Louisville Metro's Climate History and Projected Changes Complete Report

Trends in the average annual temperatures and precipitation from 1948 to 2007 were projected to the years 2015 and 2020 to test for changes in magnitude and direction (increasing, no change, decreasing). While it is recognized that the 60 year interval represents a limited time series upon which to base predictions, it is reasonable to consider that the years 2015 and 2020 represent an extension of only eight (8) and 13 years of these data (a 12% projection over the 68 year data set and 18% projection of the 72 year data set).

Procedure:

Least squares regression is perhaps the most conventional and widely applied statistical practice to investigate relationships between two or more variables (in this case, temperature and time; precipitation and time). This procedure describes the nature of this relationship in terms of three possible outcomes: 1) an increasing relationship over time (positive), 2) a decreasing relationship over time (negative) or, 3) one that demonstrates little or no relationship between the two variables. As an expression of the strength of this relationship, the correlation coefficient (r^2) is often computed for each regression output.

Simply stated, regression is a mathematical procedure that enables the determination of a "line of best fit" between the two data sets. In the event that the two data sets were perfectly correlated (that is, a change in one quantity is *exactly* proportional to another over the entire range of the data), any graphical presentation would show the data as a straight line (ascending, descending, or a horizontal line) at which time the correlation would be perfect (a maximum value of one (1) if the data indicated an increasing or positive trend; a maximum of minus one (-1) for a negative or decreasing trend; zero (0) if there was no change in one of the quantities with respect to the other (i.e. if precipitation for each year indicated no, or very little, change over time). Given that climate variables in particular are characterized by a well-recognized year-to-year variability, the data will be scattered around this computed line of best fit. The task of this procedure is, therefore, to define the equation of the line that passes through the entire data range such that the departures or variations from the computed line are minimized (hence the designation "line-of-best-fit").

Depending upon the nature of the data (or the required outcome of the user), regression lines can be specified as linear or non-linear. Non-linear relationships effectively address data sets that are characterized by systematic departures from a long-term mean in which case the resultant predicted line conforms to the curvature in the observed trends. The linear relationship simply assumes that a straight line can be passed through (fitted) to the data set and that the data set is best defined by this relationship. This is also known as a first order relationship.

The linear or first order form of the regression is typically represented as:

$$\tilde{Y} = \beta_0 + \beta_1 X \pm e \qquad \text{(Eqn. 1)}$$

Where $\tilde{Y}$ is the predicted value of the quantity, B_0 is the intercept of the line (when $X=0$), B_1 the slope of the line and e the residual error. For the Louisville data only first order regression has been applied. Correlation coefficients were also determined and are presented with regression results.

Rationale.

The time series for temperature from 1948-2007 are characterized by a bimodal distribution with a warm period (above the 60 year average) in the 1950's and consistently increasing from approximately the mid-1970's to present (2007). From 1960 to approximately 1970 the lowest temperatures for the data set were recorded. This is a consistent feature of the annual temperature time series used in this (annual) analysis.

From this bi-modal distribution it is reasonable to consider that the time series can be represented by two applications of first order regression. First, the overall 60 year data set (1948-2007) and second, the interval from 1970 to 2007 (a 38 year data set). This division is based simply upon establishing 1970 as a generally representative time at which the slopes of regression lines transition from a period of general cooling from 1950 to 1970 (negative slope) after which a consistent trend toward increasing temperatures is observable (positive slope). A general format for this division is presented in Figure 1.

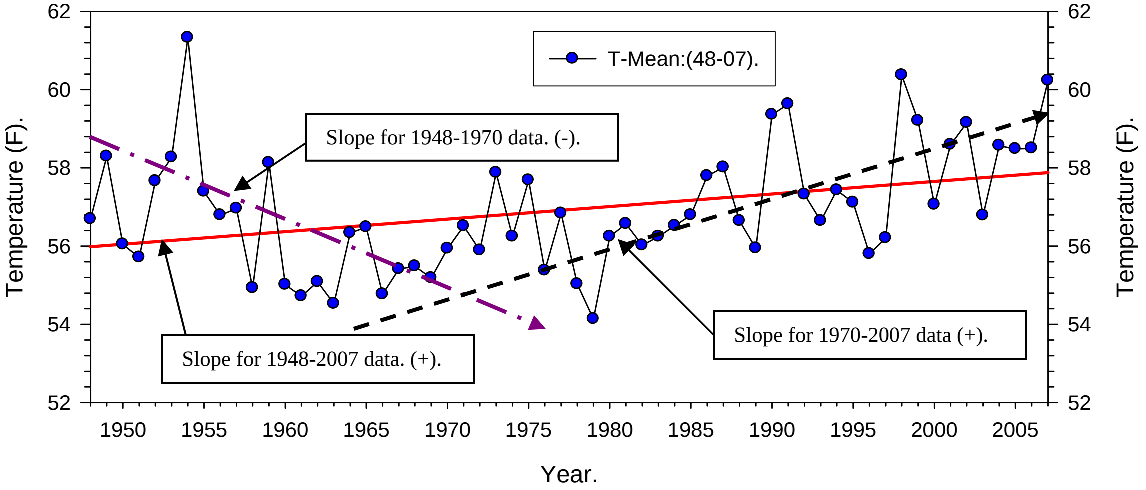

Figure 1. Generalized positioning of first order regression lines for the mean annual temperatures.

With respect to the trend lines presented in Figure 1 it is reasonable to consider the regression lines for the two time series as representing the extremes in predicted quantities. For the longer 1948-2007 interval, the slope of the line is moderated by the systematic decline (below the 60 year mean) from approximately 1950 to 1980. Therefore, the slope of the regression line (and the correlation coefficients) can be considered the most conservative of the predicted results. That is, for the longer time interval (60 years) the least amount of change in temperature and precipitation can be expected when predicted from this standard form of linear regression.

However, applying the regression to the 1970 to 2007 data set, the slope of the line is controlled by the persistent increase in temperature from 1970 onward. Thus, output of the model using these data can be expected to reflect the upper levels of predicted temperature change over time.

Table 1 presents the results of the first order regression for the two time intervals (1948-2007 and 1970-2007). For all air temperatures and time intervals results indicate a positive slope (an overall increase in temperature). The maximum temperature indicates the least increase over time (B_1 = 0.0078) which effectively represents a straight line and, with a poor correlation coefficient, it is reasonable to state that there has been no statistically significant increase in the maximum air temperature for Louisville over the period from 1948 to 2007. The greatest increase in temperature is to be found in the minimum temperature which has the steepest slope (greatest increase in temperature over time). For the period from 1970-2007, all temperatures indicate a positive change with all slopes greater (and correspondingly higher correlation coefficients) than those for the 1948-2007 period. Thus, over this later time interval (38 years) the air temperature has increased at a greater rate than over the longer (1948-2007) time period. This pattern of accelerated increases in air temperature is consistent with both national and regional assessments in air temperature change over the later part of the 20th Century (refer to IPCC report).

Linear Regression for 1948-2007 and 1970-2007

	Years	β_0	β_1	r^2
T.Mean	1948-2007	-6.6080	0.0321	0.1293
	1970-2007	-98.339	0.0782	0.3569
T.Max	1948-2007	51.261	0.0078	0.0067
	1970-2007	-66.204	0.0667	0.2547
T.Min	1948-2007	-65.032	0.0567	0.3260
	1970-2007	-130.577	0.0896	0.3902
T.Precip	1948-2007	-28.933	0.0369	0.0070
	1970-2007	98.619	-0.0270	0.0014
T.Snowfall	1948-2007	387.959	-0.1889	0.1099
	1970-2007	734.630	-0.3632	0.1984

Table 1. Results of first order (linear) regression for temperature and precipitation for Louisville from 1948-2007 and 1970 to 2007.

Precipitation is divisible into two categories: 1) total precipitation (water equivalent) and, 2) snowfall (inches). For the total precipitation the snowfall is added at the standard ratio of 10:1 (10 inches if snowfall contributing one (1) inch of liquid). The time series for precipitation indicates two distinct paths depending upon type. For the total precipitation (T.Precip), although characterized by a substantial annual range over the 60 years of measurement, there is little to suggest any systematic change over time. Snowfall, however, indicates a persistent decline since the 1960’s (Figure 2).

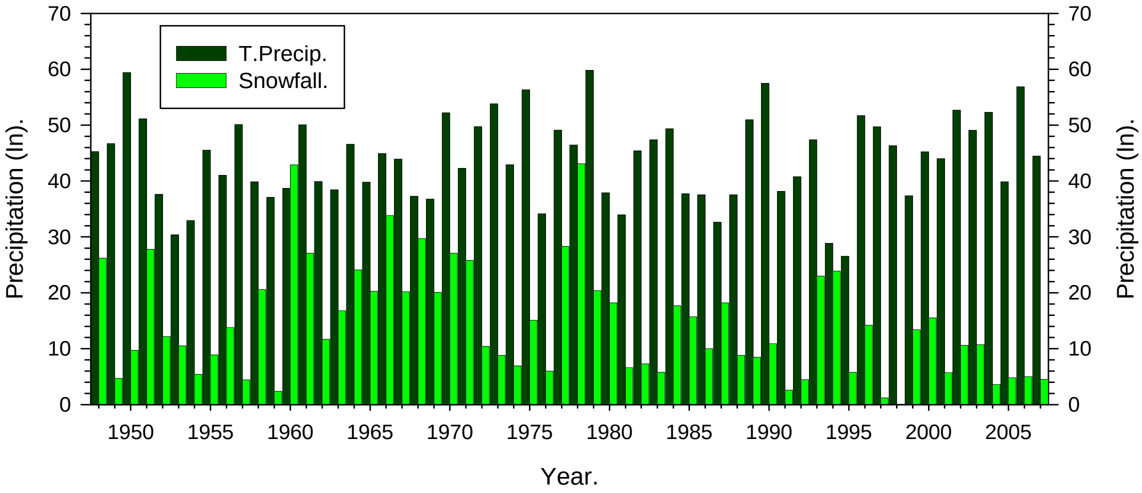

Figure 2. Time series for total precipitation (water equivalent) in inches and snowfall (inches) for Louisville from 1948 to 2007.

Table 1 presents the results for first order regression and the associated correlation coefficients for both total precipitation and snowfall. Over the interval 1948-2007 total precipitation indicates only a slight increase as estimated from the line-of-best-fit. This weak association is supported by a very poor correlation coefficient. For the interval from 1970 to 2007 the regression indicates a minor decline in total precipitation although, as with the longer time series, the relationships are very weak suggesting that over both time intervals it is reasonable to state that total annual precipitation has not changed in either magnitude or direction. For both time series snowfall indicates a persistent and significant decline to 2007. This is most notable over the shorter time interval (1970-2007) where the slope of the regression line is strongly negative. This result however does invite some speculation as to how the total precipitation exhibits little to no change over these time intervals with a constant decline in the contribution from snowfall (it is considered that these relationship will be made more evident with analyses of the precipitation totals at the monthly scale).

Extension of Results to the Years 2015 and 2020.

Using the results of the linear regression for each quantity (Eqn.1 and Table 1), iteration was carried out for each year extending to 2020 for both time series. Results were then isolated for the years 2015 and 2020. Figure 3 presents the general format of this projection with respect to the two time series for measured data (in this example, mean air temperature).

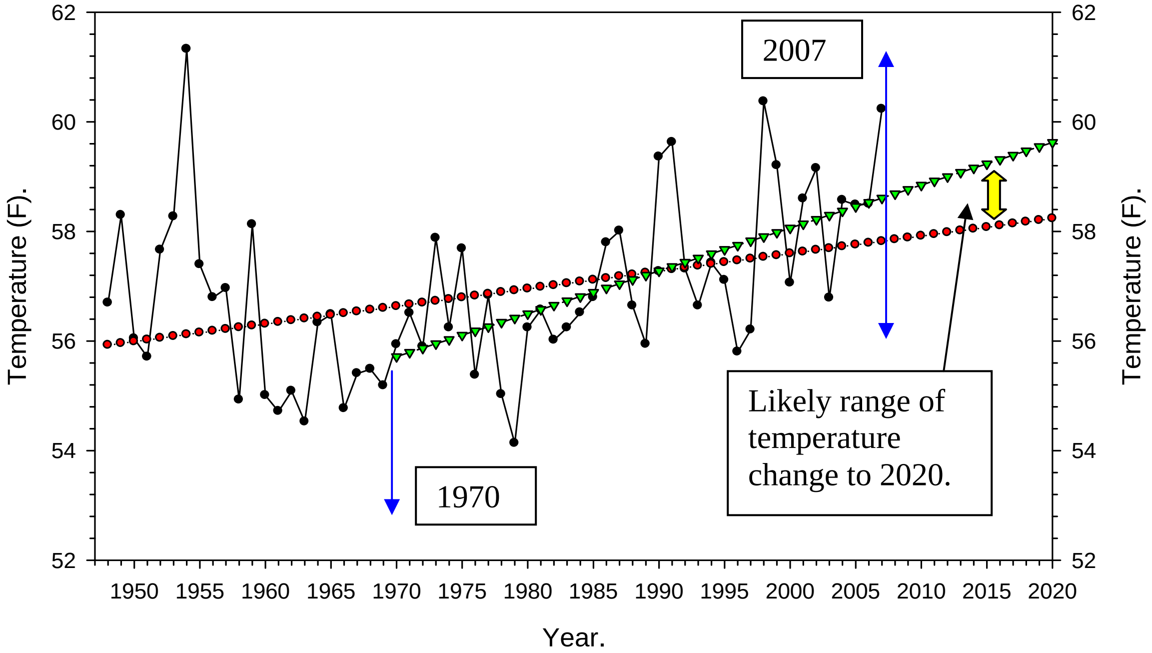

Figure 3. Extension of estimated temperature change from 2007 to 2020 using standard linear (first order) regression for a 1948-2007 and 1970 to 2007 time series.

The interval from 2007 to 2020 and the differences in the predicted temperatures for the two regression outputs effectively define the range of temperature increase to be expected (or likely). As the time interval for prediction is extended the range of the predicted temperatures increases increasing uncertainly in the true or likely temperature at the specified time.

Accepting the output for the regression as applied to each of the data sets, the predicted temperatures for 1948, 2007, 2015 and 2020 are presented in Table 2. Notable is the slight to effectively no change in the maximum temperature, minor increase in total precipitation and a significant reduction in snowfall.

Projected Results from 1948-2020				
	1948	2007	2015	2020
T.Mean	55.9	57.8	58.1	58.2
T.Max	66.5	67.0	67.0	67.1
T.Min	45.4	48.8	49.2	49.5
T.Precip	42.9	45.1	45.4	45.6
T.Snowfall	20.0	8.8	7.3	6.4

Table 2. Estimated temperature and precipitation for Louisville from 1948 to 2020 using first order regression. Temperatures are in Fahrenheit and precipitation in

inches.

Table 3 presents the results of the regression as applied to the 1970 to 2007 data sets. Relative to results as presented in Table 2, all temperatures indicate increase with both forms of precipitation decreasing to 2020. Results indicate a much greater rate of change in all quantities (both positive and negative) over this shorter time interval.

Projected Results from 1970-2020				
	1970	2007	2015	2020
T.Mean	55.7	58.6	59.23	59.6
T.Max	65.2	67.7	68.2	68.5
T.Min	45.9	49.3	50.0	50.4
T.Precip	45.4	44.4	44.2	44.1
T.Snowfall	19.1	5.7	2.8	1.0

Table 3. Estimated temperature and precipitation for Louisville from 1970 to 2020 using first order regression. Temperatures are in Fahrenheit and precipitation in inches.

Table 4 presents the predicted changes in temperature and precipitation for the year 2015 and 2020 with respect to 2007 using the regression outputs for both time series (1948-2007 and 1970-2007). For example, the increase in estimated mean air temperature as predicted from the 60 year data set indicates a 0.4 °F increase to 2015 increasing to 0.7 °F at 2020. For the 1970 - 2007 time series the increase in the minimum temperature is expected to be greater increasing 0.7 °F above 2007 estimates in 2015 to over 1.0 °F in 2020. Therefore, it is reasonable to expect that the predicted minimum temperatures for Louisville will be characterized by in a increase of between 0.4 to 0.7 °F in 2015 and between 0.7 and 1.1 °F in 2020.

Predicted changes for 2015 and 2020				
	2007-2015		2007-2020	
Qty	(1948-2007)	(1970-2007)	(1948-2007)	(1970-2007)
T.Mean	0.3	0.6	0.4	1.0
T.Max	0.0	0.5	0.1	0.8
T.Min	0.4	0.7	0.7	1.1
T.Precip	0.3	-0.2	0.5	-0.3
T.Snowfall	-1.5	-2.9	-2.4	-4.7

Table 4. Range of predicted temperatures and precipitation for Louisville at years 2015 and 2020 based on estimated (modeled) 2007 values. Temperatures are in Fahrenheit and precipitation in inches.

Predictions for total precipitation indicate the possibility of only minor changes from 2007 to 2020. Thus, for all practicable purposes the total annual receipt of precipitation can be expected to remain unchanged from the 1948-2007 levels. However, for snowfall, a consistent and significant reduction in annual total is estimated for both of the time series with a maximum possible reduction of over four and one half inches when project to 2020 (Figure 5). Preliminary investigations of monthly levels of snowfall indicate that this drop in precipitation is occurring at extremes of the winter months.

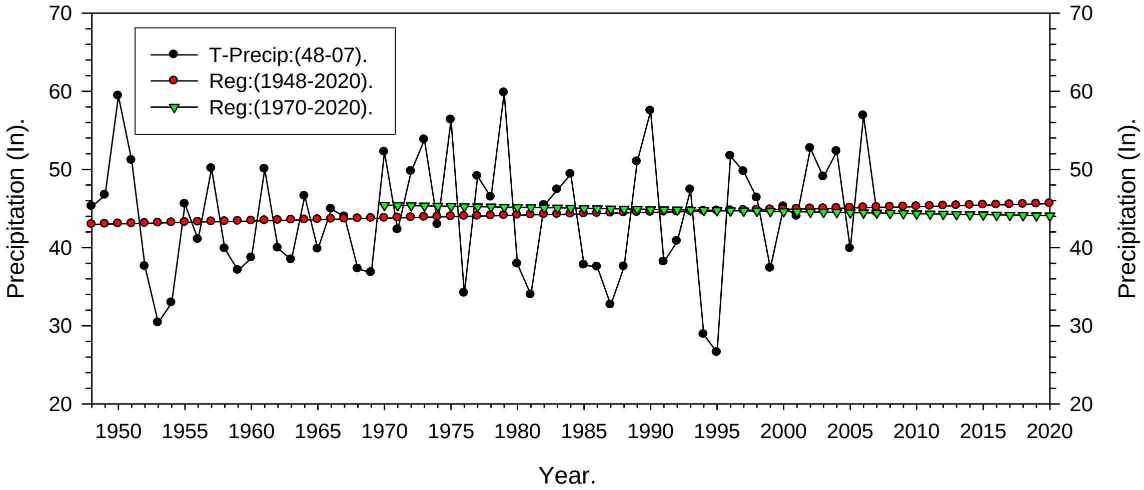

Figure 4. Extension of estimated total precipitation change from 2007 to 2020 using standard linear (first order) regression for the 1948-2007 and 1970 to 2007 time series.

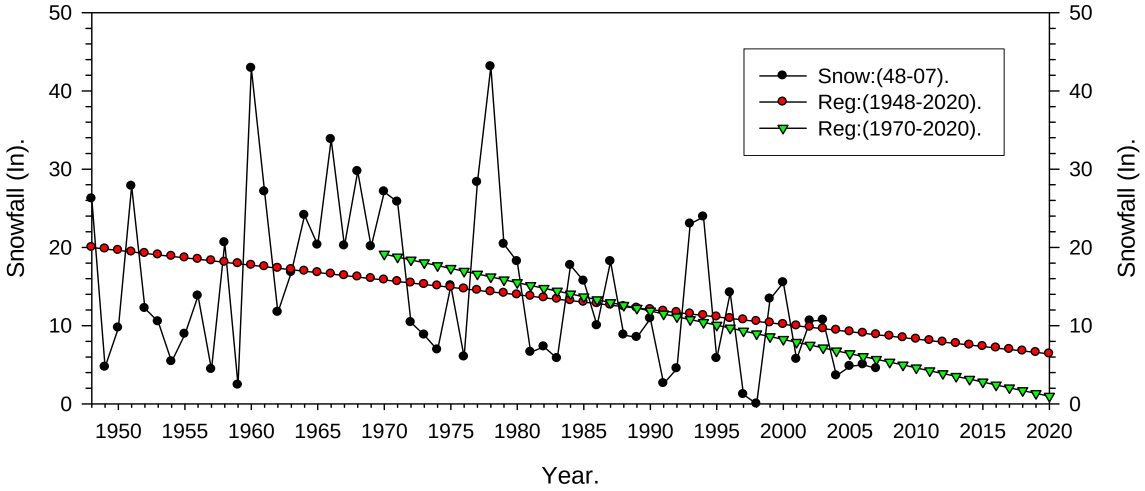

Figure 4. Extension of estimated snowfall change from 2007 to 2020 using standard linear (first order) regression for the 1948-2007 and 1970-2007 time series.