CALIBRATION OF TEMPERATURE SENSORS

With Focus on Bath Calibrations

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THE PROCESSING CHAIN

Role of Bath Calibrations

Purpose: Determine the resistance vs temperature for temperature sensors

Method: Immerse in stirred bath along with quality PRT; measure T and R

Product: Set of corresponding measurements of T and R that are then used to calibration the onboard data acquisition chain from sensor to recorded digital number.

EXPECTED RESULT

HARCO and Goodrich (formerly Rosemount) heated sensors

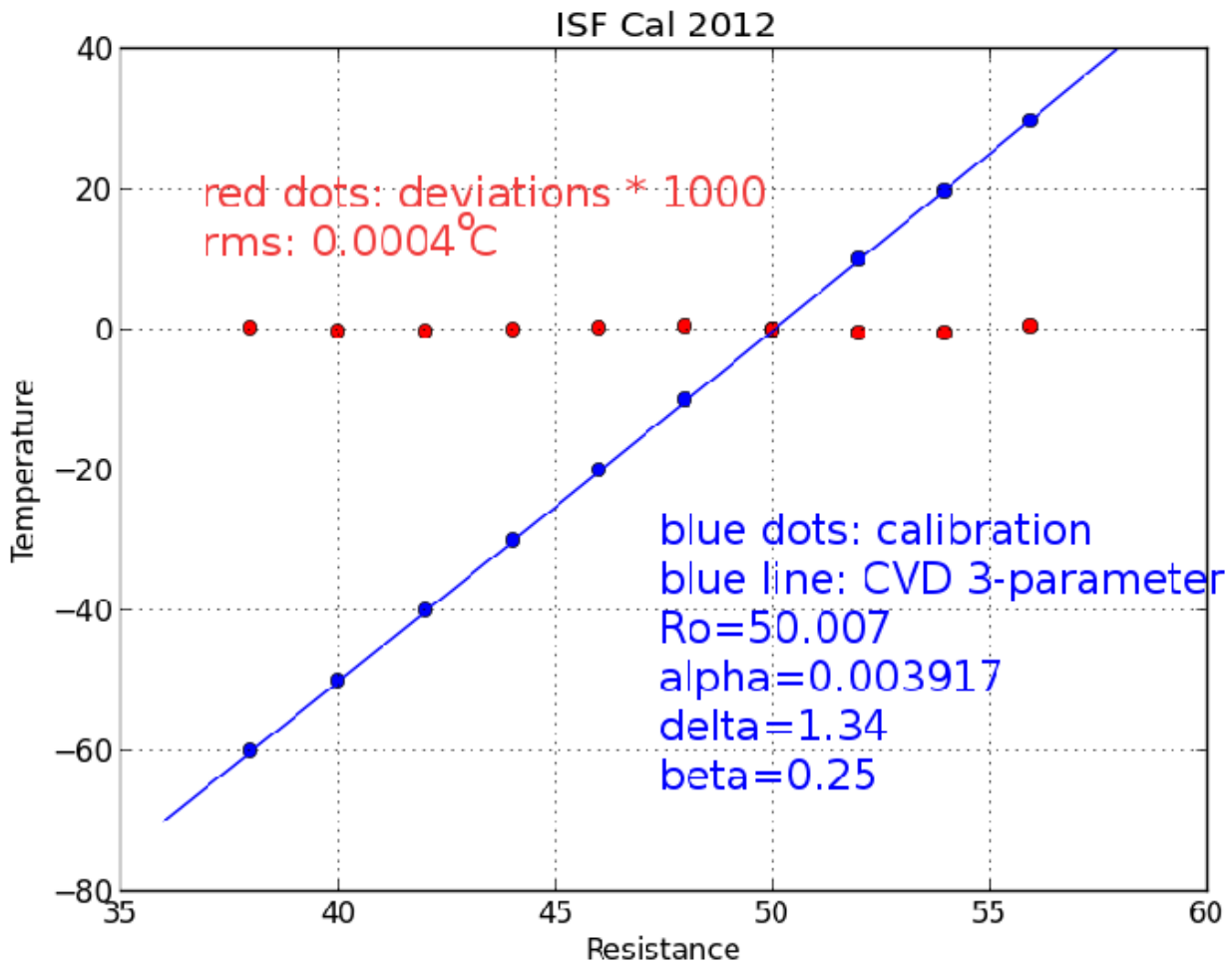
Must meet MIL SPEC MIL-P-27723E.
Part of that specifies a T-R relationship as given by the Callendar - Van Dusen equation:

$$\frac{R_T}{R_0} = 1 + \alpha \left[T - \delta \left(\frac{T}{100} - 1 \right) \left(\frac{T}{100} \right) - \beta \left(\frac{T}{100} - 1 \right) \left(\frac{T}{100} \right)^3 \right]$$

- Coefficients are specified: $\alpha = 0.003925$, $\delta = 1.45$, $\beta = 0.1$ for $T < 0$, $\beta = 0$ otherwise
- Allowed tolerance: 0.25°C at 0C, 0.5°C at -50C

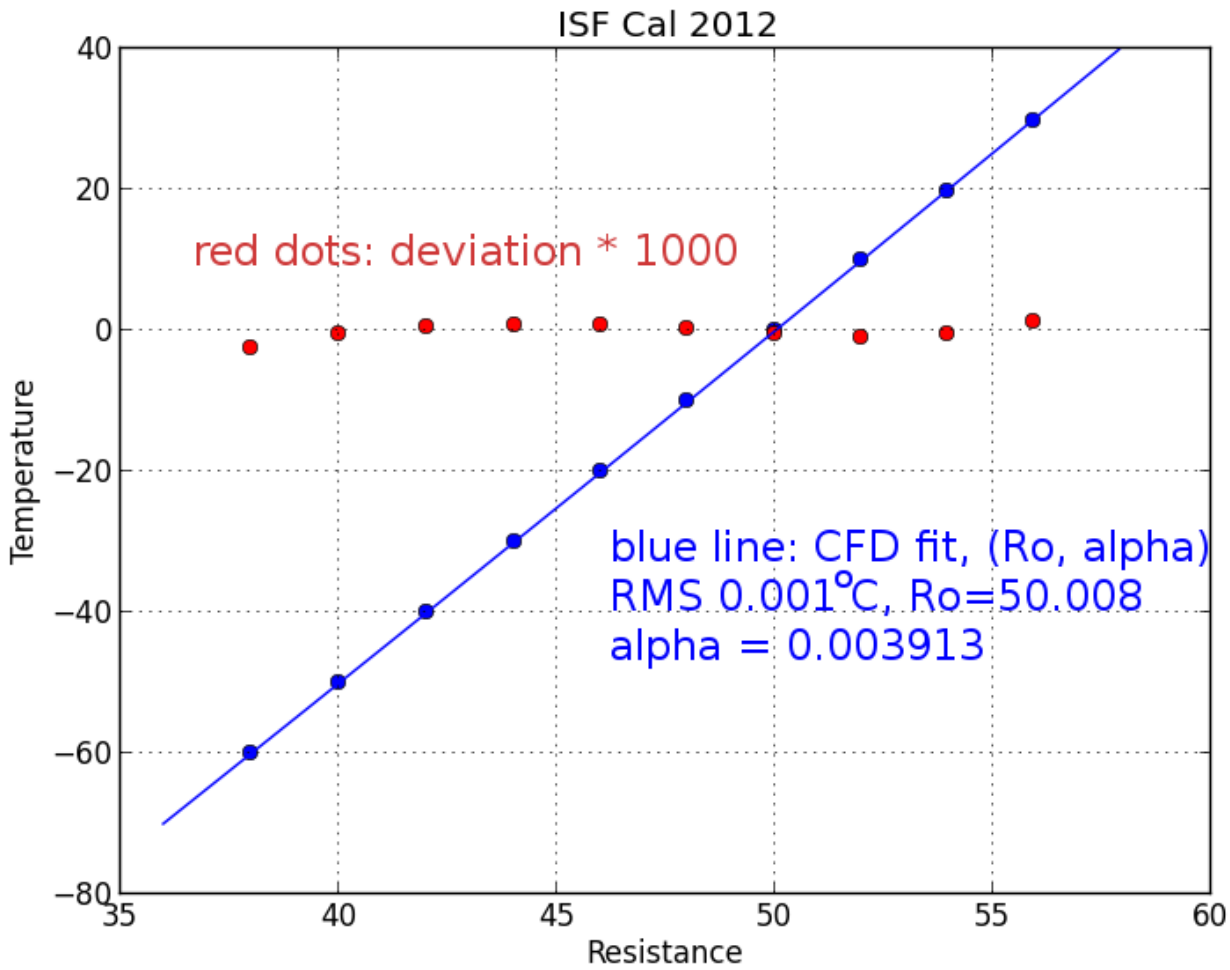
A SAMPLE CALIBRATION

ISF 2012, HARCO HEATED SENSOR



SAME CALIBRATION, CONSTRAINTED

ISF 2012, HARCO HEATED SENSOR



ASSESSMENT

Suggested Approach To Bath Cals

1. Look for near-perfect agreement with the predictions of the CVD equation.
2. The coefficient of thermal resistivity (α) is the dominant variation. Other coefficients have minor effects.
3. $\alpha \approx 0.003925$ is expected; deviations will indicate a possible problem.

SOME RECENT CALIBRATIONS

Calibrations consistent with CVD and expected coefficients:

Bath Calibration	$\alpha \times 1000$
nominal	3.925
ISF 2012	3.914
DLR 2011-6 S/N 708904 #1	3.916
" " #2	3.916
ISF TORERO 708094 #1	3.917
" " #2	3.912
ISF TORERO 708094 #1 post-cal	3.918
" " #2 post-cal	3.913
ISF Rosemount 2884 TORERO pre-cal	3.919
" " post-cal	3.920

SOME RECENT CALIBRATIONS

Other noteworthy calibrations:

Bath Calibration	$\alpha \times 1000$
NIST S/N 708904 2011-11	3.813
ISF 2011	3.754
ISF 2011-3 Rosemount Heated #1	3.615
" " #2	3.635
DLR Rosemount E102AL S/N 2603 (unheated)	3.744
" " S/N 2943	3.748
" " S/N 2980	3.741
" " S/N 3109	3.745
" " S/N 3241	3.774

SOME RECENT CALIBRATIONS

Representative RAF calibrations

Bath Calibration	$\alpha \times 1000$
RAF Low-T bath 2011-3	3.665
RAF Low-T bath 2010-6[a]	3.683
RAF Low-T bath 2010-6 RSMT heated #1	3.615
" " #2	3.635
RAF old bath 2010-6	3.715
RAF old bath 2009-03	3.708

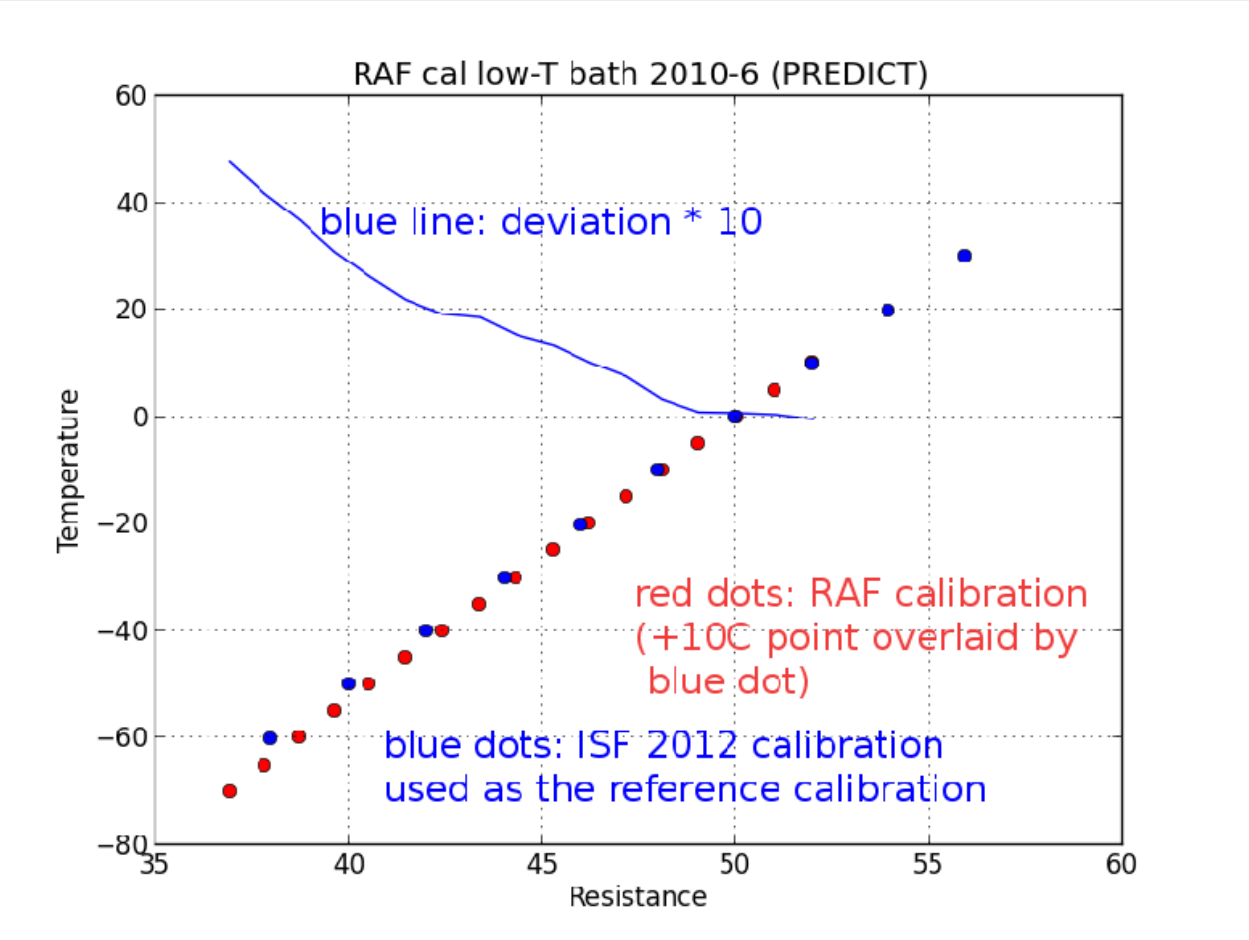
[a] used for PREDICT

TENTATIVE CONCLUSIONS

1. HARCO heated and Rosemount heated sensors conform to CVD with nominal coefficients.
2. The NIST calibration can be discounted as inconsistent
    1. Sensitivity coefficient too low – but still well above RAF cals
    2. Likely compromised by set-up tailored to stem PRTs
3. Rosemount unheated probes have a different sensitivity coefficient, variable among probes.
4. All RAF bath calibrations appear as outliers vs expectations or CVD / MIL SPECs.

PREDICT CALIBRATIONS

TTHR1: HARCO heated probe, element #1



PROCEDURES FOR RECALCULATION

1. From original calibration, find resistances used.
2. Calculate corrected temperatures associated with those resistances, from the CVD equation.
3. Use the original onboard calibration to refit to voltages, using revised temperatures.
4. Process with the new calibration.

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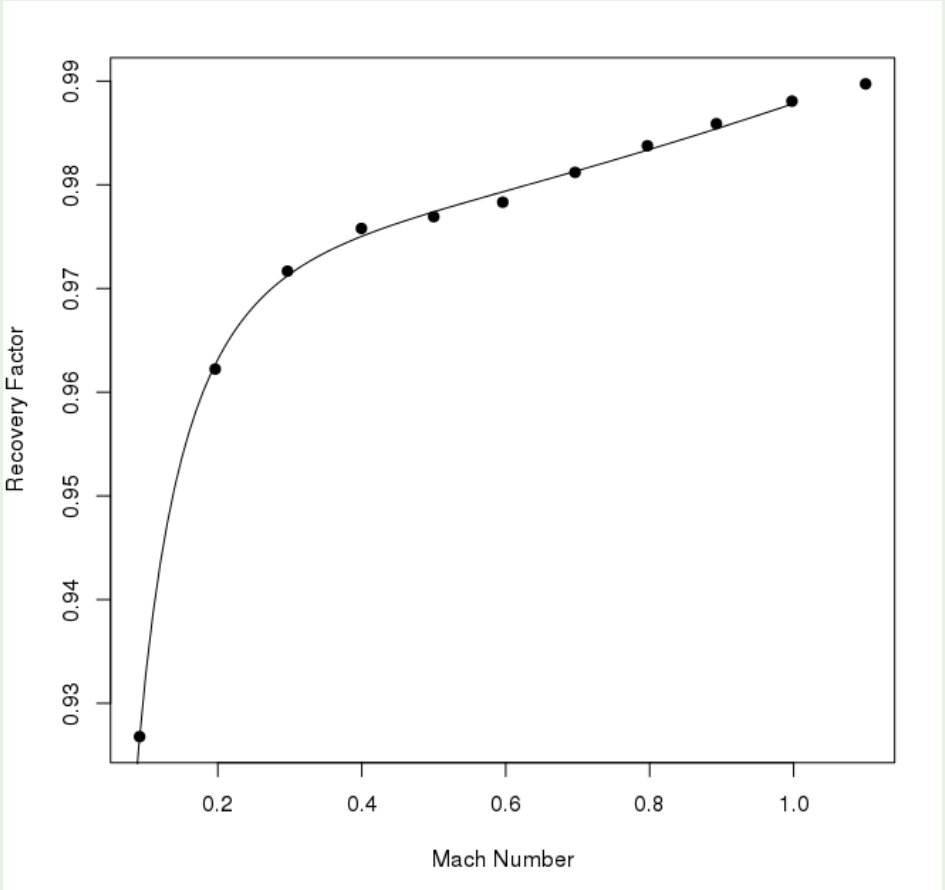
An additional consideration: Recovery factor

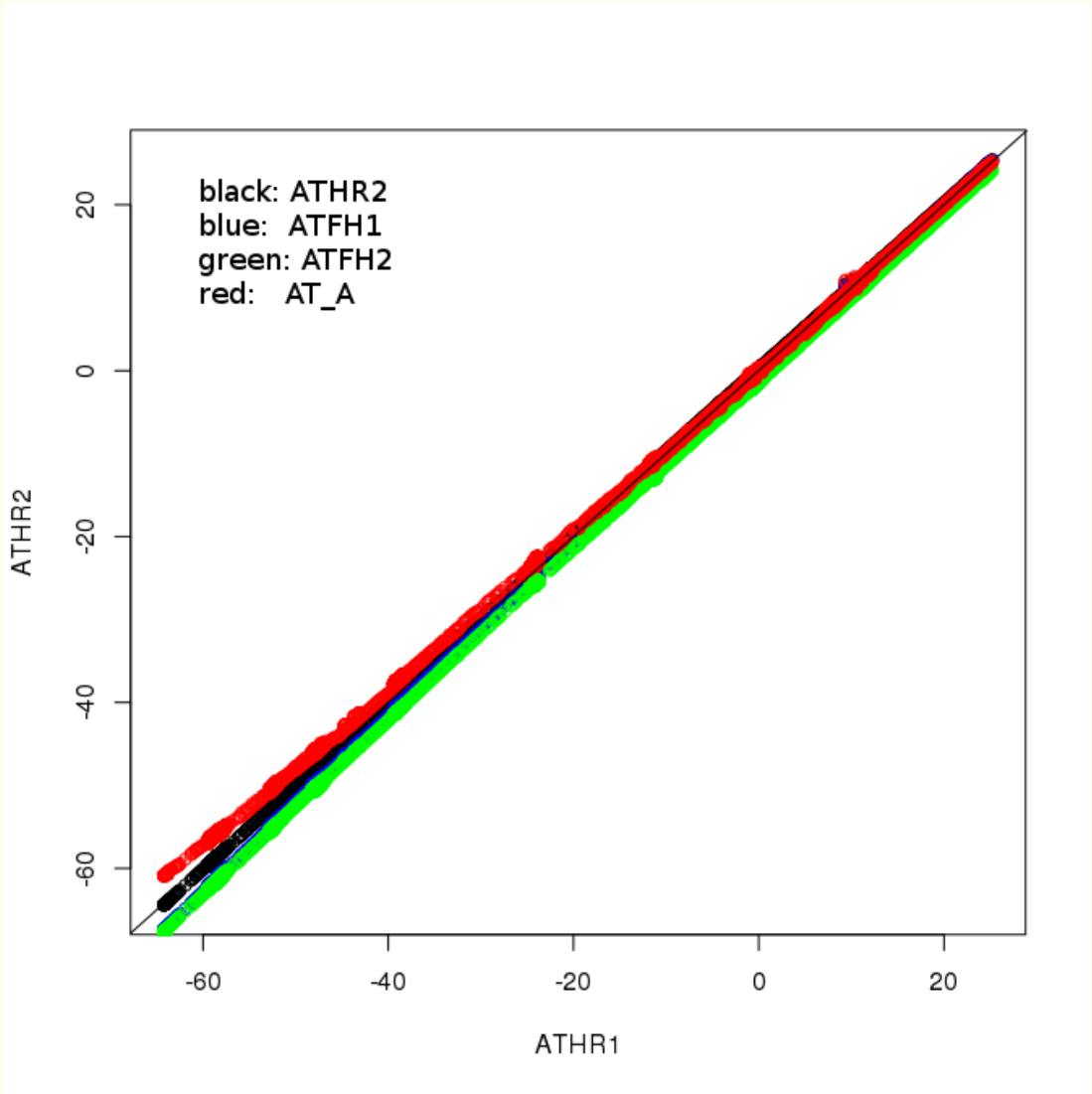
- Goodrich TN indicates that, for heated Rosemount, recovery factor depends on Mach Number
- Data are presented from which a recovery factor can be obtained and fitted for Mach dependence.

RECOVERY FACTOR

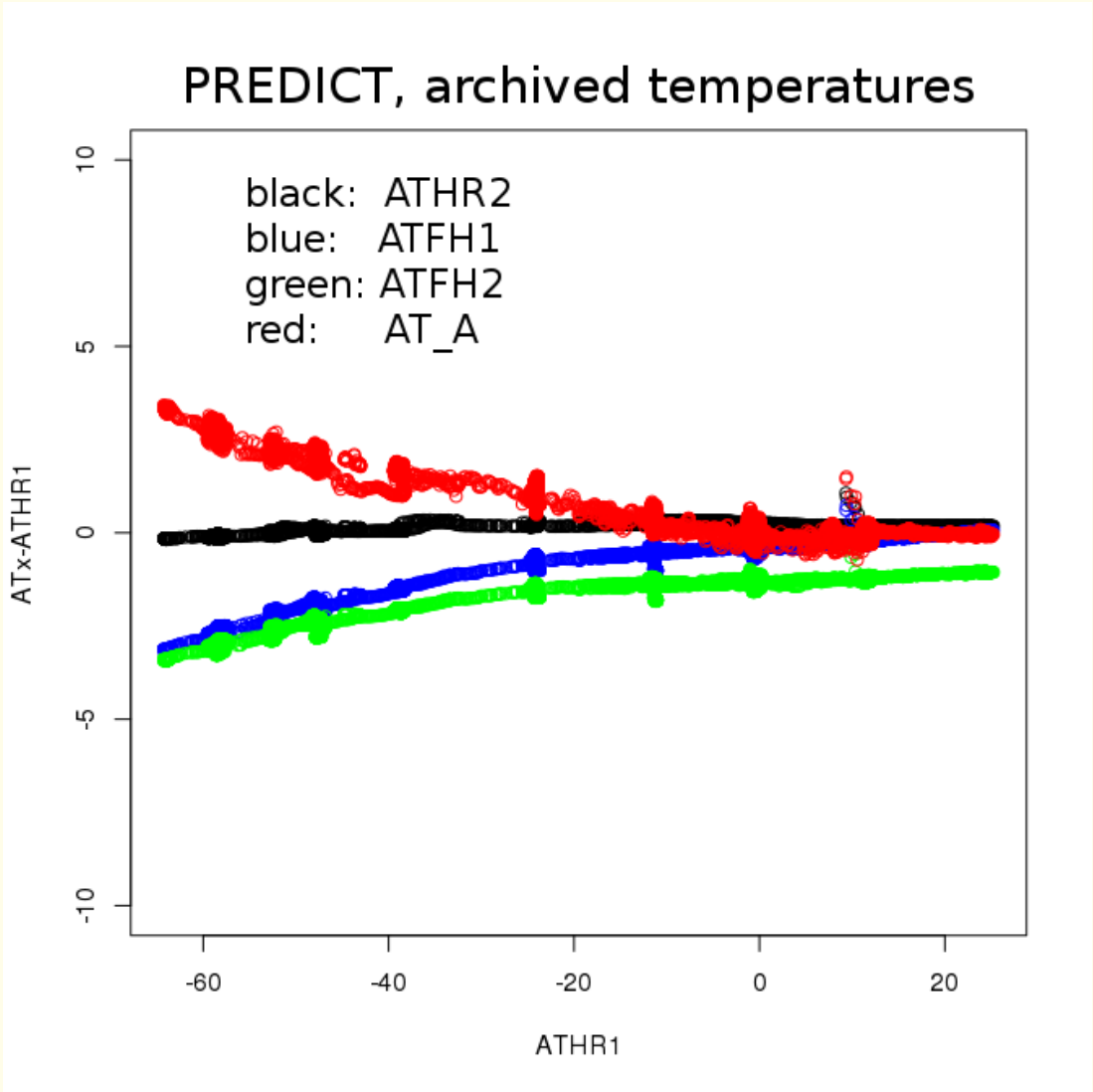


$$\alpha_R = 0.988 + 0.053 \log_{10} M + 0.090 (\log_{10} M)^2 + 0.091 (\log_{10} M)^3$$

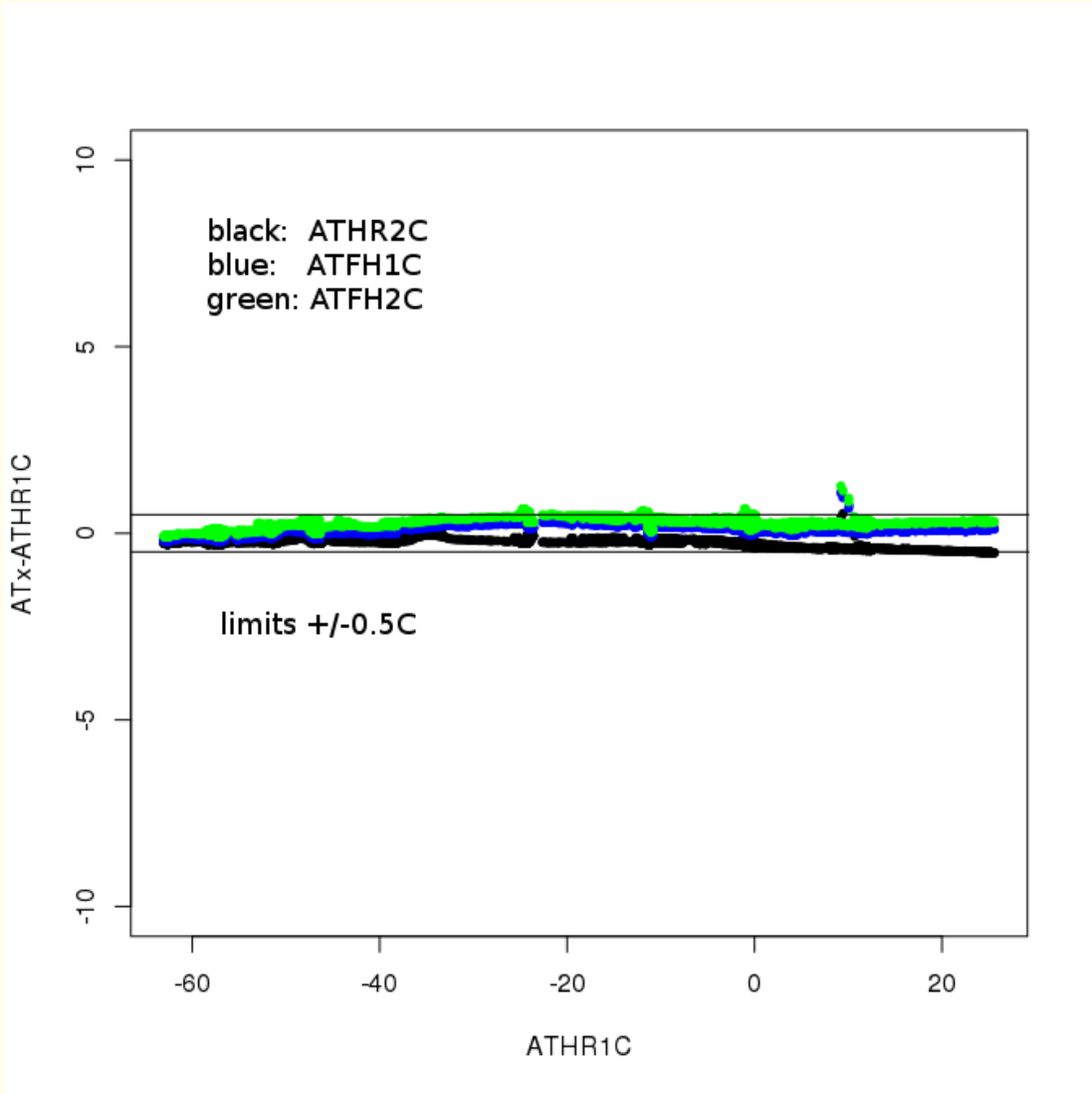
PREDICT TEMPERATURES AS ARCHIVED



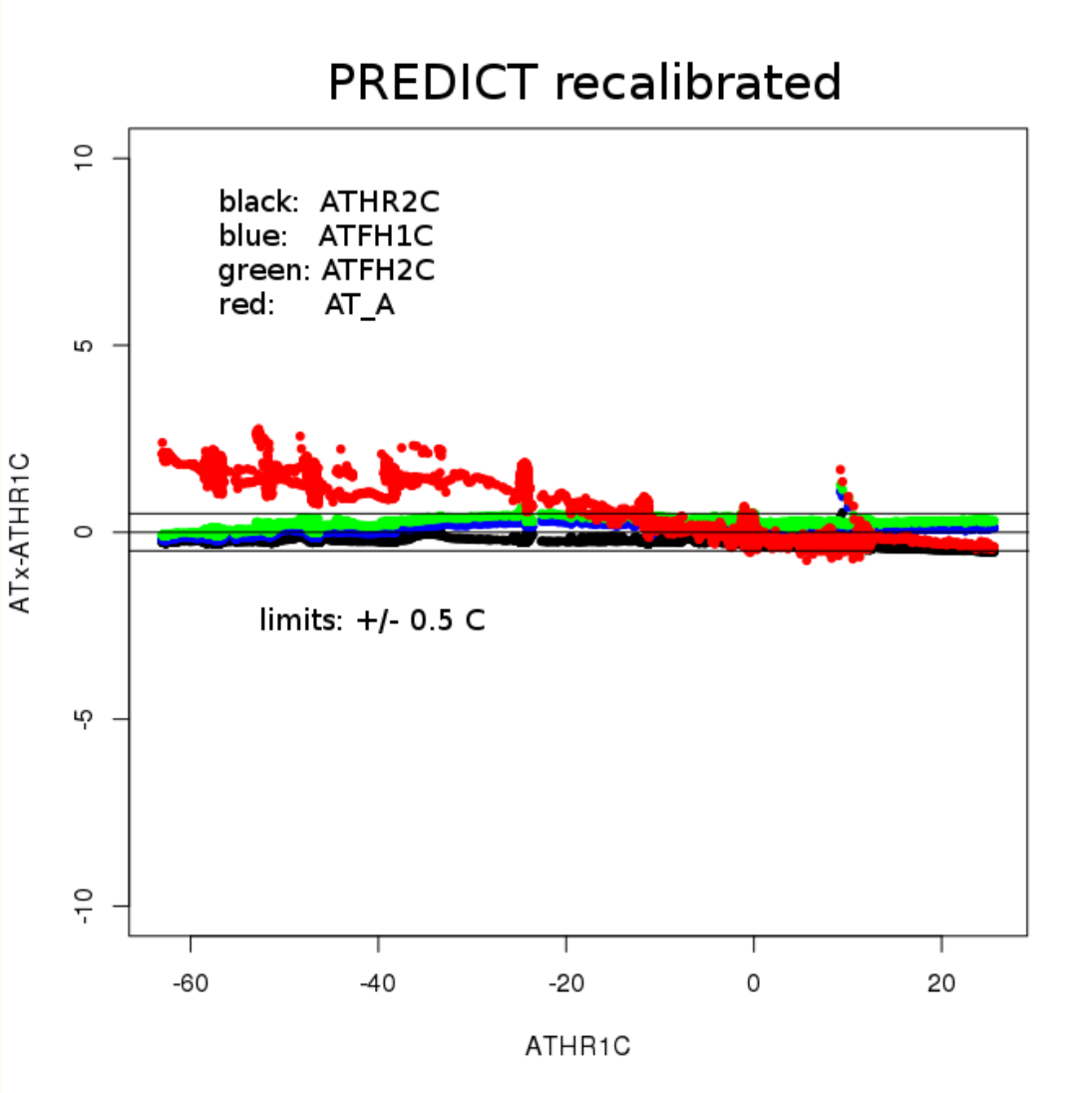
PREDICT TEMPERATURES AS ARCHIVED



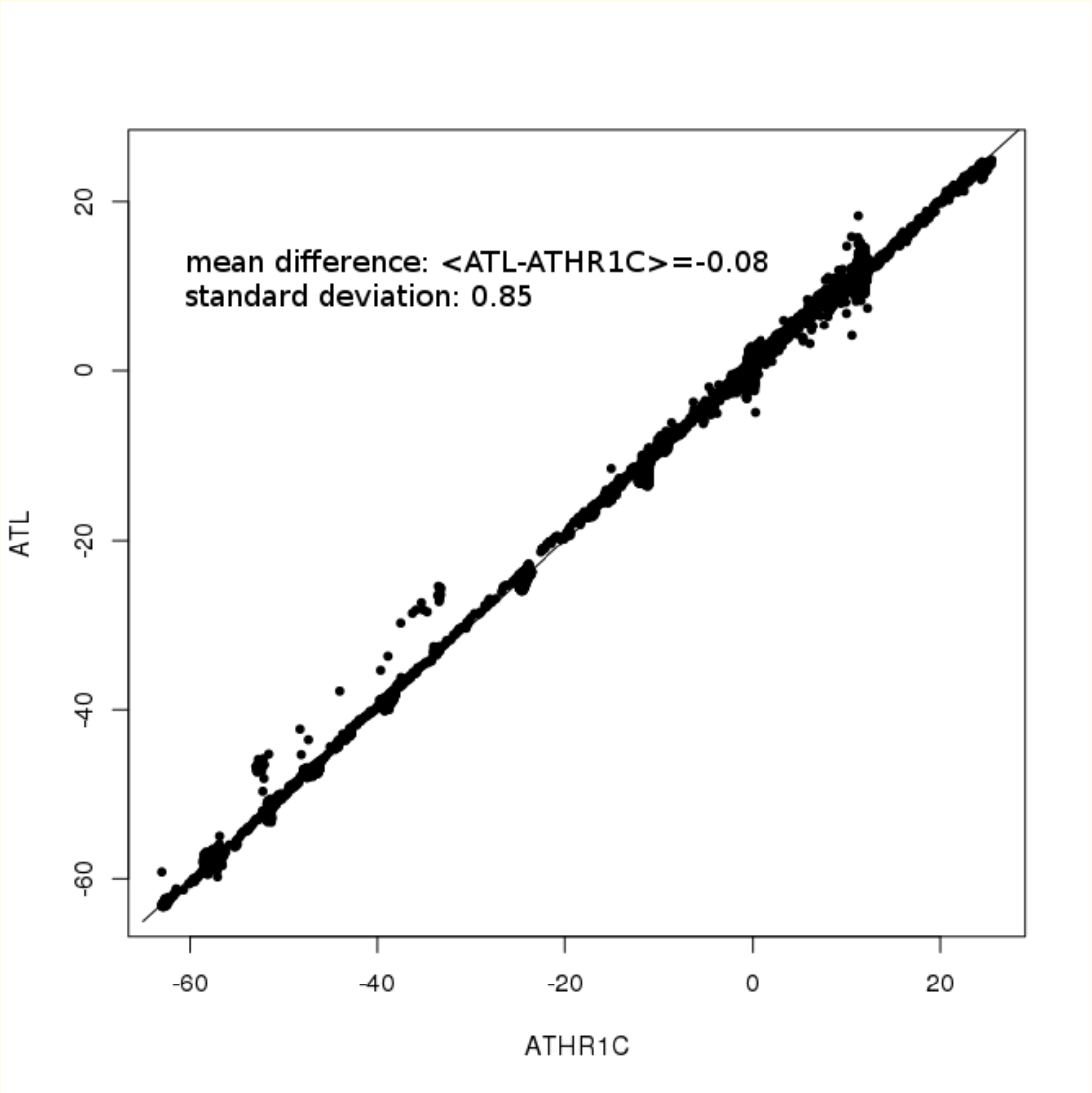
PREDICT, REPROCESSED



PREDICT, REPROCESSED



COMPARISON TO LAMS TEMPERATURE



FOR THE FUTURE

Calibration Procedures

Bath Cals:

- Use rarely, to check for problems
- Determine R vs T using CVD equation with coefficients from ISF bath cal

Onboard Cals:

- Use resistance table from CVD equation based on historical bath cals

REPROCESSING

Procedures Needed:

1. Retrieve bath cal for project: resistances vs temperature
2. Recalculate temperatures from resistances, CVD equation.
3. Retrieve onboard cal: temperature vs voltage.
   - Change temperatures to those from step 2
   - Refit to determine quadratic relationship between voltage and temperature
4. Reprocess with the new calibration.

Reasons to Consider Reprocessing

- Clear serious errors, most GV projects (except TORERO, DC3)
- Recovery factor change (but needs more study first)

THAT'S ALL FOR NOW