Land Surface Temperature retrieval and long-term pattern analysis for Phillips 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.

Phillips county lies on 80.7% cropland land-use type, with the remaining area consisting of urbanized agricultural land cover. The county itself is relatively isolated in a rural setting, with a 2010 census population of 4,442. Phillips county is driven primarily by the agricultural industry, as they have the space and climate that transitions into that of the Midwest/Great Plain region, making it suitable for crop production. 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 at higher elevations (other 5 counties observed), despite a majority of land cover being cropland vegetation. The minimum ARD8 and Retrieved LST average of Phillips county is 284.77 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 282.36 °K for Elbert county (similar landcover type, just higher elevation and more urban developement)). For the maximum metric, LST averages are 306.38 °K for ARD8 and 306.01 °K for Retrieved data, again higher than maximum temperature values of 4 of the 6 counties. Phillips county's mean metric yielded averages at 297.83 °K for ARD8 LST and 297.54 °K for Retrieved LST. Remaining metrics are consistent with this trend, yielding average median values of 298.2 °K for ARD8 and 297.93 °K for Retrieved LST. Plotted standard deviation values were 2.92 °K for ARD8 and 2.97 °K Retrieved LST, indicating that land surface temperature values are dispersed within a moderately close 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.

Phillips County

Minimum LST

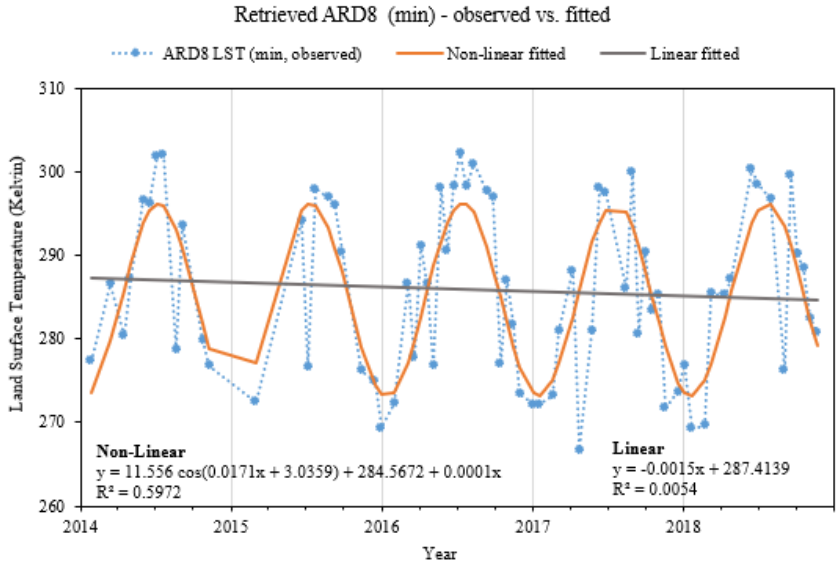

Figure 1. displays the minimum Land Surface Temperature of the Analysis Ready Data (Landsat 8) for Phillips county 2014-2018.

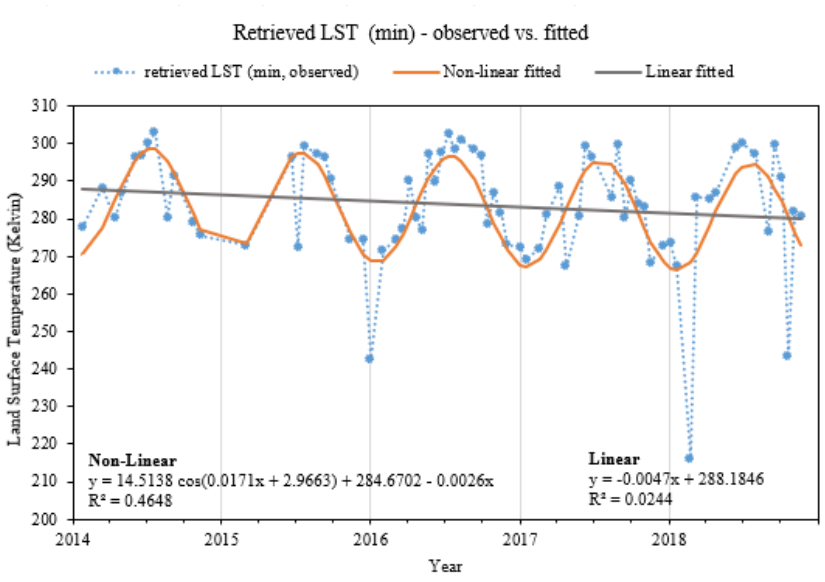

Figure 2. displays the minimum Land Surface Temperature of Phillips county's Retrieved LST series from 2014- 2018.

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

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

	ARD 8 LST	Retrieved LST
Linear R^2	0.0054	0.0244
Non-linear R^2	0.5972	0.4648
Linear Slope	-0.0015	-0.0047
Non-linear Slope	0.0001	-0.0026

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 0.0438 °K/year (miniscule increase in LST) while the Retrieved LST trend showed an annual change of -0.9617° K/year (slight decrease in LST). Non-linear R^2 values for both ARD8 and Retrieved LST averaged out to about ~0.531, indicating the model is weak-moderate and could use some adjustment for a better fit (outliers are prominent in the "minimum" metric for this county). 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. Phillips 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	0.5384	2.85 E-79	-0.0064	0.0034	282.05	292.78
Retrieved LST	0.1905	2.69 E-68	-0.0117	0.0024	280.44	295.93

As shown in *Table 2*, the *p-value(slope)* for the (minimum) ARD8 and retrieved LST data is between 0.1 and 0.6, which tells us the linear model suggests strong evidence in favor of the null hypothesis (no change in LST over the five-year period). 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 Phillips county are from 282.05 °K to 292.78 °K for ARD8 and from 280.44 °K to 295.93 °K for Retrieved LST.

Maximum LST

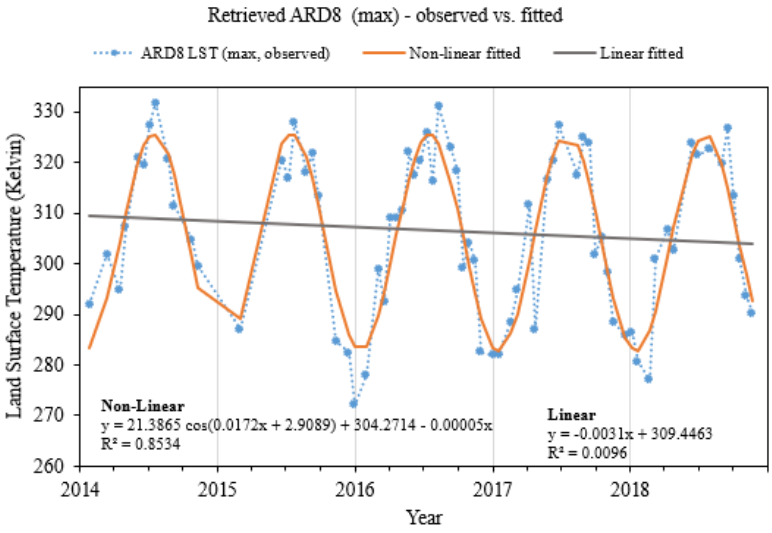

Figure 3. displays the maximum Land Surface Temperature of the Analysis Ready Data (Landsat 8) for Phillips county 2014-2018.

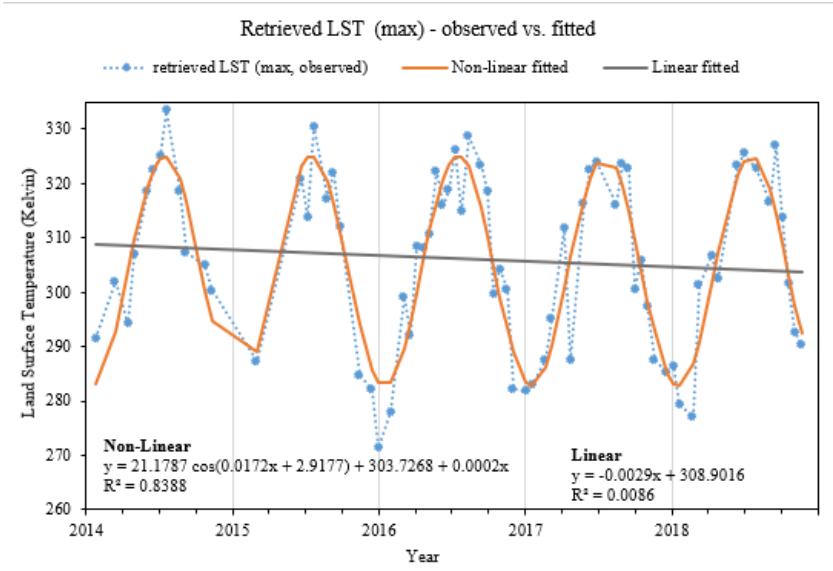

Figure 4. displays the maximum Land Surface Temperature of Phillips county's Retrieved LST series from 2014- 2018.

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

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

	ARD 8 LST	Retrieved LST
Linear R^2	0.0096	0.0086
Non-linear R^2	0.8534	0.8388
Linear Slope	-0.0031	-0.0029
Non-linear Slope	- 0.00005	0.0002

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 -0.019 °K/year (minimal decrease in LST) and the Retrieved LST trend showed an annual change of 0.0612 °K/year (minimal increase in LST). Non-linear R^2 values for both ARD8 and Retrieved LST were greater than 0.80, indicating the model is fit at least 80% 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. Phillips 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	0.4122	2.61 E-68	-0.0106	0.0044	301.14	317.76
Retrieved LST	0.4393	2.68 E-68	-0.0105	0.0046	300.6	317.2

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 301.14 °K to 317.76 °K for ARD8 and from 300.6 °K to 317.2 °K for Retrieved LST.

Median LST

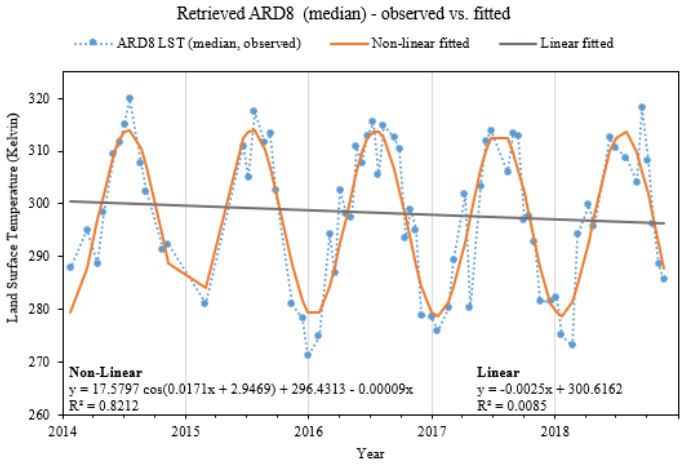

Figure 5. displays the median Land Surface Temperature of the Analysis Ready Data (Landsat 8) for Phillips county 2014-2018.

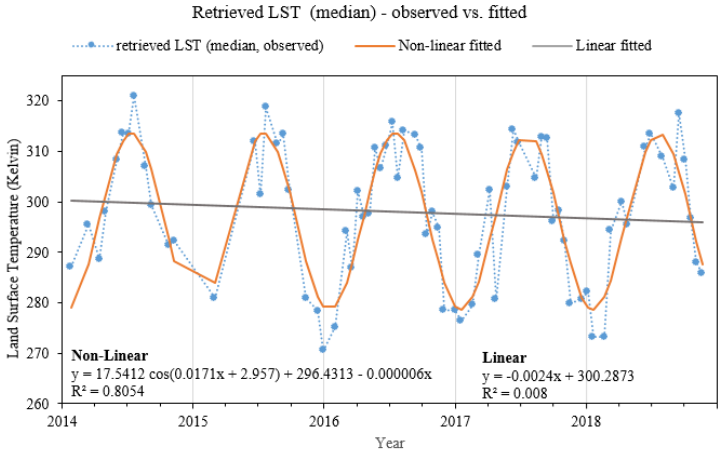

Figure 6. displays the median Land Surface Temperature of Phillips county's Retrieved LST series from 2014- 2018.

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

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

	ARD 8 LST	Retrieved LST
Linear R^2	0.0085	0.008
Non-linear R	0.8212	0.8054
Linear Slope	-0.0025	-0.0024
Non-linear Slope	-0.00009	-0.000006

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 -0.0357 °K/year (minimal decrease in LST) and an even slighter decrease in LST with the Retrieved LST trend showing an annual change of -0.0023 °K/year. Non-linear R^2 values for both ARD8 and Retrieved LST were at about ~0.80, 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. Phillips 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	0.4416	9.36 E-73	-0.0088	0.0039	293.65	307.58
Retrieved LST	0.4557	1.68 E-72	-0.0088	0.004	293.27	307.3

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 Phillips county range from 293.65 °K to 307.58 °K for ARD8 and from 293.27 °K to 307.3 °K for Retrieved LST.

Mean LST

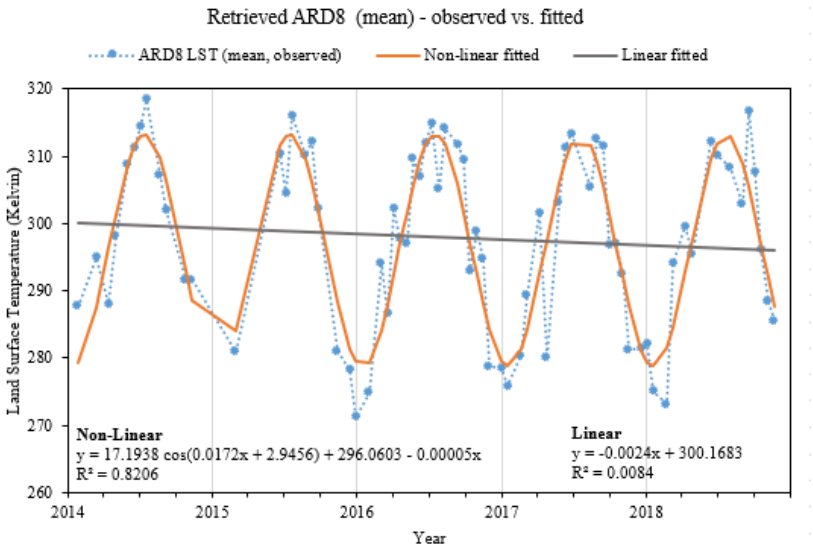

Figure 7. displays the mean Land Surface Temperature of the Analysis Ready Data (Landsat 8) for Phillips county 2014-2018.

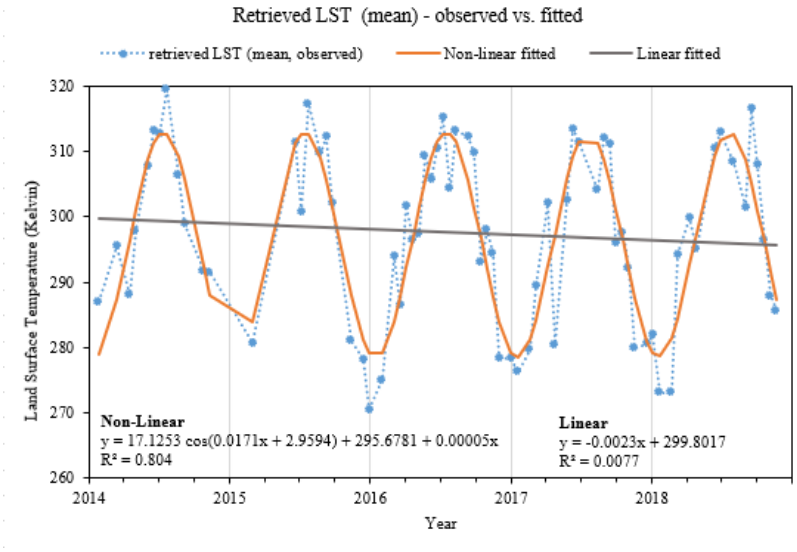

Figure 8. displays the mean Land Surface Temperature of Phillips county's Retrieved LST series from 2014- 2018.

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

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

	ARD 8 LST	Retrieved LST
Linear R^2	0.0084	0.0077
Non-linear R^2	0.8206	0.804
Linear Slope	-0.0024	-0.0023
Non-linear Slope	-0.00005	0.00005

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 -0.019 °K/year (slight decrease in LST) while the Retrieved LST trend showed an annual change of 0.0186 °K/year. Non-linear R^2 values for both ARD8 and Retrieved LST were near ~0.80, indicating the model is fit to about 80% 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. Phillips 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	0.445	2.27 E-73	-0.0086	0.0038	293.35	306.98
Retrieved LST	0.4628	3.74 E-73	-0.0085	0.0039	292.95	306.66

The *p-values(slope)* yielded by both (mean) ARD8 LST and Retrieved LST data plots are greater than 0.1 ($P < 0.1$), which demonstrates strong consistency with 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 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 293.35 to 306.98 °K for ARD8 and from 292.95 to 306.66 °K for Retrieved LST.

Standard Deviation

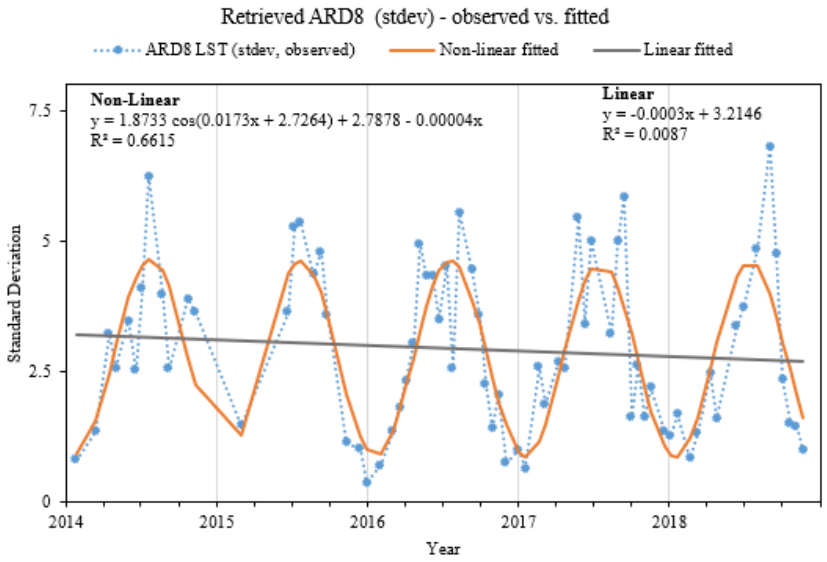

Figure 9. displays the standard deviation of Land Surface Temperature for the Analysis Ready Data (Landsat 8) in Phillips county 2014-2018.

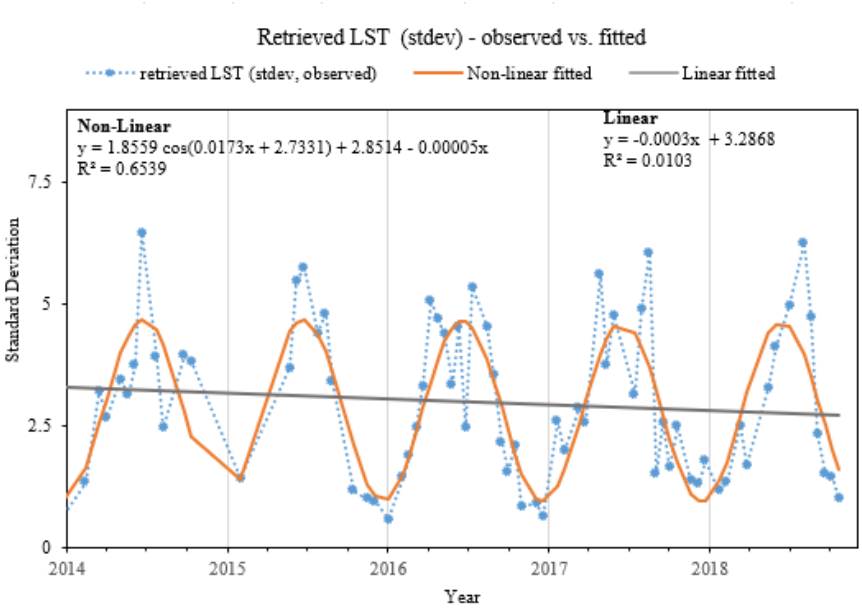

Figure 10. displays the standard deviation of Land Surface Temperature for Phillips county's Retrieved LST series from 2014- 2018.

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

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

	ARD 8 LST	Retrieved LST
Linear R^2	0.0087	0.0103
Non-linear R^2	0.6615	0.6539
Linear Slope	-0.0003	-0.0003
Non-linear Slope	-0.00004	-0.00005

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 -0.0138 °K/year which is a very slight decrease in total variation from the mean LST. The Retrieved LST trend showed an annual change of -0.0173 °K/year (again, a minor decrease in total variation). Non-linear R^2 values for both ARD8 and Retrieved LST averaged out to about 0.6577, indicating the model is fit moderately well for the standard deviation metric, considering outlying factors that usually come into play in the standard deviation of these datasets.

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. Phillips 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	0.4372	5.98 E-11	-0.0011	0.0005	2.38	4.05
Retrieved LST	0.3966	2.59 E-11	-0.0011	0.0004	2.46	4.12

The *p-values(slope)* yielded by both (standard deviation) ARD8 LST and Retrieved LST are greater than 0.1 ($P > 0.1$) which demonstrates strong evidence in favor of the null hypothesis (no change in total variation from mean LST). On the other hand, both ARD8 and Retrieved LST *p-values(y-intercept)* show values that are less than 0.001 ($P < 0.001$), showing 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 Phillips county is between 2.38 and 4.05 °K for ARD8 or from 2.46 to 4.12 °K for Retrieved LST.

Conclusion for Phillips 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 0.7508 for ARD 8 LST, and 0.7134 for Retrieved LST. These values are respectable with the average between the models representing about ~70% accuracy, but there are some things to consider when fitting their respective non-linear trends in the future to give the model more significance. One thing worth noting, is 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, which for this county was demonstrated a very slight decrease in land surface temperature. The average non-linear slope for all metrics is 0.000154 for ARD8 LST and -0.000481 for Retrieved LST. The average linear slope for all metrics is -0.0098 for ARD8 LST and -0.0025 for Retrieved LST, showing a negative trend (very slight decrease in land surface temperature over the five-year range).

Overall, Phillips county demonstrates a minimally decreasing trend land surface temperature over time, which supports the hypothesis in terms of change in LST over the five-

year period, but more statistically significant results are still desired to strengthen the study. 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.