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Los Alamos Climatology 2021 Update

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Acknowledgements

Area of Contribution	Contributor	Affiliation
Technical reviewer	Carl Mazzola	LANL Safety Basis

Acronyms and Abbreviations

Acronym	Definition
ACE	Army Corps of Engineers
AGL	above ground level
ANS	American Nuclear Society
ANSI	American National Standards Institute
DOE	Department of Energy
ENSO	El Niño Southern Oscillation
EPA	Environmental Protection Agency
Hz	Hertz
IPCC	Intergovernmental Panel on Climatic Change
KLAM	Los Alamos County Airport
LANL	Los Alamos National Laboratory
LANSCE	Los Alamos Neutron Science Center
mb	millibar
Met	Meteorological Monitoring
MDCN	Mortandad Canyon
mph	miles per hour
MSL	above mean sea level
NCOM	North Community
NNSA	National Nuclear Security Administration
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
PDO	Pacific Decadal Oscillation
PJMT	Pajarito Mountain
QA	Quality Assurance
SODAR	Sound detection and ranging
TA	Technical Area
WMO	World Meteorological Organization

1 Introduction

The Los Alamos National Laboratory (LANL or the Laboratory) operates a Meteorological Monitoring (Met) Program to support LANL emergency response, engineering designs, environmental compliance, environmental assessments, safety evaluations, weather forecasting, environmental monitoring, research programs, and environmental restoration. Weather data has been collected in Los Alamos since 1910. A 30-year averaging period is termed by the National Weather Service (NWS) as a climatic normal, and these statistics are updated every 10 years to represent the current climatic normal conditions. Previous climate statistics are provided in Bowen (1990) for the 1961–1990 averaging period and Dewart et al. (2017) for the 1981–2010 averaging period. No climate statistics were developed for the 1971-2000 averaging period. This report provides climate statistics for the current 30-year 1991–2020 averaging period.

Since 1990, the LANL Met Program has evolved through the retirement of older monitoring locations and the installation of new monitoring locations. The most significant changes include:

- Installation of 10-meter (33-foot) towers at Technical Area (TA)-63, TA-16, and TA-54,
- Installation of 46-meter (150-foot) towers at TA-53 and TA-54,
- Installation of a 10-meter tower in Mortandad Canyon (TA-5 MDCN),
- Retirement of the TA-41 tower, and 10-meter towers at Area G and East Gate, and
- Relocation of the 92-meter (300-foot) tower from TA-50 to TA-6.

Since the 10-meter TA-63, TA-16, and TA-54 towers were added in 2021 (Bruggeman et al. 2020), they are not included in this report. Statistics from these new towers will be provided in future LANL technical reports.

1.1 Site Description

LANL is located in north central New Mexico, approximately 60 miles north-northeast of Albuquerque and 25 miles northwest of Santa Fe (Figure 1). The 39-square-mile Laboratory is situated on the Pajarito Plateau, which consists of a series of fingerlike mesas separated by deep east-to-west-oriented canyons cut by streams. Mesa tops range in elevation from approximately 7800 feet above mean sea level (MSL) on the flanks of the Jemez Mountains to approximately 6200 feet MSL at the edge of White Rock Canyon. The Laboratory is bounded on the north by the Los Alamos townsite; on the west by the Santa Fe National Forest; on the south by Bandelier National Monument; and on the east by San Ildefonso Pueblo, the community of White Rock, and the Rio Grande River.

1.2 Los Alamos Climate

The World Meteorological Organization (WMO) defines a climate normal as the arithmetic average of a climate element (e.g., temperature) over a 30-year period (WMO 1989). A 30-year period is sufficiently long to filter out any interannual variation or anomalies, but short enough to be able to show longer climatic trends. The 30-year climate normal is updated every 10 years. Previous reports analyzed 1961–1990 (Bowen 1990) and 1981–2010 (Dewart et al. 2017). No climate statistics were developed for the 1971-2000 averaging period. The current climate normal data presented in this report are calculated from January 1, 1991, to December 31, 2020.

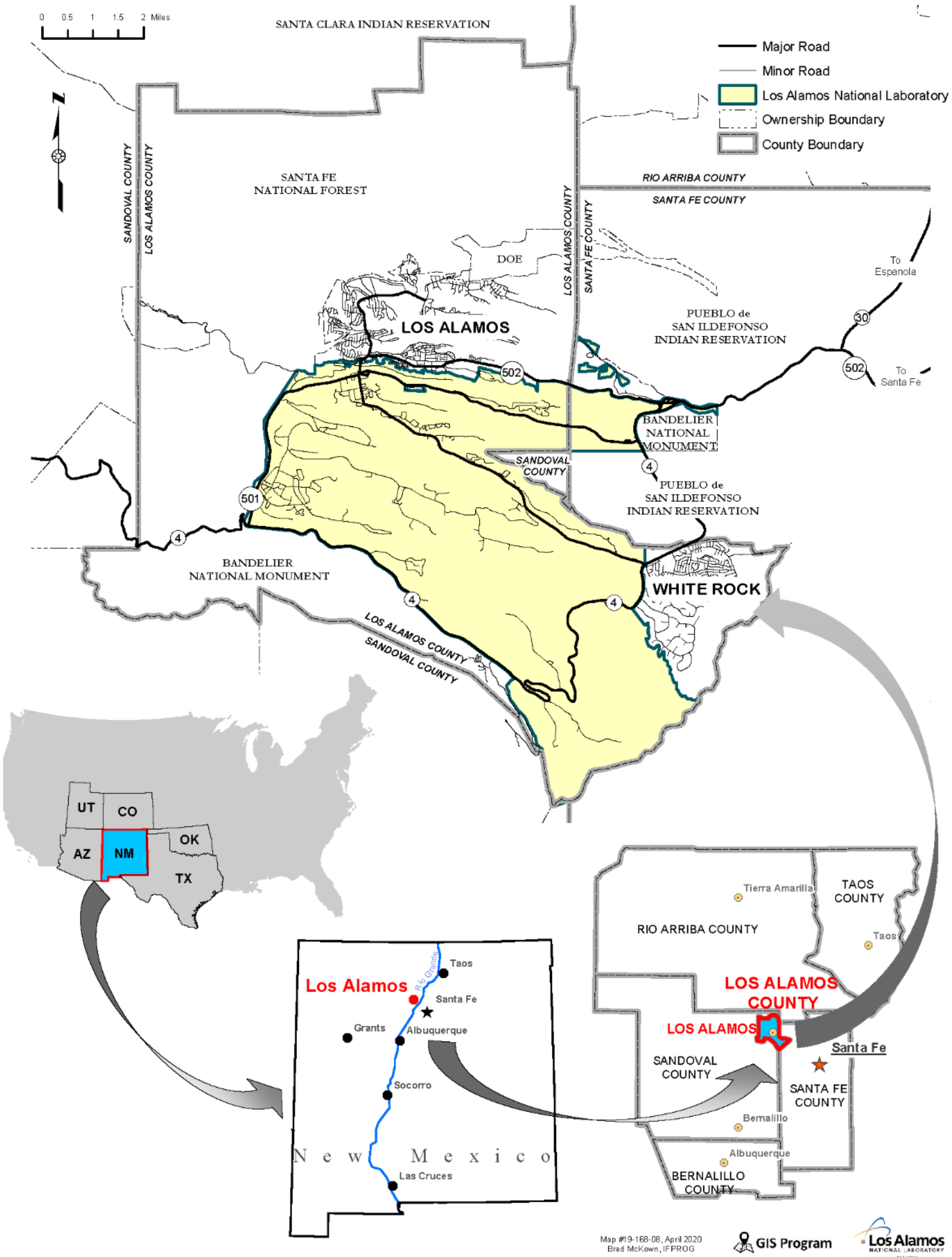

Figure 1. Regional location of Los Alamos.

The climate of Los Alamos is driven by its southern mid-latitude location (approximately 36°N), large distance from the Pacific Ocean and Gulf of Mexico (approximately 700–800 miles), and its relatively high altitude (6200–7800 feet MSL across the Laboratory property). During the fall, winter, and spring, Los Alamos is impacted by mid-latitude westerly storms that produce only 8–12 inches of precipitation annually, reflecting a semi-arid climate. During the summer, most of New Mexico experiences a seasonal wind shift, with winds coming from the south. These southerly winds, known as the North American

Monsoon (Adams and Comrie 1997), bring warm, moist air from the Gulf of Mexico and produce an additional 4 inches of rain annually. The annual average rainfall (measured at 7400 feet MSL) of approximately 19 inches falls into the semi-arid range (Peel et al. 2007).

Daily temperatures are highly variable because of the limited amount of moisture in the air. On average, winter temperatures range from 35–50°F during the day and from 20–25°F during the night. The Sangre de Cristo Mountains to the east of the Rio Grande valley act as a barrier to wintertime arctic air masses that descend into the central United States, which cause infrequent local subzero temperatures. Average summer temperatures range from 75–85°F during the day and from 50–55°F during the night.

The complex topography of the Pajarito Plateau, shown in Figure 2, influences local wind patterns. Quite often a distinct diurnal cycle of wind occurs. Daytime winds measured in the Los Alamos area are predominately from the south to south-southwest, consistent with the typical upslope flow of heated daytime air moving up the Rio Grande valley. Nighttime winds on the Pajarito Plateau are light and typically from the west to northwest because of downslope flow of cool air from the Jemez Mountains.

Figure 2. Aerial photo looking west along state road 502 showing the complex terrain surrounding LANL.

Los Alamos is designated as a light wind site, with an annual average wind speed of approximately 7 miles per hour (mph). On average, spring (April, May, and June) is the windiest season due to strengthening low pressure systems as they flow downstream from the Rocky Mountains. The highest wind gust recorded at a LANL meteorology tower was 85 mph in May 2007 located at TA-53.

Severe storms with life-threatening conditions are infrequent on the Pajarito Plateau. However, during a typical summer monsoon season, thunderstorms due to the influx of moisture from the Gulf of Mexico are observed every three to four days. These thunderstorms are often accompanied by strong wind gusts (>40 mph), lightning, and occasionally hail. Dust devils have also been observed periodically in Los Alamos County with winds up to 50 mph. No tornadoes have occurred at LANL.

2 LANL Meteorological Monitoring

A National Weather Service (NWS) cooperative weather station operated by a local rancher began measuring precipitation in Los Alamos in November 1910 (Machen et al. 2014). The station was first taken over by the Los Alamos Ranch School, and then subsequently by the Laboratory. Over time, the cooperative station records include measured daily maximum and minimum temperature, midnight temperature and relative humidity, 24-hour rainfall, and 24-hour snowfall. The Los Alamos cooperative weather station has moved several times over 110 years, but the locations have not varied by more than 2 miles in distance and 200 feet in elevation MSL.

The modern digitally-recorded meteorology monitoring began in 1979 and has been improved and expanded since that time (Dewart and Boggs 2014). Currently active tower locations are presented in Figure 3 and described in Table 1. TA-6 is designated as the official meteorological station and regulatory tower for Los Alamos and the Laboratory. Included in this report are two stations that have a significant operational history but are no longer being operated (i.e., TA-41 and PJMT [Pajarito Mountain]). LANL has operated meteorology towers at locations other than those presented in Table 1 and Figure 3. These locations are summarized in Dewart and Boggs (2014). The data from these active and historic locations continues to be available through the LANL Weather Machine website on the internal site, https://weather.lanl.gov, and on the public site, https://weathermachine.lanl.gov.

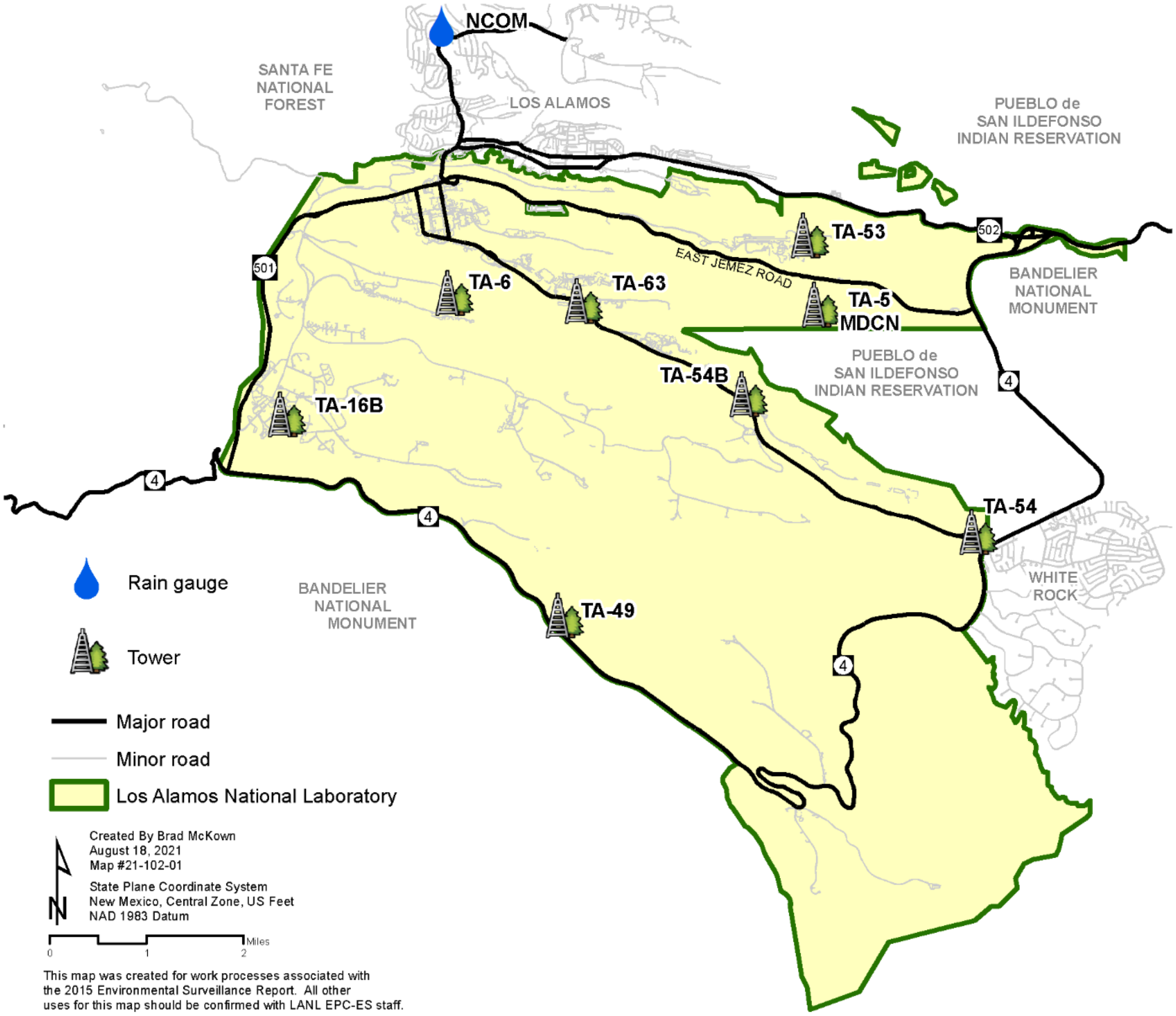

Figure 3. Location of active meteorological monitoring stations at Los Alamos.

Table 1. Meteorological Monitoring Stations and Summary of Meteorological Measurements at Each Location

Station Name	Alternate Name(s)	LANL Structure Number	Latitude/Longitude Coordinates (°)		Elevation (feet)	Surface Measurements (at 1.5 meters)	Levels of Measurements (meters)	Measurements	Record of Obs.
			Latitude	Longitude					
TA-6	Los Alamos	TA-06-0078	35.8615	106.3195	7424	Temperature, pressure, humidity, shortwave radiation, longwave radiation, precipitation	12, 23, 46, 92	Wind speed, wind direction, temperature	Feb 1990–present
TA-6 SODAR[a]	SODAR	TA-06-0100	35.8615	106.3187	7417	N/A[b]	40–1000[c]	Wind speed, wind direction, temperature	Dec 2014–present
TA-49	Bandelier	TA-49-0123	35.8133	106.2993	7045	Temperature, humidity, shortwave radiation, precipitation	12, 23, 46	Wind speed, wind direction, temperature	Jun 1987–present
TA-53	LANSCE[d]	TA-53-1020	35.8701	106.2543	6990	Temperature, humidity, shortwave radiation, precipitation	12, 23, 46	Wind speed, wind direction, temperature	Feb 1992–present
TA-54	White Rock	TA-54-0088	35.8259	106.2232	6548	Temperature, pressure, humidity, shortwave radiation, longwave radiation, precipitation	12, 23, 46	Wind speed, wind direction, temperature	Jan 1992–present
TA-5 MDCN	Mortandad Canyon	TA-05-0061	35.8597	106.2522	6750	Temperature, solar radiation	10	Wind speed, wind direction	Oct 2002–present
NCOM	North Community	N/A	35.9009	106.3216	7420	Precipitation	~10[e]	N/A	Jan 1996–present
TA-41[f]	Los Alamos Canyon	N/A	35.8764	106.2964	6914	Temperature, solar radiation	12, 23	Wind speed, wind direction, temperature	Nov 1993–Oct 2015
PJMT[f]	Pajarito Mountain	N/A	35.8864	106.3948	10,360	Temperature, precipitation	36	Wind speed, wind direction, temperature	Aug 1997–Aug 2013

[a] SODAR = Sound detection and ranging
[b] N/A = not applicable.
[c] Measurements every 20 meters depending upon current weather conditions.
[d] LANSCE = Los Alamos Neutron Science Center
[e] Located on the rooftop.
[f] Station no longer in operation.

In addition to the five active meteorology towers, the Met Program installed a remote-sensing sound detection and ranging (SODAR) instrument nearby the TA-6 meteorology tower in 2014. The SODAR produces sound waves which are projected vertically into the atmosphere to indirectly measure wind speed, wind direction, and temperature structure above the tower measurement levels. Under certain meteorological conditions, vertical data can be collected as low as 40 meters and as high as 1 kilometer above the surface. SODAR data will be analyzed and presented in future technical publications.

LANL meteorological instrumentation meets specifications in the Department of Energy (DOE) handbook, *Environmental Radiological Effluent Monitoring and Environmental Surveillance* (DOE 2015). The handbook adopts the American National Standards Institute (ANSI 2010) consensus standard and the Environmental Protection Agency (EPA 2000) guidance for meteorology monitoring. LANL measures meteorology parameters once every 3 seconds (0.33 Hz), averages these 300 instantaneous measurements over a 15-minute period, and then calculates 24-hour means and extremes from the 3-second data. Quality assurance (QA) review of the data is performed using automated range checks and visual inspections of trend plots on a daily, weekly, monthly, and annual basis by the project meteorologists. LANL meteorology data are made available to customers via the LANL Weather Machine.

As noted earlier, the long-term climatological averages presented in this report are for Los Alamos and White Rock data collected from 1991–2020. To make comparisons across the Pajarito Plateau, the 1993–2020 period was selected to allow the comparison of data from all the mesa-top towers (TA-6, TA-54, TA-49, and TA-53). Since this period is drier and warmer than the 1981–2010 period, thus the focus on these site-wide comparisons will be the relative differences rather than the absolute differences in meteorology parameters. Data are also analyzed for two canyon locations, TA-41, and TA-5 MDCN, and on Pajarito Mountain to compare with the mesa-top tower data. TA-41 has complete data available for 1994–2013, TA-5 MDCN for 2003–2020, and PJMT for 1998–2012.

For the following sections, the tabular data for the graphs are provided in Appendix A.

3 Temperature

Various temperature measurements are available in Los Alamos going back to 1918. Complete years of temperature measurements are available for Los Alamos since 1924 and in White Rock since 1964. These data are used to characterize the basic temperature patterns on the Pajarito Plateau. The expansion of the meteorological tower network during the late-1980s and early-1990s has provided a larger data base for characterizing temperature differences across the Laboratory.

3.1 Average Temperatures

Surface temperatures at approximately 1.5 meters above ground level (AGL) are influenced by the time of day, amount of sunshine, large-scale (synoptic) weather patterns, and local geography. The local influences on temperature include length of day, altitude, topography, vegetation type and density, cloud cover/humidity, and wind speeds. Therefore, the many variables result in temperatures varying significantly across LANL. The 1991–2020 average temperatures are presented for Los Alamos and White Rock in Figure 4, as these stations represent the primary LANL monitoring locations. Additional station data are presented in Section 4.5 to demonstrate the temperature variability across LANL.

Average temperatures in White Rock are a few degrees higher than Los Alamos throughout the year due to its lower elevation. During the summertime, daily average high temperatures in White Rock are as much as 5°F warmer than Los Alamos. On average, White Rock is warmer than Los Alamos because of the drier and less cloudy conditions there. White Rock also receives more incoming solar radiation (insolation), and its lower elevation results in higher air density. This higher air density, which produces warmer temperatures because of more longwave radiation from the earth’s surface, can be absorbed by the air in White Rock compared with the absorption by the air at the Los Alamos townsite. The resulting annual average difference in temperature between Los Alamos in White Rock is 1.1°F.

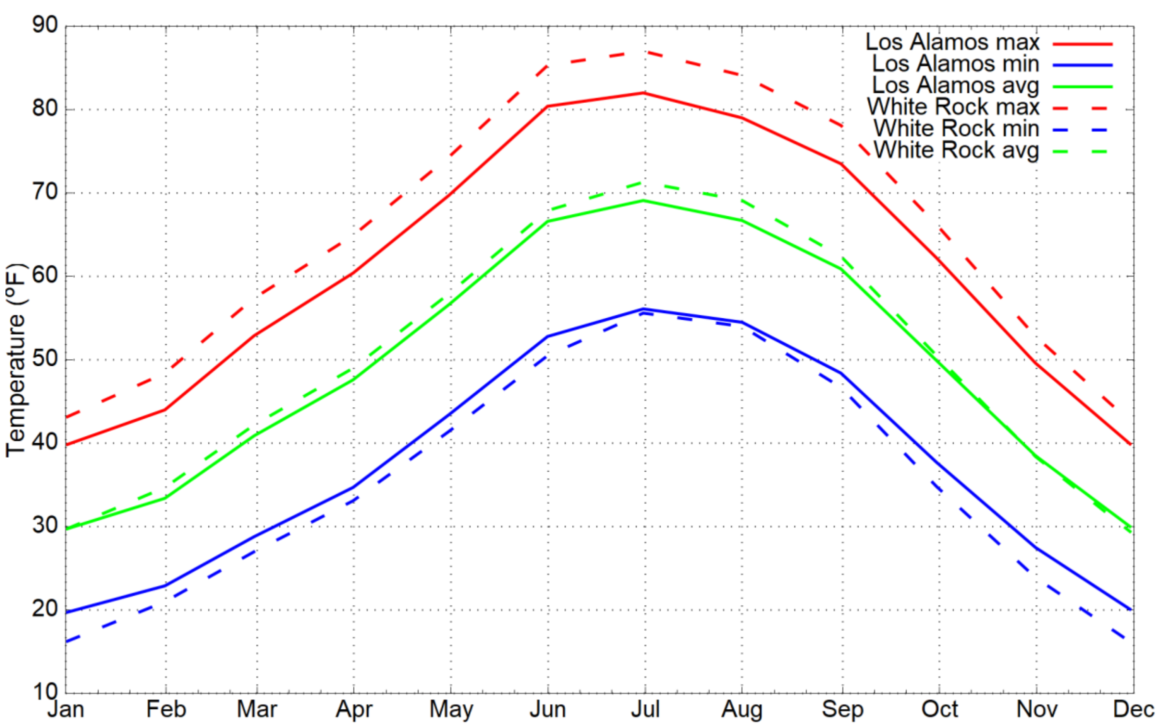

Figure 4. Monthly average temperatures for Los Alamos and White Rock (1991–2020).

Temperature

The overnight low temperatures in White Rock during the fall, winter, and spring months are colder than Los Alamos. Colder temperatures in White Rock are mostly produced during calm nights, when cold air drains from the Jemez Mountains, and pools in White Rock where the topography levels out. Since White Rock is less cloudy than Los Alamos, the surface cools off more at night than in Los Alamos, and this also contributes to the colder air temperatures at night. On average, White Rock is as much as 3°F colder than Los Alamos on winter nights.

The differences in temperature from day to night reflect the significant number of days with clear skies and generally low humidity. Since the skies are often clear, solar radiation heats up the surface of the earth and the air next to the ground is heated. At night, with few clouds and low humidity, the ground radiates heat away and the air adjacent to the ground cools off quickly. The average day/night fluctuation in temperatures is 20–30°F, depending upon the time of year and frequency of clear skies.

From 1991–2020, Los Alamos averaged 4.5 days per year with high temperatures of 90°F or greater compared to the 1981–2010 average of 3 days per year. Historically, it has ranged from no days above 90°F (multiple years) to 22 days above 90°F in 1980. During 1980, the large number of days with high temperatures above 90°F was the product of a very weak (i.e., dry) monsoon season. Total precipitation during the summer monsoon season of 1980 was 3.5 inches, compared with the average of 9.95 inches. In White Rock, the 1991–2020 average was 26 days per year with high temperatures of 90°F or greater, with a range of four days above 90°F (1992) to 50 days above 90°F in 2002 and 2020. During 2002, the large number of days with high temperatures above 90°F was also the product of a weak monsoon season. Total precipitation in White Rock during the summer of 2002 was 5.32 inches, compared with the average of 6.91 inches.

From 1991–2020, Los Alamos averaged 0.9 day per year with an overnight low temperature of 0°F or below compared to the 1981–2010 average of 1.5 days per year. Historically, it has ranged from no days below 0°F (multiple years) to eight days with temperatures below 0°F during 1963. These episodes are usually produced by a cold arctic air outbreak that has pushed westward from eastern New Mexico into Los Alamos. Typically, the Sangre de Cristo Mountains to the east protect Los Alamos from these cold arctic air intrusions. For White Rock, there are two days per year with low temperatures at and below 0°F, ranging from no days (multiple years) to 13 days during 1967. Since 2014, there have only been seven days at or below 0°F in White Rock.

3.2 Extreme Temperatures

The warmest temperatures in Los Alamos and White Rock are observed during the pre-monsoon dry periods of June or July. The coolest temperatures are observed on calm, clear winter nights, often with snow on the ground that enhances longwave radiation loss. These nights may be accompanied by cold air outbreaks when arctic air from the eastern plains pushes westward across New Mexico. The record high temperatures in Los Alamos and White Rock are 98°F, and 101°F, respectively. Recent warm temperatures in April and July 2020 broke their respective monthly records in Los Alamos and White Rock. The record low temperatures in Los Alamos and White Rock are -18°F and -29°F, respectively. A summary of Los Alamos and White Rock extreme temperatures, by month, are presented in Tables 2 and 3.

Table 2. Monthly Extreme Temperatures and Dates for Los Alamos (1910–2020)

	Highest Max. Temperature (°F)	Lowest Min. Temperature (°F)
January	64 (1/12/1953)	-18 (1/13/1963)
February	69 (2/25/1986)	-16 (2/3/2011)
March	74 (3/31/2012)	-3 (3/11/1948)
April	80 (4/30/2020)	5 (4/9/1928)
May	93 (5/10/1934)	22 (5/3/2013)
June	96 (6/19/2016)	28 (6/3/1919)
July	98 (7/11/2020)	37 (7/7/1924)
August	92 (8/11/2012)	38 (8/24/1918)
September	94 (9/11/1934)	23 (9/29/1936)
October	84 (10/1/1980)	6 (10/30/1993)
November	72 (11/1/1950)	-14 (11/28/1976)
December	69 (12/2/1927)	-12 (12/9/1978)

Table 3. Monthly Extreme Temperatures and Dates for White Rock (1964–2020)

	Highest Max. Temperature (°F)	Lowest Min. Temperature (°F)
January	65 (1/19/1986)	-29 (1/7/1971)
February	73 (2/25/1986)	-22 (2/3/2011)
March	80 (3/24/2015)	-5 (3/3/1971)
April	85 (4/30/2020)	12 (4/5/1983)
May	96 (5/31/2002)	18 (5/2/1967)
June	101 (6/19/2016)	33 (6/14/2001)
July	100 (7/11/2020)	41 (7/4/1995)
August	98 (8/6/1977)	36 (8/24/1968)
September	94 (9/13/1990)	27 (9/25/2000)
October	90 (10/1/1980)	9 (10/30/1993)
November	73 (11/13/1967)	-14 (11/28/1976)
December	65 (12/5/1965)	-17 (12/9/1978)

When the maximum temperature does not get above freezing for consecutive days, it can be an engineering design and operational concern for buildings and evaporation ponds. Each year since 1951 in Los Alamos, except for 1998, 1999, 2000, and 2003, there were several occurrences of multiple consecutive days with temperatures at or below freezing. These events have occurred between late-November and early-March. The maximum number of consecutive days with temperatures below freezing at Los Alamos was 11, from December 24, 1987, through January 3, 1988.

3.3 Heating and Cooling Degree Days

Average temperatures are used to estimate fuel use for heating and cooling buildings. A heating or cooling "degree day" refers to the difference between the daily average temperature and a reference temperature for indoor comfort (65°F). For example, if the average temperature for a day is 70°F, a building would require cooling by 5°F to reach the reference temperature of 65°F and thus that day registers five cooling degree days. Conversely, if the average temperature for a day is 60°F, a building would require warming by 5°F and that day registers five heating degree days.

The monthly average heating and cooling degree days for Los Alamos and White Rock are presented in Figure 5. The greatest difference between the two sites occurs in mid-summer because of the significantly warmer temperatures in White Rock.

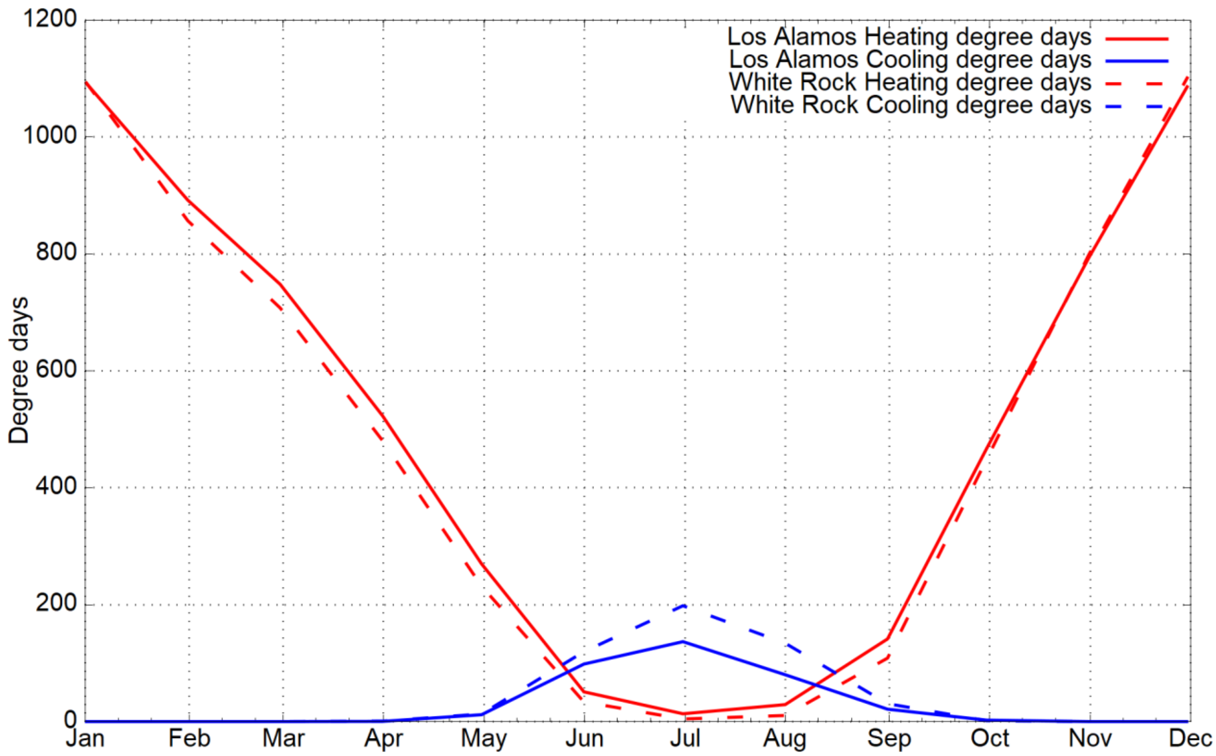

Figure 5. Monthly average heating and cooling degree days for Los Alamos and White Rock (1991–2020).

3.4 Growing Season

The growing season is defined as the number of days between the last day with freezing temperatures in the spring and the first day with freezing temperatures in the late-summer or early-fall. Typically, in Los Alamos and White Rock, the last day with freezing temperatures occurs in early May and the first day with freezing temperatures occurs in early October. With exposure to an air temperature of 32°F, plants can be damaged depending upon the amount of moisture in the air and the length of time the temperature is at or below 32°F. A hard freeze, when almost all plants will be damaged, is 28°F.

The date of the average first freeze in the late-summer and early-fall, the date of the last freeze in the spring, and the length of the growing season for Los Alamos and White Rock are presented in Table 4. The averages for 1961–1990 are from Bowen (1990) and the averages from 1981 – 2010 are from Dewart et al. (2017). The Los Alamos growing season appears to have shifted earlier by two to three days for the 1981–2010 and 1991–2020 periods compared to the 1961–1990 period, but the total number of days in the growing season are similar. For White Rock, the growing season increased by six days for the 1981–2010 period, but recently has returned to a similar number of days as the 1961–1990 period.

Table 4. Average Spring and Fall Freeze Dates

	Los Alamos			White Rock		
	1961–1990	1981–2010	1991–2020	1961–1990	1981–2010	1991–2020
Date of last freeze in the spring	May 7	May 4	May 5	May 11	May 4	May 11
Date of earliest freeze in the fall	Oct 11	Oct 7	Oct 8	Oct 7	Oct 6	Oct 5
Number of days in the growing season	157	156	156	149	155	147

The latest and earliest freeze dates on record are presented in Table 5. The dates are not strictly comparable between Los Alamos and White Rock since records for Los Alamos date from 1924 and records for White Rock date from 1964.

Table 5. Record Dates of Last Freeze in the Spring and Earliest Freeze in the Fall

	Los Alamos	White Rock
Date of last freeze in the spring	June 11, 1975	May 31, 2011
Date of earliest freeze in the fall	September 9, 2020	September 9, 2020

3.5 Temperature Variation Across the Laboratory

LANL operates four meteorology towers (TA-6, TA-49, TA-53, and TA-54) on the mesa tops. Data were collected for the years 1993–2020 at each of these mesa towers. TA-5 MDCN began data collection in late-2002, so for this analysis, the years 2003–2020 are included (i.e., 18 years). Data for the full years 1998–2012 are available for PJMT (i.e., 15 years). The data for TA-5 MDCN and PJMT compared with the other sites will not have the same years as the other towers and this will be considered in making comparisons.

The annual average daily maximum and minimum temperatures at each tower are presented in Figures 6 and 7. Highest summertime and wintertime maximum temperatures occur at the lowest elevations (TA-54 and TA-5 MDCN), while the lowest temperatures occur at PJMT, which is 3000–4000 feet higher in altitude than other LANL monitoring locations. Daily maximum temperatures at PJMT are 10–20°F lower than the other locations.

The lowest summertime minimum temperatures occur at the highest elevations (PJMT) and in canyons and lower elevations where nighttime cold air drainage (katabatic winds) occurs (TA-5 MDCN, TA-41, and TA-54). The lowest wintertime minimum temperatures occur in the lowest elevations (TA-54 and TA-5 MDCN) and at TA-41 because of nighttime cold air drainage.

Temperature

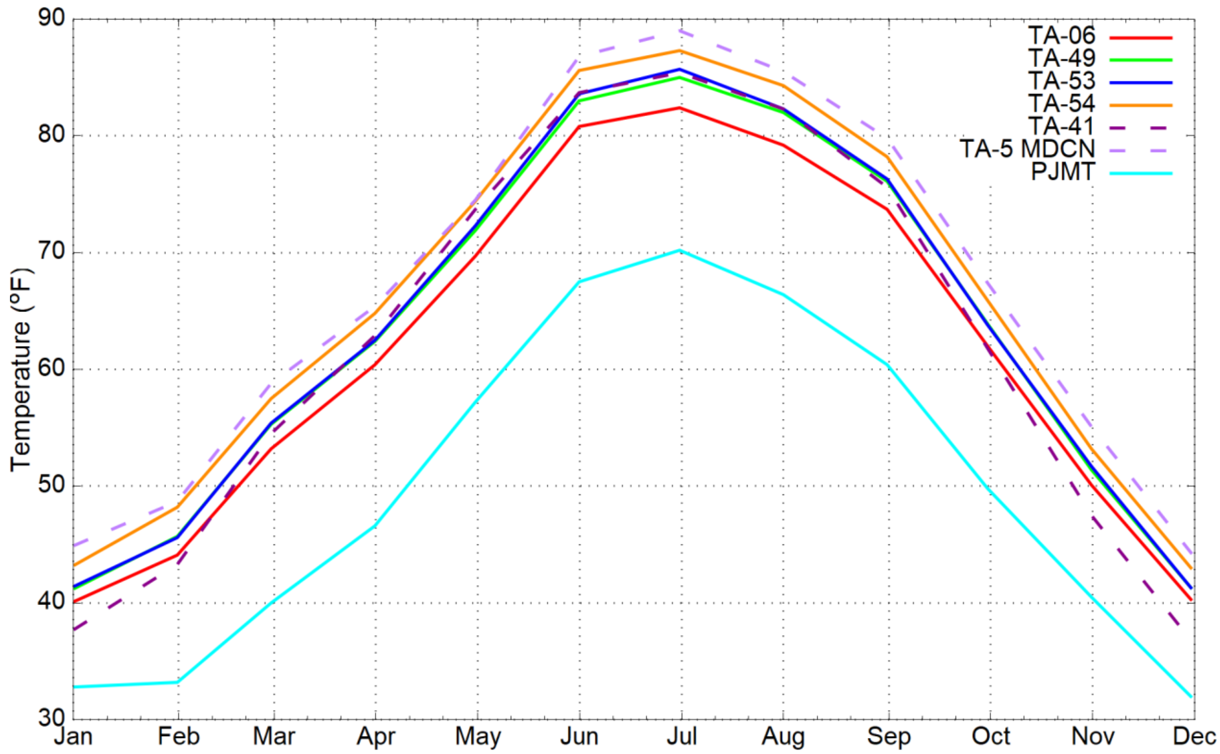

Figure 6. Monthly average maximum temperatures across Los Alamos County (1993–2020, except TA-41 is 1994–2013, TA-5 MDCN is 2003–2020, and PJMT is 1998–2012).

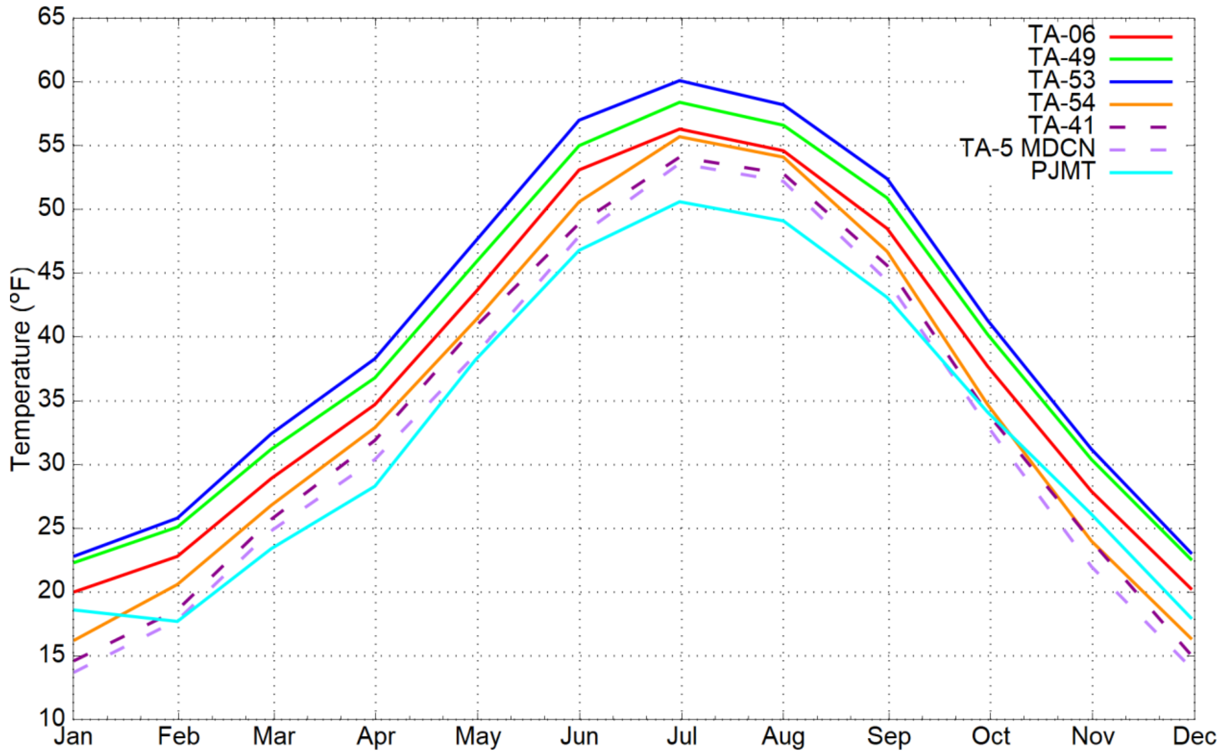

Figure 7. Monthly average minimum temperatures across Los Alamos County (1993–2020, except TA-41 is 1994–2013, TA-5 MDCN is 2003–2020, and PJMT is 1998–2012).

4 Precipitation and Atmospheric Moisture

The collection of rainfall and snowfall data began in November 1910 on the Pajarito Plateau by a scientifically-minded dryland farmer (Machen et al. 2014). However, the data collected during the early years include many months/years with incomplete measurements. Thus, precipitation and moisture statistics are presented for as early as 1951 where complete years of data are generally available.

In addition to rainfall and snowfall measurements, atmospheric humidity parameters have been collected at all tower locations from 1987–1992. These data are the precursors of precipitation.

4.1 Average Precipitation

The annual average precipitation (rain plus melted snow) in Los Alamos is 17.36 inches (Figure 8), which is 1.61 inches less than the 1981–2010 average. Approximately 50% of the annual precipitation falls during the summer monsoon season of June 15–September 30. White Rock has a similar annual distribution of precipitation, but at 74% of the Los Alamos averages, with an annual average of 12.92 inches, which is 1.25 inches less than the 1981–2010 average. Precipitation in October is often enhanced by the impact of moisture carried into New Mexico from dying hurricanes or tropical storms off the coast of Mexico in the Eastern Pacific.

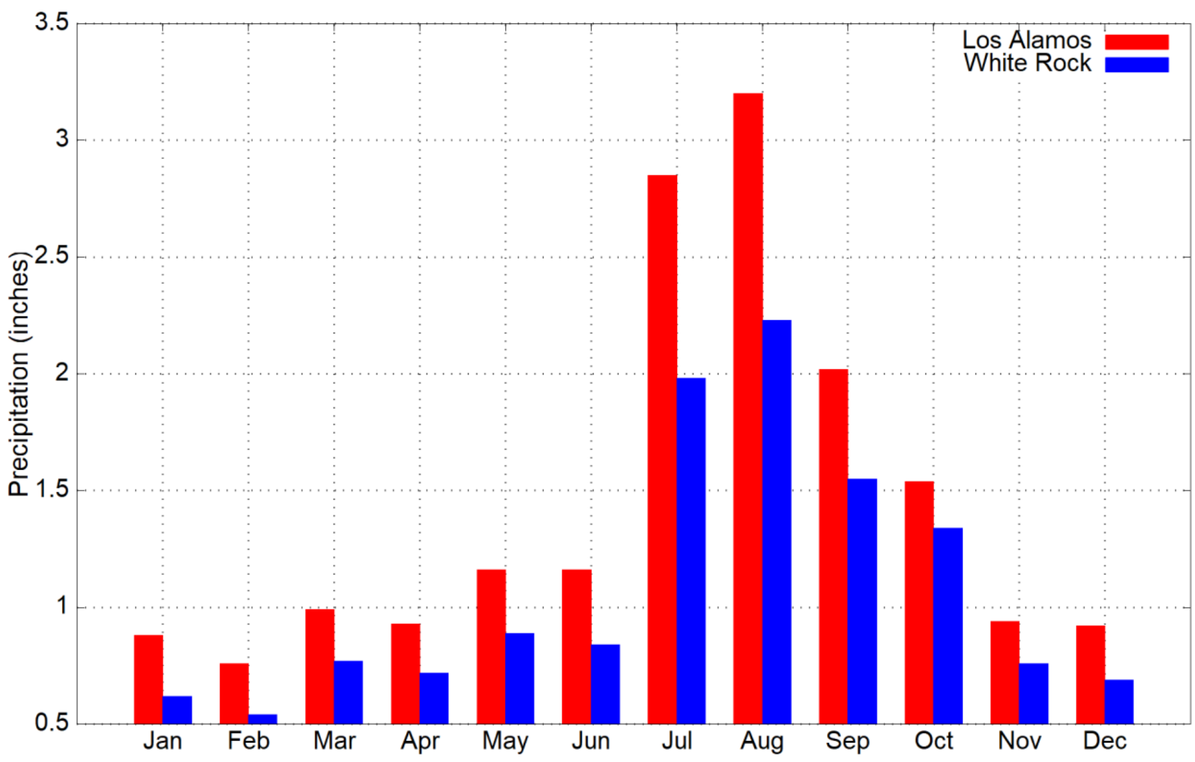

Figure 8. Monthly average precipitation for Los Alamos and White Rock (1991–2020).

Winter season precipitation generally falls as snow. Los Alamos receives about 43 inches of snow per year (Figure 9). Snow has been recorded in every month of the year, except for June, July, and August. Measurable snow (>0.1 inch) has fallen as early as September 9 (2020) and as late as May 28 (1962). The Los Alamos 1991–2020 average first measurable snow is November 12 and the average last date for measurable snow is April 7. A typical snowfall to precipitation (melted snow) ratio is between 10 inches of snow to 1 inch of rain and 20 inches of snow to 1 inch of rain. In the colder, drier, winter months of December, January, and February, when the capacity of the air to hold moisture is low, the snowfall to precipitation ratio is typically 20 to 1 and sometimes even higher. In the warmer winter months of November, March, and April, the snowfall to precipitation ratio is closer to 10 to 1 as more moisture is available from the weather system.

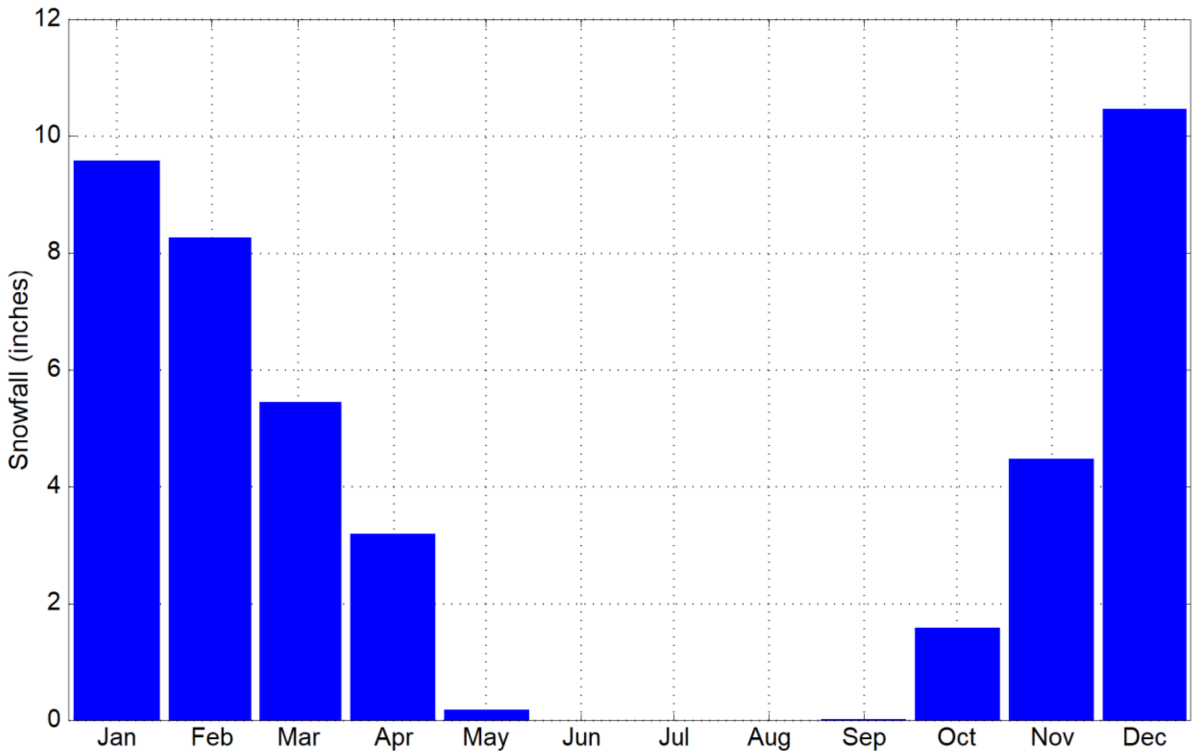

Figure 9. Monthly average snowfall in Los Alamos (1991–2020).

The greatest snowstorm and total snowfall for the year occurred in 1986–1987. On January 15–17, 1987, Los Alamos measured 48 inches of snow. The snowfall to precipitation ratio for this storm was 33 to 1 because the average temperature over these three days was 18°F. Another storm on February 18–19, 1987, produced 26 inches of snow. For the 1986–1987 winter season, a total of 153 inches of snow fell, more than 250% of normal.

4.2 Monsoon Season Precipitation

Precipitation is brought to New Mexico via the mid-latitude westerly winds during the fall, winter, and spring. As the jet stream moves north in the late spring/early summer, Los Alamos typically comes under the influence of the North American Monsoon weather pattern (Adams 1997). During the summer months, the Bermuda high pressure area moves west into the Gulf of Mexico and the central high plains of the United States and a thermal low-pressure area is created by the high temperatures of the Phoenix, Arizona–Las Vegas, Nevada areas. These circulations combine to bring moisture into Mexico and produce southerly winds that advect this moisture into Arizona and New Mexico (Figure 10). In 2008, the NWS defined the North American Monsoon season as June 15 to September 30 (Sampson and Pytlak 2008). This report uses this definition even though significant rainfalls that have a moisture source in Mexico typically begin during the first week in July in Los Alamos.

The 1991–2020 average monsoon precipitation in Los Alamos is 8.68 inches and has ranged from as low as 3.15 inches in 1956 to as high as 17.58 inches in 1952. The 1991–2020 average monsoon precipitation in White Rock is 6.29 inches and has ranged from as low as 1.66 inches in 1980 and as high as 13.33 inches in 2013.

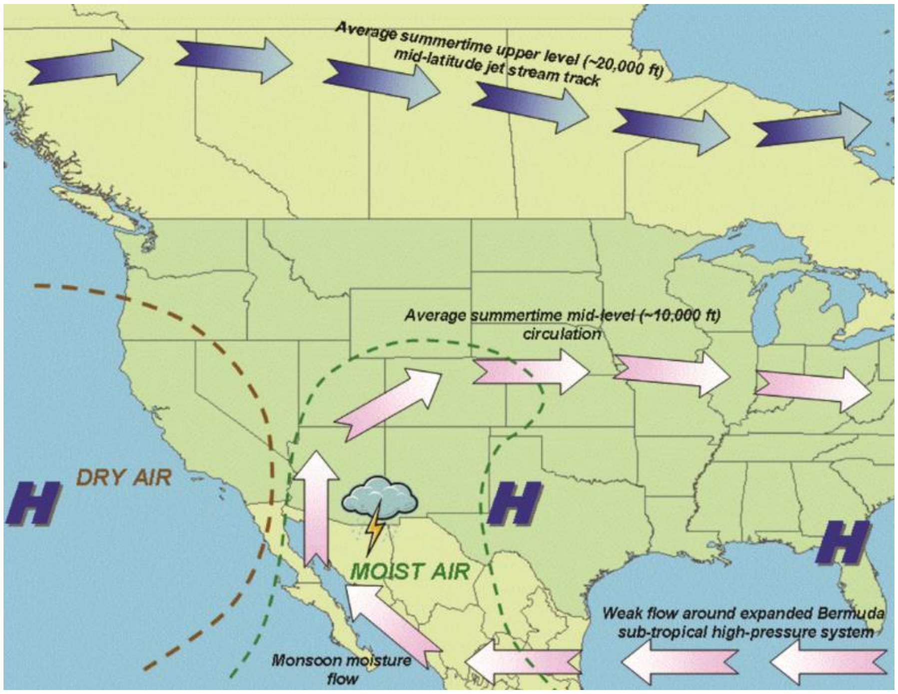

Figure 10. Schematic of surface wind patterns during the North American Monsoon (Crimmins 2006).

4.3 Precipitation Across Los Alamos

Precipitation across the LANL site varies with altitude and distance from the steep rise of the terrain just west of LANL. When the wind blows from the east or from the south, air is lifted by the mountains (i.e., orographic lifting), causing the air to cool, promoting cloud and rain or snow formation. Thus, the highest average total precipitation consisting of rain and melted snow occurs at the stations with highest altitude and closest to the mountains (TA-6 and NCOM, respectively). All stations record the highest average precipitation during the summer monsoon season. The average precipitation across the Laboratory is presented in Figure 11. TA-49 and TA-53 are at similar altitudes, but TA-49 is about 1 mile closer to the mountains than TA-53, and this produces higher precipitation. TA-54 is located at the lowest elevation and is the farthest distance from the mountains, resulting in the lowest average precipitation. It should be noted that the NCOM station is missing a significant amount of data during the summer of 2005, so the NCOM averages for August and September are biased low.

The spatial pattern is similar for the summer monsoon season, where precipitation is greatest at the stations with the highest altitude and closest to the mountains, as shown in Figure 12. However, there are two interesting exceptions to this pattern, as precipitation at the NCOM station in 2001 and 2011 dropped to lower levels in comparison with other stations. This may have been a result of reduced soil moisture following the 2000 Cerro Grande and 2011 Las Conchas fires. More study would be needed to understand the effects of wildland fires on precipitation patterns. The NCOM station is the closest station to areas with significant burns during these fires, and the severe burns produced hydrophobic soils. Since these soils cannot hold moisture, there is no recycling of soil moisture after rainstorms to support the seeding of the next rainstorm.

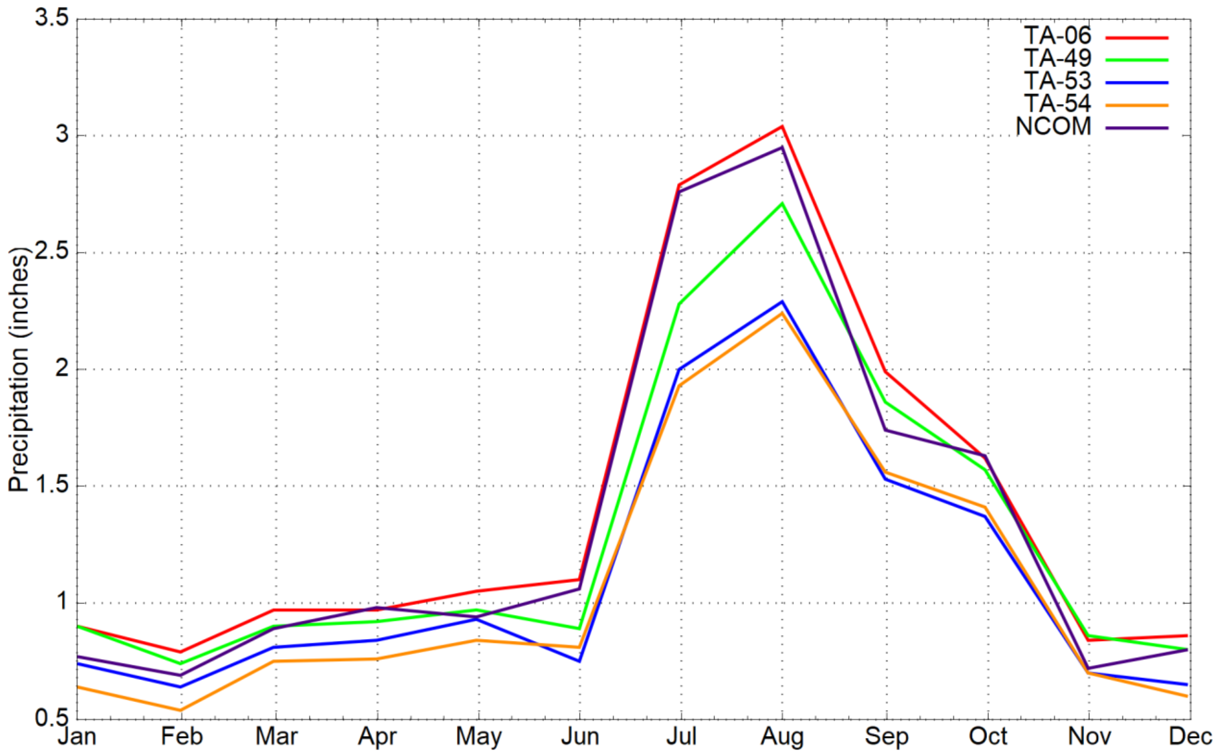

Figure 11. Monthly average precipitation across the Laboratory (1993–2020, except NCOM is 1996–2020).

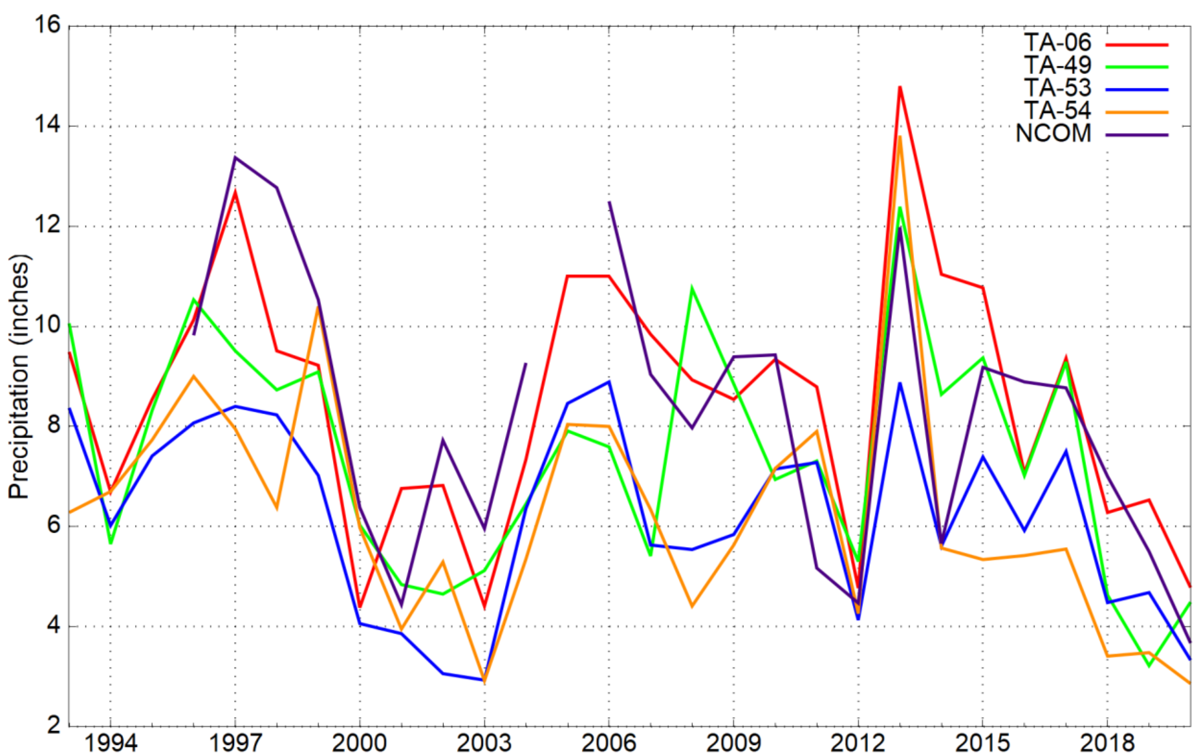

Figure 12. Annual average monsoon season precipitation (1993–2020, except NCOM is 1996–2020). A significant amount of data is missing for NCOM for August–September 2005; this point was eliminated from the graph.

4.4 Extreme Precipitation Events

Daily precipitation totals greater than 0.5 inch can be considered extreme rainfalls with the potential to cause local flooding and property or infrastructure damage. The annual average number of days in Los Alamos recording greater than 0.5 inch of precipitation is 9 days, and in White Rock is 6 days. Most of these days (55%) occur during the summer monsoon season. The record for highest daily precipitation occurred on September 13, 2013, when Los Alamos measured 3.52 inches and White Rock measured 2.49 inches. A description of the September 2013 rainfall event and its causes is found in Bruggeman 2016. The 10 greatest daily rainfall totals on record for Los Alamos and White Rock are presented in Table 6. Most of these extreme rain events occurred during the summer monsoon season, but a few have occurred in the spring and winter due to synoptic-scale effects. Note that due to the much longer record for Los Alamos, there are only two days where the Los Alamos and White Rock stations recorded the highest precipitation on the same dates.

Table 6. Top 10 Greatest 1-day Rainfall Events for Los Alamos and White Rock

Los Alamos		White Rock	
Rainfall in Inches (1910–2020)	Date	Rainfall in Inches (1964–2020)	Date
3.52	September 13, 2013	2.49	September 13, 2013
3.48	October 5, 1911	2.11	June 17, 1999
2.51	June 10, 1913	1.93	October 31, 1989
2.47	July 31, 1968	1.88	July 31, 1968
2.45	January 27, 1916	1.79	September 12, 2013
2.26	August 1, 1951	1.75	April 11, 1969
2.25	March 30, 1916	1.71	August 18, 2000
2.23	August 23, 1957	1.61	September 28, 2005
2.21	September 22, 1929	1.60	December 11, 1965
2.20	October 17, 1944	1.60	July 17, 1975

4.5 El Niño/La Niña Influence on Precipitation

The El Niño Southern Oscillation (ENSO) is one of the most important ocean-atmosphere circulations impacting the weather across the planet. The circulation is characterized by above normal (called El Niño) or below normal (called La Niña) equatorial Pacific Ocean sea surface temperatures. The changes in ocean surface temperature significantly impacts the wind and precipitation patterns over the equatorial Pacific and North America. These patterns and their impact on weather in the United States are illustrated in Figure 13.

Precipitation and Atmospheric Moisture

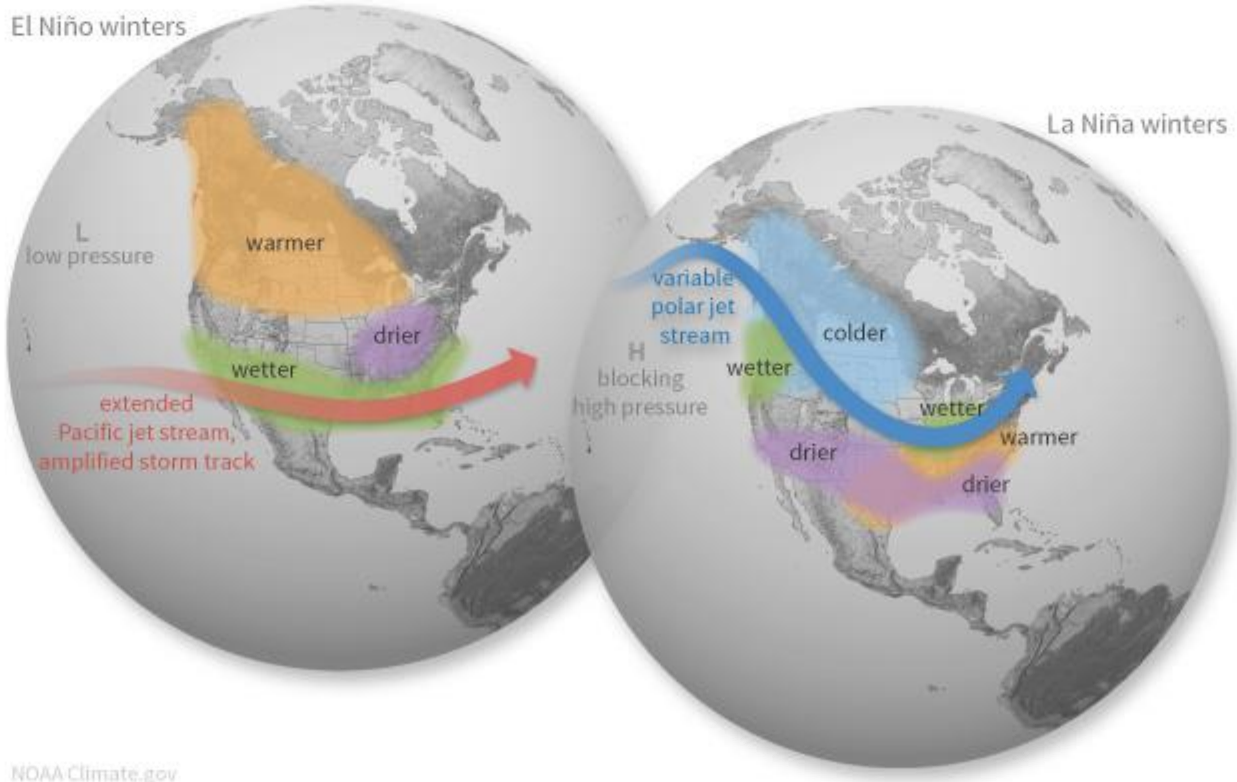

Figure 13. Atmospheric circulation patterns during El Niño and La Niña winter events (NOAA 2021a).

The presence of an El Niño or La Niña pattern is determined by the three-month average Pacific equatorial sea surface temperature anomaly (i.e., difference from the long-term average). El Niño (La Niña) is defined when the three-month average sea surface temperature is greater than 0.5°C above (below) normal. As shown in Figure 13, wintertime precipitation in Los Alamos is expected to be above average during El Niño years and below average during La Niña years. Figure 14 identifies the month-by-month Pacific Ocean sea surface temperature anomaly with major Los Alamos weather events. Values between ±0.5°C, are looked at as El Niño/La Niña neutral. Since 1950, there have been 19 El Niño events and 15 La Niña events. The other years without El Niño and La Niña events are known as El Niño/La Niña neutral years. The average length of La Niña events is 16 months and 11 months for El Niño events. Much more research is needed on the ENSO phenomenon in order to use it as an effective weather forecasting tool.

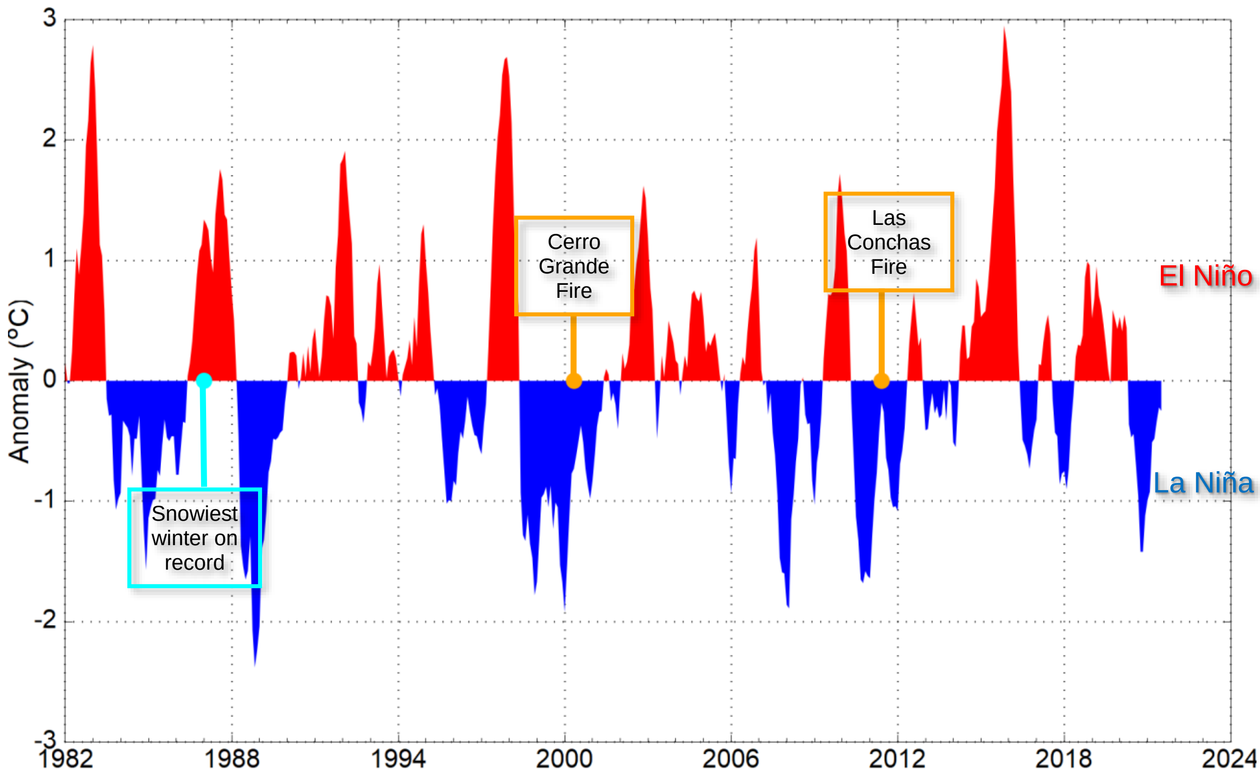

Figure 14. Pacific sea surface temperature anomalies (1981–2021) and major Los Alamos weather events.

To compare Los Alamos precipitation during El Niño and La Niña winters, winter precipitation of rain plus melted snow is summed for each year between November 1 and March 31. The average winter precipitation for Los Alamos from 1951–1980 is 4.75 inches; from 1981–2010 is 5 inches; and from 1991–2020 is 4.58 inches. During the El Niño winters for this same period, the average precipitation was 5.84 inches; during the La Niña winters, the average precipitation was 3.5 inches. There is a tendency for Los Alamos to receive slightly greater than normal precipitation in El Niño years and much less than average precipitation in La Niña years. These data, including the winters from 1952–2020, are presented in Figures 15 and 16. The data demonstrate that an El Niño year is not a guarantee of a wet winter, and a La Niña year is not a guarantee of a dry winter.

Los Alamos average winter precipitation during El Niño/La Niña neutral years from 1991–2020 is 4.47 inches, slightly below climatological averages. Los Alamos winter precipitation during El Niño/La Niña neutral years are presented in Figure 17. Precipitation during neutral years has a larger variability than in either El Niño or La Niña winter years. Accordingly, the winter precipitation during an El Niño/La Niña neutral winter can be well above or below normal.

Other factors impact winter precipitation in Los Alamos beyond the large-scale ENSO circulation. The Pacific Decadal Oscillation (PDO) impacts the amount of winter precipitation received in Los Alamos (Gutzler et al. 2016). The PDO is a cycle of Pacific sea surface temperatures in the middle latitudes. In years when the PDO is positive and El Niño is present, New Mexico tends to receive more winter precipitation. In years when La Niña is present and the PDO is negative, New Mexico tends to receive less winter precipitation. However, the PDO does not fully explain each Los Alamos winter when high winter precipitation occurs in La Niña years or when low winter precipitation occurs in El Niño years.

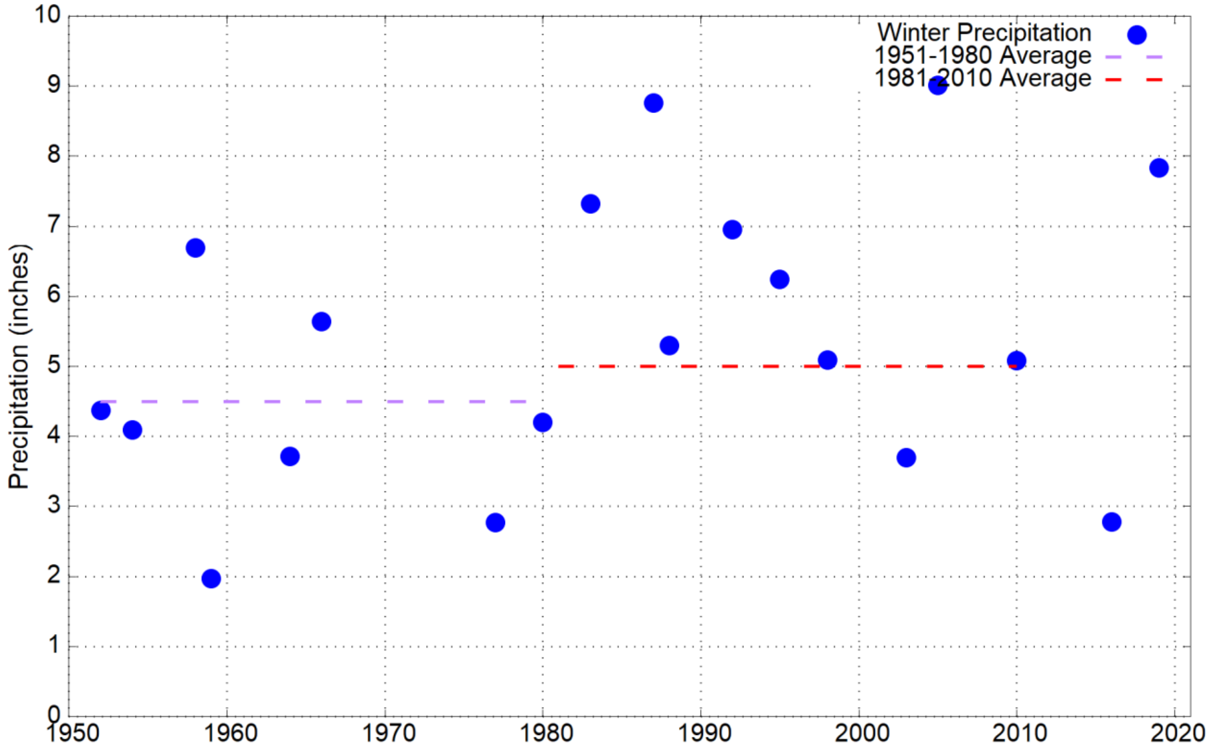

Figure 15. Los Alamos precipitation during El Niño winters. The year represents the year of the end of the winter (e.g., 2020 is the winter of 2019–2020).

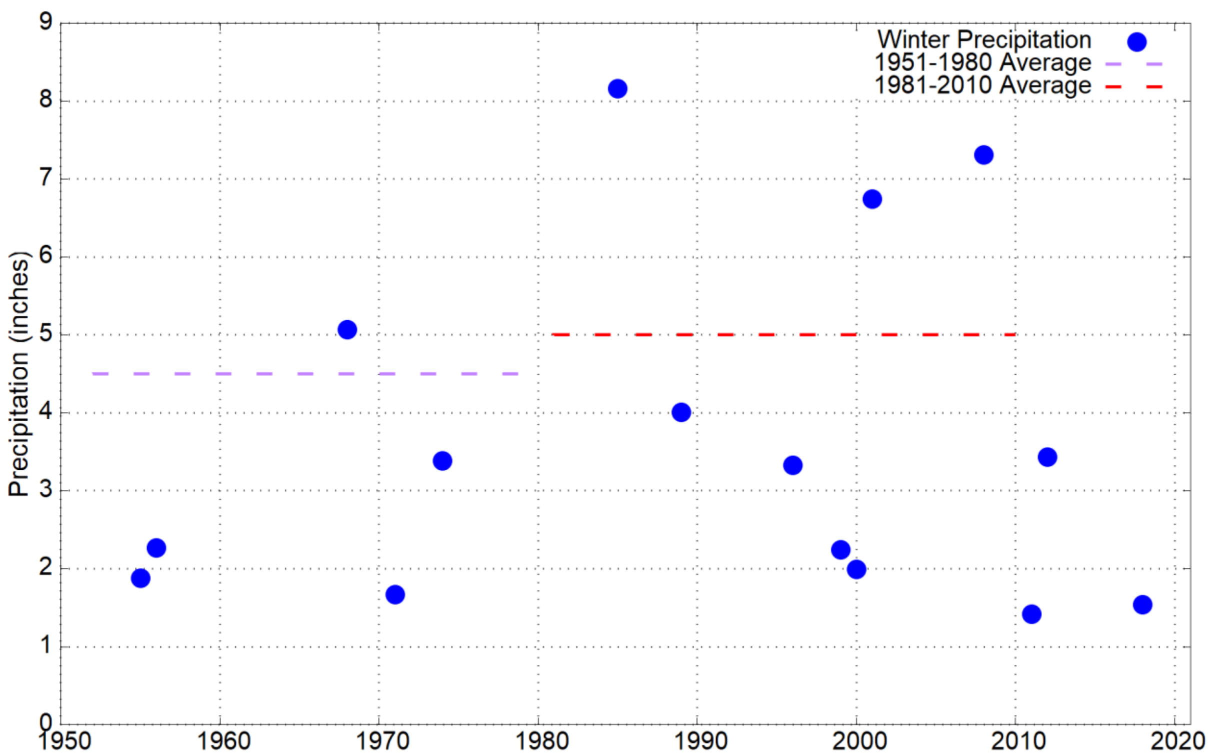

Figure 16. Los Alamos precipitation during La Niña years. The year represents the year of the end of the winter (e.g., 2020 is the winter of 2019–2020).

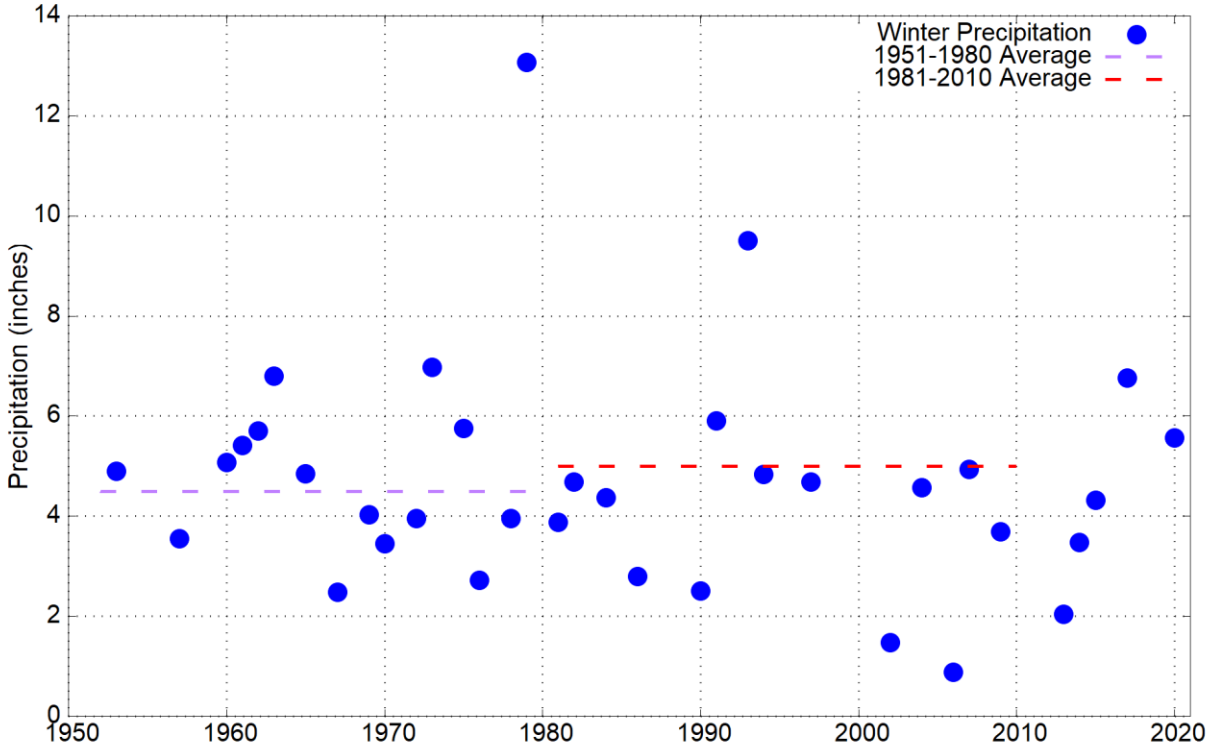

Figure 17. Los Alamos precipitation during El Niño/La Niña neutral years. The year represents the year of the end of the winter (e.g., 2020 is the winter of 2019–2020).

The analysis of monsoon precipitation during the June 15–September 30 monsoon season, following an El Niño or La Niña event is inconclusive. Gutzler (2000) identifies a negative correlation between Colorado spring snowpack and the Southwestern summer monsoon. A high spring season snowpack in Colorado produces a lower summer monsoon season precipitation total in the southwest. Other factors should be considered in future evaluations of monsoon variability in Los Alamos.

4.6 Atmospheric Moisture

The dew point temperature provides an estimate of the total amount of water vapor in the atmosphere at a specific pressure or altitude. Relative humidity also provides an estimate of the water content of the atmosphere, but, as the name implies, it is a relative measurement that is highly dependent on the temperature of the air. Relative humidity is a percentage of the total possible moisture that the atmosphere can hold at a given temperature. Therefore, dew point temperature is a better proxy for determining atmospheric moisture. Figure 18 presents monthly average dew point temperatures at 1.5 m AGL for the LANL mesa-top towers for 1993–2020. TA-49 dew point measurements are only available from 2000–2020. Figure 19 presents the monthly average humidity for the LANL mesa-top towers.

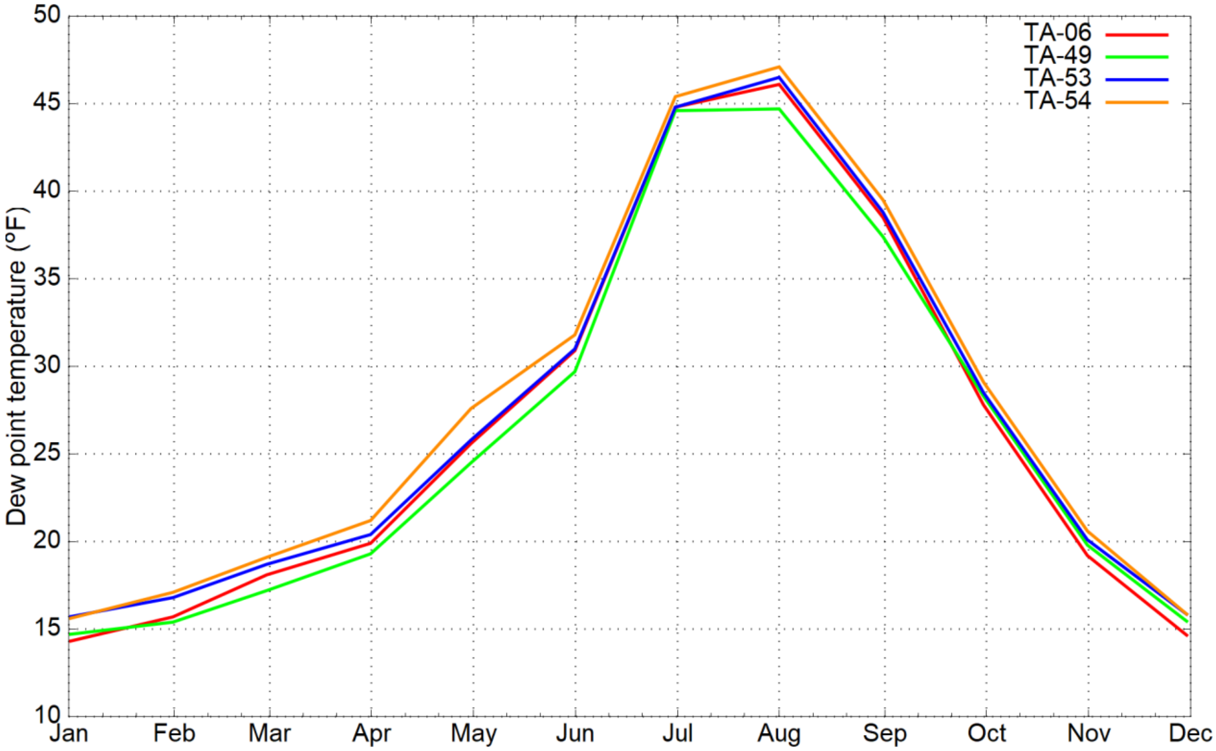

Figure 18. Monthly average dew point temperatures (1993–2020).

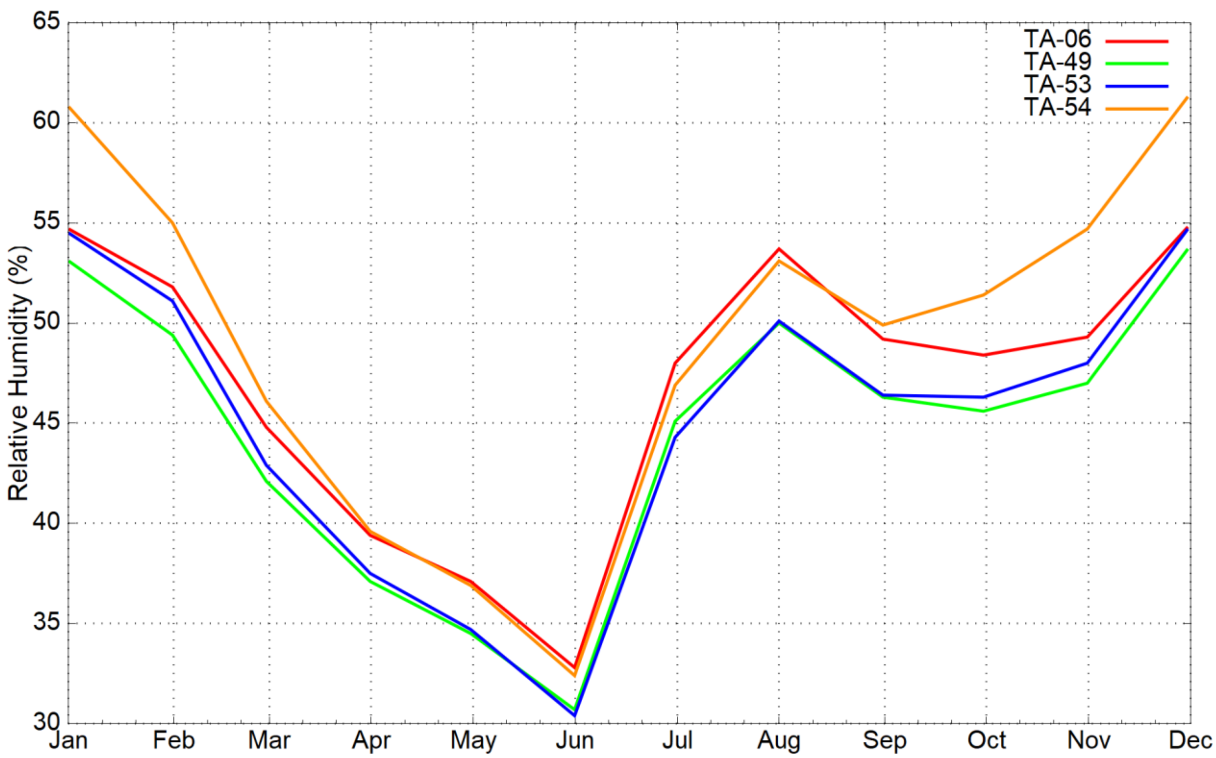

Figure 19. Monthly average relative humidity (1993–2020).

Los Alamos has a fairly dry atmosphere due to its large distance from the Gulf of Mexico (approximately 750 miles) and the Pacific Ocean (approximately 650 miles). The highest dew point temperatures occur in July and August, averaging around 45°F, with September only slightly lower at approximately 38°F. These are the months of the summer monsoon season when Los Alamos records as much as 50% of the annual precipitation. Daily dew point temperatures can reach into the mid 60’s during the monsoon season. The lowest values occur in the winter and early spring months, with average values between 15°F and 20°F. Very low dew point temperatures of 10°F occur on many days of the winter due to the very dry and cold conditions.

Since relative humidity is dependent upon temperature, it has a near inverted annual distribution (Figure 19) when compared with the average dew point temperature (Figure 18). In warmer temperatures the atmosphere has a greater capacity to hold moisture, so the lowest average humidity is measured on the warmest days in May and June before the summer monsoon season. Daily minimum relative humidity values can be less than 10% during the warm spring months. Relative humidity increases during July and August because of moisture brought into New Mexico by southerly winds from Mexico. Relative humidity increases during the winter months due to colder temperatures when the air can hold less water vapor. Relative humidity is measured above 90% on many cloudy winter nights.

5 Wind

5.1 Average Wind Speed

As previously mentioned, Los Alamos is a light wind site; annual average wind speeds on the mesas (measured at 12 meters) range from 6.2–7.4 mph. The highest average wind speeds occur during April, May, and June (Figure 20) when low-pressure systems deepen as they move east of the Rocky Mountains. The highest speeds, excluding Pajarito Mountain, are measured at TA-49 due to the more open terrain surrounding this tower location, with very few trees present to cause frictional drag on the wind. Wind speeds at TA-53 are also higher than average for mesa top locations, due to the very narrow aspect of the mesa where the tower is located. Wind speeds at the TA-53 location reflect the deep canyons to the north and south of the tower, where very little surface friction impacts the wind speed. Wind speeds within the canyons (TA-41 and TA-5 MDCN) are as much as 50% lower than at mesa top locations because the canyon bottom locations are often protected from high mesa top wind speeds. This effect is greatest at TA-41 since Los Alamos Canyon is a much deeper and narrower canyon at the TA-41 tower location than Mortandad Canyon where the TA-5 MDCN tower is located. The TA-41 tower is protected due to the following factors:

- its location below the mesa top (approximately 250 feet below mesa top level),
- a heavy tree cover at the canyon bottom which slows wind speeds due to friction, and
- mesa top peak wind speeds are often perpendicular to the WNW/ESE axes of the canyons, so that high mesa top wind speeds do not easily mix downward to the canyon bottom.

Average wind speeds at PJMT demonstrate a much different pattern than mesa top and canyon winds. PJMT winds (measured at 10,000 feet MSL) represent winds produced by the large-scale synoptic weather patterns and are not produced by the smaller-scale local topographic influences on wind commonly found on the mesas and within canyons. There are very little surface friction impacts at this height and very little impact from surface heating. (This is in part due to the height of the wind speed measurement at 36 meters, which is much greater than the 12-meter measurement height of the mesa and canyon towers.) The highest average wind speeds are observed in the spring and winter, like the mesa top winds, but there is a distinct wind speed minimum during the summer months. This reflects the monsoon circulation that affects the southwestern United States during the summertime. The midlatitude jet stream moves north and is replaced by the Four Corners high-pressure system (Adams and Comrie 1997) characterized by lower wind speeds at 10,000 feet, the height of Pajarito Mountain.

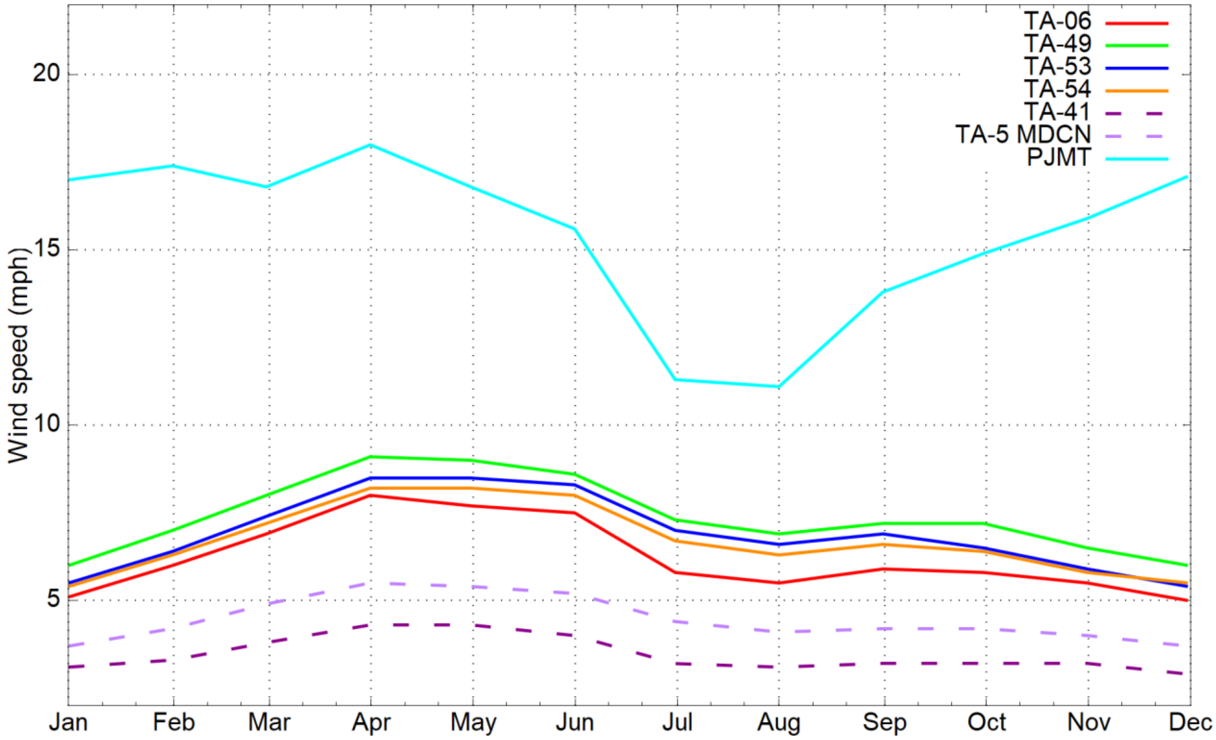

Figure 20. Monthly average wind speeds at 12 meters AGL for mesa-top and canyon towers (1993–2020, except TA-41 is 1994–2013 and PJMT is 1998–2012). PJMT is measured at 36 meters AGL.

5.2 Peak Gusts

Average peak gust wind speeds range from 20–33 mph across the Pajarito Plateau, as shown in Figure 21. Average peak gusts are much higher at PJMT, reaching an average of 43 mph in the spring. Peak gusts at each tower site follow a similar pattern to the average wind speeds. Highest average peak gusts occur in the spring at all locations.

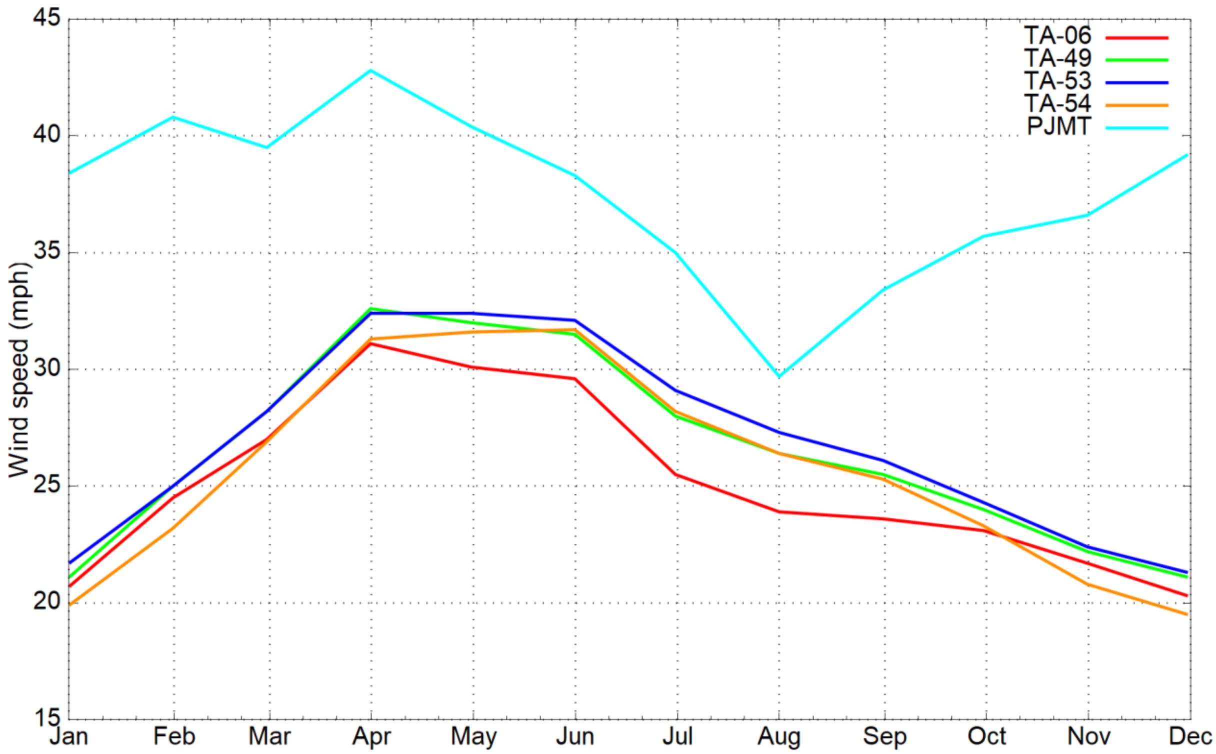

Figure 21. Monthly average peak wind gusts at 12 meters AGL (1993–2020, except PJMT is 1998–2012). PJMT is measured at 36 meters AGL.

5.3 Wind Direction

Daytime winds (i.e., sunrise to sunset) and nighttime winds (i.e., sunset to sunrise) are shown in wind roses in Figures 22 and 23. The wind roses are based on 15-minute-averaged wind observations for 2007 in order to capture all of the data from the four mesa-top stations, PJMT, and the canyon stations. Wind roses depict the percentage of time that wind blows from each of 16 direction bins and the distribution of wind speed. For example, the TA-6 wind rose during the day can be interpreted as measuring winds directly from the south over 12% of the time. The wind speeds range from 2.5 to 5 meters/second under 8% of the time, 5 to 7.5 meters/second over 2% of the time and exceed 7.5 meters/second only a fraction of 1% of the time. Although not shown here, wind roses from different years are almost identical in terms of the distribution of wind directions, indicating that wind patterns are constant when averaged over a year.

Wind

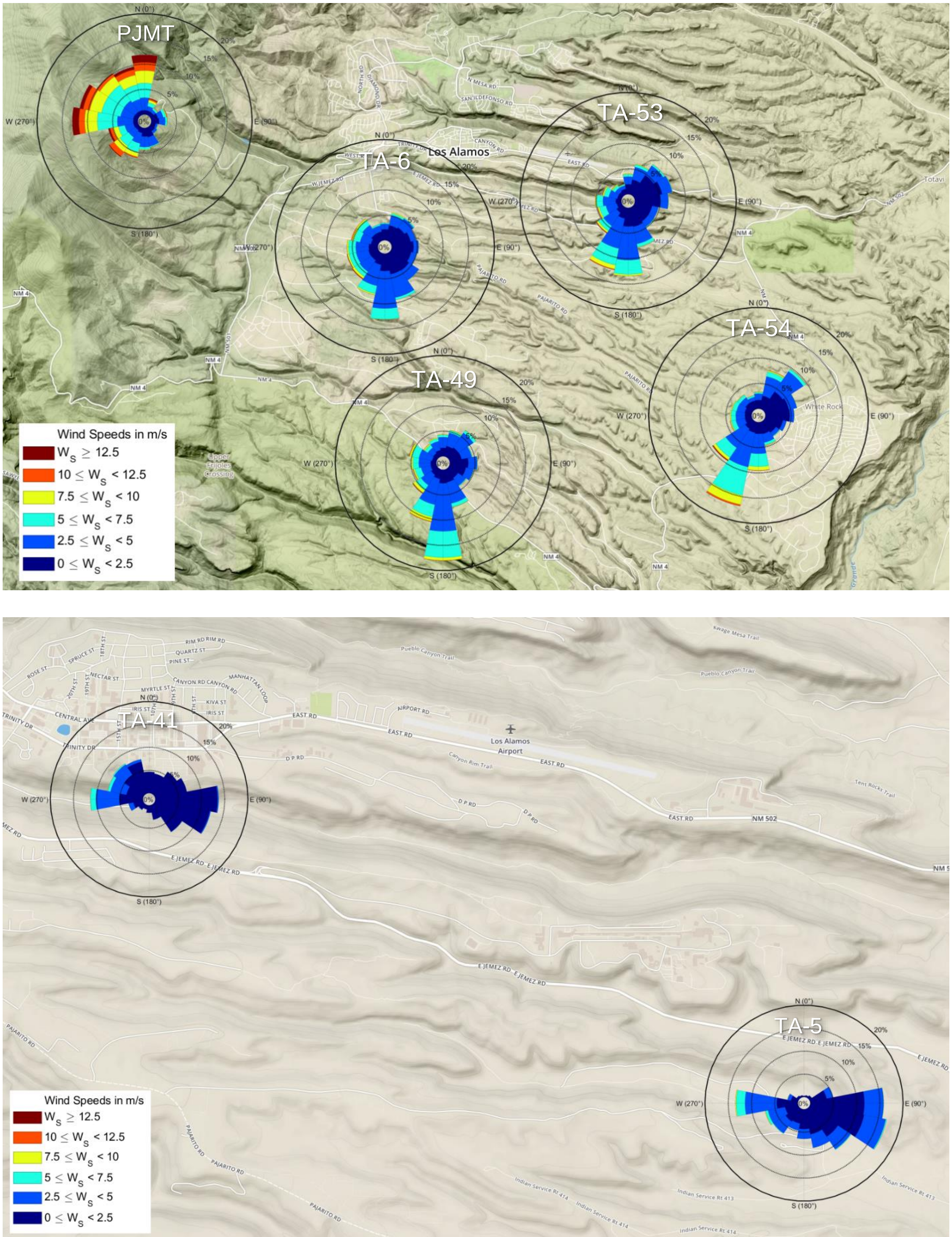

Figure 22. Daytime wind roses during 2007.

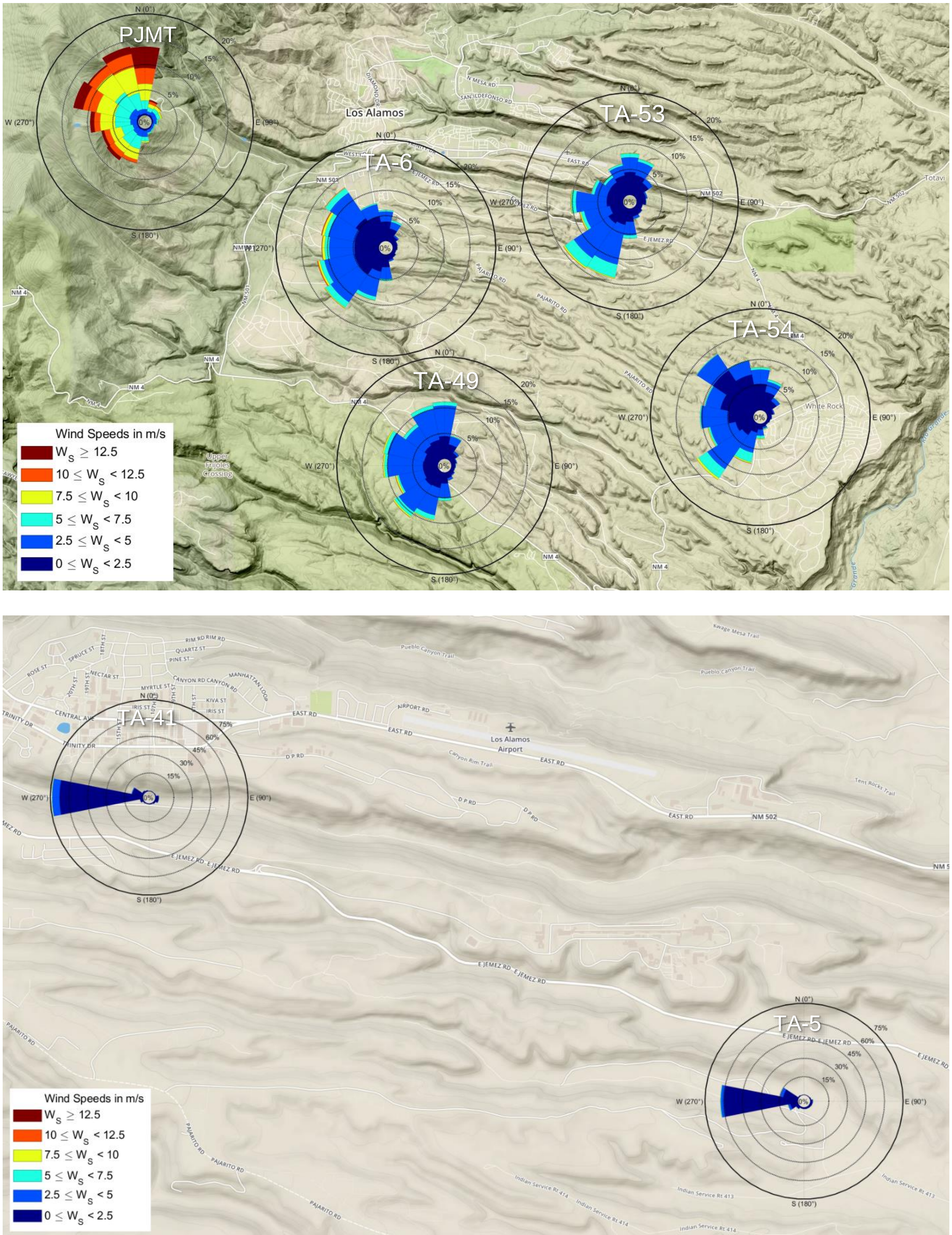

Figure 23. Nighttime wind roses during 2007.

6 Pan Evaporation

Average evaporation rates are used as design criteria for LANL evaporation ponds and basins. However, evaporation is not a measured parameter at LANL. Evaporation rate is a function of temperature, humidity, rainfall, solar radiation, and wind speed. The closest stations that can provide insight into evaporation rates at Los Alamos are at Abiquiu Dam and El Vado Dam. These data are collected by the Army Corps of Engineers (ACE) and are made available through the National Centers for Environmental Information (NOAA 2021b). Abiquiu Dam is at 6260 feet elevation MSL, 30 miles north of LANL, and El Vado Dam is at 6900 feet elevation MSL, 60 miles north of Los Alamos. Both stations have long-term records (57 and 85 years, respectively), and are used for managing the reservoirs behind the dams.

Evaporation rates are measured in a Class A Pan, a cylinder with a diameter of 47.5 inches that has a depth of 10 inches. Evaporation is measured daily as the depth of water (in inches) evaporates from the pan. The measurement day begins with the pan filled to exactly 2 inches (5 centimeters) from the pan top. At the end of 24 hours, the amount of water to refill the pan to exactly 2 inches from its top is measured. If precipitation occurs in the 24-hour period, it is considered in calculating the evaporation. Pan evaporation is typically measured between March and October when the water in the pan will not freeze.

The 1991–2020 average pan evaporation was calculated using daily measured evaporation values. The annual value at Abiquiu Dam is 64 inches and at El Vado Dam is 49 inches. The value for Abiquiu Dam is like an expected value for White Rock since the elevation and summertime temperatures are very similar. The evaporation rate for Los Alamos would be expected to be higher than at El Vado Dam. El Vado Dam has a similar elevation to Los Alamos, but the summertime temperatures are slightly cooler, and the precipitation is greater than in Los Alamos. The monthly distribution of pan evaporation totals for Abiquiu Dam and El Vado Dam are presented in Figure 24. Highest monthly totals occur during the warmest months of the year when there is the highest incoming solar radiation.

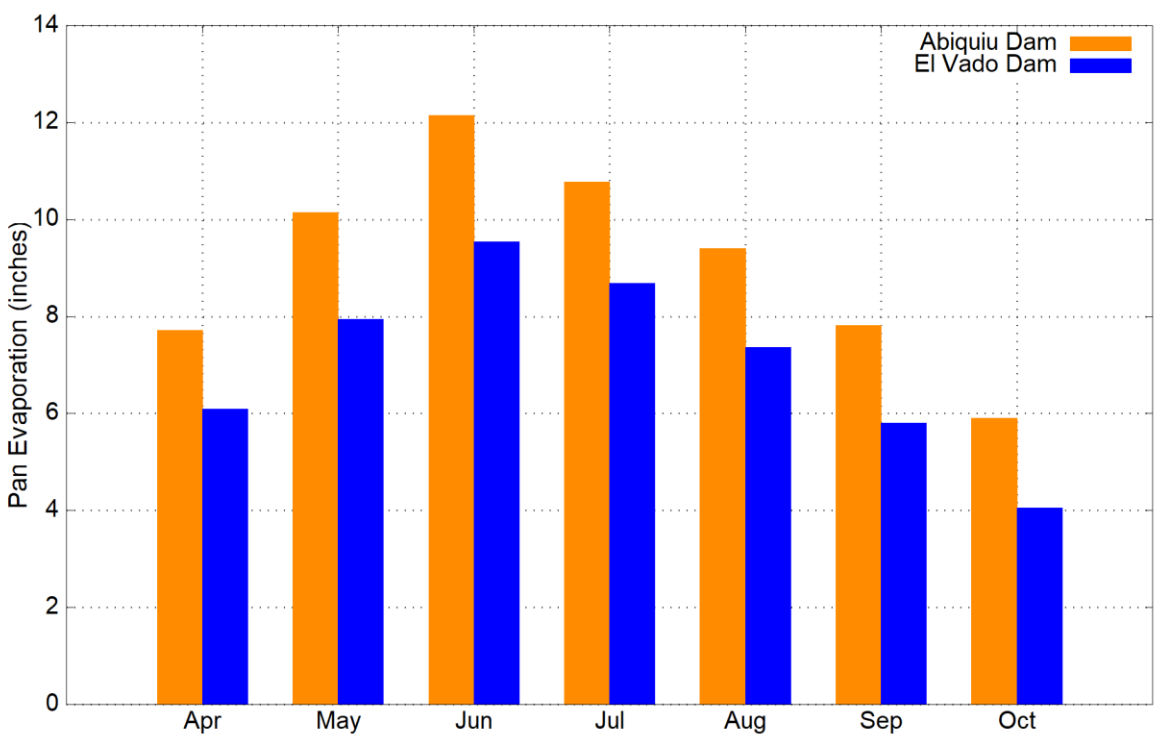

Figure 24. Monthly average pan evaporation at Abiquiu Dam and El Vado Dam (1991–2020).

7 Insolation

LANL measures the radiation components of the earth's surface energy budget, as shown in Figure 25, at ground level. LANL measures incoming (i.e., shortwave in) and reflected solar radiation in the visible range of light, from 0.3–2.8 micrometers. Longwave radiation emitted by the atmosphere (i.e., longwave in) and the surface of the earth (i.e., longwave out) is measured in the infrared range from 3.5–50 micrometers. Incoming longwave radiation represents an integrated temperature of the atmosphere above the monitoring location whereas outgoing longwave radiation represents the temperature of the surface of the earth. Incoming solar radiation is measured at most LANL tower locations for use in LANL solar energy projects. These data can also be used in atmospheric dispersion calculations for turbulence typing purposes. Reflected solar radiation and longwave radiation (incoming and outgoing) are also measured at TA-6 and TA-54, and along with incoming solar radiation, can be used in calculating surface energy budgets and estimating evaporation rate.

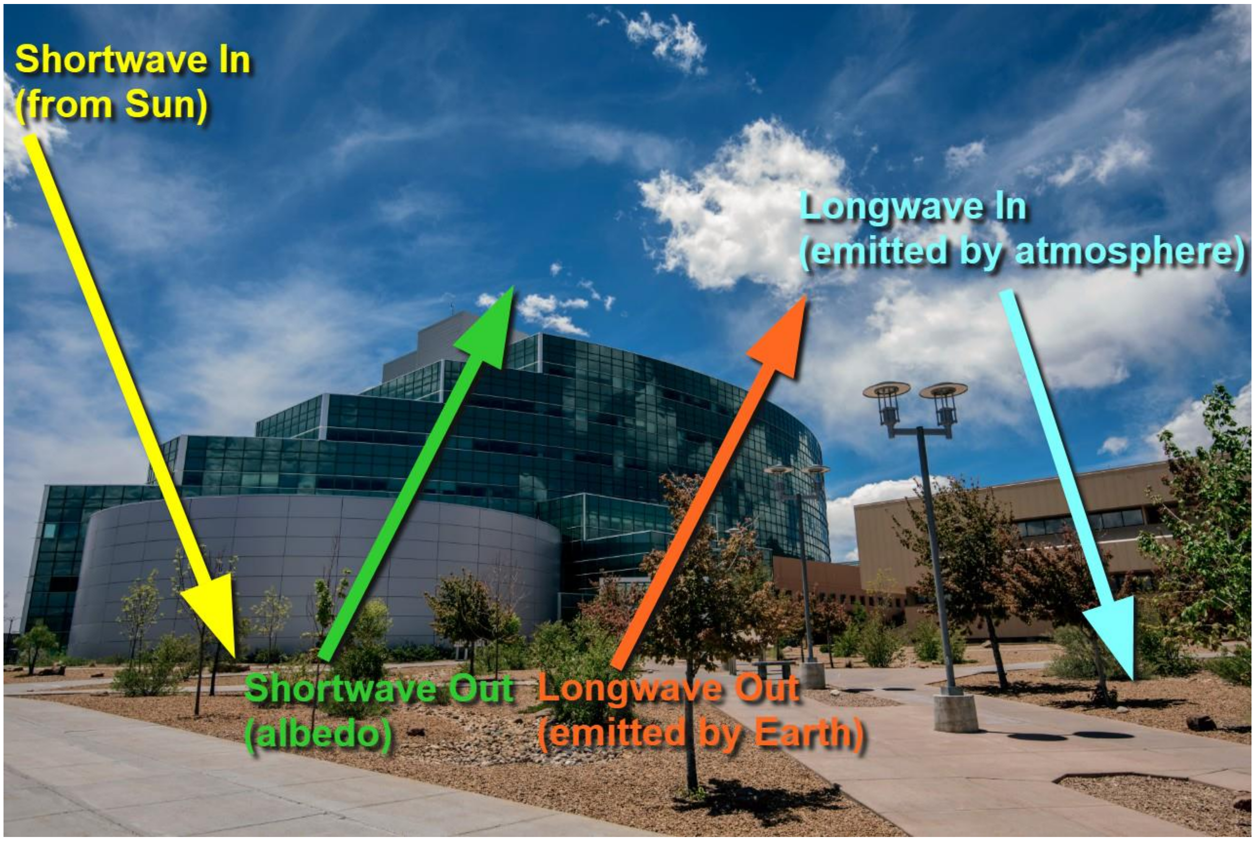

Figure 25. Conceptual diagram of radiation measured at TA-6 and TA-54.

Monthly average incoming solar radiation at all towers is presented in Figure 26. All towers have very similar values, except for TA-41. Los Alamos Canyon, the location of the TA-41 tower, is a very narrow (100 feet) and deep (300 feet) canyon where incoming solar radiation is partially blocked by the canyon walls throughout the year, especially during the winter months. Although the TA-5 MDCN tower is also located in the bottom of a canyon, Mortandad Canyon is very wide (~700 feet) and shallow (~170 feet deep) at the tower location, thus incoming solar radiation is not significantly blocked by the canyon walls at that location. TA-54 measures slightly greater amounts of incoming solar radiation in the summer because of less rainfall and cloudiness at this location compared with other tower locations.

Insolation

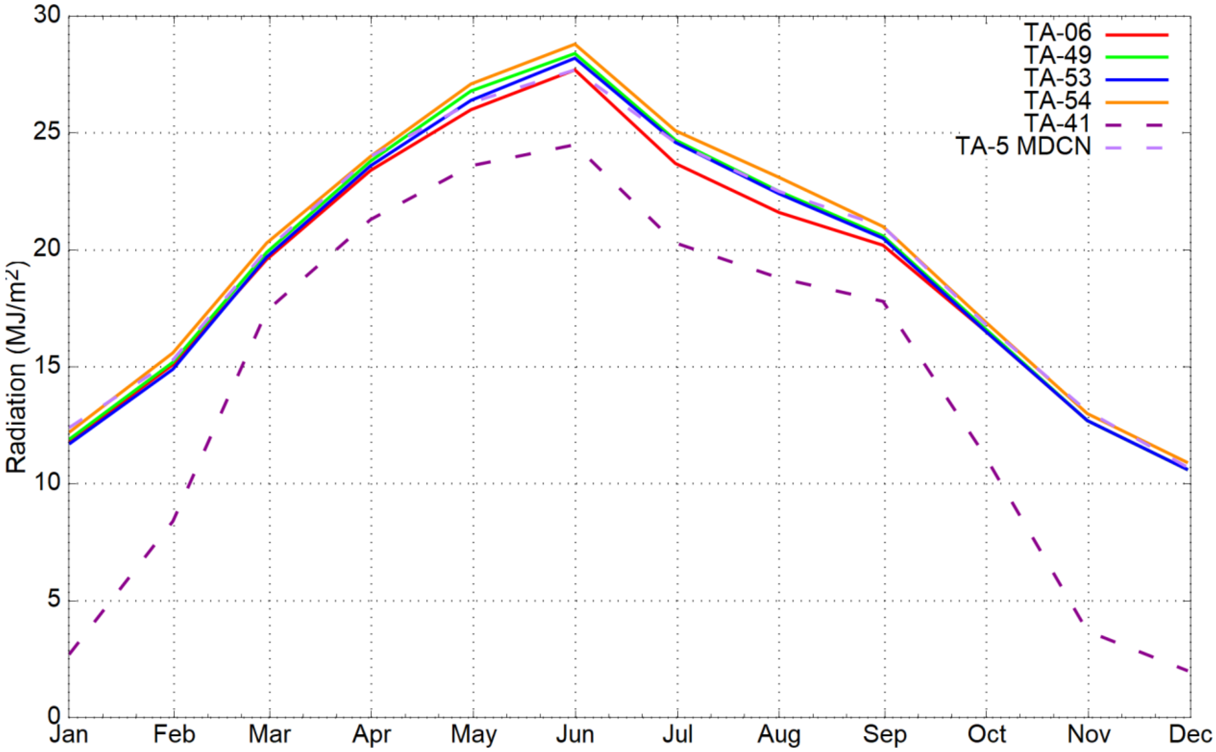

Figure 26. Monthly average incoming solar radiation (1993–2020, except TA-41 is 1994–2013 and TA-5 MDCN is 2003–2020).

The albedo of a surface, which is a measure of how much light that hits the surface is reflected without being absorbed; the "whiteness" of a surface, is calculated as the ratio of the reflected solar radiation/incoming solar radiation. Bare rocks and soils are more reflective of sunlight than green grasses and trees. The albedo at TA-54, of 0.26, is greater than the albedo at TA-6, of 0.22, due to the greater prevalence of bare and rocky soils at TA-54, in comparison with the greater amounts of green grasses and trees at TA-6.

The atmosphere and the surface both radiate energy in the long wavelengths, so the energy budget at the surface of the earth is measured as the sum of incoming shortwave and longwave radiation minus the reflected shortwave and outgoing longwave radiation. The monthly average values for each radiation measurement at TA-6 and TA-54 are presented in Figures 27 and 28.

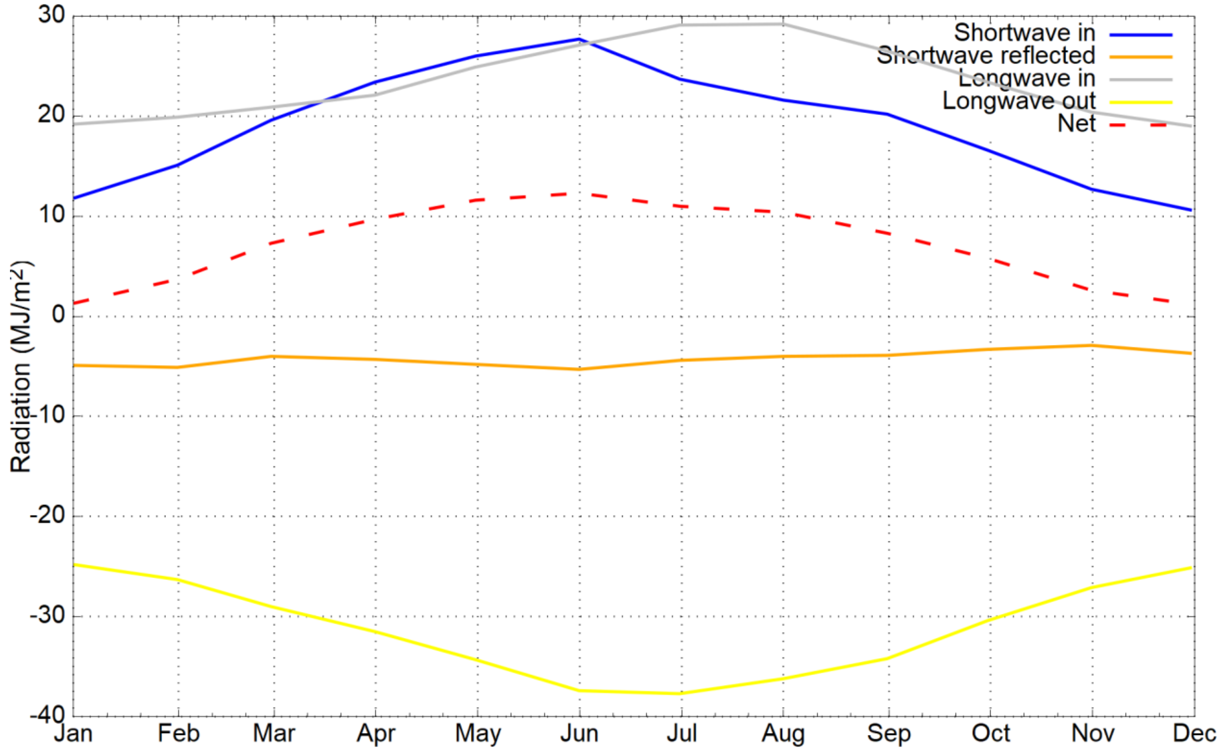

Figure 27. Monthly average surface radiation energy balance at TA-6 (1993–2020).

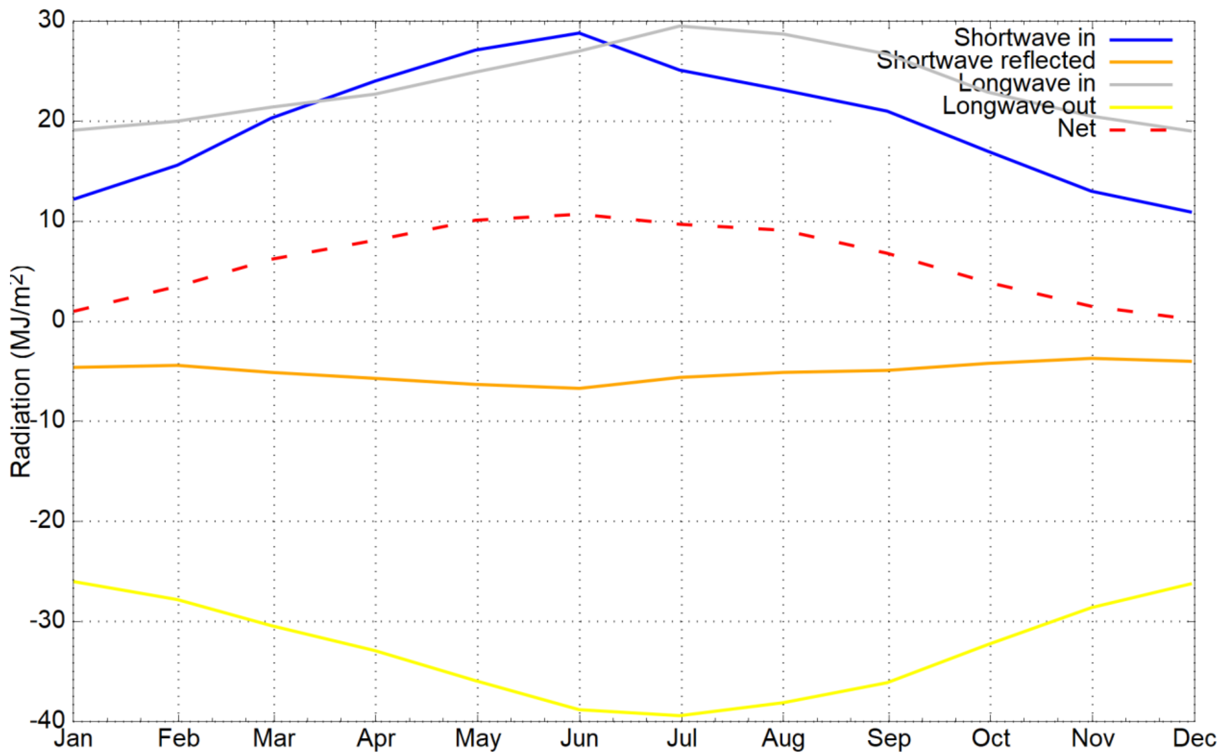

Figure 28. Monthly average surface radiation energy balance at TA-54 (1993–2020).

Insolation

The maximum reflected shortwave radiation follows the pattern of incoming solar radiation, and peaks in June at both TA-6 and TA-54. Longwave radiation is a function of the temperature of the atmosphere or the ground surface and peaks in July as the maximum temperature of the atmosphere and the surface lags the solar maximum. The maximum net positive radiative energy at the surface is measured in June with the net energy approaching zero in the colder winter months.

8 Pressure

The United States Standard Atmosphere is an atmospheric model of how the pressure, temperature, and density of the Earth's atmosphere changes over a wide range of altitudes or elevations. The standard atmospheric pressure is the weight of a column of air from sea level to the top of the atmosphere. At sea level, this pressure is 29.92 inches of mercury or 1013.3 millibars (mb). As the surface of the earth rises with terrain, there is less atmosphere above the ground, so the pressure at the elevated surface decreases. The standard atmospheric pressure is about 22.73 inches of mercury (770.0 mb) at the TA-6 elevation, 7424 feet above sea level. The atmospheric pressure at Los Alamos is ~76% of the sea-level pressure. Pressure measurements are available for Los Alamos beginning in 1979 and for White Rock beginning in 1992. Long-term averages are calculated for 1993–2020 following the convention for other meteorology parameters across the Laboratory.

Monthly mean atmospheric pressure is shown in Figure 29 for TA-6 and TA-54. Because TA-54 is approximately 900 feet lower elevation than TA-6, the average pressures are about 25 mb higher than at TA-6. There is an annual cycle, with a summer maximum and a spring minimum. The spring minimum is caused by frequent mid-latitude low-pressure storms. The summertime maximum is caused by the upper-atmosphere westerlies moving to the north and the subtropical high-pressure systems moving northward into the southern United States. Variations from the mean are greatest in the spring and winter seasons and least during the summer.

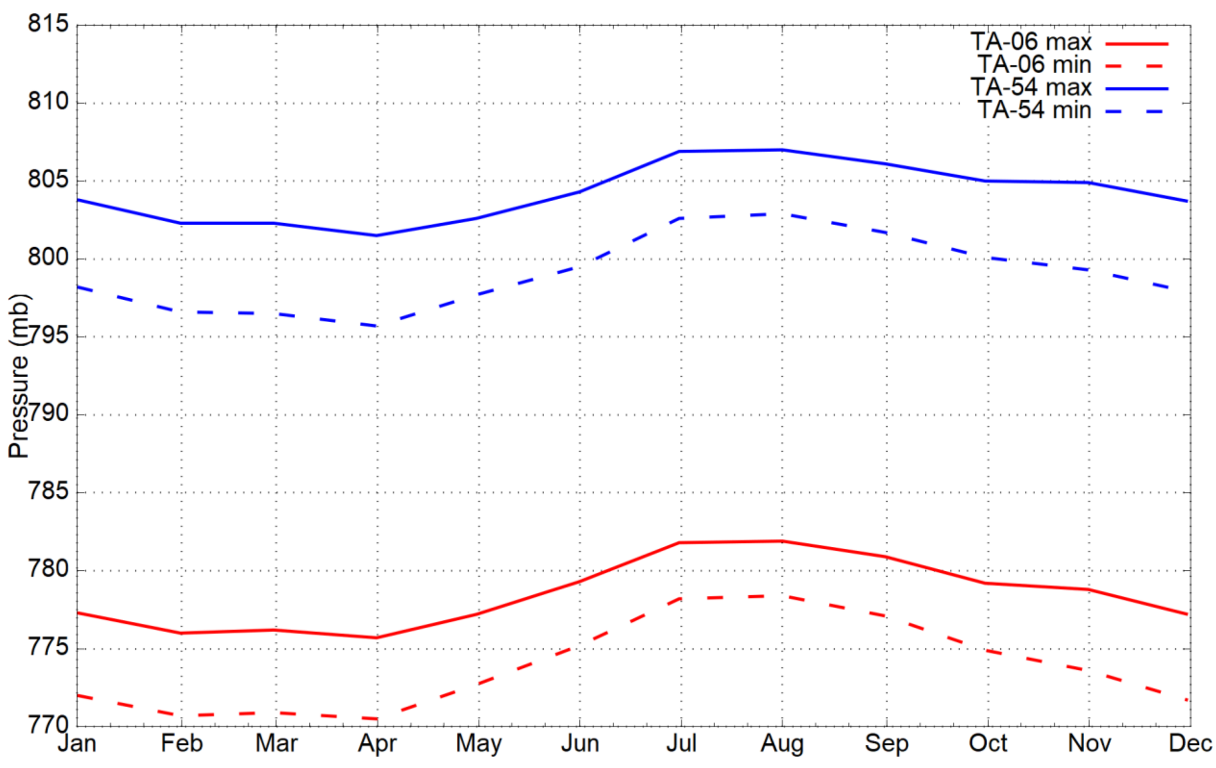

Figure 29. Monthly average maximum and minimum pressure at TA-6 and TA-54 (1993–2020).

Even though the average pressure is highest during the summer, the highest 15-minute pressure measurements tend to occur in the wintertime. High wintertime pressure readings can result from cold, arctic air high-pressure systems pushing their way into New Mexico from the Great Plains; the cold air is very dense and so it produces higher pressure values. The highest 15-minute pressure measured at TA-6 is

792 mb; the highest 15-minute pressure measured at TA-54 is 819 mb. The lowest pressures recorded at TA-6 and TA-54 are 739 mb and 771 mb, respectively.

In addition to an annual cycle of pressure, there is a semi-diurnal (i.e., 12-hour) cycle in pressure measurements, caused by the heating of the upper atmosphere by the sun. Hourly average pressure at TA-6 and TA-54 demonstrates minimum values at 4 AM and 4 PM and maximum values at 9 AM and midnight, as shown in Figure 30.

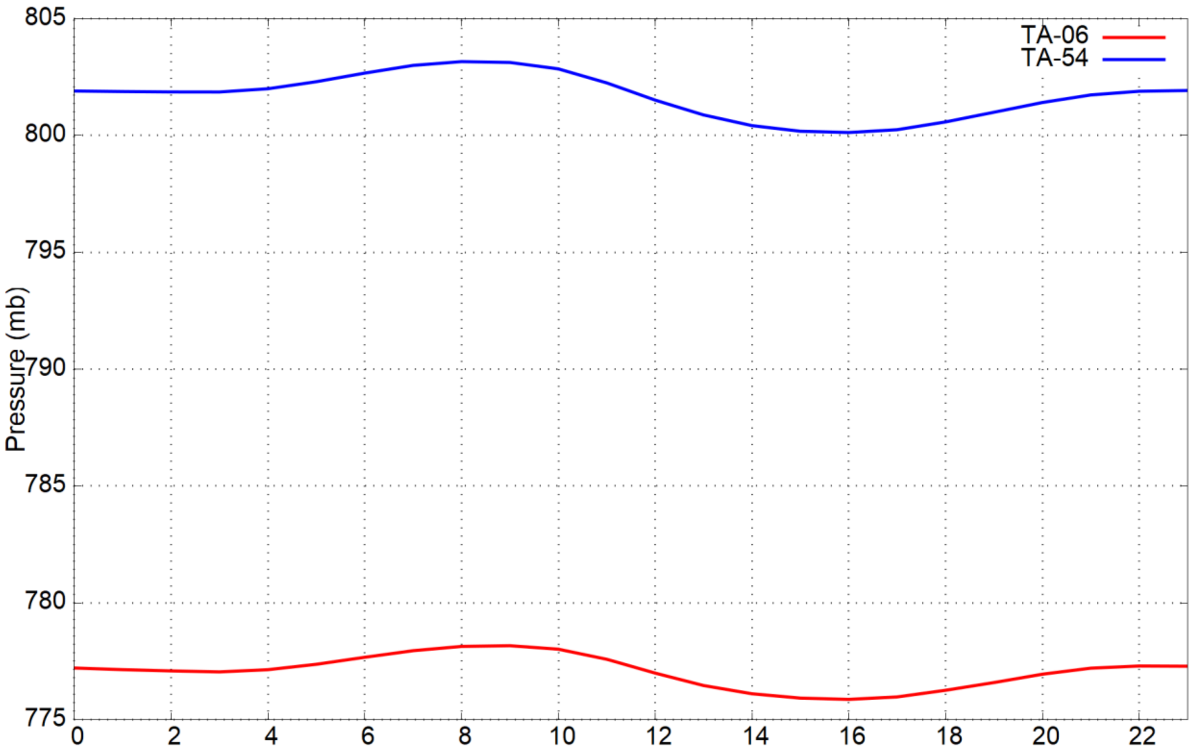

Figure 30. Hourly average pressure at TA-6 and TA-54 during 2020.

9 Climate Trends

In the last half of the twentieth century, greenhouse gas emissions from human activity have begun to make a long-term impact on the Earth's climate. The global surface temperature from 2011–2020 was 1.96°F higher than 1850–1900 (IPCC 2021). For the Southwest United States, temperatures warmed by more than 1.5°F between 1901–1960 and 1986–2016. Temperatures are predicted to rise over the next century, snowfall is expected to decrease (due in part to rising temperatures), and extended droughts (with resulting wildland fires) are expected to be more severe (Hayhoe et al. 2018). In this section, the Los Alamos data are evaluated to determine what climate changes are being measured in Los Alamos. Other LANL data will be available in the future to further characterize climate changes in Los Alamos, including stormwater runoff and locations of bird species with altitude.

9.1 Temperature

Figure 29 shows the historical record of temperatures in Los Alamos from 1924–2020. The annual average temperature is the average of the daily high and low temperatures averaged over the year. One-year averages are shown in grey in Figure 29. To aid in showing longer-term trends, the 5-year running mean (black) is also shown. The 5-year average shows the warm spell during the past 20 years is almost as extreme as the warm spell during the early-to-mid 1950s and is currently longer-lived.

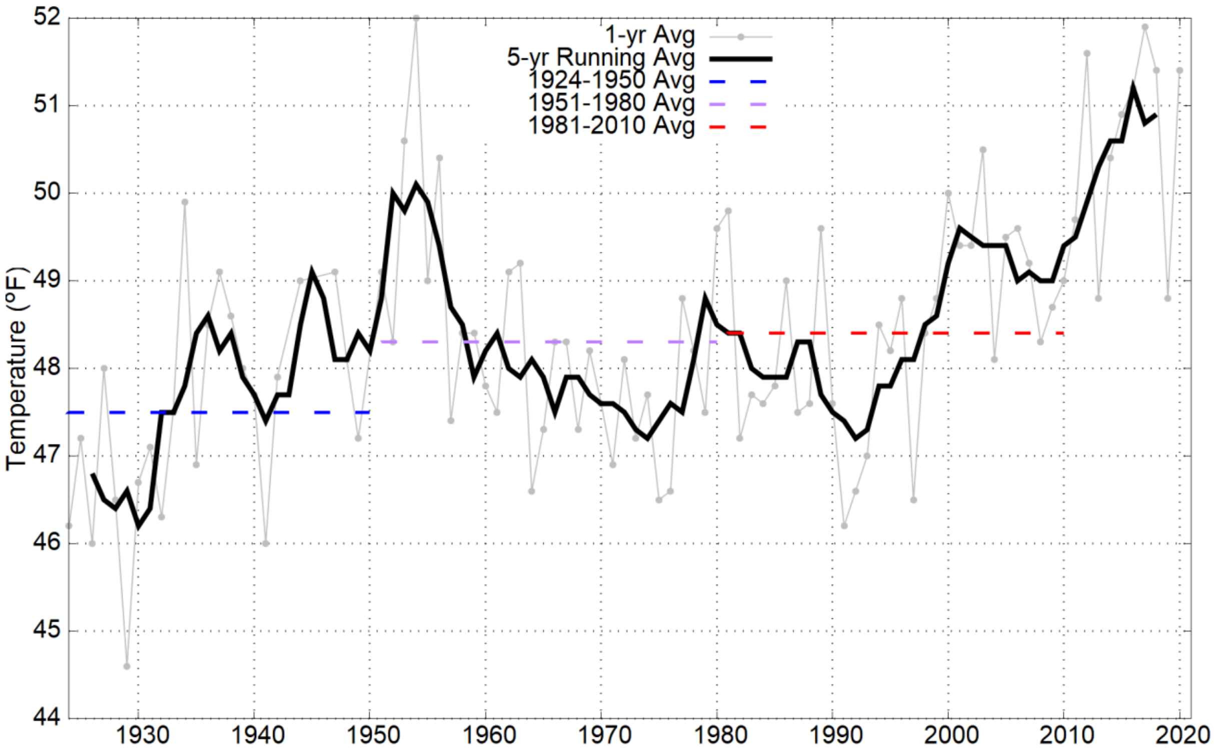

Figure 29. Temperature history for Los Alamos (1924–2020).

The average temperatures per decade, along with two times the standard deviation, are plotted in Figure 30. Ninety-five percent of the annual average temperatures during each decade are found within the error bars. During the decades between 1960 and 2000, the annual average temperatures in Los Alamos vary only slightly from 48°F. During the 2001–2010 decade, the annual average temperature increased to above 49°F; this value can be considered a statistically significant higher value than previous decades. The most recent decade increased to above 50°F to continue to demonstrate a warmer climate for Los Alamos. This is consistent with predictions for a warming climate in the southwestern United States (IPCC 2021).

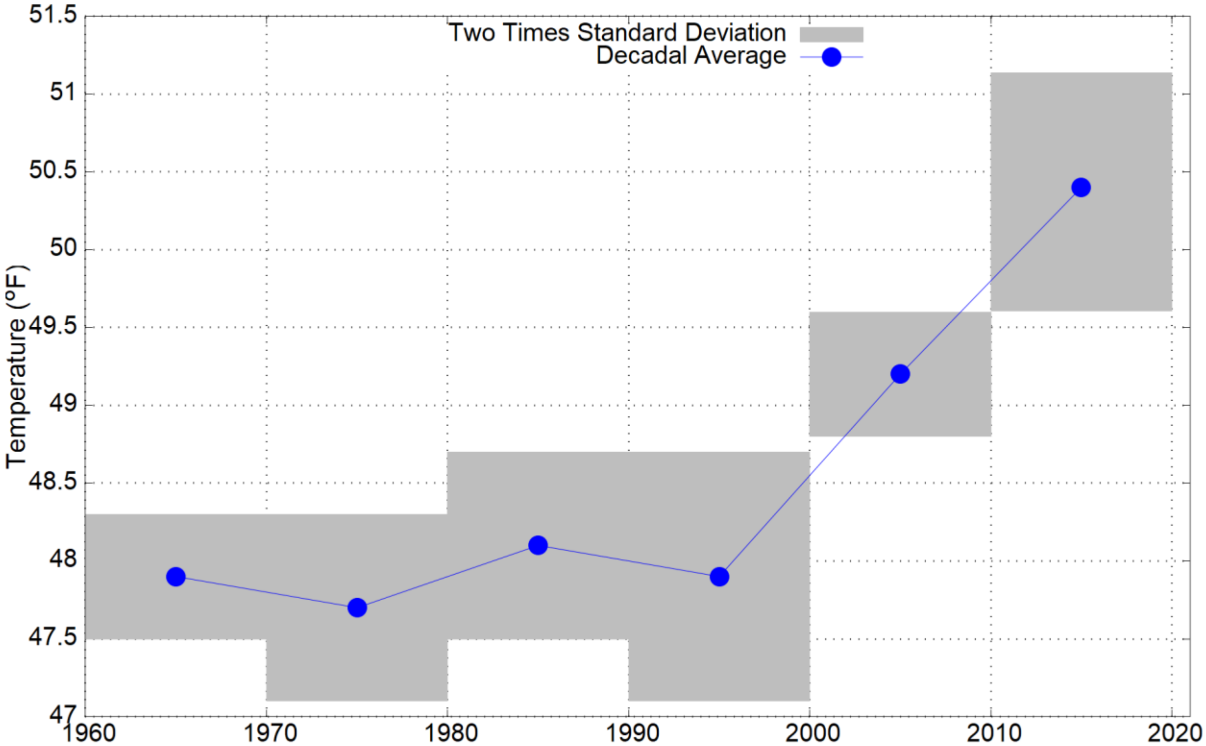

Figure 30. Decadal average temperatures and two times the standard deviation for Los Alamos (1960–2020).

Summertime (June–August) maximum, minimum, and average temperatures since 1990 demonstrate a positive trend as shown in Figure 31. Fall and spring temperatures also demonstrate a positive trend, but not as strong as summer temperatures.

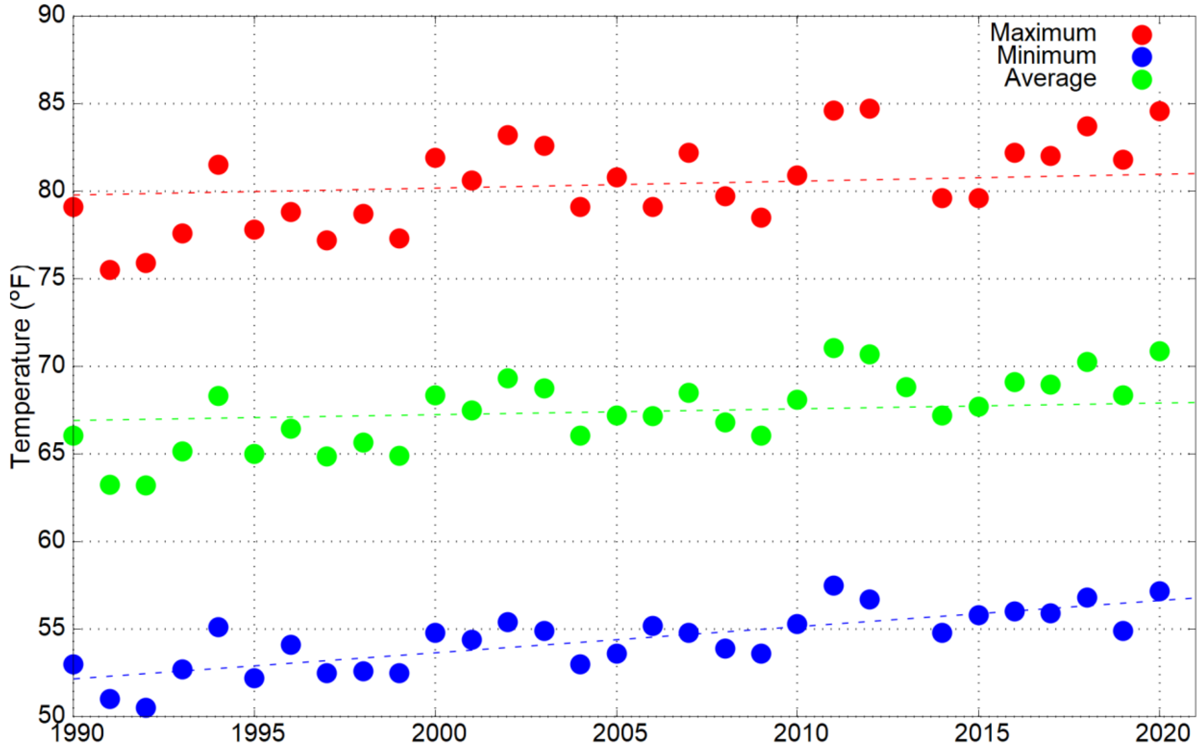

Figure 31. Annual average summertime temperatures for Los Alamos (1990–2020).

Noteworthy, the Top 10 of the hottest summers have all occurred since 2002. The highest summertime average temperature on record was 71.1°F, recorded during 2011. There is a positive trend in the number of days with a maximum temperature greater than 90°F as shown in Figure 32 and a negative trend in the number of days with a minimum temperature less than 0°F as shown in Figure 33. There have only been two days less than 0°F since 2014.

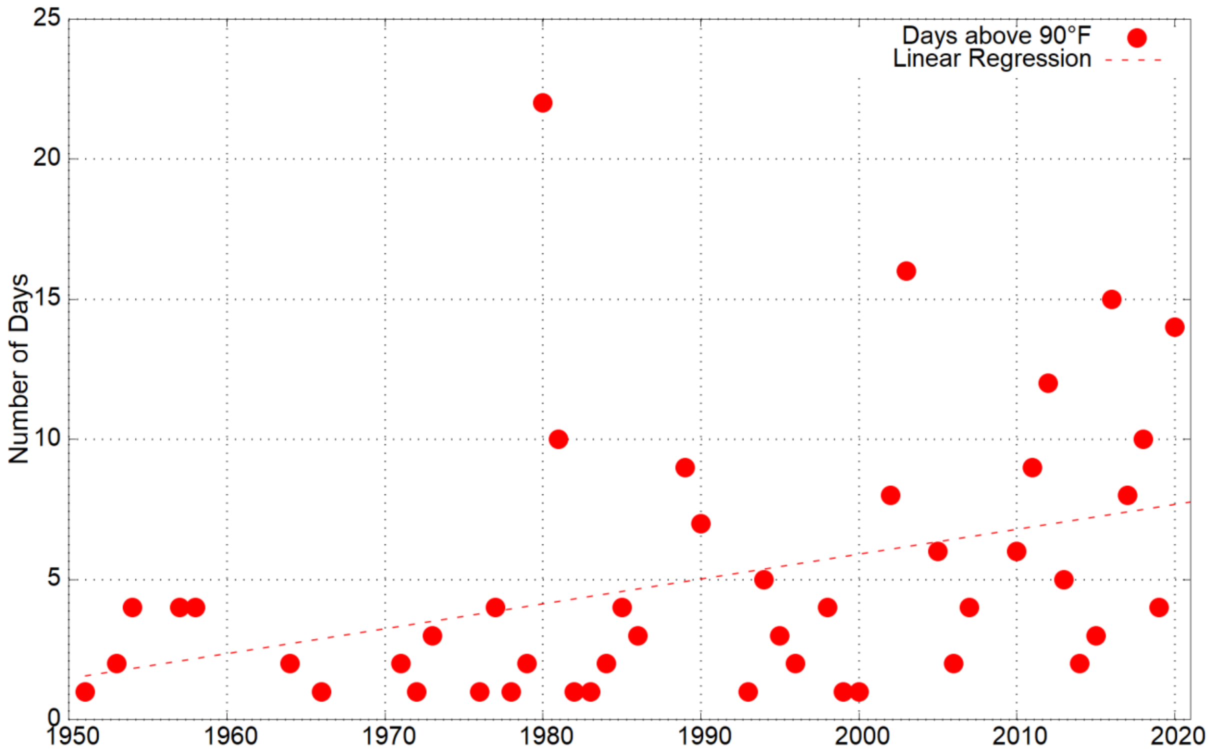

Figure 32. Number of days per year with maximum temperature above 90°F for Los Alamos.

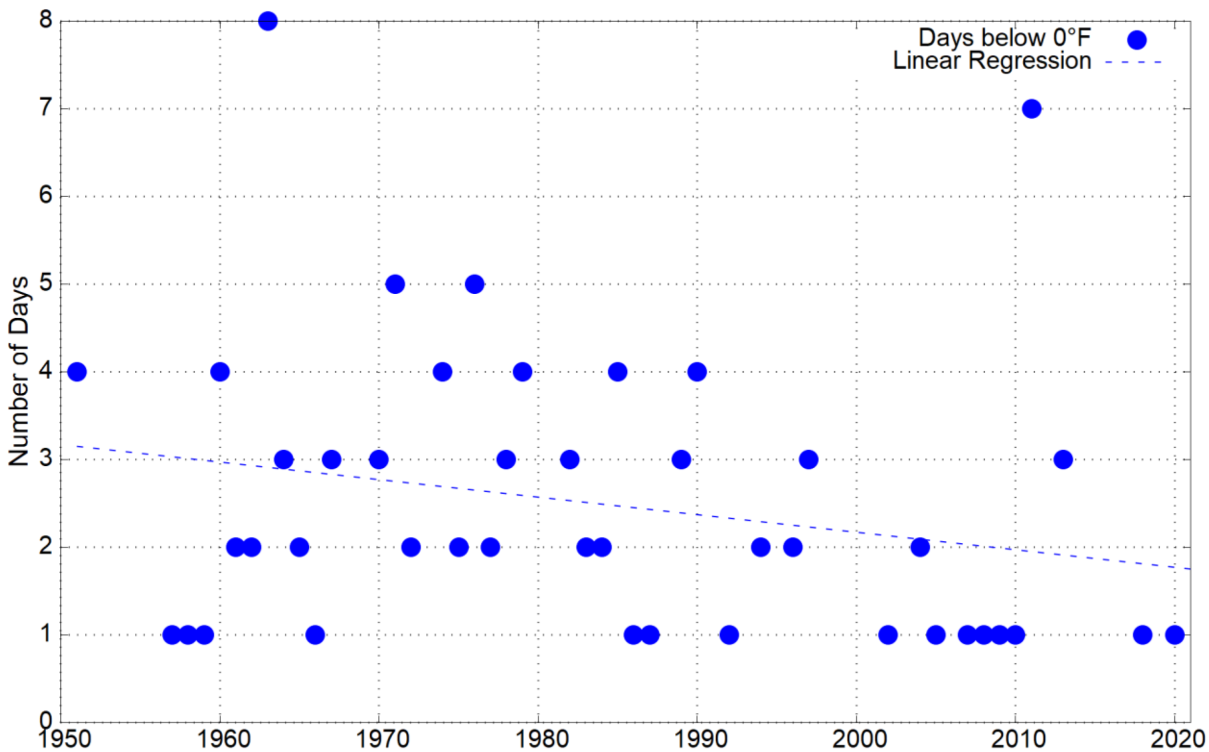

Figure 33. Number of days per year with minimum temperature less than 0°F for Los Alamos.

9.2 Precipitation

Figure 34 presents the historical record of the annual precipitation at Los Alamos. As with the historical temperature profile, the 5-year running mean and the 30-year normal values are also shown. There is a slight positive trend through the twentieth century followed by drought. The current drought has occurred since 1998, although near-average precipitation years occurred from 2004–2010 and above average precipitation occurred in 2013 and 2015.

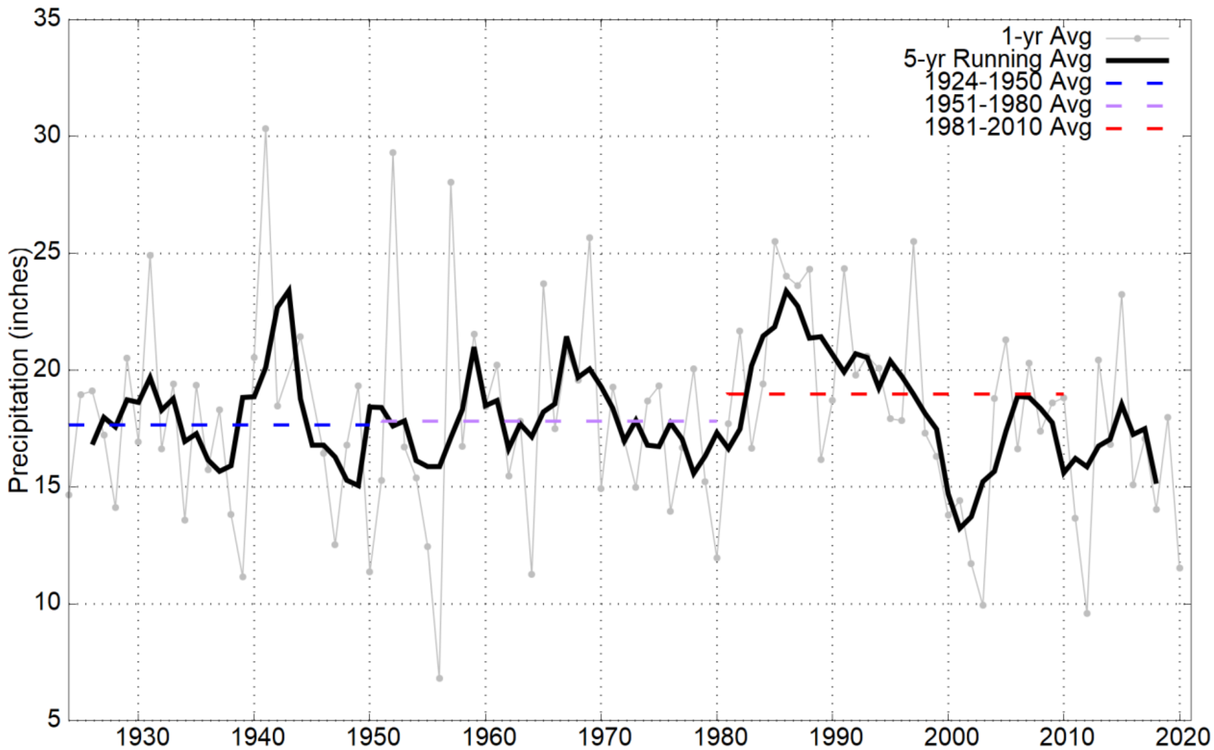

Figure 34. Precipitation history for Los Alamos (1924–2020).

Although the 30-year climatological average annual precipitation values have increased over the last century, this is in large part due to the very wet period of 1982 through 1997. Average annual precipitation exhibits a downward trend for 1981 to the present and snowfall (Figure 35) exhibits a downward trend for 1951 to the present. This is consistent with the impact of the most recent drought years.

In addition to the total amount of snowfall decreasing over the past 70 years, there is a decrease in the length of the snowfall season, the number of days between the average first measurable snowfall in the fall and the last measurable snowfall in the spring. Figure 36 presents the Julian date of the first and last snowfall of the year. In the early 1980s, the first day of snow for the year was about November 4 and the final snowfall of the year was about April 18. Recently, the first snowfall of the year occurs in late November and the final snowfall of the year occurs at the end of March, although the first snowfall in the past three years occurred in October and September.

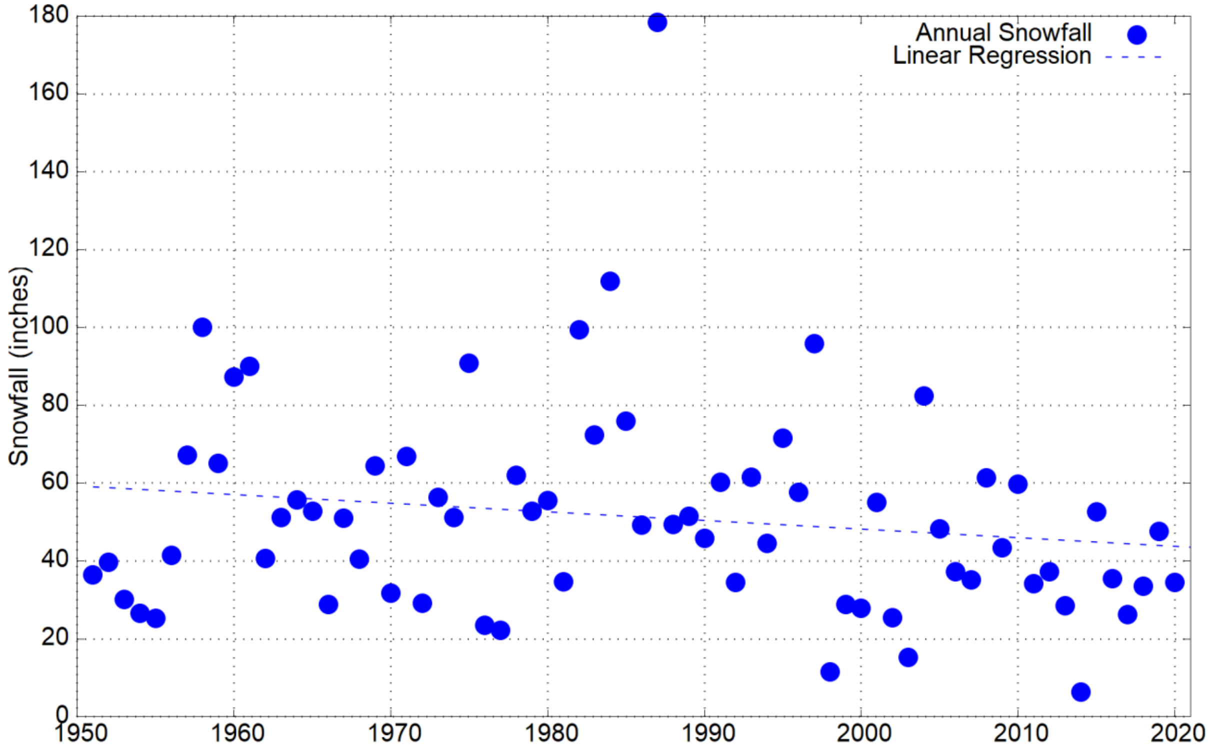

Figure 35. Annual snowfall (July 1–June 1) for Los Alamos (1951–2020).

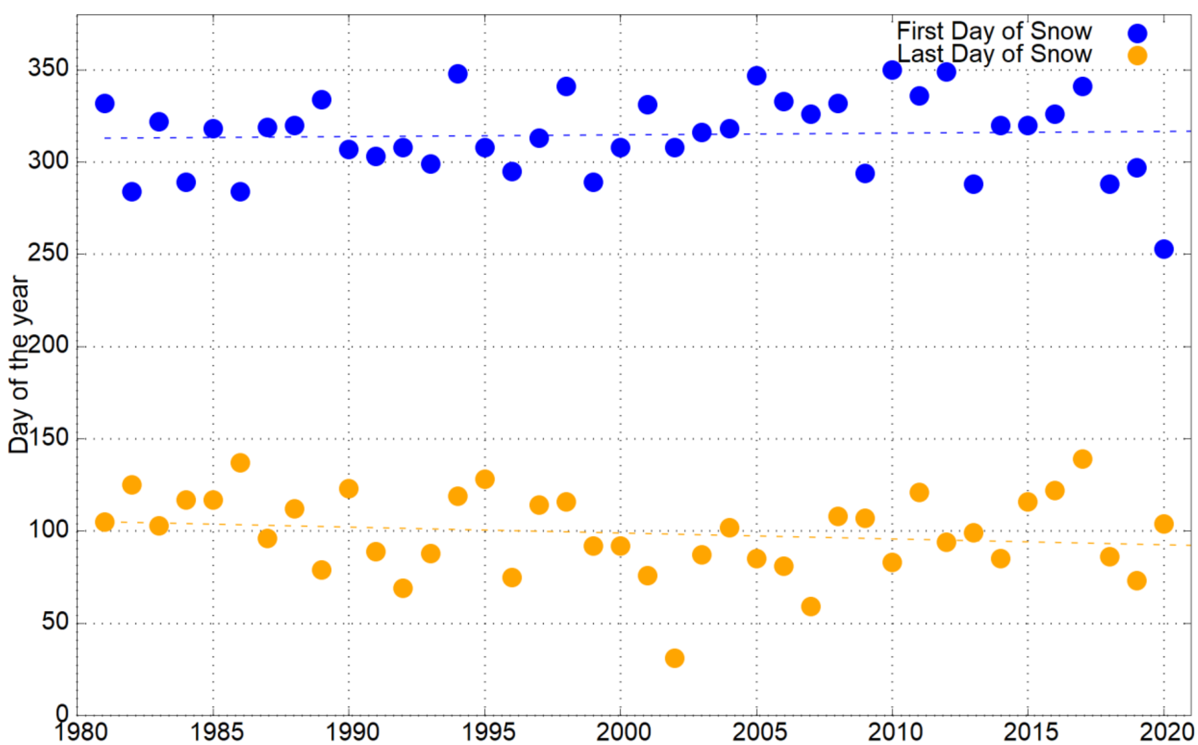

Figure 36. First and last day of snow for Los Alamos (1981–2020).

Figure 37 presents the Los Alamos monsoon precipitation (June 15–September 30) and demonstrates a downward trend from 1951 to the present, particularly with recent low precipitation in four of the past five monsoon seasons.

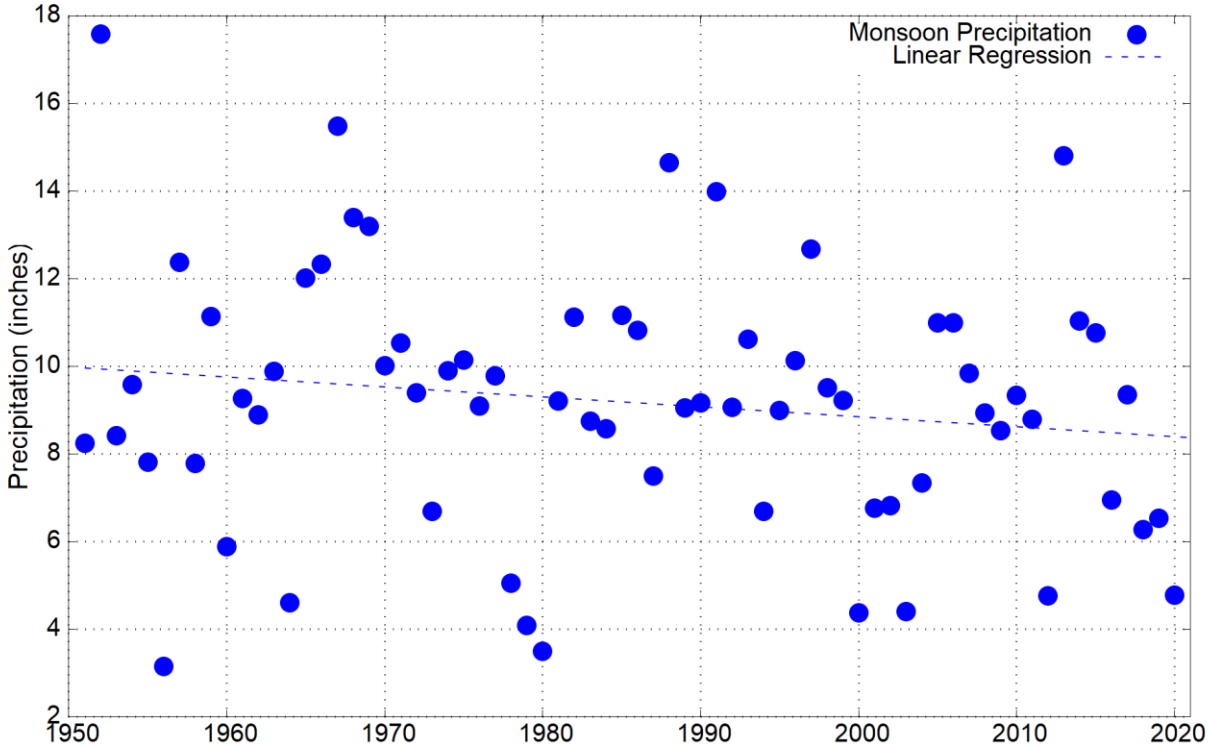

Figure 37. Annual monsoon precipitation for Los Alamos (1951–2020).

Heavy precipitation events demonstrate a very slight downward trend for the years 1951–present as shown in Figure 38. However, most of the trend occurs during the 1981–present period, reflecting the very wet years of the 1980s and the early 1990s followed by the drought from the late 1990s to 2020. The number of days per year with precipitation greater than 0.75 inch also demonstrates a downward trend. For the years 1951–2020, the number of days with precipitation >1.0 inch has stayed very steady, at about two days per year.

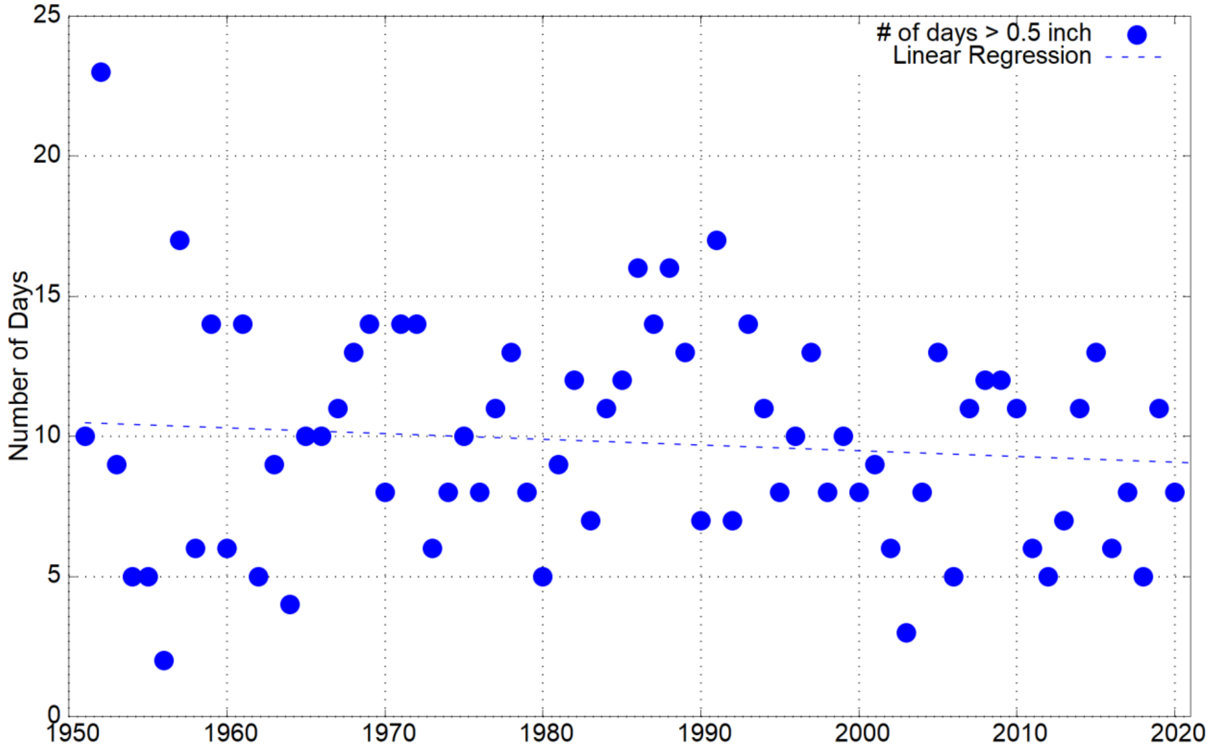

Figure 38. Number of days per year with measured rainfall (>0.5 inches) for Los Alamos (1951–2020).

9.3 Wind Speed

Wind speeds are fundamentally driven by temperature differences (i.e., pressure gradient effect). The temperatures at the Earth's poles are increasing faster than at the equator, due to the impact of decreasing surface area of ice. This produces a decreased equator to pole temperature difference, and this should produce a decrease in average wind speeds (Barton 2014). However, there are other forces that impact wind speed at the surface, primarily surface vegetation coverage. The impact of vegetation can be to slow down or speed up wind speeds due to frictional drag (Wever 2012). When there is more vegetation, wind speeds can be slowed by friction; when there is less vegetation, winds can speed up due to less friction.

The Laboratory has measured wind speed at the TA-6 tower location since 1992. TA-6 is approximately 7400 feet in elevation; at this altitude, in 1992, the vegetation consisted of ponderosa pine and mixed conifer forests. In the past 28 years, the landscape at the Laboratory at this altitude has changed dramatically. The impact of forest fires in 2000 and 2011, the drought and bark beetle infestations in the early 2000s, and the ongoing LANL forest thinning projects (to reduce wildland fire danger) have reduced the amount of ponderosa pine and mixed conifer forest coverage since 1992 (McKown et al. 2003).

Figure 39 presents the annual average 12-meter-height wind speed at TA-6 from 1993 through 2020. Essentially no change in wind speed was measured between 1994 and 2001. The annual average wind speed increased by approximately 20% between 2001 and 2014. Since 2012, the annual average wind speed has remained between 2.9–3 m/s, except for a temporary decrease in 2015 by about 10%. The increase in wind speed between 2001 and 2014 is consistent with a reduction in frictional drag due to the reduction of ponderosa pine and mixed conifer forests at LANL due to the effects of the Cerro Grande and Las Conchas wildland fires.

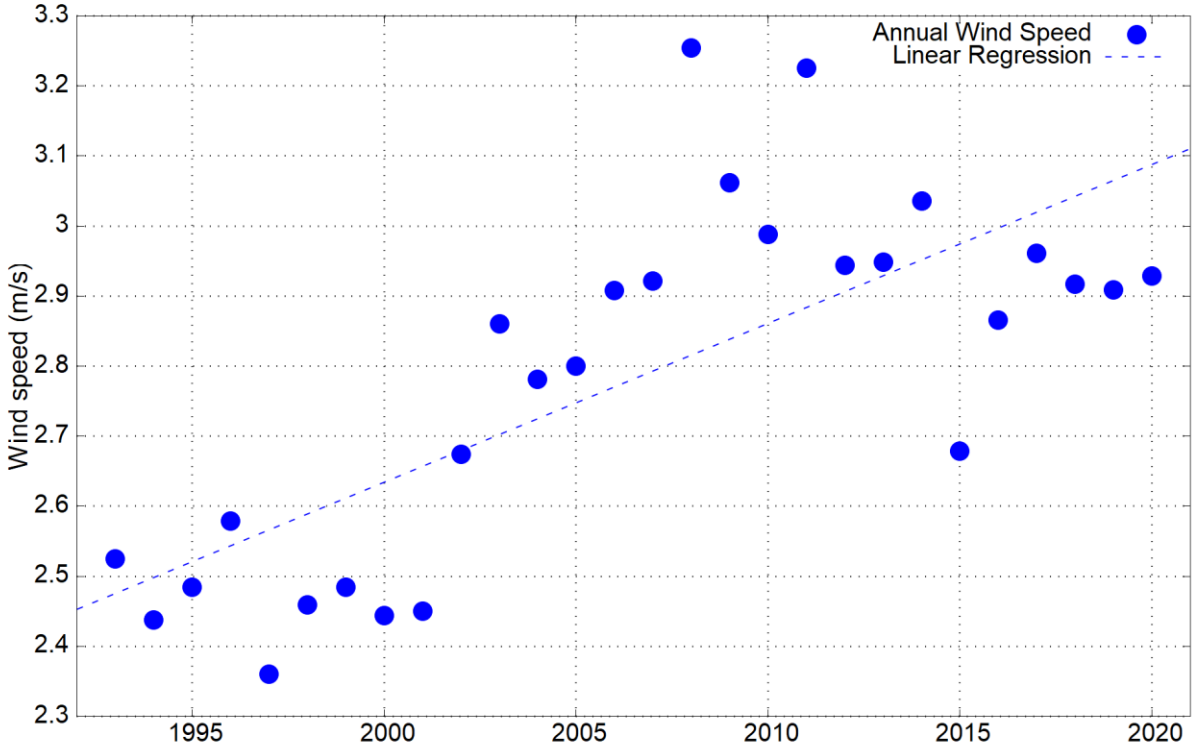

Figure 39. Annual average wind speed at 12 meters AGL at TA-6 (1993–2020).

However, there are likely other factors that may be influencing the change in average wind speed. The measured increase in surface temperatures should also lead to an increase in the vertical mixing of the atmosphere. Increased mixing of the atmosphere should produce higher surface wind speeds as higher wind speeds aloft are mixed to the surface. Further analysis of wind speed data is needed to determine the driving mechanisms for these observations.

9.4 Climate Summary

In summary, Los Alamos measurements have shown an increase in annual average temperature along with an increase in days above 90°F and decrease in days below 0°F, and a recent decrease in precipitation, snowfall, and precipitation during the monsoon season.

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Appendix A: Tabular Data

Table A-1. Monthly Average Temperatures for Los Alamos and White Rock in °F (1991–2020)

	Los Alamos			White Rock		
	Max. Temp.	Min. Temp.	Ave. Temp.	Max. Temp.	Min. Temp.	Ave. Temp.
January	39.8	19.7	29.7	43.1	16.2	29.7
February	44.0	22.9	33.4	48.4	21.0	34.7
March	52.9	28.8	40.9	57.4	27.0	42.2
April	60.4	34.7	47.6	64.9	33.1	49.0
May	69.7	43.4	56.6	74.3	41.4	57.9
June	80.4	52.8	66.6	85.3	50.5	67.9
July	82.0	56.1	69.1	87.0	55.6	71.3
August	79.0	54.5	66.7	84.1	54.0	69.1
September	73.5	48.4	60.9	78.1	46.7	62.4
October	62.2	37.7	49.9	66.2	34.8	50.5
November	49.6	27.5	38.5	52.8	23.9	38.4
December	39.8	20.0	29.9	42.5	16.1	29.3
Annual	**61.2**	**37.3**	**49.2**	**65.4**	**35.1**	**50.3**

Table A-2. Monthly Average Heating and Cooling Degree Days for Los Alamos and White Rock (1991–2020)

	Los Alamos		White Rock	
	Heating Degree Days	Cooling Degree Days	Heating Degree Days	Cooling Degree Days
January	1093.6	0	1094.7	0
February	892	0	856.8	0
March	748	0	707.5	0
April	523.2	0.5	480.7	0.9
May	269.9	11.9	231.9	13.1
June	51	98.5	33.7	119.7
July	13.5	136.8	4.6	198.3
August	29.2	80.2	10.6	134.1
September	141.5	21.3	108.7	30.7
October	466.9	2.6	448.4	1.6
November	793.8	0	798.9	0
December	1088.2	0	1103.3	0
Annual	**6110.7**	**351.7**	**5879.7**	**498.4**

Appendix A: Tabular Data

Table A-3. Monthly Average Maximum Temperatures in °F (1993–2020, except TA-5 MDCN is 2003–2020, TA-41 is 1994–2013, and PJMT is 1998–2012)

	TA-6	TA-54	TA-53	TA-49	TA-41	TA-5 MDCN	PJMT
January	40.1	43.2	41.4	41.2	37.7	44.9	32.8
February	44.1	48.2	45.6	45.7	43.3	48.7	33.2
March	53.2	57.5	55.4	55.3	54.5	58.8	40.0
April	60.4	64.8	62.5	62.4	62.9	65.4	46.6
May	69.7	74.4	72.3	71.9	73.7	74.5	57.2
June	80.8	85.6	83.6	83.0	83.7	86.8	67.5
July	82.4	87.3	85.7	85.0	85.4	89.0	70.2
August	79.2	84.3	82.3	82.0	82.3	85.5	66.4
September	73.7	78.2	76.3	76.1	75.6	79.8	60.4
October	62.0	65.9	63.8	63.9	61.8	67.4	49.8
November	50.1	53.2	51.7	51.4	47.5	55.1	40.5
December	40.2	42.9	41.2	41.2	36.7	44.2	31.9
Annual	**61.4**	**65.6**	**63.6**	**63.3**	**62.1**	**66.7**	**49.7**

Table A-4. Monthly Average Minimum Temperatures in °F (1993–2020, except TA-5 MDCN is 2003–2020, TA-41 is 1994–2013, and PJMT is 1998–2012)

	TA-6	TA-54	TA-53	TA-49	TA-41	TA-5 MDCN	PJMT
January	20.0	16.2	22.8	22.3	14.6	13.7	18.6
February	22.8	20.6	25.8	25.1	18.6	17.8	17.7
March	28.9	26.8	32.4	31.2	25.7	24.8	23.4
April	34.7	32.9	38.3	36.8	31.9	30.4	28.3
May	43.5	41.3	47.5	45.8	40.8	38.6	38.2
June	53.1	50.6	57.0	55	48.9	47.9	46.8
July	56.3	55.7	60.1	58.4	54.1	53.6	50.6
August	54.6	54.1	58.2	56.6	52.8	52.2	49.1
September	48.5	46.7	52.4	50.9	45.6	44.4	43.1
October	37.7	34.7	41.3	40.2	34.0	33.0	34.1
November	27.9	24.0	31.2	30.4	24.0	22.0	26.1
December	20.2	16.3	23.0	22.5	15.0	14.0	17.9
Annual	**37.4**	**35.1**	**41.1**	**39.6**	**33.8**	**32.7**	**32.8**

Table A-5. Monthly Average Precipitation and Snowfall in Inches for Los Alamos and White Rock (1991–2020)

	Los Alamos Average Precipitation	Los Alamos Average Snowfall	White Rock Average Precipitation
January	0.88	9.6	0.62
February	0.76	8.3	0.54
March	0.99	5.5	0.77
April	0.93	3.2	0.72
May	1.16	0.2	0.89
June	1.16	0	0.84
July	2.85	0	1.98
August	3.2	0	2.23
September	2.02	0	1.55
October	1.54	1.6	1.34
November	0.94	4.5	0.76
December	0.92	10.5	0.69
Annual	**17.36**	**43.4**	**12.92**

Table A-6. Monthly Average Precipitation Across the Laboratory in Inches (1993–2020, except NCOM is 1996–2020)

	TA-6	TA-54	TA-53	TA-49	NCOM
January	0.90	0.64	0.74	0.90	0.77
February	0.79	0.54	0.64	0.74	0.69
March	0.97	0.75	0.81	0.90	0.89
April	0.97	0.76	0.84	0.92	0.98
May	1.05	0.84	0.93	0.97	0.94
June	1.10	0.81	0.75	0.89	1.06
July	2.79	1.93	2.00	2.28	2.76
August	3.04	2.24	2.29	2.71	2.95*
September	1.99	1.56	1.53	1.86	1.74*
October	1.62	1.41	1.37	1.57	1.63
November	0.84	0.70	0.70	0.86	0.72
December	0.86	0.60	0.65	0.80	0.80
Annual	**16.92**	**12.77**	**13.24**	**15.38**	**15.93***

*These data are biased low due to a significant amount of data missing in 2005.

Table A-7. Monthly Average Dew Point Temperatures in °F (1993–2020)

	TA-6	TA-54	TA-53	TA-49
January	14.3	15.6	15.7	14.7
February	15.7	17.1	16.8	15.4
March	18.1	19.1	18.7	17.2
April	19.9	21.2	20.4	19.3
May	25.6	27.6	25.8	24.5
June	30.9	31.8	31.0	29.7
July	44.8	45.4	44.8	44.6
August	46.1	47.1	46.5	44.7
September	38.5	39.5	38.8	37.4
October	27.8	29.1	28.5	28.3
November	19.2	20.6	20.1	19.8
December	14.6	15.8	15.8	15.4
Annual	**26.4**	**27.6**	**27.0**	**25.9**

Table A-8. Monthly Average Relative Humidity in Percent (1993–2020)

	TA-6	TA-54	TA-53	TA-49
January	54.7	60.8	54.5	53.1
February	51.8	55.0	51.1	49.4
March	44.8	46.1	42.9	42.1
April	39.4	39.6	37.5	37.1
May	37.1	36.9	34.7	34.5
June	32.8	32.4	30.4	30.7
July	48.0	46.9	44.3	45.1
August	53.7	53.1	50.1	50.0
September	49.2	49.9	46.4	46.3
October	48.4	51.4	46.3	45.6
November	49.3	54.7	48	47.0
December	54.8	61.3	54.7	53.7
Annual	**47.0**	**49.1**	**45.2**	**44.6**

Table A-9. Monthly Average Wind Speeds at 12 meters AGL in mph (1993–2020, except TA-5 MDCN is 2003–2020, TA-41 is 1994–2013, and PJMT is 1998–2012)

	TA-6	TA-54	TA-53	TA-49	TA-5 MDCN*	TA-41	PJMT*
January	5.1	5.4	5.5	6.0	3.7	3.1	17.0
February	6.0	6.3	6.4	7.0	4.2	3.3	17.4
March	6.9	7.2	7.4	8.0	4.9	3.8	16.8
April	8.0	8.2	8.5	9.1	5.5	4.3	18.0
May	7.7	8.2	8.5	9.0	5.4	4.3	16.8
June	7.5	8.0	8.3	8.6	5.2	4.0	15.6
July	5.8	6.7	7.0	7.3	4.4	3.2	11.3
August	5.5	6.3	6.6	6.9	4.1	3.1	11.1
September	5.9	6.6	6.9	7.2	4.2	3.2	13.8
October	5.8	6.4	6.5	7.2	4.2	3.2	14.9
November	5.5	5.8	5.9	6.5	4.0	3.2	15.9
December	5.0	5.5	5.4	6.0	3.7	2.9	17.1
Annual	**6.2**	**6.7**	**6.9**	**7.4**	**4.4**	**3.5**	**15.5**

*TA-5 MDCN measurement height is 10 meters AGL and PJMT measurement height is 36 meters AGL.

Table A-10. Monthly Average Peak Wind Gusts at 12 meters AGL in mph (1993–2020, except PJMT is 1998–2012)

	TA-6	TA-54	TA-53	TA-49	PJMT*
January	20.7	19.9	21.7	21.1	38.4
February	24.5	23.2	25.0	25	40.8
March	27.0	26.9	28.2	28.2	39.5
April	31.1	31.3	32.4	32.6	42.8
May	30.1	31.6	32.4	32.0	40.4
June	29.6	31.7	32.1	31.5	38.3
July	25.5	28.2	29.1	28.0	35.0
August	23.9	26.4	27.3	26.4	29.7
September	23.6	25.3	26.1	25.5	33.4
October	23.1	23.3	24.3	24.0	35.7
November	21.7	20.8	22.4	22.2	36.6
December	20.3	19.5	21.3	21.1	39.2
Annual	**25.1**	**25.7**	**26.9**	**26.5**	**37.5**

*PJMT is measured at 36 meters AGL.

Appendix A: Tabular Data

Table A-11. Monthly Average Incoming Solar Radiation in MJ/m^2* (1993–2020, except TA-5 MDCN is 2003–2020)

	TA-6	TA-54	TA-53	TA-49	TA-5 MDCN
January	11.8	12.2	11.7	11.9	12.4
February	15.1	15.6	14.9	15.2	15.3
March	19.6	20.3	19.7	19.9	20.0
April	23.4	24.0	23.6	23.8	24.0
May	26.0	27.1	26.4	26.8	26.3
June	27.7	28.8	28.2	28.4	27.7
July	23.7	25.1	24.6	24.7	24.6
August	21.6	23.1	22.4	22.5	22.5
September	20.2	21.0	20.5	20.6	21.0
October	16.6	17.0	16.6	16.7	16.9
November	12.7	13.0	12.7	12.7	13.1
December	10.6	10.9	10.6	10.6	10.7
Annual	**19.1**	**19.9**	**19.4**	**19.5**	**19.6**

* MJ/m^2 = megajoule per square meter.

Table A-12. Monthly Average Pressure at TA-6 and TA-54 in mb (1993–2020)

	TA-6	TA-54
January	774.7	801.0
February	773.4	799.4
March	773.6	799.4
April	773.1	798.6
May	774.9	800.1
June	777.2	801.9
July	780.0	804.7
August	780.1	805.0
September	779.0	803.9
October	777.0	802.5
November	776.2	802.1
December	774.5	800.8
Annual	**776.2**	**801.6**