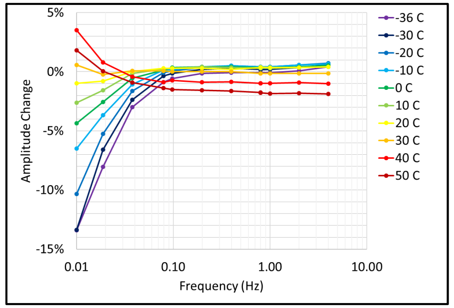
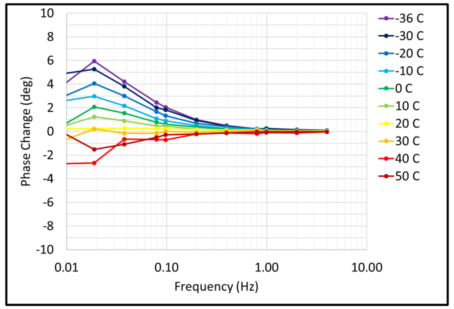
SAND2024-14810C

Sandia National Laboratories

Infrasound Sensor Performance at Extreme Temperatures and Low Frequencies





PRESENTED BY

B. John Merchant and Doug Bloomquist

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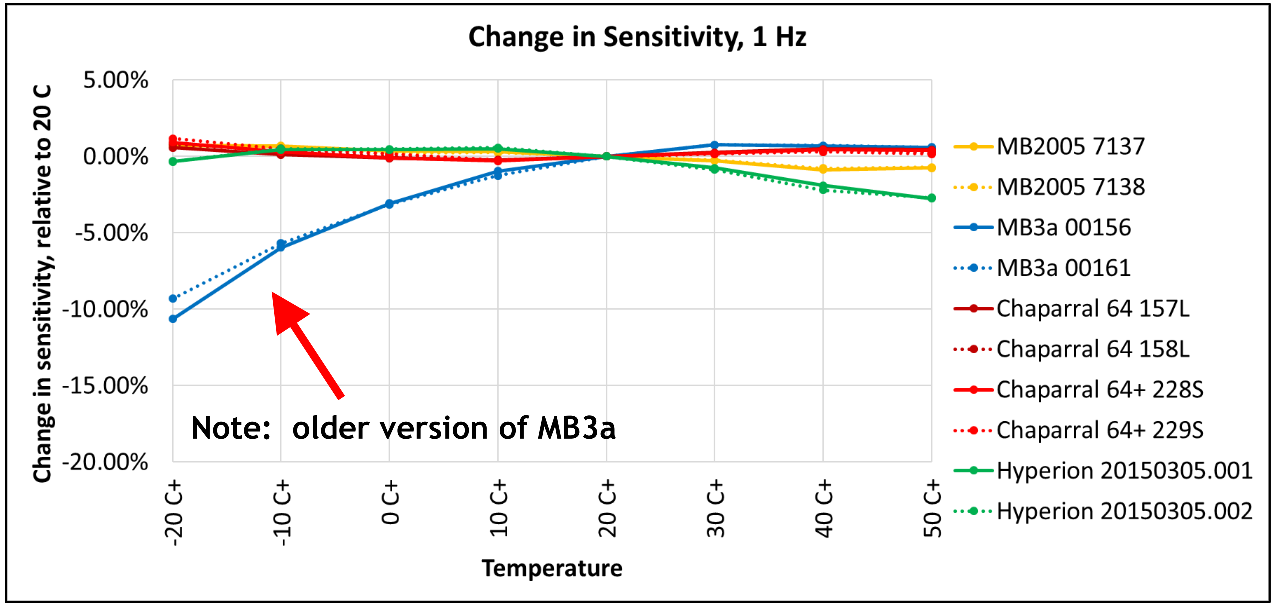
Motivation

- Past infrasound sensor laboratory evaluations (ITW 2019) have shown measurable changes in frequency response due to temperature:
  - Frequency passband of 0.1 Hz to 10 Hz
  - Temperature range of -20 C to + 50C



Change in Sensitivity at 1 Hz, due to temperature (Merchant, ITW 2019)

- Recent field comparison data have demonstrated issues at lower frequencies and colder temperatures.

Installation at I53

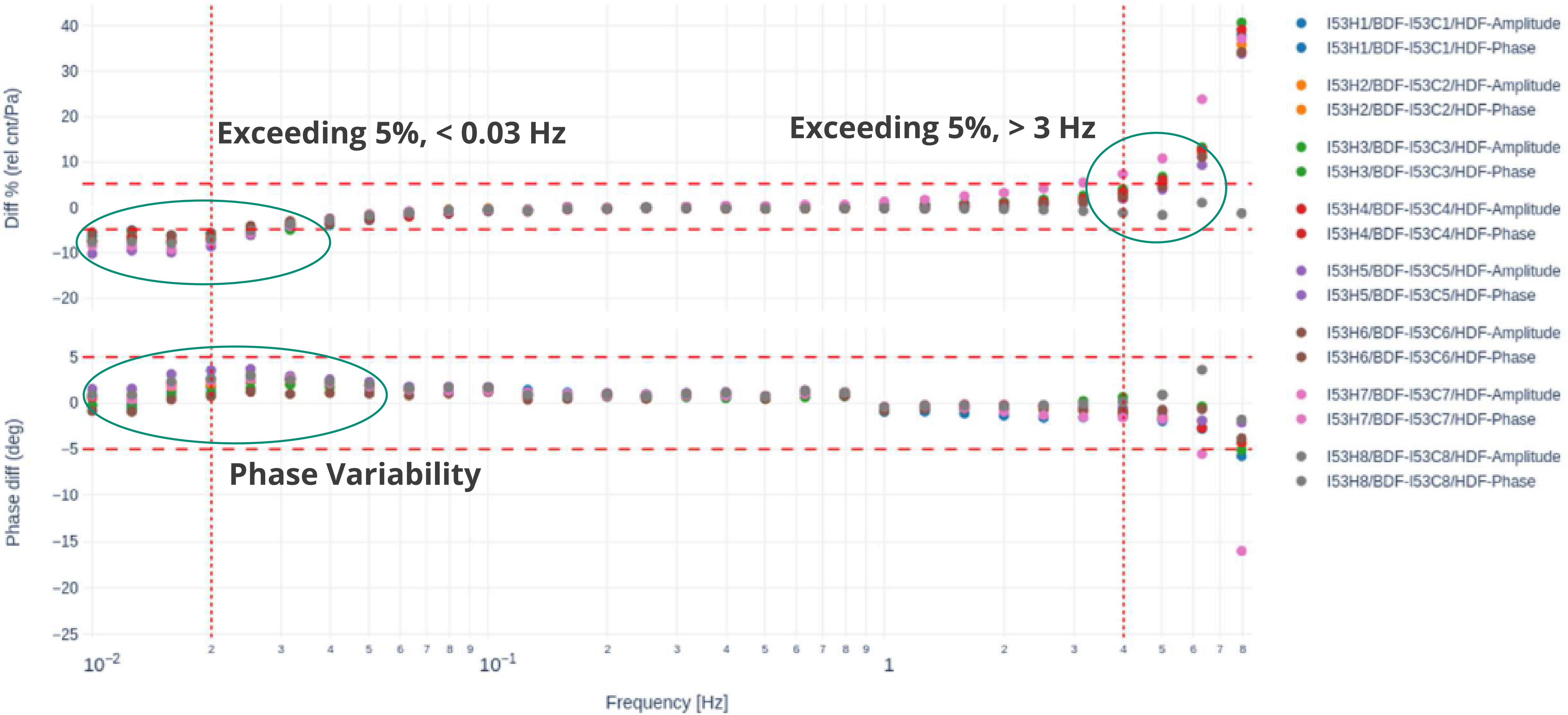
UAF has installed a co-located in-situ reference infrasound sensor at the US IMS Station I53:

- Operation Sensor: Hyperion 5313A-LP
- In-situ Sensor: Chaparral 64S

In-situ reference sensors have been operating since 2021 as a trial, data is being sent to PTS, although not officially running as calibration channel.

In-situ Comparison Results, variability in frequency response

Across I53 sites – August to December 2021 – Site specific responses for C sites



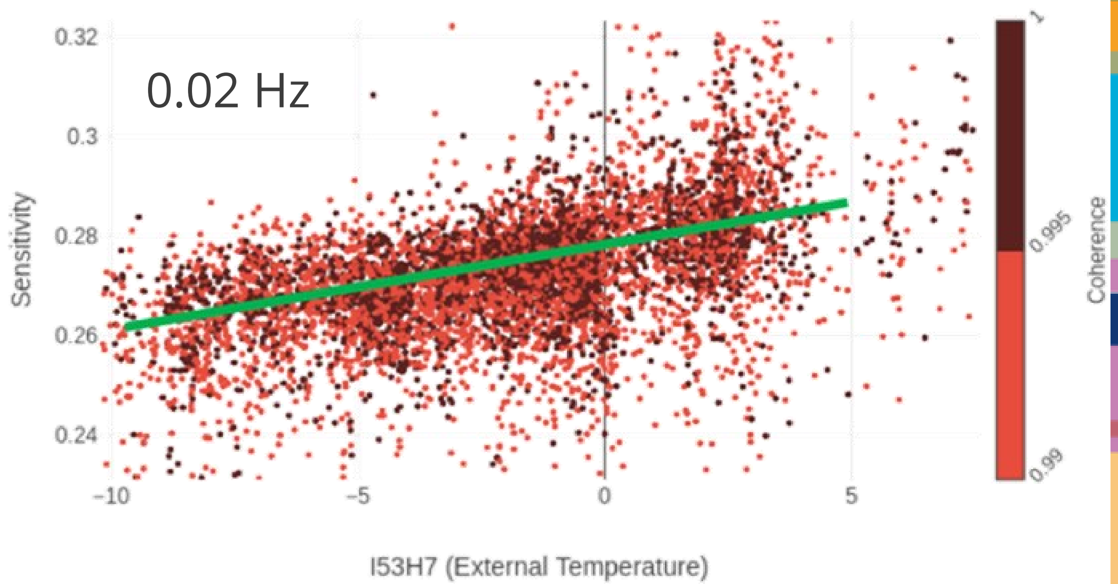
CalxPy, Benoit Doury, 2023

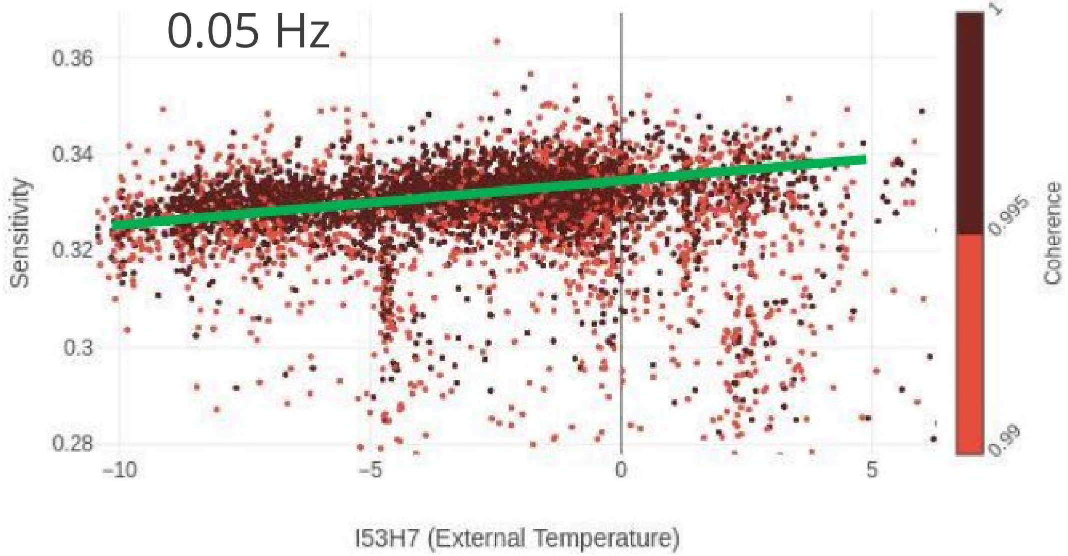
In-situ Comparison Results, dependence on frequency and temperature

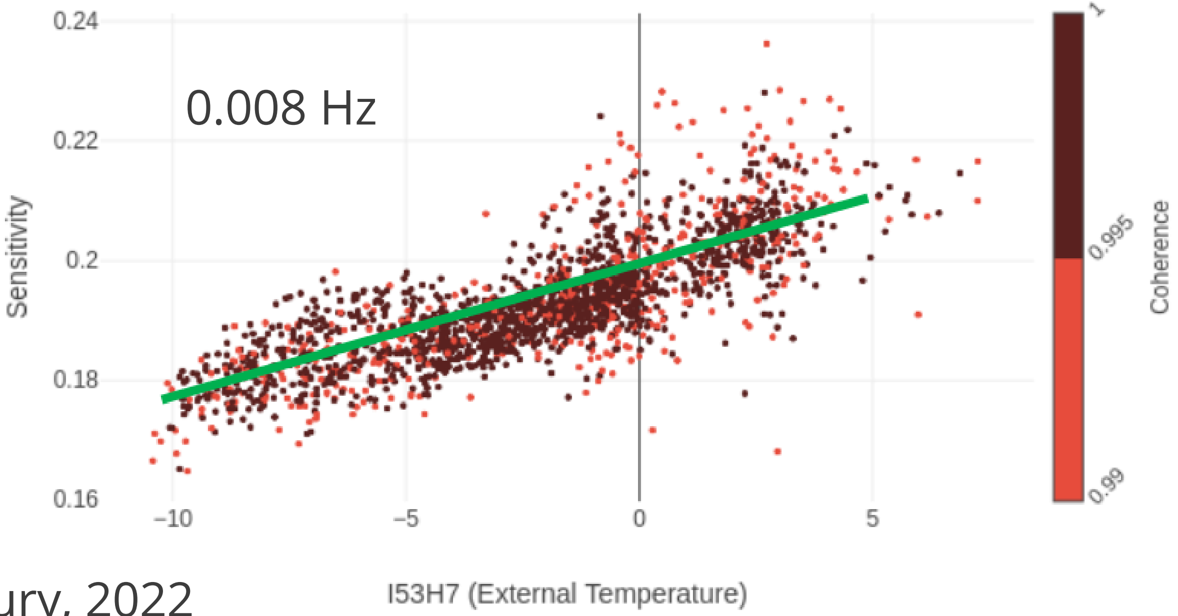
In-situ comparison over -10 C to +7 C shows clear correlation between sensitivity and temperature.

Stronger correlation as frequency decreases:

- At 0.05 Hz: 0.3 % / C
- At 0.02 Hz: 0.5 % / C
- At 0.008 Hz: 1.0% / C



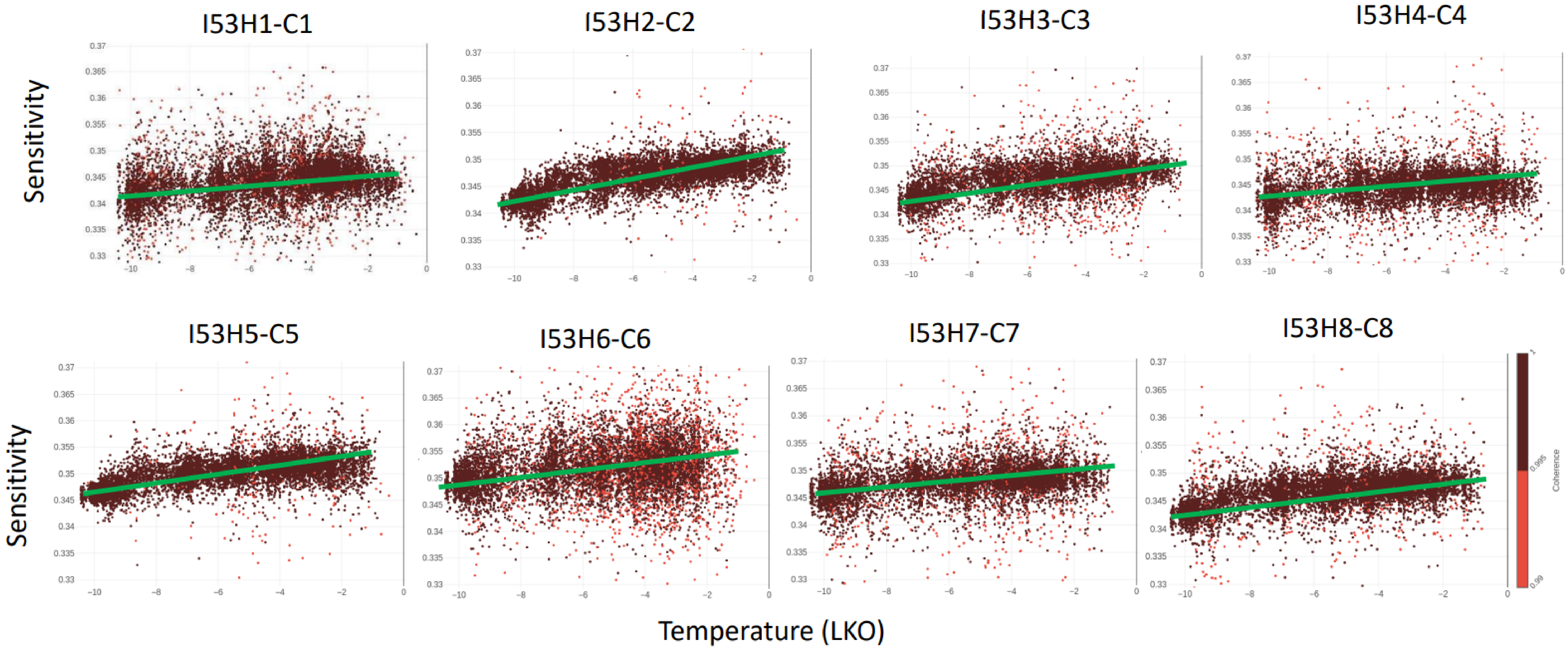




CalxPy, Benoit Doury, 2022

In-situ Comparison Results: All Sites at 0.25 Hz

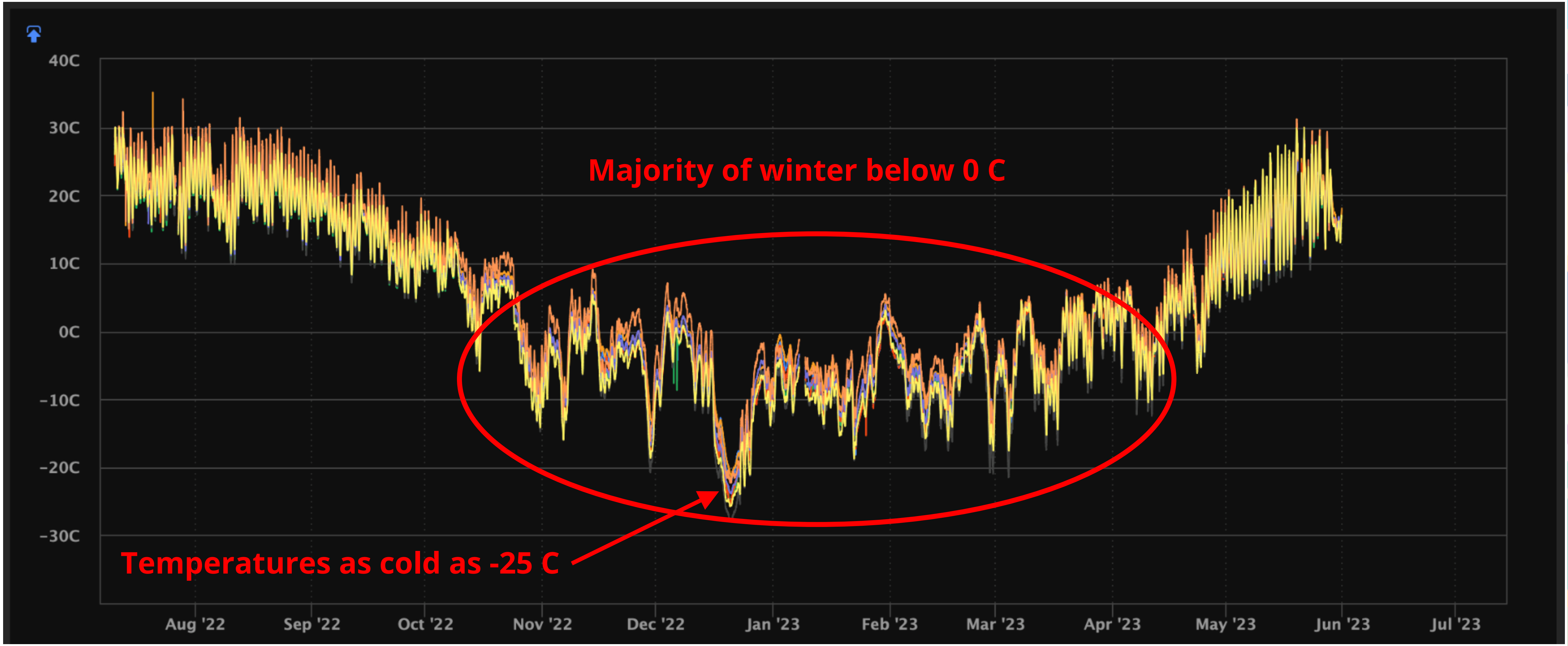
All IS53 elements exhibit a similar correlation with temperature, shown at 0.25 Hz over -10 C to 0 C



CalxPy, Benoit Doury, 2022

I53 Vault Temperature

I53 vault temperatures regularly colder than 0 C during the winter, sometimes as low as -25 C



Temperature Susceptibility Testbed

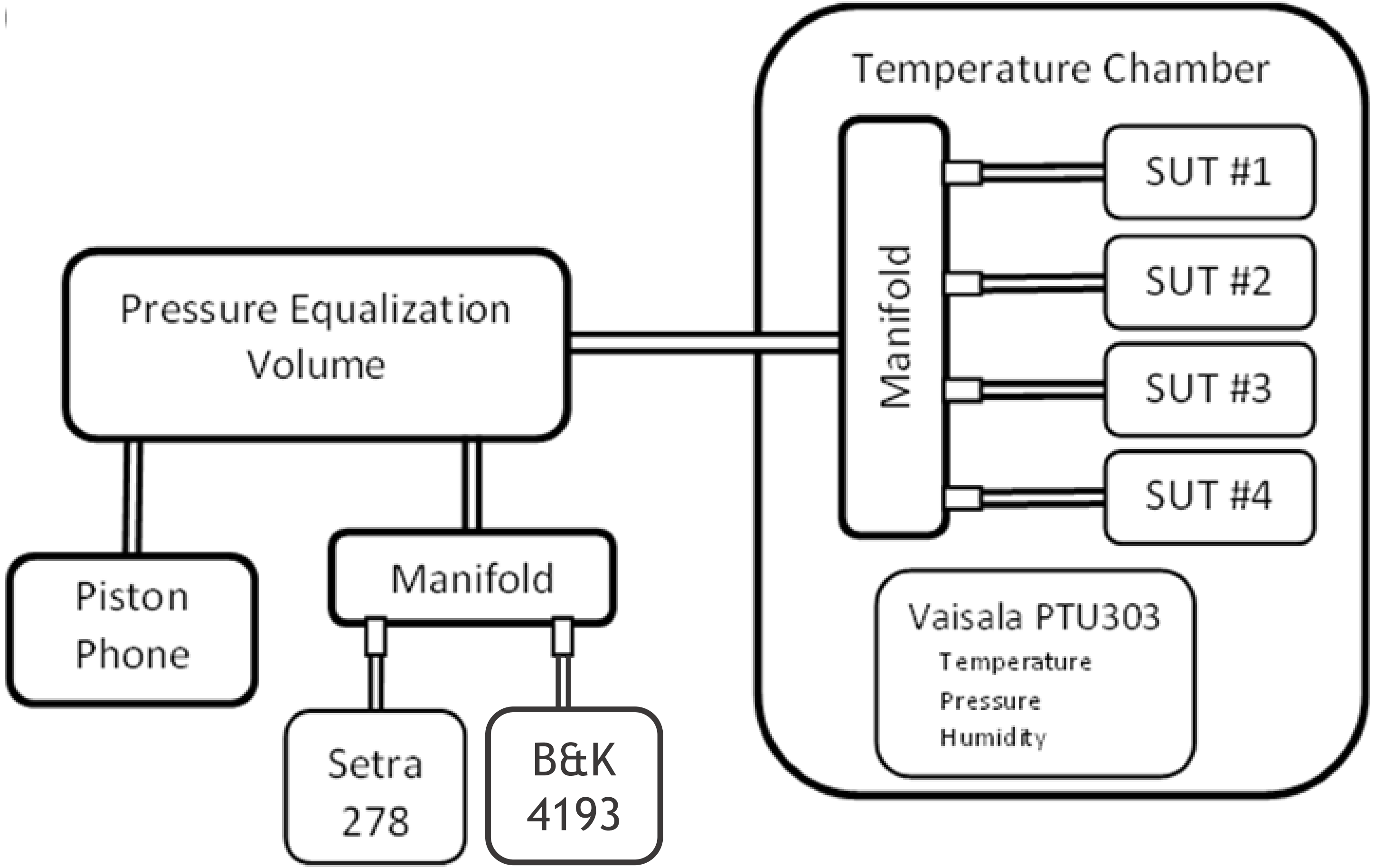
SUT inside Temp Chamber

Reference Sensors outside, not influenced by temperature.

Added Setra 278 microbarometer as a reference, more stable below 0.1 Hz

Testbed not suitable for absolute calibration, but can be used for relative measurements.

e.g., SUT response changes
at -30 C vs 20 C



Devising a new experiment, extending to lower temps and frequencies

Tested over -36 C to +50 C, both increasing and decreasing directions

12 hours at each temperature step, no more than 10 C steps.

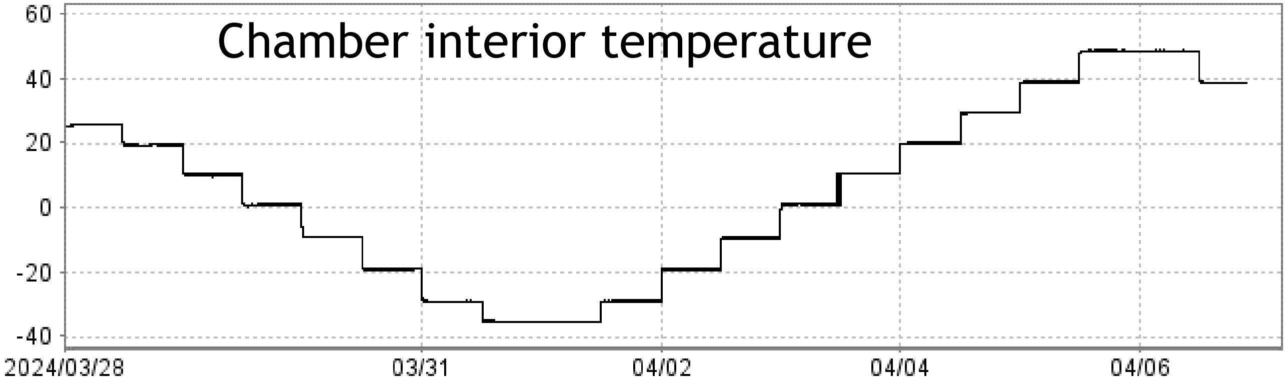
- 4 hours to thermally equalize
- 8 hours of calibration signals, repeated averaging

Test took 2 weeks to run

Setra (< 0.5 Hz) and B&K (>= 0.5 Hz) references, outside of chamber, only used for relative measures.

Sensors Under Test Included:

- MB3a
- Chaparral 64S
- Hyperion 5113A
- Hyperion prototype (modified low-frequency corner)



Improved amplitude and phase measurement uncertainty:

1. Longer temperature stabilization times (4 hours to settle with a 10 C change)

2. Modified algorithm for fitting sinusoidal signals used for calibration by comparison:

   Previous:

   - Least-squared fit of 10 cycles for amplitude, phase, frequency, DC Offset, and linear slope

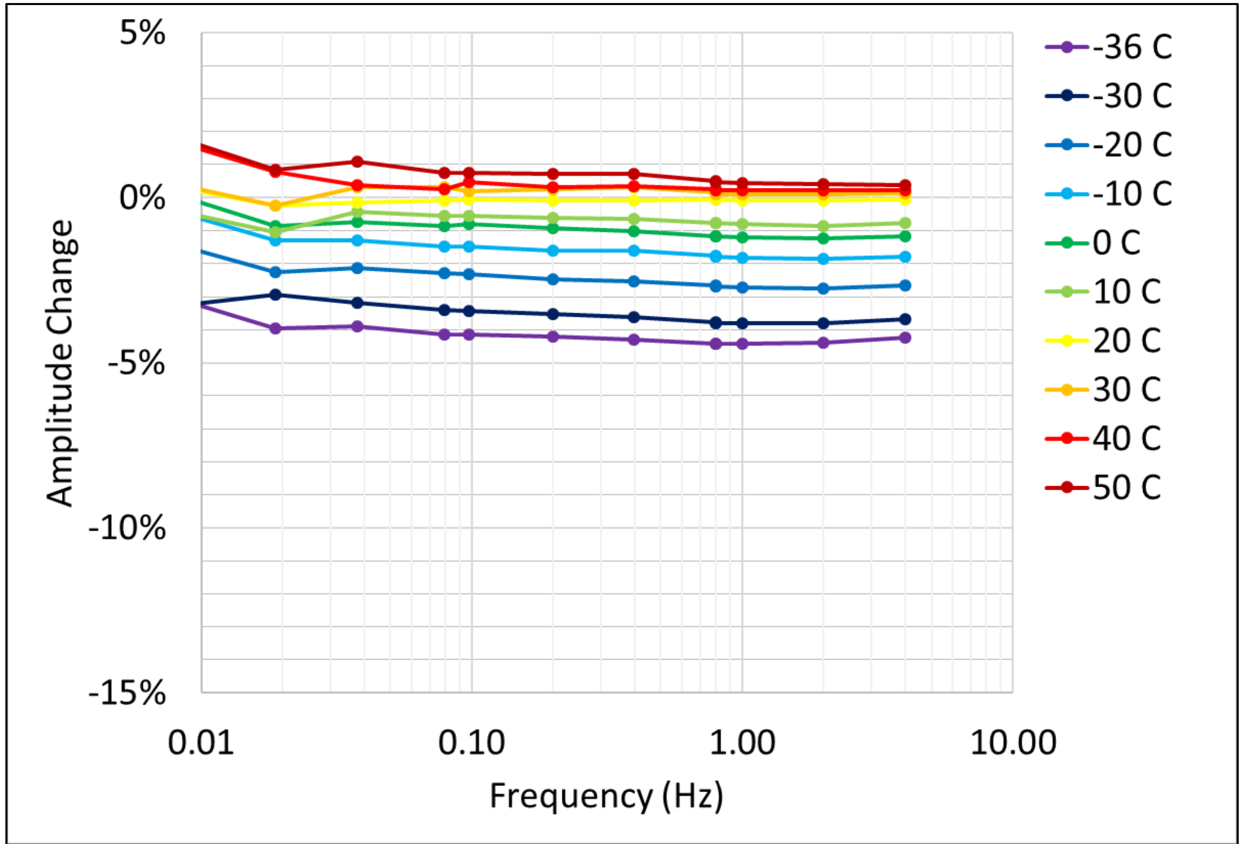
   New:

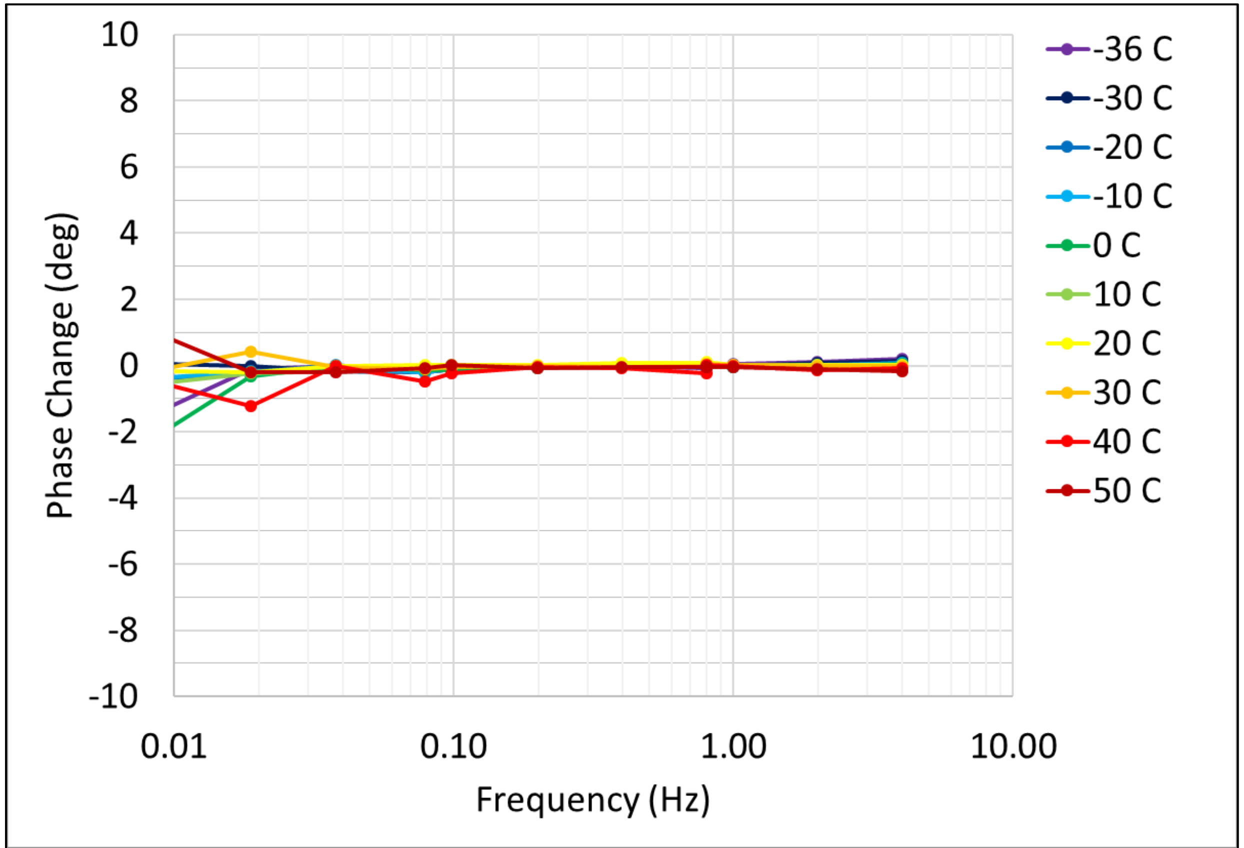
   - Compute multiple sine-fits on 10-cycles of data, using 3 cycle sub-windows, shifted 1/8 cycle
   - Solve for all same sine-fit parameters, exclude outliers, and compute average.

3. Measure frequency response repeatedly 7 times across 0.01 to 10 Hz over 8 hours at each temperature, compute the median value for amplitude and phase response.

Results: MB3a

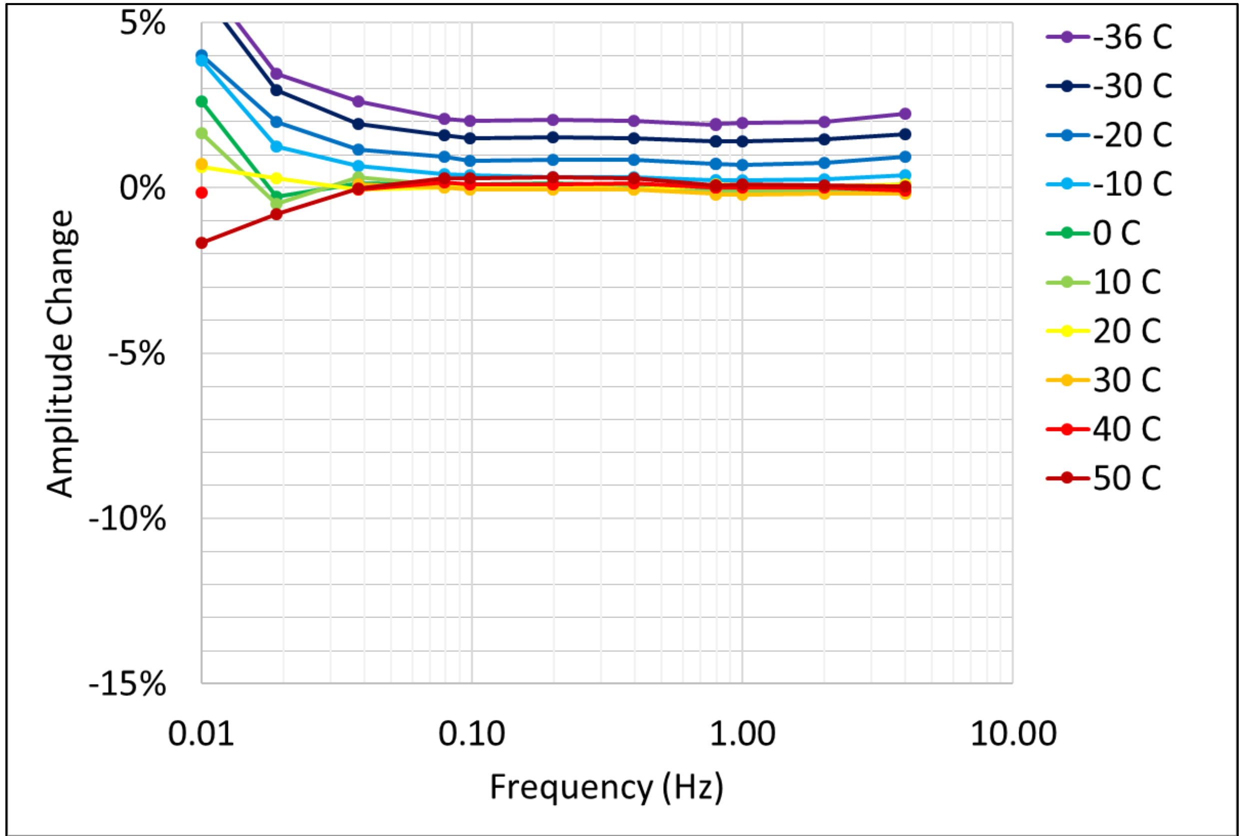
- Newer MB3a version (since 2022) has less amplitude variability at cold temperatures:
  - Latest measurement is **-3 %** at 1 Hz and -20 C vs **-10 %** for earlier MB3a versions
  - Colder temperatures have some continued decrease in amplitude response, **-4% at -36 C**
  - No significant variability in phase response

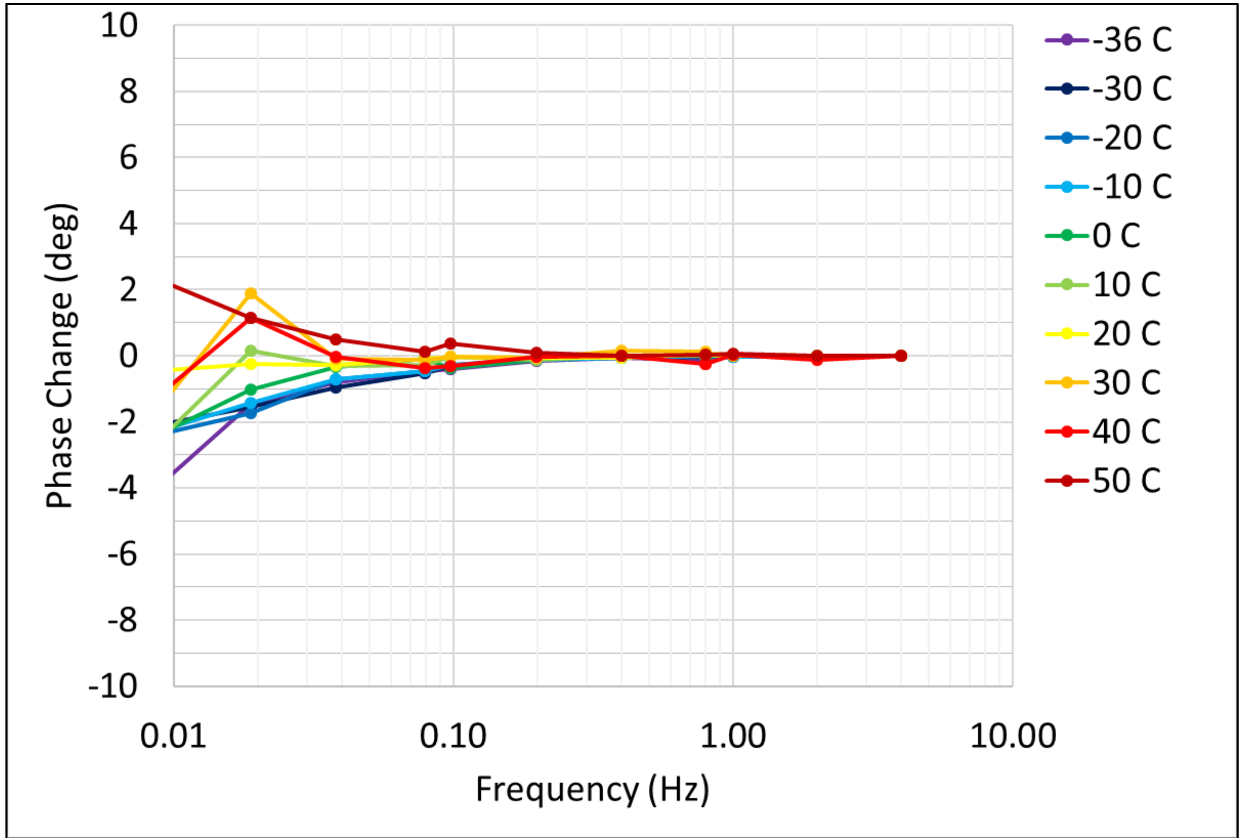




Results: Chaparral 64S

- Amplitude variability > 0.1 Hz consistent with earlier measurements, as much as **+2% at -36 C**
- Evidence of corner frequency shifting due to temperature, over 0.02 to 4 Hz:
  - **-1% to +3%**
  - **-2 to +2 degrees**

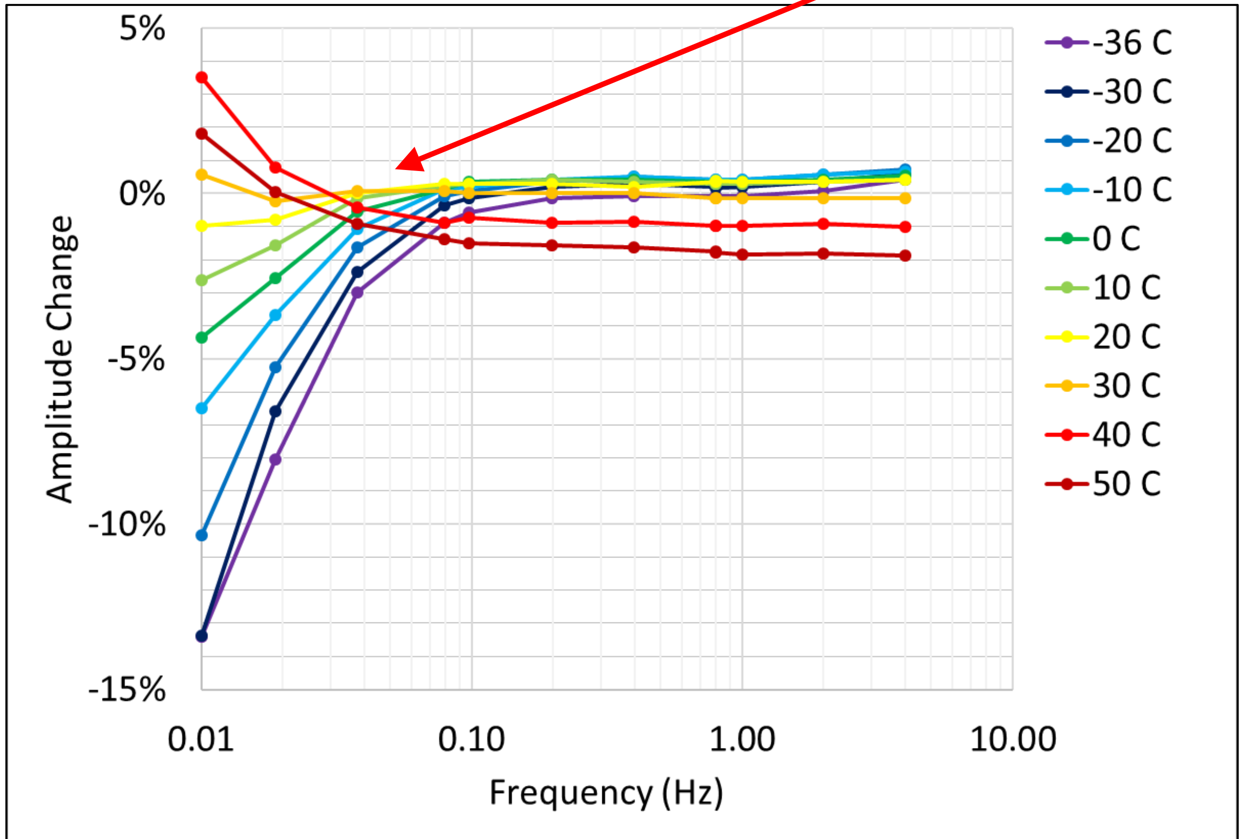


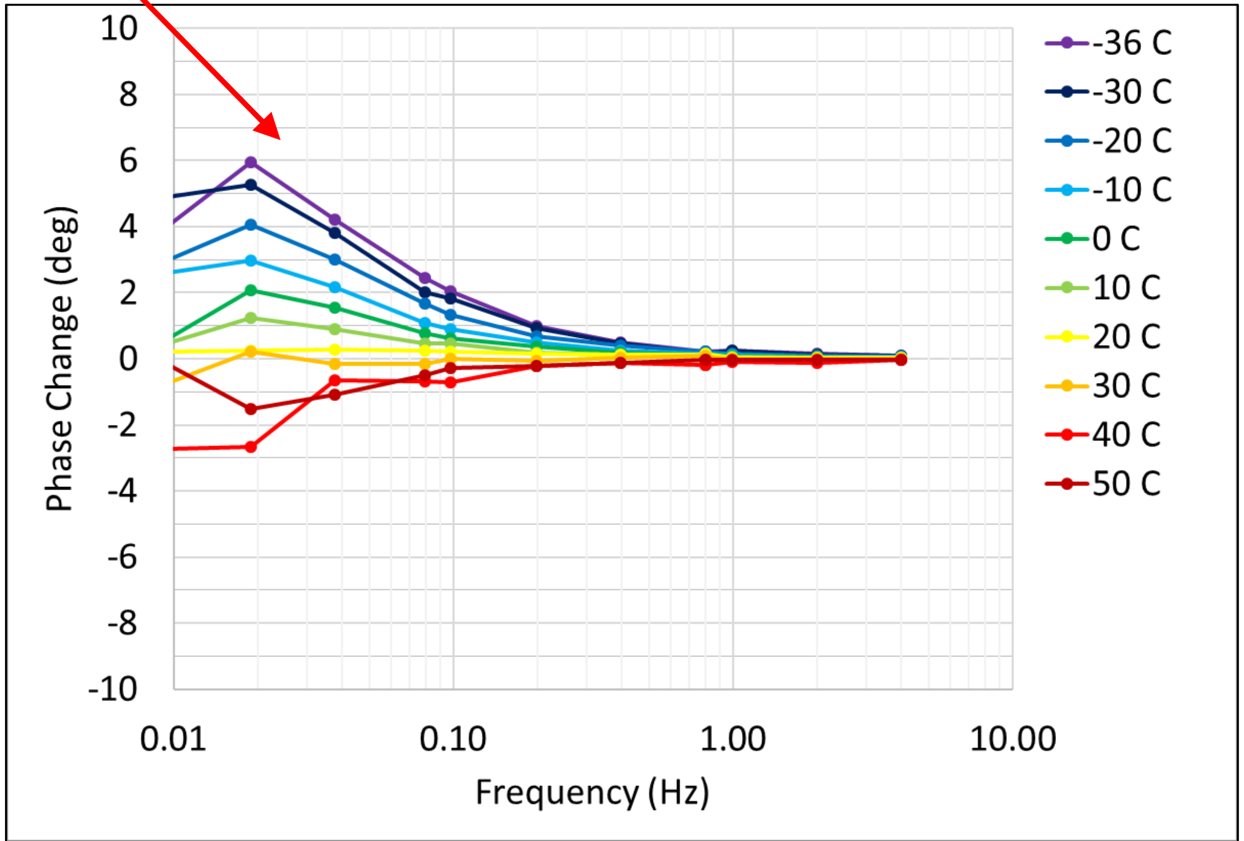


Results: Hyperion 5113A

- Amplitude variability > 0.1 Hz consistent with earlier measurements, as much as **-2% at +50 C**
- Evidence of corner frequency shifting due to temperature, over 0.02 to 4 Hz:
  - **-8% to +1%**
  - **-3 to +6 degrees**

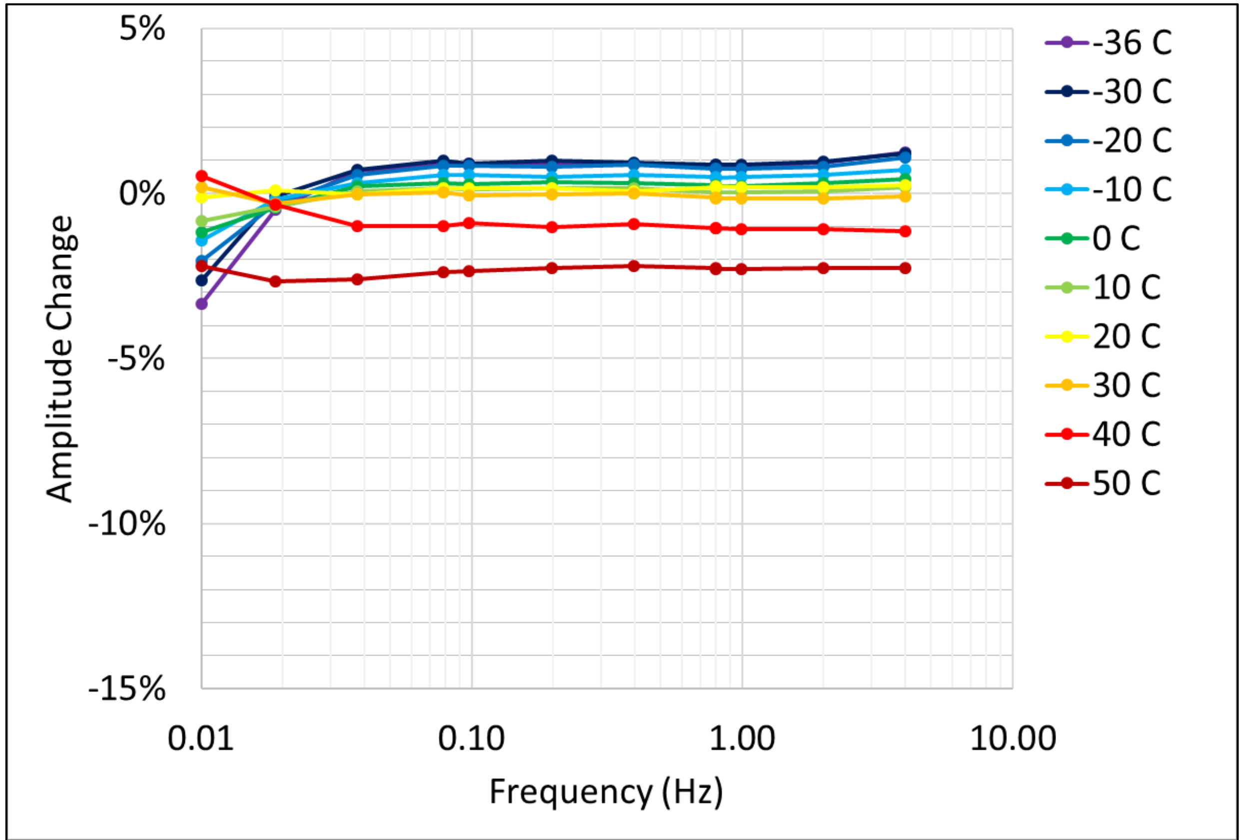
Note significant corner frequency shift

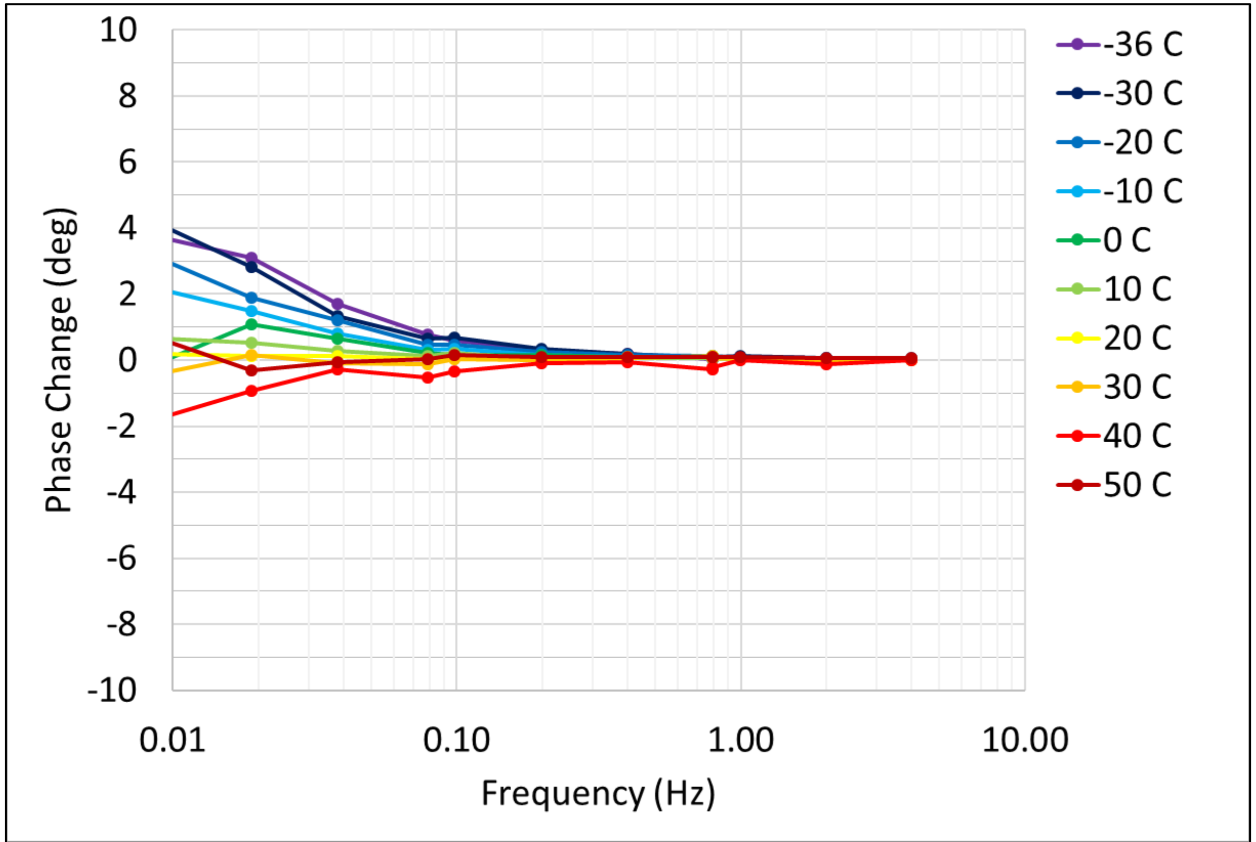




Results: Hyperion Prototype

- Prototype Hyperion produced with corner frequency moved from **0.015 Hz** to **0.0058 Hz**, moves the corner frequency temperature variability further outside IMS passband.
- Amplitude and phase variability reduced by more than half, over 0.02 to 4 Hz:
  - **-3% to +1%**
  - **-1 to +3 degrees**





Summary

- The In-Situ reference comparison method (Gabrielson) employed at IMS stations has demonstrated the ability to identify previously unknown issues with infrasound sensors in the field. This example also highlights the importance of the In-Situ Reference being a different model from the Operational sensor.

- Installation at I53 was an example of an extreme scenario:
  - Hyperion 5000 as operational sensor, performance changing more significantly in one direction
  - Chaparral 64S as in-situ reference, performance changing in an opposite direction
  - Temperatures down to -25 C exacerbating the issues.

- Enhanced Temperature Susceptibility laboratory evaluations have improved the ability to resolve infrasound sensor performance down to lower temperatures (-36 C) and frequencies (0.01 Hz)

- Traceable measurement of sensor performance and susceptibility to environmental conditions provides manufacturers with the information needed to make improvements to their sensor designs.

Acknowledgements:

- UAF, for the I53 dataset and discussions of diagnosing potential issues
- Benoit Doury at the PTS, for analysis of I53 data with CalxPy
- NCPA and Hyperion for providing a prototype Hyperion sensor