A Symmetrical Calibration Procedure for Microwave Sounding Units used in Studies of Climate Trends

— An alternative to the Sequential Calibration Procedure

Blaza Toman and Antonio Possolo
Statistical Engineering Division
NIST — January 14, 2008

Problem

Produce a well-calibrated data set of Earth radiance based on data from several satellites

Use the fact that there are pairs of data points from different satellites which give information about nearly the same location at nearly the same time — *Simultaneous Nadir Overpass* (SNO) match-ups

Reference

- C. Zou, M. Goldberg, Z. Cheng, N. Grody, J. Sullivan, C. Cao, and D. Tarpley (2006)
  - Recalibration of microwave sounding unit for climate studies using simultaneous nadir overpasses
  - *Journal of Geophysical Research*, 111, D19114

We base our procedure on: Equation (8) of Zou et. al. (2006)

For satellite *i* and time point *j*, the error-free radiance measurement R_{eij} can be written as

$$R_{eij} = R_{Lij} + \mu_i Z_{ij}$$

where

R_{Lij} (the linear part of the Earth-view radiance)

Z_{ij} (factor for non-linear adjustment)

are based on data from the satellite.

μ_i is determined by the calibration procedure (pre-launch values are available)

Illustration using a Simulated Data Set

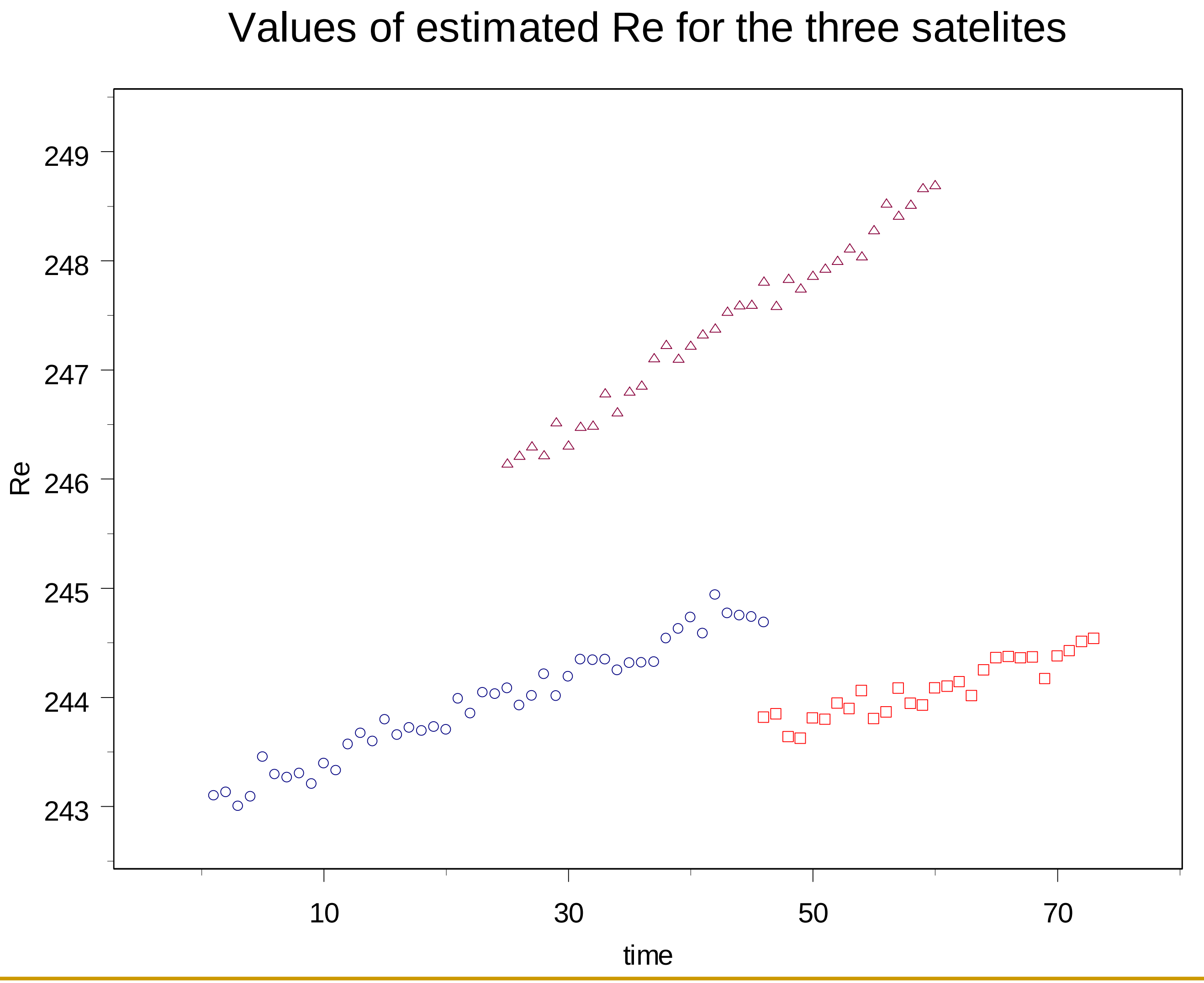
3 overlapping time series:

- Series 1: R_{L1j} ~ N(240.5 + 0.04*$time_j$, 0.1)
  $Z_{1j} \sim N(0.5, 0.001)$
  Pre-launch $\mu_1 = 5$

- Series 2: R_{L2j} ~ N(240.0 + 0.075*$time_j$, 0.1)
  $Z_{2j} \sim N(0.6, 0.001)$
  Pre-launch $\mu_2 = 7$

- Series 3: R_{L3j} ~ N(240.8 + 0.03*$time_j$, 0.1)
  $Z_{3j} \sim N(0.5, 0.001)$
  Pre-launch $\mu_3 = 3$

Plot of the data using the pre-launch μ_i



NOAA Sequential Calibration

(based on our understanding of Dr. Zou's NIST presentation)

- Take one of the satellites (say 1) as the reference satellite, assume its coefficient μ_1 as true

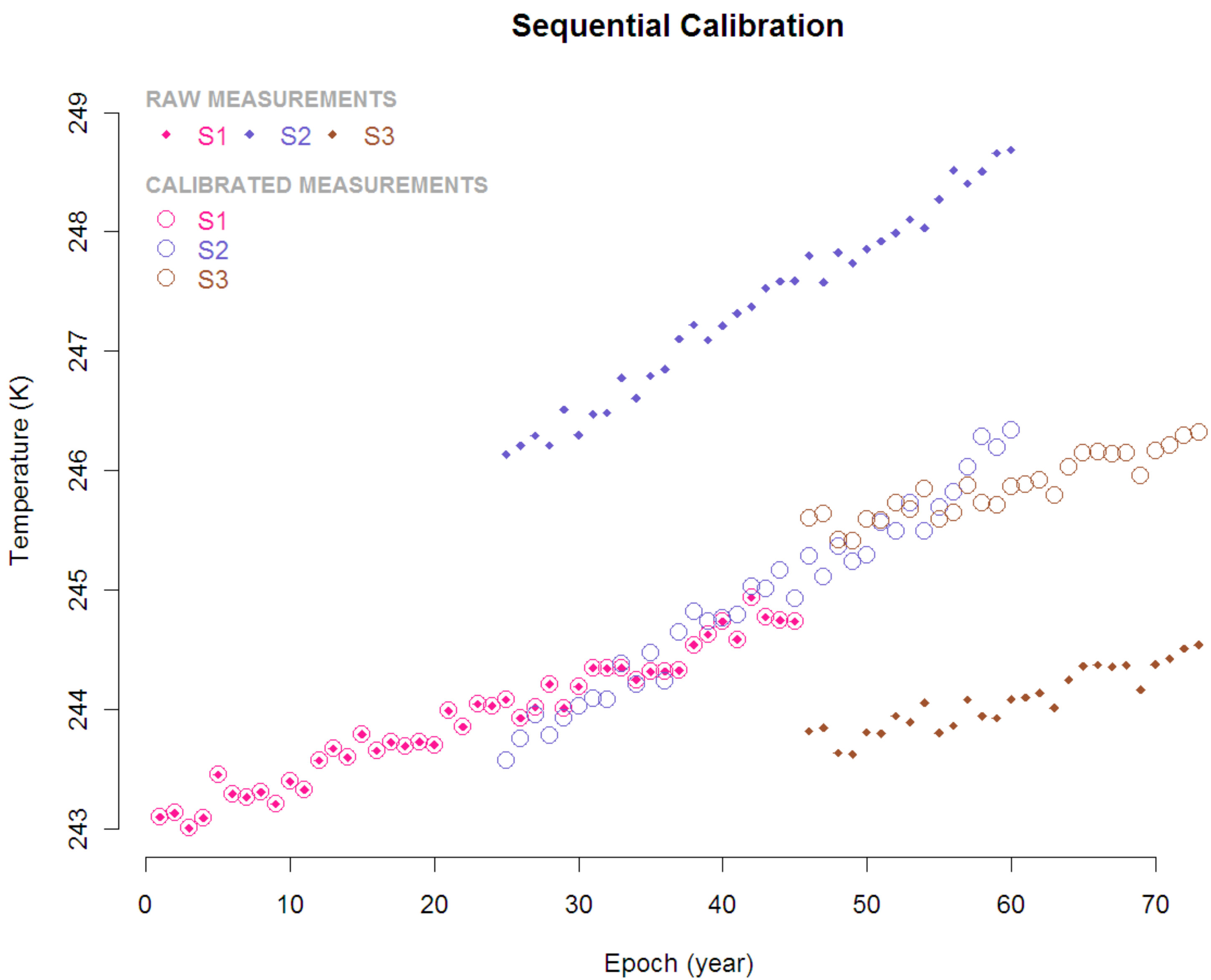
- Find $\hat{\mu}_2$ which minimizes the squared error in equation (28) of Zou et. al., that is in,

$$\mu_1 Z_{1j} + R_{L1j} - R_{L2j} = \alpha_2 + \mu_2 Z_{2j} + E_{2j}$$

for the SNO pairs.

- Repeat the above procedure for satellite 3 using

$$\hat{\mu}_2 Z_{2j} + R_{L2j} - R_{L3j} = \alpha_3 + \mu_3 Z_{3j} + E_{3j}$$


Sequential Calibration
RAW MEASUREMENTS
S1
S2
S3
CALIBRATED MEASUREMENTS
S1
S2
S3
Temperature (K)
243
244
245
246
247
248
249
Epoch (year)
0
10
20
30
40
50
60
70

Symmetrical Calibration Procedure

For satellite 1 and 2 SNO points *j*:

find $\hat{\beta}_1$, and $\hat{\beta}_2$ which minimize the total squared error in

$$\mu_1 Z_{1j} + R_{L1j} - R_{L2j} = (\beta_2 + \delta_{2j}) Z_{2j} + E_{12j}$$

$$\mu_1 Z_{1j} = (\beta_1 + \delta_{1j}) Z_{1j} + E_{11j}$$

$$\delta_{1j} \sim N\left(0, \sigma_{\delta 1}^2\right)$$

$$\delta_{2j} \sim N\left(0, \sigma_{\delta 2}^2\right)$$

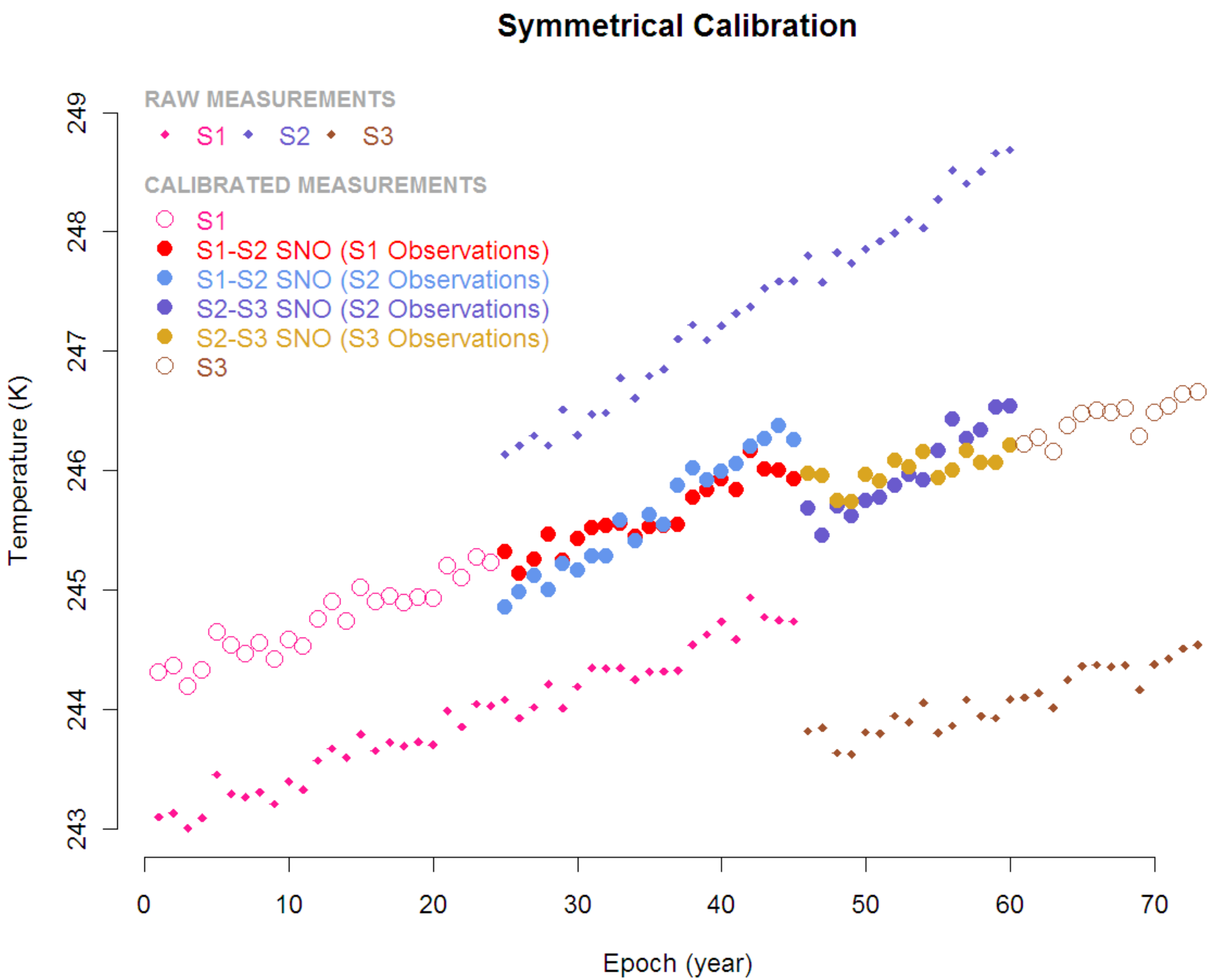
$$\mu_2 Z_{2j} + R_{L2j} - R_{L1j} = (\beta_1 + \delta_{1j}) Z_{1j} + E_{21j}$$

$$\mu_2 Z_{2j} = (\beta_2 + \delta_{2j}) Z_{2j} + E_{22j}$$

$$E_{i1k} \sim N\left(0, \tau_{1k}^2\right)$$

$$E_{i2k} \sim N\left(0, \tau_{2k}^2\right)$$

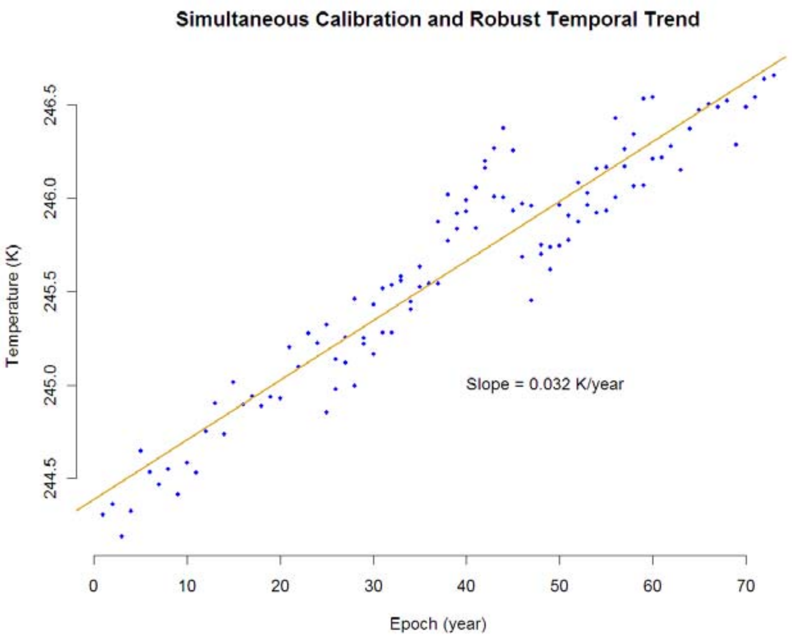
Repeat process for satellite 2 and 3 SNO points *j.*

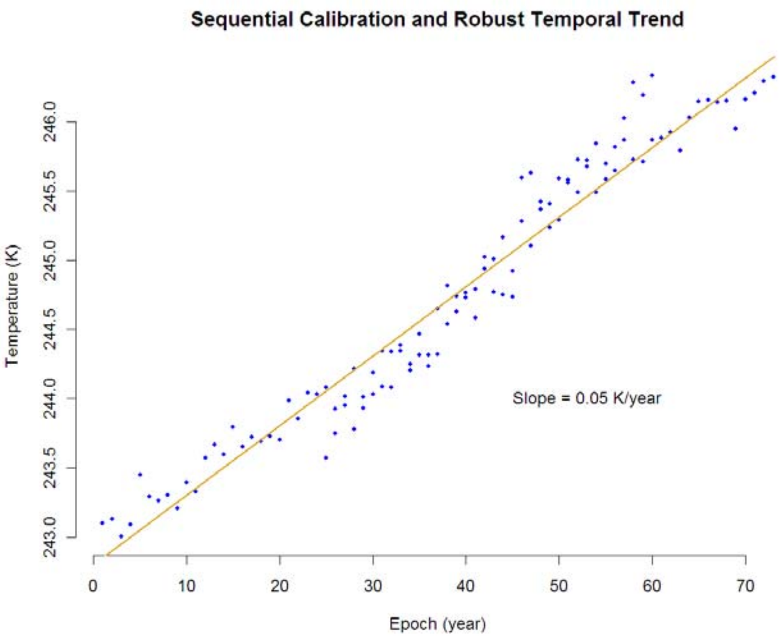

Symmetrical Calibration
RAW MEASUREMENTS
S1
S2
S3
CALIBRATED MEASUREMENTS
S1
S1-S2 SNO (S1 Observations)
S1-S2 SNO (S2 Observations)
S2-S3 SNO (S2 Observations)
S2-S3 SNO (S3 Observations)
S3
Temperature (K)
243
244
245
246
247
248
249
Epoch (year)
0
10
20
30
40
50
60
70

Notes

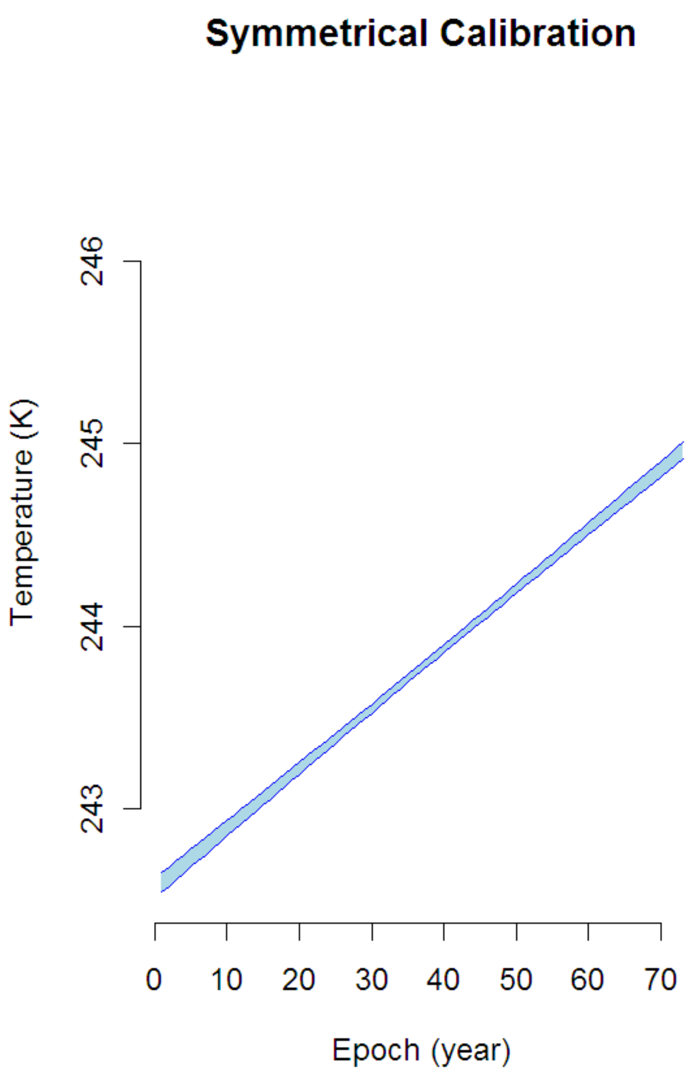
- Symmetrical calibration (SYM) adjusts all data points, while sequential calibration (SEQ) adjusts only data from satellites 2 and 3
- In both calibration schemes, individual slopes are preserved, and points are shifted up and down
- Sequential calibration results depend on choice of initial satellite, while symmetrical calibration is invariant to permutations of the satellites
- Symmetric calibration adjusts readings made in non-overlapping time segments independently

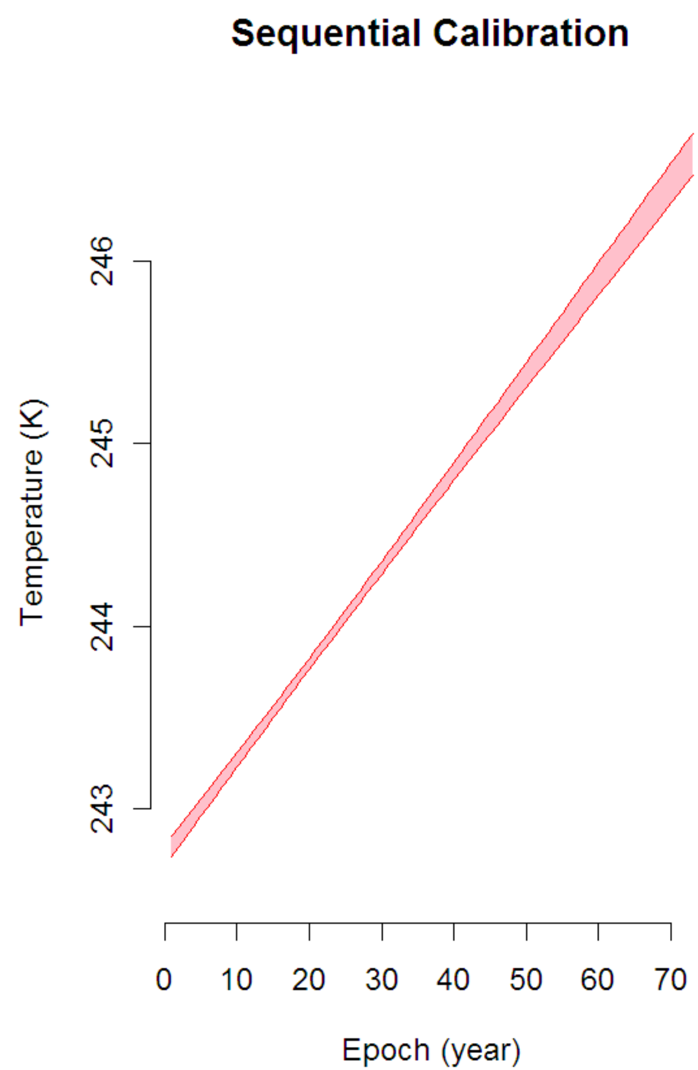
Temporal Trend after Calibration





95% Confidence Bands for Temporal Trend





Comparison of Procedures

- Slope of trend corresponding to sequential calibration (0.05) is quite a bit larger than that of the symmetric calibration (0.032)
  - Data was generated with slopes of 0.04 (S1), 0.075(S2) and 0.03 (S3).
  - What if satellite 2 is an anomaly?

- Approximate 95% confidence intervals for slope :
  - SYM (0.0317, 0.0341)
  - SEQ (0.0506, 0.0548)

  SEQ's is about 1.7 times wider than SYM's

Comments

- SYM calibration procedure builds a "consensus" data set rather than one calibrated to a particular satellite's data
- Procedure is symmetric in that it treats all satellites equally
- Procedure can be modified to include additional information about the μ_i