Land Surface Temperature retrieval and long-term pattern analysis for Elbert County, Colorado between 2014 and 2018

This study retrieves Land Surface Temperature (LST) maps using a single-channel algorithm (Jiménez-Muñoz et al. 2009, 2014) on the thermal band (i.e., band 10) of Landsat 8 satellite images, then compares them to Landsat 8's available Analysis Ready Data (ARD8) in order to distinguish a LST trend over the five-year period (i.e., 2014-2018). Each of the datasets (mean, standard deviation, and other metrics for the retrieved and observed times series) resembles a "wave-like" curve, which is common when observing temperature graphs over an annual time-series.

Elbert county lies on about 82.7% grasslands, with the remaining land-use type consisting of developed/ urban land cover. Though Elbert county is less developed than Denver county, it still encompasses several agriculturally driven suburbs, and is located southeast of the Denver metropolitan area. Regions in Colorado that are east of the front range tend to have warmer annual temperature averages, especially urbanized agricultural land-cover types near metropolitan areas, suggesting that Elbert county surfaces may absorb more heat and take longer to cool. The annual cycle of the solar zenith angle variation and the subsequent variation of solar shortwave down welling energy result in the "wave-like" LST curve for each of the metrics (minimum, maximum, median, mean and standard deviation) to be distributed amidst higher LST (Kelvin) values than one would see while observing a county that lies primarily on Crops, higher elevation Grasslands, Forests, or Shrubland land-cover types. The minimum ARD8 LST average of Elbert county is 284.95 degrees kelvin (°K), which is the second highest (following Denver county) minimum ARD8 LST average of the 6 counties observed (e.g., average minimum LST between ARD8 and Retrieved is 269.14 °K for Gilpin county (75.9% forest)). For the maximum metric, LST averages are 309.12 °K for ARD8 and 308.61 °K for Retrieved data, again higher than maximum temperature values of 4 of the 5 counties (Moffat county, located in the northwestern most corner of Colorado, represents similar temperature values due to its relatable climate in the western front range). Elbert county's mean metric yielded averages at 299.34 °K for ARD8 LST and 299.22 °K for Retrieved LST. Remaining metrics also display this consistent trend with average median values of 299.45 °K for ARD8 and 299.39 °K for Retrieved LST. Plotted standard deviation values were 2.98 °K for ARD8 and 2.98 °K Retrieved LST,

indicating that land surface temperature values are dispersed within moderate proximity of the mean.

Once acquired LST (°K) values for both ARD8 and Retrieved datasets were plotted, a standard sinusoidal model was used to best-fit the "wave-like" curve generated by the plots. The equation used for fitting each non-linear regression is as follows:

$$y = A\cos(B \cdot x + C) + D + E \cdot x$$

where '*y*' is the optimized LST value (data point fit to each date-index), '*A*' represents the amplitude (height from mean value), '*B*' represents the period (frequency of the cycle; in this case days throughout an annual cycle) and '*x*' is the date-index from the starting date (of the five-year period). '*C*' represents the phase- shift, '*D*' is the displacement (vertical shift) and '*E*' is the long-term slope of each metric over the five-year period.

In order to acquire parameters for the *A*-*E* values in the equation, the 'Solver' add-in tool of Excel Office 2016 was used to calculate optimized values. The optimizer asks for a set of parameters to base the optimization on. In this case, "Set objective: (desired cell)", "To: (min objective cell value)" and "By changing variable cell: (cells containing initial estimations of *A*-*E* values) are the only parameters modified. Every 'desired cell' contained an objective function outputting the 'Sum of Square Error" (*SSE*) of fitted y-values in comparison with the original y-values (here y refers to either ARD8 or retrieved LST). The initial *A*-*E* values were estimated using a-priori information and optimized via the default Excel "GRG non-linear" method that accommodates problems that are smoot non-linear.

For the non-linear regressions, R^2 values were calculated for every metric using the following equation:

$$R^2 = 1 - (SSE / SST)$$

where *SSE* (Sum of Square Error) is the 'error variation' (e.g., sum of the squared distances from the fitted to the original y-values) and *SST* (Total Sum of Squares) being the 'total variation' in the 'y-value'. R^2 allows us to determine how close the model's prediction is to the true values or how much of the total variation can be explained by the model (the closer to 1, the more accurate the model), which is essential in the validation process.

In addition, a linear regression was conducted and plotted for each metric as a second measure of the respective long-term increase and decrease patterns. This was done by plugging the calculated slope and y-intercept values (gathered using LINEST function built into Excel Office 2016) into the standard $Y = mx + B$ equation, then plotting the start and end-date LST values for each counties' metrics. *Note: LINEST function uses "least squares" method to calculate a straight line to fit the data, as well as returning an array describing the regression statistics. The structure of the function is LINEST ([known_y's], [known_x's], [const], [stats]), where setting 'const' to 'True' allows a non-zero intercept, and 'stats' to 'True' returns additional regression statistics.

Elbert County

Minimum LST

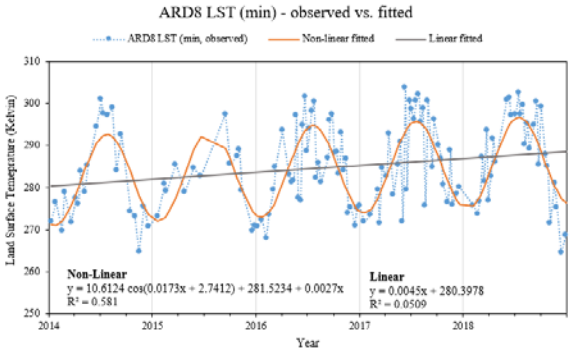

Figure 1. displays the minimum Land Surface Temperature of the Analysis Ready Data (Landsat 8) for Elbert county 2014-2018.

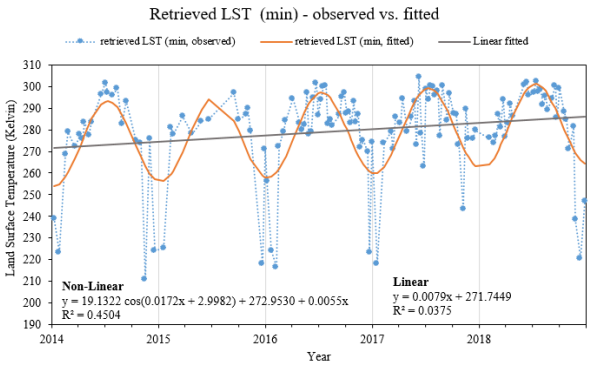

Figure 2. displays the minimum Land Surface Temperature of Elbert county's Retrieved LST series from 2014- 2018.

Table 1. shows linear and non-linear R^2 values (minimum) from *Figures 1 & 2.*

Table 1. Elbert County Minimum Regression Slopes and R^2 Values

	ARD 8 LST	Retrieved LST
Linear R^2	0.0509	0.0375
Non-linear R^2	0.581	0.4504
Linear Slope	0.0045	0.0079
Non-linear Slope	0.0027	0.0055

Calculations drawn from *Figures 1 & 2* of the 'minimum' metric for ARD LST and Retrieved LST yielded R^2 values that indicate a low linear correlation due to the annual wave-like pattern (non-linear). ARD8 LST showed an annual temperature change value of 1.0005 °K/year (increase in LST) while the Retrieved LST trend showed an annual change of 2.0145 °K/year (significant increase in LST). Non-linear R^2 values for both ARD8 and Retrieved LST were less than 0.5, indicating the model could use some adjustment for a better fit. R^2 values for non-linear regressions more accurately depict the 'fit' because the data points are not linearly changing with days.

Table 2. gives more statistical detail on the **linear** regressions from *Figures 1 & 2* the minimum temperature for both ARD 8 LST and retrieved LST.

Table 2. Elbert County Minimum Linear Descriptive Statistics

	P-value *Slope*	P-value *Y-intercept*	Lower 95% *Slope*	Upper 95% *Slope*	Lower 95% *Y-intercept*	Upper 95% *Y-intercept*
ARD 8 LST	0.0085	3.73 E-149	0.0012	0.0078	276.63	284.17
Retrieved LST	0.0244	5.64 E-106	0.001	0.0147	263.95	279.54

As shown in *Table 2*, the *p-value(slope)* yielded by the (minimum) ARD8 LST linear regression lies between 0.001 and 0.01, meaning that there is strong evidence against the null hypothesis (no change over time), or in equivalent, there is significant evidence in favor of the alternative (minimum ARD8 LST changes over time). The *p-value(slope)* for the (minimum) retrieved LST data is between 0.01 and 0.05, which tells us the linear model has moderate evidence supporting minimum retrieved LST changes over the five-year period in Elbert county. Both ARD8 and Retrieved LST *p-values(y-intercept)* show values that are less than 0.001 ($P < 0.001$), proving strong evidence against the null hypothesis, in favor of a non-zero minimum LST. Since the slope terms are not significantly different from zero for both (minimum) ARD8 and retrieved LST, it can be inferred that the minimum LST values for Elbert county are from 276.63 °K to 284.17 °K for ARD8 and from 263.95 °K to 279.54 °K for Retrieved LST.

Maximum LST

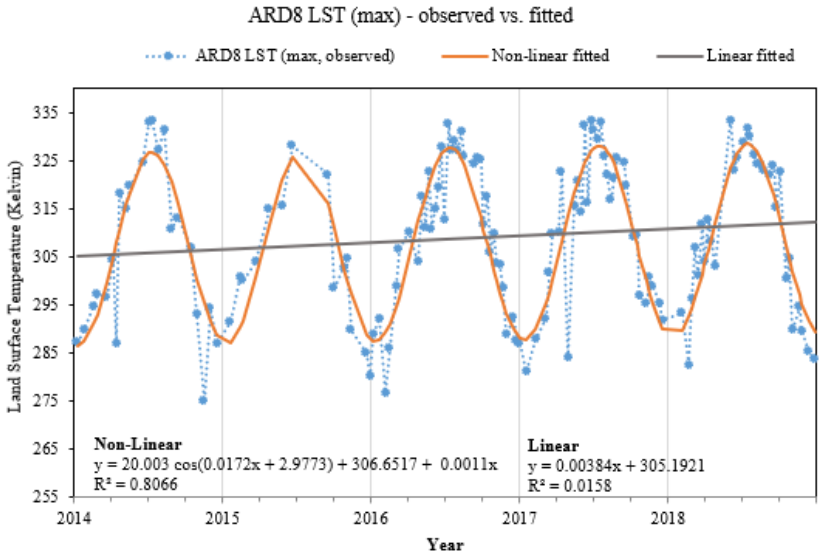

Figure 3. displays the maximum Land Surface Temperature of the Analysis Ready Data (Landsat 8) for Elbert county 2014-2018.

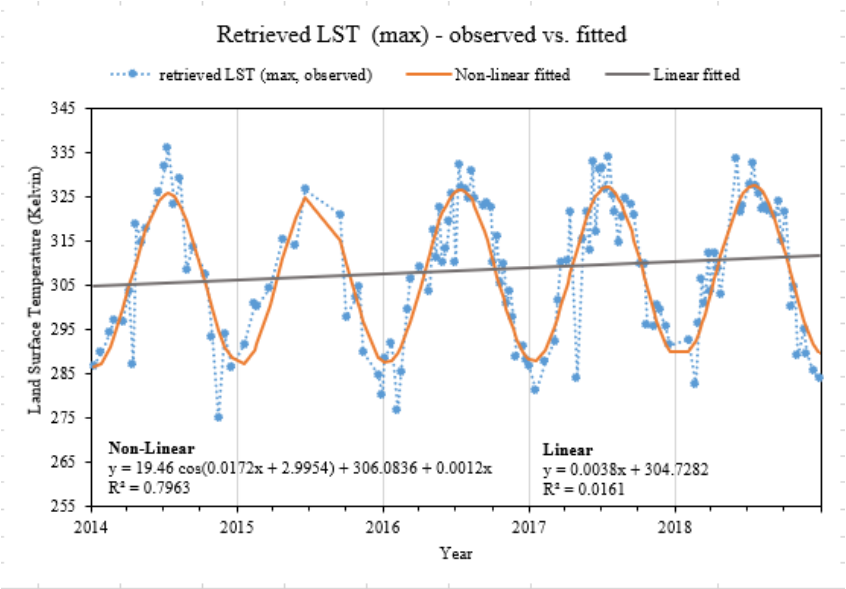

Figure 4. displays the maximum Land Surface Temperature of Elbert county's Retrieved LST series from 2014- 2018.

Table 3. shows linear and non-linear R^2 values (maximum) from *Figures 3 & 4.*

Table 3. Elbert County Maximum Regression Slopes and R^2 Values

	ARD 8 LST	Retrieved LST
Linear R^2	0.0158	0.0161
Non-linear R^2	0.8066	0.7963
Linear Slope	0.0038	0.0038
Non-linear Slope	0.0011	0.0012

The 'maximum' metric calculations from *Figure 3 & 4* for ARD LST and Retrieved LST also yielded R^2 values that indicate a low linear correlation due to the annual wave-like pattern. ARD8 LST showed an annual temperature change value of 0.4149 °K/year (slight increase in LST) while the Retrieved LST trend showed an annual change of 0.4498 °K/year (also slight increase in LST). Non-linear R^2 values for both ARD8 and Retrieved LST were greater than 0.75, indicating the model is fit at least 75% accurate.

Table 4. gives more statistical detail on the **linear** regressions for the maximum temperature of ARD 8 LST and retrieved LST datasets.

Table 4. Elbert County Maximum Linear Descriptive Statistics

	P-value *Slope*	P-value *Y-intercept*	Lower 95% *Slope*	Upper 95% *Slope*	Lower 95% *Y-intercept*	Upper 95% *Y-intercept*
ARD 8 LST	0.1465	5.81 E-128	-0.0014	0.009	299.25	311.13
Retrieved LST	0.1424	4.80 E-129	-0.0013	0.0089	298.91	310.55

The *p-values(slope)* yielded by both (maximum) ARD8 LST and Retrieved LST data plots are greater than 0.1 ($P > 0.1$), which demonstrates consistency with the null hypothesis (no change). Both ARD 8 and Retrieved LST *p-values(y-intercept)* show values that are less than 0.001 ($P < 0.001$), proving strong evidence against the null hypothesis, in favor of a non-zero maximum LST. Because the slope terms were not significantly different from zero for both (maximum) ARD8 and retrieved LST, a suggestion that the maximum LST values for Elbert county lie from 299.25 °K to 311.13 °K for ARD8 and from 298.91 °K to 310.55 °K for Retrieved LST.

Median LST

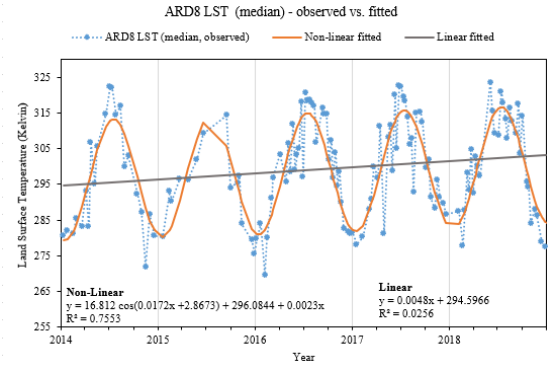

Figure 5. displays the median Land Surface Temperature of the Analysis Ready Data (Landsat 8) for Elbert county 2014-2018.

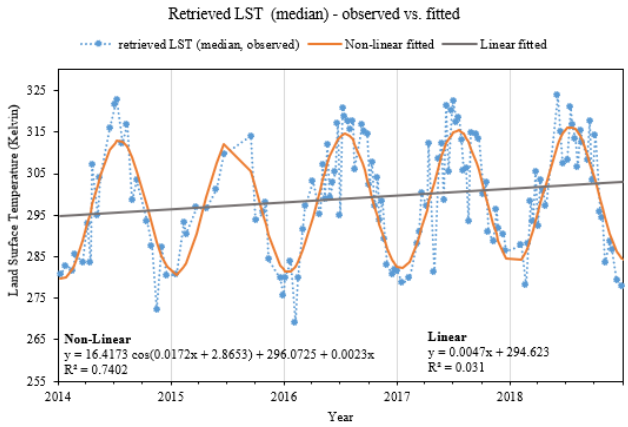

Figure 6. displays the median Land Surface Temperature of Elbert county's Retrieved LST series from 2014- 2018.

Table 5. table shows linear and non-linear R^2 values (median) from *Figures 5 & 6.*

Table 5. Elbert County Median Regression Slopes and R^2 Values

	ARD 8 LST	Retrieved LST
Linear R^2	0.0256	0.031
Non-linear R^2	0.7553	0.7402
Linear Slope	0.0048	0.0047
Non-linear Slope	0.0023	0.0023

Again, *Figure 5 & 6* displaying the 'median' metric for ARD LST and Retrieved LST yielded R^2 values that indicate a low linear correlation due to the annual wave-like pattern (non-linear). ARD8 LST showed an annual temperature change value of 0.8293 °K/year (increase in LST) and similarly, the Retrieved LST trend showed an annual change of 0.8217 °K/year. Non-linear R^2 values for both ARD8 and Retrieved LST were at about ~0.75, indicating the model is fit relatively well. One thing to note is that R^2 values for non-linear regressions more accurately depict the 'fit' because the data points are not linearly changing with days.

Table 6 gives more statistical detail on the **linear** regressions for the median temperature of ARD 8 LST and retrieved LST datasets.

Table 6. Elbert County Median Linear Descriptive Statistics

	P-value *Slope*	P-value *Y-intercept*	Lower 95% *Slope*	Upper 95% *Slope*	Lower 95% *Y-intercept*	Upper 95% *Y-intercept*
ARD 8 LST	0.0647	3.65 E-132	-0.0003	0.0089	289.874	300.40
Retrieved LST	0.041	1.25 E-134	0.0002	0.0091	289.52	299.72

The *p-values(slope)* results for both(median) ARD8 LST and Retrieved LST data plots are less than 0.1 (P > 0.1), demonstrating moderate evidence against the null hypothesis (no change). Both ARD8 and Retrieved LST *p-values(y-intercept)* show values that are less than 0.001 (P < 0.001), proving strong evidence against the null hypothesis, in favor of a non-zero median LST. As a result of the slope terms not showing significant difference from zero for both (median) ARD8 and retrieved LST, one can infer that the median LST values for Elbert county range from 289.874 °K to 300.40 °K for ARD8 and from 289.52 °K to 299.72 °K for Retrieved LST.

Mean LST

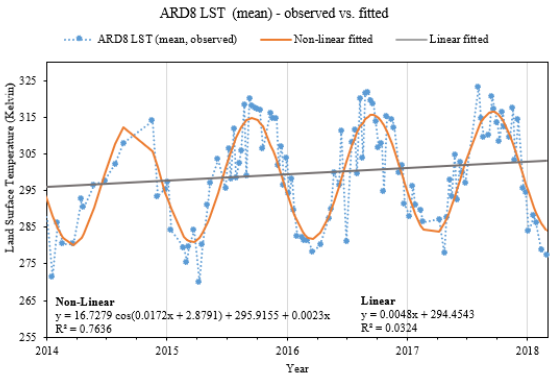

Figure 7. displays the mean Land Surface Temperature of the Analysis Ready Data (Landsat 8) for Elbert county 2014-2018.

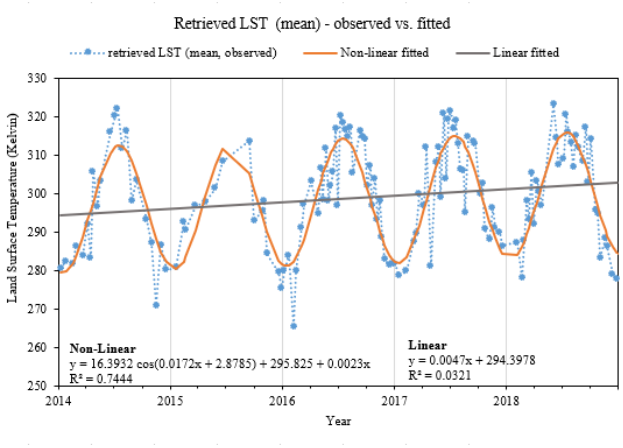

Figure 8. displays the mean Land Surface Temperature of Elbert county's Retrieved LST series from 2014- 2018.

Table 7. shows linear and non-linear R^2 values (mean) from *Figure 7 & 8* (ARD 8 & retrieved LST).

Table 7. Elbert County Mean Regression Slopes and R^2 Values

	ARD 8 LST	Retrieved LST
Linear R^2	0.0324	0.0321
Non-linear R^2	0.7636	0.7444
Linear Slope	0.0048	0.0047
Non-linear Slope	0.0023	0.0023

Just as previous metrics, the 'mean' in *Figures 7 & 8* for ARD LST and Retrieved LST yielded R^2 values that indicate a low linear correlation due to the annual wave-like pattern (non-linear). ARD8 LST showed an annual temperature change value of 0.8473 °K/year (slight increase in LST) while the Retrieved LST trend showed an annual change of 0.8483 °K/year. Non-linear R^2 values for both ARD8 and Retrieved LST were near ~0.75, indicating the model is fit to about 75% accuracy. As previously mentioned, there is a common R^2 value pattern for non-

linear regressions more accurately depict the ‘fit’ because the data points are not linearly changing with days.

Table 8. gives more statistical information on the **linear** regressions for the mean temperature of ARD 8 LST and retrieved LST plots.

Table 8. Elbert County Mean Linear Descriptive Statistics

	P-value *Slope*	P-value *Y-intercept*	Lower 95% *Slope*	Upper 95% *Slope*	Lower 95% *Y-intercept*	Upper 95% *Y-intercept*
ARD 8 LST	0.0368	1.9 E-134	0.0003	0.0093	289.34	299.57
Retrieved LST	0.0376	7.93 E-135	0.0003	0.0092	289.32	299.48

The *p-values(slope)* yielded by both (mean) ARD8 LST and Retrieved LST data plots are less than 0.05 ($P < 0.05$), which demonstrates moderate evidence against the null hypothesis (no change). Both ARD8 and Retrieved LST *p-values(y-intercept)* show values that are less than 0.001 ($P < 0.001$), again proving strong evidence against the null hypothesis, in favor of a non-zero mean LST. Once again since the slope terms do not show significant difference from zero for both (mean) ARD8 and retrieved LST, one can infer that the mean LST values for Elbert county range from 289.34 to 299.57 °K for ARD8 and from 289.32 to 299.48 °K for Retrieved LST.

Standard Deviation

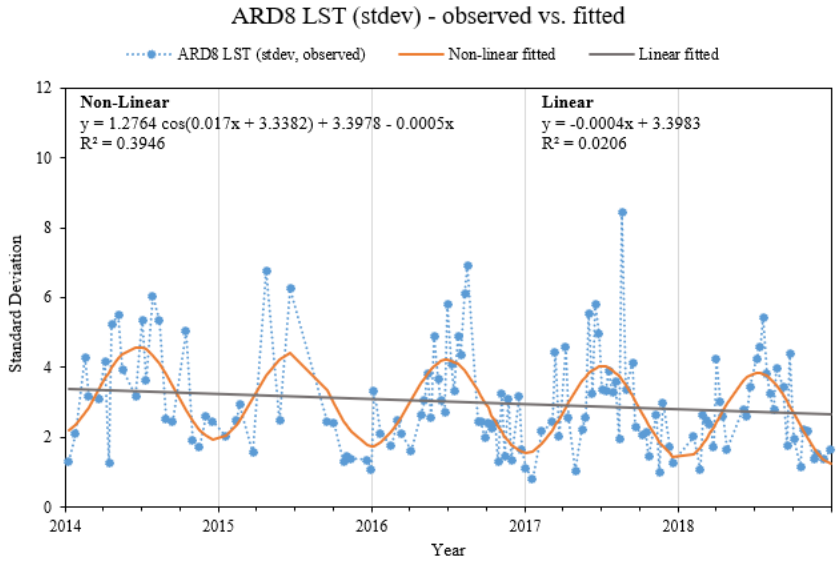

Figure 9. displays the standard deviation of Land Surface Temperature for the Analysis Ready Data (Landsat 8) in Elbert county 2014-2018.

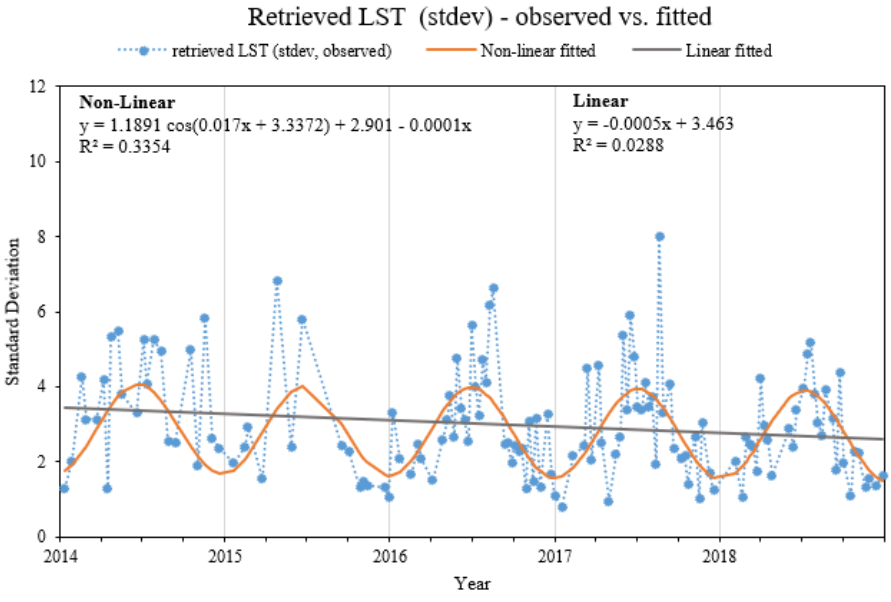

Figure 10. displays the standard deviation of Land Surface Temperature for Elbert county's Retrieved LST series from 2014- 2018.

Table 9. shows linear and non-linear R^2 values (standard deviation) of regressions in *Figures 9 & 10* (ARD 8 & retrieved LST).

Table 9. Elbert County Standard Deviation Regression Slopes and R^2 Values

	ARD 8 LST	Retrieved LST
Linear R^2	0.0206	0.0288
Non-linear R^2	0.3946	0.3354
Linear Slope	-0.0004	-0.0005
Non-linear Slope	- 0.0005	- 0.0001

The standard deviation for ARD LST and Retrieved LST also yielded R^2 values that indicate a low linear correlation due to the annual wave-like pattern. ARD8 LST showed an annual temperature change value of -0.1835 °K/year which is a minor decrease in total variation from the mean LST. The Retrieved LST trend showed an annual change of -0.0439 °K/year (minor decrease). Non-linear R^2 values for both ARD8 and Retrieved LST were below 0.5, indicating the model is fit is weak-moderate for the standard deviation metric.

Table 10. gives more statistical background on the **linear** regressions for the standard deviation of temperature for ARD 8 LST and retrieved LST datasets.

Table 10. Elbert County Standard Deviation Linear Descriptive Statistics

	P-value *Slope*	P-value *Y-intercept*	Lower 95% *Slope*	Upper 95% *Slope*	Lower 95% *Y-intercept*	Upper 95% *Y-intercept*
ARD 8 LST	0.0985	3.18 E-23	-0.0009	7.68 E-05	2.84	3.95
Retrieved LST	0.05	1.68 E-24	-0.001	1.88 E-08	2.92	4.01

The *p-values(slope)* yielded by both (standard deviation) ARD8 LST and Retrieved LST lie between 0.05 and 0.1 which demonstrates moderate evidence against the null hypothesis (no change in total variation from mean LST). Both ARD8 and Retrieved LST *p-values(y-intercept)* show values that are less than 0.001 ($P < 0.001$), again proving strong evidence against the null hypothesis, in favor of a non-zero standard deviation LST. Once again since the slope terms do not show significant difference from zero for both ARD8 and retrieved LST, is safe to say that the variation from the mean for LST values for Elbert county is between 2.84 and 3.95 °K for ARD8 or from 2.92 to 4.01 °K for Retrieved LST.

Conclusion for Elbert County

After running these analyses on land surface temperature data for both ARD 8 and Retrieved images, there are a few conclusions that can be drawn as this research moves forward. The average R^2 value yielded for all non-linear regression metrics is 0.6602 for ARD 8 LST, and 0.6133 for Retrieved LST. Though these values are greater than 0.50 which is acceptable, there are some things to consider when fitting their respective non-linear trends in the future to give the model more significance. For example, it is noticeable that the "fit" is much more accurate at winter and summer peaks on the curve, while the transitional periods appear to show larger model uncertainty.

The outliers were more apparent in some metrics of this county, also skewing the way our non-linear model fit the general trend represented. This could be due to possible inaccuracy in the way snow cover and emissivity were interpreted on certain days of image retrieval.

Linear trends were in close enough proximity for both non-linear and linear regressions to be able to say they show a similar pattern. Whether that pattern demonstrates enough significance is a different story. The average non-linear slope for all metrics is 0.0021 for ARD8 LST and 0.0068 for Retrieved LST. This shows a minor positive trend (increase in land surface temperature over the five-year range). The average linear slope for all metrics is 0.0088 for

ARD8 LST and 0.103 for Retrieved LST, also showing a positive trend (increase in land surface temperature over the five-year range).

Generally speaking, there is a minor trend (slightly more than Denver county) that is in favor of increasing land surface temperature over time, but more statistically significant results are still desired. Applying certain changes to the model as previously mentioned, as well as exceeding the annual date-range to be at least two or three times greater could create a foreseeable trend that will carry much more value in this research.

References

Jiménez-Muñoz, J. C., Cristóbal, J., Sobrino, J. A., Sòria, G., Ninyerola, M., & Pons, X. (2008). Revision of the single-channel algorithm for land surface temperature retrieval from Landsat thermal-infrared data. *IEEE Transactions on geoscience and remote sensing*, *47*(1), 339-349.

Jiménez-Muñoz, J. C., Sobrino, J. A., Skoković, D., Mattar, C., & Cristóbal, J. (2014). Land surface temperature retrieval methods from Landsat-8 thermal infrared sensor data. *IEEE Geoscience and remote sensing letters*, *11*(10), 1840-1843.