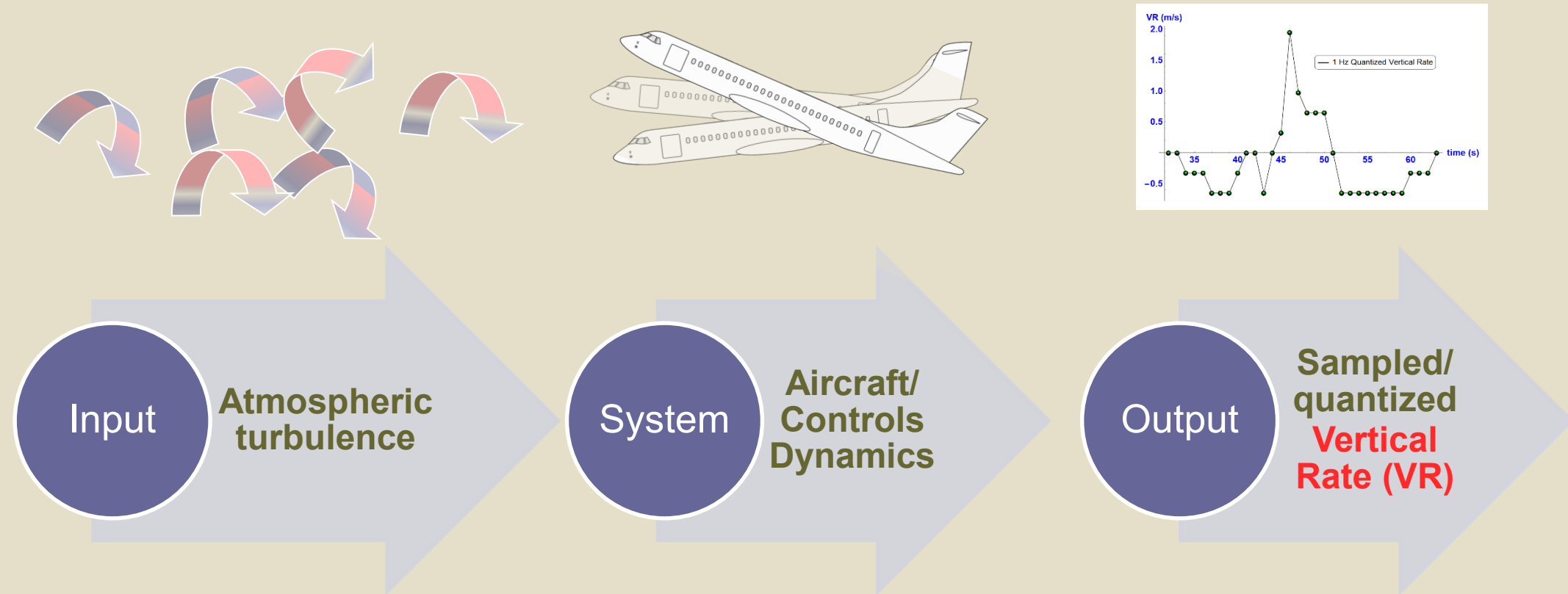*In situ* **EDR reports overlaid on GTG**

ADS-B Infrastructure
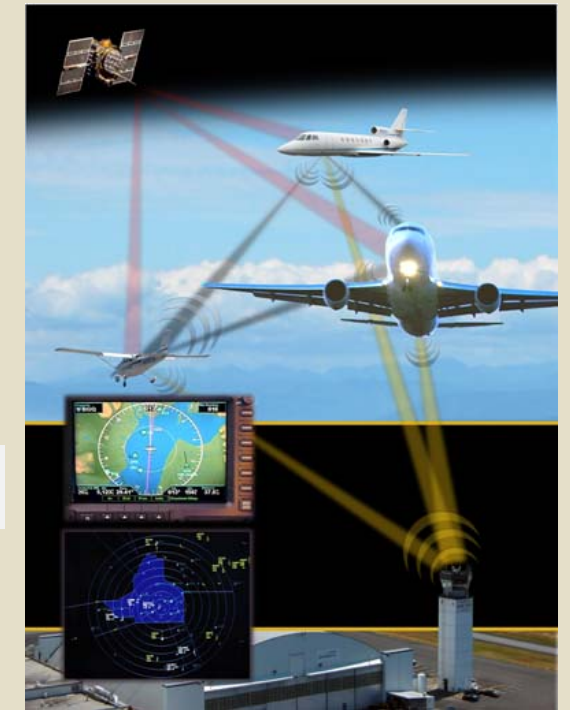
Potential Benefit of ADS-B Turbulence Reports is Significant

- **Large numbers of a/c**
  - Most a/c in US controlled airspace are now required to have ADS-B Out.
  - *As of Oct 1, 2021 there are 158,406 US a/c reporting, including 107,378 GA a/c. (Int'l carriers = 2785 a/c)*
  - Compare to ~1400 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**.
- **Potential use space-based ADS-B reports for oceanic/remote regions.**

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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

Algorithm Development Approach - Ground-based Reports

- **Developing signal processing methods to address:**
  - Sampling rate (~1 sec) and quantization (64 ft/min) of vertical rate data
  - Maneuver/wave mitigation

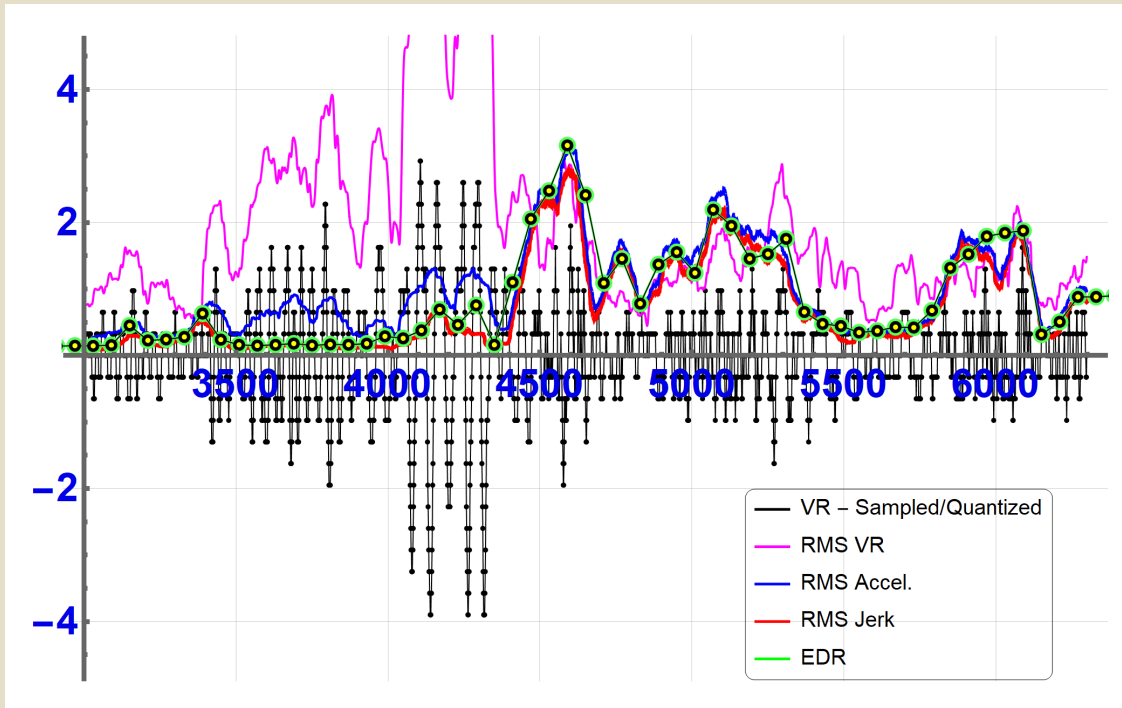- **Developing scaling algorithm to produce EDR from vertical rate**

- **Verification/Development using:**
  - Wind/vehicle simulation (737-800)
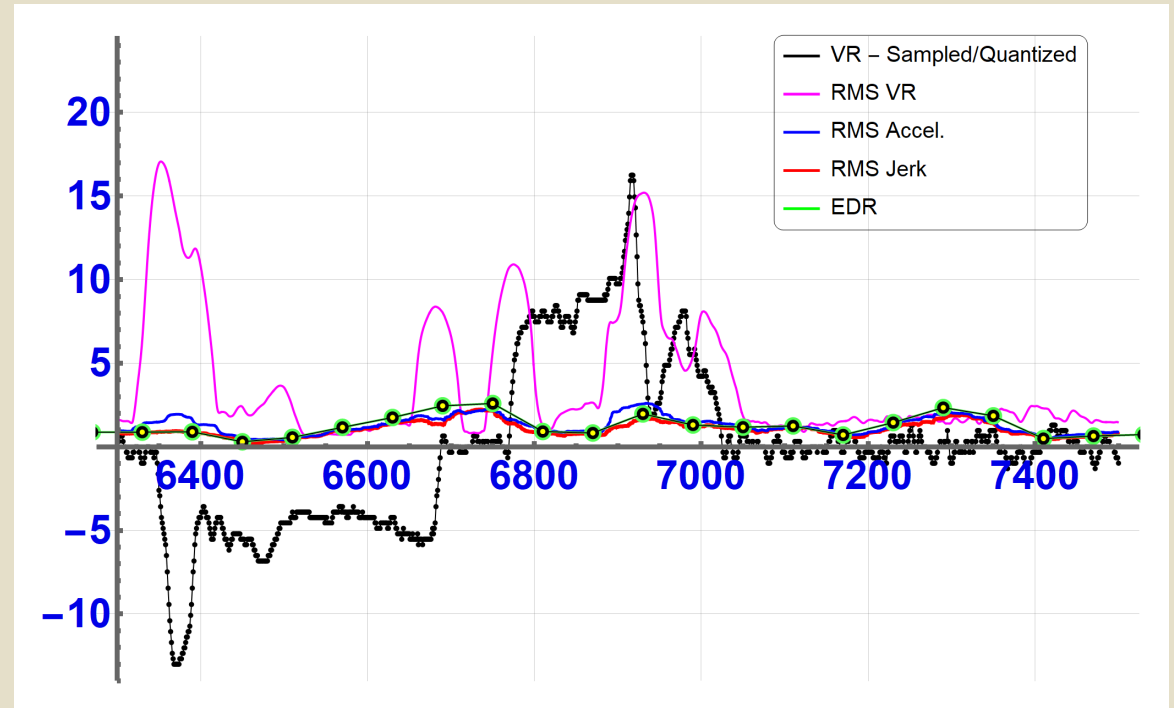 - High-rate, in-service aircraft data (737-800)
  - Real-world ADS-B reports

$$EDR = k\,\sigma_{VR}$$
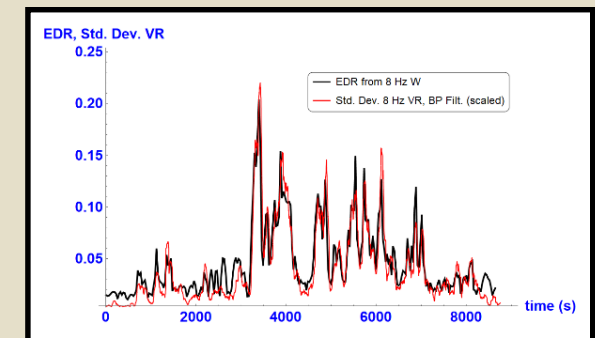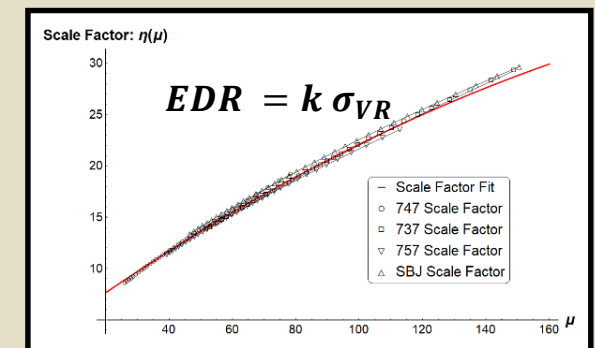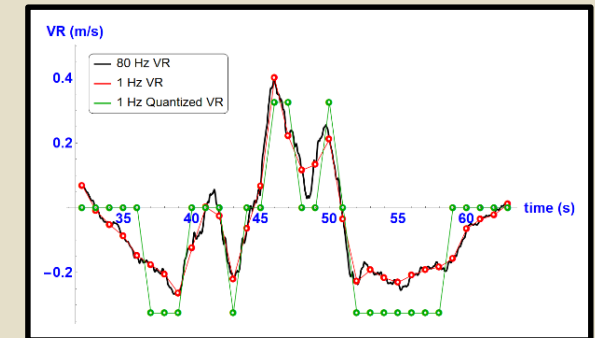
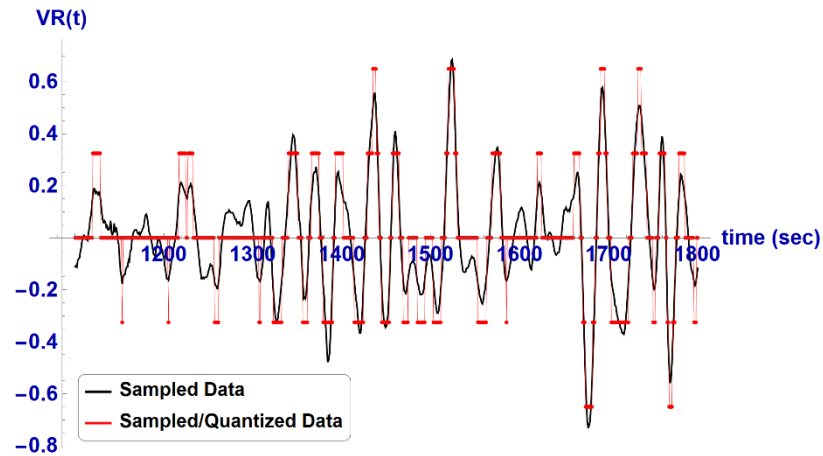# Use of 3rd Derivative of Position,"Jerk"

Wave-Turbulence Region

Maneuver-Turbulence Region

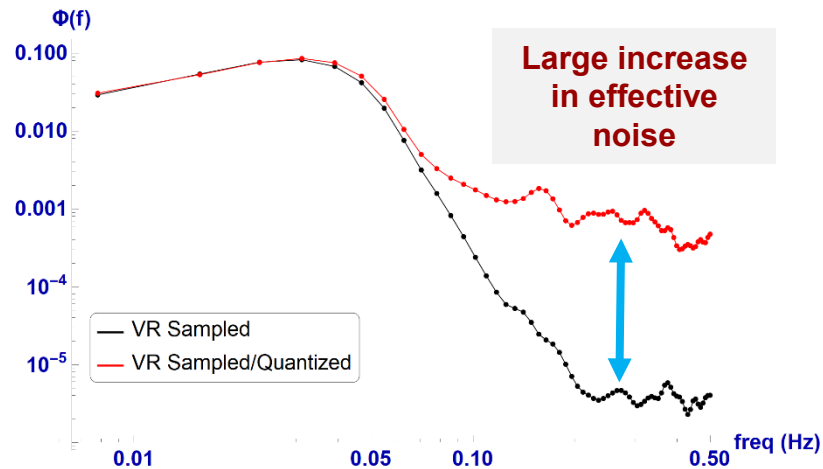RMS Jerk – for *high-rate* data – has remarkable skill wrt EDR

(Jerk = 2rd derivative of vertical rate)

Contamination Due to Quantization

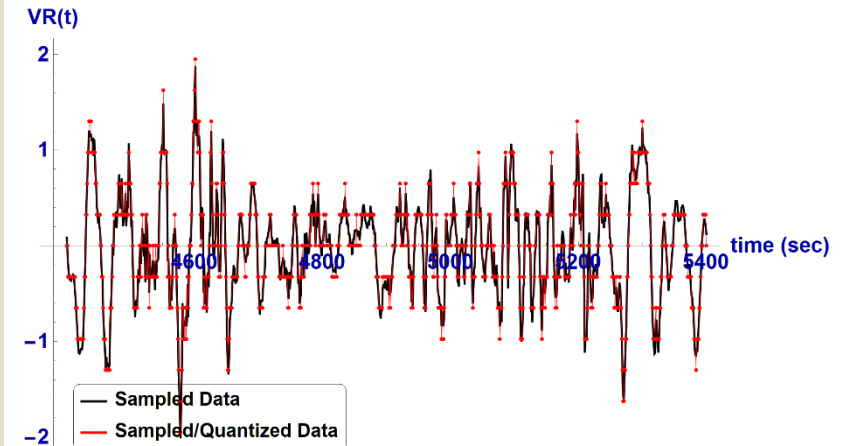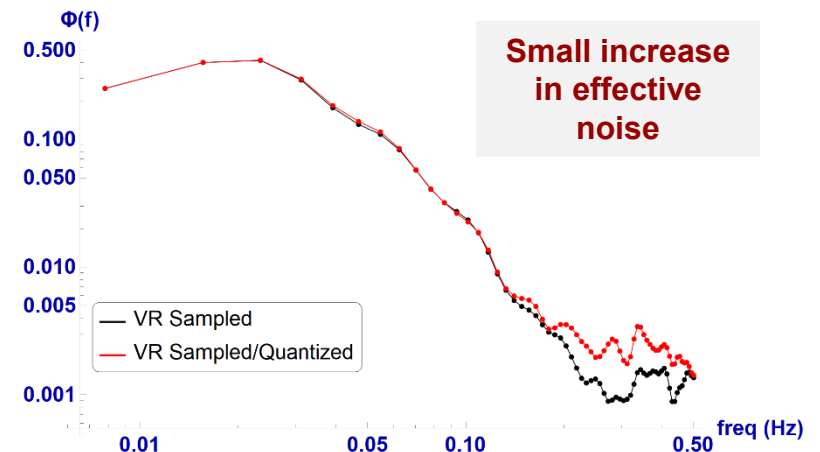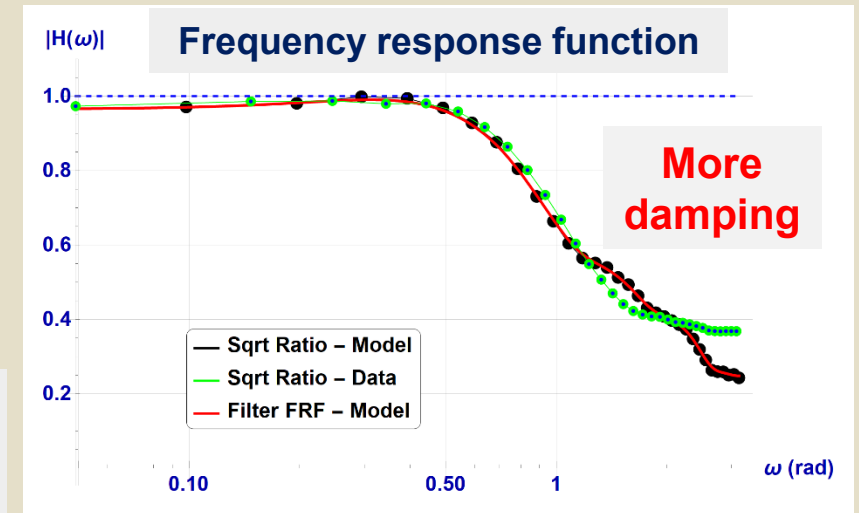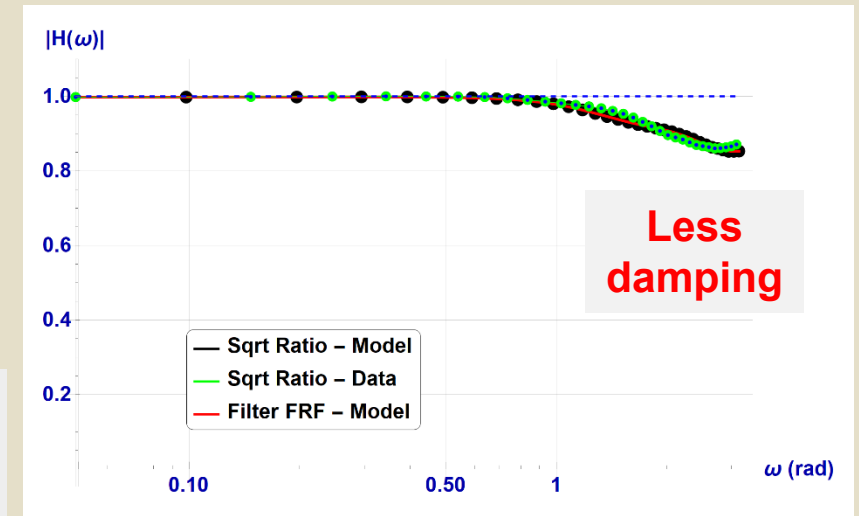Time Series

Quiescent Period — Turbulent Period

Power Spectra

Quantization affects quiescent periods more than active ones

Resolving the "Quantization Problem"

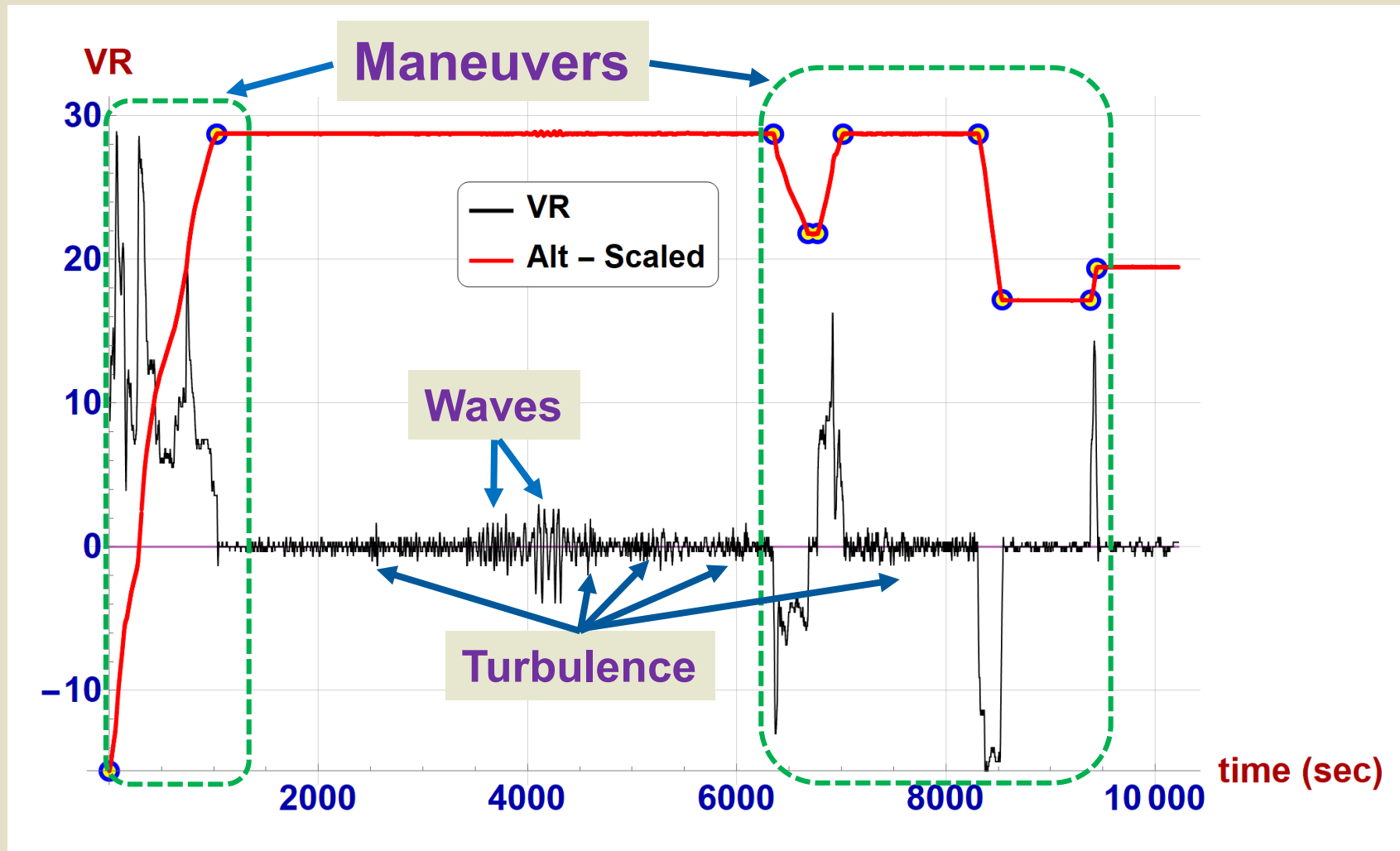**Quiescent data**

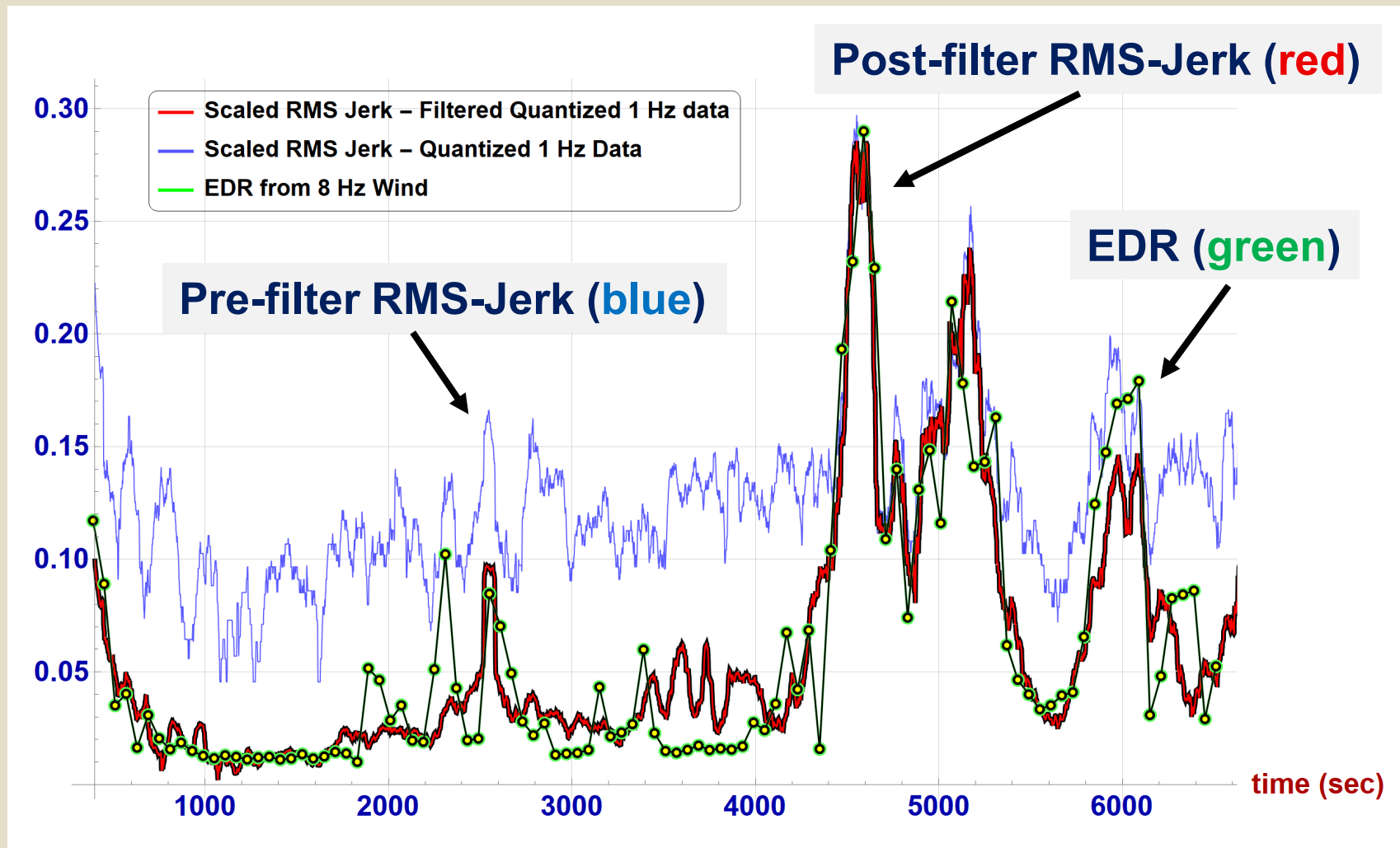**Turbulent data**

Frequency response function

Case Study: Data from Mid-Size Transport

**Sampled/Quantized Vertical Rate (black) and Scaled Altitude (red)**

Results for the First Half of Case Study Flight

Post-filter RMS-Jerk (red)

EDR (green)

Pre-filter RMS-Jerk (blue)

Legend:
- Scaled RMS Jerk – Filtered Quantized 1 Hz data
- Scaled RMS Jerk – Quantized 1 Hz Data
- EDR from 8 Hz Wind

time (sec)

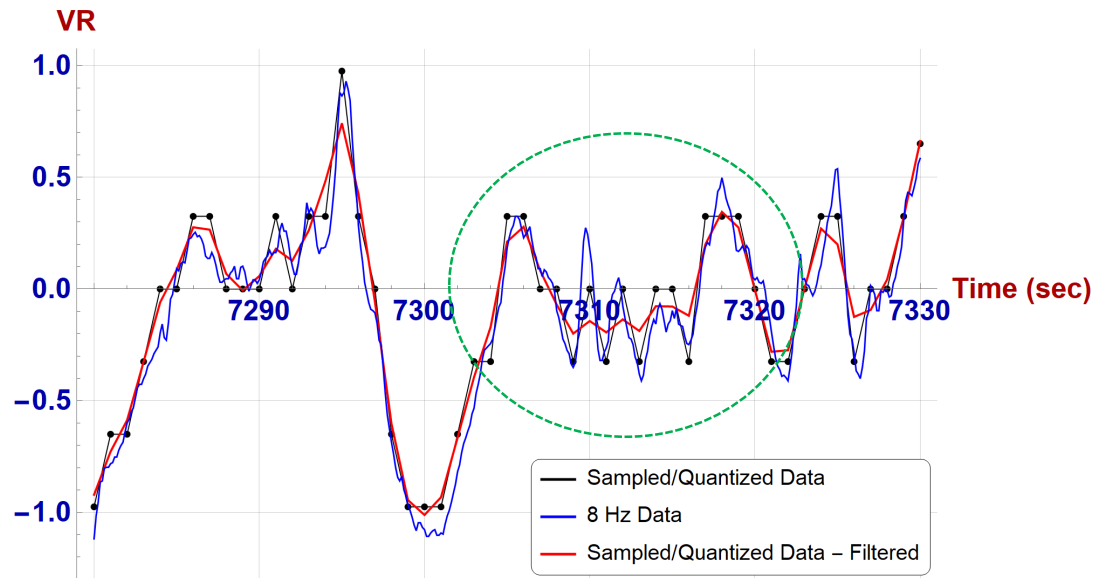**The quantization-adaptive filter method works well here…**

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Results for the Second Half of Case Study Flight
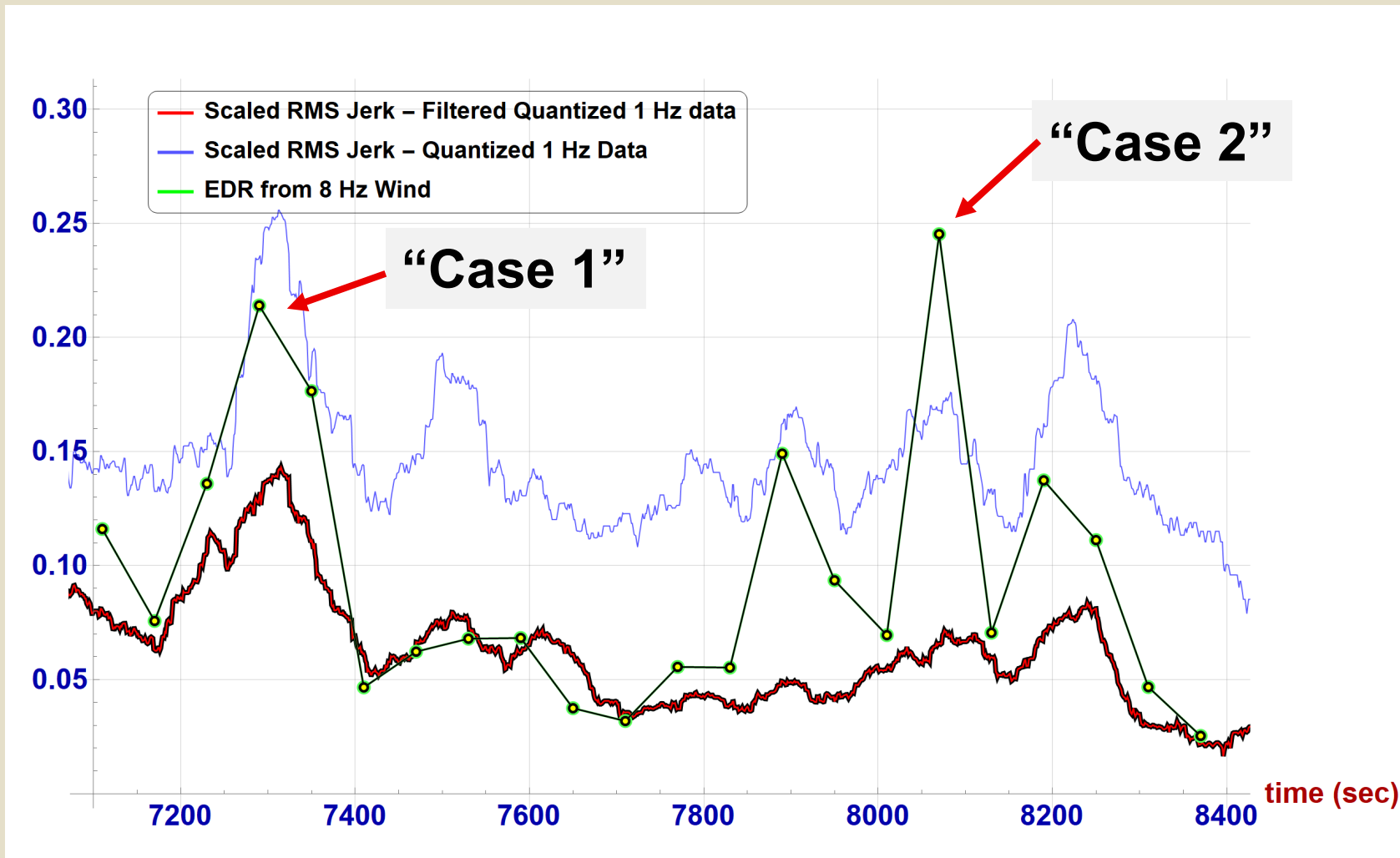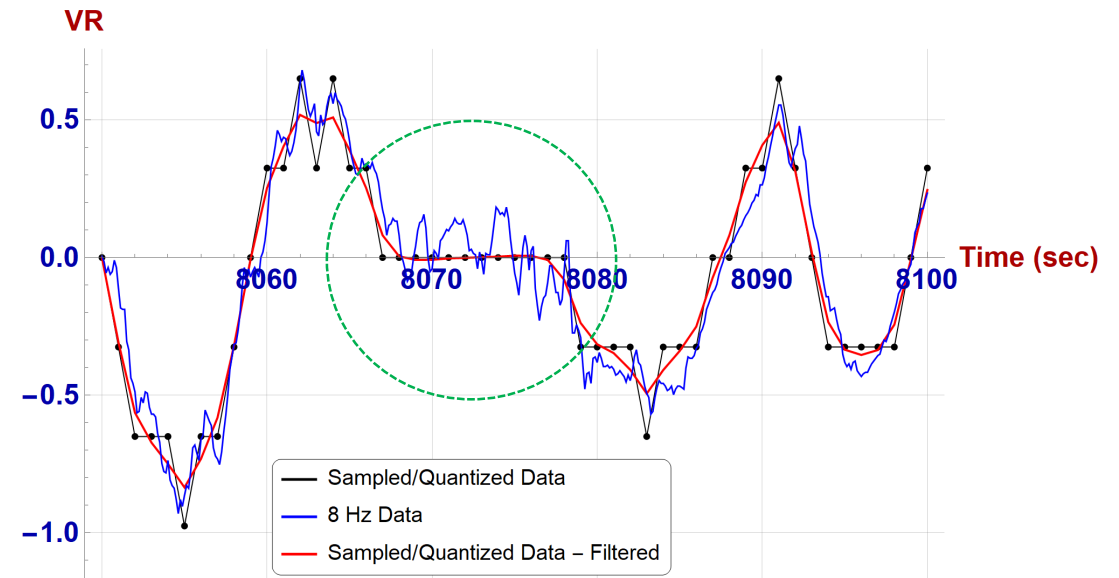

Missed Detections

Missed Detections – Closer Look
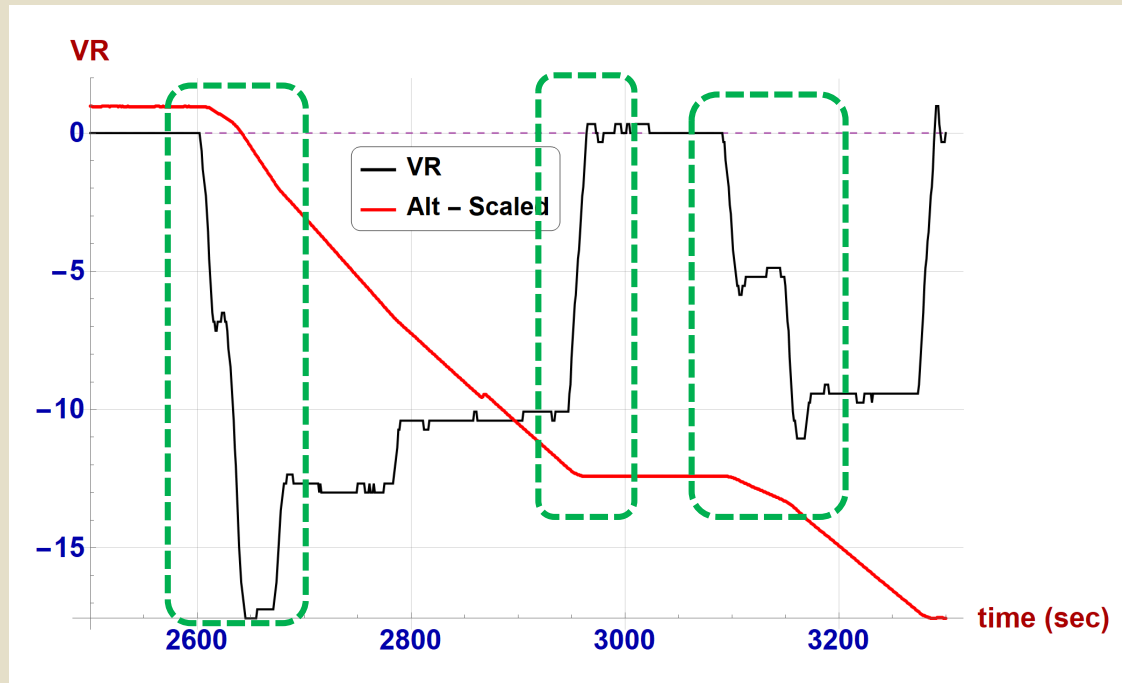

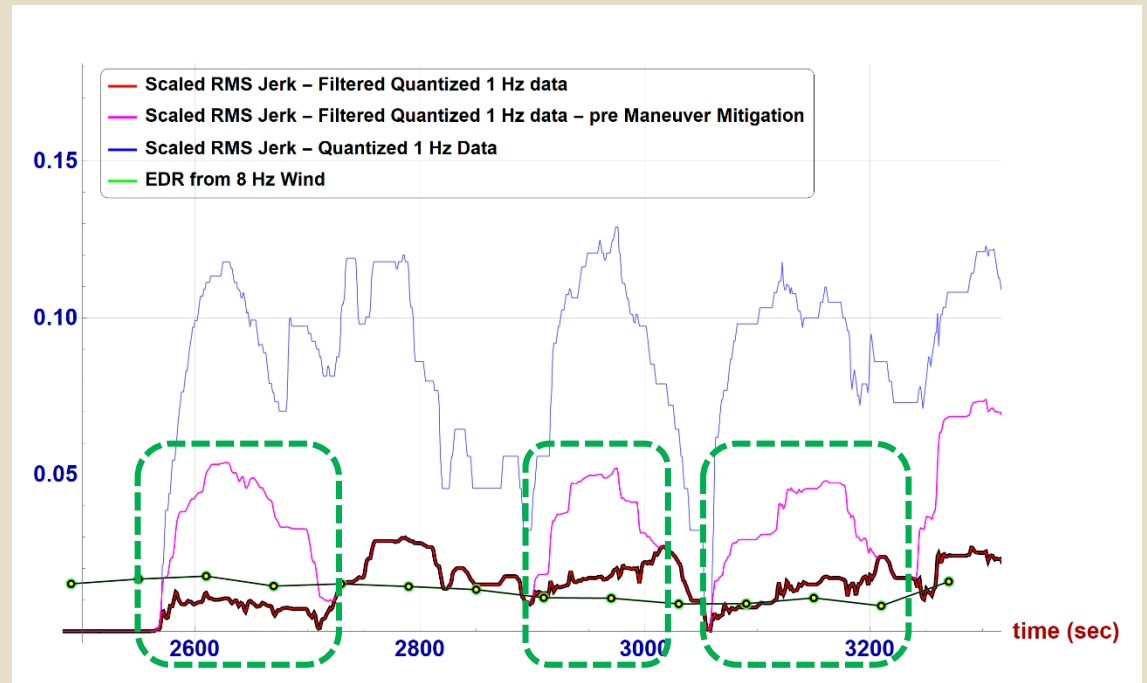## Case 1

Over-filtering – recoverable (?)

Case 2

Quantization - unrecoverable

Maneuver Mitigation

Jerk calculation removes "smooth" (linear) part of maneuvers, but not maneuver "transitions"

Maneuver transition regions

Pre-maneuver mitigation (magenta) vs. post-maneuver mitigation (red)

Ongoing Efforts

- **Continue algorithm developments**
  - Adaptive-quantization filtering
  - Maneuver rejection
  - Aircraft-scaling
  - Data quality assessment and QC algorithms
  - Evaluate utility of space-based ADS-B (SBA) reports.
- **Offline verification**
  - Simulation
  - High-rate real-world data
  - ADS-B reports

Near-Term and Future Efforts

- **Operational demonstrations/verification**
- **Operational deployment**
  - Develop phased release plan
    - Standalone "Pireps"
    - Integration into GTGN
- **Provide recommendations on future releases of ADS-B standards**
  - Decrease quantization levels for vertical rate
  - Increase sampling rate (not necessarily reporting rate).

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