DRAFT: Temperature correction for UV scans

Purpose: Spectral UV solar irradiance measurements from the Mark IV Brewer spectrophotometer are known to be dependent on [Weatherhead et al, 2001; Cappelani et al., 1999]. This describes a method to 1) correct the spectral responsivity measurements determined by an external field calibrator and 2) how to correct the UV solar irradiance measurements for the changing internal temperature of the instrument.

Overview: The Brewer spectrophotometers were originally designed for total ozone measurements. For the ozone measurements the count rates are corrected for the temperature dependent band-pass of the various filters and components inside the assembly, and therefore the instruments are not typically temperature stabilized. Also, because total ozone calculations rely on ratios, the temperature dependence is not as critical as long as the temperature dependence is wavelength independent. (Figures 1-12 show that this the temperature dependence is wavelength dependent for wavelengths less than 325 nm but not in all instruments. Is this adequately corrected for in ozone measurements in the F values at each slit, section 15.3 or will there be a residual in the R6 due to temperature especially since each instrument is different?) However, this is not the case for UV solar irradiance measurements where temperature changes can cause a significant error in the solar irradiance measurements. The instrument is not temperature stabilized but is heated giving internal temperatures typically between 0 and 40 deg Celsius for the NEUBrew sites.

Temperature coefficients:

1. We used temperature coefficients from Panel 1 in Weatherhead et al. (2001). Weatherhead et al. [2001] used SL scans and external lamp scans to determine the temperature coefficients for the majority of instruments in the UV EPA Network. The data from the Panel were digitized as there was no available ascii data files.

We identified BR# from Panel 1 legend:

BR#	NEUBrew Site	Old EPA Network Site
101	Boulder	Boulder
105	Boulder	Gathersburg
108	Boulder	Atlanta
131	Boulder	Theodore
134	Boulder	Glacier
135	Boulder	Everglades
139	Boulder	Sequoia
140	Raleigh	Hawaii NP, **NA in Panel 1**
141	Boulder	Denali
144	Bondville	Virgin Islands
146	MRS	MRS
147	Ft.Peck	Olympic
154	Houston	Smokey Mt, **NA in Panel 1**

In attached figures 1-11, we plotted data lifted off Panel 1 and the approximation that we are using in NEUBrew UV scan corrections. We decided to assume that temperature coefficient is independent of wavelength for $\lambda>325$ when $NiSO_4$ filter is not engaged. And for $\lambda\leq325$nm we assumed a straight-line approximation that connects the point at 325nm and the point that produces the smallest slope.

2. Temperature coefficients for Brewer spectrophotometers at Houston, TX and Raleigh, NC were not available for the work of Weatherhead et al., 2001. There were several possibilities to determine the temperature coefficients of these two instruments.
    a. External Lamp Scans: External lamp scans are more ideal to use to determine temperature coefficients because the power supply and field calibrator are stabilized for current changes and temperature. The lamps are also very carefully chosen for their stability over time. Therefore, changes in the responsivity of the instrument are primarily due to the changing temperature and not the lamp. However, the caveat is there are very few measurements to use for the determination of the temperature coefficients. Calculations were made using external responsivity measurements from the old and new EPA network. Results for instruments 140 and 154 are shown in Figure 13 (*what happened to actual data). Beside the 140 and 154 instruments, calculations were performed for two others instruments and the results were in agreement with the previous work within the uncertainty [Weatherhead et al., 2001]. However, the spread of points was quite large ~ 0.2 degrees/C (check!). See Table 1 for number of scans and temperature range used in the calculations.
    b. CI scans: Internal lamp scans (ci scans) can also be used to determine the temperature coefficient. The multiple daily measurement of the internal lamp provides a sufficient data-set but the lamp is not very stabilized and is degrading with time. To use the internal lamps, changes with temperature need to be calculated over a short period of time to avoid changes due to the lamp and not due to temperature. A plot of the internal lamp photon count and the voltage drop across the lamp are highly correlated (Figure 14). Data need to be screened for periods between large changes in the voltage across the lamp. Separate time periods are chosen for the calculations and results are compared for consistency. See Table 1 for number of scans and temperature range used in the calculations. Note: Weatherhead used a statistical approach where the data were fitted using a temperature and a drift-time term. In addition, a term for the voltage drops would need to be included in the fitting equation or the data limited to regions where lamp voltage drops do not occur as in this study.
    c. Results:
        i. The external lamp scans did not provide a sufficient data-set to determine the temperature coefficients for instruments 154 and 140, but could be used as a guide, i.e. the uncertainties were too large.
        ii. The internal lamp scans could be used if the lamp photon count was sufficiently large and the scans carefully screened, e.g. the data needed

to be carefully screened for large changes in the voltage drop across the lamp.

iii. Checks using different time periods of approximately 75 days* from 2006 to 2008 gave similar temperature coefficients for instruments 140 and 154 indicating the robustness of the results. *State uncertainties in measurements and in reproducibility of results! It's about 0.1 %/degree.

iv. Cross checks of instruments 134 and 144 gave the same results within the uncertainties as earlier studies of Weatherhead et al., 2001. See figures 14 – 17 for sites Bondville_IL and TM_Boulder_CO.

v. The photon count of the internal lamp on instruments 146 and 147 was insufficient to determine temperature coefficients and could not be cross-checked against earlier studies of Weatherhead et al., 2001.

Temperature correction scheme of Peter Kiedron:

Two consecutive responsivities $R(d_i, \lambda)$ and $R(d_{i+1},\lambda)$ were obtained at days d_i and d_{i+1}, respectively. Temperatures $T(d_i)$ and $T(d_{i+1})$ were recorded during the lamp calibrations.

For any day d within the interval (d_i, d_{i+1}) we calculate by linear interpolation:

$T(d)=[T(d_{i+1})- T(d_i)]/(d_{i+1}- d_i)*(d- d_i)+ T(d_i)$

$R(d,\lambda)=R(d_{i+1},\lambda) -R(d_i, \lambda)]/(d_{i+1}- d_i)*(d- d_i)+ R(d_i,\lambda)$

The for any scan at day d with recorder temperature T_{scn} we calculate temperature corrected responsivity:

$R_{scn}(d,\lambda)= R(d,\lambda)*\{1+TC(\lambda)/100*[T_{scn}- T(d)]\}$ (*.*)

Where $TC(\lambda)$ are the relative temperature coefficients in percent.

For $d< d_0$, i.e., before the first calibration we assume that $R(d,\lambda)= R(d_0,\lambda)$ and $T(d)=T(d_0)$ and then we use formula (*.*).

File header information (described by KL):

The calibrated spectral solar irradiance, I, is calculated by the following equation for a given day "d". This is based on the original file structure and column values developed by Peter Kiedron.

$I(d,\lambda)= [S/R(d_i,\lambda)]$*Signal_corr*Cosine_corr*Resp_corr (*.2)

Resp_corr = $1/\{1 + [(R_{scn}(d,\lambda) – R(d_i,\lambda))/R(d_i,\lambda)]\} = R(d_i,\lambda)/R_{scn}(d_{scn},\lambda)$ (*.3)

Where,

$I(d,\lambda)$ is the spectral solar irradiance for day "d" in W/m^2/nm.

S is the signal in photons per second.

$TC(\lambda)$ are the relative temperature coefficients in percent given in file TC_uvScans.txt

$R(d_i,\lambda)$ is the measured responsivity using the external field calibrator with NIST traceable 1000W lamps on day i in (photons/sec)/W/m^2/nm), e.g. filename = resp_yyyyjjj.sss, where sss=serial number.

$R_{scn}(d_{scn},\lambda)$ is the calculated responsivity for a given scan with a given temperature.

Signal_corr = correction to the signal for stray-light, spikes, and dead-time, e.g. see NEUBrew document on signal corrections.

Cosine_corr = angular response correction due to imperfect input optics, e.g. see NEUBrew document on angular corrections.

Resp_corr = correction to the responsivity due to temperature and drift.

Temperature correction scheme by Kathy Lantz:

$$I(d,\lambda)= [S/R_c(d_i,\lambda)]*Signal\_corr*Cosine\_corr*Resp\_corr \qquad (*.4)$$

$$I(d,\lambda)= [S/R_c(d_i,\lambda)]*Signal\_corr*Cosine\_corr*Resp\_corr1*Resp\_corr2 \qquad (*.5)$$

The above equation is based on the original file structure developed by Peter Kiedron. I separated the responsivity temperature correction and the responsivity drift correction into two steps as indicated in equation*.5.

1. Responsivity temperature correction.
    a. Correct measured responsivities to 25degC [Patrick's measurements].
    b. $R_c(d_i,\lambda)=R(d_i,\lambda)[1+(TC/100)(T_i-25)]$; where R is the average responsivity on day d_i, where d_i is the day the responsivities were measured by Patrick, and Ti is the average temperature of the average responsivity scans, and TC is the percent change in responsivity per degree C from tables, and R_c is then the temperature corrected responsivity on day d_i
    c. $R_{tscn}(d_{scn},\lambda) = R_c(d_i,\lambda)[1+(TC/100)(T_{scn}-25)]$
    d. $Resp\_corr1(d_{scn},\lambda, T_{scn}) = R_c(d_i,\lambda)/R_{tscn}(d_{scn},\lambda)$, correction for temperature only
2. Responsivity drift correction (assumes drift is linear).
    a. $R_{dscn}(d_{scn},\lambda)= [(R_c(d_{i+1},\lambda)- R_c(d_i,\lambda))/(d_{i+1}-d_i)]*(d_{scn}-d_i) + R_c(d_i,\lambda)$
    b. Percent drift at day d_{scn} = $\Delta R(d_{scn},\lambda)$ = $[R_{dscn}(d_{scn},\lambda)-R_c(d_i,\lambda)]/R_c(d_i,\lambda)*100$

   c. Resp_corr2(d_{scn},λ) = R_c(d_i,λ)/R_{dscn}(d_{scn},λ), correction for drift only.

3. Responsivity corrected for drift and temperature combined as in eq *.4.
   a. R_{tdscn}(d_{scn},λ)= R_{tscn}(d_{scn},λ)*(1+(ΔR(d_{scn},λ)/100))
   b. Resp_corr(d_{scn},λ, T_{scn}) = R_c(d_i,λ)/R_{tdscn}(d_{scn},λ), correction for drift and temperature

Header information: Use R_c(d_i,λ) in responsivity column. Use Resp_corr for the correction to the responsivity for drift and temperature.

Files:

R(d_i,λ): The average responsivity from the given file measured on day d_i;
filename = resp_yyyyjjj.iii,
location= ftp.srrb.noaa.gov/pub/data/neubrew/characterization/responsivity_files/.

R_c(d_i,λ): Corrects the first scan in each R(d_i,λ) file after the average scan to 25 degrees,
filename = tc_resp_yyyyjjj.iii,
location= ftp.srrb.noaa.gov/pub/data/neubrew/data/characterizations/responsivity_files/.

TC = Temperature correction file with instruments 134,139,140,141,144,146,147,and 154
Files = tempCorr_forUVscans.txt
Location= ftp.srrb.noaa.gov/pub/data/neubrew/data/characterization/uv_temp_corr_files/

Comments: For responsivity drifts between calibrations, the question is whether or not it is linear in time, and if not how to correct the UV solar irradiance measurements between calibrations. Most likely the drift is not linear, but there are potentially many factors affecting the responsivity each day.

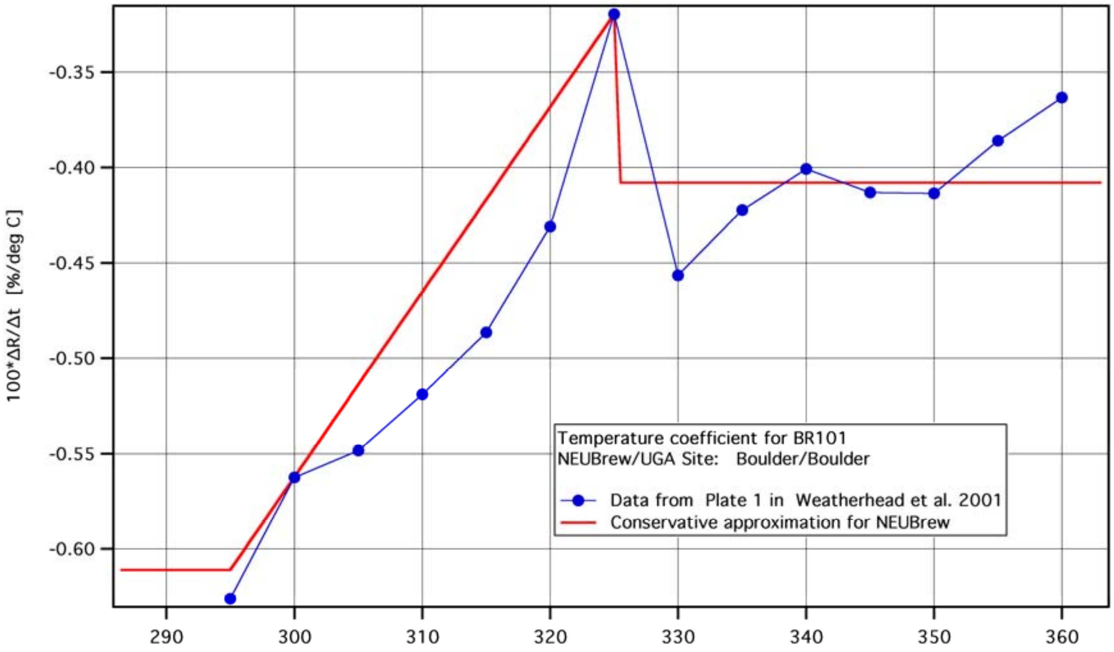
1) Is there a possibility of using the daily CI scans, i.e. the internal lamp measurements, to determine changes in the instrument between calibrations? The CI scans reflect changes in the optical components but also represents changes in the internal lamp itself. Changes in the internal lamp is the major factor affecting the lamp photon count as can be seen in how well the voltage drop across the lamp mimics the photon count, i.e. changes in the photon count are due to the lamp not changes in the optical components in its path. However, could the voltage drop across the lamp be used to remove this effect and see if the residual represents changes in the optical components between external responsivity measurements?
2) Is there a possibility of using R6 values to correct the responsivity for wavelengths less than 325 nm? The R6 possibly could reflect the effect of the humidity etc on the responsivity (throughput of the filters, e.g. NiSO4)? Note: The R6 in theory is corrected for temperature and the change of the photon count due to the lamp is mostly removed in the ratio. (?)

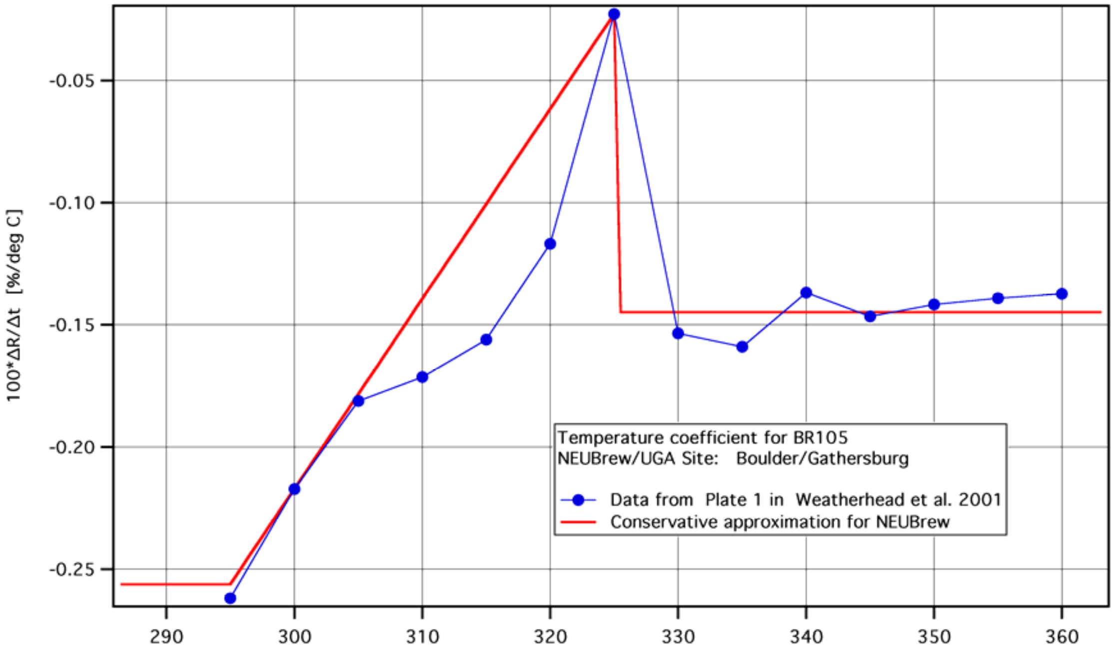
References

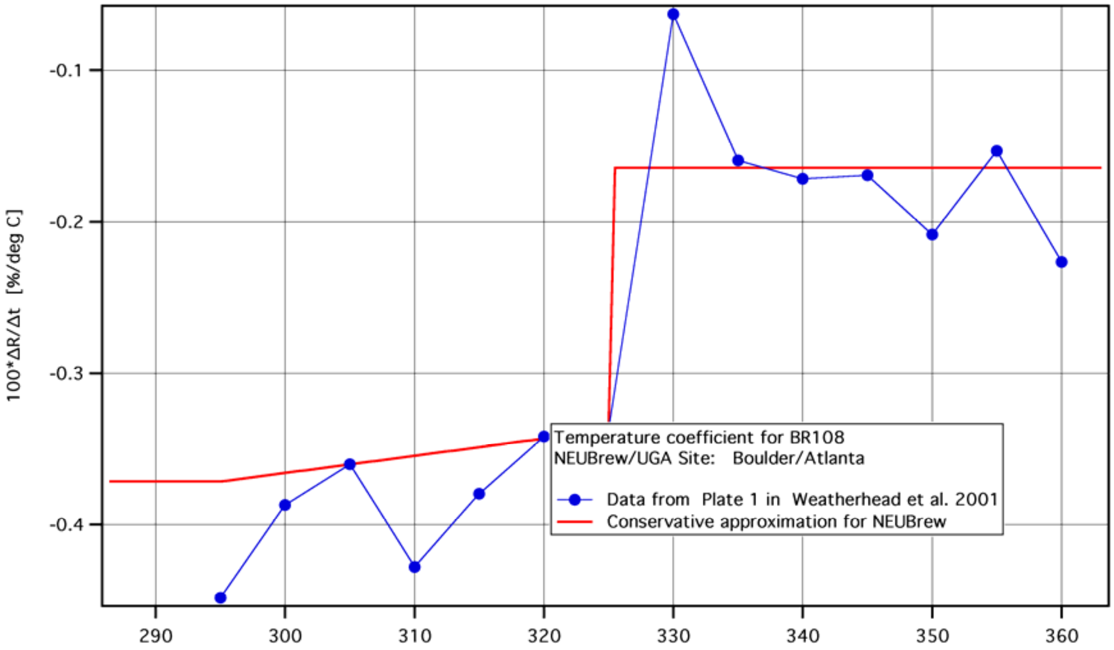
Weatherhead, E. D. Theisen, A. Stevermer, J. Enagonio, B. Rabinovitch, P. Disterhoft, K. Lantz, R. Meltzer, J. Sabburg, J. DeLuisi, J. Rives and J. Shreffler, "Temperature dependence of the Brewer ultraviolet data," J. Geophys. Res. 106, 13,121-13,129, 2001.

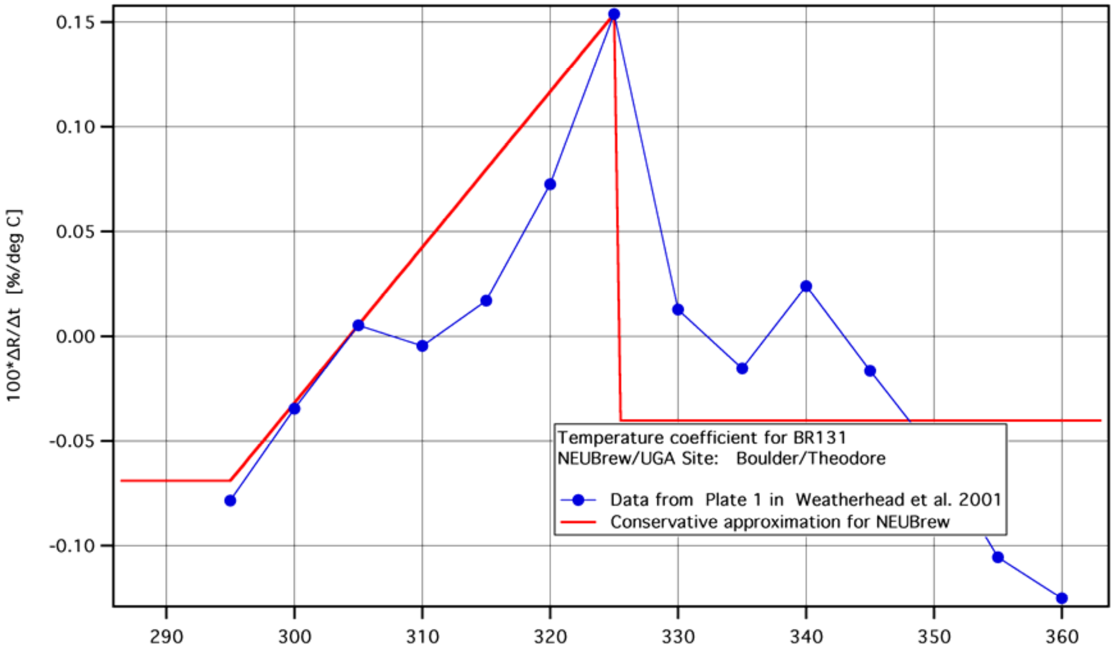
Cappellani, F. and C. Kochler, "Temperature effects correction in a Brewer MKIV spectrophotometer for solar UV measurements," J. Geophys. Res. 105, 4829-4831, 1999.

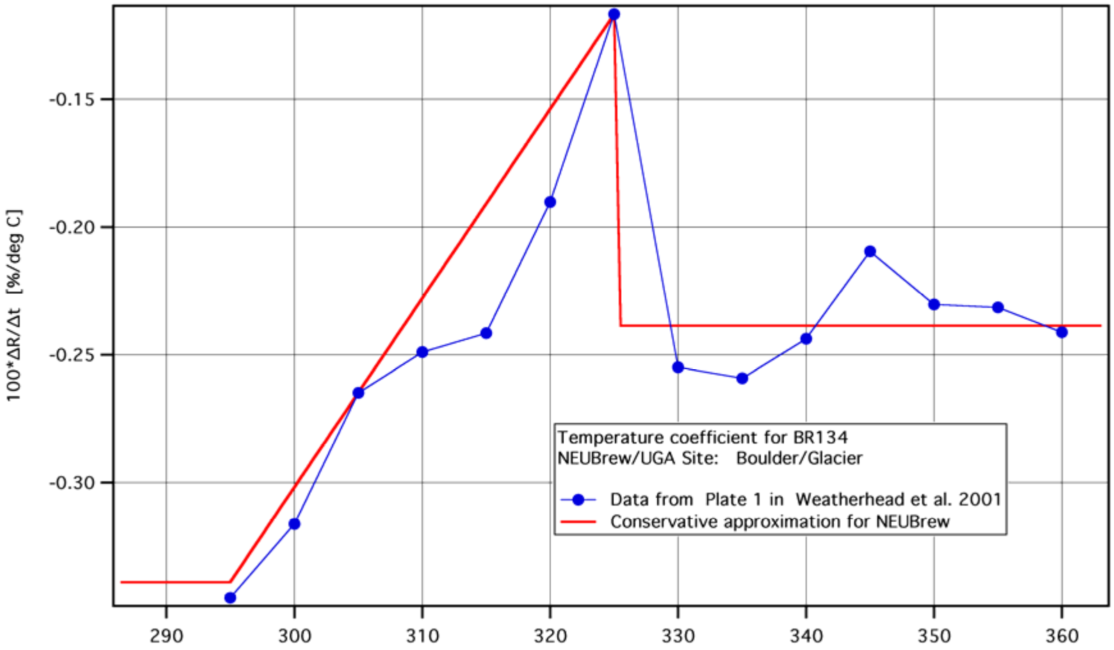
Figures 1 – 11: % change in responsivity with temperature from Weatherhead et al., 2001 [Blue dots] and linear fit to data [red line].

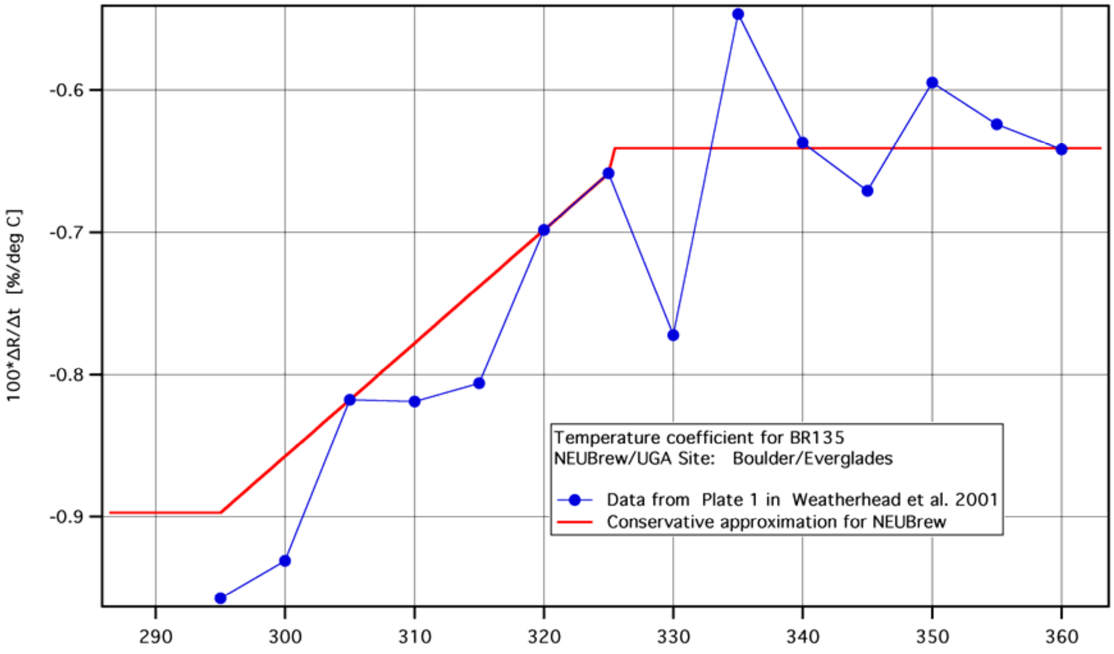


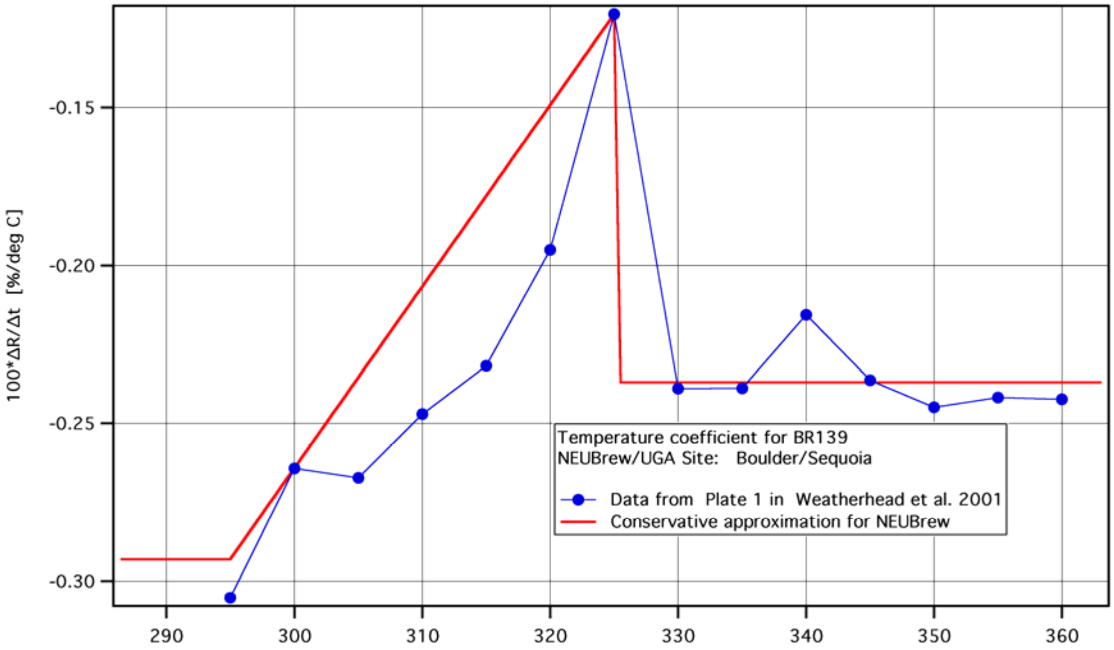

100*ΔR/Δt [%/deg C]
-0.05
-0.10
-0.15
-0.20
-0.25
290
300
310
320
330
340
350
360
Temperature coefficient for BR105
NEUBrew/UGA Site: Boulder/Gathersburg
Data from Plate 1 in Weatherhead et al. 2001
Conservative approximation for NEUBrew

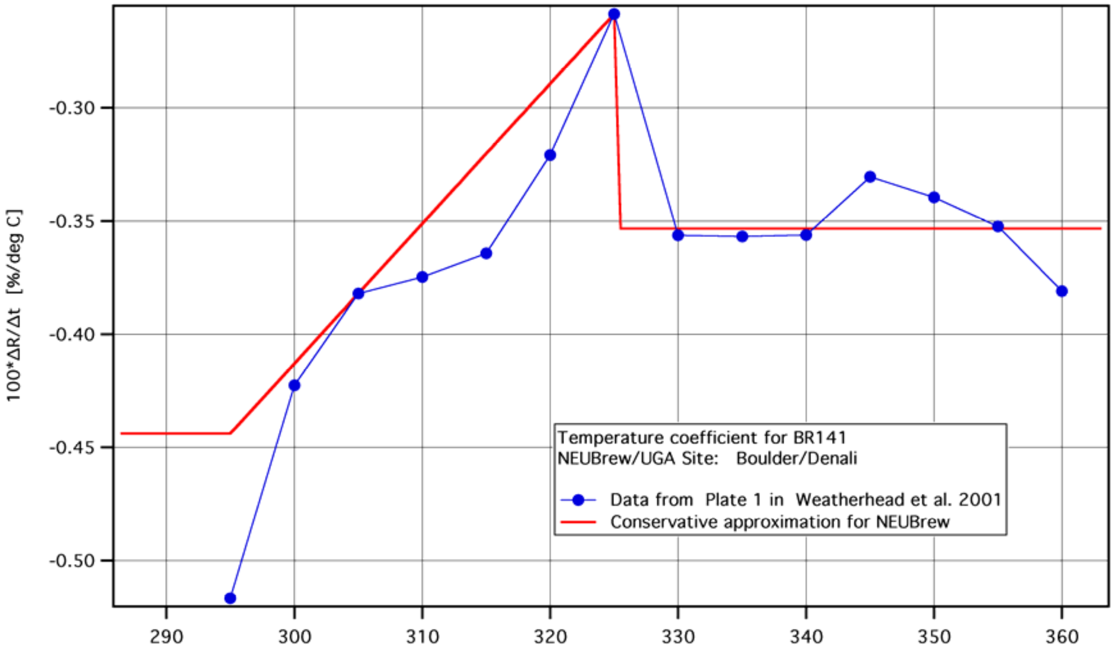

100*ΔR/Δt [%/deg C]
-0.1
-0.2
-0.3
-0.4
290
300
310
320
330
340
350
360
Temperature coefficient for BR108
NEUBrew/UGA Site: Boulder/Atlanta
Data from Plate 1 in Weatherhead et al. 2001
Conservative approximation for NEUBrew

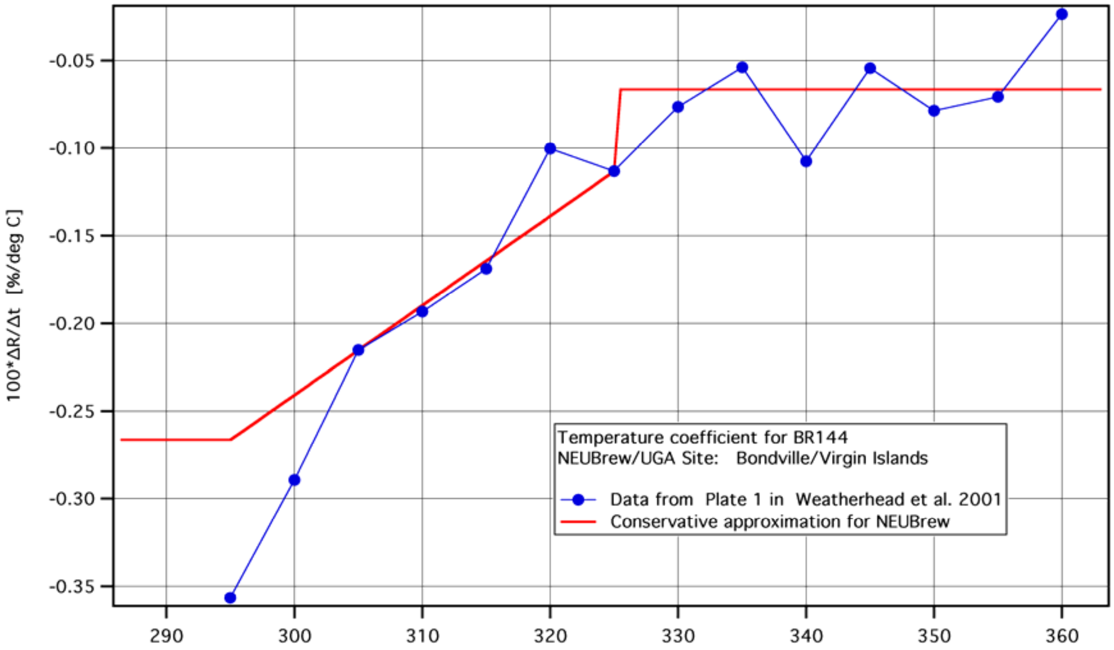

100*ΔR/Δt [%/deg C]
0.15
0.10
0.05
0.00
-0.05
-0.10
290
300
310
320
330
340
350
360
Temperature coefficient for BR131
NEUBrew/UGA Site: Boulder/Theodore
Data from Plate 1 in Weatherhead et al. 2001
Conservative approximation for NEUBrew

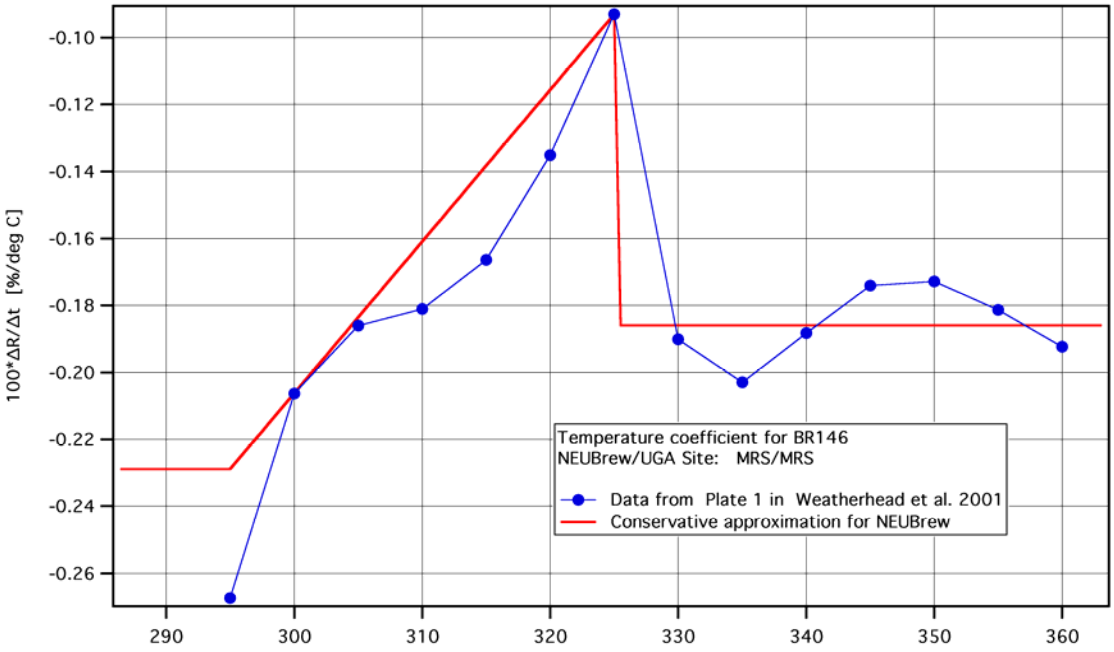

100*ΔR/Δt [%/deg C]
-0.15
-0.20
-0.25
-0.30
290
300
310
320
330
340
350
360
Temperature coefficient for BR134
NEUBrew/UGA Site: Boulder/Glacier
Data from Plate 1 in Weatherhead et al. 2001
Conservative approximation for NEUBrew

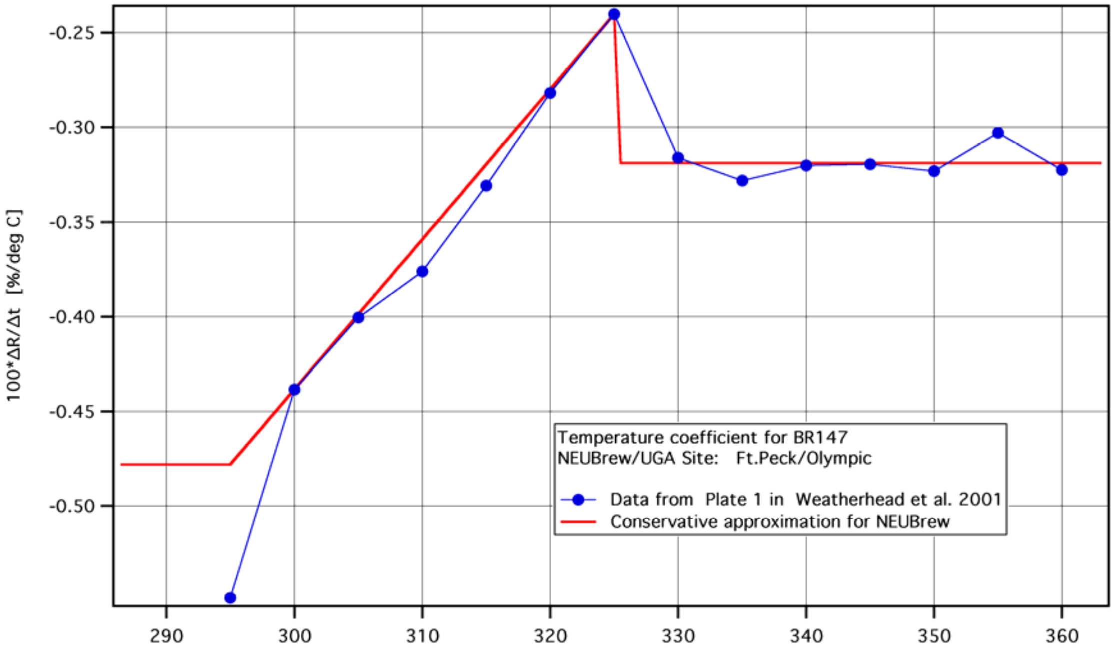

100*ΔR/Δt [%/deg C]
-0.6
-0.7
-0.8
-0.9
290
300
310
320
330
340
350
360
Temperature coefficient for BR135
NEUBrew/UGA Site: Boulder/Everglades
Data from Plate 1 in Weatherhead et al. 2001
Conservative approximation for NEUBrew


100*ΔR/Δt [%/deg C]
-0.15
-0.20
-0.25
-0.30
290
300
310
320
330
340
350
360
Temperature coefficient for BR139
NEUBrew/UGA Site: Boulder/Sequoia
Data from Plate 1 in Weatherhead et al. 2001
Conservative approximation for NEUBrew


100*ΔR/Δt [%/deg C]
-0.30
-0.35
-0.40
-0.45
-0.50
290
300
310
320
330
340
350
360
Temperature coefficient for BR141
NEUBrew/UGA Site: Boulder/Denali
Data from Plate 1 in Weatherhead et al. 2001
Conservative approximation for NEUBrew


100*ΔR/Δt [%/deg C]
-0.05
-0.10
-0.15
-0.20
-0.25
-0.30
-0.35
290
300
310
320
330
340
350
360
Temperature coefficient for BR144
NEUBrew/UGA Site: Bondville/Virgin Islands
Data from Plate 1 in Weatherhead et al. 2001
Conservative approximation for NEUBrew


100*ΔR/Δt [%/deg C]
-0.10
-0.12
-0.14
-0.16
-0.18
-0.20
-0.22
-0.24
-0.26
290
300
310
320
330
340
350
360
Temperature coefficient for BR146
NEUBrew/UGA Site: MRS/MRS
Data from Plate 1 in Weatherhead et al. 2001
Conservative approximation for NEUBrew


100*ΔR/Δt [%/deg C]
-0.25
-0.30
-0.35
-0.40
-0.45
-0.50
290
300
310
320
330
340
350
360
Temperature coefficient for BR147
NEUBrew/UGA Site: Ft.Peck/Olympic
Data from Plate 1 in Weatherhead et al. 2001
Conservative approximation for NEUBrew

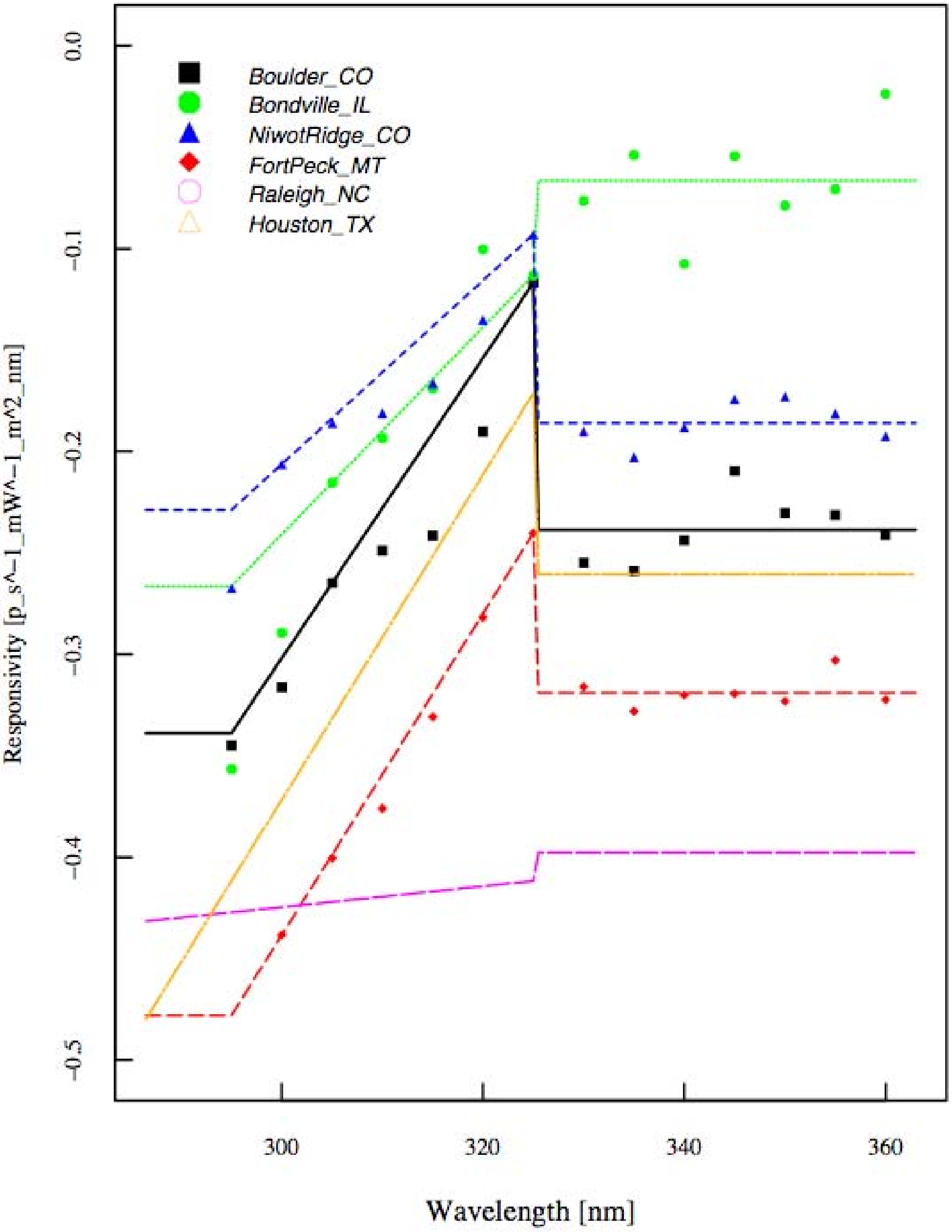


Figure 12: The % change in responsivity per degree as a function of wavelength for the six sites (note y axis here is incorrect), where Brewer 154 and 140 are calculated using external lamp scans from CUCF calibration using an external calibrator from the current and previous network. Conservative approximation as defined by Peter Kiedron. For the other instruments this is the same as figures 1 – 11.

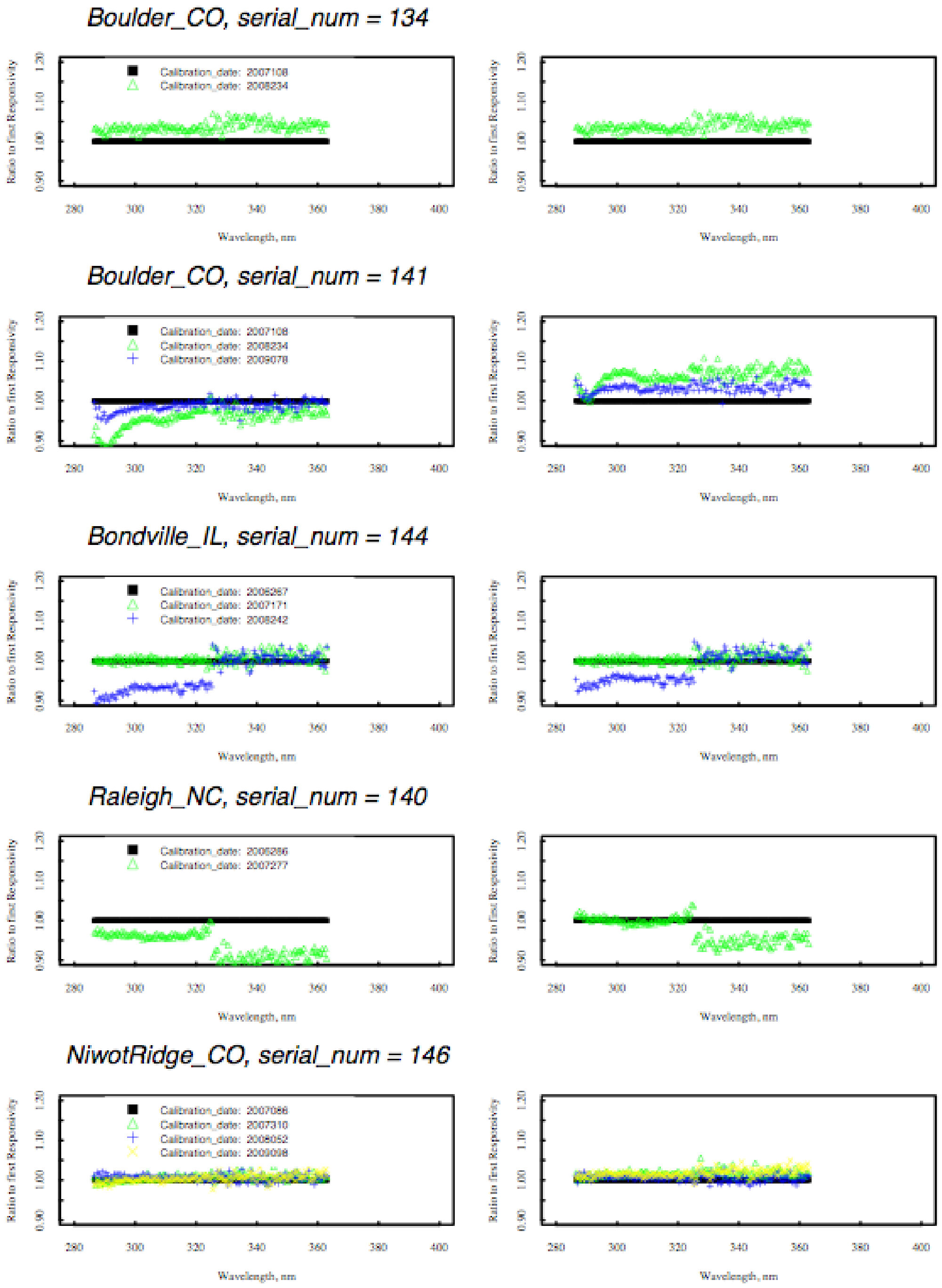
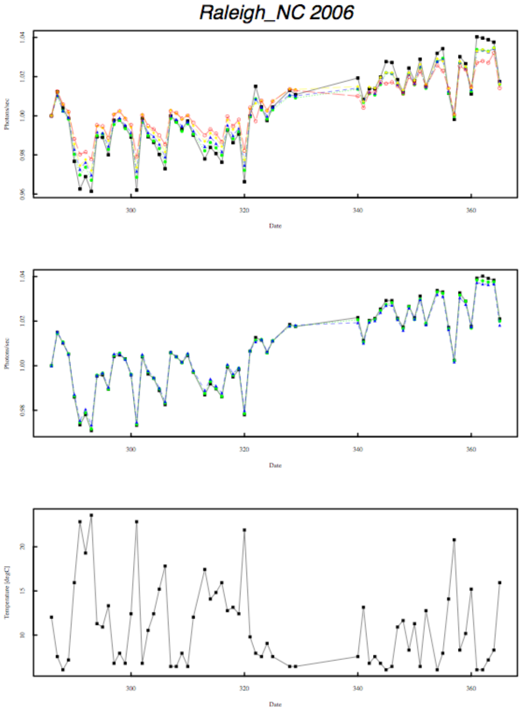
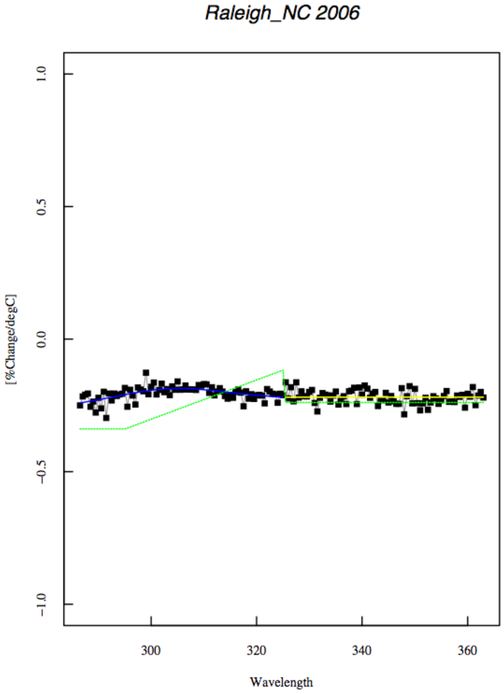
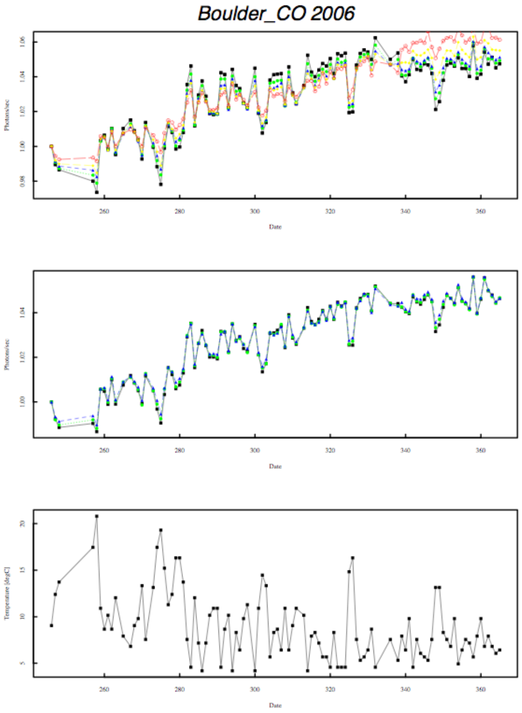


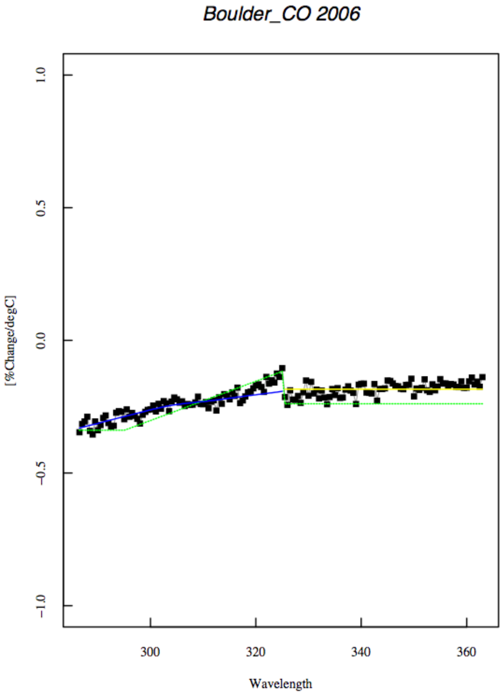
Figure 13: Responsivity measurements using the external field calibrator with 1000W Tungsten Halogen lamp, where the first column is the uncorrected measurements $R(d_i,\lambda, T_\iota)$ and the second column is the responsivity corrected to 25 deg C, $R_c(d_i,\lambda, T= 25)$.

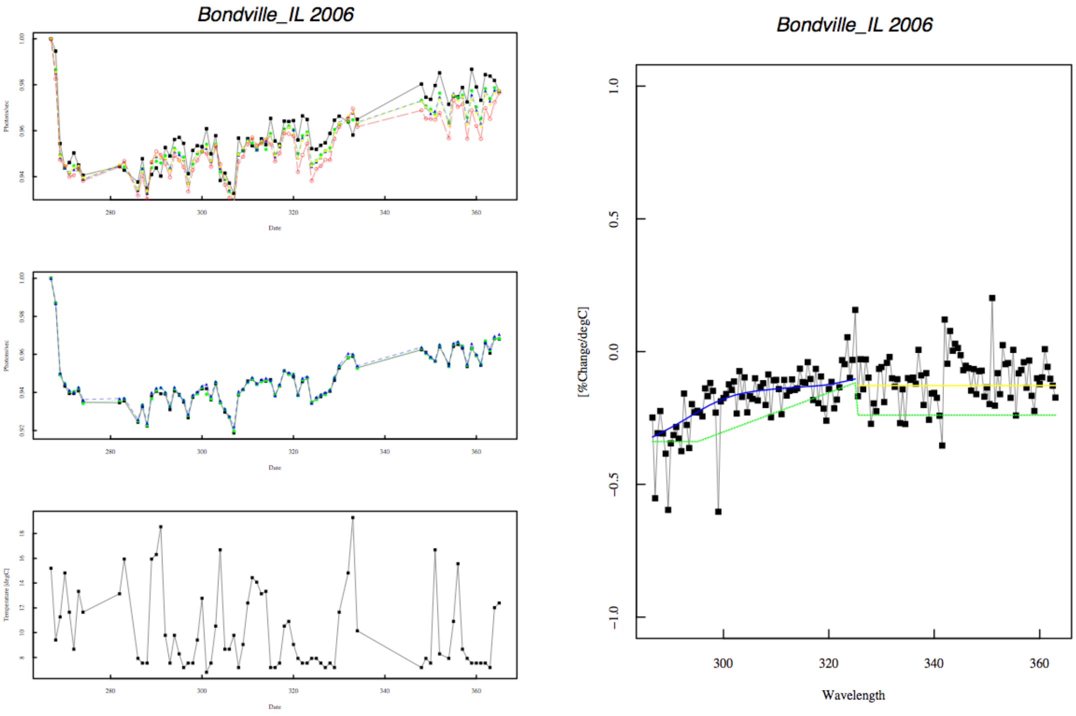
Figures 14 – 17:

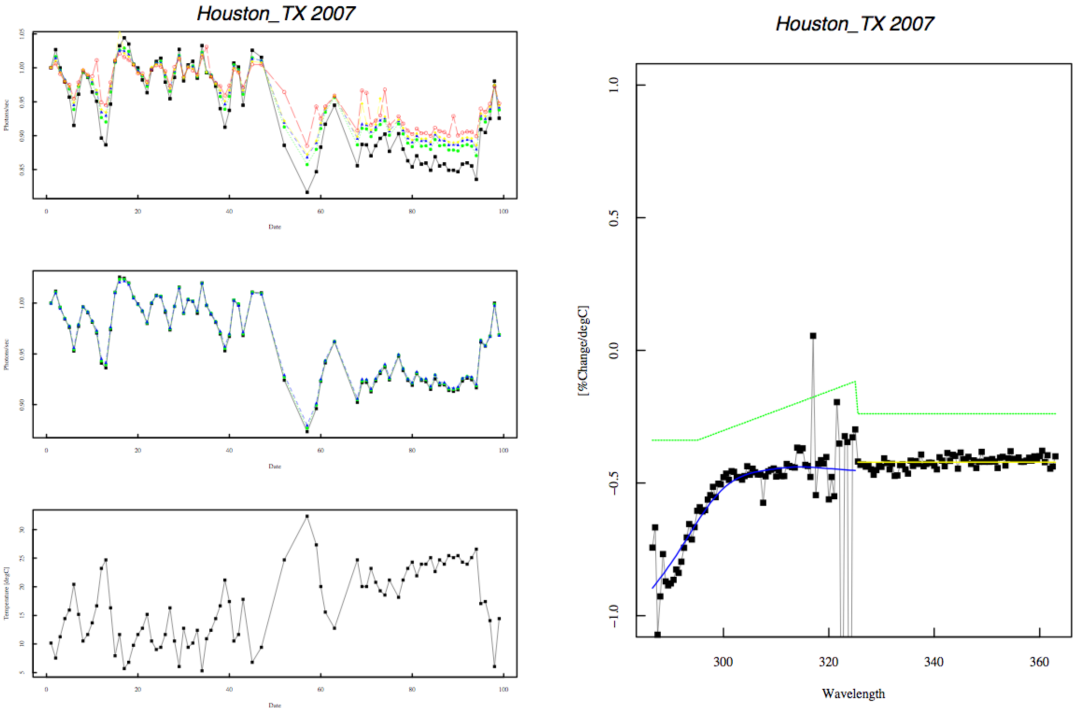












Figures 14 – 17 a and b: The figures in the column to the left a) are the Brewer internal lamp scans for 4 sites (i.e. BR140, BR144, BR134, BR154) for 4 sites (Raleigh_NC, Bondville_IL, TM_Boulder_CO, Houston_TX). The lamp scans on the left are used to generate the temperature coefficients as a function of wavelength for the four instruments as shown in the four plots to the right. Original data used is given in the black points, the fit to the data is in the blue and yellow. The green is either Weatherheads values or the values determined from the external lamp files as described above. Specifically, this is compared to the Weatherhead results shown as the green line for the Boulder_CO and Bondville_IL sites (instruments 134 and 144). For the Raleigh_NC and Houston_TX sites (instruments 140 and 154) the green line is the temperature coefficients from the CUCF external lamp calibrations.