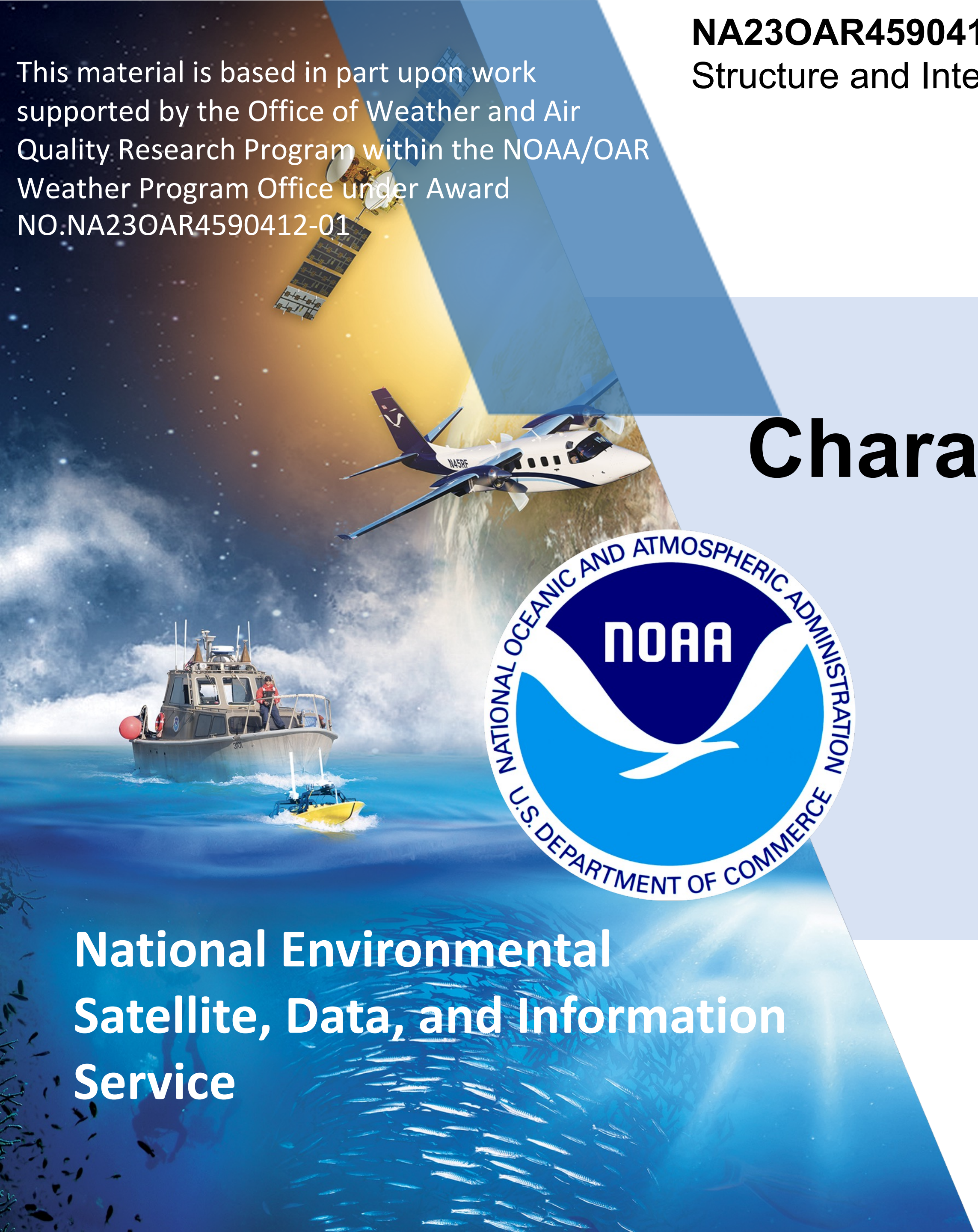

This material is based in part upon work supported by the Office of Weather and Air Quality Research Program within the NOAA/OAR Weather Program Office under Award NO.NA23OAR4590412-01

NA23OAR4590412 “Real-time Visualization and Interpretation of the Hurricane Wind Structure and Intensity: From Flight Level to the Surface”

Hardware Performance Characterization as a Foundation for Reliable SFMR Extreme Wind Retrievals

Ocean Winds Team:

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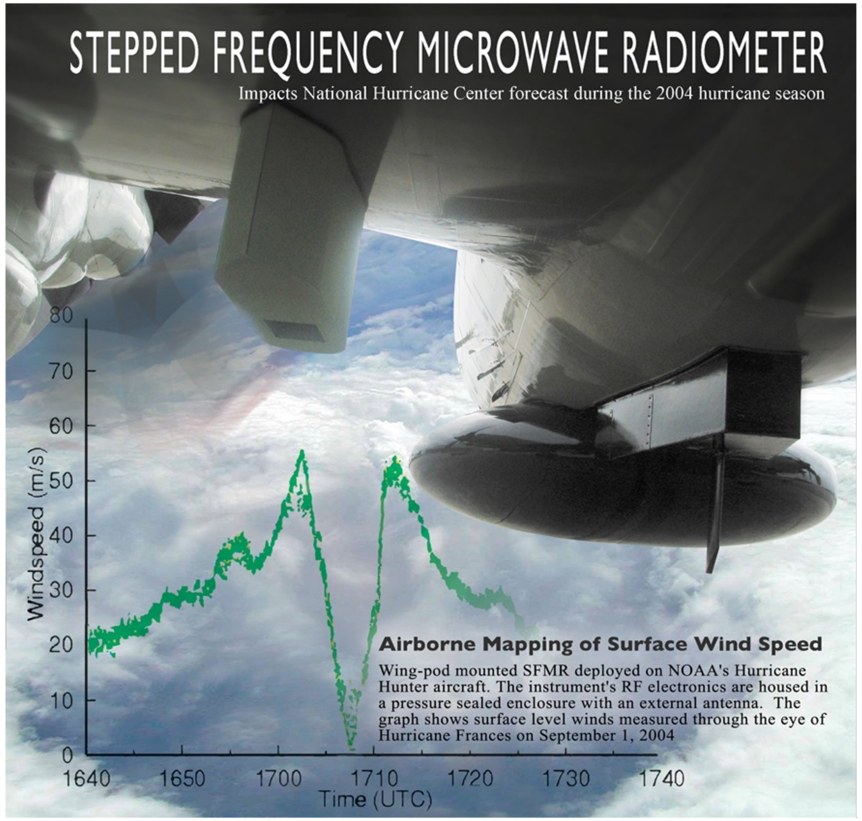
[3]Global Science & Technology, Inc.
[4]UCAR

National Environmental Satellite, Data, and Information Service

The Stepped Frequency Microwave Radiometer



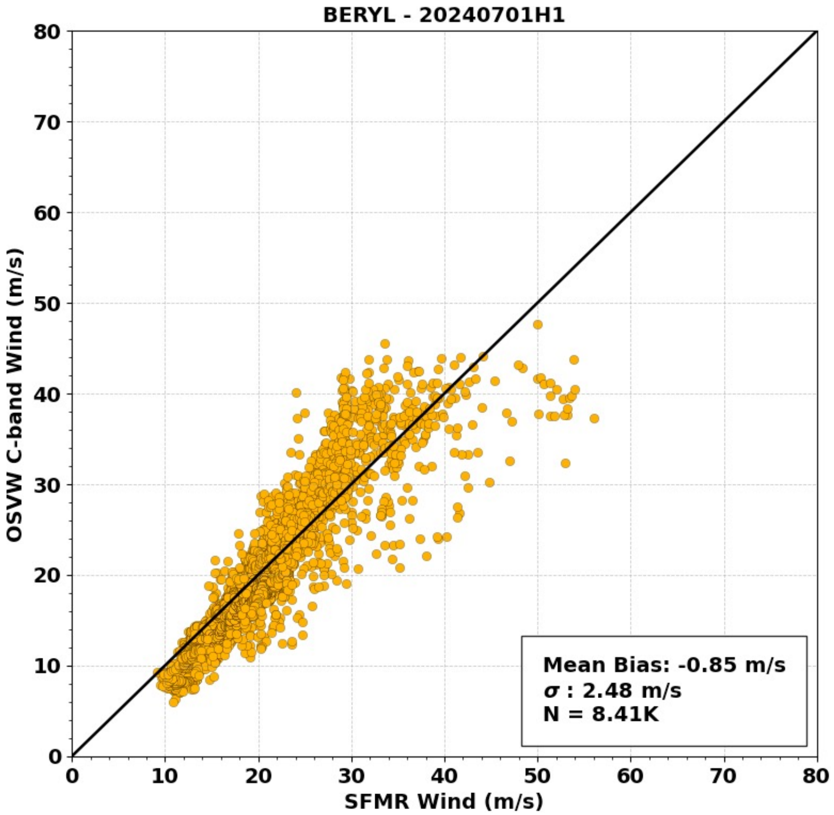
- **Designed by ProSensing**
  - **25 units: 3 NOAA, 22 AirForce**
  - **Operational data stream since 2006**

- **SFMR dissemination from NOAA P3's was terminated by NHC and data assimilation into NOAA hurricane models was stopped by EMC from both NOAA and Airforce instruments mid 2024 hurricane season.**

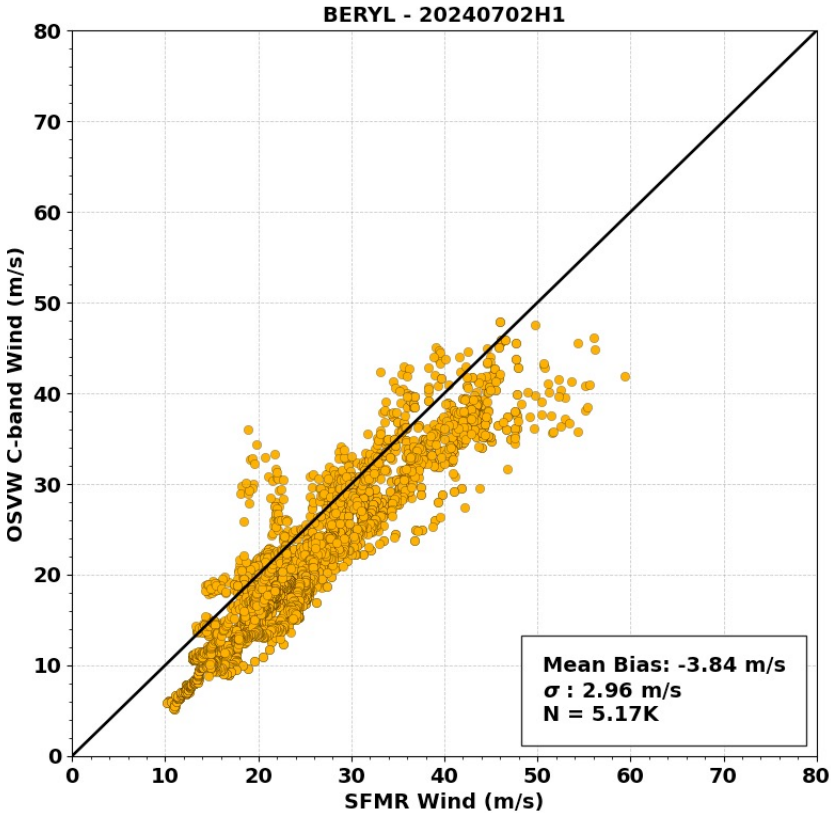
- **There was no SFMR's on NOAA planes during 2025 Season. Airforce still continued dessiminating measurements in NRT**

Assessing NOAA SFMR Units with IWRAP

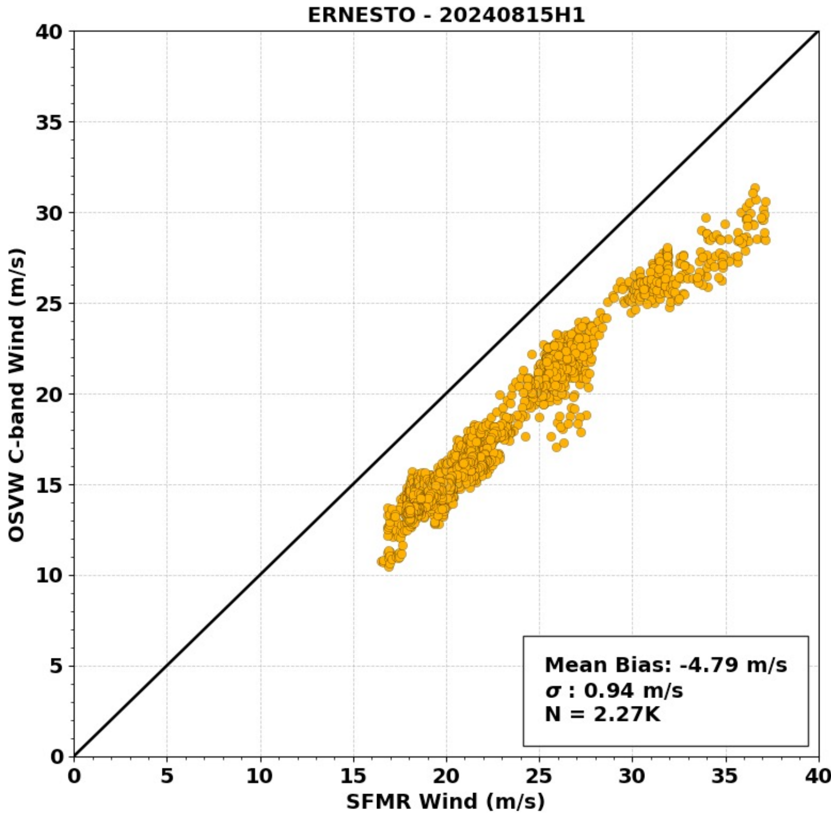
US002



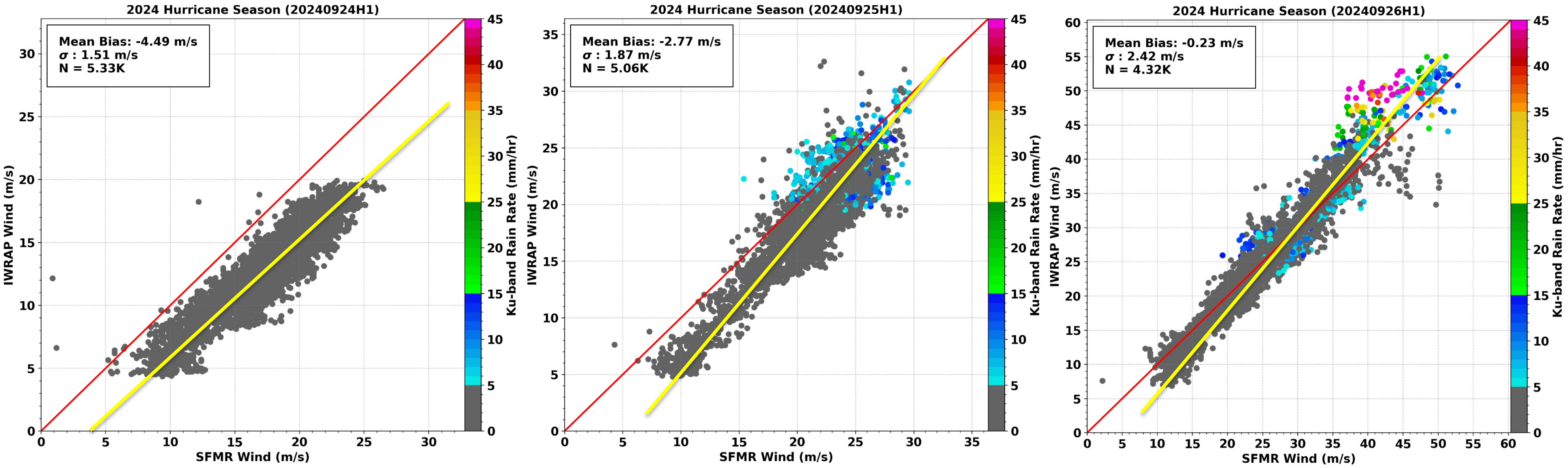
US001



US003

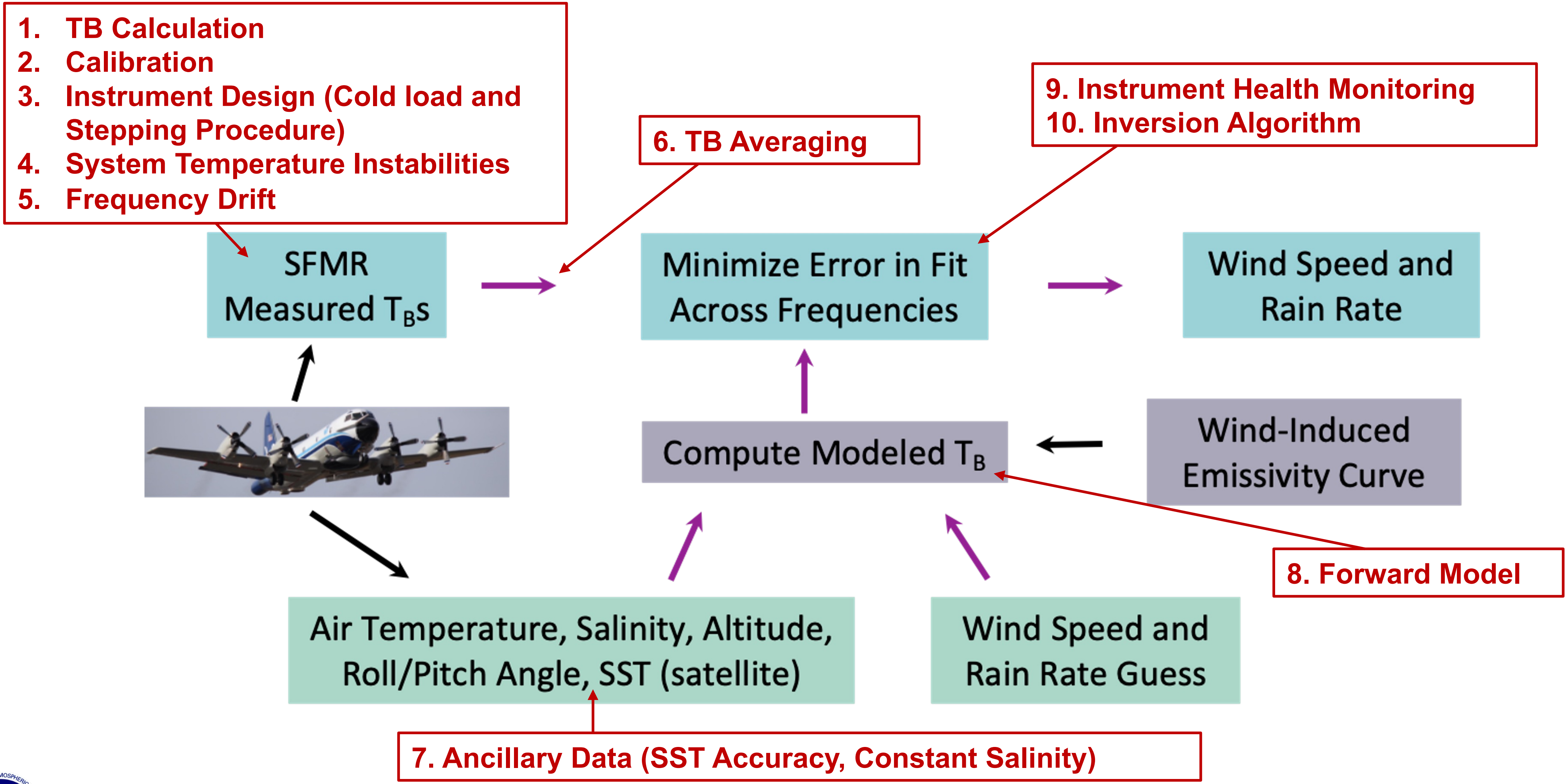


Three Consecutive Flights with the same SFMR Unit



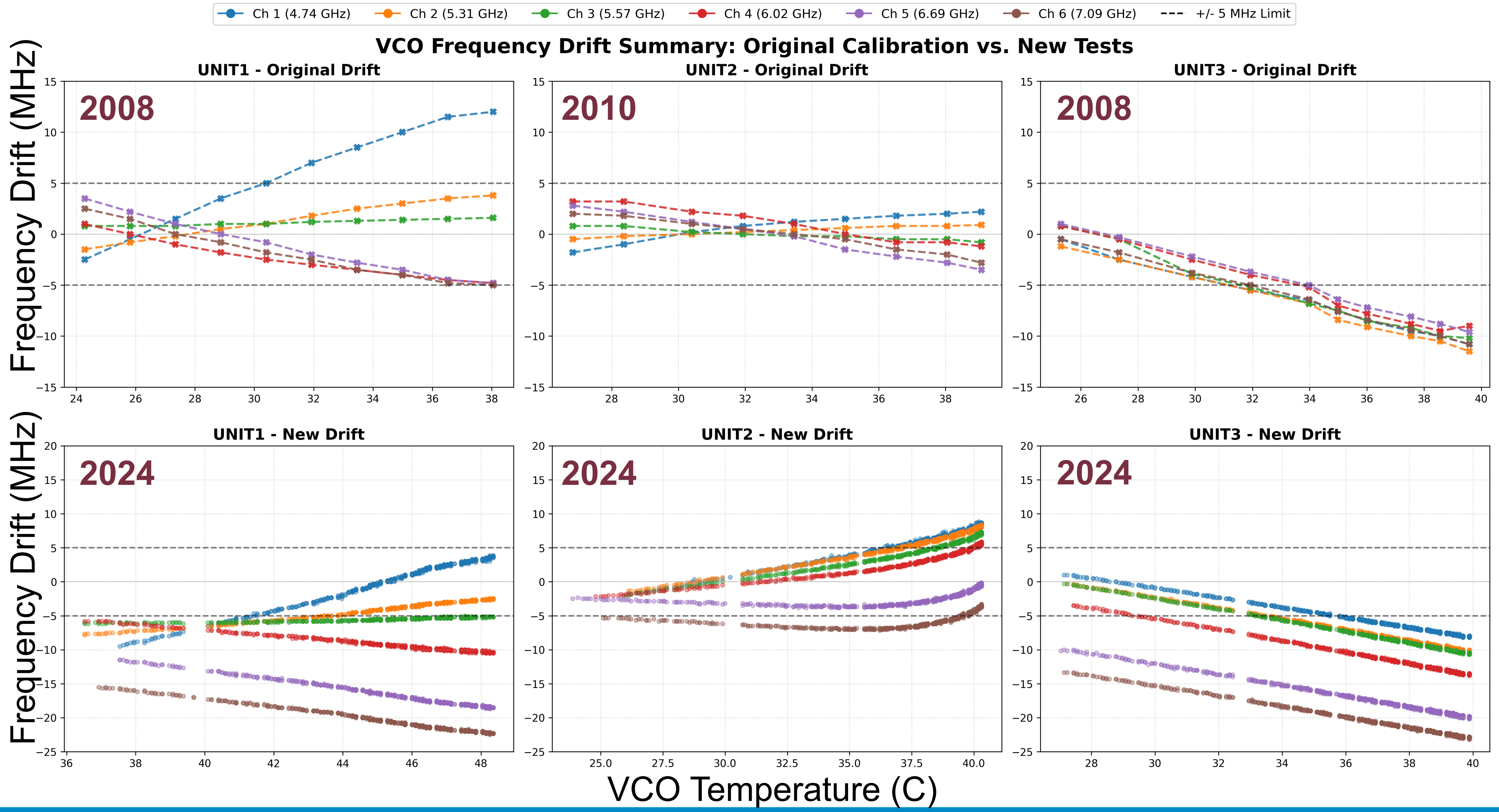
Instability from one flight to the next makes it virtually impossible to use these measurements for decision-making purposes.

Sources of Error



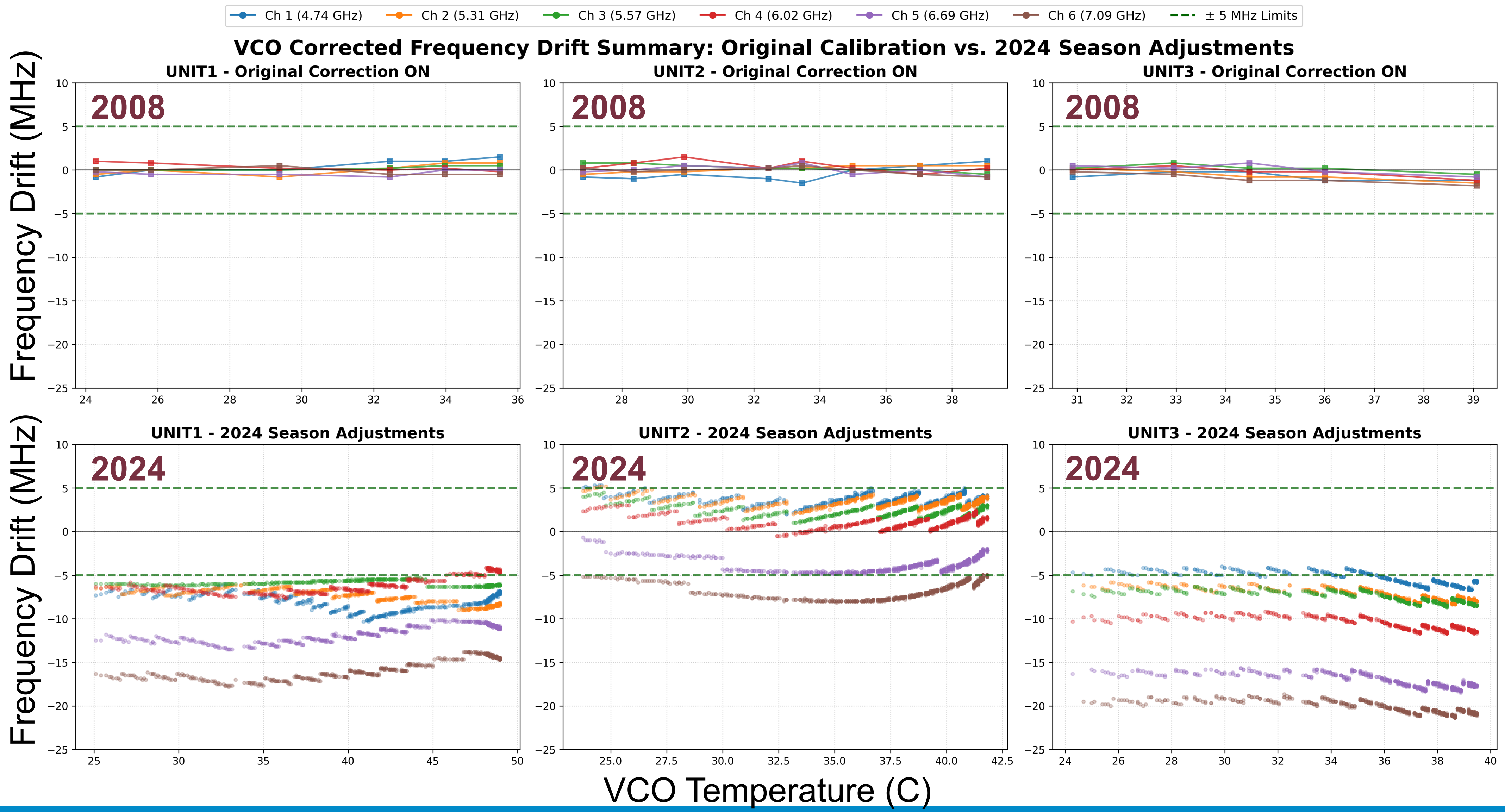
Lab Testing with ProSensing: 2008 vs 2024

No Correction

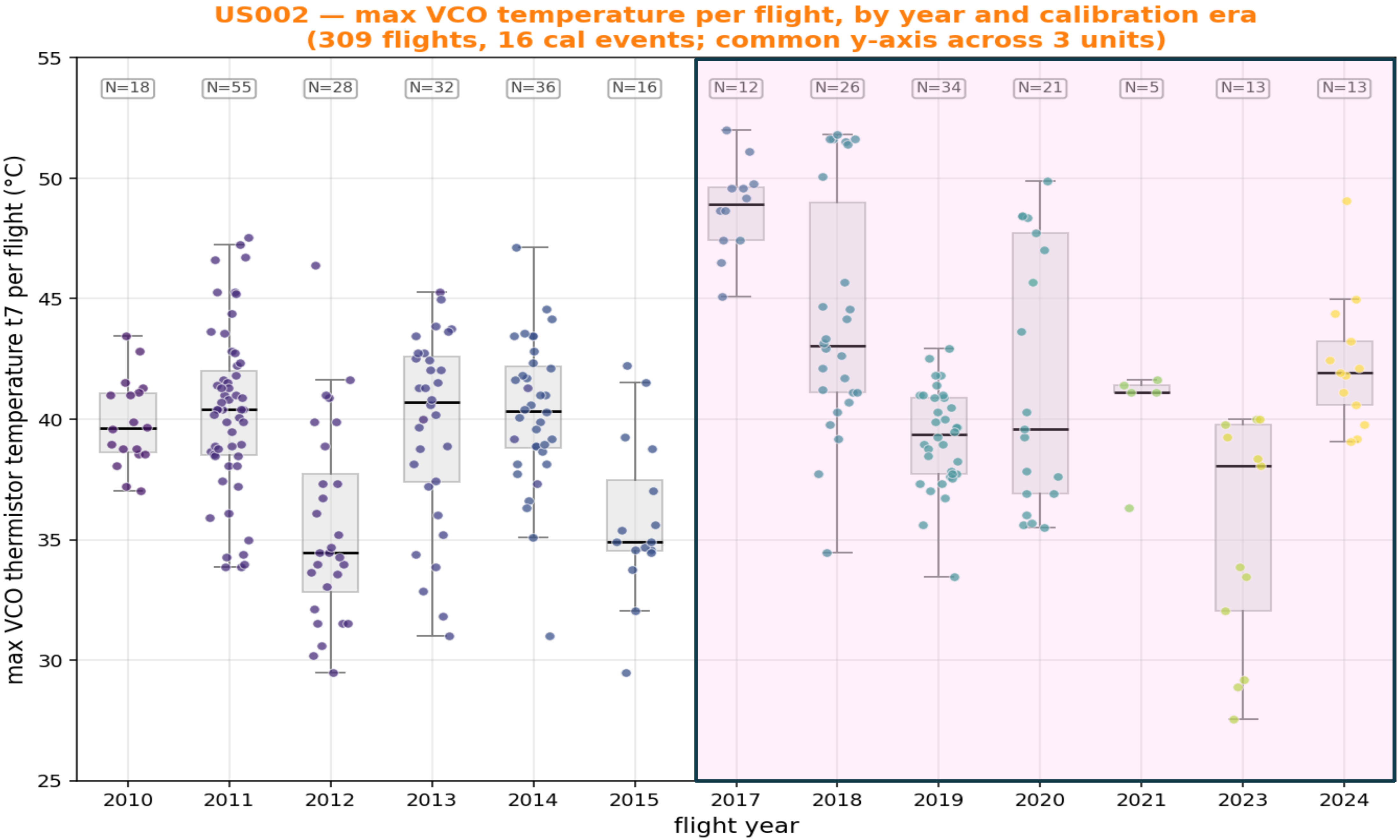


Lab Testing with ProSensing: 2008 vs 2024

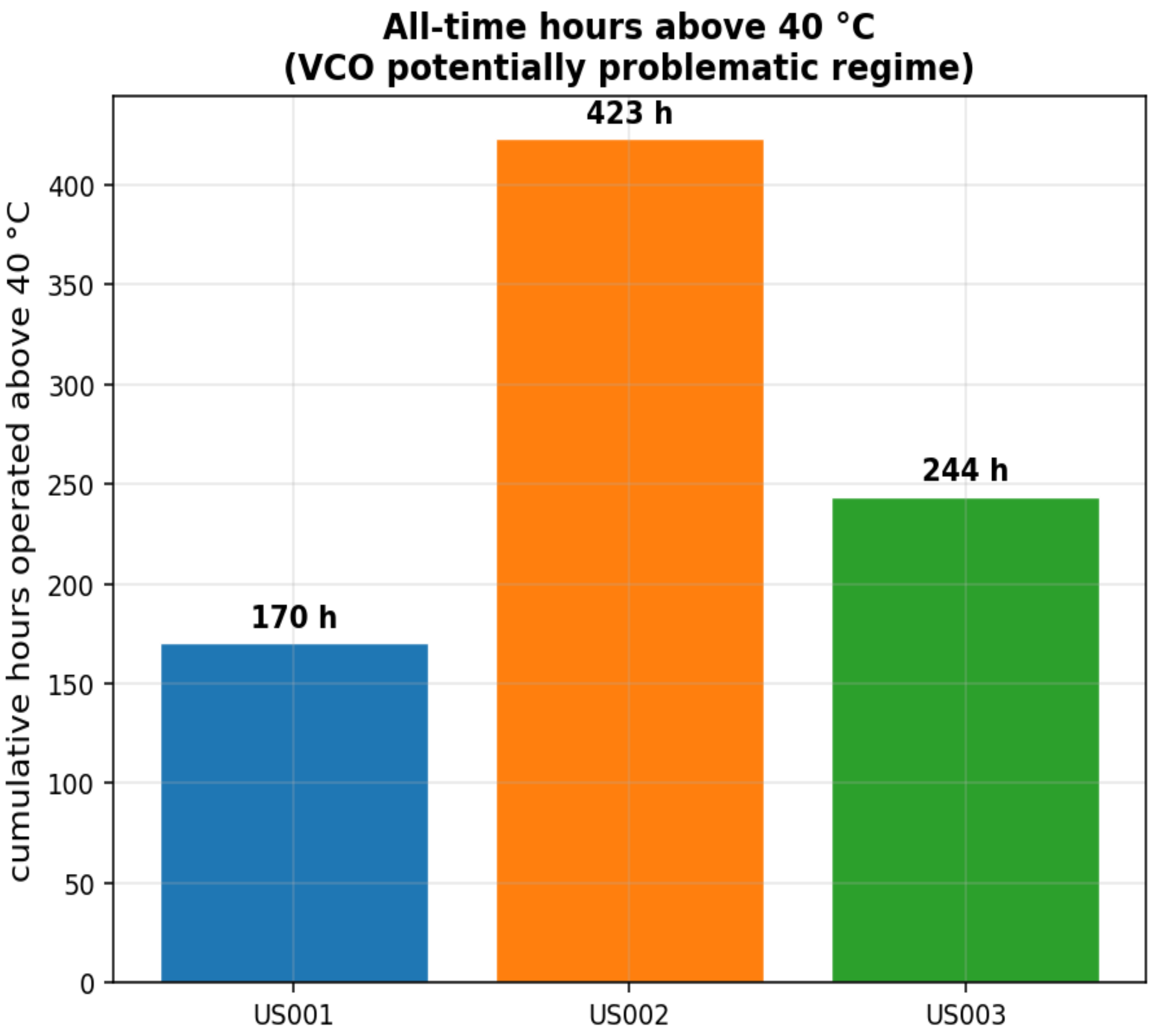
2008 Correction On

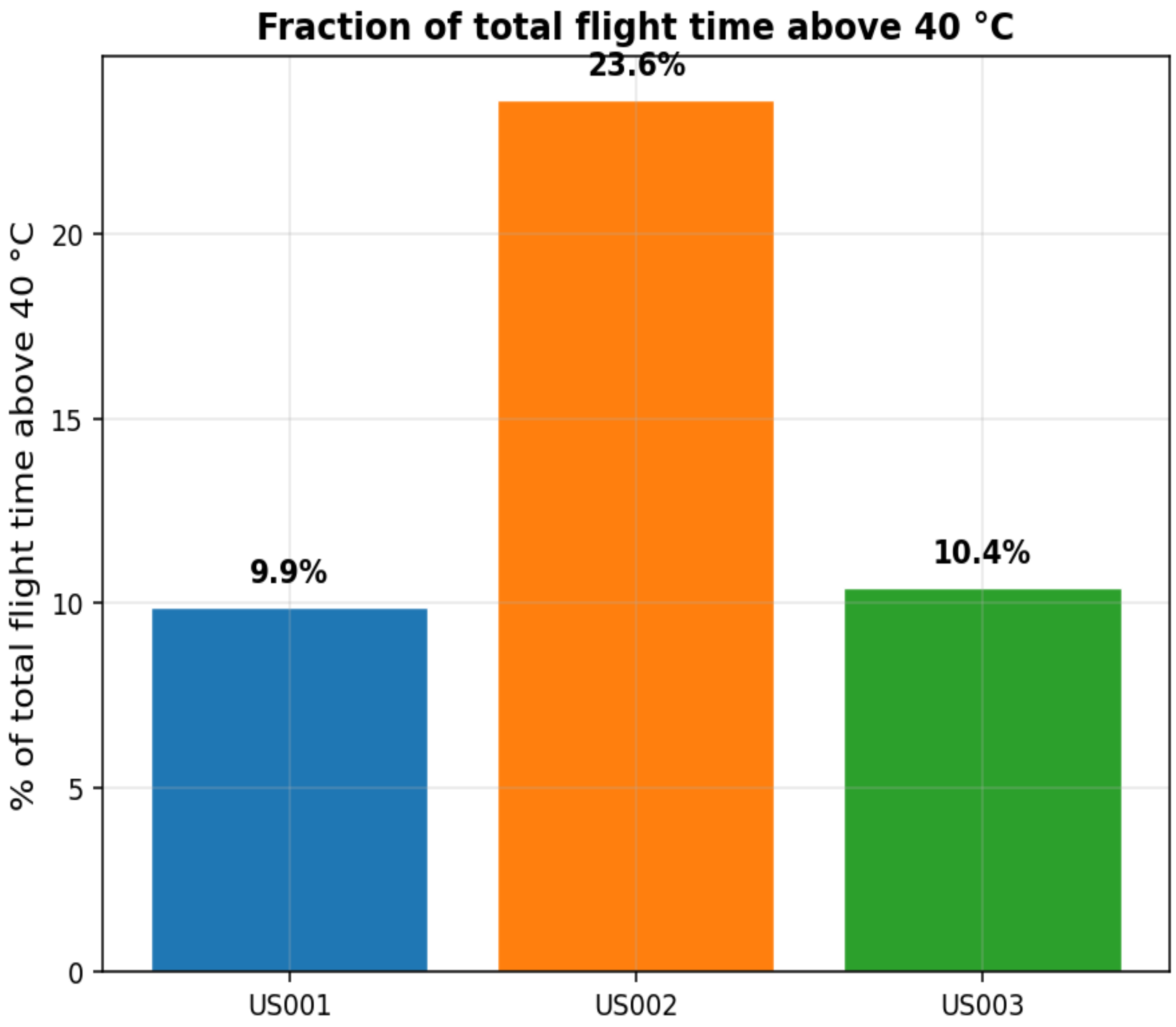


US002 Temperature Exposure over Years



Lifetime VCO Thermal Exposure per NOAA SFMR Units

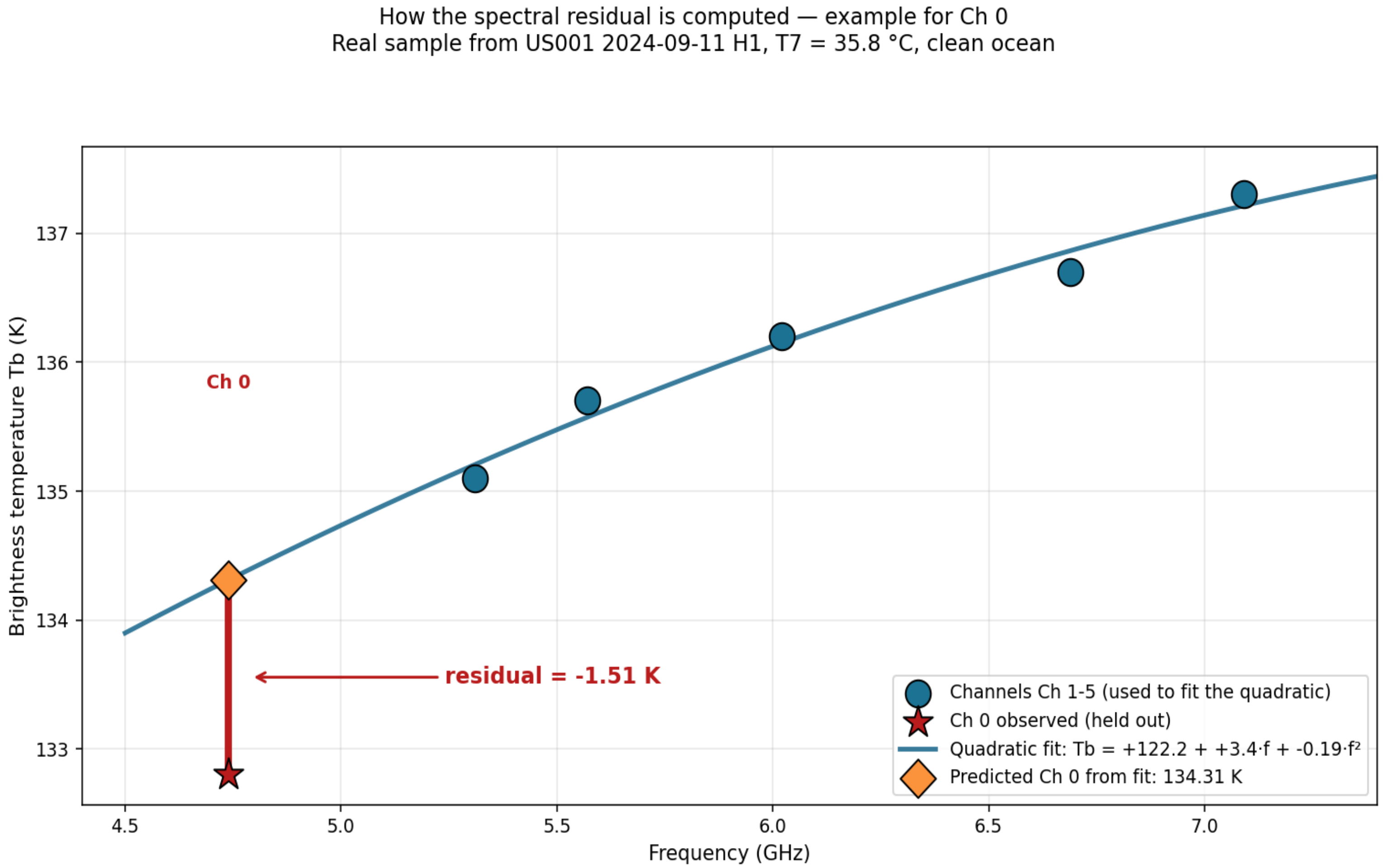




Computing the Spectral Residual

The ocean + atmosphere Tb spectrum across C-band is smooth (wind, rain, SST, salinity will change frequency response continuously).

Any 6-point Tb spectrum must fall on a smooth curve, hence the quadratic fit through 5 channels absorbs ALL of this scene variability.



THE 4 STEPS

1. Take Tb at 5 of the 6 channels (Ch 1–5)

2. Fit quadratic $Tb = a + b \cdot f + d \cdot f^2$ through them

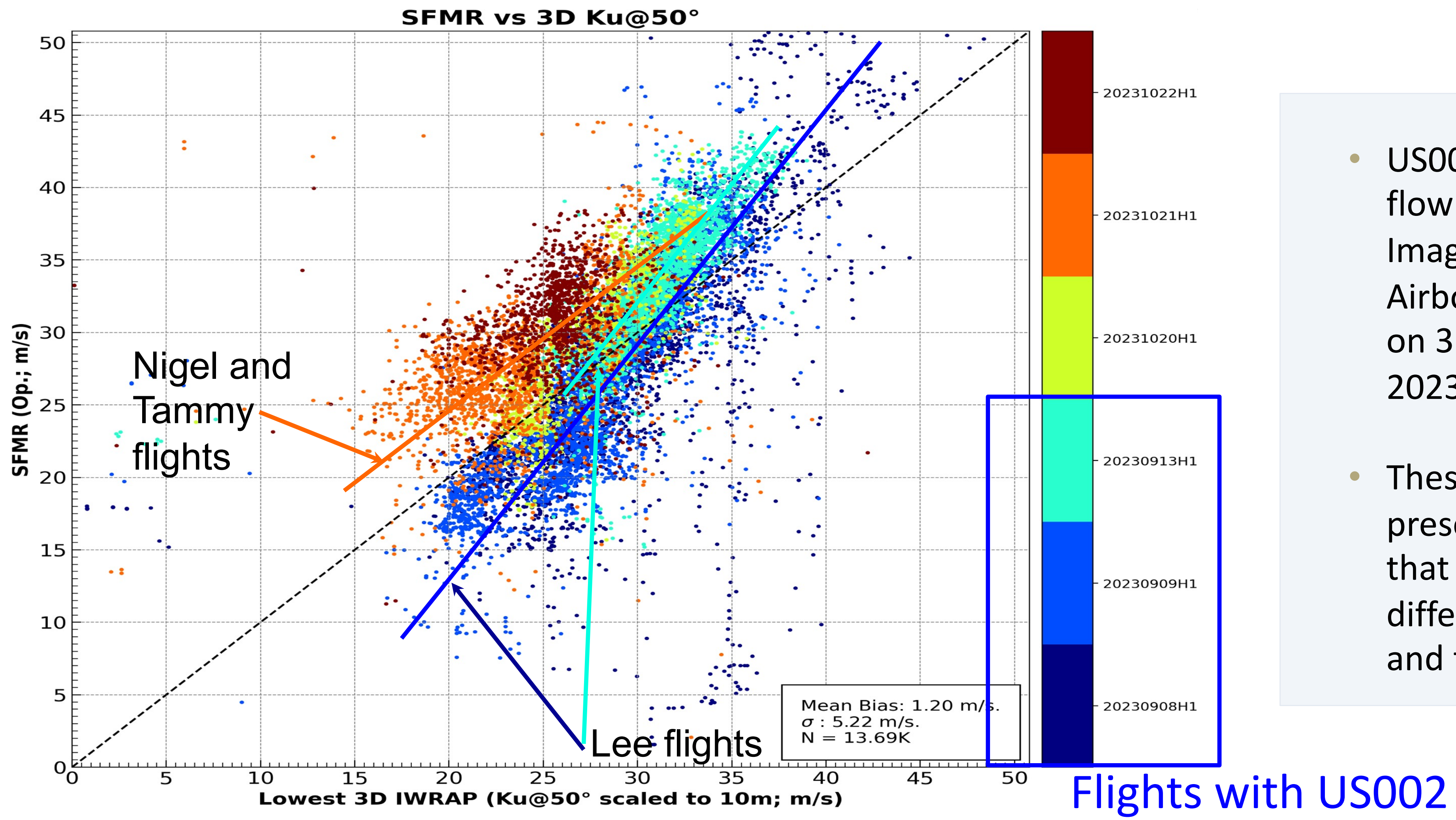
3. Predict Ch 0 from the fit at f = 4.74 GHz

4. Residual = observed − predicted

Here: Ch 0 obs = 132.80 K; predicted = 134.31 K; **residual = −1.51 K**

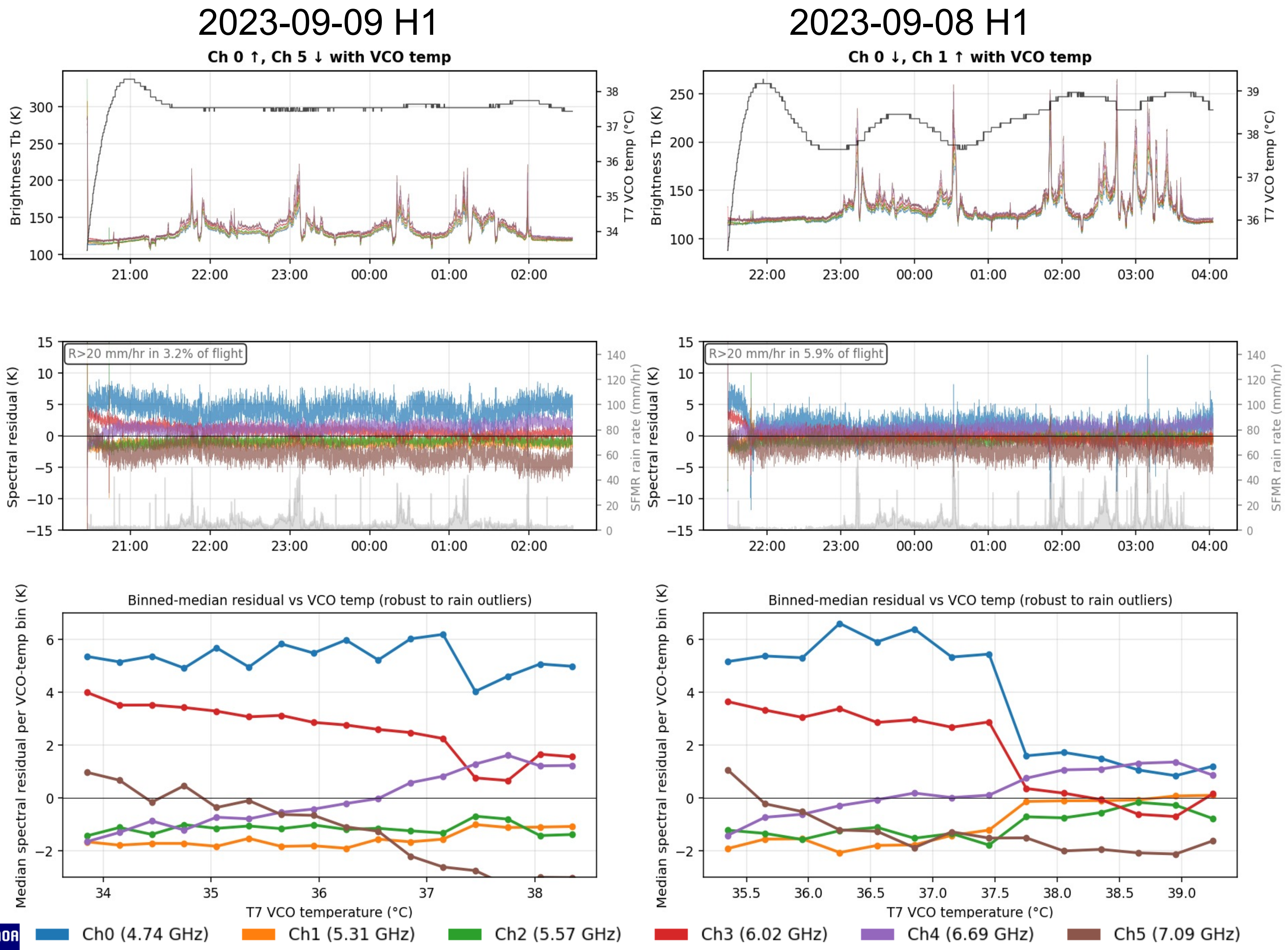
What's left in the residual is whatever DOESN'T look like a smooth scene spectrum: per-channel hardware bias, frequency drift, or per-channel calibration error.

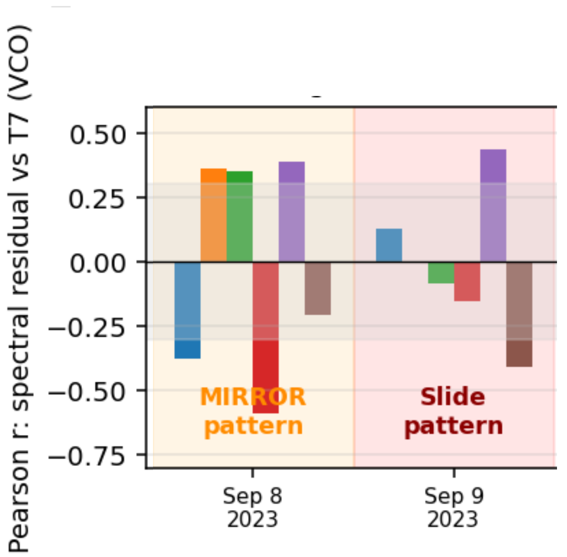
2023 SFMR & IWRAP Comparisons



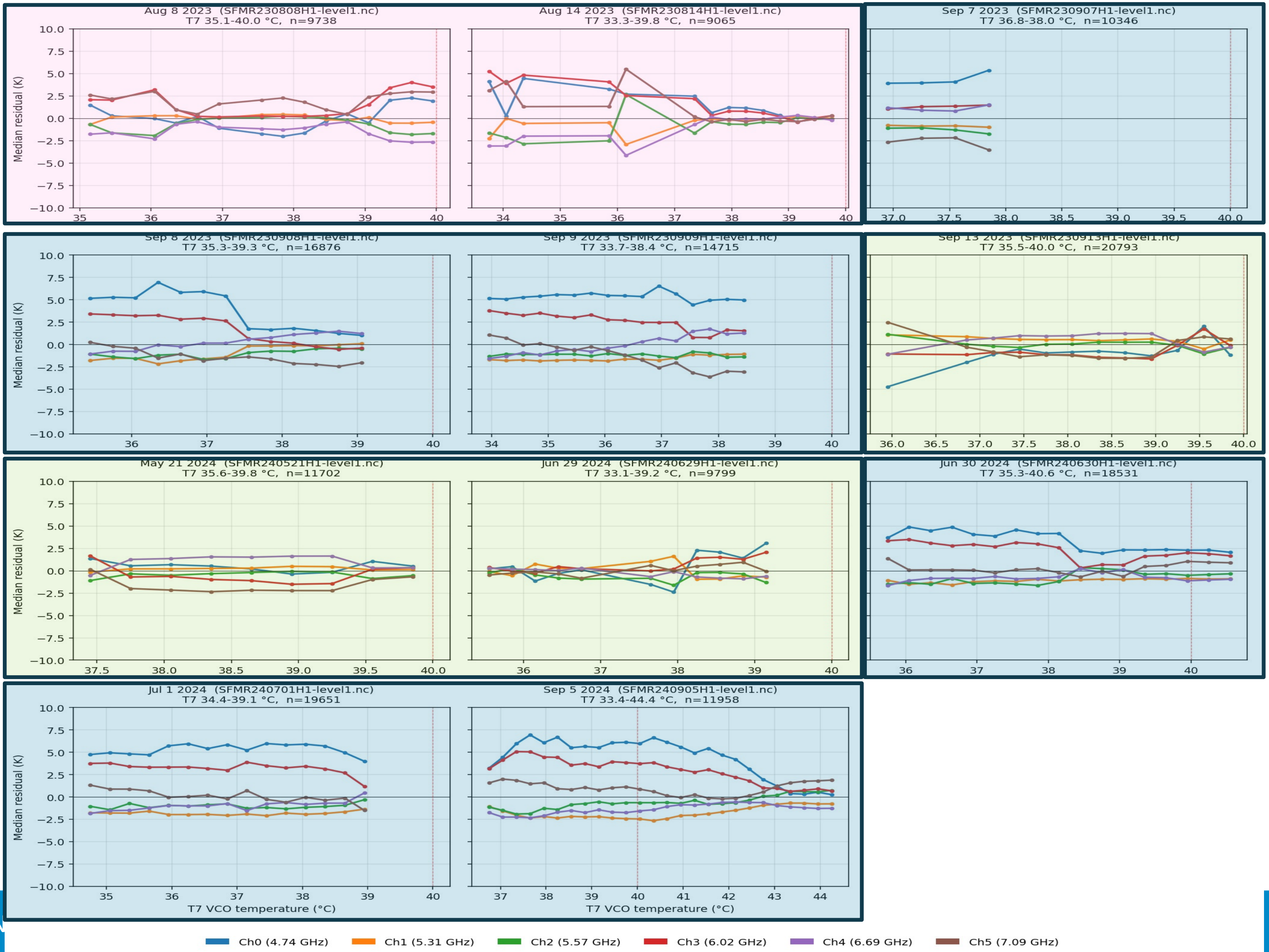
- US001 and US002 were flown coincident with Imaging Wind and Rain Airborne Profiler (IWRAP) on 3 flights during the 2023 season
- These measurements present first indication that performance is different from unit to unit and flight to flight

US002 – Flight to Flight Instability



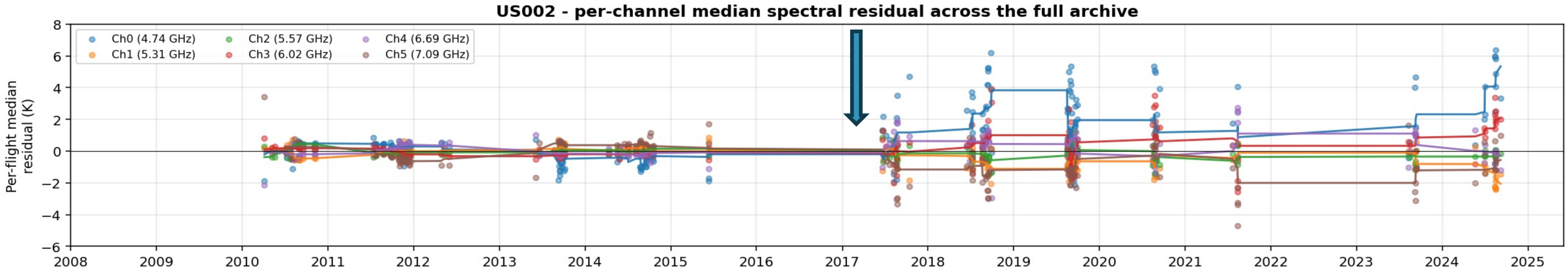


US002 Exhibits Few Distinct Spectral-Residual Patterns

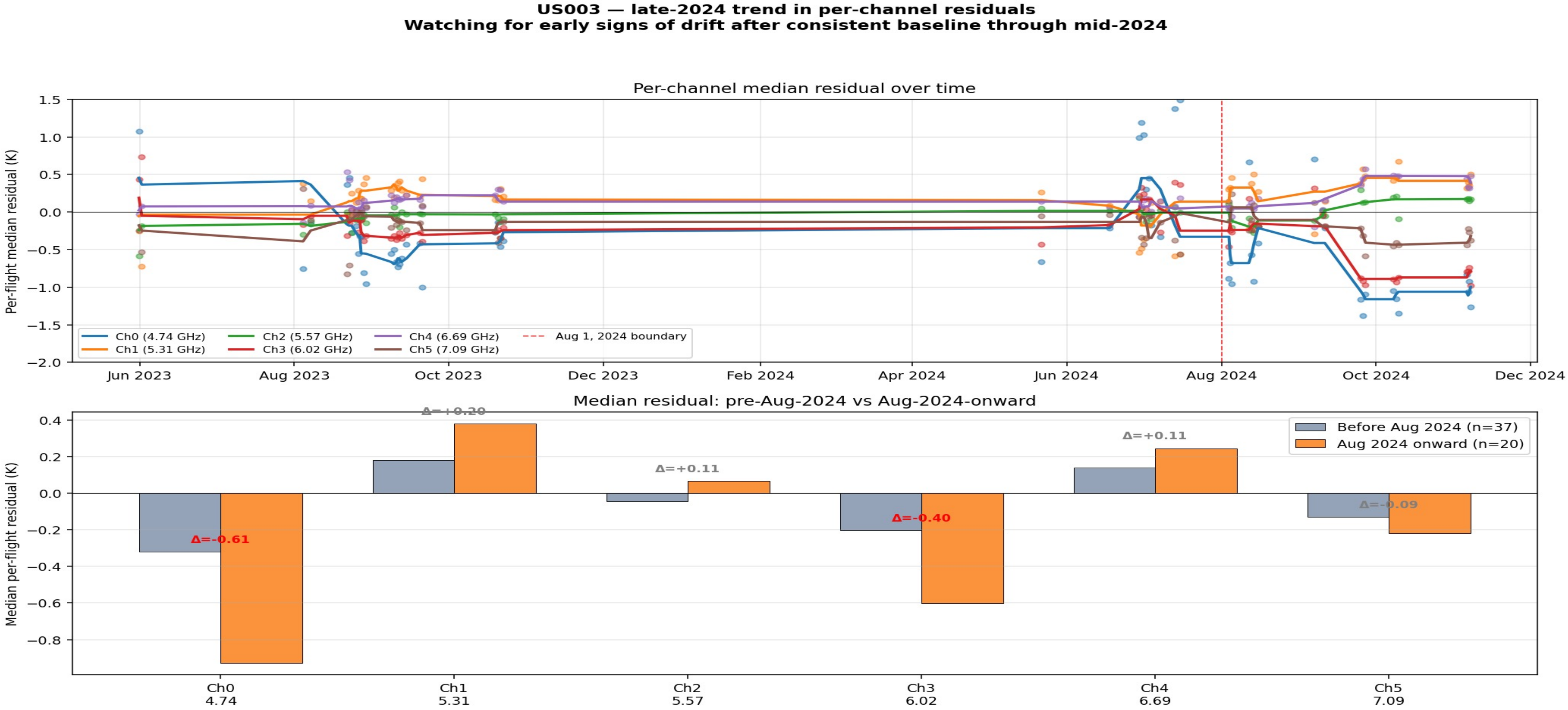


Per-channel Median Spectral Residual Across the Full Archive - All Three NOAA Units

Each dot = one flight's median spectral residual per channel; lines = 15-flight rolling median.

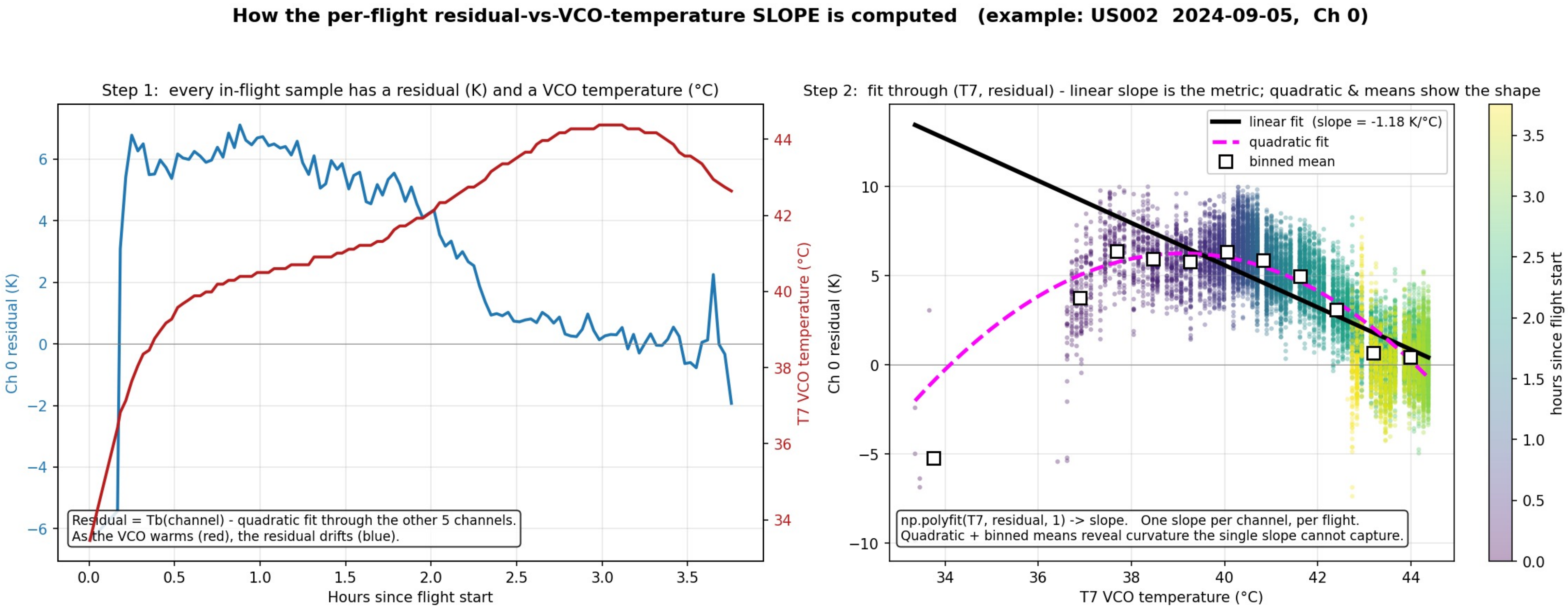


Observed US003 Degradation after Aug 2024



How the residual-vs-VCO-temperature slope is computed

Worked example: US002, 2024-09-05, Channel 0 - one straight-line fit per channel, per flight



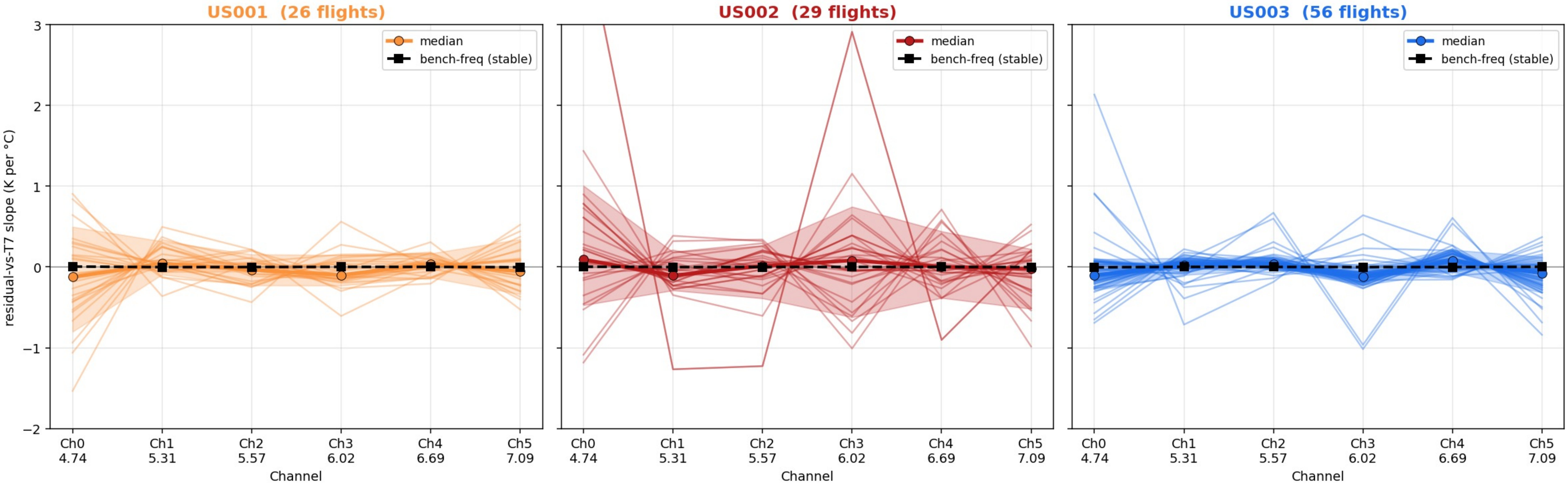
Each in-flight sample yields a spectral residual and a VCO temperature T7.

Fitting a straight line through (T7, residual) gives one slope, in K per °C, for that channel and flight.

The next slide plots this slope for every channel and every flight - a stable instrument would repeat the same slope each time.

Drift-vs-VCO-Temperature Slope 2023-2024

*Per-channel spectral-residual slope vs VCO temperature (T7), **every entire flight database** - each faint line is one flight; thick line = median, band = 10-90th pct*



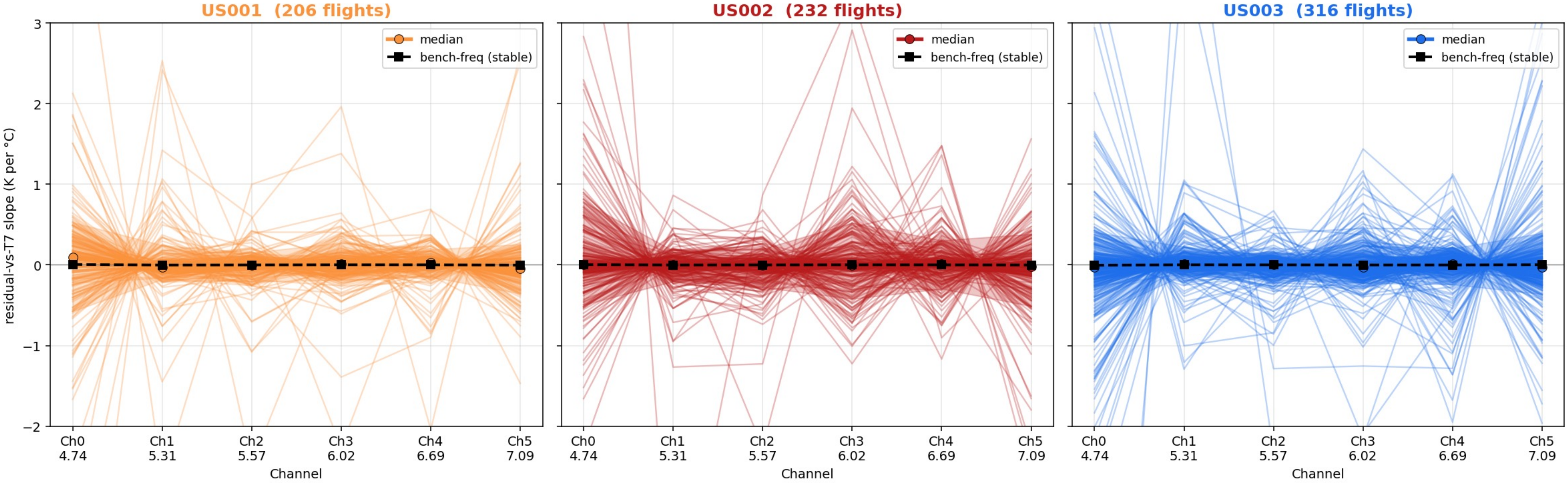
A stable, calibratable drift would put every flight on the same profile.

US001 and US002 similar performance to 2023-2024 seasons

US003 now also shows instabilities similar to US001

Drift-vs-VCO-Temperature Slope Entire Flight Database

Per-channel spectral-residual slope vs VCO temperature (T7), every 2023-2024 flight - each faint line is one flight; thick line = median, band = 10-90th pct



A stable, calibratable drift would put every flight on the same profile.

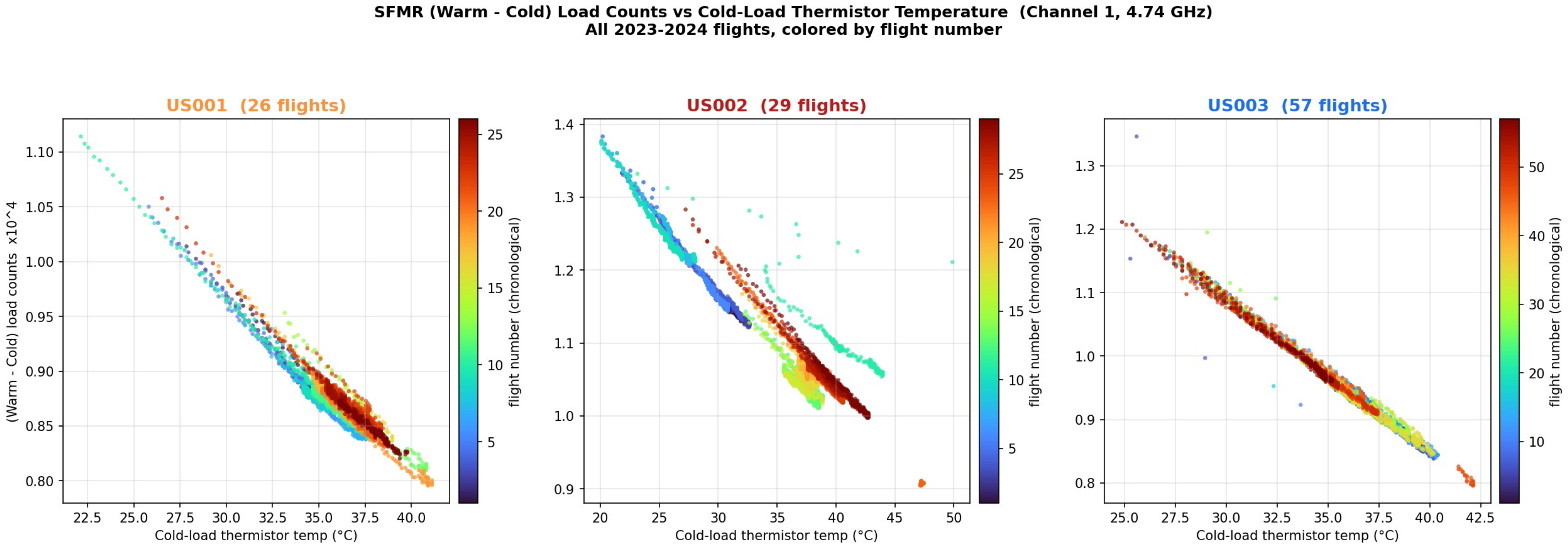
US001 and US002 scatter widely and flip sign (Ch 0 spread ~1.3-1.5 K/°C);

US003 is ~3-4x tighter and much closer to the stable bench-frequency reference (dashes).

The medians sit near zero, so the issue is not a fixed bias but flight-to-flight instability - the same conclusion as the gain plot, from an independent diagnostic.

Checking System Linearity: Gain vs Cold Load Temperature

SFMR (Warm - Cold) load counts vs cold-load thermistor temperature, Channel 1 (4.74 GHz) - all 2023-2024 flights, colored by flight number



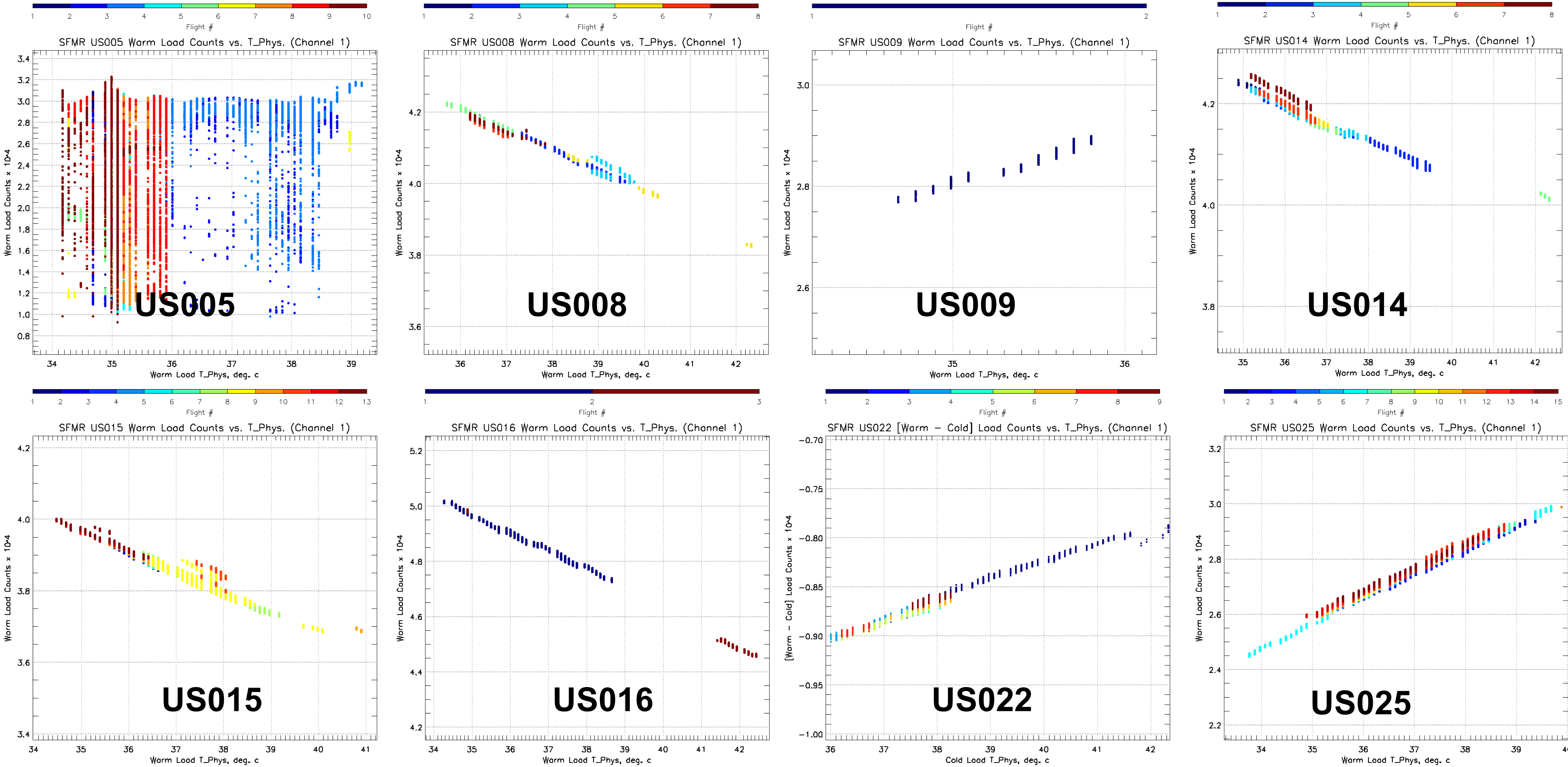
If the system was stable, every flight would lie on one common gain-temperature curve.

US003's = STABLE 57 flights collapse onto a single tight line (stable).

US001 and US002 = UNSTABLE: Flights vertically offset from one another at the same temperature - the gain-temperature relationship shifts flight to flight, the signature of hardware instability that a fixed calibration cannot track.

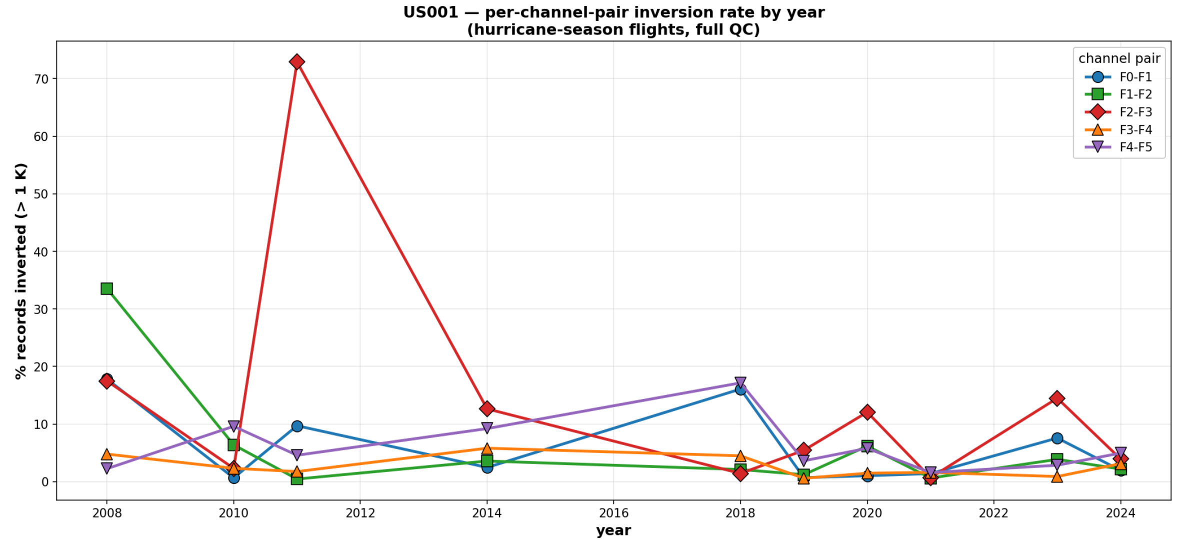
Checking System Linearity with Thermistor Temperatures

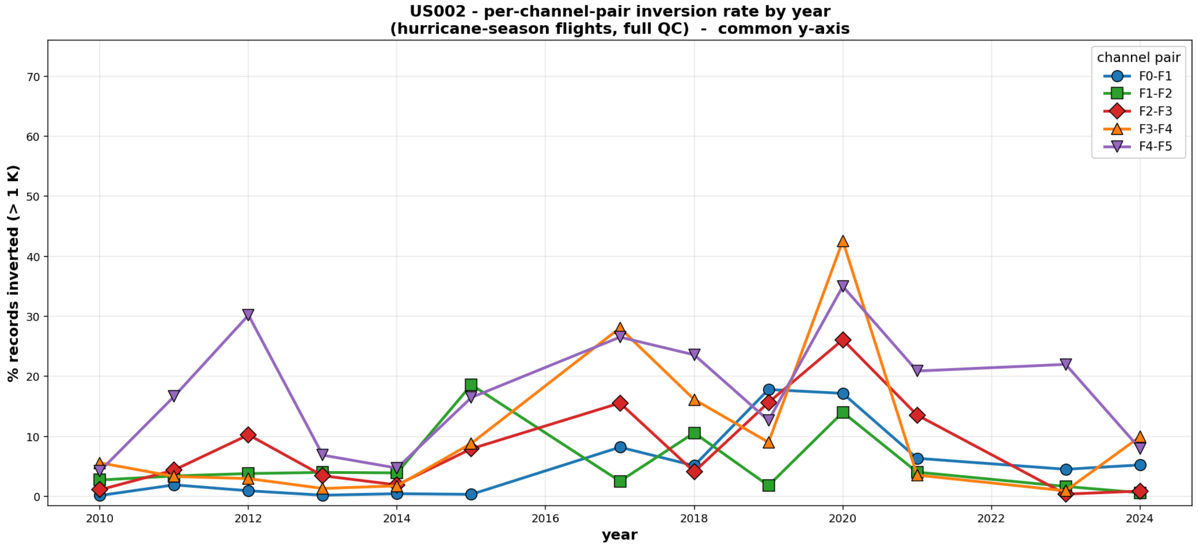
2025 Season – Channel 1 Test

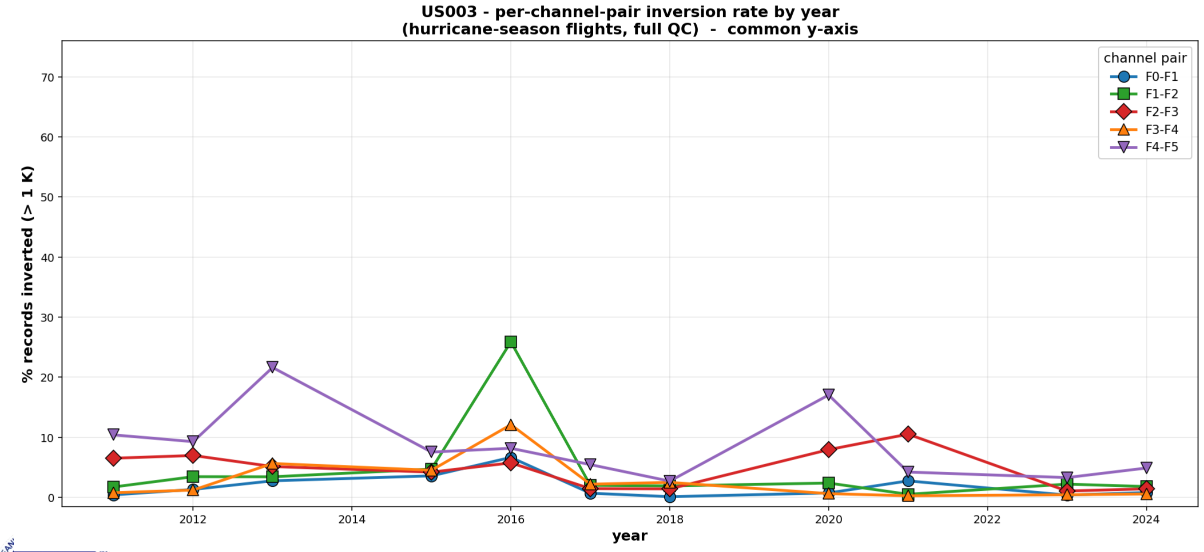


Per-channel-pair inversion rate by year - all three units

% of records where an adjacent channel pair's Tb ordering flips by more than 1 K (hurricane-season flights, full QC)







A spectral inversion = an adjacent channel pair's brightness-temperature ordering flips by >1 K

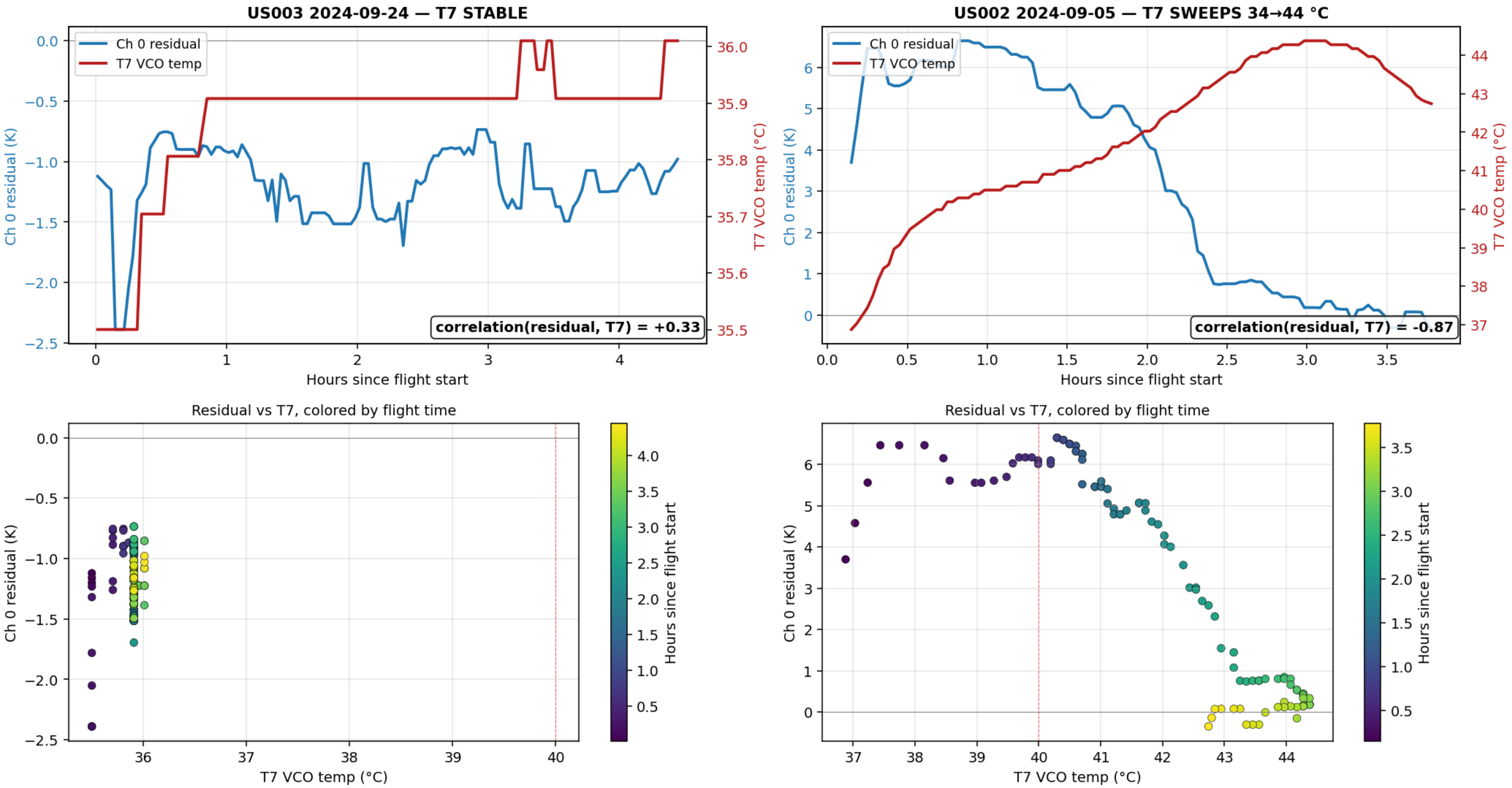
All three units show large, year-to-year swings with no stable pattern - different pairs spike in different years (US001 F2-F3 in 2011; US002 a broad rise after 2015; US003 F4-F5 in 2013/2020, F1-F2 in 2016).

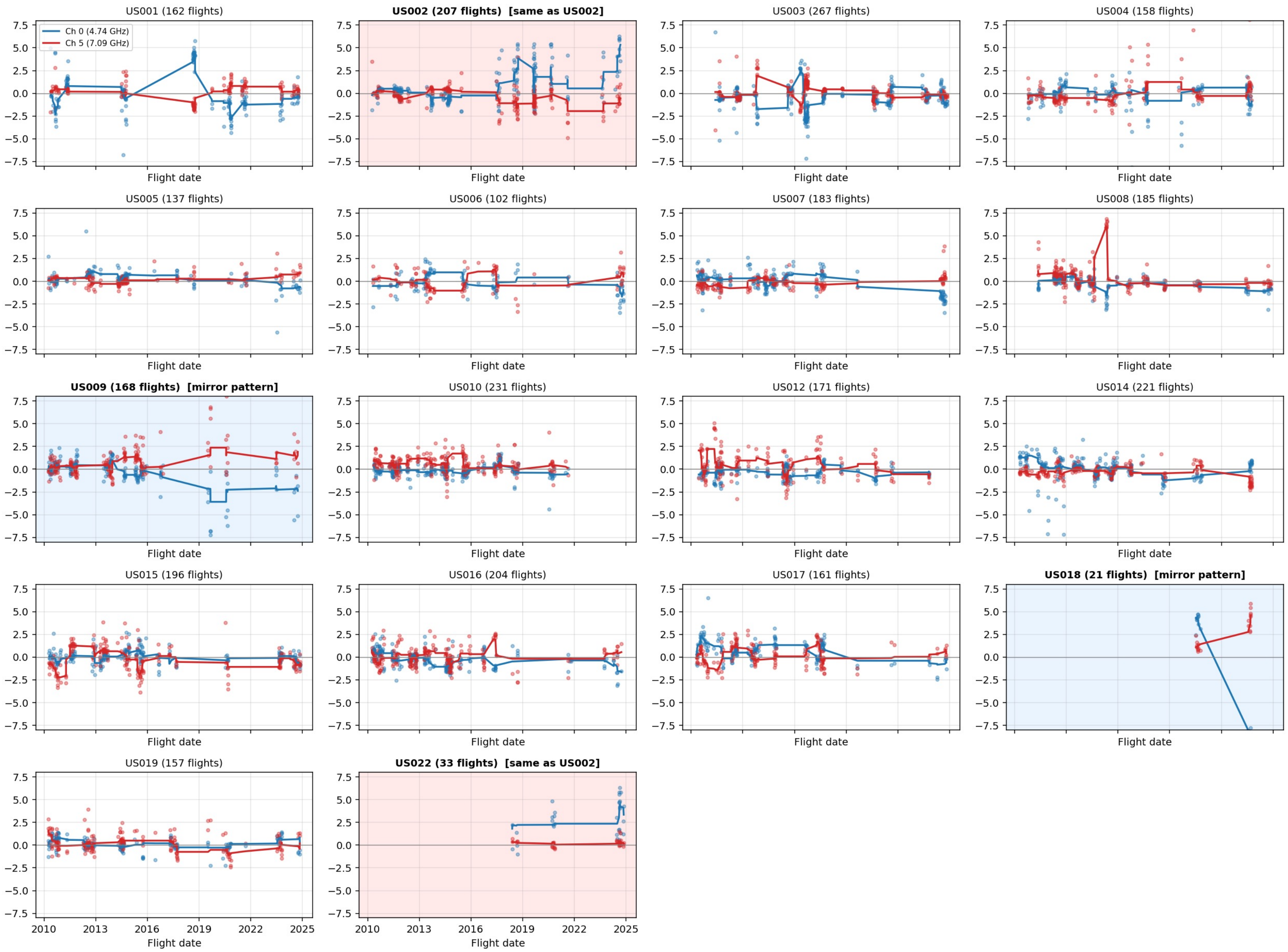
Frequent and non-repeatable inversions are consistent with the per-channel gain instability seen in the gain-vs-temperature and residual-slope diagnostics.

Lessons Learned from SFMR

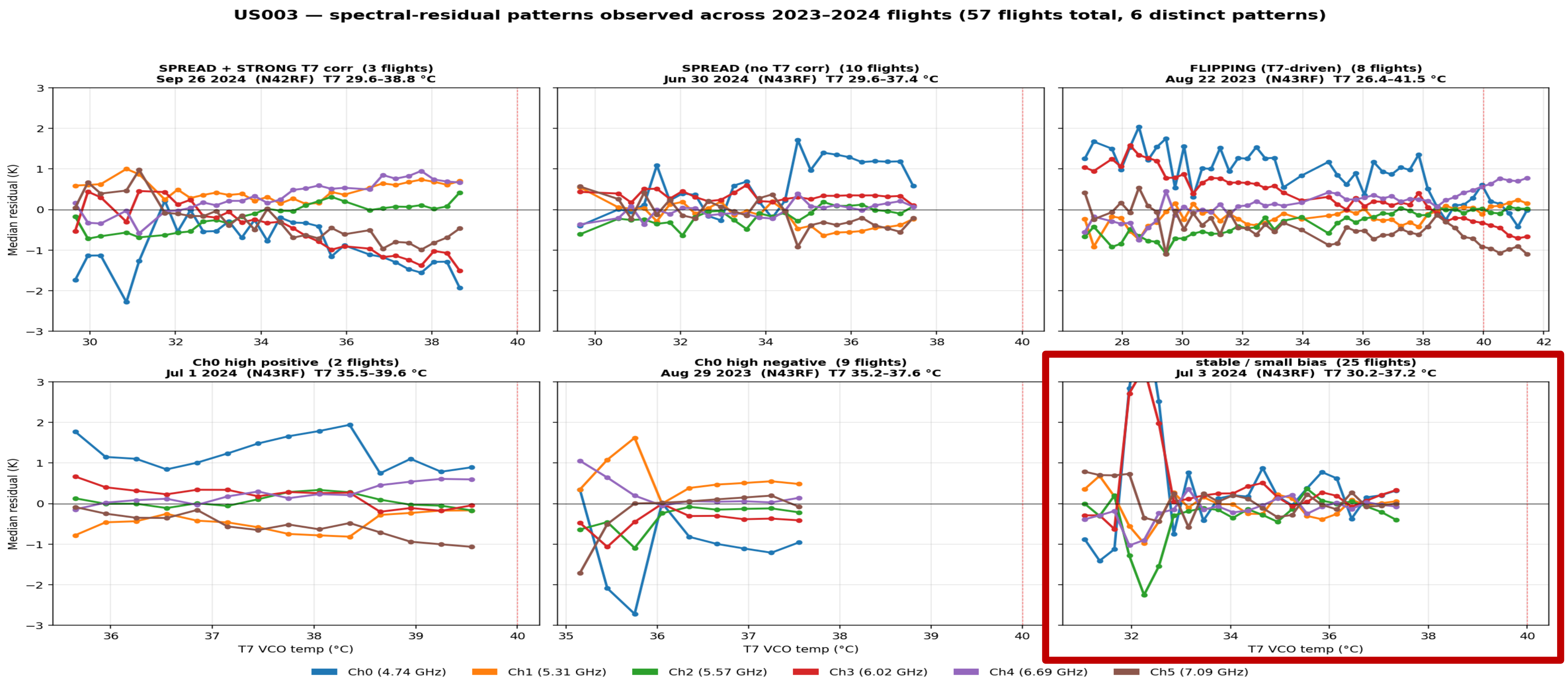
- **Independent (Government-Led) Oversight Is Critical**
  - Vendor-driven validation without systematic, independent review creates blind spots. Government agencies should either possess and maintain internal Cal/Val expertise to ensure data integrity or have access to independent expertise.
- **Appropriate Expertise Is Non-Negotiable**
  - Cal/Val is a technically demanding process that requires specialized expertise in remote sensing and algorithm development. Assigning this responsibility to groups without such capabilities leads to missed errors and prolonged operational impacts.
- **Robust Methodologies Matter**
  - Reliance on standard or simplistic validation approaches is insufficient, particularly for complex and high-impact instruments. Advanced statistical analysis, cross-comparison techniques, and repeatability checks are essential.
- **Cross-Instrument Consistency Must Be Enforced**
  - Requirements should mandate inter-channel and cross-platform calibration to ensure that multi-sensor systems deliver coherent, trustworthy observations.
- **Systematic Performance Monitoring Reduces Risk**
  - Calibration and validation should begin early and continue throughout the instrument's operational life. Detecting and correcting issues early prevents the accumulation of errors in downstream products and decisions.

Extra Slides


US003 2024-09-24 — T7 STABLE
Ch 0 residual
T7 VCO temp
correlation(residual, T7) = +0.33
Ch 0 residual (K)
T7 VCO temp (°C)
Hours since flight start
US002 2024-09-05 — T7 SWEEPS 34→44 °C
Ch 0 residual
T7 VCO temp
correlation(residual, T7) = -0.87
Ch 0 residual (K)
T7 VCO temp (°C)
Hours since flight start
Residual vs T7, colored by flight time
Ch 0 residual (K)
T7 VCO temp (°C)
Hours since flight start
Residual vs T7, colored by flight time
Ch 0 residual (K)
T7 VCO temp (°C)
Hours since flight start

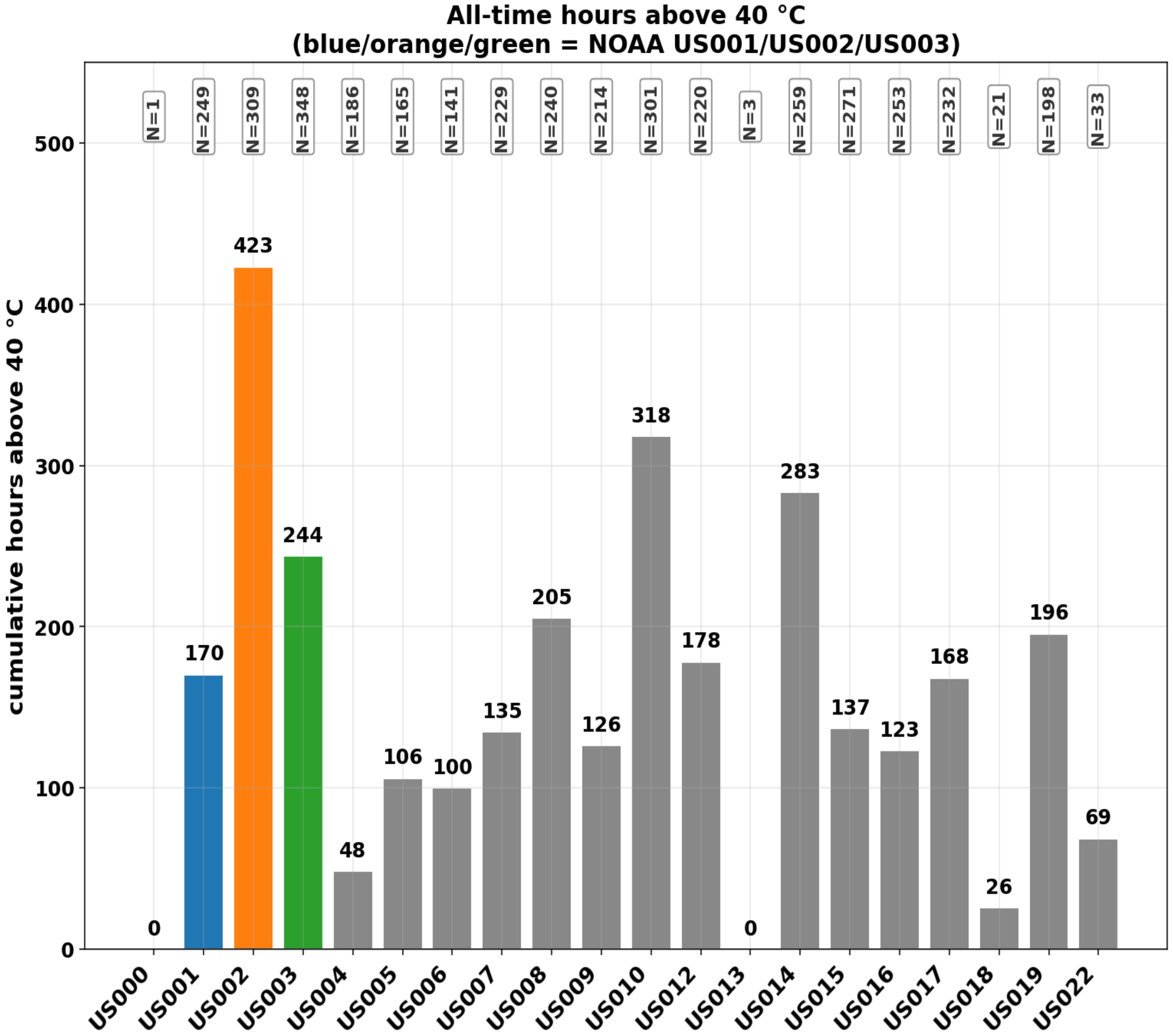

US001 (162 flights)
Ch 0 (4.74 GHz)
Ch 5 (7.09 GHz)
US002 (207 flights) [same as US002]
US003 (267 flights)
US004 (158 flights)
US005 (137 flights)
US006 (102 flights)
US007 (183 flights)
US008 (185 flights)
US009 (168 flights) [mirror pattern]
US010 (231 flights)
US012 (171 flights)
US014 (221 flights)
US015 (196 flights)
US016 (204 flights)
US017 (161 flights)
US018 (21 flights) [mirror pattern]
US019 (157 flights)
US022 (33 flights) [same as US002]
Flight date
2010
2013
2016
2019
2022
2025
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5

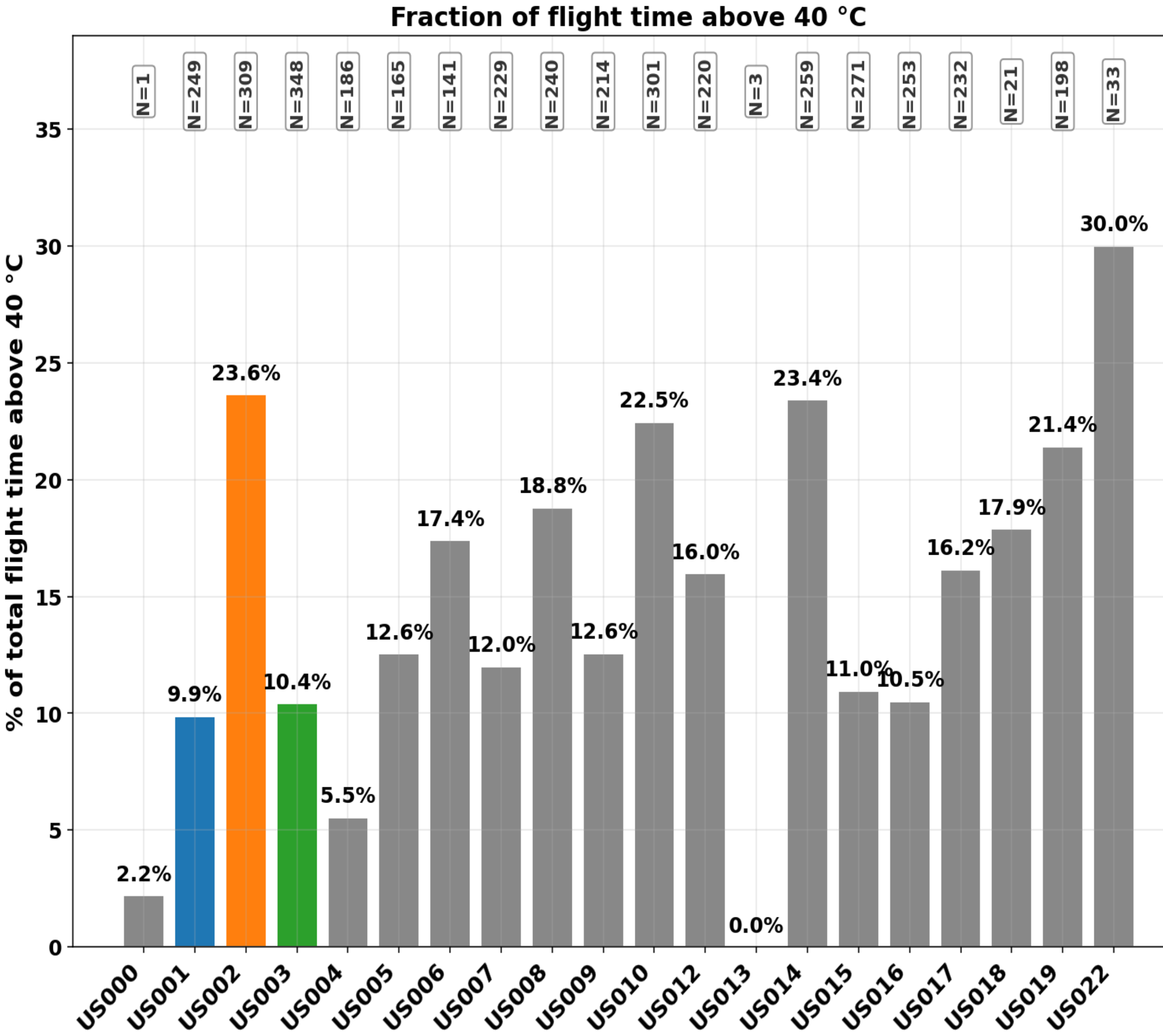
US003 exhibits MULTIPLE distinct spectral-residual patterns



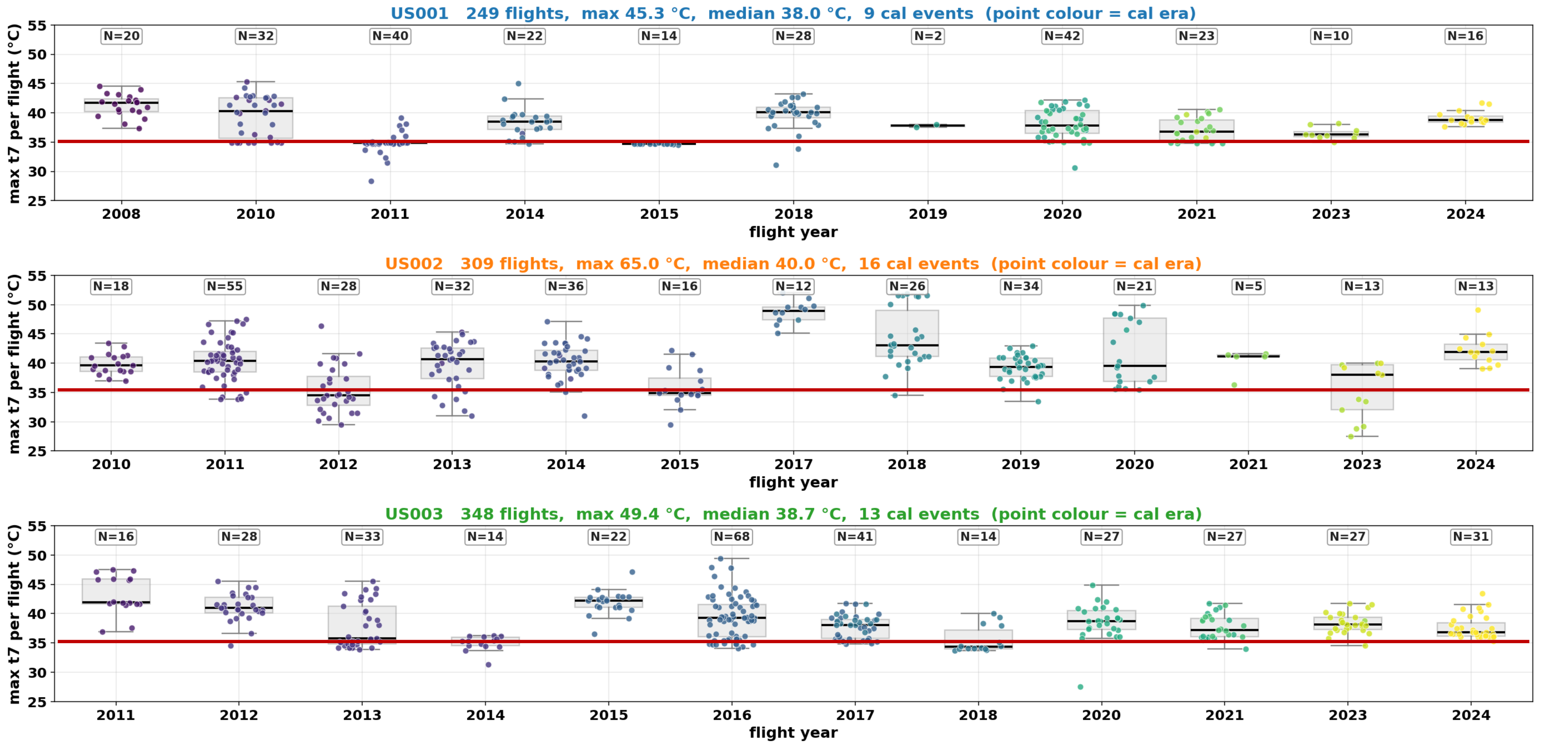
US003 shows all 6 pattern categories, but the dominant one is 'stable / small bias' (25/57 flights). Apparent SPREAD patterns on US003 have much smaller amplitudes (~1-2 K) than the same patterns on US001 or US002 (3-7 K). Late-2024 flights show Ch 0 trending more negative - worth watching.

Lifetime VCO Thermal Exposure per All SFMR Units

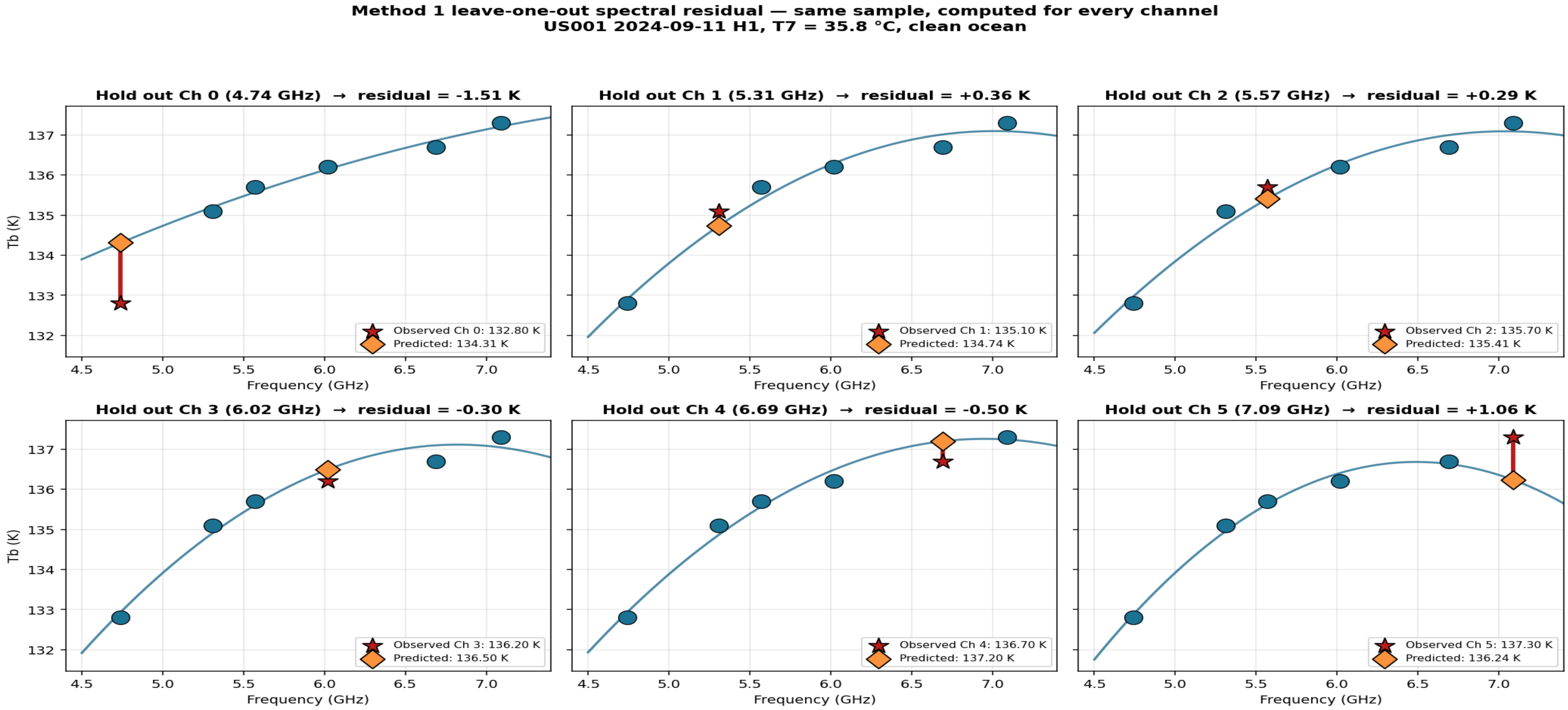




Maximum VCO Temperatures per Year and per Flight

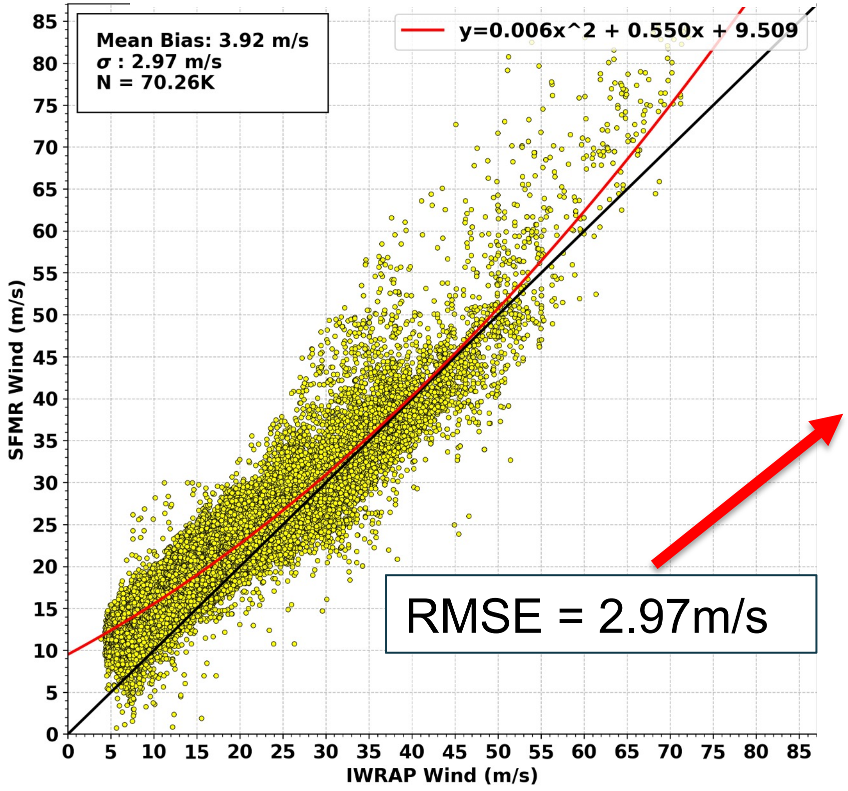


Repeat Leav-one-Out for every Channel



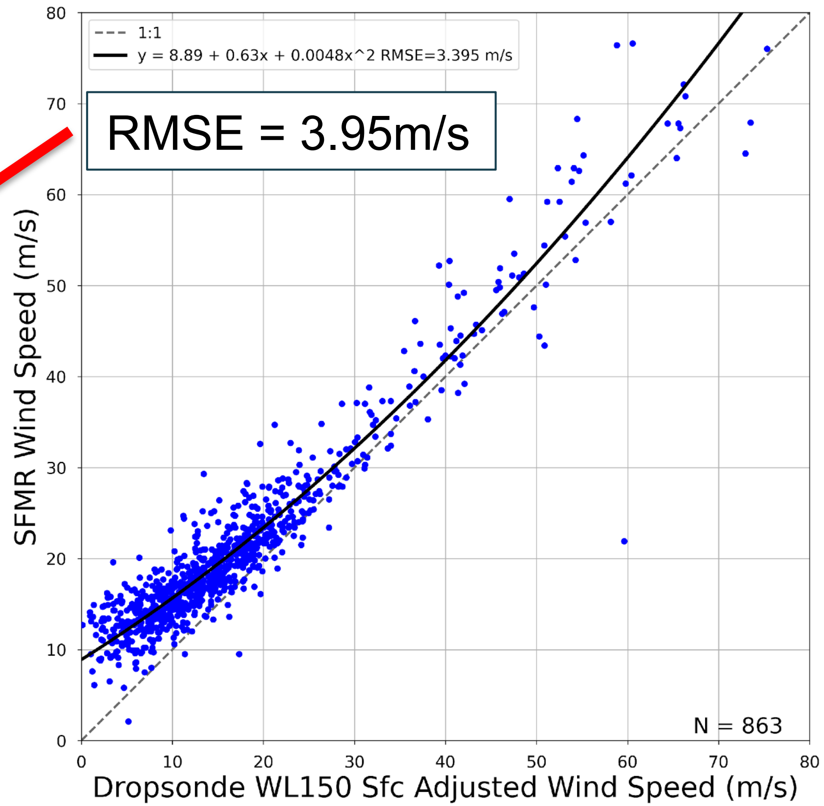
SFMR Performance vs Mission Reqt., 2024 Hurricane Season

SFMR vs IWRAP



Requirement RMSE=5m/s

SFMR vs Dropsondes



- **Data error is better than the mission requirement**
  - **Performance is similar with both Imaging Wind and Rain Profiler (IWRAP) or dropsonde wind sources.**
- **NHC is still questioning SFMR performance. What are we missing?**