# Analysis of TEMPO Solar Measurements

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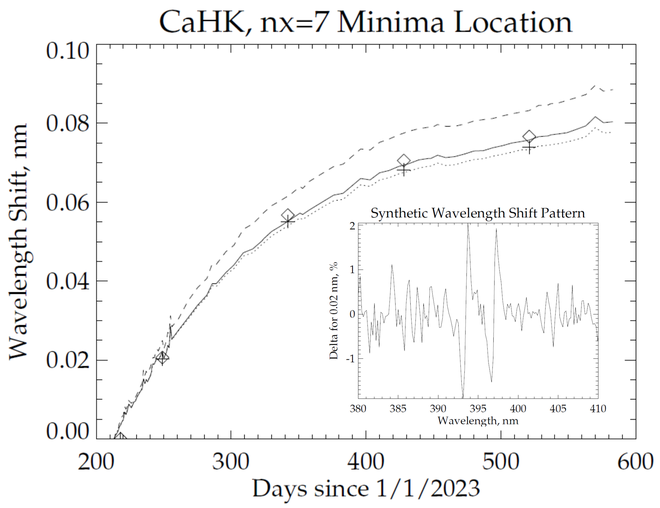
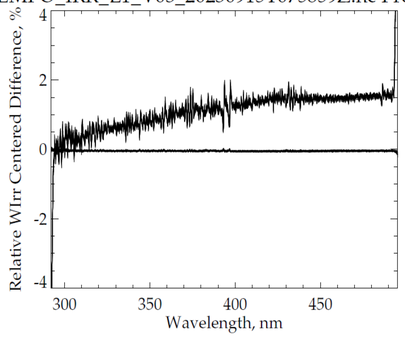
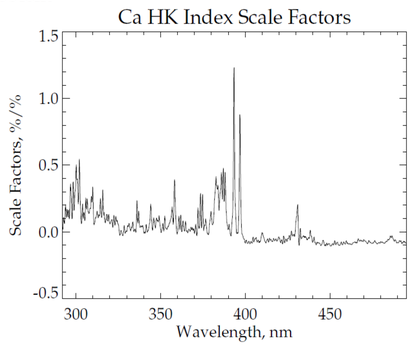
**Introduction:** The Tropospheric Emissions: Monitoring of Pollution (TEMPO) instrument uses a dual diffuser system to track changes in the optical performance. This poster presents results from analysis of the first 91 working and five reference diffuser measurement. This independent work confirms many of the finding of the Tempo Project's Level 1 Team for the wavelength range from 290 nm to 490 nm for the Version 3 product. Additional results are also presented. (Sample files names for this study – TEMPO_IRR_L1_V03_20240516T041153Z.nc and TEMPO_IRRR_L1_V03_20231222T053009Z.nc )




**Time-dependent wavelength shifts:** The diffuser measurements have been combined into twenty N/S spectra by averaging 100 N/S spectra together with filtering for outliers. For each measurement, for each N/S grouping, for each wavelength the average of the 80 middle values of the 100 values after sorting by size is computed. The figure above shows the values from Ca H & K minima shift estimates for the working diffuser (dotted and solid lines) and reference diffuser (plus and diamond symbols) and the L1B provided wavelength scale model-based shift estimates (dashed line) for the northernmost group of 100 measurements. (The locations of the Ca H&K lines minima are found by using quadratic fits of seven measurements nearest to 393.45 nm or 396.95 nm, respectively.) Similar results are obtained for other N/S groupings. Level 1B users need to be aware of these shifts which are not in the nominal wavelength datasets. The shift pattern from a pair of synthetic spectra, with a 0.02 nm shift between them, is shown in the inset figure for the 380 to 410 nm range.

TEMPO_IRR_L1_V03_20230915T075859Z.nc Problem




**Out-of-Family:** One of the Working Diffuser measurements is out-of-family. The figure above on the left shows the centered difference for 20230915 with its neighbors as well as a centered difference for three measurements earlier. This measurement was taken 180 degrees away from the standard orbital position. In addition to the wavelength dependent bias, there is small wavelength shift pattern that would be associated with a 0.008 nm shift, suggesting that there could be a diurnal variation of the wavelength scale.
**CaHK Index:** This figure shows preliminary estimates of the Ca H&K center-to-cores Index scale factors. These give scaled variations by using three solar measurements with large down / up / down values for a CaHK center-to-cores Index. They can be compared to solar activity spectral results for OMI in https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2019EA000624 .

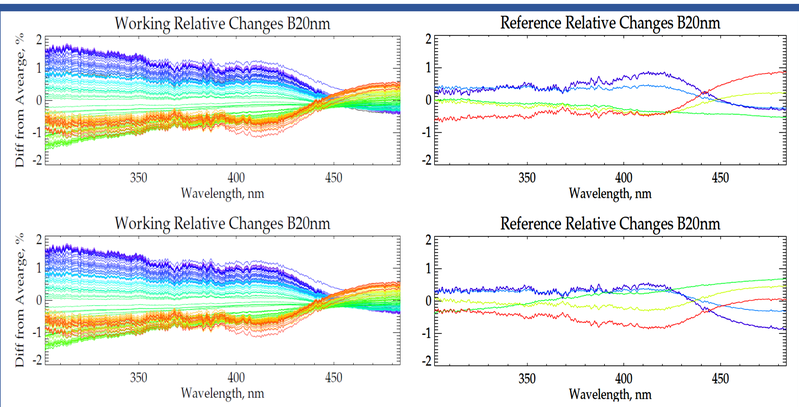
**Acknowledgements** Elements of this work were supported by the NOAA JPSS and GeoXO programs. We would also like to thank the TEMPO Level 1 Team for their willingness to cheerfully answer both our basic and advanced questions.

**Disclaimer:** "The scientific results and conclusions, as well as any views or opinions expressed herein, are those of the authors and do not necessarily reflect those of NOAA or the Department of Commerce."

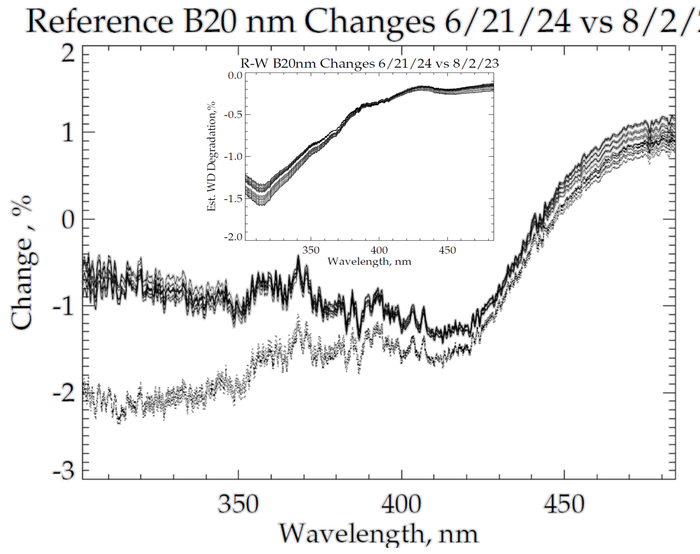
**References**

Marchenko, et al. (2019). Improved Aura/OMI solar spectral irradiances: Comparisons with independent data sets and model predictions. *Earth and Space Science*. 6 . https://doi.org/10.1029/2019EA000624.

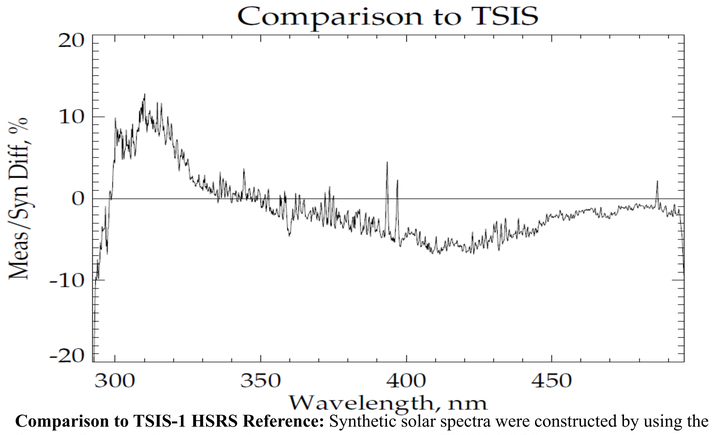
Coddington, O. M., et al. (2023). Version 2 of the TSIS-1 Hybrid Solar Reference Spectrum and Extension to the Full Spectrum. *Earth and Space Science,* 10, e2022EA002637. https://doi.org/10.1029/2022EA002637 .



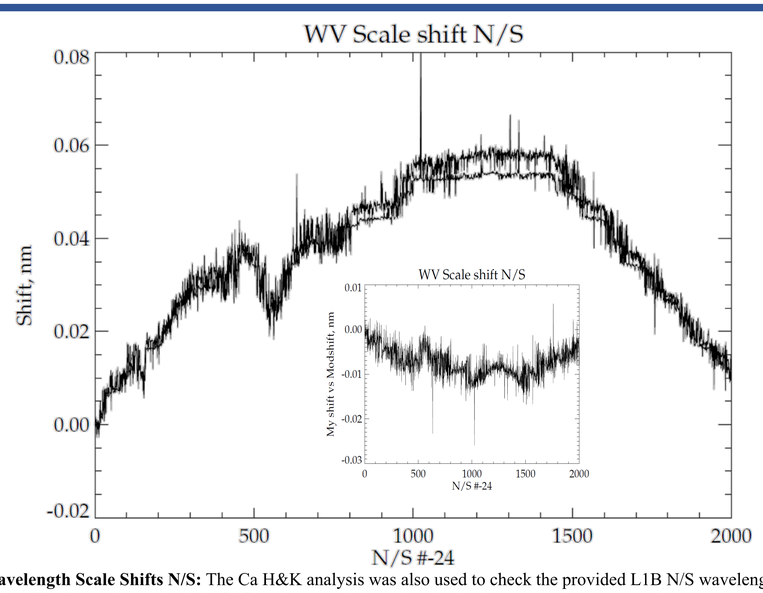

**Relative Changes over Time:** Because of the large wavelength shift over time, the solar data were further processed by smoothing with 100 wavelength (~20 nm) moving averages. The two figures above on the left show the deviations of the 91 spectra from their averages for the northernmost (upper) and southernmost (lower) groupings for the working solar. The two on the right show the same results for the five reference solar measurements. The colors are time ordered cold to warm.



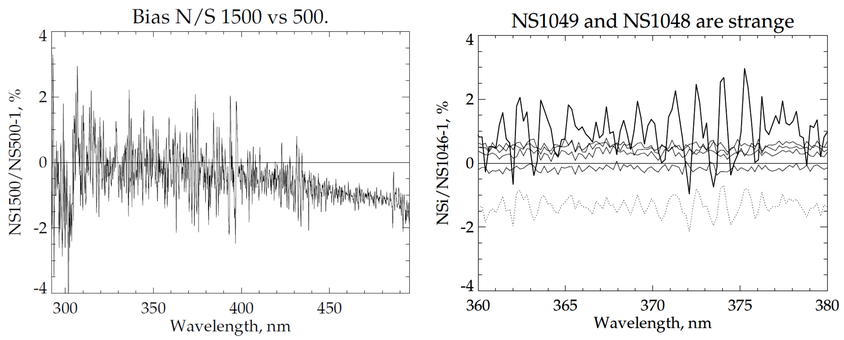

If we take the difference between the last and first reference measurements (and the closely matched 6th and 81st working measurements) for each N/S group, we find a wavelength pattern of degradation and brightening. The thicker line results are for the 20 reference comparisons and the lighter line results are for the working comparisons. The difference between the two sets of results is attributed to diffuser degradation. (See the inset.) One can use an assumption that the degradation rates of the two diffusers are equal per exposure to make a small adjustment to the reference results to get the non-diffuser instrument degradation/ brightening over this 10 ½ month period, or to estimate the time-dependent changes for the working diffuser measurements relative to the Earth radiances .



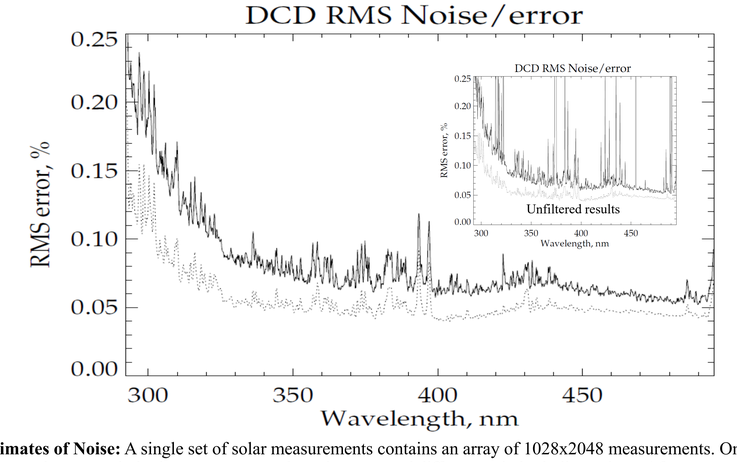

**Comparison to TSIS-1 HSRS Reference:** Synthetic solar spectra were constructed by using the TEMPO Spectral Response Functions and wavelength scale and the TSIS-1 HSRS reference solar dataset (https://lasp.colorado.edu/lisird/data/tsis1_hsrs_p1nm). One typical example comparing a TEMPO measurement to a synthetic spectrum is shown in the figure above. The features in the 390-400 nm interval can be related either to solar activity or to imprecision in the bandpass FW1e values or both.




**Wavelength Scale Shifts N/S:** The Ca H&K analysis was also used to check the provided L1B N/S wavelength scales. The figure shows both the L1B and this study's results for the changes in the wavelength scale versus the northernmost one for the 500th wavelength. The differences between the two are shown in the inset. Note the jump in both estimates just beyond N/S position 1024. These use the spectra without any N/S aggregation or averaging.




**Flat Fielding Checks:** By comparing the solar for different N/S positions, one can check to see if the solar spectra are internally consistent. The figure above on the left compares the solar for the 500th N/S spectrum with the 1500th one. The small scale features may be associated with wavelength scale differences, but the larger scale biases show inconsistencies. This is not necessarily a problem, as most users use the radiance / irradiance ratios.
**Unusual Spectra:** The figure above on the right compares the N/S spectra for 1045 to 1050 to the one for 1044 for a smaller wavelength range. The spectra at positions 1048 and 1049 (dotted and thick lines, respectively) are known to have interesting behavior, perhaps due to a "burr" on the viewing slit for that N/S region. The wavelength shifts for these two are reported/identified in the N/S shift plot, but they also have ~±1% biases with their neighbors. Again, if these biases are shared by the radiance calibration, then they will cancel in the ratios.




**Estimates of Noise:** A single set of solar measurements contains an array of 1028x2048 measurements. One can estimate the uncertain in the measurements by using centered differences in both dimensions. After computing these for the full array, the averages for each wavelength are computed with an outlier cutoff, as the quality flag information in the files was not used. The RMS results are shown with the solid lines. The dotted line shows the values form the L1B uncertainty given in the files. The Double Centered-Differences are ~50% larger. The unfiltered results are in the inset figure with values over 0.25% cut off.