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Spatial and temporal distribution of solar radiation in Louisiana

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SPATIAL AND TEMPORAL DISTRIBUTION OF SOLAR RADIATION IN LOUISIANA

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

The Department of Geography and Anthropology

by
Michael U. Kemp
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ABSTRACT

The purpose of this study is to examine temporal and spatial trends in surface global horizontal solar radiation in Louisiana using a 30-year dataset (1961-1990) of the four stations in Louisiana from the National Solar Radiation Database (NSRD) and a 6-year dataset (2001-2006) of the 25 stations in the Louisiana Agriclimatic Information System (LAIS). Three of the four NSRD stations exhibit a downward linear trend in surface solar radiation over the 30-year period of record, similar to the global trends uncovered in previous studies. Only one station exhibits a slightly upward trend. Surface solar radiation exhibits a positive correlation with maximum temperature but a negative correlation with minimum temperature. A higher solar radiation transmissivity in summer is found in Shreveport than at the three sites in southern Louisiana, despite a more direct sun angle in the south. Southeastern Louisiana (represented by New Orleans) is found to have lower transmissivity values than southwestern Louisiana (represented by Lake Charles), probably because of the stronger influence of large water bodies in the southeast. A summertime slump in transmissivity is found at all NSRD stations for a ‘normal’ averaged year. Data from the NSRD were used to validate data values from each LAIS station. While most LAIS stations have inadequate data, at least in some sections of the six-year time series, some stations appear adequate for future research applications.

CHAPTER 1

INTRODUCTION

1.1 Introduction

The sun is the driving force for all atmospheric processes. Solar radiant intensity is the expression of that input of energy upon the planet. Therefore, the ability to understand and quantify its value and distribution accurately is important in the initial understanding and modeling of any other thermodynamic or dynamic process in the earth-ocean-atmosphere system. Unfortunately, however, too little is known about the spatial and temporal distribution of incoming solar radiation. A more complete and precise description of that distribution will prove useful to many fields of study that rely on atmospheric energy input, such as agricultural planning (Changnon and Changnon, 2005), architectural design (Yang *et al*., 2006), and engineering (Amer and Younes, 2006). For these reasons, analysis of the solar radiation distribution in Louisiana – a state with a relatively high loading of input radiation and relatively high spatial and temporal variability – is both important and relevant.

1.2 Solar Radiation

The solar constant is the generally accepted value for the flux density of shortwave radiant energy (1366 W m^{-2} (Geuymard, 2004)) intercepted on a plane perpendicular to the sun's rays at the "top" of the atmosphere at mean earth-sun distance. This value represents the theoretical maximum solar radiation input. Successively larger decreases from this theoretical maximum occur with latitudes more distant from the subsolar point, times of day more distant from solar noon, and times of year when the earth-sun distance increases. The theoretical maximum amount of radiation at the top of the atmosphere *at a given point* – the extraterrestrial solar radiation – is a known function of latitude, time of day, and time of year (Ye, 1996).

While the intensity of *total* solar radiation received at the top of the atmosphere at the subsolar point is 1366 W m^{-2}, *mean* solar radiant intensity incident upon the top of earth's atmosphere is a smaller value, but is totally predictable. For this averaged total, the spherical shape of the earth requires that the solar constant be calculated across a circle onto which the solar radiation intercepted by the earth is projected at a given time. This cross sectional area is equivalent to the area of a circle $\left(\pi R^2\right)$. However, the earth rotates under this solar radiation and therefore distributes its intensity across the area of a sphere $\left(4\pi R^2\right)$. Therefore, mean extraterrestrial solar radiation is equal to one-fourth of the solar constant, or approximately 341 W m^{-2}.

Once the incoming solar radiation moves through the atmosphere, its intensity is reduced by attenuation (the combined effect of absorption and scattering) by atmospheric gases (particularly ozone and water vapor) and aerosols (clouds and particulate matter). Reflection (*i.e.*, albedo) in the atmosphere and on the surface is also responsible for reduction of the radiant flux density from the solar constant. The uneven distribution of these atmospheric constituents, as well as the myriad of surfaces with different reflective properties and the irregular elevation of the earth's surface (and the resulting unequal atmospheric thickness), ensure that the radiant flux density that ultimately reaches the ground will vary greatly across space. The fact that the earth is moving relative to the sun and the atmosphere is moving relative to the earth ensures that the radiation distribution will vary significantly at a point over time.

1.3 Measurement and Data

Two separate, non-overlapping data sets are used in this study. One data set, which can be retrieved from the National Solar Radiation Database (NSRD, 2007), consists of 30 years of data from four locations in Louisiana (Figure 1.1) from among approximately 233 stations nationwide. This data set spans the period from 1961 to 1990 except for the Lake Charles station, which begins in 1962. It is a federally-managed dataset that has undergone extensive quality control methods to ensure higher quality data.

The other data set is a component of the Louisiana Agriclimatic Information System (LAIS). This data set consists of a network of 25 solar radiation recording stations across Louisiana (Figure 1.2). It spans the time period of 2001-2006 generally, but there are missing and spurious data values throughout.

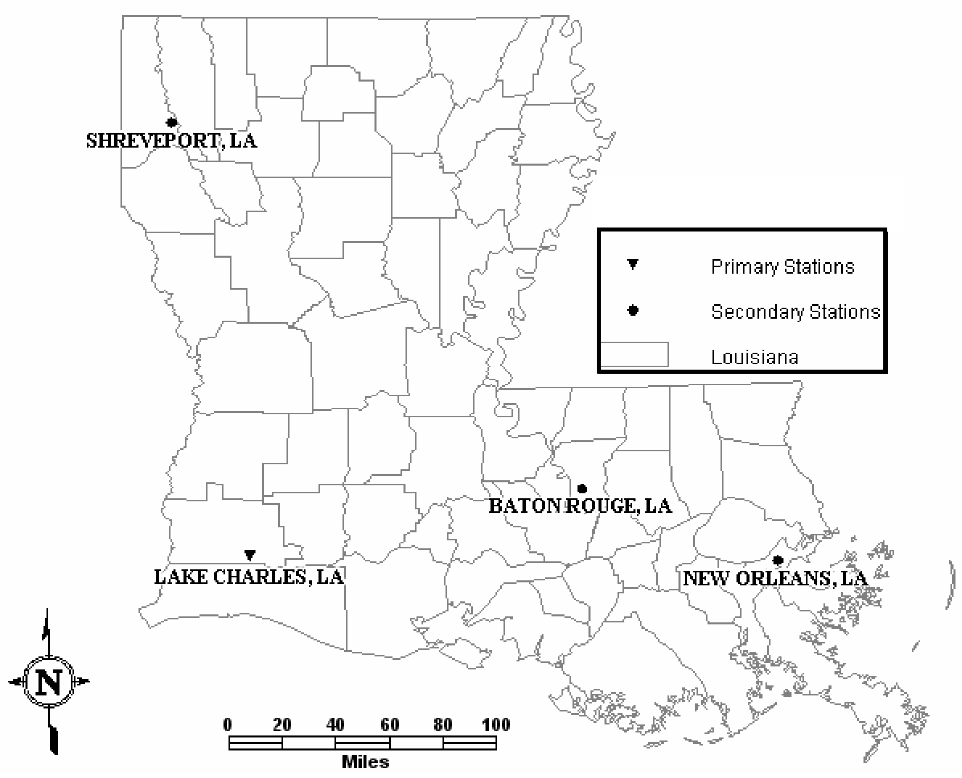


Figure 1.1 Stations in the NSRD

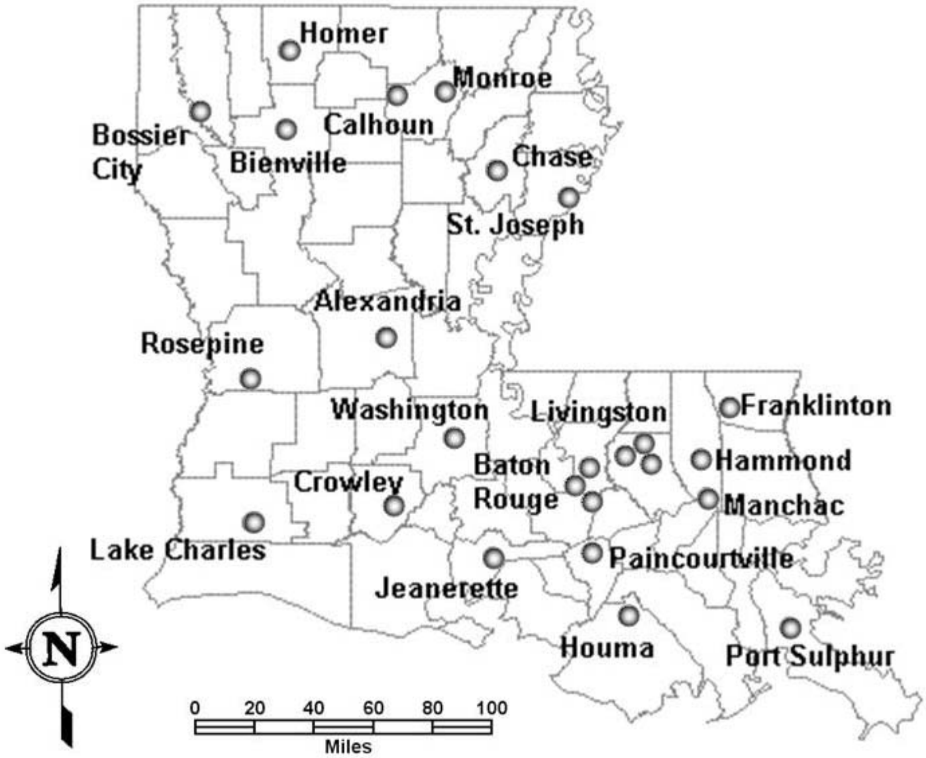


Figure 1.2 Stations in the LAIS

Generally, solar radiation values are either measured with instrumentation or derived from empirical models. Data from some stations in the NSRD are directly measured. Data at most of the NSRD stations in Louisiana, however, are modeled. All of the data from the stations in the LAIS are measured directly with LiCor® pyranometers.

1.4 Objectives

A climatology of solar radiation in Louisiana will be examined for spatial and temporal patterns. Previous research suggests that, due to the influence of the Gulf of Mexico, the coastal region of Louisiana has a different solar radiation climatology from those areas farther inland (Ye, 1996). But further research is warranted, primarily because of a lack of previous temporal examination of solar radiation in Louisiana.

Scholarly literature suggests that the amount of solar radiation reaching the surface of the earth has been reduced significantly in the past few decades (Stanhill and Cohen, 2001; Liepert, 2002), particularly in the period from 1961to1990 – the so-called “global dimming” phenomenon. Analyses will be conducted on the NSRD dataset to determine whether Louisiana’s input of solar radiation values mirror this global trend. Individual months will be examined in order to determine possible intra-annual trends. Explanations will be postulated regarding the reasons for and significance of any observed spatial patterns and trends.

The issue of data quality within the LAIS dataset, which has been a source of concern from the beginning, must be addressed more comprehensively. Therefore, another objective is to provide a means of testing the reliability of LAIS data. Data from the NSRD will be used as a means of assessing the reliability of the LAIS data.

1.5 Hypotheses

The following hypotheses are offered:

1. A negative trend in global solar radiation values exists over the 1961-1990 period in Louisiana, similar to the global dimming trend identified in previous studies.
2. Surface solar radiation in summer is greater in the northern part of the state than in the southern part, despite a more intense sun angle in the south, due to longer summer day lengths in the north and more intense afternoon cloud cover in the south.
3. Transmissivity increases with latitude across Louisiana in all months, as cloud cover and water vapor diminishes inland.
4. The southwestern corner of the state has greater transmissivity values than the southeastern corner, because the southeastern part of the state is influenced by water from three directions (the Gulf of Mexico, Lake Borgne, and Lake Pontchartrain) (Figure 1.3).

5. There is an inverse relationship between solar radiation and minimum temperature, because intense solar radiation would be associated with clear skies which would result in an increased loss of longwave energy at night, thus reducing the minimum temperature. It is also expected that there will be varying degrees in the intensity of this relationship depending on the time of year.
6. The relationship between solar radiation and maximum temperature involves complicated feedback mechanisms associated with convective cloud cover.
7. Data collected from the LAIS can be verified by a comparison with day-of-year averages calculated from the 30 years of data in the NSRD.

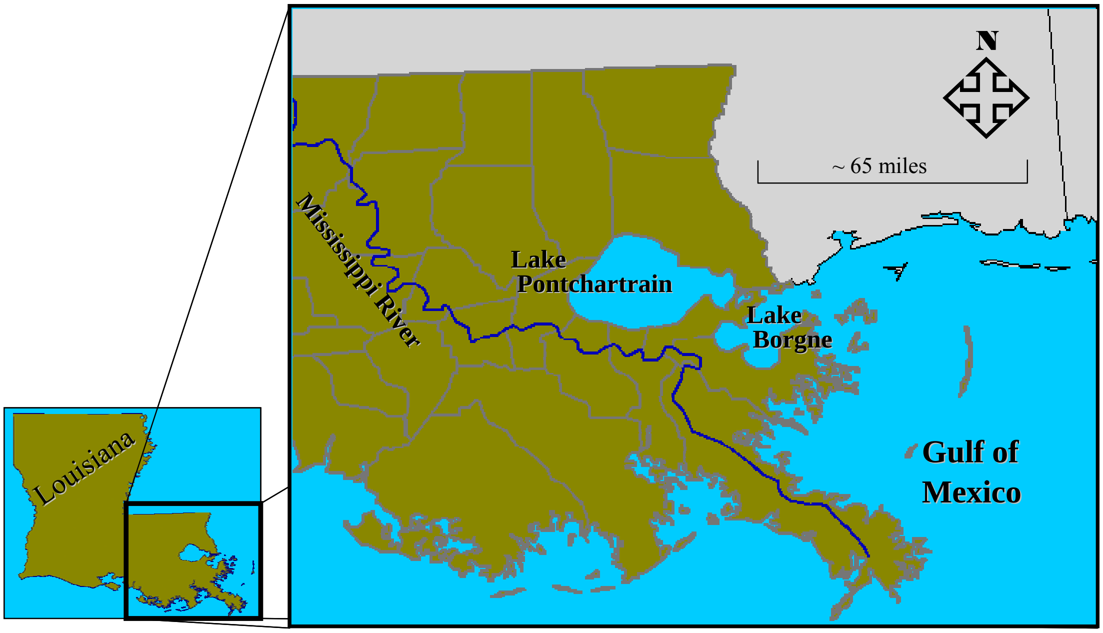


Figure 1.3: Southeastern Louisiana

CHAPTER 2

LITERATURE REVIEW

2.1 Solar Radiation

While solar radiation data are not utilized as frequently as other climatic variables, researchers nevertheless understand that as the primary driving force for all atmospheric processes, solar radiation is an important factor for a complete understanding of the workings of many of earth's systems. This chapter will illustrate the importance of solar radiation data, describe the collection of such data in previous studies, and summarize pertinent literature on the use of solar radiation in Louisiana.

Solar radiation data are important in a wide variety of applications in various environmental and agricultural applications in Louisiana, including the study of marine biochemical processes (e.g., Engelhaupt *et al.*, 2003; Chen *et al.*, 2004), livestock health (*e.g.*, Johnston *et al.*, 1959), and temperature regulation in aquacultural facilities (Lamoureaux *et al.*, 2006a; 2006b). Furthermore, solar radiation data are important as input to regional and global-scale atmospheric models (Yucel *et al.*, 2002). This is particularly true in locations such as Louisiana where cloud coverage and intensity can vary extensively over short distances due to the large localized influence of water on the climate in the area. Often model coefficients used in predicting solar radiation intensity at the surface are derived and tested by regression relationships established using data collected by ground-based pyranometers (Tovar and Baldasano, 2001). These model coefficients often perform better when they are specific to the region rather than if they are generalized to represent all areas (Muneer *et al.*, 2007). Therefore, precision in the models describing solar radiation receipt in Louisiana can be improved by using coefficients derived from accurate, local solar radiation measurements. It is therefore understandable that these issues are of great importance in the Gulf of Mexico coastal region; an area where large discrepancies in modeled projections of climatic change under global warming scenarios still exist (Ning *et al.*, 2003). All solar energy applications require readily-available, site-oriented and long-term solar radiation data (Muneer *et al.*, 2007). Therefore, increases in the number of locations recording solar radiation data benefit not only the study of solar radiation itself but also many other fields of study.

2.2 Local Scale Solar Radiation Studies

The physics involved in the transfer of solar energy through the atmosphere at the global scale is well-understood. Ratios have been derived that describe the relative importance of transmission of radiation through the atmosphere both from the sun (shortwave) and from the surface (longwave). However, these ratios are not spatially or temporally consistent. Furthermore, the global energy budget is sure to change with a changing atmosphere. These complexities have led researchers to attempt to understand local variability in solar radiation which will no doubt produce a more comprehensive view of both global and local energy budgets. According to Ye (1996),

> "…knowledge of solar energy availability and distribution at various geographic locations on the earth's surface is very limited due to the inherent difficulty in calculating radiative transfer for the atmosphere, the sparse number of surface observation sites, and the short periods of record for those sites that have collected data".

At present, values for the magnitude of input solar radiation at the surface of the earth are acquired in two basic ways. Radiation values are either measured with instrumentation or modeled from empirically-derived relationships between solar radiation and more readily-available atmospheric variables. Often, one of these methods is used to test the validity of the other (Malinovic *et al.*, 2006; Michalsky *et al.*, 2006).

The direct measurement of solar radiation is done in two basic ways as well. The values are measured either by using ground-based instrumentation known collectively as pyranometers, or remotely with satellites. These methods are often used in combination to validate one another (Kimothi *et al.*, 2004; Deneke *et al.*, 2005; Otkin *et al.*, 2005). In general, pyranometeric data from adequately maintained instruments provide an accurate description of the solar radiation values in the immediate area. It has been suggested that extrapolation of daily values beyond the discrete point represented by the location of the pyranometer can result in the misrepresentation of the extrapolated areas. Suckling (1983) found that, for areas in the Tennessee Valley Authority region, permissible extrapolation distances of daily solar radiation values were ~200 km, but that these distances may vary by season. However, Younes and Muneer (2006) claimed that "…for a given location that is farther than 50 km from the measurement station the use of the respective measurement station's data is obsolete in the assessment of solar energy applications". In his study of solar radiation variability in San Diego County, California, Aguado (1986) suggested that the relative proximity of two points to the coast further complicates the abilities of researchers to extrapolate beyond the discrete points at which solar radiation was measured.

It is generally accepted that models for solar radiation prediction are necessary, because in most cases the density and number of solar radiation measuring stations cannot describe the necessary variability (Muneer *et al.*, 2007). It is understandable then that new models and improvements to existing modeling techniques are continually proposed which intend to improve estimates of solar radiation values with the use of more readily-available meteorological variables (Safi *et al.*, 2002 Donatelli *et al.*, 2003; Younes and Muneer, 2006).

However, these models must be validated. Muneer et al. (2007) refer to Gueymard's (2000) study on prediction and performance assessment of mean hourly global radiation in which a dataset of at least three years is recommended to validate radiation estimation models. Generally, researchers depend on accurately measured data to draw conclusions concerning the accuracy of the predictions made by their models (Gueymard, 2000; Younes and Muneer, 2006). However, models are also used to fill gaps in existing datasets. For example, Safi *et al*. (2002) introduced a method of solar radiation prediction using higher-order statistics intended to fill in gaps in data sets.

There are benefits and drawbacks to consider when using either measured solar radiation data or modeled data. However, the use of models calibrated and improved by directly measured data greatly increases the number of locations for which solar radiation data may be calculated (Atwater and Ball, 1978), and these models are continually improved upon and optimized to more accurately predict solar radiation values for specific locations and times of the year (Donatelli *et al*., 2003).

2.3 Previous Solar Radiation Studies

Ye (1996) examined solar radiation in Louisiana. Her study focused on two main concepts: the association between solar radiation and synoptic weather types, and the spatial and seasonal distribution of solar radiation in Louisiana. Some of the major findings of her study included descriptions of the types of weather patterns that are associated with the most and the least intense solar radiation receipt at the surface. Ye (1996) also included some findings of a spatial and temporal nature. Specifically, she noted a minimal degree of spatial variability on an annual basis (but with northern Louisiana displaying the largest range in values), a distinct south-to-north gradient in winter, and a difference across the state in the time of year of peak solar radiation receipt. It is likely that most of these spatial and temporal patterns will be corroborated in this study. Through an examination of data from the National Solar Radiation Database (NSRD), this research will also fill a gap noted by Ye (1996) in time series analysis of solar radiation data in Louisiana. Very little research has been completed that describes temporal trends in local-scale radiation in or near Louisiana. This dearth of knowledge is likely due to the relatively limited number of solar radiation monitoring stations and the lack of adequate spatial and temporal resolution to conduct an effective time series analysis.

However, work on larger spatial scales has been conducted recently which intends to explain temporal trends found in solar radiation values. Work of this nature has led to consistent reports of a downward solar radiation trend over the past half century but more specifically over the 1961 to 1990 period -- often dubbed “global dimming” similar to the much touted “global warming” catch phrase. In a study of worldwide solar radiation values, Liepert (2002) found a considerable decrease in solar radiation values worldwide and particularly in the United States where values were observed to have declined by 10 percent over the thirty-year data record (1961-1990) used in the study.

A study conducted by Stanhill and Cohen (2001), using only highly reliable data from 1958-1992, taken from thermopile pyronometers, found a global reduction in surface solar radiation values of 2.7 percent per decade. They theorized that the reduction is principally due to “…increases in man made aerosols and other air pollutants [which] have changed the optical properties of the atmosphere, [and] in particular those of clouds”. They also discussed observed impacts and possible future impacts upon agricultural productivity and water stress.

This study will attempt to determine whether solar radiation values in Louisiana over the period between 1961 and 1990 have behaved in similar fashion to those observed in other regions over the same time period.

Since these initial studies conducted on data from 1961 to 1990, further research has been conducted which suggests that this decreasing trend has reversed and that since the late 1980's there has been a globally increasing trend in surface solar radiation. Using data obtained by satellite, Pinker *et al*. (2005) found an increase of 0.10 percent per year from 1983 through 2001. Using data collected from the World Radiation Data Centre (WRDC) and the Baseline Surface Radiation Network (BSRN) comprised of a "…global network [which] measures surface radiative fluxes at the highest possible accuracy with well-calibrated state-of-the-art instrumentation at selected sites in the major climate zones", Wild *et al*. (2005) also found a "…widespread brightening… since the late 1980s."   This study by Wild *et al*.(2005) goes on to suggest that previous effects of global dimming may have acted to mask the true intensity of global warming and that a reversal in global dimming is likely to amplify predicted temperature increases under a global warming scenario.

CHAPTER 3

DATA AND METHODS

This chapter describes the study area, data, and methods used to test the hypotheses listed in Chapter 1. Results from the methods discussed in this chapter will be described in Chapters 4 and 5.

3.1 The Study Area: Louisiana

Including water area, Louisiana covers approximately 51,800 square miles, making it the 31st largest state in the United States. It is situated in the southeastern region of the U.S. and its southern border is comprised of a gradual blending of land and water which eventually becomes the Gulf of Mexico. Besides the border with the Gulf of Mexico, Louisiana is made up of over 4,000 miles of navigable waterways. The Mississippi River – part of the largest river system in North America – flows through the state, and the river's delta comprises a large portion of the southeastern quadrant of the state. Besides these flowing waterways, the state also contains several landlocked bays and inland lakes. Understandably, the influence of water upon the climate and weather in Louisiana is strong.

Relief in Louisiana is modest, ranging from several feet below sea level to a maximum 535 feet. Therefore, orographically-induced weather phenomena are *relatively* insignificant for most of the state. The abundant water availability for storm systems as well as the state's location at a land/sea interface ensures significant weather-related activity from frontal systems, convective thunderstorms, and tropical cyclones. It is therefore understandable that in Louisiana "…showers and thunderstorms occur on an average of 50 to 60 days a year in the northwest and north-central, 70 days in central and northeast…" (Southern Regional Climate Center, 2004).

This geographic situation makes Louisiana an ideal area in which to study solar radiation. Significant variability exists within the state in solar radiation intensity that reaches the surface. This spatial variability is primarily due to location relative to water and the resulting cloud cover. Often, summer convective thunderstorms will arise that absorb incoming solar radiation more efficiently in one location than in another nearby location. Frontal systems can have similar, though not as localized, effects, and tropical cyclones affect only portions of the state at a time.

An accurate description of Louisiana’s input solar radiation is also important for understanding weather and climate in the rest of the United States. The state is at the gateway from which the source region of maritime tropical air from the Gulf of Mexico provides moisture that will eventually fall as precipitation in much of the United States east of the Rocky Mountains. Louisiana’s location at a transition zone between land and water makes it an area in which modeling the advection of this moisture and forecasting its impacts are complicated by the land/water relationships.

Knowledge of solar radiation in Louisiana is also important for economic reasons. Louisiana’s economy is supported by agricultural activities including the production of cotton, soybeans, sugarcane, and rice. A better understanding of the spatial and temporal nature of solar radiation within the state will ultimately serve to enhance the productivity of crops.

3.2 National Solar Radiation Database (NSRD)

3.2.1 NSRD Data

The National Solar Radiation Database (NSRD) is a “…serially complete collection of hourly values of the three most common measurements of solar radiation (global horizontal, direct normal, and diffuse horizontal) over a period of time adequate to establish means and extremes, and at a sufficient number of locations to represent regional solar radiation climates” (NSRD User’s Manual, 2007). For the purpose of this study, the values recorded for the global horizontal variable (a total of direct and diffuse radiation) and their associated top-of-the-atmosphere (i.e., extraterrestrial) solar radiation values are used.

NSRD data are composed of hourly observations in SI (Systeme International) units of Whm^{-2} which indicate the amount of global solar radiation "…received on a horizontal surface during the 60 minutes preceding the hour indicated." According to the NSRD User's Guide (NSRD User's Manual, 2007), the World Meteorological Organization requires 30 years of data in order to establish normals, means, and extremes. While this sampling of years is not random, it is the most complete, longest-running dataset of solar radiation representing Louisiana and is the dataset used and maintained by the U.S. Department of Energy, which includes the data in many of its published studies including its "Solar Radiation Data Manual for Buildings" (Marion and Wilcox, 1995).

Of the 239 stations in the U.S., including Guam and Puerto Rico, comprising the NSRD network, four are located in Louisiana: Baton Rouge, Lake Charles, New Orleans, and Shreveport (Figure 1.1). It should be noted that the data from Lake Charles began in 1962 instead of 1961. The spatial distribution of these stations created reasonable, though not exemplary, coverage of the state. The stations of Lake Charles and New Orleans could generally be described as coastal, though neither is actually *on* the coast. The Baton Rouge station is somewhat south and east of the center of the state, and the Shreveport station is located in the northwestern corner of the state. This configuration left part of the state unrepresented, especially considering the spatial variation in input solar radiation, where local proximity to water bodies can dramatically alter the distribution and thickness of cloud cover.

These stations in Louisiana, as well as all others in the NSRD network, are divided into two types: primary and secondary (Figure 1.1). The primary stations have at least a portion of their data directly measured with instrumentation. The secondary stations have all of their values derived from models. Of the four stations in Louisiana, three are secondary stations. Only the station at Lake Charles is a primary station.

The methods used to acquire data values at the Lake Charles station are different for the pre-1976 period than for the post- 1976 era. Each data value is flagged with a letter representing the method of its collection or estimation and descriptions of these flags are provided in the NSRD User's Manual. About half of the pre-1976 data are flagged with an [E] to indicate "modeled solar radiation data using inputs of *observed* sky cover (cloud amount) and aerosol optical depths derived from direct normal data collected at the same location". The other (approximately) half of the pre-1976 data are flagged with a [C] to indicate "measured global horizontal data (direct and diffuse were not measured separately before 1976), adjusted from solar to local time, usually with a calibration correction." However, there was also a modicum of pre-1976 data values that are flagged with an [F] -- "modeled solar radiation using *interpolated* sky cover and aerosol optical depths derived from direct normal data collected at the same location." Generally the post-1976 data are flagged as [A] -- "post-1976 measured solar radiation data as received from NCDC (National Climatic Data Center) or other sources." However, it appears that several of these post-1976 values are missing and are supplemented with data flagged as [E]. This is especially true of the dataset from 1981 to 1987, where the data values are exclusively flagged as type [E]. 1988 values return to being flagged mostly as [A], but once again the values return to being flagged solely [E] in 1989 and assume a relatively even split between [A] and [E] for 1990 (NSRD User's Manual, 2007).

The data estimated at the three other stations in Louisiana (Baton Rouge, New Orleans, and Shreveport) are flagged mostly as [G] which indicates "modeled solar radiation data using *observed* sky cover and aerosol optical depths estimated from geographical relationships". The Baton Rouge station is flagged exclusively as [G]. As a cost-cutting measure instituted by

National Oceanic and Atmospheric Administration (NOAA), during 1965-1980 at New Orleans and 1965-1969 and 1975-1980 at Shreveport, only every third hourly observation of the meteorological variables required in the solar radiation estimation models was digitized. The data values that fill in these gaps are flagged [H] to indicate "modeled solar radiation data using *interpolated* sky cover and *estimated* aerosol optical depths" (NSRD User's Manual, 2007).

Modeled data, which make up all of the data at Baton Rouge, New Orleans, and Shreveport and at least some of the data from Lake Charles, were obtained through the development of "…clear sky and cloud regression equations for estimating global horizontal radiation from sunshine, opaque cloud, sky condition, and precipitation data" (NSRD User's Manual, 2007). These regression equations are unique for each primary station and were used to generate values for any missing data at that station as well as estimate data for those secondary stations which displayed similar climate conditions (NSRD User's Manual, 2007). It is important to note that because temperature is not a predictor variable for modeling solar radiation, it can be correlated with solar radiation data. Figure 3.1 is a block diagram which describes the models used to estimate solar radiation values.

The NSRD dataset also contains extraterrestrial solar radiation values for each hour at each location. These values were used to plot a theoretical maximum curve showing the intensity of extraterrestrial solar radiation above each location for each day of the year. The extraterrestrial values were also used to estimate and plot a clear-sky transmissivity of 0.75. Transmissivity is the ratio of measured surface solar radiation to extraterrestrial solar radiation incident over that location at that time of year and day. Using the suggestion by Heermann et al. (1985) that "cloudless day solar radiation values can be obtained…by plotting observed daily values to obtain an envelope curve through the high points", the clear sky transmissivity of 0.75 seemed reasonable. Also, the findings of the research conducted by Heermann et al. (1985)

suggest that clear sky transmissivity values range from 0.69 to 0.81. Further justification of a 0.75 transmissivity estimate is that the two locations closest to Louisiana which were examined in Heermann's study (Montgomery, AL and Midland, TX) both display transmissivity values that average approximately 0.75 over an entire year (being slightly higher during the summer and winter solstices and slightly lower at the spring and fall equinoxes). Examination of the data revealed that all four NSRD stations displayed values indicating a clear sky transmissivity very near 0.75 throughout the year.

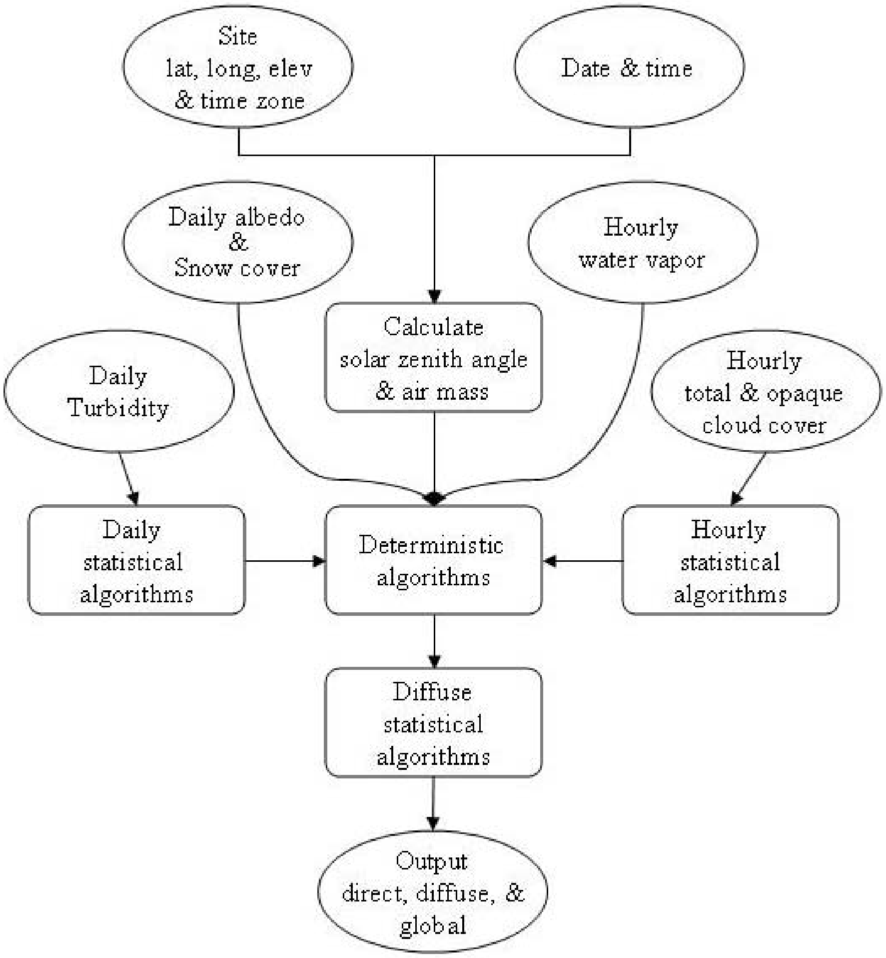


Figure 3.1: Diagram of model for estimating solar radiation from meteorological parameters (NSRD User's Manual, 2007)

The temperature data, which were correlated with the solar radiation data from the NSRD to establish a statistical relationship between the two variables, were retrieved from the Southern Regional Climate Center (SRCC) database. The stations at which these temperature measurements were taken are the same stations represented by the solar radiation data. Data coverage for the temperatures is essentially complete.

3.2.2 NSRD Methods

Most of the data manipulation and analysis were done using the programming language R. The entire program is available by request from the author. Initially, the data existed in an hourly format. For uses during different aspects of analysis, the data were aggregated to daily, monthly, annual, and day of year (DOY) and month of year (MOY) values in units of Wm^{-2}.

The descriptive statistics of these hourly and daily average values were examined to understand the basic nature of the data at each site. Tests of normality including the Shapiro-Wilk's test and the Lilliefors' (Kolmogorov-Smirnov) test were conducted in conjunction with examinations of the descriptive statistics, histograms, and density plots to determine the distribution of the data at each site. Daily and DOY means were calculated and plotted for all four stations. A single plot was generated which showed DOY means from the four sites such that the seasonal behavior of each site could be analyzed in relation to the other sites.

To arrive at a better understanding of the temporal trends in solar radiation in Louisiana, a time series analysis was conducted on the 30 years of daily-aggregated data (1961-1990) from each of the four NSRD stations. Trend is the overall tendency exhibited by the data. It can be useful in expressing the direction in which data are tending over time; upward, downward, or not at all. Data in the form of a time series present challenges in expressing trend because components such as seasonality and random fluctuations mask the overall trend of a data set. Generally, even after the seasonal and random variability has been accounted for, the remaining trend is nonlinear. Nevertheless, to visualize the nature of the trend, a least squares regression line is often calculated. This line is created by minimizing the squared residual error of all the points in the data that do not fall exactly on the trend line.

The statistical significance of the trend is an important feature of any regression line. Most data will trend slightly upward or downward, especially in the short term, but if the trend is not statistically significant, its trend is considered to be zero. If a plot of the residuals of a linear regression reveals any kind of order or shape such as toward changing variability across the time series (heteroscedasticity) or residuals tending to fall on one side of the line in one part of the time series, violations of assumptions of linear regression are possible. These assumptions include the belief that the relationship between the two variables is linear, that the errors are independent of one another, that the errors are consistent over time, and that the errors represent a normal distribution. Violations of these assumptions result in the improper interpretation of the nature of the relationship between two variables. Besides being represented by a straight line, a trend can also be curved. This could represent values that change exponentially in places and level off in other places, all within the same set of data. In the case of violations of assumptions of the linear regression model, the possibility of a curvilinear trend must be examined.

Following up on the time series analysis conducted on the daily solar radiation values from the NSRD data, a month-by-month time series analysis was conducted to determine whether specific months contributed more or less to the overall trends found at the four NSRD stations. To perform this analysis, the daily solar radiation values for each station were aggregated to monthly values. Each station’s monthly values were then plotted sequentially. A trend line was then calculated for all twelve months at all four stations. Plots were created to display these trends. Every station had one plot representing each season, and each of these seasonal graphs contained three linear trends - one for each month of the season. This resulted in the creation of 16 plots. While this technique was appropriate and helpful, there were simply too many lines on the plots for convenient comparative analysis. To reduce clutter and increase clarity, a table, which can be found in Chapter 4, was created to represent all of these linear trends in a compact form.

Because the NSRD dataset includes hourly extraterrestrial solar radiation values, the transmissivity variable may be calculated. Analyzing transmissivity values rather than surface solar radiation receipt standardizes the measurements so that they are comparable across space and time. For example, instead of simply stating that one location received 100 Wm^{-2} while another experienced 200 Wm^{-2}, we can make direct comparisons between the two areas by stating that the first location had a transmissivity value of 0.45 while the other had a transmissivity of 0.55.

The transmissivity values were plotted in sequence such that seasonal and geographic patterns may be uncovered. Time series analysis was also conducted on the transmissivity values to determine whether their trends mimic those of their representative solar radiation measurements. While it is likely that they do, the test was nonetheless necessary because there are situations when one of these variables could be more representative of the true nature of the atmosphere. For example, a 10 Wm^{-2} decrease in solar radiation receipt during the summer (when potential solar radiation exists during 15 or more hours of the day and reaches values of 1300 Wm^{-2}) over the course of 20 years would not have an equal impact as the same decrease in winter (when potential solar radiation values reach only 1100 Wm^{-2} and are only available for 11 or fewer hours each day) over the same period of time. In actuality, a 10 Wm^{-2} decrease in summer would only represent a small change in transmissivity, while the same change in winter would produce a much larger impact.

All of these variables obtained from the NSRD were then used to assess the data quality at each of the Louisiana Agriclimatic Information System (LAIS) stations. The DOY mean values were plotted so that daily average values from the LAIS could be plotted against them. The extraterrestrial values from the NSRD dataset were used to plot a DOY potential maximum solar radiation value as well as a reasonable DOY clear sky transmissivity of 0.75. Both of these variables were plotted along with the DOY mean values calculated from the hourly NSRD dataset. This was done to determine the intensity, seasonality, and overall credibility of the LAIS stations in relation to the long-term, quality-controlled data from the NSRD. To provide a framework for assessing solar radiation magnitudes of a representative year from the NSRD when plotted on top of its DOY mean values, one relatively high-intensity year and one relatively-low intensity year were chosen from each location and plotted against their DOY means. These plots provide examples of a reasonable range of values. After establishing this range of DOY values, the LAIS data were examined to determine which years at which stations could be labeled as having poor-quality data. This was done by plotting each year's data from each station in the LAIS against its nearest NSRD station's DOY mean, extraterrestrial radiation, and surface radiation assuming a transmissivity of 0.75.

The assumed clear sky transmissivity was obtained through an examination of the NSRD data. Figure 3.2 shows a single year's values from the Lake Charles NSRD station plotted against the DOY mean, extraterrestrial total, and a theoretical clear sky transmissivity of 0.75 calculated from the 29 years of data from the Lake Charles NSRD station.

From Figure 3.2, it can be seen that a transmissivity of 0.75 is reasonable. For all four stations and all 30 years, the results were similar. Nevertheless, the 0.75 clear sky transmissivity was not strictly valid throughout the entire year. In some cases the values fell slightly above or below the 0.75 transmissivity curve, but the 75 percent curve nonetheless provides an excellent frame of reference from which to examine single years of data. In fact, a plot of a single year of data from Lake Charles plotted against the DOY means, extraterrestrial radiation, and values representing a transmissivity of 0.75 calculated from the station at Shreveport do not conflict greatly with the usage of a 0.75 transmissivity as a reference (Figure 3.3).

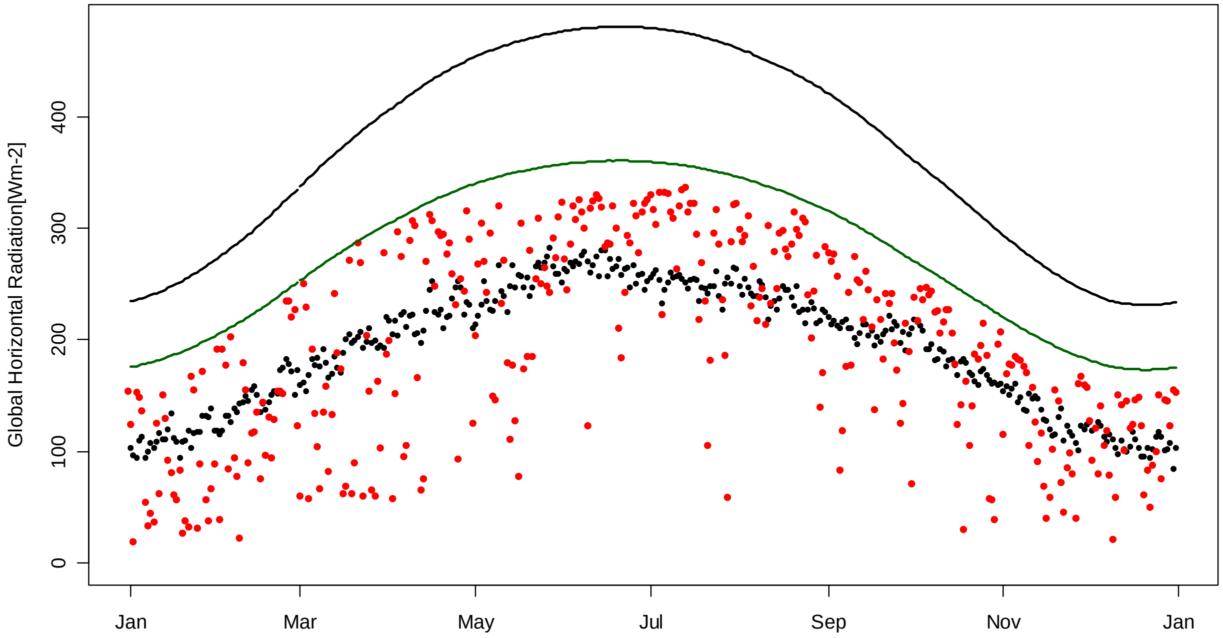


Figure 3.2: Daily solar radiation values from the Lake Charles NSRD station for 1980 (red dots) and DOY average values for the Lake Charles NSRD station from 1962-1990 (black dots). The top line (black) represents extraterrestrial solar radiation. The green line represents received radiation assuming a transmissivity of 0.75.

To understand which, if any, relationships exist between solar radiation and temperature in Louisiana, a time series analysis was conducted on the temperature data at each NSRD site. Specifically, one time series was done on daily maximum temperature and one was done on daily minimum temperature for each site because the two components could react to solar radiation differently or at least in differing degrees. The trends that were uncovered in this way were compared to the trends identified in the solar radiation data. To accomplish this, the trends were standardized by calculating the z-score, such that

$$z = \frac{x - \overline{x}}{s}$$

where x is the value to be standardized, $\overline{x}$ is the mean of the sample, and s is the standard deviation of the sample. In this way, changes in trend become directly comparable. That is, without the use of the z-score a change in temperature of 5 degrees and a change in solar radiation of 5 Wm^{-2} would appear similar to one another. When the z-score is used instead, trends among variables with different units are directly comparable. These standardized trends were plotted together for a visual examination. Then, the trend from the solar radiation variable was plotted against the trends from the maximum and minimum temperature variables to examine the relationship between solar radiation and temperature. A positive relationship would imply that as solar radiation trends in a direction, the maximum or minimum temperature variable would tend to trend in the same direction. A negative relationship would suggest the opposite: as the solar radiation variable trends in a direction, the temperature variable would tend to trend in the opposite direction. This analysis will demonstrate the degree to which a decrease in input solar radiation can be expected to be accompanied by a change in maximum and minimum temperature.

To test the hypothesis that transmissivity values are greater in the southwestern portion of the state than in the southeastern part of the state, a direct comparison of daily transmissivity values at Lake Charles, New Orleans, and Baton Rouge was conducted. In this analysis, the 75 percent assumption was not made. Transmissivity values were calculated for each day in the database at each of the three stations. Once these values were calculated, daily transmissivity values for New Orleans were subtracted from daily transmissivity values for Lake Charles. The same was done for Baton Rouge and Lake Charles. These values were then summed to compute a total cumulative difference between the stations. The results of this test, while without units, should provide some estimation of the degree of difference in transmissivity between the east and the west. Plots of the daily, monthly, and yearly differences in transmissivity between New Orleans and Lake Charles are also examined.

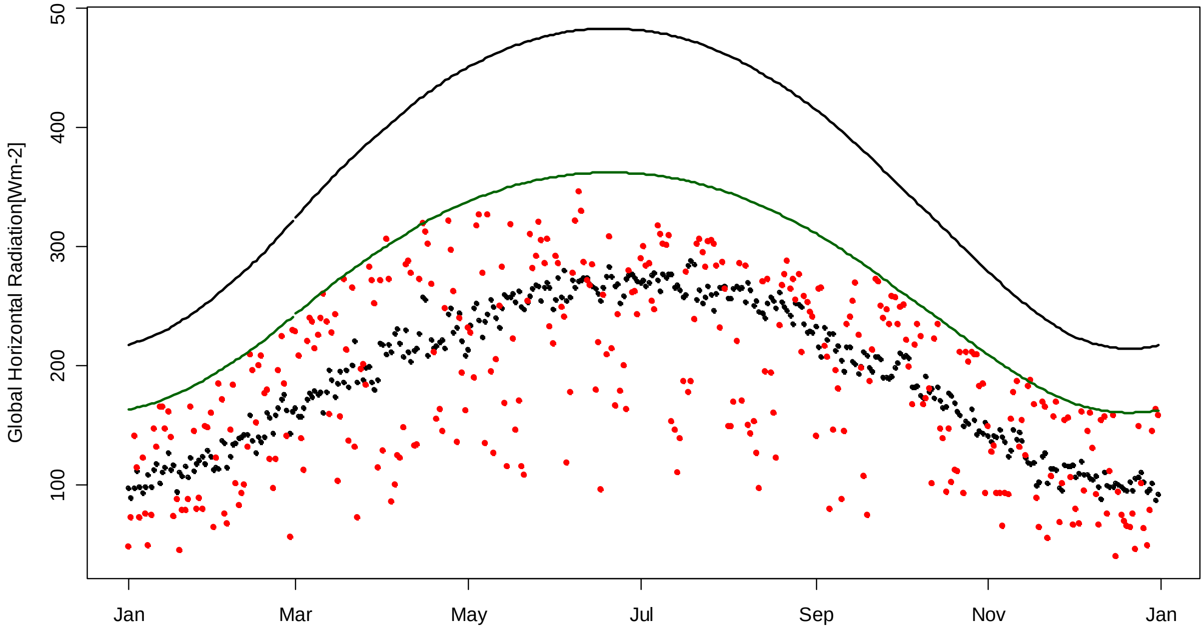


Figure 3.3: Daily solar radiation values from the Lake Charles NSRD station for 1983 (red dots) and DOY average values for the Shreveport NSRD station from 1961-1990 (black dots). The top line (black) represents extraterrestrial solar radiation for Shreveport. The green line represents received radiation assuming a transmissivity of 0.75 at Shreveport.

3.3 Louisiana Agriclimatic Information System (LAIS)

3.3.1 LAIS Data

The LAIS "is a network of 25 automated weather stations operated by the LSU AgCenter and managed by the Department of Biological and Agricultural Engineering" (Louisiana State University Agriclimatic Information System [LAIS], 2006) (Figure 1.2). These automated weather stations record atmospheric variables at 3-second time intervals. These values are aggregated to minute, hour, and twice-daily values, which are recorded and compiled using a Campbell Scientific® CR23X model datalogger. The values are transmitted via buried communications cable, radio, or telephone modem (depending on the station) to a centralized computer for storage. The LAIS data used in this study were retrieved from the LAIS website (LAIS, 2006) for the period from September 2001 to January 2006.

Solar radiation is one of many atmospheric variables available through the LAIS that include temperature (air and soil), relative humidity, wind speed and direction, precipitation, and barometric pressure. Solar radiation measurements are recorded in Langleys, which were subsequently converted to Wm^{-2} by multiplying by a conversion factor described below. Whereas Wm^{-2} represent the number of Joules of energy incident on a square meter every second, Langleys represent calories of energy incident on a square centimeter. They are an instantaneous measurement. Therefore to arrive at meaningful values in Wm^{-2}, the Langley values must be integrated over the time period for which measurements are desired. In the case of the LAIS dataset, the instantaneous solar radiation measurements have been aggregated to daily values. This creates a time component for the Langleys. In essence, the Langley values become calories per square centimeter per day.

Therefore, the conversion factor to change the daily Langley values to daily average Wm^{-2} is as follows:

$$\left(\frac{1\,cal}{cm^2 day}\right)*\left(\frac{100^2 cm^2}{1\,m^2}\right)*\left(\frac{4.18\ J}{1\,cal}\right)*\left(\frac{1\,day}{24\ hours}\right)*\left(\frac{1\,hour}{3600\ s}\right) = .4837962\ J\ s^{-1}m^{-2} \approx .4838\,W\,m^{-2}$$

All solar radiation measurements at LAIS sites are taken using LiCor® pyranometers. The LiCor® website (www.licor.com) claims that their pyranometer “compares favorably with first class thermopile-type pyranometers, but is priced at a fraction of the cost.” Specifically, LiCor® claims that, when calibrated against an Eppley® Precision Spectral Pyranometer (EPSP), under most natural daylight conditions, the error associated with their pyranometer's data is < 5 percent. It should be noted, however, that all of the references cited by LiCor® in making these claims are more than 35 years old.

The LiCor® pyranometer does not have a perfect spectral response at all wavelengths (Figure 3.4). The response is very low at 0.4 μm and increases nearly linearly to a maximum at about 0.95 μm and then decreases nearly linearly to a response of zero at about 1.2 μm. Due to this inaccuracy, it is possible that data collected at low solar elevations can show significant errors. However, the times of the day with low solar elevations is "a small part of the daily total and so the possible observed error usually has an insignificant effect on daily integrations" (LiCor® Inc., 2007). This suggests that individual minute or hour values (which are recorded in the LAIS) may have larger errors associated with them than the daily totals.

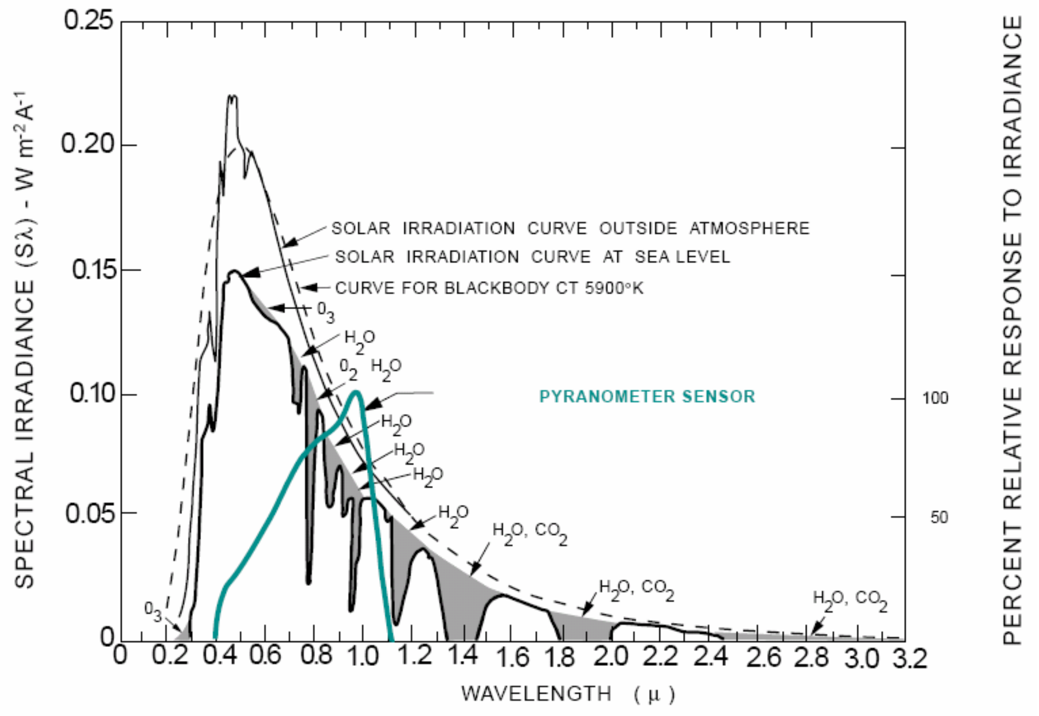


Figure 3.4: Spectral response curve of LI-200SA pyranometer along with the energy distribution in the solar spectrum (LiCor® Inc., 2004)

Regular cleaning of pyranometers is necessary to maintain the accuracy of the calibrated measurement. LiCor® Inc. (2007) recommends that its pyranometers be calibrated every two years. Also, LiCor® Inc. (2007) recommends that “the LI-200 Pyranometer sensor must be returned to Li-Cor® for recalibration”.

Note must be made here regarding the data quality. Much of the solar radiation data obtained from the LAIS seems spurious. Some values within the data set are beyond improbable and more accurately can be described as impossible. These include values that are higher than the amount of extraterrestrial solar radiation as well as values that are negative. Beyond these obviously spurious data, there are gaps in the data sets for most of the stations at one time or another and some of the gaps are rather large (lasting from six months to a year). The reason for this data inaccuracy has much to do with the instrumentation used to measure the incoming solar radiation. Pyranometers are sensitive instruments and are, by necessity, placed in open areas that expose them to the full brunt of nature. This fact re-emphasizes the importance of routine inspection, cleaning, and recalibration of pyranometers. The relatively wide geographical distribution of these stations sometimes makes the continued maintenance cost prohibitive and logistically difficult, despite being necessary for optimal performance of these instruments. A component of the analysis in this thesis will involve an assessment of the data quality among LAIS stations.

3.3.2 LAIS Methods

Similar to the NSRD dataset, much of the data manipulation and analysis conducted on the LAIS dataset was done with the programming language R. The daily solar radiation values from the LAIS were plotted against their geographically closest NSRD station’s DOY values. This was done to visualize the nature of the data in the LAIS as it relates to the quality-controlled

NSRD data set. Because of the large degree of incompleteness of the data found in the LAIS, a formal time-series analysis on the data from these stations was not possible.

Comparisons with the DOY average plots from the NSRD data set were used in several capacities for assessing the relative accuracy of solar radiation data from the LAIS. Initially, these comparisons were used to create a map of the stations with colors indicating the overall quality of the data at each site (consistently high, consistently low, reasonable, and no discernable pattern). It should be noted that a station with a description of “reasonable” could have values which were consistently unlikely throughout or even impossible in some places. Therefore, a detailed analysis of data quality at each station was provided. These descriptions explain the overall nature of the data at each site as well as provide suggestions about which dates were acceptable and could be considered useful in future studies. Perhaps more importantly, the descriptions suggest the dates at each station that should not be reported due to impossible or highly unlikely values.

The use of DOY average plots as indicators of data accuracy is justified. A comparison of the plots for single years of data from the NSRD to the DOY averages suggests a range in which acceptable years of data from the LAIS should fall. Figure 3.5 is a plot of a single year of data from the New Orleans NSRD station against the DOY means from New Orleans.

It seems intuitive that a single year of data from one station would agree with the DOY means calculated for the same station. However, even when a single year of data from Shreveport is plotted against the DOY mean values from the New Orleans station (Figure 3.6), the values corroborate each other. Figure 3.6 confirms that analysis of the LAIS data in relation to these DOY mean plots is justified because the distance between any LAIS station and its nearest NSRD site will always be far less than the distance between Shreveport and New Orleans, the two most spatially separated sites in the NSRD.

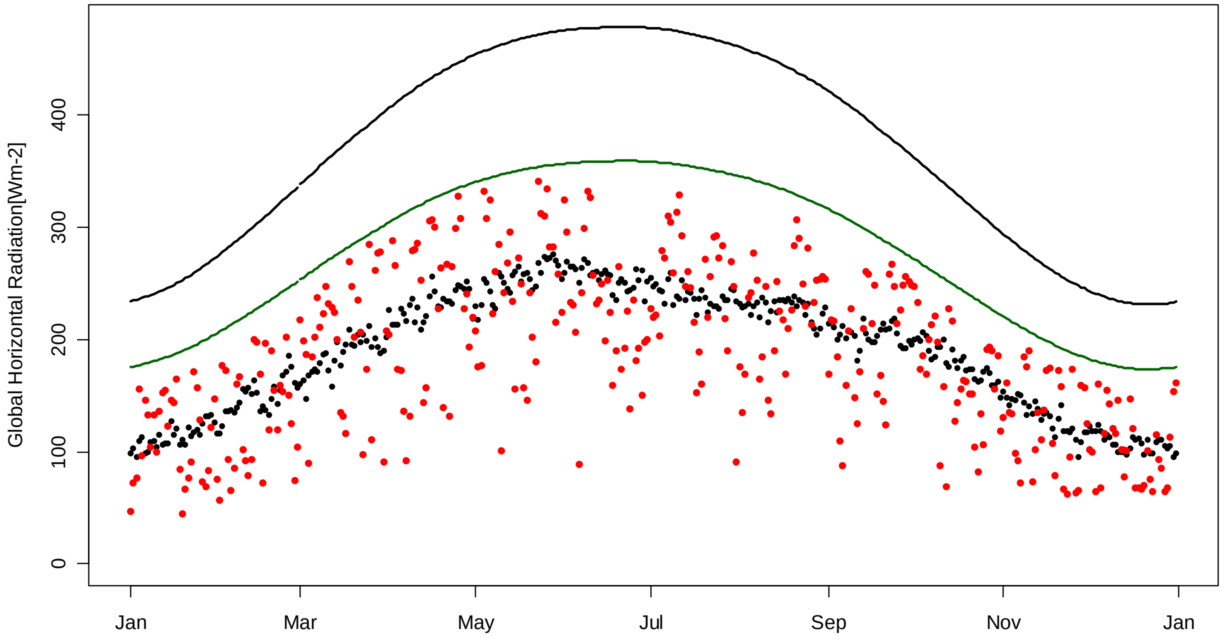


Figure 3.5: Daily solar radiation values from the New Orleans NSRD station for 1983 (red dots) and DOY average values for the New Orleans NSRD station from 1961-1990 (black dots). The top line (black) represents extraterrestrial solar radiation for New Orleans. The green line represents received radiation assuming a transmissivity of 0.75 at New Orleans.

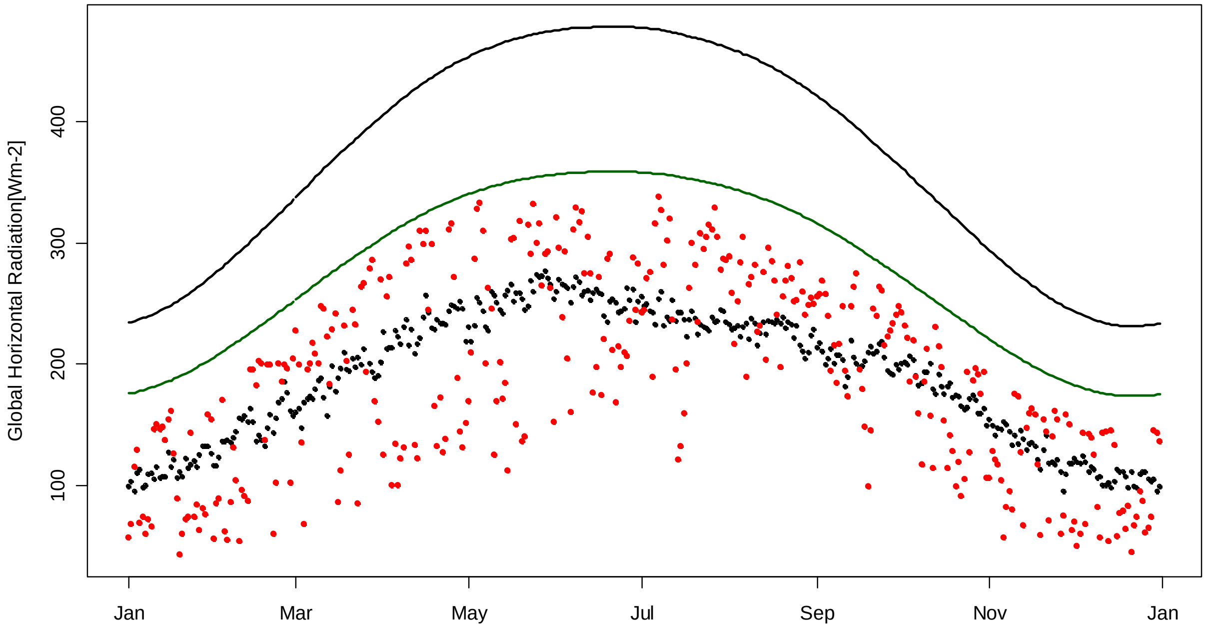


Figure 3.6: Daily solar radiation values from the Shreveport NSRD station for 1983 (red dots) and DOY average values for the New Orleans NSRD station from 1961-1990 (black dots). The top line (black) represents extraterrestrial solar radiation for New Orleans. The green line represents received radiation assuming a transmissivity of 0.75 at New Orleans.

While Figure 3.6 suggests that the DOY means from the NSRD can be used as indicators of reasonable daily solar radiation values in the LAIS dataset, it also suggests that on the whole, values across the state do not vary drastically. This means that incorrect values in the LAIS should be relatively easy to identify. Future research would be improved by discarding spurious LAIS data.

This chapter has described the study area, data sources, and the major methods used in the thesis. The next chapters will provide the results of these procedures. Explanation of these results in light of the hypotheses presented in Chapter 1 will also be presented.

CHAPTER 4

NSRD RESULTS

4.1 NSRD General Statistics and Normality Tests

To understand the basic distribution of data values in the NSRD, simple statistics were examined and tests of normality were conducted at each station. Table 4.1 provides a breakdown of the findings at each of the four NSRD stations.

Table 4.1: General statistics (including results of Shapiro-Wilk's and Lilliefors' tests for normality) on daily values at all four NSRD stations.

	New Orleans	Baton Rouge	Lake Charles	Shreveport
Minimum	40.29	36.92	18.08	34.21
Maximum	353.6	352.4	357	353.7
Mean	189.7	186.4041	192	192.2
Median	189.4	185.875	191.5	189.3
1st Quartile	130.5	125	130.1	127.8
3rd Quartile	248.6	247.3	256	260.2
Std. Deviation	72.49421	73.93182	76.32964	78.65355
Skewness	0.02535334	0.03307101	-0.01308108	0.03583494
Kurtosis	1.976897	1.946749	1.933761	1.862765
Shapiro (W)	0.9742	0.9705	0.9708	0.9618
Shapiro (p)	< 2.2 e-16	< 2.2 e-16	< 2.2 e-16	< 2.2 e-16
Lilliefors (D)	0.0449	0.0472	0.0515	0.0616
Lilliefors (p)	< 2.2 e-16	< 2.2 e-16	< 2.2 e-16	< 2.2 e-16

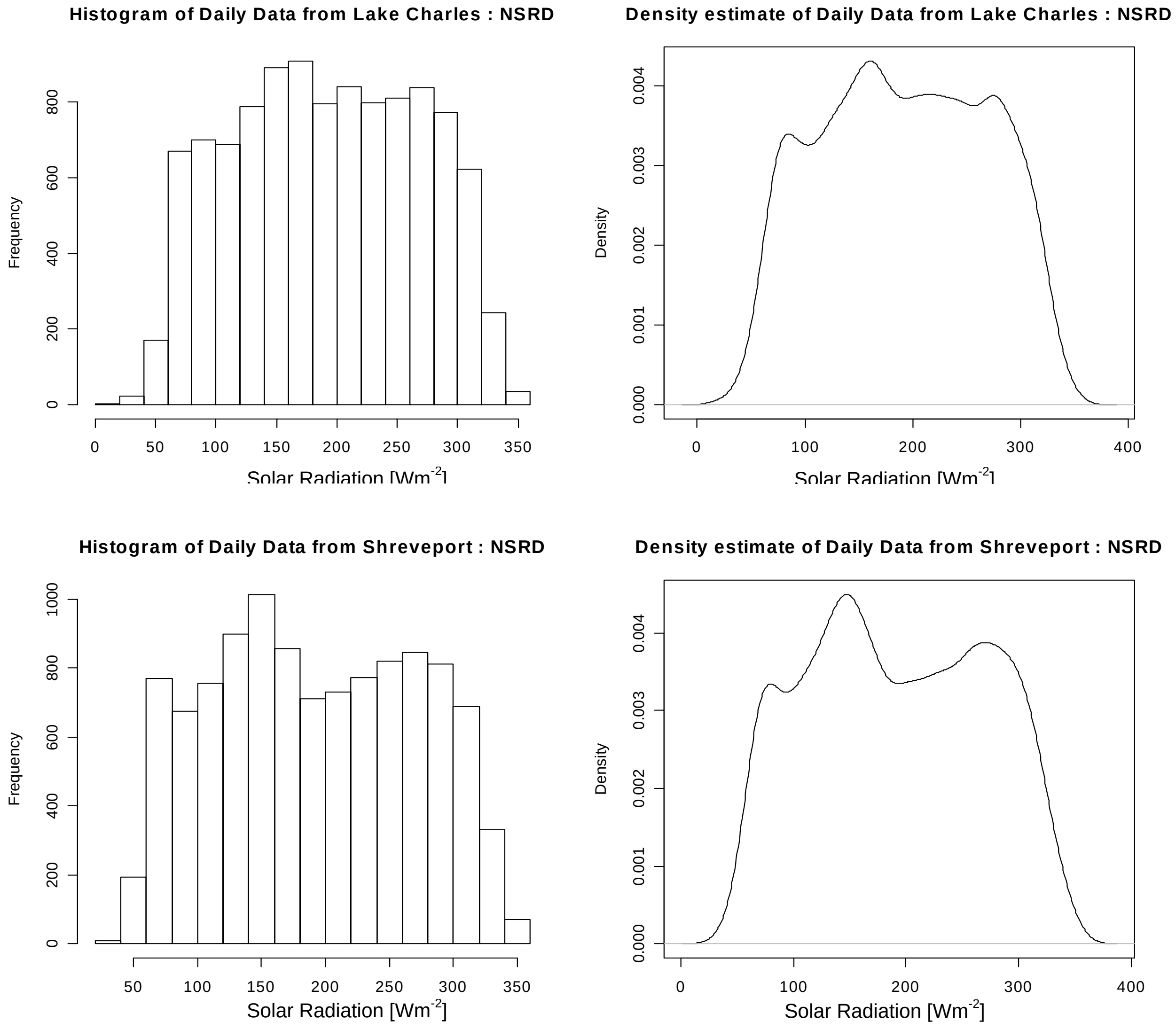
Interestingly, many of the statistics are similar at the NSRD stations. Lake Charles, the only station containing any truly measured data, displayed mean statistics that were quite similar to the others which were only modeled. However, the minimum values at the other three stations ranged from the 34.21 Wm^{-2} at Shreveport to 40.29 Wm^{-2} at New Orleans, while the minimum at the Lake Charles station was only 18.08 Wm^{-2}. The maximum value was also larger at the Lake

Charles station than at the other three. Shreveport might have been expected to display the greatest variability in solar radiation values and produce both smaller minimum and larger maximum values than the other three stations because Shreveport has both the lowest and highest daily extraterrestrial solar radiation amounts throughout the year. The greater extremes observed at Lake Charles were possibly caused by the fact that data from Lake Charles were at least partially measured whereas the data from the other three stations were solely modeled.

Tests of normality conducted on the data were done using the Shapiro-Wilk's test and Lilliefor's adaptation of the Kolmogorov-Smirnov test. Furthermore, a visual inspection of histograms and density distributions associated with the daily data from each station was conducted. While hourly data were retrieved from the NSRD, the normality tests were conducted on daily data because LAIS data had been aggregated to daily form.

An examination of the mean and median values at each station suggests that the data do not deviate significantly from normality because these two values are so similar at each site. Furthermore, the proximity of the skewness to zero at all sites further suggests normality. While all of the skewness values were quite close to zero, the closest to zero was the station at Lake Charles. This station was also the only site in the NSRD that displayed a slightly negative skewness. Once again, the differences noted between Lake Charles and the other three sites are likely due to the fact that the data from Lake Charles are at least partially measured. Regardless, all indications to this point would suggest that data from all the stations are normal.

However, the kurtosis values, a descriptor of the peakedness of a distribution, suggests otherwise at each station. The kurtosis test conducted in R returns values near three for normal distributions. Values larger than three suggest that the distribution is more sharply peaked (leptokurtic). Values smaller than three suggest a distribution which is more broadly peaked (platykurtic). In the case of all four of the NSRD stations the kurtosis values significantly (p-value < 0.01) suggest a platykurtic distribution, with Shreveport having the broadest of the four. This broadness in distribution was further verified through an examination of the histograms and density distribution plots for each site (Figure 4.1). Figure 4.1 shows the distribution of values from Shreveport (the broadest peak) as well as Lake Charles (the narrowest – though broader than a normal peak.).


Histogram of Daily Data from Lake Charles : NSRD

Density estimate of Daily Data from Lake Charles : NSRD

Histogram of Daily Data from Shreveport : NSRD

Density estimate of Daily Data from Shreveport : NSRD

Figure 4.1: Histogram and density plots representing daily data (1961-1990) from Lake Charles (top) and Shreveport (bottom).

The results of the Shapiro-Wilk test and Lilliefors (Kolmogorov-Smirnov) test (see Table 4.1) suggest that the data from all stations are not normal. This conclusion was drawn from the fact that the resulting p-value associated with each of the tests was small enough to suggest that the test statistic is significant, thus rejecting the null hypothesis that the data are distributed normally. This is likely due to the broadness of the peaks in the distributions suggested by the kurtosis values and confirmed by the histograms and density plots. In summation, the daily values at all four NSRD stations are non-normal.

4.2 General Spatial Trends in Solar Radiation in Louisiana

Figure 4.2 shows the extraterrestrial solar radiation, mean measured or modeled solar radiation at the surface, and the resulting mean transmissivity for each of the four stations in the NSRD by Julian day. This analysis allows a visual comparison of these variables between stations and throughout a climatologically-averaged year.

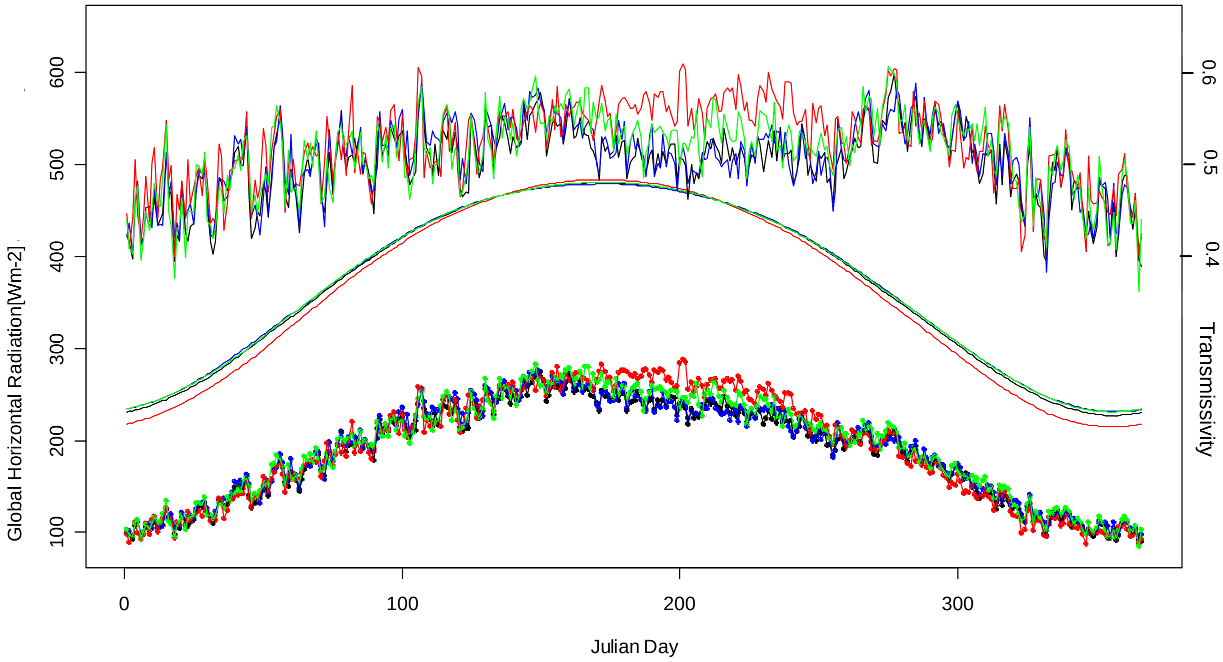


Figure 4.2: Mean values of solar radiation at the surface (bottom set of jagged lines), extraterrestrial solar radiation (set of smooth curves), and the resulting transmissivity (top set of jagged lines), by Julian day for 1961-1990. In all cases Baton Rouge is colored black, New Orleans is blue, Shreveport is red, and Lake Charles is green.

A few features from Figure 4.2 are notable. First, because of its relatively high latitude, Shreveport (red) has the largest annual range in extraterrestrial solar radiation. While transmissivity and surface solar radiation both show seasonality, they remain remarkably similar between stations throughout much of the year. Understandably, summer shows the greatest divergence in transmissivity and surface solar radiation between all stations. Summer is the time of year when patchy afternoon thunderstorms and the attendant cloud cover would have the most influence. To better inspect the summer pattern, Figure 4.3 shows the summer portion of the diurnal means calculated from the data in the NSRD.

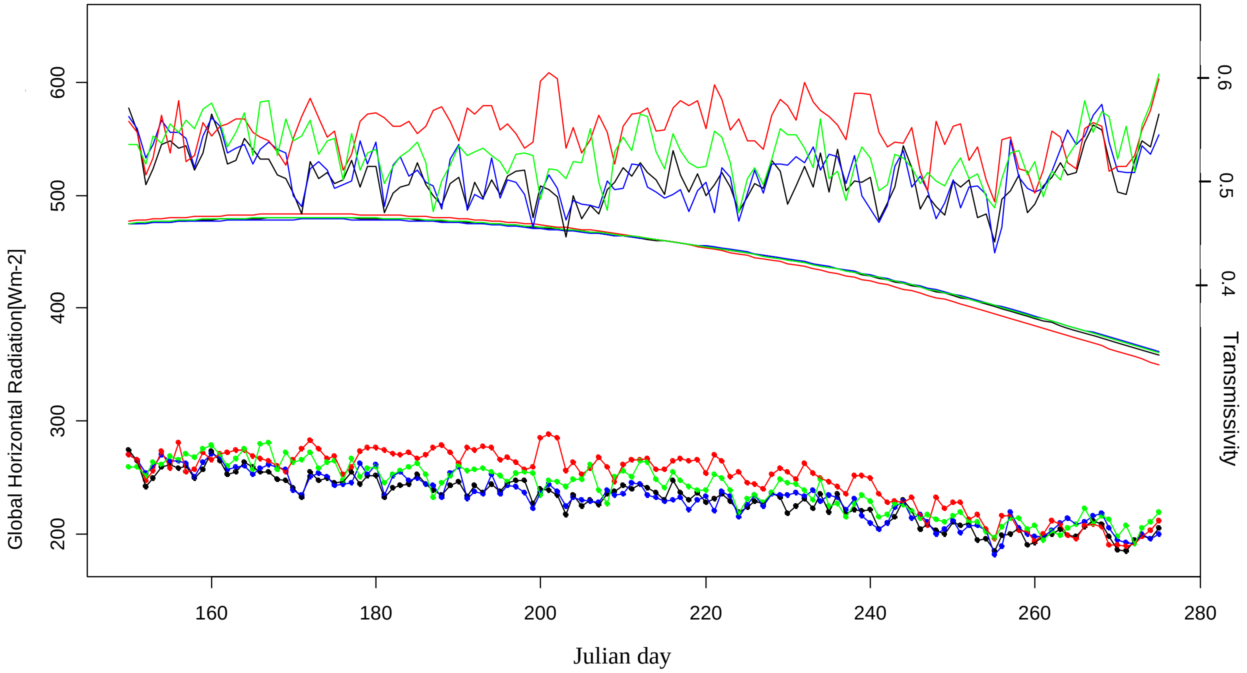


Figure 4.3: As in Figure 4.2, but for summer only.

It is apparent from Figure 4.3 that Shreveport has the highest transmissivity as well as surface solar radiation values for most of the summer. In fact, it continues to have higher values than the other stations for a time even after it stops receiving the highest extraterrestrial solar radiation loading (around Julian day 220, or August 8).

Figure 4.3 also reveals that Lake Charles (green line) generally has slightly higher summer surface solar radiation and transmissivity values than either Baton Rouge or New Orleans. It is likely that this is a result of a combination of factors including the difference in relative proximity to water (in the case of New Orleans). In addition, the circulation around the Bermuda high in summer may advect moist air more easily into the eastern portion of the state than the west. To verify that Lake Charles truly does have a higher overall transmissivity, the difference between the daily values at Lake Charles and those at the stations in the east (Baton Rouge and New Orleans) was calculated. These values were then summed to compute a total cumulative difference between the stations. The result was a difference of 60.68 between Lake Charles and New Orleans and a difference of 125.31 between Lake Charles and Baton Rouge. Therefore, the hypothesis was confirmed – southwestern Louisiana (represented by Lake Charles) does indeed have higher transmissivity than southeastern Louisiana (represented by Baton Rouge and New Orleans). However, an examination of plots of the daily, monthly, and yearly differences in transmissivity between New Orleans and Lake Charles reveals that, though transmissivity is higher at Lake Charles in total, the difference is highly variable even on a yearly basis (Figures 4.4, 4.5, and 4.6). Interestingly, these results also suggest that transmissivity at Baton Rouge is less, overall, than that at New Orleans. The causes behind this result are unclear. The result itself is unexpected because New Orleans is nearly surrounded by bodies of water.

One final interesting attribute of Figures 4.2 and 4.3 which requires note is the fact that there is a rather dramatic slump in summer transmissivity and surface solar radiation at all stations. The slump begins to occur at the beginning of the summer when extraterrestrial solar radiation values are increasing. However, while extraterrestrial solar radiation values continue to rise (or at least level off) for a time, transmissivity decreases. This is likely a result of the fact that southern Louisiana experiences a summer maximum in precipitation (Trewartha, 1981).

This slump in transmissivity and surface solar radiation begins during the time of year of peak extraterrestrial solar radiation.

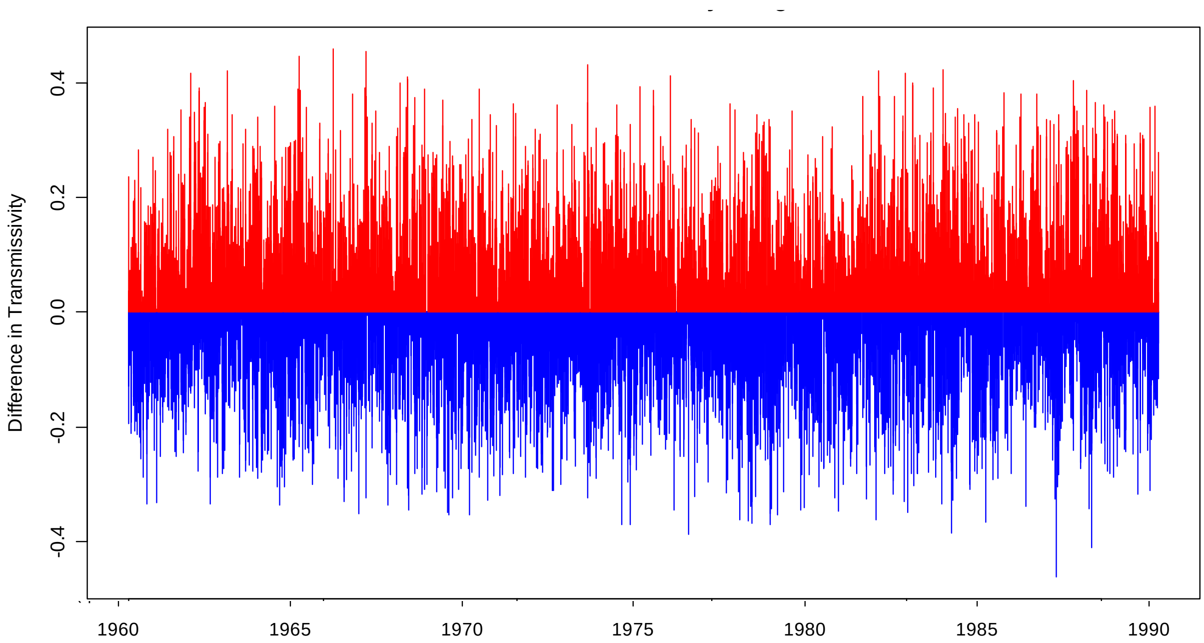


Figure 4.4: Difference in daily transmissivity between Lake Charles and New Orleans: Positive values (red) indicate transmissivity is higher at Lake Charles.

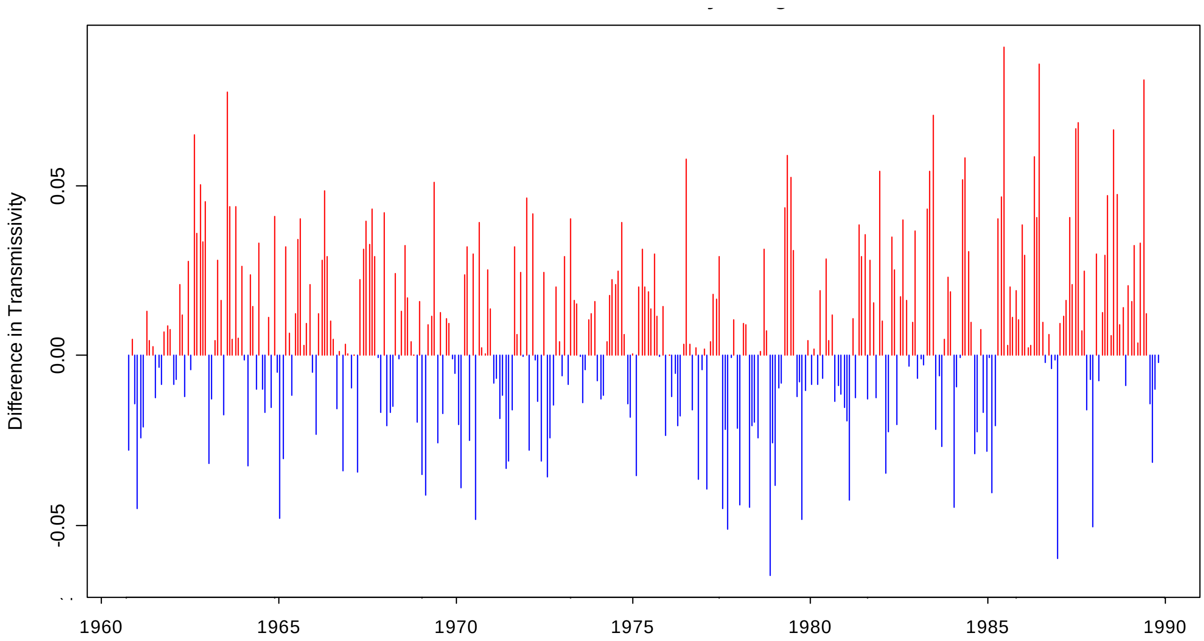


Figure 4.5: Difference in monthly transmissivity between Lake Charles and New Orleans: Positive values (red) indicate transmissivity is higher at Lake Charles.

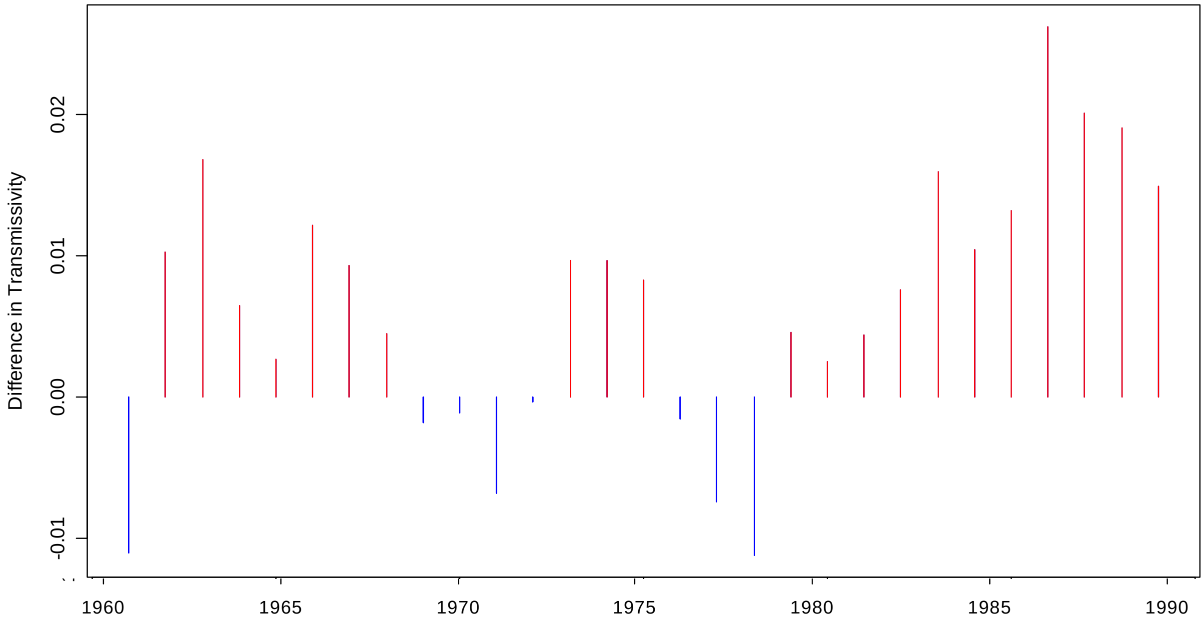


Figure 4.6: Difference in yearly transmissivity between Lake Charles and New Orleans: Positive values (red) indicate transmissivity is higher at Lake Charles.

Then, toward the end of the summer, transmissivity values and surface solar radiation begin to increase. This occurs when extraterrestrial solar radiation values are actually decreasing. This end-of-summer increase is much more pronounced for the transmissivity variable. In fact, at this time, transmissivity is higher than it was for the rest of the summer at most of the stations. Regardless, these peaks and valleys are much less pronounced in Shreveport (the station that is farthest north).

It is likely that the increase in transmissivity at the end of the summer is a result of a decrease in convective cloud cover. It is seen at the time of year when extraterrestrial solar radiation, while still relatively high, is nevertheless decreasing. This causes a decrease in cloud cover. This also explains why the fluctuations in transmissivity would be more pronounced than those in surface solar radiation because the skies are clearer, but extraterrestrial solar radiation values are decreasing. Shreveport, the station farthest from the Gulf coast, understandably displays this pattern least. It has less evaporative cloud cover in the summer and, therefore, does not show such a dramatic difference due to increased water vapor in the atmosphere. Because the decrease in surface solar radiation is less pronounced there due to the relatively limited water available for evaporation, the increase seen later in the year is also less pronounced.

4.3 NSRD Time Series Analysis

To achieve a better understanding of the temporal trends in surface solar radiation in Louisiana, a time series analysis was conducted on the 30 years of data (1961-1990) from the NSRD for the four available stations: Baton Rouge, Lake Charles, New Orleans, and Shreveport. Using additive deconstruction of the data series, the data set was separated into three components: one of each to represent the perturbations caused by seasonality, random fluctuations, and a daily trend. All three components are seen in aggregate and then separately in Figure 4.7 below. To visualize the highly variable overall trend of the data, a least squares trend line was calculated to fit the variable daily trend line created by the additive deconstruction of the time series.

The results of this deconstruction of the data and the linear trend are shown for New Orleans (Figure 4.8). This station demonstrated the steepest negative temporal trend of the four stations, on the order of approximately –0.33 Wm^{-2} per year for a total decrease of nearly 10 Wm^{-2} over the 30-year period (p-value < 2.2 e^{-16}).

Of the remaining three stations, two displayed similarly significant (p-value < 2.2 e^{-16}) negative trends, with that at Lake Charles being steeper than that at Baton Rouge. Interestingly, only Shreveport (the station farthest from the coast) demonstrated a positive trend, and this trend was statistically significant as well (p-value = 0.0003811) (Figure 4.9). These trends are presumably a result of changes in the cloud cover (increasing cloud cover in the case of the decreasing solar trend and decreasing cloud cover in the case of the increasing solar trend).

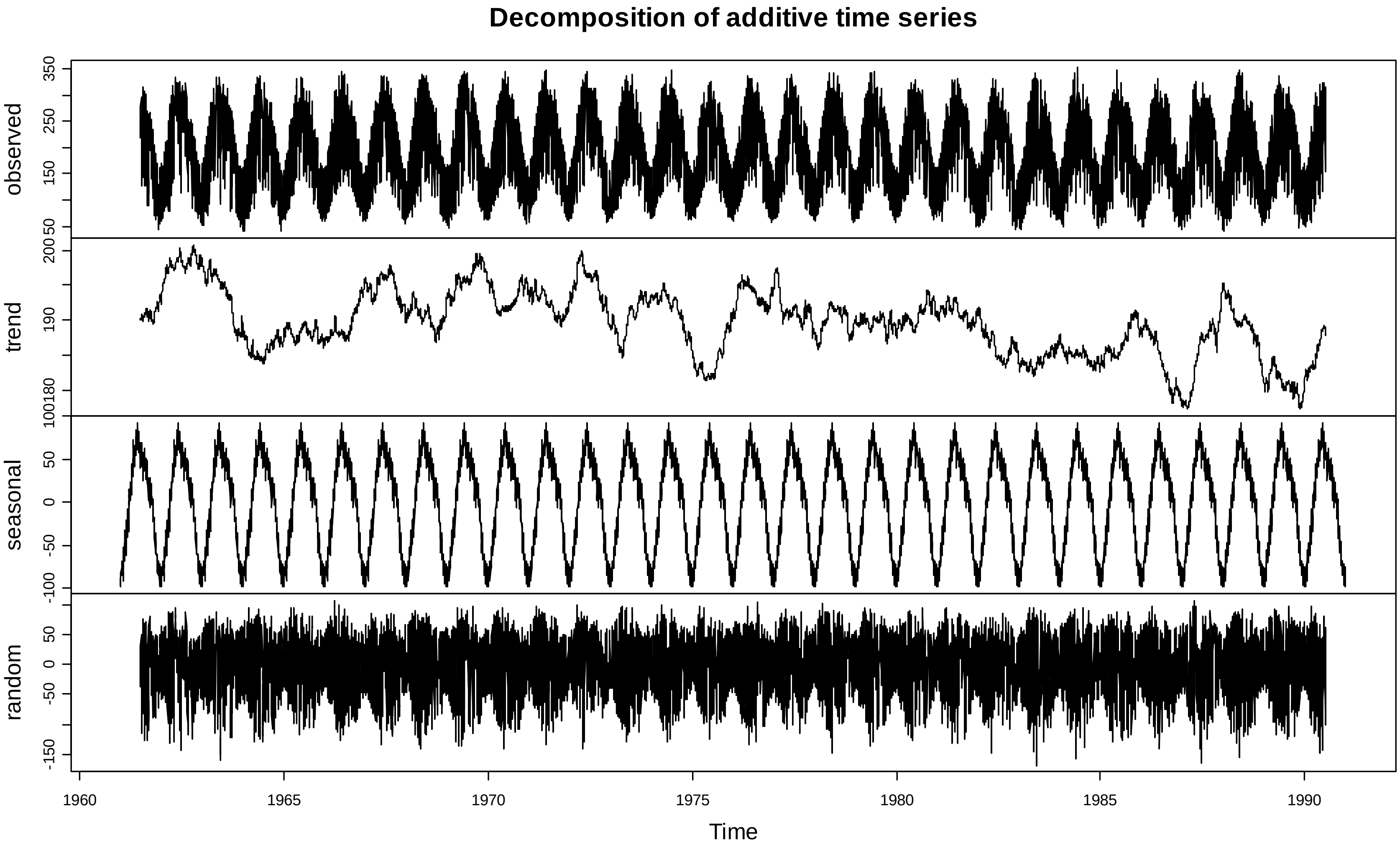


Figure 4.7: Deconstruction of additive time series – New Orleans: 1961 – 1990.

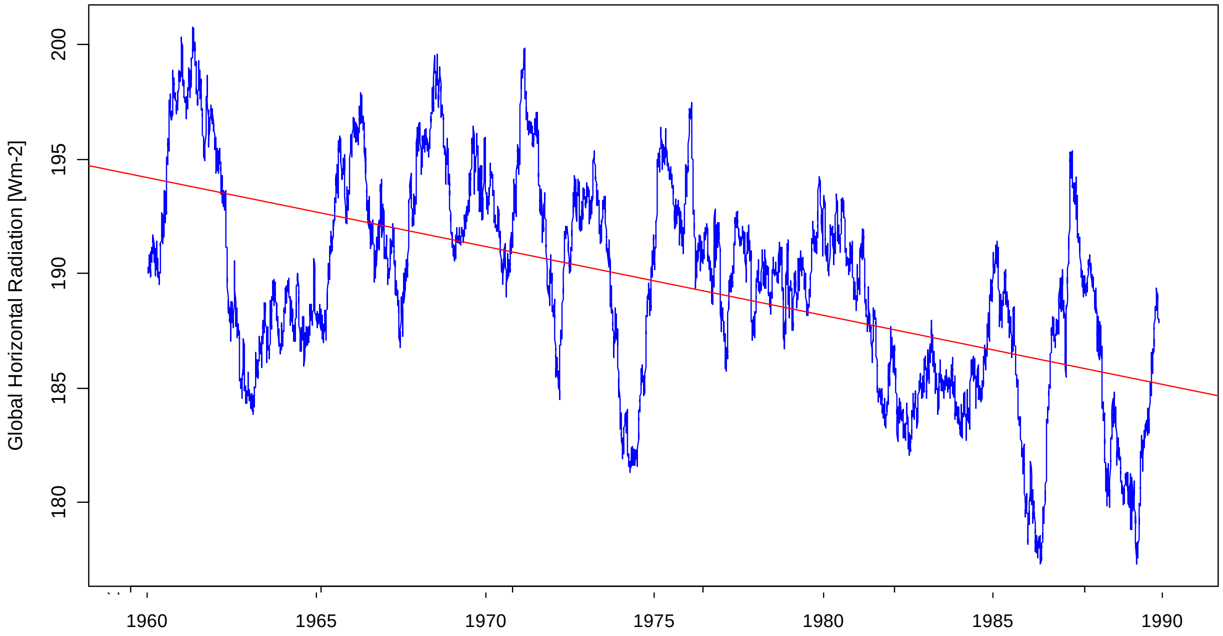


Figure 4.8: Linear trend in incoming shortwave radiation with seasonality and random fluctuations removed – New Orleans: 1961 -1990 (p-value < 2.2 e^{-16}).

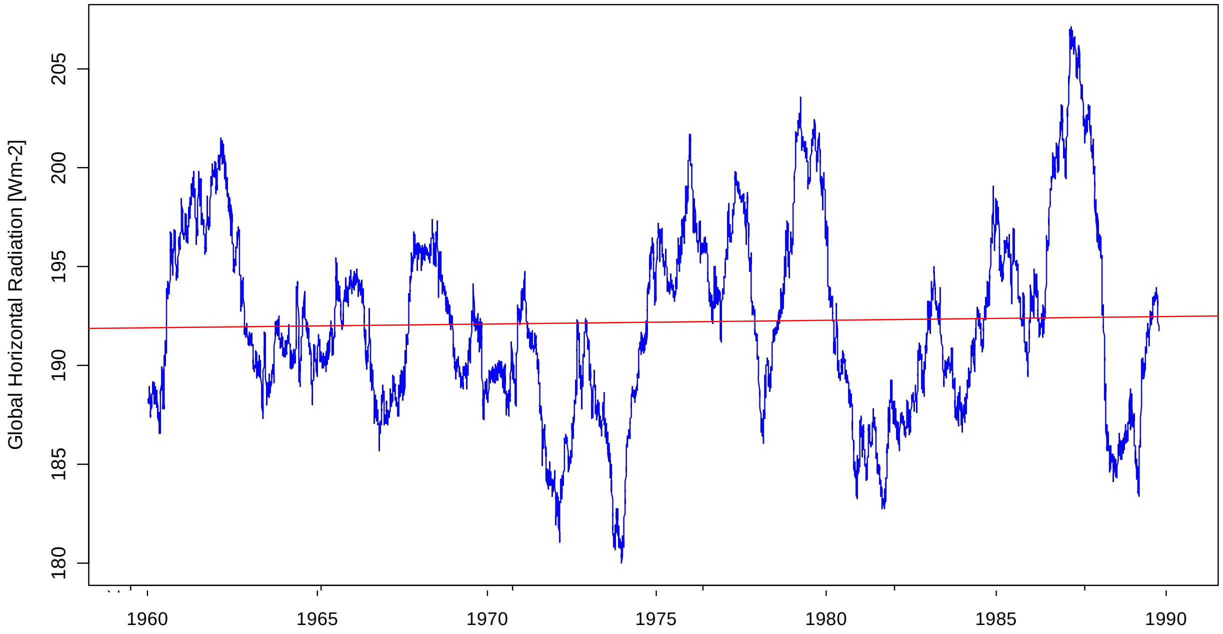


Figure 4.9: Linear trend in incoming shortwave radiation with seasonality and random fluctuations removed – Shreveport: 1961 -1990 (p-value = 0.0003811).

To corroborate the findings of these time series analyses further, annual averages of incoming solar radiation were aggregated from the daily values. These yearly average values were then plotted sequentially for each station. Of course, caution should be exercised in the interpretation of these aggregated results because the annual value may be driven by as few as one or two anomalous months within that year.

The results mirror the results found in the original time series analysis. Figure 4.10 demonstrates a plot of the annual average values for New Orleans. Comparison of this plot to that found in Figure 4.8 reveals the similar, though smoother, behavior of this annual average plot to the daily time series plot from the same location. It should be noted, however, that while the temporal trend in both graphs is highly significant, the significance in Figure 4.8 (deconstructed time series analysis) is greater than that in Figure 4.10 (annual average values).

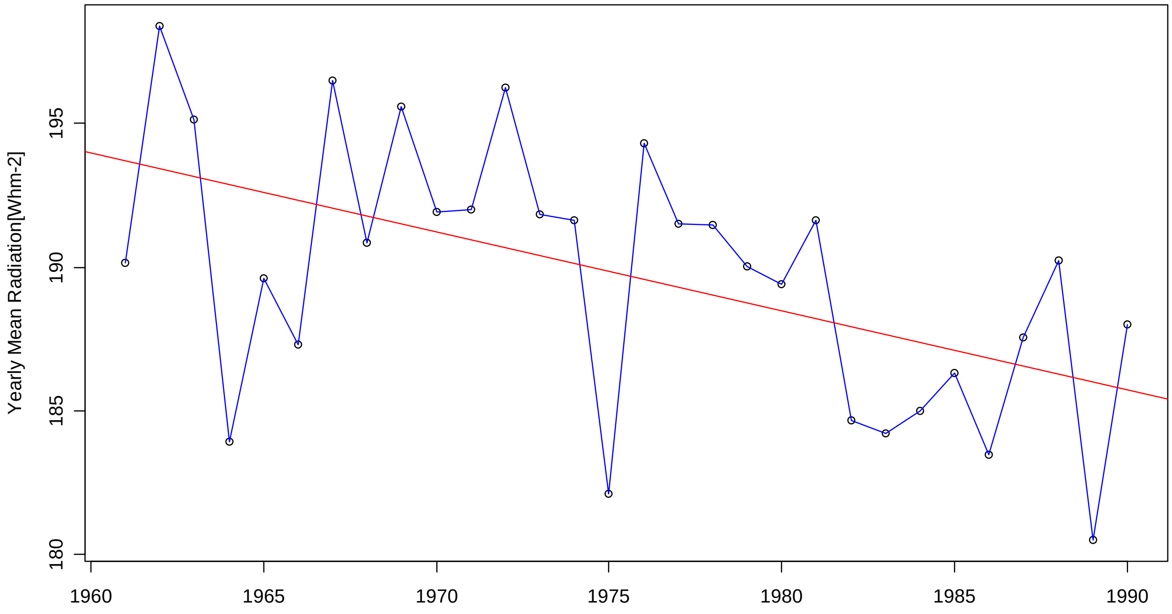


Figure 4.10: Annual mean with trend line in incoming solar radiation – New Orleans: 1961 – 1990 (p-value = 0.002515).

Time series analysis was also conducted on transmissivity values. These trends are very similar to those revealed in the solar radiation values at all four stations. Figure 4.11 shows the deconstructed time series with seasonality and random fluctuations removed from the NSRD station at New Orleans. Both transmissivity and solar radiation trend downward at Lake Charles (p-value < 2.2 e^{-16}) and Baton Rouge (p-value < 2.2 e^{-16}), and both trend upward at Shreveport. However, only the solar radiation trend is significant at Shreveport (p-value = 0.0003811). The trend in transmissivity is not nearly significant (p-value = 0.936).

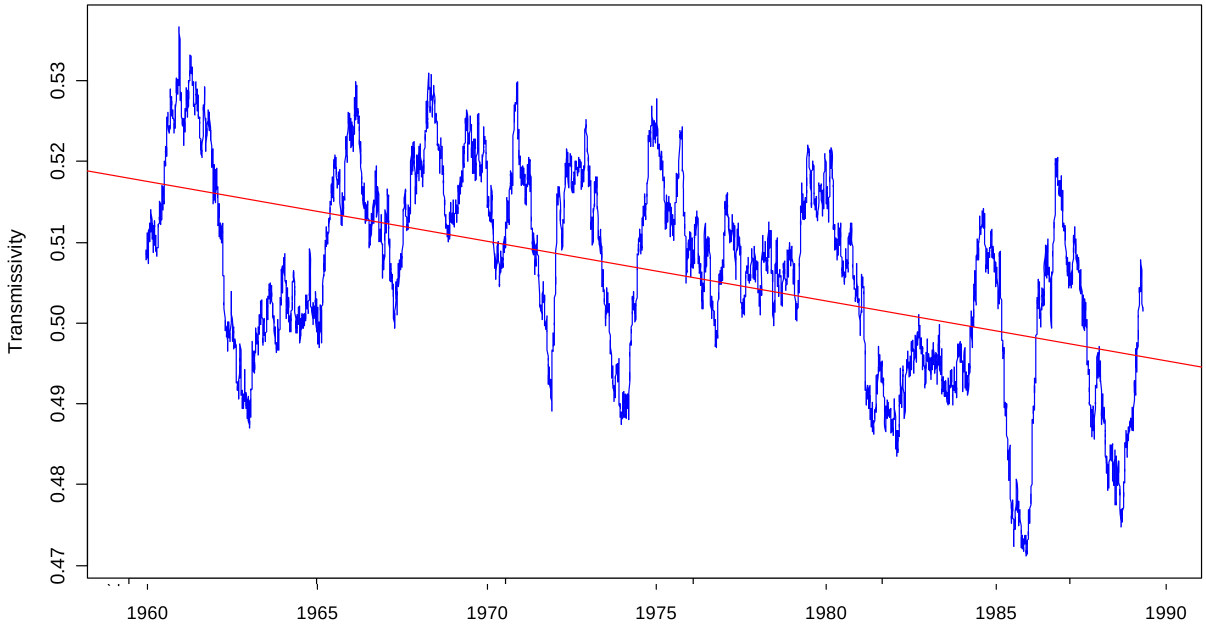


Figure 4.11: Linear trend in transmissivity with seasonality and random fluctuations removed – New Orleans: 1961 -1990 (p-value < 2.2 e^{-16}).

4.4 NSRD Month by Month Time Series Analysis

Because of the inherent difficulties with analyzing the cause of the annual trends, a month-by-month time series analysis was conducted to determine whether specific months contribute more or less to the overall trends found at the four NSRD stations. To perform this analysis, the daily solar radiation values for each station were aggregated to monthly values. Each station's monthly values were then plotted sequentially. A linear trend line was then calculated for all 12 months at all four stations. Plots representing each of the meteorological seasons (D-J-F, M-A-M, J-J-A, and S-O-N) were generated for each station. Each of these seasonal graphs contained three linear trends - one for each month within that season. This resulted in the creation of 16 plots (four plots for each station). Samples of these plots are shown in Figures 4.12 and 4.13.

While this technique is appropriate and helpful, there were simply too many lines on too many plots for convenient comparative analysis. To reduce clutter and increase clarity, Table 4.2 presents all of these linear trends in a compact form.

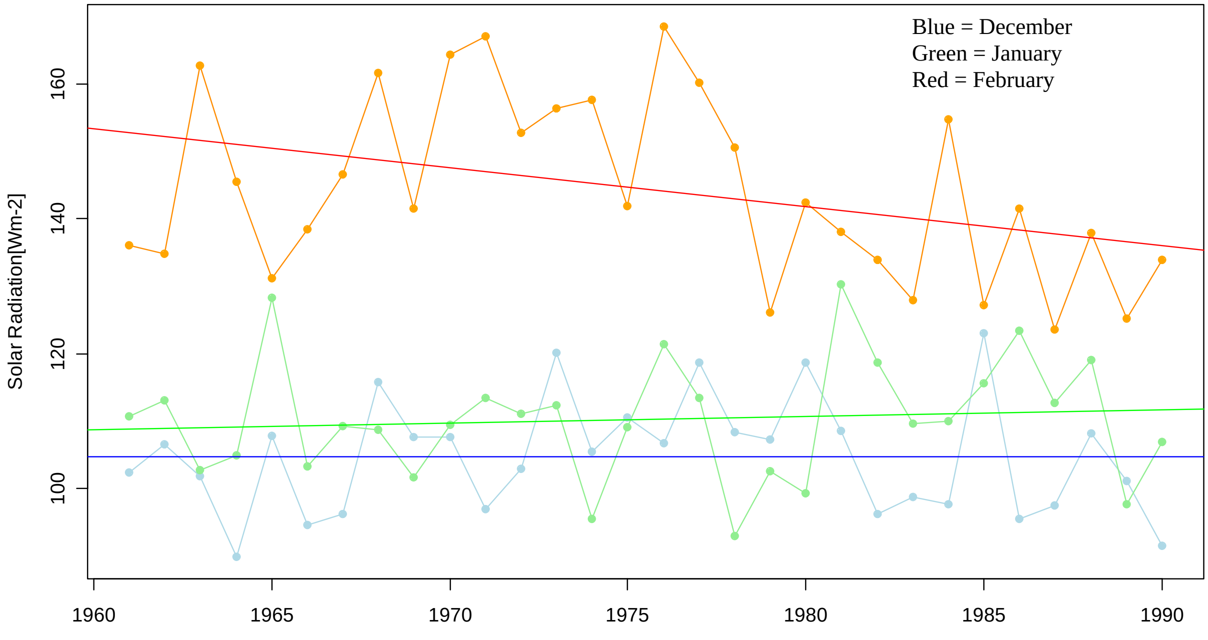


Figure 4.12: Winter monthly time series of incoming solar radiation with trend line – Baton Rouge: 1961-1990.

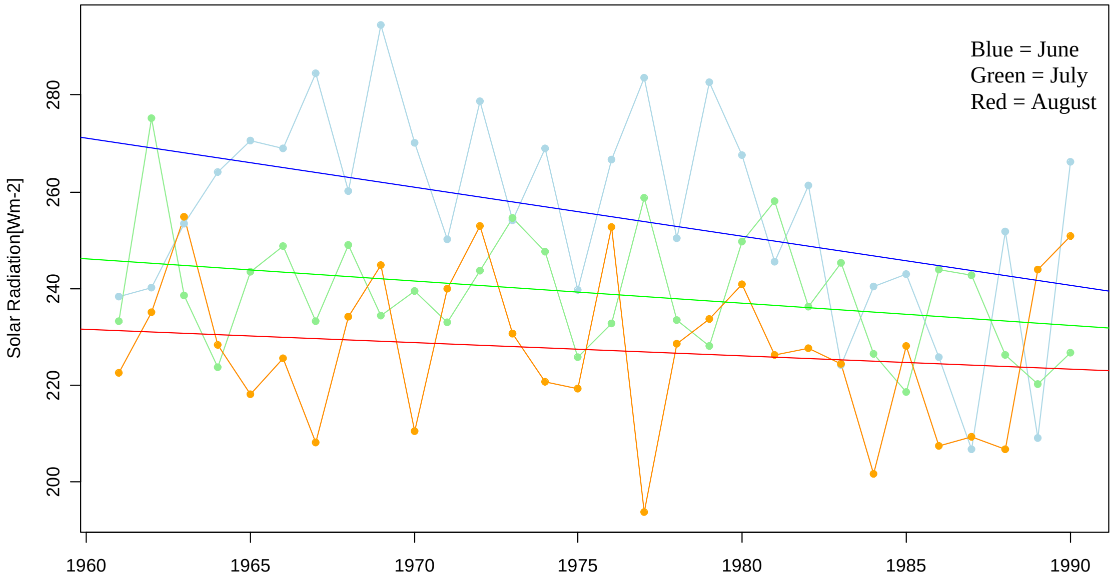


Figure 4.13: Summer monthly time series of incoming solar radiation with trend line – New Orleans: 1961 – 1990.

Table 4.2: Month by month comparison of linear temporal trends in incoming shortwave radiation, with p-values: 1961-1990 (NC = 'no change').

	New Orleans	Lake Charles	Baton Rouge	Shreveport
January	increase (0.3953)	increase (0.8556)	increase (0.5981)	increase (0.5943)
February	decrease (0.1304)	decrease (0.008384)	decrease (0.04045)	decrease (0.2004)
March	increase (0.7798)	decrease (0.8173)	increase (0.9285)	NC (0.9995)
April	increase (0.802)	increase (0.1203)	increase (0.2467)	increase (0.08792)
May	decrease (0.00575)	decrease (0.2340)	decrease (0.2275)	decrease (0.4818)
June	decrease (0.02209)	decrease (0.1715)	decrease (0.4905)	decrease (0.8216)
July	decrease (0.08796)	increase (0.8974)	increase (0.599)	increase (0.8653)
August	decrease (0.4271)	increase (0.1627)	increase (0.6445)	increase (0.2146)
September	increase (0.9005)	increase (0.5692)	increase (0.3678)	increase (0.1808)
October	decrease (0.1498)	decrease (0.1154)	decrease (0.2137)	decrease (0.1498)
November	decrease (0.5011)	decrease (0.05953)	decrease (0.7498)	decrease (0.7599)
December	decrease (0.8459)	decrease (0.5205)	NC (0.9914)	increase (0.605)

Several interesting aspects of this table are noteworthy. First, the trends existing in five months (February, May, June, October, and November) are negative at all four stations. These trends are significant (p-value < 0.05) at Lake Charles and Baton Rouge for February, and at

New Orleans for May and June. Interestingly, the negative trend appears to be more significant for stations near the coast and less significant for inland stations in June and November (more so in June).

Similar negative trends for specific months at various stations may be expected, especially because the overall trend at three of the stations is negative and the only station with a positive trend is only slightly so.

However, there are also similarities between months, stations, and *positive* trends. Trends for January, April, and September are positive at all stations. However, only the increasing trend in April at Shreveport is even marginally significant (p = 0.08792). For January, Lake Charles exhibits the smallest increase while the other three sites show greater increases, though none of these changes can be considered significant. For April, New Orleans displays the least significant increase (which was much less significant than the other three stations). In September, Shreveport exhibits a more significant increase than the other three sites. However, none of the changes seen in September are statistically significant.

Therefore, for two-thirds of the months of the year, incoming solar radiation at all four stations displays similar trends. Only March, July, August, and December display discrepancies among the sites, but upon further examination, these remaining months have interesting properties as well. For both July and August, solar radiation at New Orleans is unique among the stations. In both months, New Orleans displays a decreasing trend while the remaining stations all experience increasing trends to varying degrees. However, only the month of July at New Orleans is significant (p = 0.08796). Baton Rouge exhibits a moderately increasing trend in both months, yet neither is statistically significant. Lake Charles and Shreveport have similar trends in both months; for July, they both have insignificant increases, while in August, they both exhibit increases of greater (though still not considerable) significance.

The month of March is rather anomalous. There seems to be very little pattern to the changes seen in that month. However, it may be noted that all of the stations experience only moderate changes at best and none are significant. Baton Rouge displays only a very slight increase and Shreveport shows no change at all. Perhaps the transitional nature of March causes differences to exist among the sites. In some years, cold fronts and their accompanying cloud cover stall in one region of the state while in others they tend to stall elsewhere.

The stations' trends for December seem to be related to their coastal proximity. Both New Orleans and Lake Charles exhibit decreasing trends (particularly Lake Charles). Baton Rouge experienced no change at all, and Shreveport actually demonstrates a slightly increasing trend. However, none of these trends is statistically significant. The cause for these trends should be investigated further in future research.

In summary, the most significant changes in incoming solar radiation are seen at the two coastal stations and both are decreases. The month of May at New Orleans and February at Lake Charles demonstrate highly significant decreasing trends (p-value < 0.01), with the trend at New Orleans being ever so slightly more significant.

4.5 Solar Radiation's Influence on Temperature

Solar radiation's influence on temperature in Louisiana was inspected through an examination of their trends in relation to one another. Similar to the process used to extract trend from the solar radiation data, additive deconstruction of the time series was performed to remove seasonality and random fluctuations from the minimum and maximum temperature data representing the stations in the NSRD. Once these confounding fluctuations were removed and the resulting trend exposed, the variables could be compared. However, to facilitate direct comparisons, z-scores were calculated to represent the values in each trend line. In this manner, all of the trends could be plotted on the same plot using the same scale.

Figure 4.14 compares trends in solar radiation, transmissivity, maximum temperature, and minimum temperature for the 30 years in the NSRD database for Lake Charles. It is readily apparent that the solar radiation and transmissivity trends, and the maximum and minimum temperature trends, remain as coupled pairs. However, the two pairs of trends do not seem to remain together. In fact, the two pairs of trends diverge greatly at some parts of the graphs. To quantify the relationship between the trends in solar radiation and the two temperature variables, the variables were plotted against one another and a least squares line was calculated to explain the distribution. Figures 4.15 and 4.16 display solar radiation trend plotted against maximum temperature trend and against minimum temperature trend, respectively. Both are from data at the Lake Charles station which was at least partially measured.

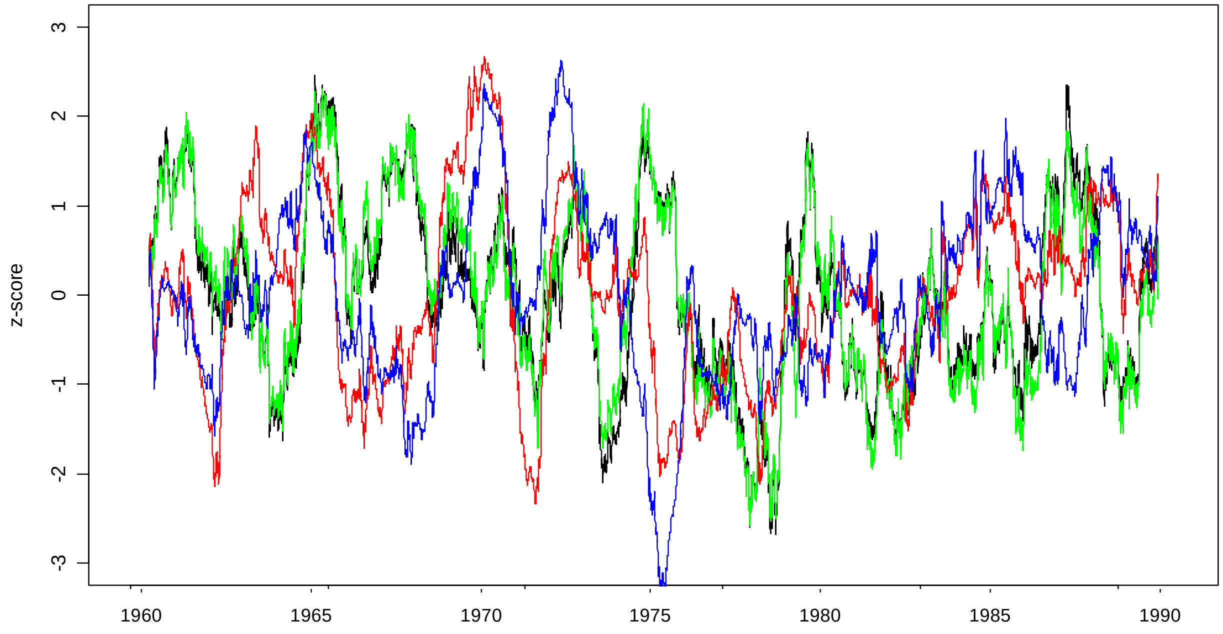


Figure 4.14: Comparison of trend in solar radiation (black), transmissivity (green), maximum temperature (red), and minimum temperature (blue) – Lake Charles: 1962-1990.

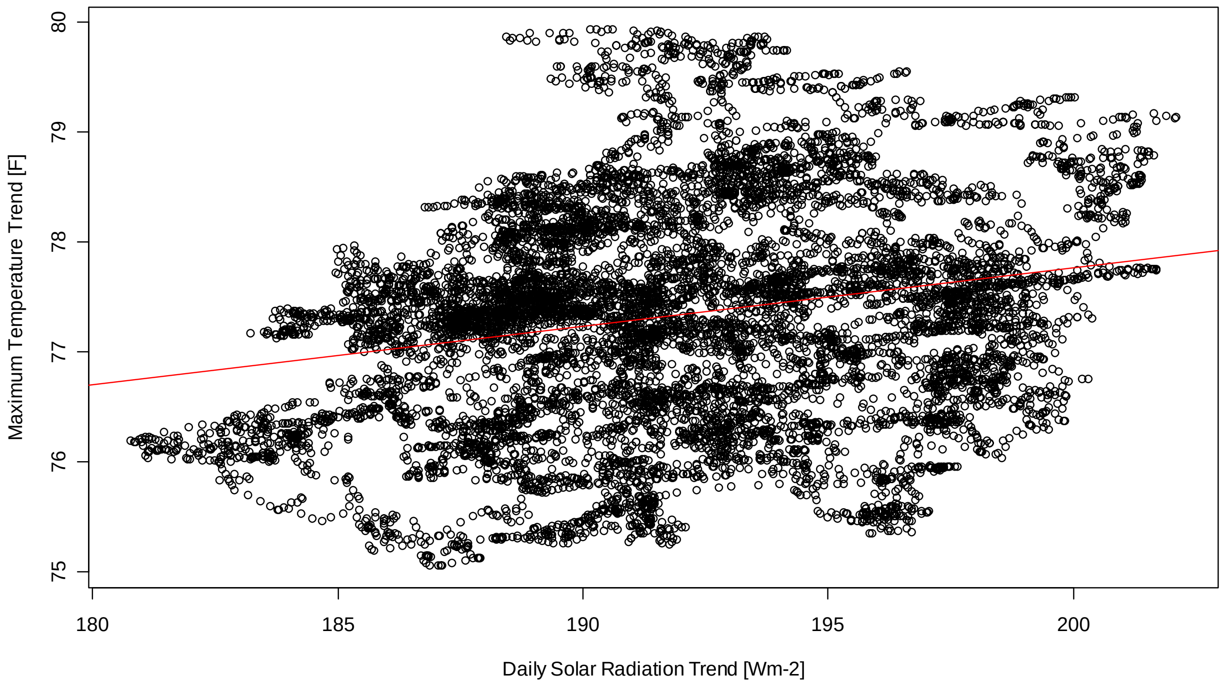


Figure 4.15: Solar radiation trend plotted against maximum temperature trend with a least squares regression line – Lake Charles: 1962 – 1990 (p-value < 2.2e^{-16}).

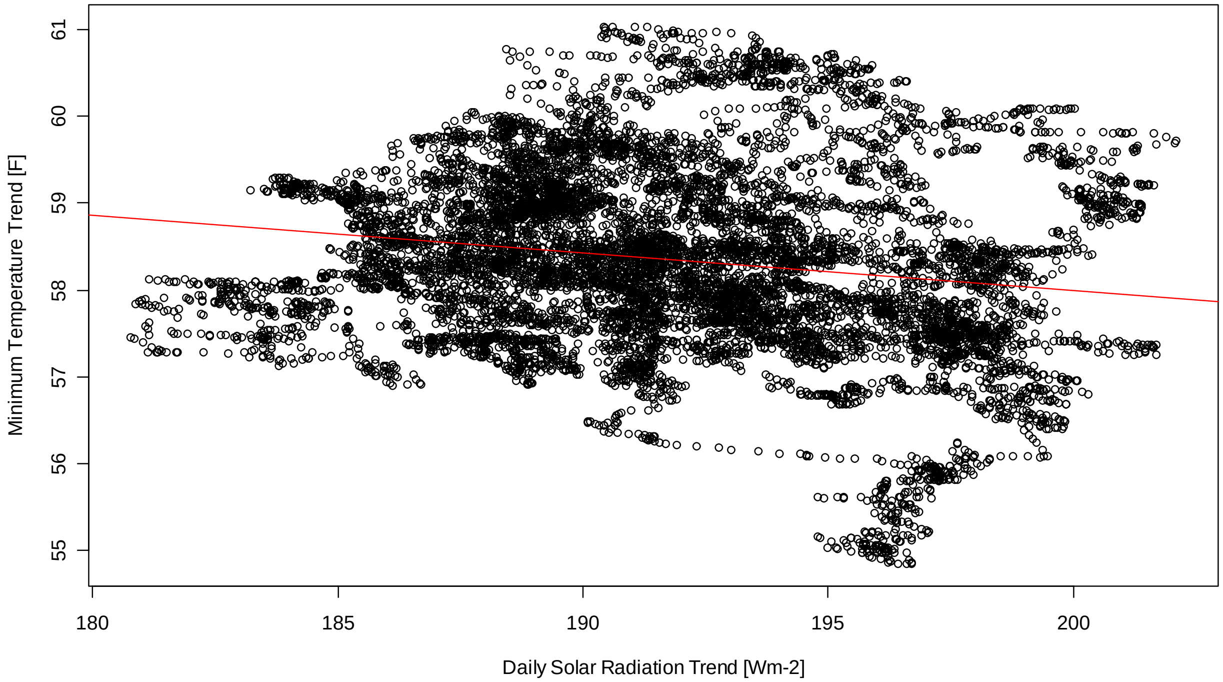


Figure 4.16: Solar radiation trend plotted against minimum temperature trend with a least squares regression line – Lake Charles: 1962 – 1990 (p-value < 2.2 e^{-16}).

It appears that at all four NSRD stations, as solar radiation trends upward over time, maximum temperatures also trend upward, but minimum temperatures trend downward. This is true in reverse order as well. As solar radiation trends downward, maximum temperatures trend downward while minimum temperatures trend upward. The steepest positive relationship (solar radiation against maximum temperature) was seen at Shreveport, but the associations at all of the stations was significant (p-value < 2.2 e^{-16}). The gentlest slope was at Baton Rouge. The slope of the negative relationships (solar radiation against minimum temperature) was of a similar steepness and significance at all stations (p-value < 0.001).

The result suggests that, as solar radiation values decrease (which they have been shown to do at three of the four stations), maximum temperatures would also decrease just as minimum temperatures would increase. This result is important because increasing minimum temperatures have different impacts than increasing maximum temperatures. For example, growing season length is dictated by the minimum temperatures, and increasing minimum temperatures would tend to lengthen the growing season.

Figures 4.17, 4.18, and 4.19 show trends in daily global horizontal radiation, maximum temperature, and minimum temperature, respectively, for the Lake Charles station.

In the case of the Lake Charles station, over the thirty years of the study, solar radiation decreased rather dramatically, maximum temperature increased slightly, and minimum temperature increased more steeply and at a higher significance level than did maximum temperature. This is not exactly what would be expected in the context of the apparent relationships described earlier between solar radiation trend and trends in maximum and minimum temperature. Instead, while minimum temperature did increase as expected, maximum temperature unexpectedly increased as well. However, the trend in maximum temperature had the lowest significance of the three. It is postulated that the apparent increase in maximum temperature could be in response to other factors, most probably the urban heat island effect.

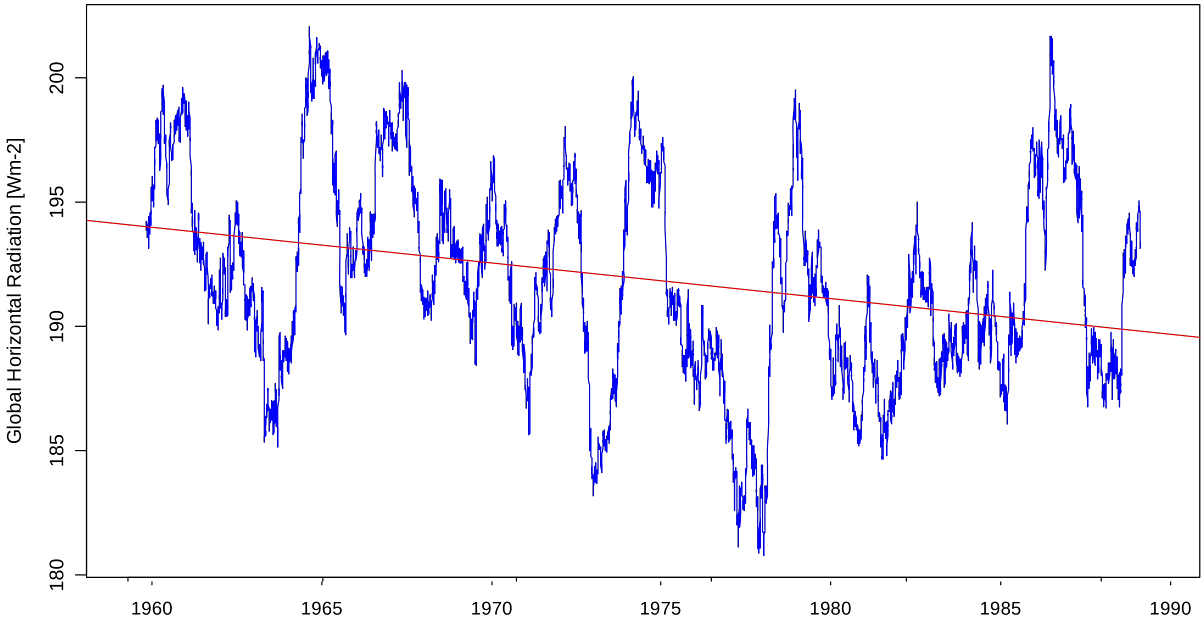


Figure 4.17: Linear trend in global horizontal radiation with seasonality and random fluctuations removed – Lake Charles: 1962-1990 (p-value < 2.2 e^{-16}).

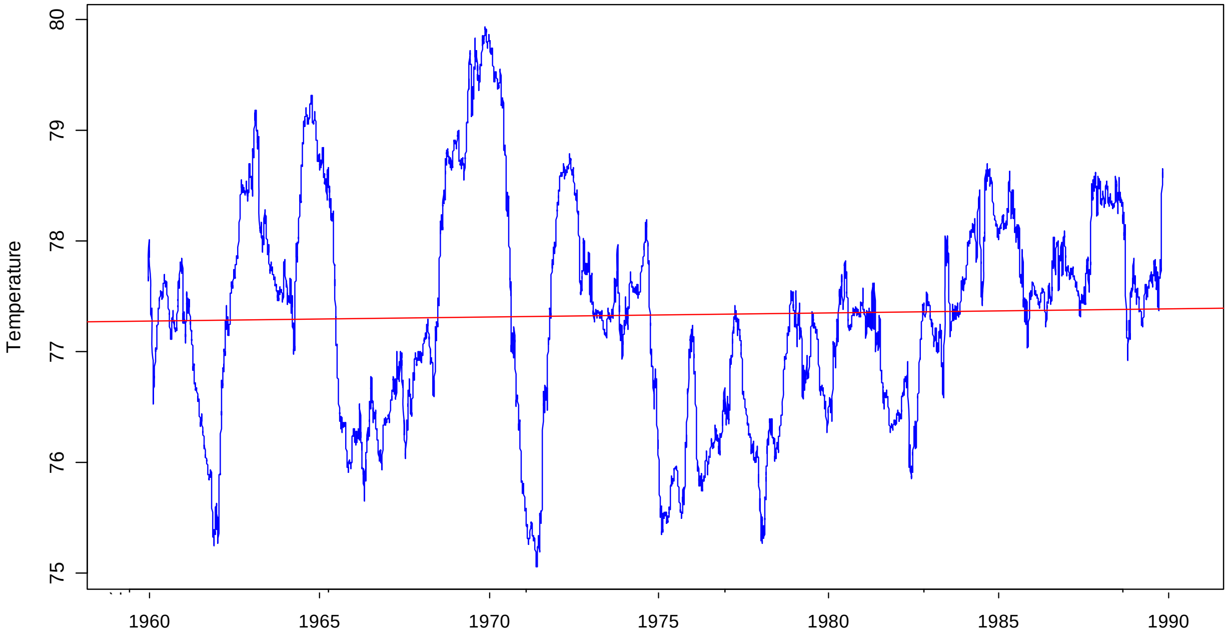


Figure 4.18: Linear trend in daily maximum temperature with seasonality and random fluctuations removed – Lake Charles: 1962 – 1990 (p-value = 0.00163).

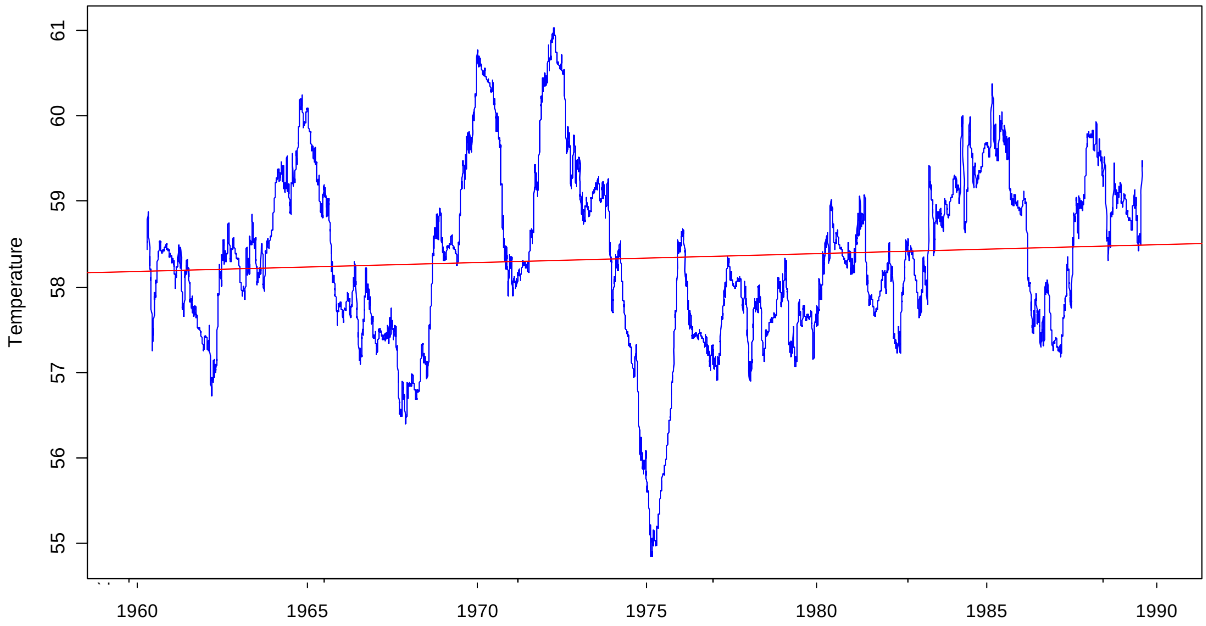


Figure 4.19: Linear trend in daily minimum temperature with seasonality and random fluctuations removed – Lake Charles: 1962 – 1990 (p-value < 2.2 e^{-16}).

Trends in solar radiation and temperature at the other three NSRD stations were similar to those at the Lake Charles station. The other three stations display the following results:

New Orleans: solar radiation decreased (p-value < 2.2 e^{-16}), maximum temperatures increased (p-value < 2.2 e^{-16}), minimum temperatures increased (p-value < 2.2 e^{-16}).

Baton Rouge: solar radiation decreased (p-value < 2.2 e^{-16}), maximum temperature decreased (p-value < 3.856 e^{-10}), minimum temperature increased (p-value < 2.2 e^{-16}).

Shreveport: solar radiation increased (p-value = 0.0003811), maximum temperature increased (p-value < 2.2 e^{-16}), minimum temperatures decreased (p-value < 2.2 e^{-16}).

The inverse relationship between solar radiation and minimum temperature is apparent in the overall trends at all stations and is of the highest significance at all stations. That is, at all stations, whether solar radiation increased or not, minimum temperatures did the opposite. This result is explained by the presence of relatively little cloudiness when solar radiation is anomalously high. The lack of cloudiness would facilitate the loss of longwave terrestrial radiation, resulting in significant nocturnal cooling. The same lack of cloudiness would allow maximum temperatures to increase under conditions with less atmospheric absorption and scattering of shortwave solar radiation. On the other hand, an increase in surface solar radiation receipt is associated with increased evaporation if water is readily available and therefore increased water vapor in the atmosphere. This, in turn, could reflect more incoming shortwave solar radiation and absorb more longwave radiation. This feedback would theoretically cause maximum temperatures to decrease and minimum temperatures to increase. By contrast, decreases in incoming shortwave solar radiation would decrease evaporation and decrease water vapor in the air. This results in an increase in maximum temperatures and a decrease in minimum temperatures. These are complex negative feedback mechanisms that work against one another with the result of stabilizing the system.

Nevertheless, the positive relationship between solar radiation and maximum temperature does not hold true in the overall trends at all stations. In the two “coastal” NSRD stations (Lake Charles and New Orleans), the overall trend in incoming solar radiation is downward, even while the overall trend in maximum temperature is upward. Interestingly, in the only cases that do not behave as expected (the maximum temperature trends at New Orleans and Lake Charles) the trends in maximum temperature are upward. This adds further credibility to the suggestion that the urban heat island effect has a marked influence on maximum temperature. Furthermore, *mean* daily temperatures at these two locations significantly increased (p-value < 0.01) over this period as well.

However, because these results were not as expected, further examination of the relationships between solar radiation and temperature was necessary. Actual solar radiation and temperature values were plotted against one another. Not surprisingly, a strong positive relationship was found between solar radiation and maximum temperatures, and also between solar radiation and minimum temperatures. This is largely expected because summer is associated with greater solar radiation intensity as well as increases in both maximum and minimum temperatures, while winter is the opposite.

One final set of tests was conducted to examine the possibility that these relationships might be different for different times of the year. The months of January and July were selected to represent a winter month and a summer month, respectively. The January solar radiation values were compared to the minimum and maximum temperature values for that month and similarly for the month of July. The associations identified in the comparison of actual values are quite interesting. A breakdown of the results appears as Table 4.3 below.

Table 4.3: Relationships and p-values associated with solar radiation values and maximum/minimum temperatures for January and July at the four NSRD stations.

	Stations	Solar Radiation/Max Temps	Solar Radiation/Min Temps
January	Baton Rouge	Negative (0.2296)	negative (< 0.001)
	Lake Charles	positive (0.2697)	negative (< 0.001)
	New Orleans	Negative (0.006778)	negative (< 0.001)
	Shreveport	positive (< 0.001)	negative (< 0.001)
July	Baton Rouge	positive(< 0.001)	positive (< 0.001)
	Lake Charles	positive(< 0.001)	positive (< 0.001)
	New Orleans	positive(< 0.001)	positive (0.2725)
	Shreveport	positive(< 0.001)	positive (0.001455)

For January at all stations, there is a strong inverse relationship between solar radiation values and minimum temperatures. This is likely because in winter, the coldest days are associated with clear skies which result from cold-core anticyclones being advected southward on the ridge-to-trough side of the upper-level midlatitude Rossby waves. These clear skies facilitate the increase in terrestrial radiation transmission upward through the atmosphere and out to space. On the other hand, the relationship between solar radiation values and minimum temperatures in July is positive (and highly significant for all stations except New Orleans). Apparently, summer heat waves add moisture to the atmosphere and also provide abundant storage of heat near the ground sufficient to keep minimum temperatures higher than normal.

It was also found that the relationship between solar radiation values and maximum temperature is strongly positive and highly significant for July. However, the relationships between these variables in January vary depending on the station. Only New Orleans (which has a negative association) and Shreveport (which has a positive association) display statistically significant relationships. These results suggest that the warmest (coldest) January afternoons in Shreveport are associated with clear (cloudy) conditions, but that warmest (coldest) January afternoons in New Orleans are associated with cloudy (clear) conditions. In Shreveport, warm winter afternoons seem to require clear skies to heat the surface, while the passage of cold fronts with attendant frontal overrunning that stall south of Shreveport would create the cold, cloudy conditions. For New Orleans, the warmest January afternoons are linked to maritime tropical air masses with abundant cloudiness and moisture, while cold-core anticyclones produce the relatively-cloud free conditions.

These results are interesting as they suggest that not only is solar radiation associated dissimilarly with maximum and minimum temperature in January, but also that the associations are dependent upon time of year (especially in the case of minimum temperature). Location within the state also seems to be important in explaining the association between solar radiation and maximum temperature in January. These results could help to explain the apparent inconsistencies uncovered in the original examination of the relationships between solar radiation and temperature.

A re-examination of the month-by-month time series indicates that three months – May, June, and July – contributed most significantly to the overall decrease in solar radiation at New Orleans. Yet, temperatures still increased, perhaps due to the urban heat island. Had the most significant decreases in solar radiation been seen in winter months, it would have been possible that the anomalous overall maximum temperature trend at New Orleans was partly in response to the fact that the greatest decreases in solar radiation occurred in times of the year in which increased solar radiation is associated with decreased maximum temperature.

Lake Charles' most significant decreases in solar radiation were in February and November (with February being the most significant). However, the relationship between solar radiation and maximum temperature at Lake Charles is still positive for its representative winter month. Therefore, it seems likely that the urban heat island may have been a contributing factor to the observed disassociation between solar radiation and maximum temperature.

According to data from the United States Census Bureau, the population of Calcasieu Parish, of which Lake Charles is a part, grew from 145,475 in 1960 to 168,134 in 1990 and Jefferson Parish, in which the New Orleans airport lies, grew from 208,769 in 1960 to 448,306 in 1990 (United States Bureau of the Census, 2007). The Lake Charles Regional Airport (at which the Lake Charles NSRD station is located) began operation in 1961 and has no doubt grown from its inception and today includes a 300 acre industrial park (Lake Charles Regional Airport, 2007). The New Orleans Airport (the Louis Armstrong Airport today) opened in 1946 and underwent its first major expansion project in 1974 (Louis Armstrong International Airport, 2007). It seems plausible that these increases in population and infrastructure led to an increased urban heat island effect which in turn increased the maximum temperature regardless of the decrease in solar radiation.

4.6 Summary

The overall temporal trend in solar radiation from 1961 to 1990 at three of the four stations in the NSRD in Louisiana is negative (and significantly so). Shreveport, the only station which displays an increasing trend, is the farthest north and the farthest from a large water body. This positive trend at Shreveport is also the least significant (though still significant at p-value < 0.001) of the trends in solar radiation from the four NSRD sites. A positive association between solar radiation and maximum temperatures was identified. However, because two of the stations' overall trends do not reflect this association and in both cases the maximum temperature trend is upward, it seems likely that the effect of the urban heat island is a greater contributing factor to the increase in maximum temperature. The significant negative association between solar radiation and minimum temperatures holds true across all stations and the overall trends at all stations behave as would be expected under this association. Finally, it was found that the positive and negative relationships between solar radiation and maximum/minimum temperature are, in some instances, dependent on season and location. In the next chapter, the results derived from examinations conducted on data from the LAIS will be explored.

CHAPTER 5

LAIS RESULTS

5.1 LAIS General Statistics and Normality Tests

To understand the basic distribution of data values in the LAIS, general statistics were examined and tests of normality were conducted at each station for the sake of completeness. Because the distributions from the NSRD data set were found to be non-normal, it was assumed that the stations in the LAIS should be non-normal as well. The tests also provided descriptive statistics and information about the relative normality at each site. Not surprisingly, the distribution of data at all of the LAIS stations was found to be non-normal. Appendix A provides a complete breakdown of the statistical findings at each of the 25 LAIS stations including: maximum value, minimum value, mean, median, first quartile, third quartile, standard deviation, skewness, kurtosis, number of missing values, and the results of the Shapiro-Wilk and Lilliefors tests for normality. The general statistics of the data from the stations in the LAIS are highly variable from one site to the next; much more so than the variability between stations in the NSRD. This, also, was to be expected in the LAIS data set because there was so much variability in the values from one station to another.

5.2 LAIS Station's Data Descriptions

Figure 5.1 shows the subjectively-determined data quality for the LAIS stations. It must be noted that a green dot at a station in Figure 5.1 does not guarantee (and in some instances should not even suggest) that the data from that station are high-quality. It simply means that the data from that particular station could not be deemed to be inaccurate. Therefore, a more concise description of the data at each station follows. The descriptions indicate the likely accuracy of the data collected at each station. These descriptions also indicate some stations that, while portrayed with a green dot, should still be used cautiously.

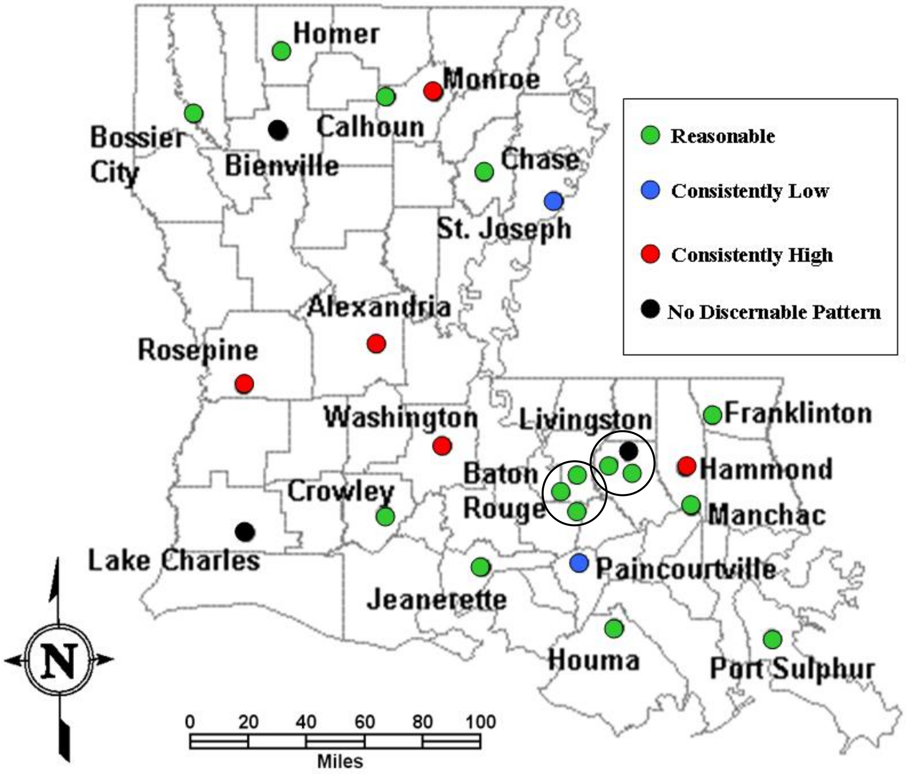


Figure 5.1: Stations in the LAIS with colors representing the overall data quality at each site.

Ben Hur (Baton Rouge West)

Overall, the Ben Hur station has high-quality data, with the time series beginning in September 2001. Measurements in the early part of the time series appear to underestimate solar radiation slightly. By the beginning of 2002, the data values become erratic and quite a few erroneous values are reported. The situation progressively deteriorated during the year until the middle of July 2002 when, apparently, a correction was made. The values from that point forward are reasonable, but there are several low values each year that cause the data to be slightly spurious.

Bienville

The data from the Bienville station are deemed spurious for the duration of the data set. Overall, there are too many missing and obviously inaccurate data values at this site to identify any sizable portions that may be reasonable. No values were reported until the middle of July 2002. These data values are impossibly large (even up to twice the value of the extraterrestrial solar radiation!). These data remained erroneous, if values were recorded at all, until May of 2003, when no subsequent measurements were taken until the beginning of July 2003. These values, while apparently low, nevertheless might be considered reasonable. However, by October of the same year these data had fallen to values that were well below reasonable. The data remained low or missing for the rest of the data set. Interestingly, around the time of April through June and again in September in 2004, 2005, and 2006 the values inexplicably approach the range of normal. However, each time they fall back down into the range of unreasonable values.

Burden (Baton Rouge North)

The data retrieved from the Burden station are generally acceptable. The values, while somewhat lower than expected, are not so low as to exclude the possibility of accuracy. It must be stated, however, that the data values do appear to be below the range of probable values. Nevertheless, it cannot be concluded that the data coming from that station are erroneous. For this reason the data are labeled as “reasonable”. There is a large gap in which missing or zero values are given from July 2004 to June 2006. When measurements begin again in June 2006, the values appear to be too low to be reasonable. Overall, the data coming from the station at Burden for the entirety of the study are dangerously close to being too low and should be viewed with some skepticism.

Calhoun

The data from the Calhoun station are generally of high quality. Overall, the data set is very complete with no large gaps. The only concern with the data from this station is that it appears to be slightly lower than would be expected. Interestingly, data collected from the first half of each year have larger values than data collected from the last half of each year. This phenomenon is apparent from 2002 to 2006. However, the data from 2006 displays this phenomenon least.

Citrus (Port Sulphur)

The data quality from the Citrus station is quite good. The values appear to be reasonable throughout the entirety of the data set. There are a few incorrect values, but overall the data from Citrus fell within a reasonable range of the NSRD data at New Orleans. Unfortunately, the time series stops around the middle of October 2005 and did not resume as of December 2006.

Dean Lee (Alexandria)

The data values from the station at Dean Lee are deemed to be too high to be reasonable, throughout the entire data set. The values continually exceed a reasonable clear-sky transmissivity of 0.75 and often approach values equal to the extraterrestrial. For this reason, it was concluded that the data values from Dean Lee are too large to be considered possible. Figure 5.2 shows a representative year (2002) of solar radiation data from the Dean Lee station plotted against the DOY averages from 1961-1990 for the Baton Rouge NSRD station. Figure 5.2 is representative of the magnitude of values that would result in a station being labeled as "consistently high."

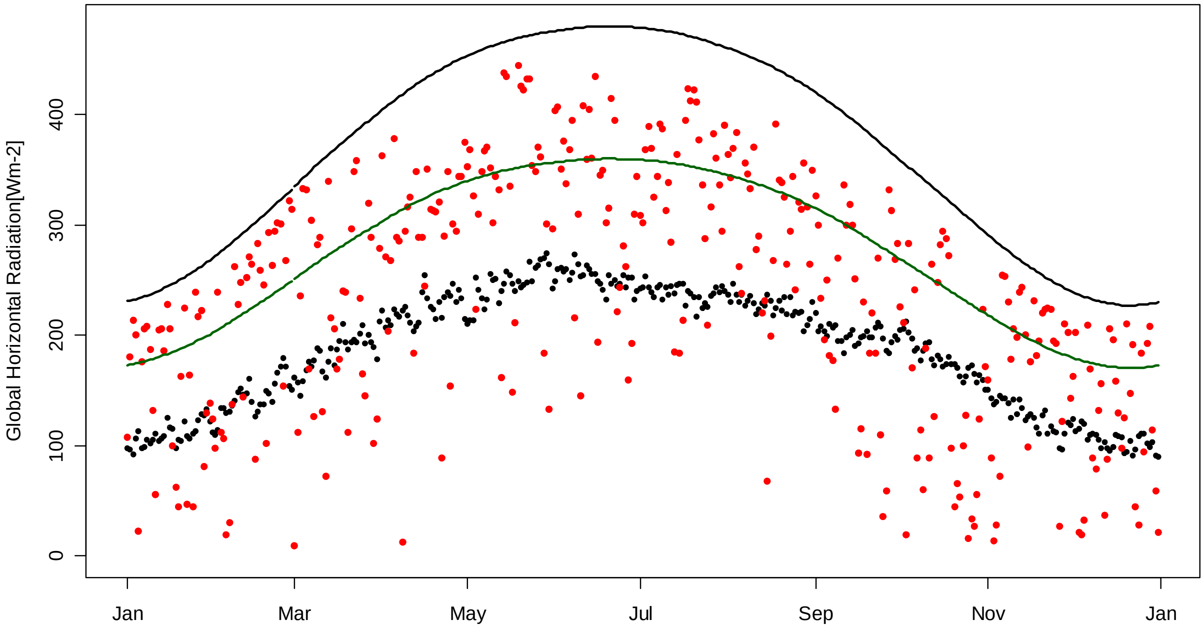


Figure 5.2: Daily solar radiation values from the Dean Lee LAIS station for 2002 (red dots) and DOY average values for the Baton Rouge NSRD station from 1961-1990 (black dots). The top line (black) represents extraterrestrial solar radiation. The green line represents received radiation assuming a transmissivity of 0.75.

Hammond

The values given for the Hammond station are deemed too large throughout the entire data set. Similar to the station at Dean Lee, the values are consistently greater than a clear-sky transmissivity of 0.75 would allow and some approach values similar to those at the top of the atmosphere.

Hill Farm (Homer)

The data from the Hill Farm station appear to be accurate throughout the entire span of the data. There was, however, a brief interval of time during August and September of 2006 when the values inexplicably increase to a point that make them spurious. This short-lived yet considerable increase suggests that values from that period of time should be scrutinized if not discarded.

Houma

The data from the Houma station are labeled “reasonable”. However, these data values are probably too low. It could not be proven without a doubt that the data from this station are incorrect, but use of data from this station should probably be discouraged due to the high probability of the station reporting consistently low values. Regardless, the station stopped reporting values in June of 2005 and had not resumed reporting by the end of the study period.

Figure 5.3 shows a representative year (2003) of data from the Houma station plotted against the DOY means from 1961-1990 for the New Orleans NSRD station. Figure 5.3 is an effective representation of the magnitude of values that would result in a station being labeled as “reasonable”, yet quite likely being too low.

Iberia (Jeanerette)

Overall, the Iberia station’s data are acceptable, but with a few caveats. There are seemingly random smatterings of points that fall well outside the acceptable range of values. A series of successive days have the same impossibly high value from late October through early November of 2003. There are at least two daily values that are too high (and much higher than the values surrounding them) during 2004 and a cluster of missing values during October of 2004. Also, beginning in December of 2005 and continuing through May of 2006, several values appear haphazard. Some, if not all, of the values reported during this time period are incorrect.

Lake Charles (LAIS Lake Charles)

The data set representing the station at Lake Charles is the most fractured and incomplete of the entire network. Data from May of 2003 through December of 2004 are the only reasonable values retrieved from this site. However, even some of the values from this time period are too low. Regardless, there are no more reasonable data values given throughout the rest of the data set except perhaps one month of data from September of 2005, which, by itself, is of little value.

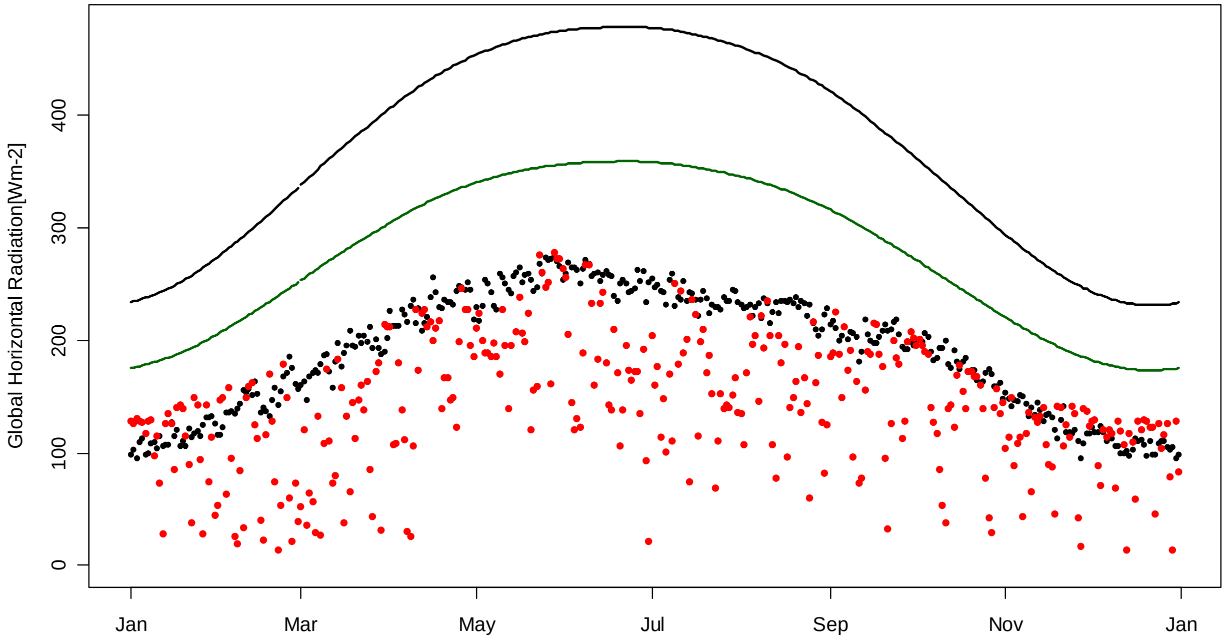


Figure 5.3: Daily solar radiation values from the Houma LAIS station for 2003 (red dots) and DOY average values for the New Orleans NSRD station from 1961-1990 (black dots). The top line (black) represents extraterrestrial solar radiation. The green line represents received radiation assuming a transmissivity of 0.75.

LIGOcorner (Livingston North)

Data from the LIGOcorner station are deemed spurious. Specifically, the data from the beginning of the data set (September 2001 – June 2004) appear to be slightly too high. This period was followed by a long stream of missing values, zero values, or values far too low to be considered remotely possible. That period lasted from June of 2004 to the end of May 2006 at which point the data return to somewhat normal values. However, these values are systematically lower than those provided in the first part of the data set. Therefore, it is unclear which, if either, of the two sections of somewhat reasonable values is more accurate. In actuality, the true magnitude of the values likely falls somewhere between the high values found in the beginning and the low values toward the end. With no reasonable way to decide which of these sets of values is more accurate, or whether either is accurate at all, the entire station is considered suspect.

LIGOsouth (Livingston South)

The data from LIGOsouth appear of good quality until they fell to zero in June of 2005. At that point, the station began reporting only zero values throughout the rest of the data set.

LIGOwest (Livingston West)

The data from LIGOwest appear reasonably accurate throughout almost all of the data set. There is a brief section of missing values from April through July of 2004. This section of missing values was preceded by only one anomalously high data point reported in late March early April of 2004. Otherwise, the entire data set appears in good condition.

Northeast (St. Joseph)

It was concluded that the bulk of the data from the station at Northeast is consistently too low. Data from the station were tested against both the Baton Rouge NSRD station and the Shreveport site, but both comparisons suggest that the LAIS data are too low. This result is further confirmed by the fact that, after a short interruption in the reporting of data values, the station rebounded and produced much more reasonable values. Unfortunately, these values only appear at the very end of the data set from October to December of 2006.

Figure 5.4 shows a representative year (2003) of daily data from the Northeast station plotted against DOY means from 1961-1990 for the Baton Rouge NSRD station, and Figure 5.5 shows the same station and year plotted against the DOY means from 1961-1990 for the Shreveport NSRD station. Figures 5.4 and 5.5 are representative of the magnitude of values that would result in a station being labeled as "consistently low".

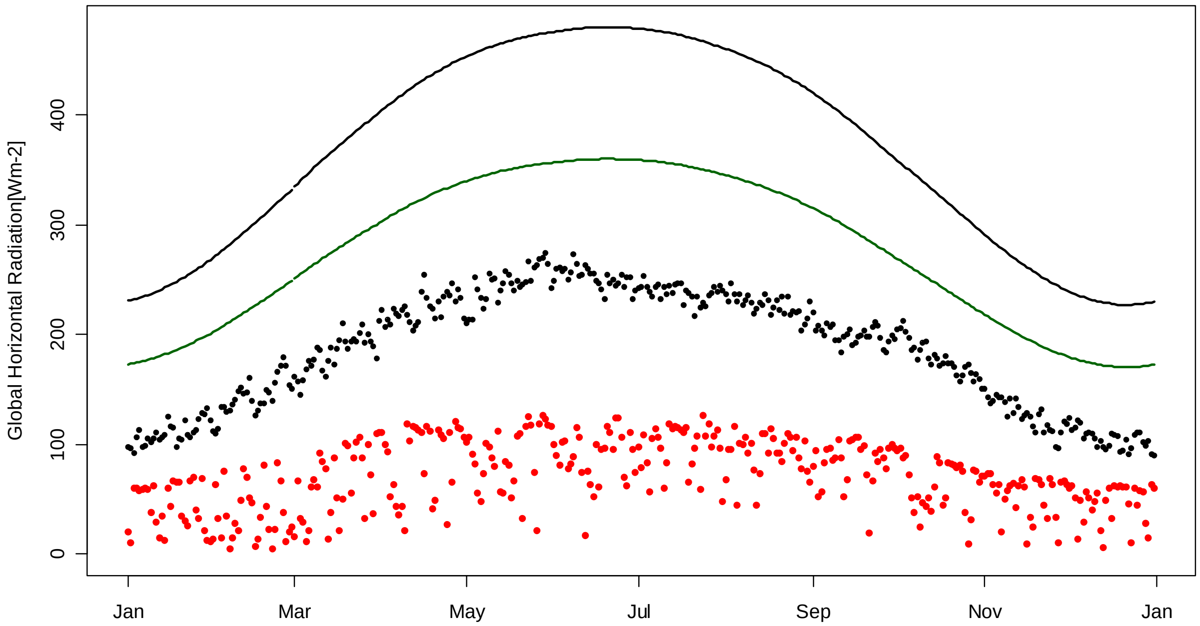


Figure 5.4: Daily solar radiation values from the Northeast LAIS station for 2003 (red dots) and DOY average values for the Baton Rouge NSRD station from 1961-1990 (black dots). The top line (black) represents extraterrestrial solar radiation. The green line represents received radiation assuming a transmissivity of 0.75.

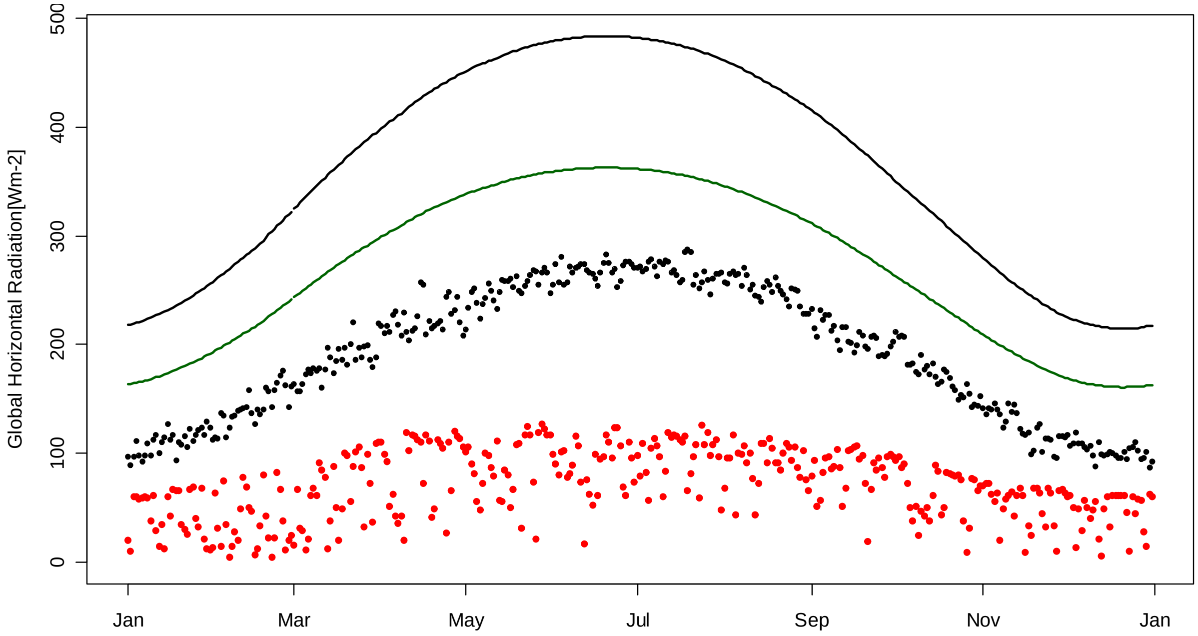


Figure 5.5: Daily solar radiation values from the Northeast LAIS station for 2003 (red dots) and DOY average values for the Shreveport NSRD station from 1961-1990 (black dots). The top line (black) represents extraterrestrial solar radiation. The green line represents received radiation assuming a transmissivity of 0.75.

Red River (Bossier City)

The data from Red River are dubbed “reasonable”. However, this conclusion was only reached because the data could not be proven *without a doubt* to be too low. It is unlikely that many of the values are correct. The data set is relatively complete without any out of character data values reported other than the fact that all of them appear to be slightly too low. Once again, the degree to which they were low is not sufficient to guarantee that they are incorrect, but it seems quite likely that they are in fact systematically too low.

Rice (Crowley)

The data reported from the Rice station are of high quality. The set is relatively complete and overall the values are credible. Nevertheless, there is one span from February through April of 2005 when the data are missing and then they return with spuriously high values. However, by the end of April the station appears to have been corrected and continues reporting reasonable values for the remainder of the data set. It should be noted that there were three singular, uncharacteristically high data points in July 2002, December 2002, and the end of February 2004. These values are not so high as to suggest impossibility; however, they are far enough away from the character of the rest of the values as to provoke suspicion.

In Figure 5.6, a representative year (2003) of daily data from the Rice station is plotted against the DOY means from 1962-1990 for the Lake Charles NSRD station. Figure 5.6 is representative of the magnitude of values that would result in a station being labeled as "reasonable". In this case, the values are on an order that would be expected at a station that is recording accurate values.

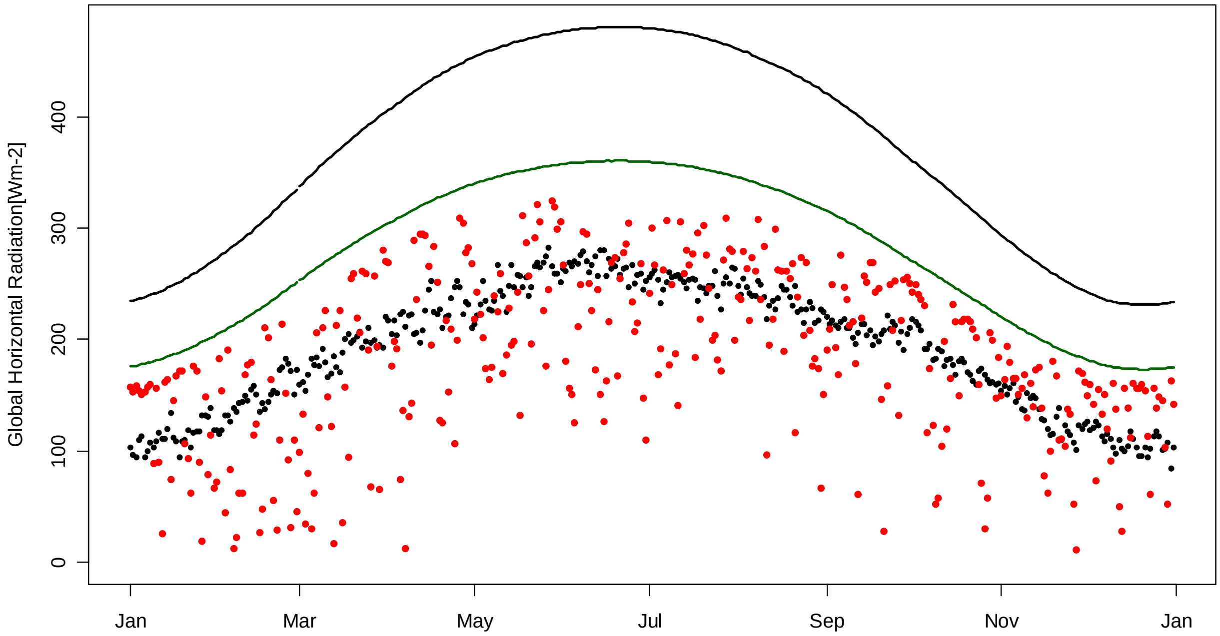


Figure 5.6: Daily solar radiation values from the Rice LAIS station for 2003 (red dots) and DOY average values for the Lake Charles NSRD station from 1962-1990 (black dots). The top line (black) represents extraterrestrial solar radiation. The green line represents received radiation assuming a transmissivity of 0.75.

RnD (R & D Research Farm, Washington)

The data from RnD are consistently too high to be reasonable. The values are regularly higher than a reasonable clear-sky transmissivity of 0.75 and often approach and occasionally eclipse values equal to those at the top of the atmosphere. This is true throughout the entire data set until the values fall to zero at the end of July 2006 and continue at zero for the remainder of 2006.

Rosepine

The values reported for Rosepine are consistently too high for the entire data set. Also, the quality of the data set appears to degrade over time so that by 2006, the values are wildly variable (ranging from 0 to values greater than those at the top of the atmosphere).

Southeast (Franklinton)

The data from the station at Southeast are labeled “reasonable”. Once again, however, it is quite likely that the values are too low but not so low as to confirm without a doubt that they are impossible. The curve created by each year’s data points appears very reasonable. It is therefore postulated that the relative positioning of the data points to one another may be accurate; however, it seems that the station was simply reporting value that are below the actual values.

St. Gabriel (Baton Rouge South)

Data collected at the St. Gabriel station are considered acceptable. However, three data points fell uncharacteristically higher than those around them (and higher than would be generally acceptable) during November and December of 2004 and March of 2005, respectively. Also, there was a period with values of zero returned from June through November of 2005. There also appear to have been some missing values scattered through 2006. Otherwise, the data set is complete and the values are generally reasonable.

Sweet Potato (Chase)

The Sweet Potato station is also dubbed “reasonable” but only marginally. The values are lower than would be expected and probably are too low. However, they are not quite low enough to rule out the possibility that they could be accurate. Like Northeast, Sweet Potato is closer to the NSRD station at Baton Rouge yet closer in latitude to the NSRD station at Shreveport. To ensure accurate results, the data values from Sweet Potato are checked against both of these NSRD stations. In both cases, the values are lower than would be expected yet not quite low enough to suggest strongly that the values are dubious.

Turtle Cove (Manchac)

Data from the Turtle Cove station are quite acceptable overall. Three data points are anomalously high and much higher than the values near them in sequence. These values occurred in June of 2002, January of 2003, and October of 2004 respectively. Otherwise, the data values are reasonable until the station began reporting values of zero at the end of September 2005 and had not resumed reporting any reasonable values as of December 2006.

ULM (Monroe)

The ULM station’s data are categorized as “consistently high”. The values tend to be much too high to be considered reasonable from the beginning of the data set until approximately

May of 2005 when the data values became sporadic and haphazard until they finally fell to zero by September of 2005 and remained there until the end of September 2006. At that point, some correction was made. Once the data values began to be reported again, they actually appear to be accurate. Unfortunately, the data set ended in December of 2006 which meant that the reporting of these accurate values was short-lived.

USDA (Paincourtville)

Data collected at the USDA station are systematically too low. The data ended in May of 2005 and, as of December 2006, the station had not begun to report values again.

5.3 Summary

Overall, 15 of the 25 LAIS stations are deemed to report values which cannot be proven incorrect for the period from 2001 to 2006. Of these 15, six were reporting values that were quite likely lower than they should have been. The best spatial coverage is in the southeastern section of the state which is understandable because technicians at Louisiana State University in Baton Rouge likely maintained the stations closer to Baton Rouge more frequently. The region of central Louisiana has extremely poor coverage and the northern portion of the state is quite underrepresented. Future research that makes use of LAIS data should exercise caution in the use of the stations for the 2001 to 2006 period.

5.4 Time Series Analysis and Spatial Interpolation

Unfortunately, the poor quality and short periods of record of these data in the LAIS prevent any meaningful time series analysis. Time series analysis requires, at minimum, three cycles of continuous data with no missing values. With data at so many of the stations being inaccurate, very few stations were even considered candidates for time series analysis. Of the stations that were not proven inaccurate, missing values were distributed throughout the record.

Even if any station had the entire 6-year period with no missing values, a time series analysis would have only been marginally informative. If one were to inspect any two sets of six years of data in the NSRD, one would likely find conflicting trends.

It was hoped that some spatial interpolation technique could have been applied to the LAIS data to produce maps that represent the spatial distribution of solar radiation. Monthly average maps for four months of each year (January, April, July, and October) representing the four seasons could have been used to corroborate any spatial trends that appeared in the examination of the NSRD data. Unfortunately, the number of stations and data that would be available for spatial interpolation was not sufficient. Table 5.1 shows the stations at which data values are assumed good, and months for which data are available at those stations.

At best, nine stations are available for spatial interpolation. For all years, at least one station is missing for at least one month. For most years, there are several missing months. This situation alone would generally prohibit the use of spatial interpolation due to the relatively few data points over a relatively large area even if all of the stations were equally distributed throughout the state. However, the distribution of acceptable stations is anything but equally distributed. All but one of the stations is located in the southeastern corner of the state. Hill Farm (Homer) is the only station that is not in the southeast. There is no representation in the center of the state or most of the entire western half of the state. This configuration of acceptable stations does not allow for meaningful spatial interpolation. The sole station in the north would create a bias by being the only representative in the area, thereby exerting undue influence on the position of isolines. This problem is particularly severe in cases where data are suspect at “acceptable” stations that are geographically isolated from other acceptable sites. Furthermore, a great deal of the state would have no representation whatsoever.

Table 5.1: LAIS stations with data deemed acceptable and the years and months for which the data are available.

	2001	2002	2003	2004	2005	2006
Ben Hur		Oct	Jan-Apr-Jul-Oct	Jan-Apr-Jul-Oct	Jan-Apr-Jul-Oct	Jan-Apr-Jul-Oct
Citrus	Oct	Jan-Apr-Jul-Oct	Jan-Apr-Jul-Oct	Jan-Apr-Jul-Oct	Jan-Apr-Jul	
Homer	Oct	Jan-Apr-Jul-Oct	Jan-Apr-Jul-Oct	Jan-Apr-Jul-Oct	Jan-Apr-Jul-Oct	Jan-Apr-Jul-Oct
Iberia	Oct	Jan-Apr-Jul-Oct	Jan-Apr-Jul	Jan-Apr-Jul	Jan-Apr-Jul-Oct	Jul-Oct
LIGO_S	Oct	Jan-Apr-Jul-Oct	Jan-Apr-Jul-Oct	Jan-Apr-Jul-Oct	Jan-Apr	
LIGO_W	Oct	Jan-Apr-Jul-Oct	Jan-Apr-Jul-Oct	Jan-Apr*-Oct	Jan-Apr-Jul-Oct	Jan-Apr-Jul-Oct
Rice	Oct	Jan-Apr-Jul*-Oct	Jan-Apr-Jul-Oct	Jan-Apr-Jul-Oct	Jan-Jul-Oct	Jan-Apr-Jul-Oct
St. Gabriel	Oct	Jan-Apr-Jul-Oct	Jan-Apr-Jul-Oct	Jan-Apr-Jul-Oct	Jan-Apr	Jan-Apr-Jul-Oct
Turtle Cove	Oct	Jan-Apr-Jul-Oct	Jan*-Apr-Jul-Oct	Jan-Apr-Jul-Oct*	Jan-Apr-Jul	

*acceptable after the removal of a few anomalous points

CHAPTER 6

CONCLUSION

6.1 General Overview

This study examined the spatial and temporal nature of surface global horizontal solar radiation in Louisiana. Using a 30-year dataset (1961-1990) from the National Solar Radiation Database (NSRD) comprised of four stations in Louisiana and a 6-year dataset (2001-2006) from the Louisiana Agriclimatic Information System (LAIS) comprised of 25 stations in Louisiana, several aspects of solar radiation distribution were examined.

A time series analysis of the solar radiation data from the NSRD was conducted to determine whether Louisiana's solar radiation receipt had declined at a similar magnitude as the globally-observed decline uncovered in other studies which has since been dubbed the "global dimming" phenomenon. Furthermore, examinations were made and postulations provided for observed trends in temperature which were seen in conjunction with these solar radiation trends. Beyond the specific solar radiation values, transmissivity – the ratio of surface shortwave radiation to extraterrestrial solar radiation – was calculated from the NSRD dataset and examined via time series analysis.

A "day of year" (DOY) mean value was calculated for surface solar radiation, extraterrestrial solar radiation, and transmissivity to produce a single averaged year of values. This allowed examination of the typical behavior of solar radiation and its accompanying variables throughout a "normal" year. These DOY mean values were then plotted and used to assess the validity of individual years of data for each station from the LAIS dataset.

6.2 Solar Radiation Trends

It was hypothesized that solar radiation values in Louisiana would show a decreasing temporal trend similar to the global trend identified in previous studies (Stanhill and Cohen, 2001; Liepert, 2002). The most reliable data that were available, those from the NSRD, were examined through a time series analysis to determine the direction and significance of trends in surface solar radiation for the period from 1961 to 1990. The surface solar radiation trends identified at the NSRD stations at New Orleans, Baton Rouge, and Lake Charles were all observed to have been declining (p-value < 0.001) over the NSRD's period of record. Shreveport, the northernmost NSRD station in the state, was shown to have a slightly increasing trend. Though slightly less significant than the negative trends found at the other stations, this trend was nonetheless significant (p-value < 0.001). Other stations representing the northern portion of Louisiana are sorely needed to determine whether the trend at Shreveport is anomalous or whether it is indicative of the true nature of the entirety of the northern portion of the state. Perhaps future research conducted on data from Texas, Mississippi, or Arkansas could be examined to help determine whether this trend at Shreveport is anomalous.

Because of the limited number of stations in the NSRD, it is difficult to determine the cause of the discrepancy in trends between stations. It is hypothesized that proximity to the coast and the resulting degree of cloud cover plays a role in determining the direction and intensity of the observed trends in surface solar radiation. However, it is possible that other factors, including the location and intensity of the Bermuda high, the frequency and intensity of frontal boundaries, and the mode of various global teleconnection patterns, play a role in determining these observed results. Unfortunately, the dataset from the LAIS is too discontinuous and unreliable for a proper time series analysis which would provide greater insight into the spatial distribution of these temporal trends and a more complete picture of the causes of these trends.

6.3 Surface Solar Radiation: North vs. South

It was hypothesized that the northern part of Louisiana would display higher surface solar radiation values in the summer than the south. This hypothesis was formulated because the combined effects of greater cloud cover and atmospheric moisture content in the south and longer summer daylight hours in the north compensate for the more direct sun angle in the south. An examination of the DOY values from the four stations in the NSRD suggests that this hypothesis was indeed supported. Until approximately Julian day 160 (June 9) the surface solar radiation and transmissivity values remain fairly similar. Even for a time after extraterrestrial solar radiation at Shreveport exceeds that of the stations in the south around Julian day 130 (May 10), the stations all report similar values. However, eventually the greater extraterrestrial solar radiation values in the north overcome the more direct sun angle in the south and the values in the north begin to exceed those in the south. Both surface solar radiation and transmissivity values remain higher at Shreveport until approximately Julian day 260 (September 17), at which point the values are similar across the state once again.

6.4 Transmissivity: North vs. South

It was hypothesized that transmissivity would increase with increasing latitude during all times of the year as cloud cover and water vapor from the coast diminished. However, results did not support this hypothesis. An examination of the DOY values from the NSRD stations shows that, although during the summer there appear to be times when this is the case, tranmisissivity does not consistently increase with latitude even throughout the summer. In the rest of the year the relationship between transmissivity and latitude is even more tenuous. In fact, for much of the year, transmissivity at all four stations in the NSRD is markedly similar. Once again, it is likely that an examination of additional stations, if such data were available, would reveal a more distinct spatial pattern in transmissivity.

6.5 Transmissivity: Southeast vs. Southwest

It was postulated that southeastern Louisiana (represented by New Orleans) would demonstrate lower transmissivity values than southwestern Louisiana (represented by Lake Charles) because the southeastern part of the state is influenced by water from three directions (the Gulf of Mexico, Lake Borgne, and Lake Pontchartrain). It was determined, in fact, that the station in the southeast did demonstrate smaller transmissivity values in total but the differences were highly variable over time. However, it was also determined that the station at New Orleans which would presumably have the lowest transmissivity as a result of its proximity to the above mentioned water bodies, actually demonstrated greater transmissivity values than those at Baton Rouge. This finding is puzzling and warrants further inspection.

6.6 Solar Radiation Trends vs. Minimum and Maximum Temperature Trends

The hypothesis that minimum temperature trends and solar radiation trends would demonstrate an inverse relationship at all stations was also tested. It was presumed that very intense incoming solar radiation would be associated with clear skies that would facilitate the loss of longwave energy at night thus reducing minimum temperatures. It appears that solar radiation trends do indeed demonstrate a negative relationship with minimum temperature at all four NSRD sites and these relationships do vary in intensity throughout the year. It appears, however, that solar radiation has a positive relationship with maximum temperature. If radiation is intense, it is likely because of a lack of afternoon cloud cover to absorb, scatter, and reflect the incoming shortwave radiation and keep maximum temperatures down. A comparison of the trends in solar radiation versus the trends in minimum and maximum temperature reveals that these relationships are significant at all stations. The overall trends in minimum temperature at each station match the overall trends in solar radiation. If the overall trend in solar radiation was positive then the overall trend in minimum temperature was negative and vice versa. However, the positive relationship uncovered between solar radiation and maximum temperature did not hold true in the overall trends at all stations.

At Lake Charles and New Orleans, both of which demonstrated decreasing temporal solar radiation trends overall, the trends in maximum temperature were found to be positive. This result is possibly an effect of the urban heat island phenomenon which also plays an important role in the intensity of maximum temperatures. Shreveport, which also displays an increasing temporal trend in maximum temperature, is not anomalous in this regard because it also demonstrates an increasing temporal trend in solar radiation over the period of record. It is therefore possible that the urban heat island did assist in the increase in maximum temperature at Shreveport. Baton Rouge, however, demonstrates a decreasing temporal trend in solar radiation as well as a decreasing temporal trend in maximum temperature. It is believed that the urban heat island effect was less intense at the Baton Rouge station than at the other stations in the NSRD. The Baton Rouge airport (the location represented by the solar radiation and temperature data) is described as "…notably small for a city and metro area of its size and, until Hurricane Katrina, was largely eclipsed by New Orleans' Louis Armstrong International… and load factors [at the Baton Rouge airport] were low (below 800,000 passengers per year) and fares were among the highest in the region" (Baton Rouge Metropolitan Airport, 2007). The Baton Rouge airport's website (www.flybtr.com) does not specify any large expansion projects occurring but rather states that it "…has experienced various patterns of growth since its inception in August of

1948" (Baton Rouge Metropolitan Airport website, 2007). Further, the airport has been described as "struggling" (Verma, 2005). The area in which it exists has not undergone any major urban expansion during the period covered by the data other than the creation of Interstate 110. And, while it is true that the city of Baton Rouge grew over the period of record of the data, very little of that growth occurred near the Baton Rouge airport (10 miles north of Baton Rouge's central business district). Instead, Baton Rouge's growth was seen largely on its south and east sides (growing towards New Orleans). It is therefore understandable that the urban heat island effect would have been minimal for this location.

6.7 NSRD Used to Validate LAIS

It was presumed in the beginning of the study that the DOY values calculated from the thirty years of data in the NSRD could be used as a measure of the validity of the surface solar radiation values in the LAIS. In actuality, it may be stated more accurately that the 30 years of data from the NSRD can be used as a measure of the *invalidity* of the surface solar radiation values in the LAIS. Because solar radiation values across the state are not extremely variable, it is difficult to determine that solar radiation measurements obtained by stations in the LAIS network are in fact accurate; however, the use of the NSRD dataset and the resulting DOY values do a remarkable job of eliminating invalid values. As a result, a detailed description of whether or not data from each station can be proven incorrect was possible. It is hoped that these assessments will prove useful to future researchers using data from the LAIS network.

6.8 Possible Future Research and Suggestions for the Continued Operation of the LAIS

Many possibilities for future research became evident over the course of this study. Unfortunately, many of these research questions would depend upon the availability of a reliable dataset of a sufficient number of stations and over an uninterrupted temporal period sufficient for appropriate time series analysis. A dataset of sufficient size and quality would allow for the implementation of spatial interpolation techniques, such as kriging, which could be useful in understanding (at a much greater resolution) the spatial nature of the seasonal variability of solar radiation in Louisiana. Also, a dataset of sufficient size and reliability would allow a researcher to examine the effect of proximity to large water bodies and other local effects on transmissivity, especially regarding the unexpected findings uncovered in the relationship between transmissivity at the New Orleans and Baton Rouge stations. Another interesting study could be conducted which would examine the relationship between surface solar radiation and cloud cover or precipitation. A similar study to the one conducted here could be performed using DOY *median* values rather than means. Due to the non-normal distribution of solar radiation values, it is possible that an examination of medians would identify previously undetected attributes in the spatial and temporal nature of solar radiation in Louisiana.

This research also yielded some recommendations for future maintenance of the LAIS. First, the pyranometers used in the LAIS network should, as per manufacturer instructions, be returned to LiCor® approximately every two years for recalibration. This act, along with *routine* cleaning and inspection, would dramatically increase the accuracy of the entire network. Beyond the actual instrumentation used to collect the solar radiation data, the website which facilitates the acquisition of the LAIS data could be improved. At present, only two years of data from any individual station may be downloaded or viewed at any one time. It seems that the designers of the site intended for more than two years to be available at the same time since they offer users the option. Also, the data available for download is available only in comma separated (.csv) format. This in and of itself is not a problem. However, when any variable at a station returns error messages, or produces values greater than 999, the values include commas as a thousand place mark. This disrupts the natural alignment of columns because each comma is seen as an indicator of a change from data in one column to data in the next column. This error could be rectified by the simple removal of commas as thousands place markers.

Finally, the LAIS website claims that solar radiation data are in either kWm^{-2} or Langleys depending upon which data description one encounters. This discrepancy is further complicated by the fact that hourly and daily solar radiation values are orders of magnitude different from one another. While it was concluded that daily solar radiation values are in Langleys, it is only speculated that the hourly values are in Langleys as well. It seems that the vast difference in the magnitude of these two forms of data is a result of the fact that Langleys do not have an intrinsic variable for time. If the use of Langleys is continued in the LAIS network, a better description of the method of temporal aggregation of the data should be available via the website. Perhaps a simpler solution to this issue would be to record data in units which do include an intrinsic time value such as Wm^{-2} which are equivalent to Joules per second per square meter. This revised data description should also remove the claim that solar radiation values are negative at night due to the escape of that solar radiation back out to space. This claim is simply incorrect; longwave radiation is lost at night rather than shortwave radiation. Because these pyranometers only measure diffuse and direct *shortwave* solar radiation, legitimate values will never be negative.

Despite the pitfalls, future uses of solar radiation data in Louisiana are encouraged because of the importance of this atmospheric variable. All thermodynamic and dynamic processes in the atmosphere rely on the input of solar radiant energy. Therefore, more accurate assessments of the magnitude of incident solar radiation would improve atmospheric models of all types, from those designed to represent and simulate global energy balances, cloud microphysics, weather forecasting, and long-term changes to the general circulation of the atmosphere and ocean.

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APPENDIX A: LAIS STATISTICS AND NORMALITY RESULTS

	BenHur	Bienville	Burden	Calhoun	Citrus	DeanLee
Min	-470.3	3.87	-0.9676	1.935	-6.773	0
Max	483.3	1448	345.4	310.6	483.3	451.4
Mean	177	207	119.6	159.7	194.6	238.9
Median	177.6	191.6	127.7	161.6	193.5	243.8
1st Quartile	121	106	0	107.9	142.7	161.6
3rd Quartile	246.7	254.5	197.9	223.3	257.4	325.4
Std. Deviation	89.78939	162.8064	96.55005	77.06386	80.42618	107.0334
Skewness	-0.807864	2.886142	0.130135	-0.18755	-0.19469	-0.27043
Kurtosis	6.444483	16.38495	1.765651	2.074227	2.498524	2.158921
NAs	51	306	3	4	9	3
Shapiro (W)	0.9572	0.7548	0.9107	0.9703	0.983	0.9722
Shapiro (p)	< 2.2 e-16	< 2.2 e-16	< 2.2 e-16	< 2.2 e-16	5.02 e-12	< 2.2 e-16
Lilliefors (D)	0.0383	0.187	0.1664	0.0594	0.0452	0.0598
Lilliefors (p)	5.494 e-07	< 2.2 e-16	< 2.2 e-16	< 2.2 e-16	2.728 e-07	< 2.2 e-16

	Hammond	HillFarm	Houma	Iberia	LakeCharles	LIGOcorner
Min	-18.87	-6.773	-6.289	-18.38	-6.773	-23.22
Max	452.4	364.3	483.3	483.3	483.3	378.3
Mean	224.1	170.4	101.3	182.7	1778.1	128.9
Median	228.4	168.8	110.8	183.8	185.8	133.5
1st Quartile	157.7	111.8	1.935	129.7	120.2	15
3rd Quartile	300.4	240.4	167.9	240.4	248.4	223.5
Std. Deviation	96.89041	84.63689	82.7147	78.64484	85.80465	110.6616
Skewness	-0.23881	-0.0867	0.204324	0.135264	-0.30672	0.251237
Kurtosis	2.314113	2.060079	2.115113	3.541296	2.310781	1.677594
NAs	5	10	6	19	19	33
Shapiro (W)	0.9831	0.9746	0.9066	0.9794	0.9633	0.8963
Shapiro (p)	1.979 e-14	< 2.2 e-16	< 2.2 e-16	7.966 e-16	4.11 e-12	< 2.2 e-16
Lilliefors (D)	0.0446	0.0512	0.1679	0.0353	0.0702	0.1826
Lilliefors (p)	1.259 e-9	7.419 e-13	< 2.2 e-16	1.13 e-5	1.372 e-8	< 2.2 e-16

	LIGOsouth	**LIGOwest**	**Northeast**	**RedRiver**	**Rice**	**RnD**
Min	0	6.773	0	-2.903	-21.29	0
Max	335.3	321.2	249.6	279.6	398.2	462
Mean	118.7	166.7	76.42	134.8	186.3	223.1
Median	126.3	170.8	77.89	135.9	189.6	232.7
1st Quartile	0	116.6	49.83	89.99	132.6	137.9
3rd Quartile	204.9	225.5	105	190.6	249.6	322.9
Std. Deviation	100.3852	71.71763	39.36217	64.6625	78.59644	122.609
Skewness	0.150709	-0.27302	0.293932	-0.16722	-0.22213	-0.30494
Kurtosis	1.643155	2.202417	3.592498	2.040704	2.305231	2.109135
NAs	37	33	1	9	53	4
Shapiro (W)	0.8928	0.9751	0.9771	0.97	0.9836	0.9584
Shapiro (p)	< 2.2 e-16	< 2.2 e-16	< 2.2 e-16	< 2.2 e-16	6.031 e-14	< 2.2 e-16
Lilliefors (D)	0.1819	0.0606	0.03887	0.0649	0.0442	0.0564
Lilliefors (p)	< 2.2 e-16	< 2.2 e-16	3.703 e-7	< 2.2 e -16	3.37 e-9	7.892 e-16

	Rosepine	**Southeast**	**StGabriel**	**Sweetpotato**	**TurtleCove**	**ULM**	**USDA**
Min	-6.773	-15	-0.9676	1.935	0	0	-2.903
Max	483.3	483.3	330.4	281.6	483.3	464	163.5
Mean	232.4	148.4	161.8	151.2	154.1	181.7	76.75
Median	232.7	147.6	169.8	156.8	163	187.7	76.92
1st Quartile	151.9	98.94	103	104	58.06	48.86	52.73
3rd Quartile	322.2	203.7	233.7	206.6	241.4	295.6	105
Std. Dev.	114.1804	69.01667	85.5635	68.18844	103.6298	134.0837	34.26887
Skewness	-0.10634	-0.01722	-0.33933	-0.31907	-0.12122	0.085279	-0.18899
Kurtosis	2.216557	2.664019	2.190213	2.160557	1.817502	1.785773	2.191371
NAs	62	10	42	1	24	8	2
Shapiro (W)	0.9833	0.9827	0.9595	0.9671	0.9337	0.9324	0.979
Shapiro (p)	2.614 e-15	1.703 e-14	< 2.2 e-16	< 2.2 e-16	< 2.2 e-16	< 2.2 e-16	4.446 e-13
Lilliefors (D)	0.0411	0.0413	0.0532	0.0639	0.0932	0.0946	0.0535
Lilliefors (p)	4.329 e-9	4.371 e-8	6.485 e-13	< 2.2 -16	< 2.2 e-16	< 2.2 e-16	1.226 e-9

VITA

Michael Ulric Kemp was born in Knoxville, Tennessee, in December of 1978. He lived in several different states with his parents before settling in Louisiana in 1983. He graduated from West Feliciana High School in 1997, whereupon he accepted a full scholarship to Louisiana Tech in Ruston, Louisiana, to study mechanical engineering. Feeling out of place in both the direction and location of his studies, he left Louisiana Tech after one year and began to study history as an undergraduate at Louisiana State University in Baton Rouge. Upon being reintroduced to geography by way of Dr. Robert Rohli's Physical Geography: The Atmosphere course, he decided that geography would be the field of study to which he would dedicate his college years. He received a Bachelor of Science degree in geography from LSU in December 2003 and returned for the master's program at LSU a year and a half later.

Always enjoying travel and the exciting and new experiences which it entails, he has attempted to see as much of the world as possible. And, with a background in geography, his travels were much more rewarding. He has visited nearly every state in the union as well as 10 foreign countries. The benefits of these trips to his overall education about the world, its people, and the startling similarities and differences in both have been unparalleled.

Beyond the time dedicated to formal education, he has been involved in several forms of employment over the course of his graduate and undergraduate career. He has been an IT manager for a pest control company in Baton Rouge, a sound technician at a live music venue in Baton Rouge, a lift operator at a ski resort in New Mexico, and a freelance repairman working with everything from plumbing to automobiles to computers.

Upon completion of the master’s program at LSU, he plans to gain work experience in a field that will allow him to advance his understanding and abilities in the geographical sciences before pursuing a doctoral degree at a university outside the United States.