PERFORMANCE ASSESSMENTS OF THERMOMETER RESISTANCE BRIDGES

Michal Chojnacky, Jesse Kosior, Luis Chaves-Santacruz, Greg Strouse

NIST Thermodynamic Metrology Group, Sensor Science Division

PHYSICAL MEASUREMENT LABORATORY

National Institute of Standards and Technology
U.S. Department of Commerce

RESISTANCE RATIO BRIDGES

- Fundamental to ITS-90 dissemination
- Primary measurement instrument for calibration of SPRTs
- Functional SPRT use depends on bridge to determine temperature
- AC or DC

NIST disclaimer: Commercial equipment identified in this presentation does not imply recommendation or endorsement by NIST, nor does it imply that identified equipment is the best for the purpose.

BRIDGE ERRORS AND UNCERTAINTIES

- Contributions to overall SPRT measurement uncertainty
  - ITS-90 fixed point cell realizations
  - SPRT calibrations and customer use

- Performance-based assessments
  - Estimate uncertainty contributions
  - Measure of compliance – does it meet mfg. spec?
  - NOT used to “calibrate” or “correct”
  - Incorporated into quality system to ensure lab meets assigned uncertainties

- Past evaluations (1997, 2002) found 1 in 5 bridges did not meet manufacturer uncertainty specifications

UNCERTAINTY COMPONENTS & ASSESSMENT TOOLS

Ratio Error	Measurement Repeatability
Type A Uncertainty RBC ASL RTU 2-way compliments check	Type A Uncertainty Reference resistor SPRT TPW or Ga TP
Non-linearity	**Type B Uncertainties**
Type A Uncertainty RBC ASL RTU 3-way complements check	AC vs. DC frequency dependence AC – Quadrature AC – Parasitic capacitance DC – thermal EMFs Reference resistor stability – TCR

UNCERTAINTIES ASSIGNED TO NIST F18 BRIDGES

Uncertainty Component	Type	NIST
non-linearity	A	0.02
ratio error	A	0.02
ac quadrature/frequency dependence	B	0.01
measurement repeatability	A	0.002
Total Uncertainty (k =1)		**0.03**

Uncertainties expressed in parts per million

Non-linearity and ratio error are the most statistically significant components

ASSESSMENT TOOLS AND TECHNIQUES

Two-way compliments check

- assessment of ratio error
- two resistors of nominally the same value (e.g. 100 Ω)
- measurement of normal and reciprocal resistance ratio values

$$\delta(10^6) = \frac{[(1-(R_1/R_2)(R_2/R_1)]x10^6}{2}$$

Three-way compliments check

- assessment of ratio error and non-linearity
- three different resistors (e.g. 10 Ω, 25 Ω, 100 Ω)

$$\delta(10^6) = \left[\frac{\left(\frac{R_{25}}{R_{100}}\right)\left(\frac{R_{10}}{R_{25}}\right) - \left(\frac{R_{10}}{R_{100}}\right)}{\left(\frac{R_{10}}{R_{100}}\right)}\right]x10^6$$

RESISTANCE BRIDGE CALIBRATOR (RBC)

Switchable Hamon-type network of four base resistors

Designed by D. R. White of MSL (New Zealand)

Series & parallel combinations yield 35 resistances from 16.8 Ω to 129.9 Ω

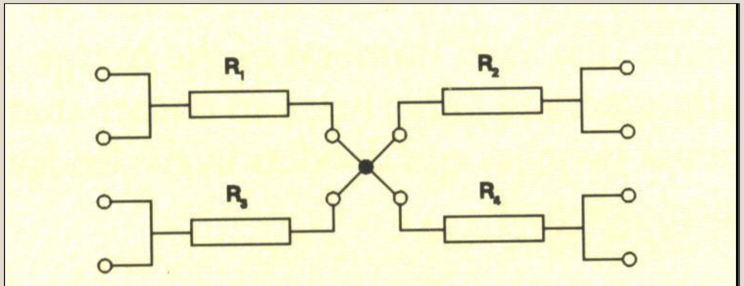
- assess non-linearity

up to 35 reciprocal values

- 10 for ac resistance ratio bridge, 35 for dc resistance ratio bridge
- assess ratio error

large number of combinations verifies proper use of internal relays on ac bridge

Stated accuracy: 1 ppb (AC bridges), 0.1 ppb (DC bridges)



The network

RBC – MANUAL VS. AUTOMATIC

Manual RBC

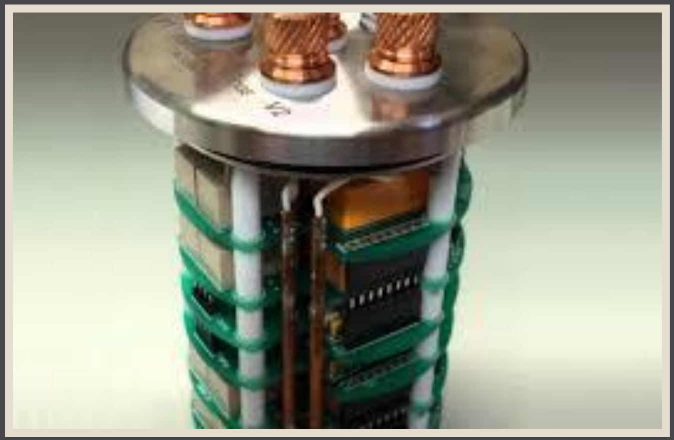
Manual switches, 8+ hrs of hands-on staff time

Manual data entry for uncertainty analysis

Stated accuracy: 0.01 ppm (original model)

Stated accuracy: 0.1 ppm (current model)

Uncertainty limits tied to ambient temperature control



Automatic RBC

Operated via USB to PC

Automatic, unattended measurements

Reduction in hands-on staff time

May be kept in a temperature-controlled resistor bath

Decreased uncertainty contribution from TCR

Stated accuracy: 0.01 ppm at 100 Ω

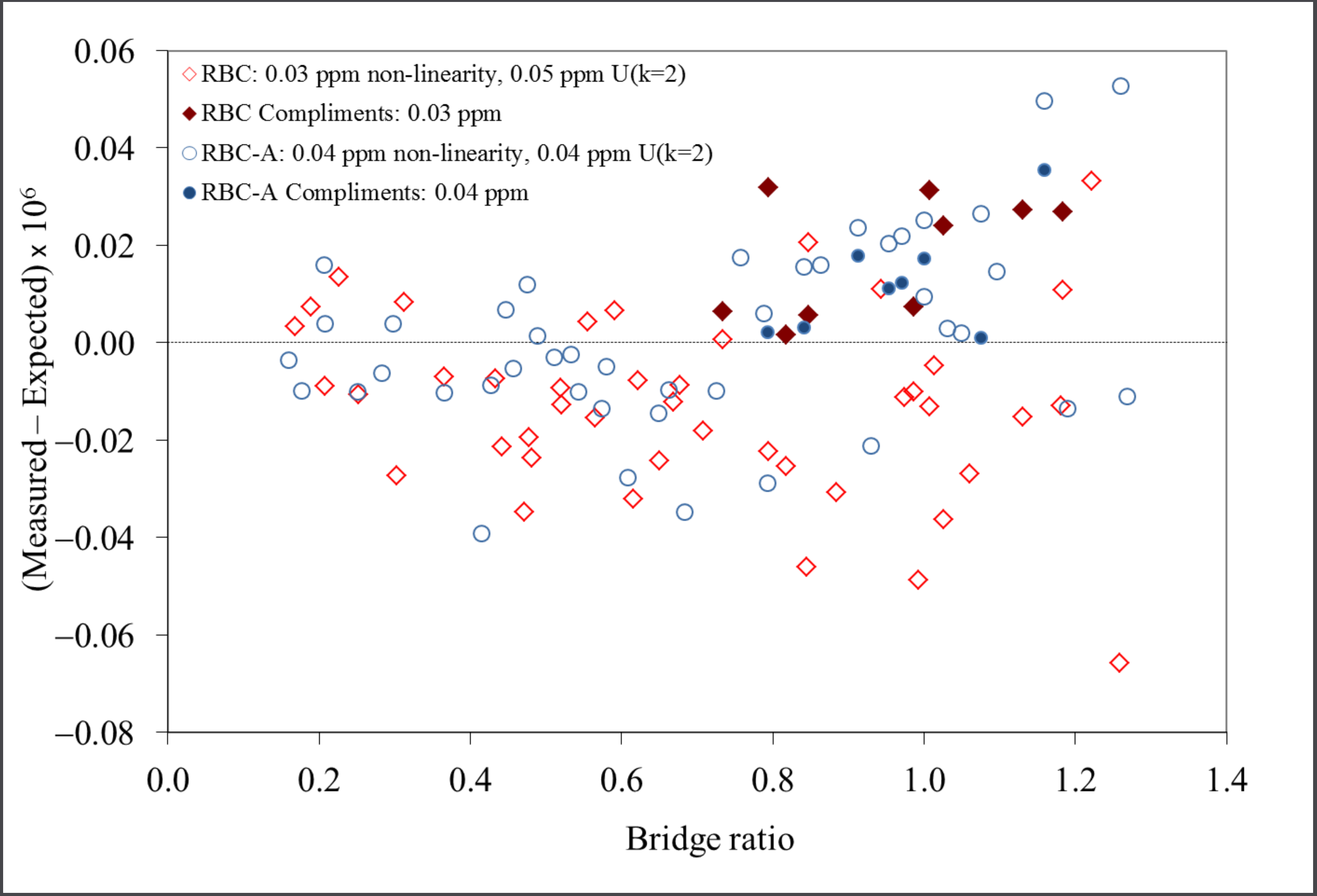
Electrical switching-induced errors possible:

noise, thermal EMFs (DC)

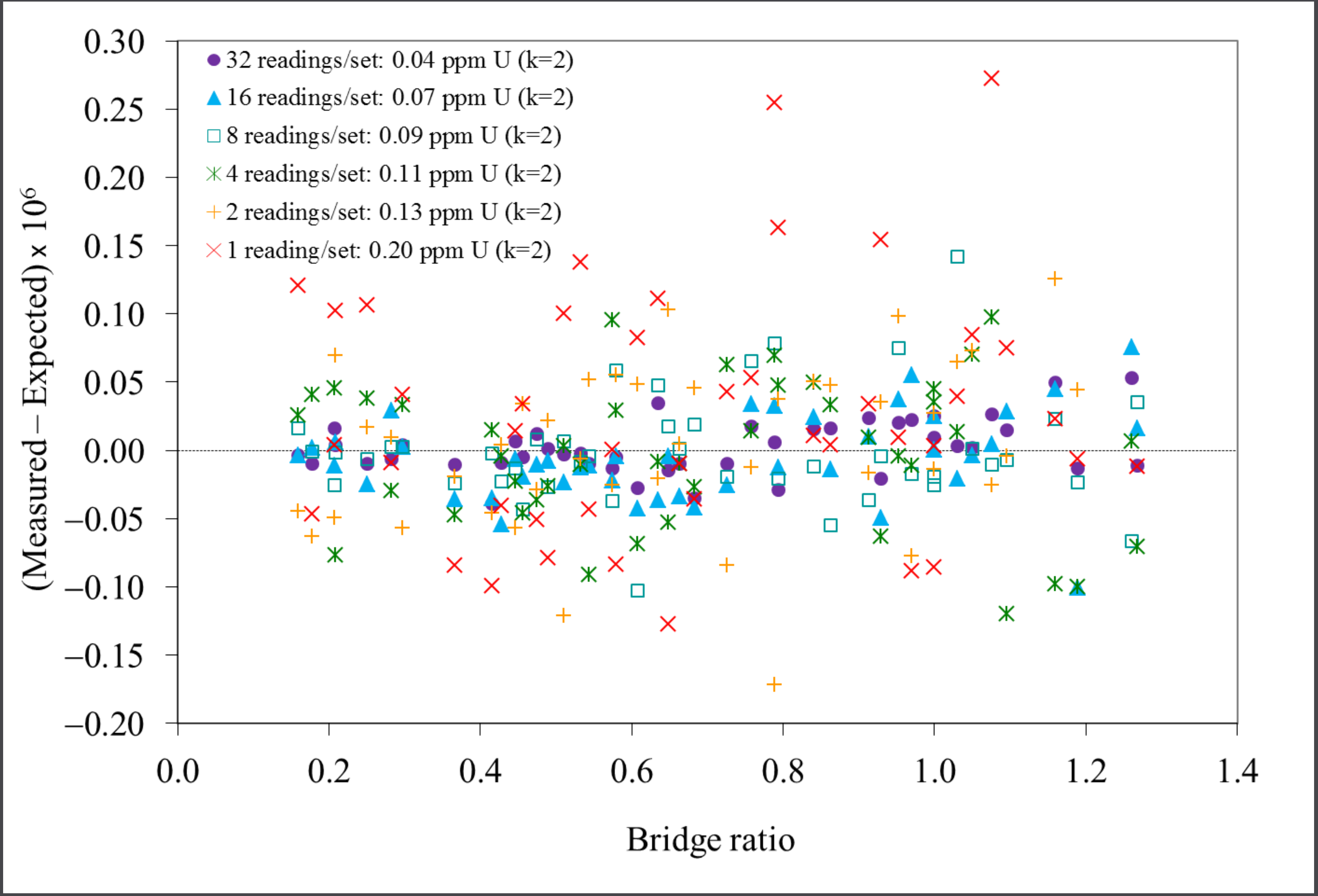
BRIDGE ASSESSMENT CASE STUDY #1: ISOTECH MICROK-70

- Measurement objectives
  - Evaluate bridge performance with respect to manufacturer specifications
    - SPRT calibration range (ratios from 0 to 1.299 - ASL F18/F900 equivalent)
  - Compare manual and automated RBC uncertainty estimates
  - Determine optimal measurement parameters for automatic RBC operation
- Manual RBC test
  - AEONZ RBC-100, kept in a thermally-insulated enclosure
- Automated RBC tests
  - RBC-100A, kept in temperature-controlled resistor air bath, stability < 10 mK
  - Tested range of measurement parameters
    - Wait time after automatic combination switching: 10 s, 30 s, 45 s
    - # of readings averaged for each combination measurement: 1, 2, 4, 8, 16, 32
- MicroK-70 manufacturer specifications
  - "ADC" bridge, square wave
  - 0.07 ppm
  - Similar to NBS Cutkosky square wave bridge designed 1980s

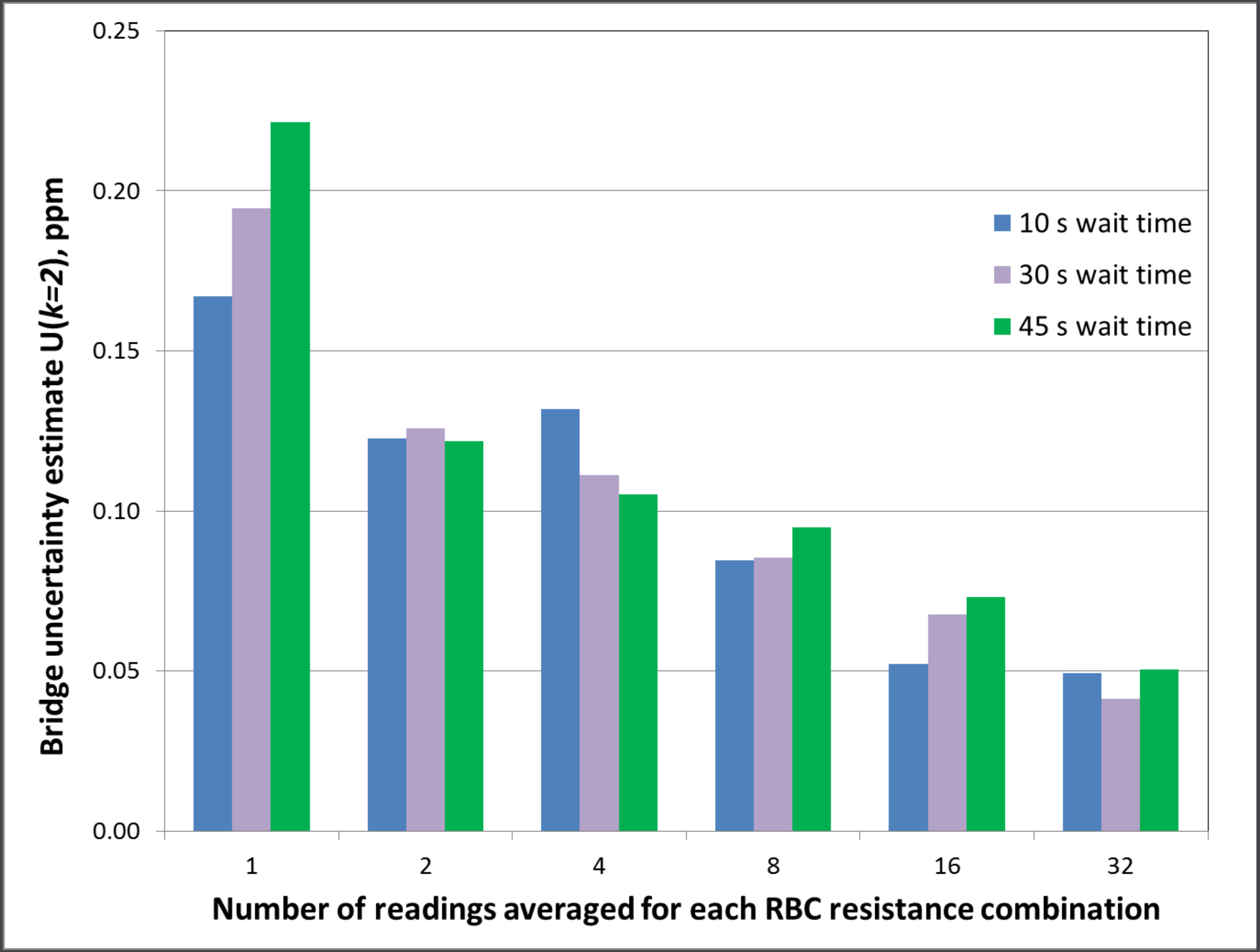
ISOTECH MICROK-70: COMPARISON OF MANUAL AND AUTOMATED RBC RESULTS



MICROK-70 RBC-A RESULTS:
ESTIMATED UNCERTAINTY SAMPLE SIZE DEPENDENCE



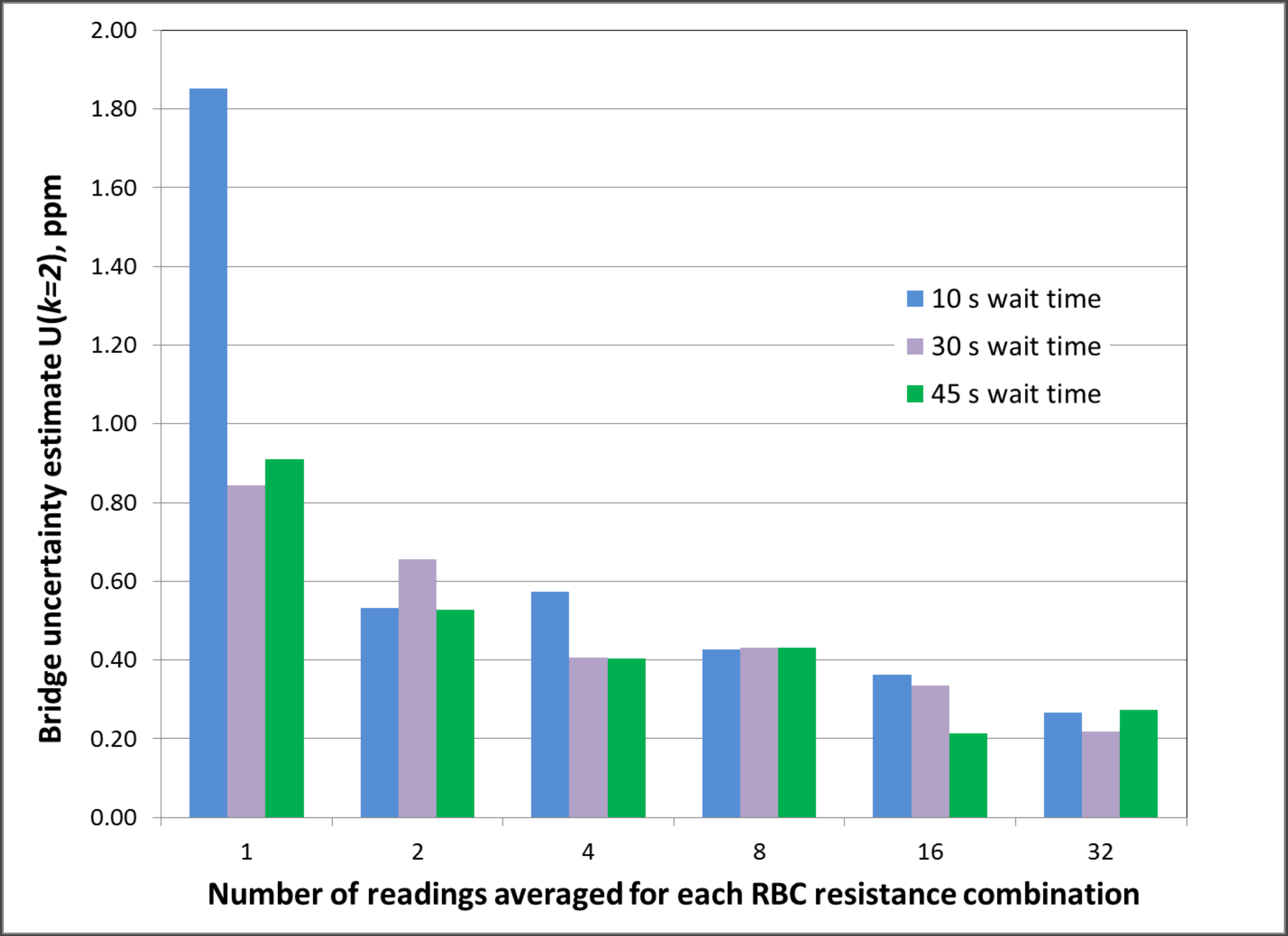
MICROK-70 RBC-A: SUMMARY OF RESULTS



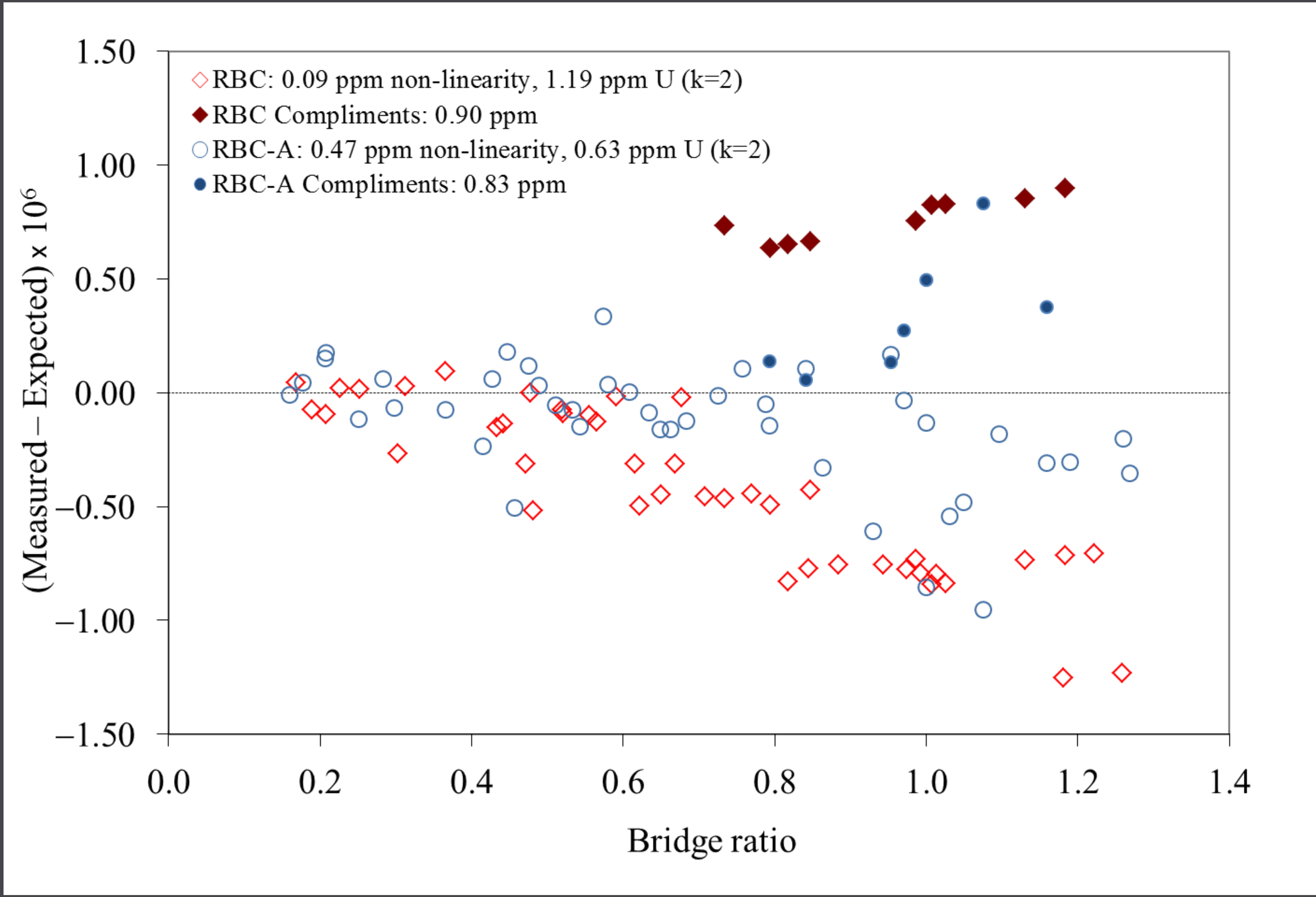
BRIDGE ASSESSMENT CASE STUDY #2: ASL F18

- Measurement objectives
  - Evaluate bridge performance with respect to manufacturer specifications
  - Compare manual and automated RBC uncertainty estimates
  - Determine optimal measurement parameters for automatic RBC operation
- Manual RBC test
  - AEONZ RBC-100, kept in a thermally-insulated enclosure
- Automated RBC tests
  - RBC-100A, kept in temperature-controlled resistor air bath, T ± 2 mK
  - Tested range of measurement parameters
    - Wait time after automatic combination switching: 10 s, 30 s, 45 s
    - # of readings averaged for each combination measurement: 1, 2, 4, 8, 16, 32
- ASL F18 manufacturer specifications
  - AC resistance ratio bridge
  - Inductive voltage divider
  - Accuracy: <0.1ppm
  - Linearity: <0.01ppm
  - Stability: <0.02ppm/year
  - Settings: 30 Hz, 10^4 Gain, 0.1 Hz bandwidth, 1 mA, 100 Ω reference resistor

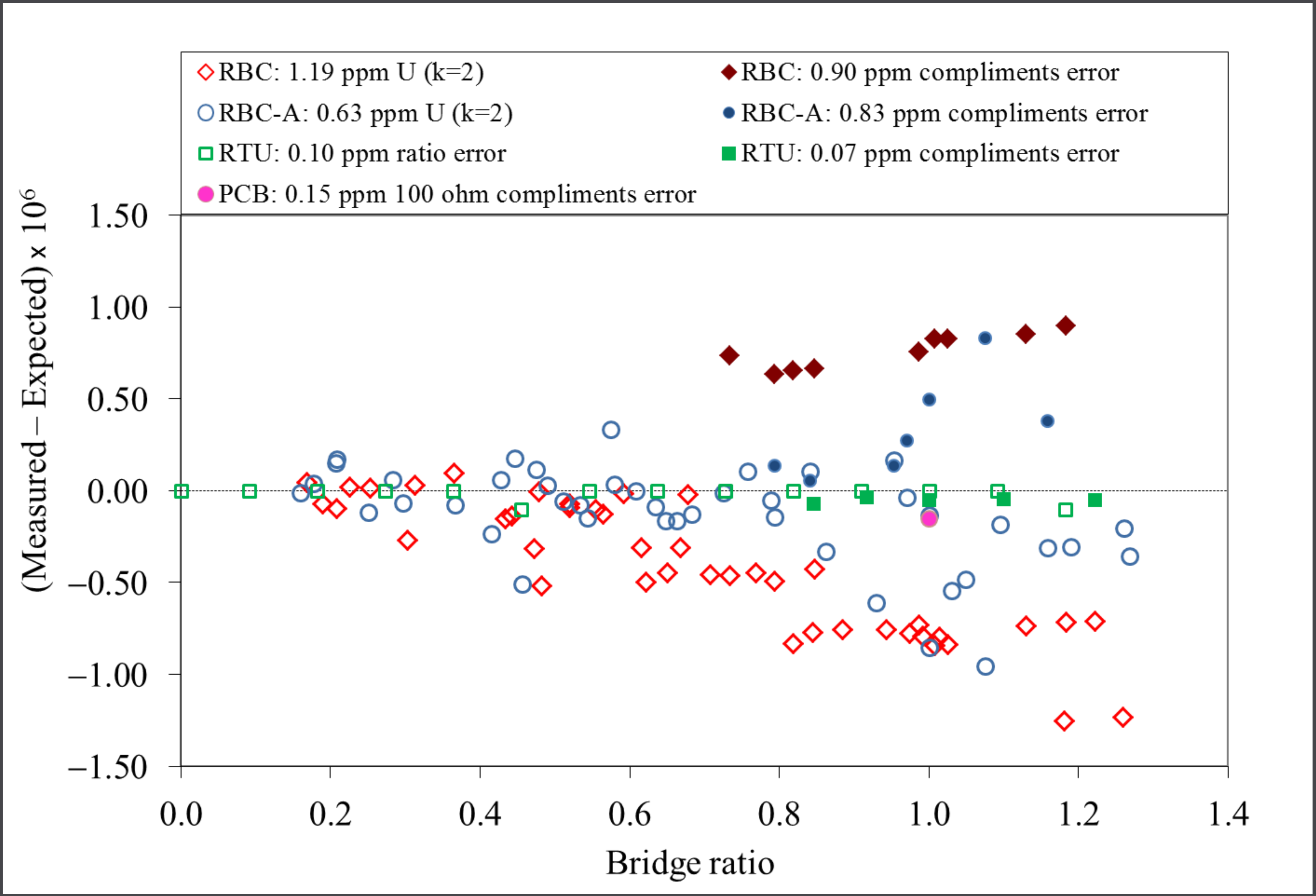
ASL F18 RBC-A: SUMMARY OF RESULTS



ASL F18: MANUAL & AUTOMATED RBC RESULTS

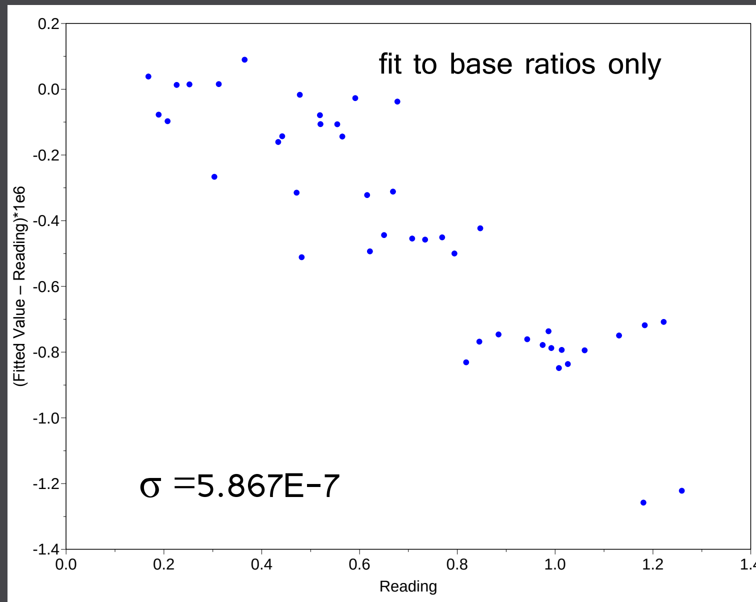


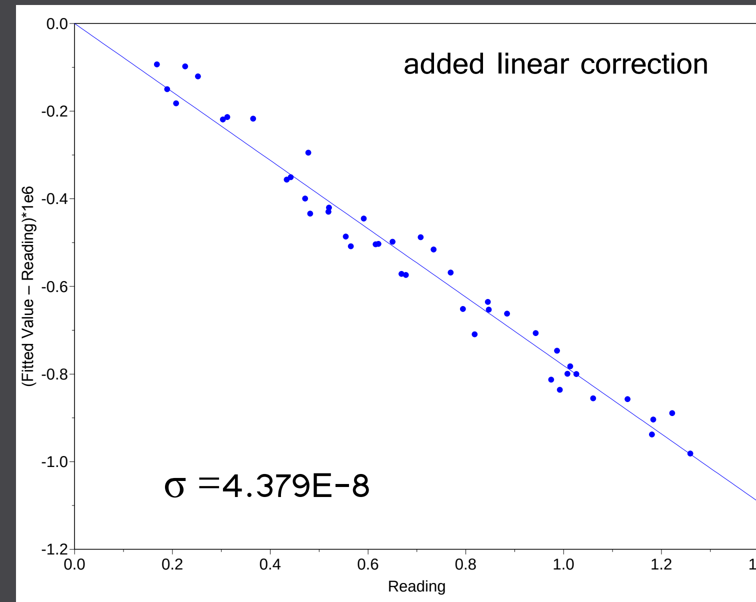
ASL F18: MULTIPLE ASSESSMENT METHODS



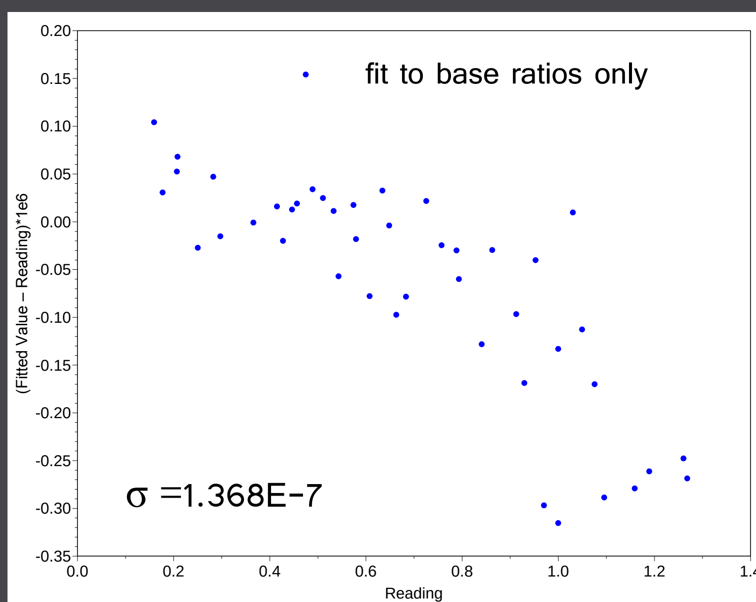
ASL F18: RBC ERROR ANALYSIS

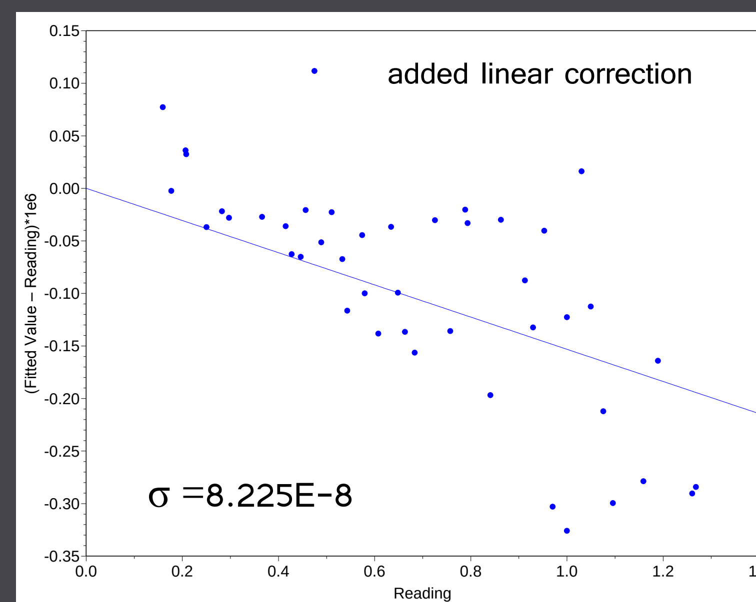
Manual RBC





Auto RBC
32 rdgs
45 s





BRIDGE ASSESSMENT CASE STUDY #2: ASL F18

- ASL F18 manufacturer specifications
  - Accuracy: <0.1ppm, linearity: <0.01ppm
- Parasitic capacitance error
  - effect of three 100 Ω series lead resistance combinations: 0.4 ppm
  - parasitic capacitance test: 0.2 ppm for 35 m
- Multiple assessment methods to cross-check results
  - Uncertainty estimates exceed mfg. spec, bridge requires adjustment
- Manual and automatic RBC both provide indicators of possible bridge issue
  - RBC error analysis – correction terms provide clues
  - RTU alone not a complete assessment of bridge health

SUMMARY + NEXT STEPS

- Bridge health assessments critical to ITS-90 dissemination
  - Out-of-box uncertainty estimates and regular compliance checks
  - Incorporated into Quality System
  - RBC provides most complete assessment of ratio error and non-linearity
- Automatic RBC performance comparable to manual unit
  - Simplified thermal control
  - Significant savings in hands-on staff time
  - Planned integration with automated calibration measurement and quality assurance program
- Continued bridge assessment tests with RBC-A
  - Last large-scale evaluation in 2002 (NIST/NRC) - 18 bridges
  - Test multiple units from pool of commercially-available bridge models
  - Assess current state - ability to meet manufacturer specifications


Thank You!