Climate data by elevation in the Great Smoky Mountains: a database and graphical displays for 1947 – 1950 with comparison to long-term data

Data Series Report DS 115

U.S. Department of the Interior
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Richard T. Busing, Luther A. Stephens and Edward E.C. Clebsch

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Richard T. Busing, Luther A. Stephens and Edward E.C. Clebsch

Abstract

A climate data set is presented for four sites spanning the elevation gradient in the Great Smoky Mountains from Gatlinburg to Clingmans Dome. Monthly mean values for cloud cover, temperature, humidity, precipitation, and soil moisture are included. Stephens (1969) is the source of all summarized mean monthly data. Values are the averages of four years (1947-1950) with moderate to high precipitation. Graphical displays show strong climatic patterns of variation among seasons and elevations. The upper stations had lower temperatures and higher precipitation totals; however, temperature lapse rates and variation in vapor pressure deficits decreased at upper elevations. To examine how well the four-year sample represents the long-term climate, temperature and precipitation for the Gatlinburg (1460 ft elevation at park headquarters) station were compared between the years in the sample and the years in the full record from 1928 to 2003. Trends related to season and elevation are consistent with earlier studies and provide a basis for interpretation of climate dynamics in the southern Appalachian Mountains.

Introduction

The broad range of elevations in the Great Smoky Mountains (<1000 to 6642 ft asl) contributes to the wide variety of climates therein (Shanks 1954). At the lower elevations (ca. 1000 ft) the climate is humid mesothermal (Thornthwaite 1948, Shanks 1954) with precipitation distributed throughout the year. At the uppermost elevations, which are among the highest attained in the Appalachian chain, the relatively cool, wet climate is perhumid microthermal. It supports evergreen coniferous forest vegetation rather than the deciduous forest vegetation typical of lower elevations. Total annual precipitation in the high-elevation coniferous forests rivals that of some of the wettest regions of the United States. This climatic gradient occurs within an air line distance of less than 11 miles. Four climate stations along the gradient in Great Smoky Mountains National Park serve as the basis for the database presented here. The purpose of this report is to make these data readily available and to facilitate their interpretation.

Methods

The 1947-1950 data

A set of monthly mean climate data from four climate stations in Great Smoky Mountains National Park was entered into computer spreadsheet files. Monthly mean summaries for four years (1947-1950) were taken from tables of numeric data in Stephens (1969). The four climate stations were located in Sevier County, Tennessee or in Swain County, North Carolina (Fig1; latitude 36°N, longitude 83°W). They spanned the elevation gradient from 1460 to 6300 ft (Table 1). The station at 1460 ft was located at park headquarters near Gatlinburg; the station at 3850 ft was located at the Alum Cave Bluffs parking lot; the station at 5000 ft was located near Newfound Gap; and the station at 6300 ft was located at the Forney Ridge parking area just south of the Clingmans Dome summit. Climate station sites were discussed in detail by Shanks (1954).

Data collection involved instrumentation (Shanks 1954) and field observation. Precipitation type and sky conditions were noted once a day from visual observations at each station. Other raw data consisted of hourly temperature and relative humidity, and daily precipitation amount. Missing data were filled in with interpolated estimates (Stephens 1969).

The hourly data were compiled into daily values including maximum, minimum, range and 24-hr mean. Monthly values were then computed as the sum of daily means divided by the number of days. Monthly mean values for the four-year period of study were used for this dataset. Soil moisture balance calculations presented here were based on daily as well as monthly mean estimates of potential evapotranspiration (Thornthwaite 1957). The monthly calculations were based on monthly mean temperature, monthly total precipitation, and latitude. The daily calculations were based on daily mean temperature and daily mean precipitation. Further details on data compilation methods are provided by Stephens (1969).

Comparison of the sample to the long-term record

To examine how well the four-year sample represents the long-term climate, temperature and precipitation for the Gatlinburg (1460 ft elevation at park headquarters) station were compared between the years in the sample and the years in the full record from 1928 to 2003. Annual values were compared first, then monthly values were compared. Similar comparisons at higher elevation stations were not made because of the relatively incomplete long-term records at those stations.

Sources of the long-term data summaries

While all short-term data (1947-1950), which constitute the majority of the data presented in this report, were taken from Stephens (1969), long-term data (ca. 1928 to 2003) were taken from the Southeast Regional Climate Center internet site (http://www.dnr.state.sc.us/climate/sercc/). The data records of monthly mean temperature and monthly total precipitation for the Gatlinburg SW station (at park headquarters) were obtained in 2004. They spanned the period from the late 1920s to 2003.

Results and discussion

The short-term sample vs. the long-term record

Comparison of the sample of four years selected by Stephens (1969) to the long-term record (1928 to 2003; >60 yr with fairly complete temperature and precipitation data) indicates that, on average, the years sampled are wetter and cooler than the long-term record. Mean annual values from the years sampled lie within one standard deviation of the long-term means, however (Figure 2a & b).

Mean monthly values showed more variation, with values from the four-year sample often deviating substantially from the long-term values. For example, means of monthly temperatures were more than one standard deviation less than the long-term means in August, September and November (Figure 3). The mean of monthly precipitation was about one standard deviation greater than the long-term mean in January (Figure 4). On average, the short-term study had cooler late summer and fall temperatures, and wetter winters than the long-term record.

Climatic patterns 1947 - 1950

Temperature

Temperature decreased with elevation and varied strongly with season (Figure 5). Mean maximum monthly temperatures occurred in July (Figure 6). Mean minimum monthly temperatures occurred in December (Figure 7). Maximum temperatures were attained in July and August, depending on the station (Figure 8). Minimum temperatures occurred in November and January (Figure 9). The lapse rate, or decrease in temperature with increasing elevation, declined with increasing elevation (Figure 10a, b & c). It also declined in winter.

Precipitation

Monthly precipitation tended to increase substantially with elevation (Figure 11). The relatively high levels of winter precipitation at the 5000 ft site were an exception to this trend. Nonetheless, annual precipitation was highest at the 6300 ft site. Monthly precipitation peaked in January and August. September and October had relatively low precipitation. Daily precipitation followed the same pattern, but there were some differences; for instance, the months having maximum and minimum values often differed (Figure 12).

The temporal distribution of rainfall showed seasonal patterns. The number of precipitation days peaked in winter and summer (Figure 13). The same was true for the number of consecutive precipitation days (Figure 14). At all stations the number of consecutive dry days peaked in the fall (Figure 15).

Relative humidity

Relative humidity was high (>70 %) at all stations. It tended to peak in January and August (Figure 16). It was low in April and November. A simple elevation gradient for relative humidity was not evident. The mid-elevation stations tended to have maximal relative humidity. Presumably, topography had a strong influence on relative humidity, with concave, north-facing sites (e.g. the station at 3850 ft; Table 1) having higher humidity.

Vapor pressure deficit

The vapor pressure deficit indicates the atmospheric capacity for additional water regardless of the temperature. Deficit values were high at the low-elevation site, particularly during spring and summer (Figure 17). Differences among the other three sites were relatively minor. Annual variation was evident; the greatest deficits occurred in April and May.

Cloud cover

Cloudiness varied by season and elevation (Figure 18 a, b, c & d). Spring and fall months had the least cloudiness. Fog was most frequent in winter. The frequency of clear and scattered cloudy days decreased with elevation. The frequency of fog increased with elevation.

Potential evapotranspiration

Potential evapotranspiration peaked in summer when temperatures were high (Figure 19 a, b, c & d). Rarely did potential evaporation exceed precipitation; this occurred only at the low-elevation station. The estimates of potential evapotranspiration based on monthly values (Figure 20 a, b, c & d) were often less than those based on daily values (Figure 21 a, b, c & d). This resulted primarily from cold months with occasional daily values elevated above the monthly mean.

Soil moisture

Soil moisture deficits were not projected when the monthly values were used for estimation (Figure 20 a, b, c & d). By contrast, moisture deficits were projected for May through October when daily values were used (Figure 21 a, b, c & d). The soil moisture balance increased with elevation. It peaked in spring and winter. Overall, minimum values were projected for the low elevation site in summer and fall (Figure 22).

Potential applications and limitations

The database has many potential uses in addition to the fundamental analyses demonstrated above. The short-term climate data can be further analyzed for relationships among variables. It may also provide baseline information for long-term studies of climate. Ecological implications of climate can be explored as well. For example, patterns of soil moisture have strong implications for vegetation. However, the soil moisture balance estimates presented here may be inadequate for ecological analyses (Stephens 1969). More advanced techniques may be helpful in estimating climate effects on soil moisture. In such cases the precipitation and temperature data should be very useful. Many existing models can make use of these monthly temperature and precipitation statistics to simulate climate and the ecological environment. For example, these data can be used in parameterization of climate-driven models of hydrology, nutrient transport, and vegetation.

It is possible to apply these data to other sites within the Great Smoky Mountains. For example, the daymet climate dataset (http://*www.daymet.org*) consists of daily climate values for landscapes, including the Great Smoky Mountains, extrapolated from nearby climate stations (1980-1997 data). The climate stations in this report span almost the entire elevation range of the southern Appalachian Mountains. Yet, not all microsite conditions are represented. For this reason, caution must be used in extrapolating these data to other sites in the region. Identification and consideration of important microsite influences are necessary.

Use of the database

The data are stored in a single file (CLIMGSM1.wk1). Different types of data are presented in tabular format with separate tables for each type of climate information. The tables are presented in a series, from left to right, in the file. Each line in the database usually represents a monthly value for the given climate variable. Identification of variables or climate station sites typically occurs in the first row. Further information is provided to the left of each table. Most values are present, but a few values are missing. Measures are in English units unless noted otherwise. The major variables and abbreviations are described in Table 2.

Summary of major climatic patterns

Temperature decreased with elevation, yet the lapse rate diminished at higher elevations. Inversions and cold-air drainage are likely explanations for the diminished lapse rate at high elevations. The lapse rate also decreased from a maximum in July to a minimum in December and January. Precipitation increased with elevation. Amounts at the two highest stations were influenced by microclimate and precipitation type. The 6300 ft station had the highest precipitation in summer, but the 5000 ft station had the highest precipitation in winter. Relative humidity increased from low to middle elevations, but was also affected by microclimate. The range of relative humidity decreased in summer. Declines in vapor pressure deficits with elevation were relatively minor above the middle elevations.

Soil moisture balance calculations, based on several simplifying assumptions, suggested that soil moisture content increased with elevation. By contrast, estimates of evapotranspiration decreased with elevation. Although water balance could not be calculated accurately from climate data alone, these climate data were sufficient for exploratory analyses. Soil moisture minima occurred at low elevations in late summer and early fall. Indications of extremely low soil moisture were not obtained at any elevation or season.

Table 1. Climate stations in the database.

Station name	Site Description
Gatlinburg., Sevier Co., Tennessee	1460 ft elev. in a valley bottom
Alum Cave Bluffs Parking Area, Sevier Co., Tennessee	3850 ft elev. in an upper valley facing N
Newfound Gap, Sevier Co., Tennessee	5000 ft elev. near a ridge crest facing N
Clingmans Dome, Swain Co., North Carolina	6300 ft elev. on an upper slope facing S

Table 2. Variables in the database.

Variable name	Description	Units or format
Month	Month of the year	Single character
Clear	No clouds	Percent frequency
SCloudy	Scattered clouds	Percent frequency
PCloudy	Partly cloudy	Percent frequency
Cloudy	Clouds	Percent frequency
Overcast	Overcast sky	Percent frequency
Fog	Low fog	Percent frequency
MeanTLR	Mean temperature lapse rate	Deg. F per 1000 ft
MaxTLR	Maximum temperature lapse rate	Deg. F per 1000 ft
MinTLR	Minimum temperature lapse rate	Deg. F per 1000 ft
MeanT	Mean temperature	Deg. F
MeanMaxT	Mean maximum temperature	Deg. F
MeanMinT	Mean minimum temperature	Deg. F
Temp	Mean temperature	Deg. F
PET	Potential evapotranspiration	Inches
Prec	Mean precipitation	Inches
P-PET	Prec minus PET	Inches
SM	Soil moisture content	Inches
MD	Soil moisture deficit	Inches
MS	Soil moisture surplus	Inches
SMB	Soil moisture balance	Inches

Acknowledgements

Mary Lou Taisey's assistance in preparing the database file is greatly appreciated. The climate data were originally made available by the Hydraulic Data Branch of the Tennessee Valley Authority. Dr. Jason Fridley and Dr. Ken Orvis kindly provided objective reviews of the draft manuscript.

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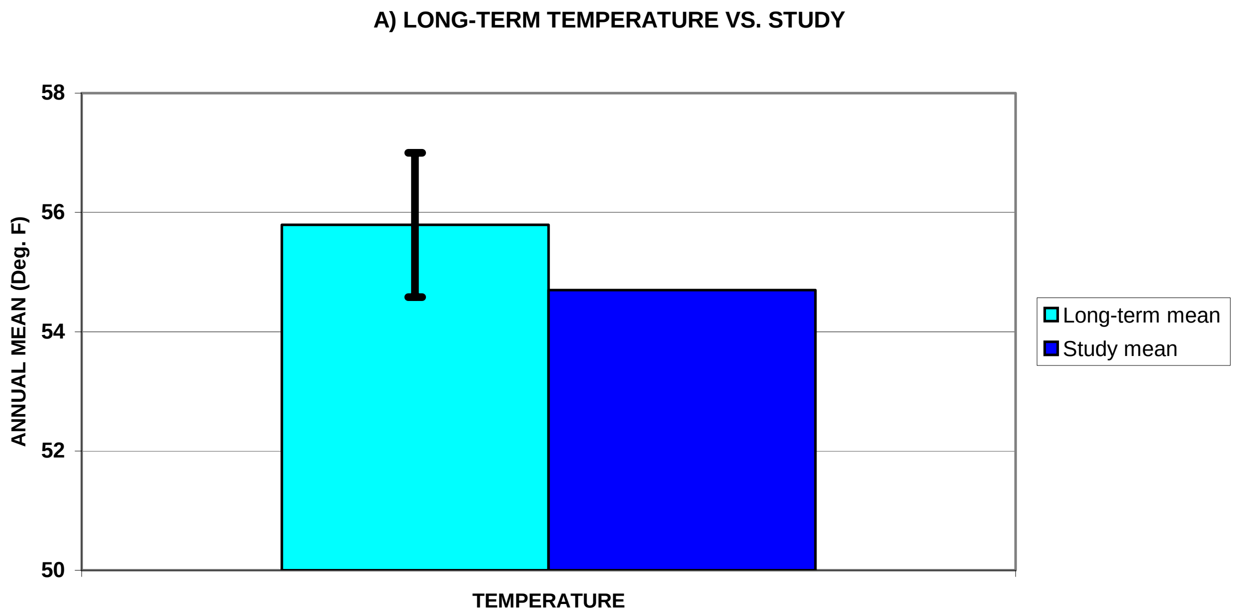
Shanks, R.E. 1954. Climates of the Great Smoky Mountains. Ecology 35:353-361.

Stephens, L.A. 1969. A comparison of climatic elements at four elevations in the Great Smoky Mountains National Park. M.S. Thesis, University of Tennessee, Knoxville, Tennessee.

Thornthwaite, C.W. 1948. An approach toward a rational classification of climate. Geogr. Rev. 38:55-94.

Thornthwaite, C.W. 1957. Instructions and tables for computing potential evapotranspiration and the water balance. Drexel Inst. Tech., Lab. Of Climatology, Publ. in Climatology, No. 1, Centerton.

Figure 1. Map showing the four climate stations in Great Smoky Mountains National Park from which the database was developed. The sites, marked with black circles, are located along paved roads from park headquarters (near Gatlinburg) to Clingmans Dome.



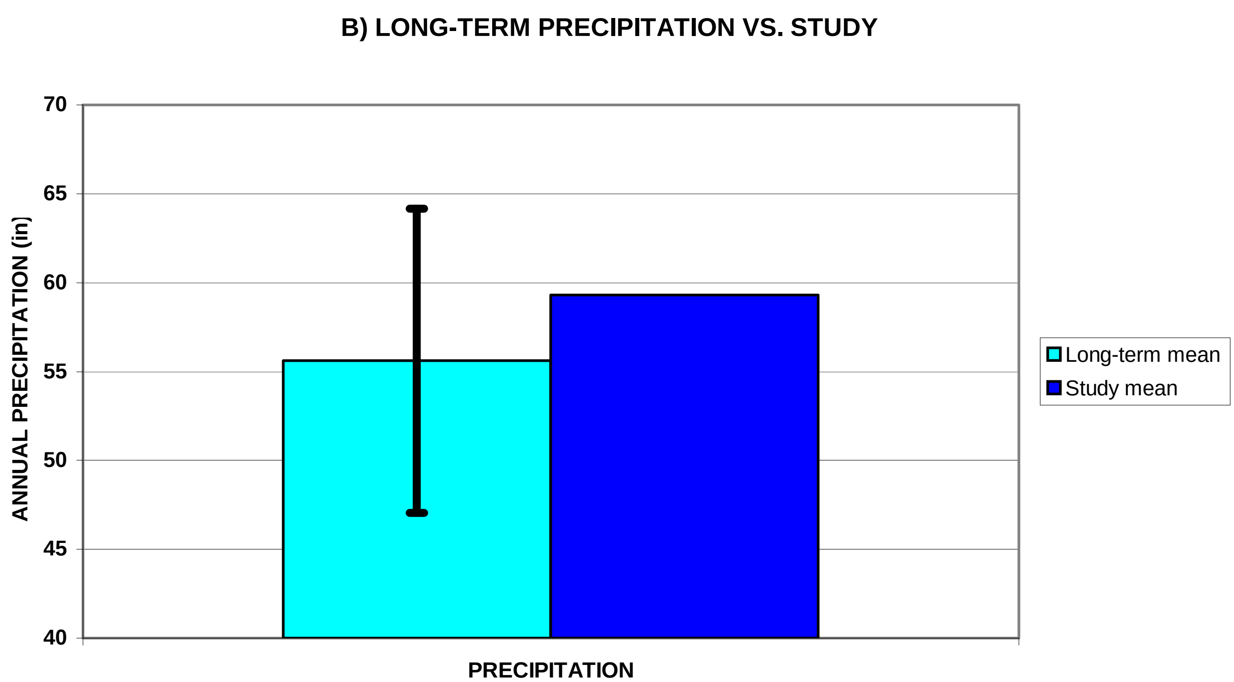


Figure 2. Comparison of the study period climate (1947-1950) to long-term climate (ca. 1930-2003) at the Gatlinburg SW station (1460 ft). Variables include A) annual temperature, and B) annual precipitation. Standard deviations are for the long-term data.

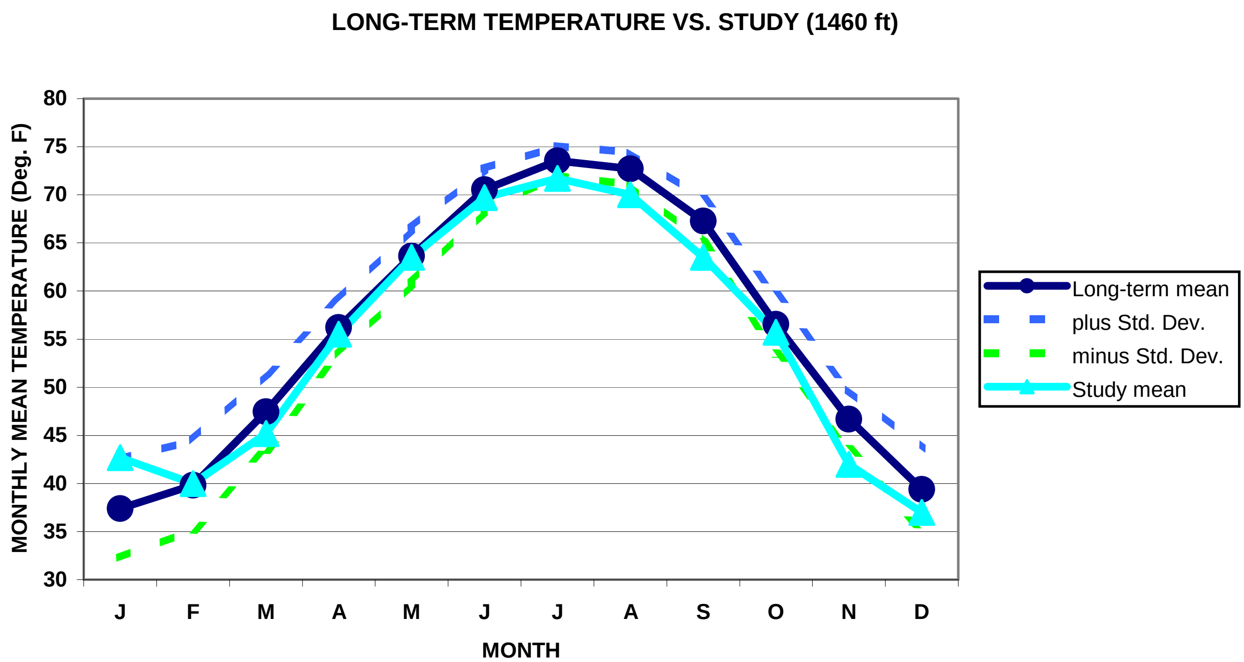


Figure 3. Comparison of monthly mean temperatures during the study period (1947-1950) to long-term values (ca. 1930-2003) at the Gatlinburg SW station (1460 ft).

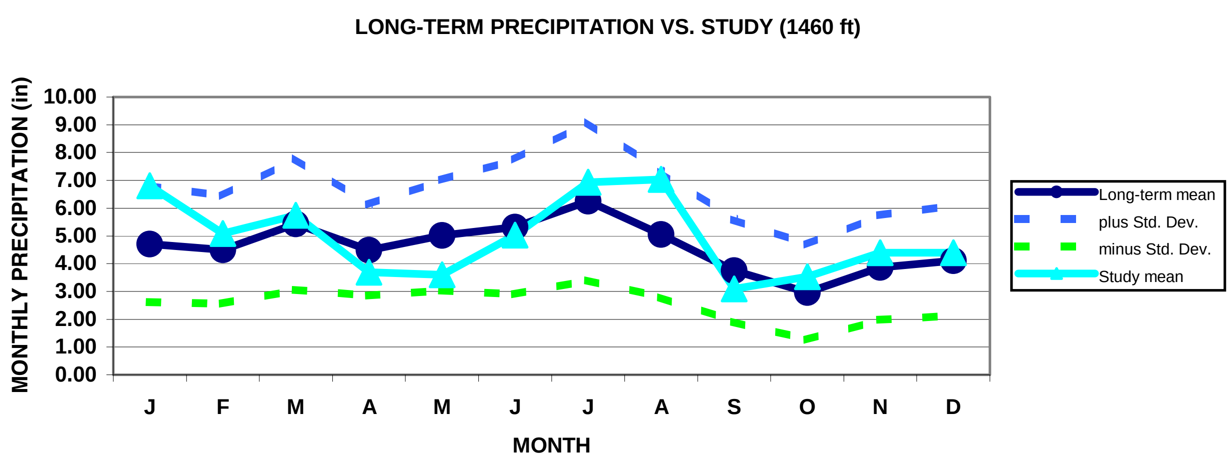


Figure 4. Comparison of monthly precipitation during the study period (1947-1950) to long-term values (ca. 1930-2003) at the Gatlinburg SW station (1460 ft).

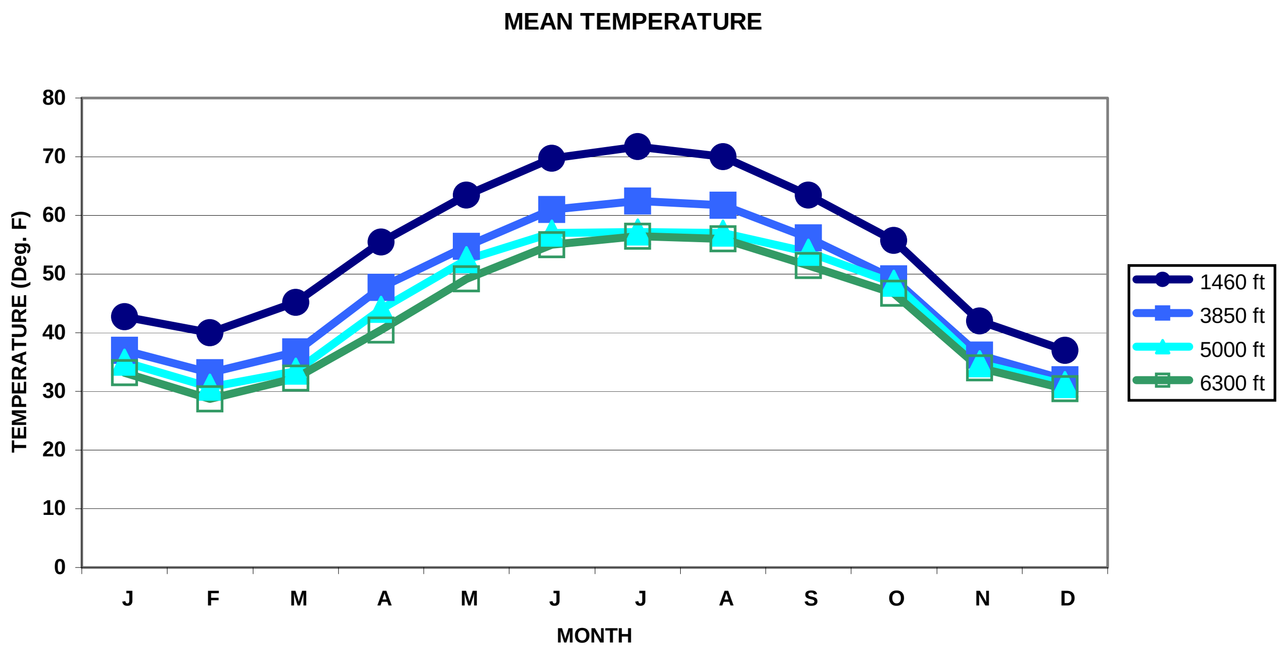


Figure 5. Monthly temperature means (1947-1950) by elevation.

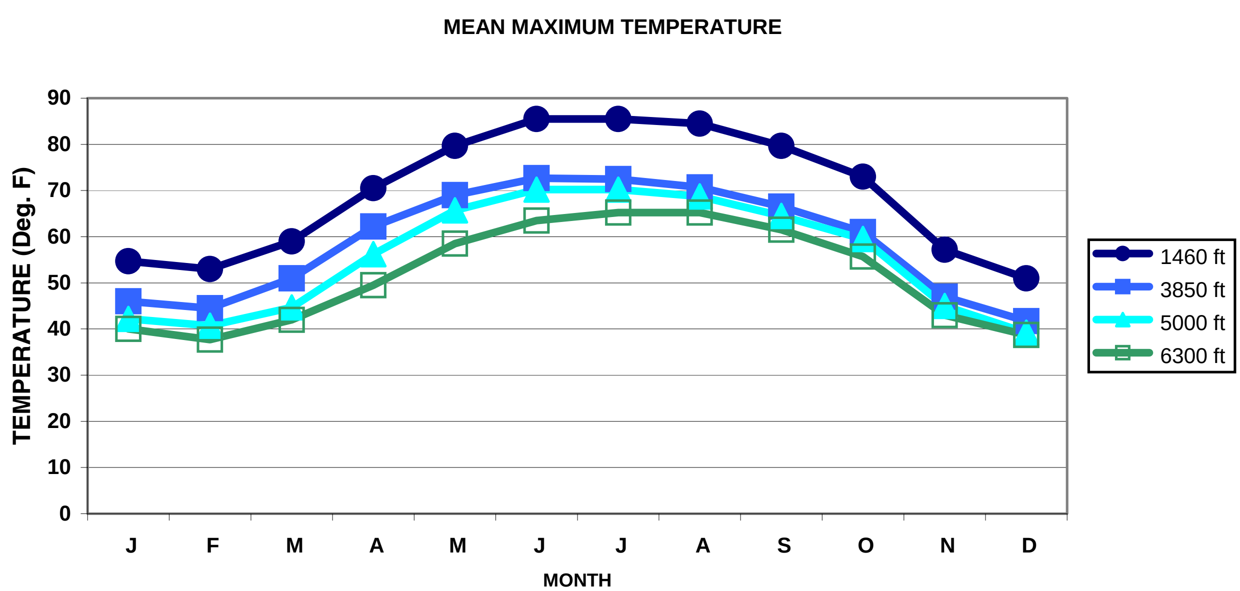


Figure 6. Mean maximum temperature (1947-1950) by month and elevation.

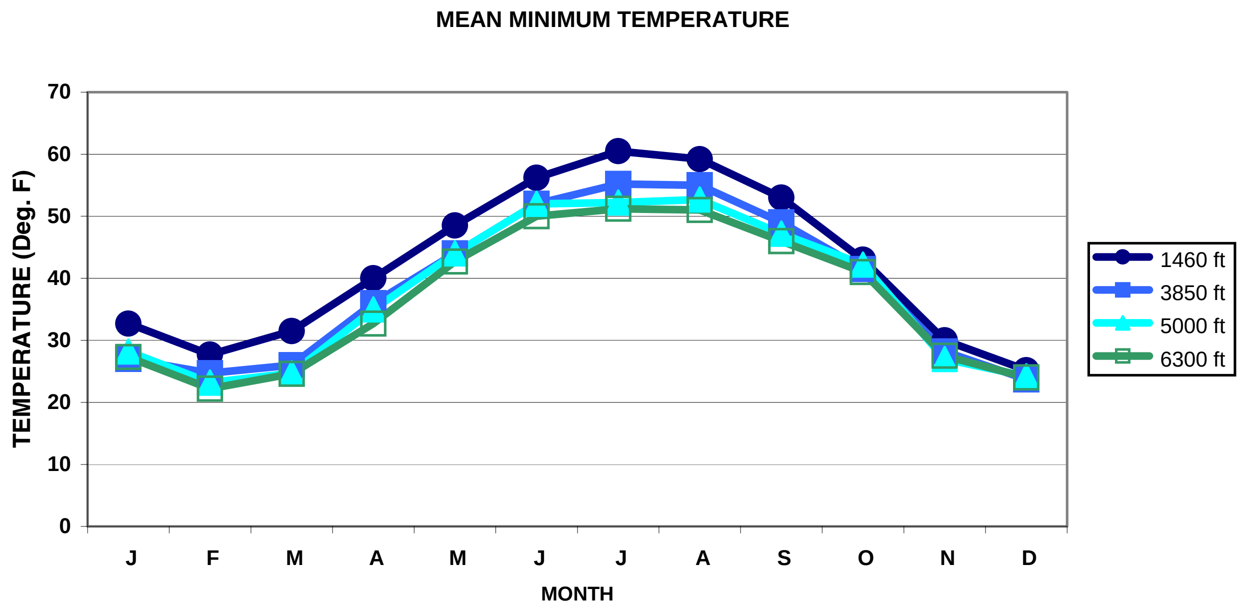


Figure 7. Mean minimum temperature (1947-1950) by month and elevation.

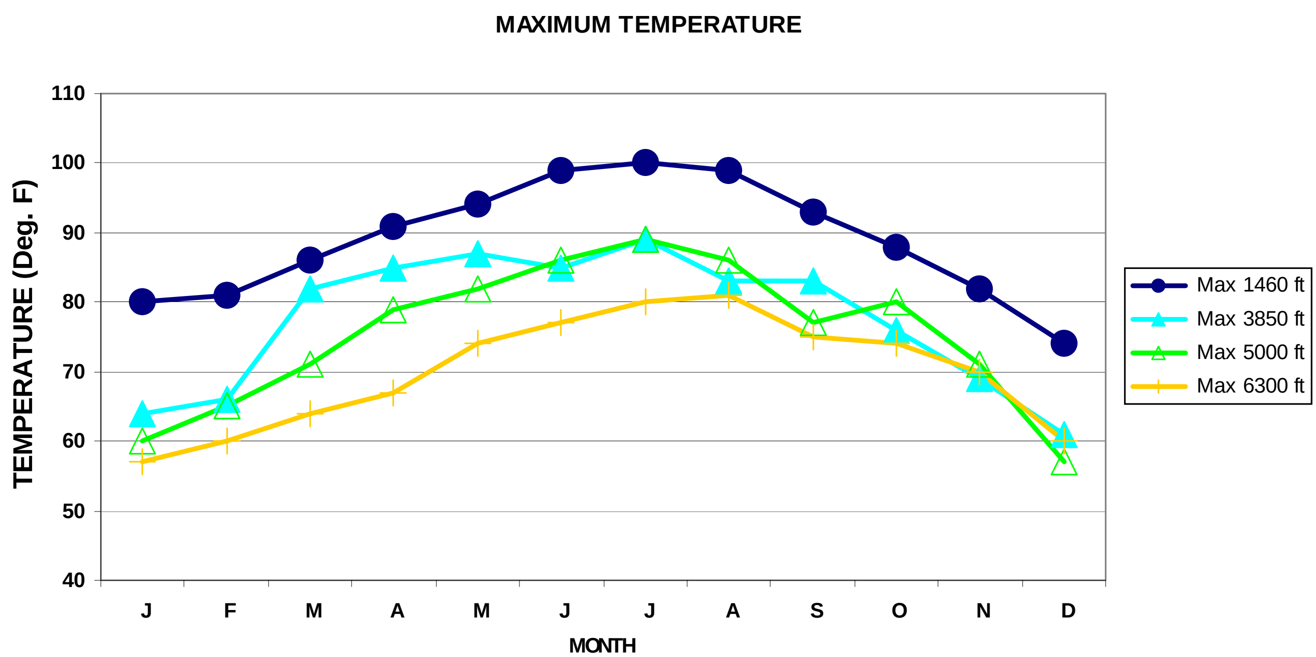


Figure 8. Maximum temperature (1947-1950) by month and elevation.

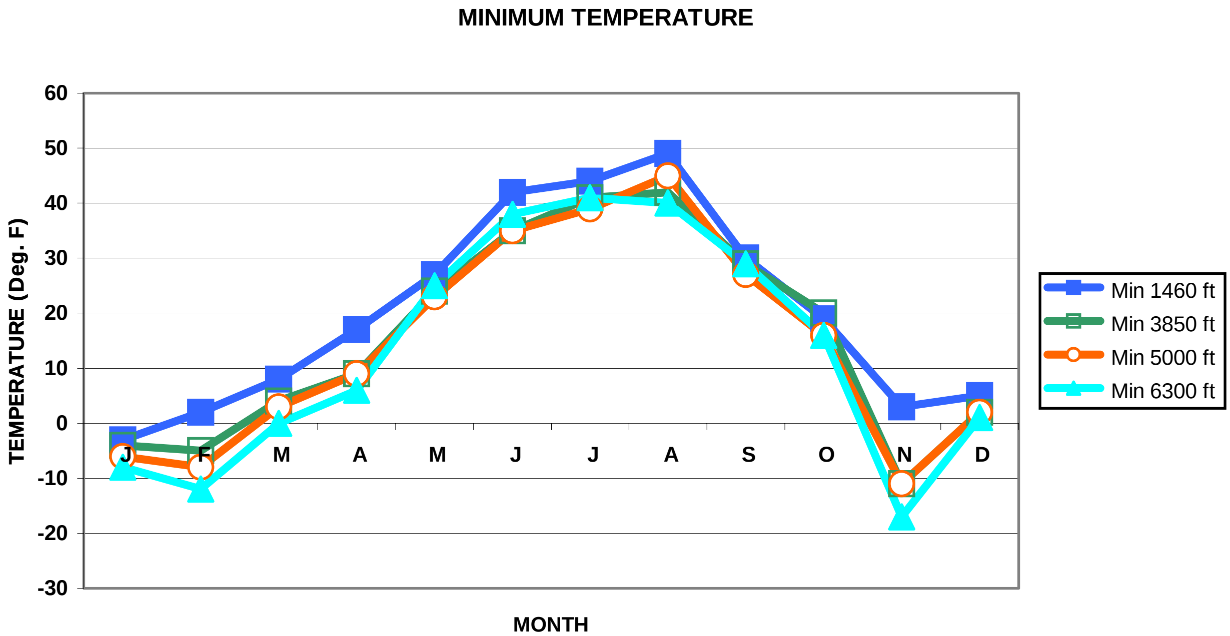
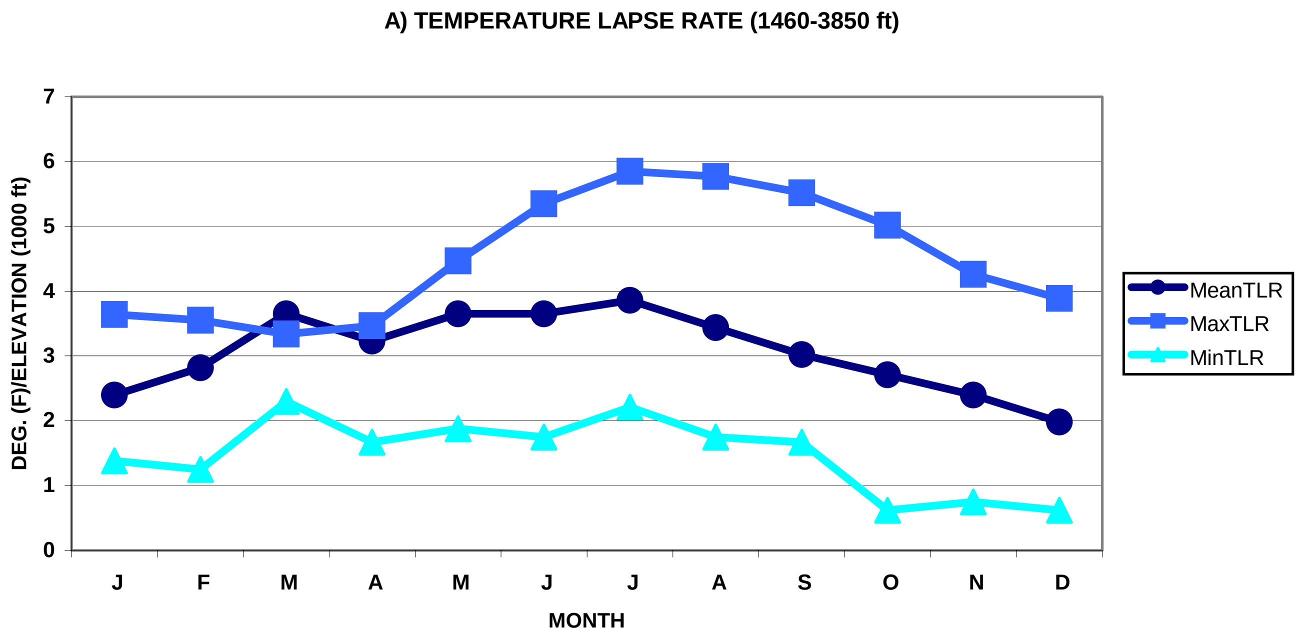
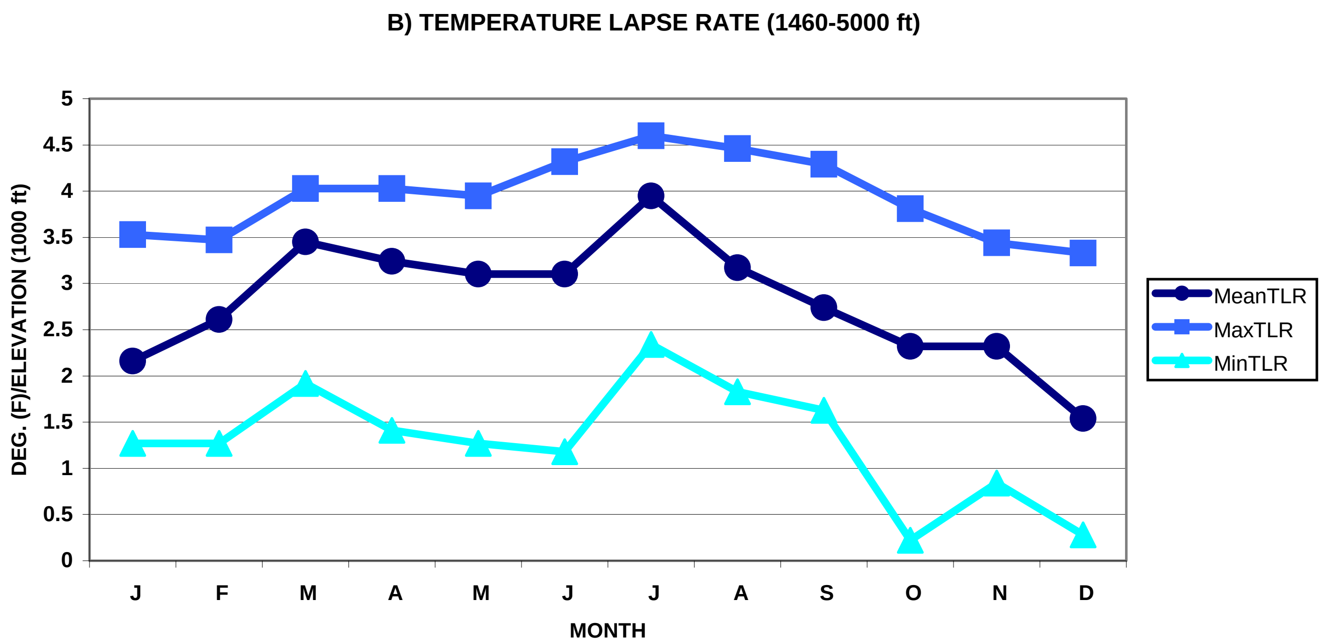


Figure 9. Minimum temperature (1947-1950) by month and elevation.


A) TEMPERATURE LAPSE RATE (1460-3850 ft)
DEG. (F)/ELEVATION (1000 ft)
0
1
2
3
4
5
6
7
J
F
M
A
M
J
J
A
S
O
N
D
MONTH
MeanTLR
MaxTLR
MinTLR


B) TEMPERATURE LAPSE RATE (1460-5000 ft)
DEG. (F)/ELEVATION (1000 ft)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
J
F
M
A
M
J
J
A
S
O
N
D
MONTH
MeanTLR
MaxTLR
MinTLR

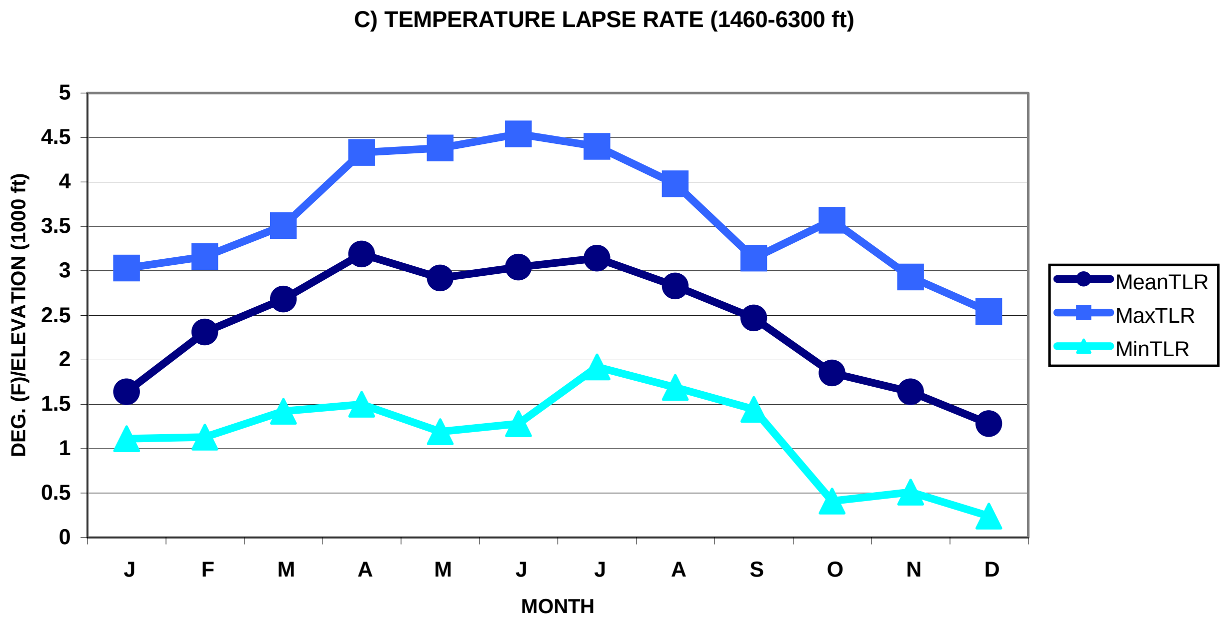


Figure 10. Temperature lapse rates (1947-1950) by month for A) 1460 to 3850 ft elevation, B) 1460 to 5000 ft elevation, and C) 1460 to 6300 ft elevation.

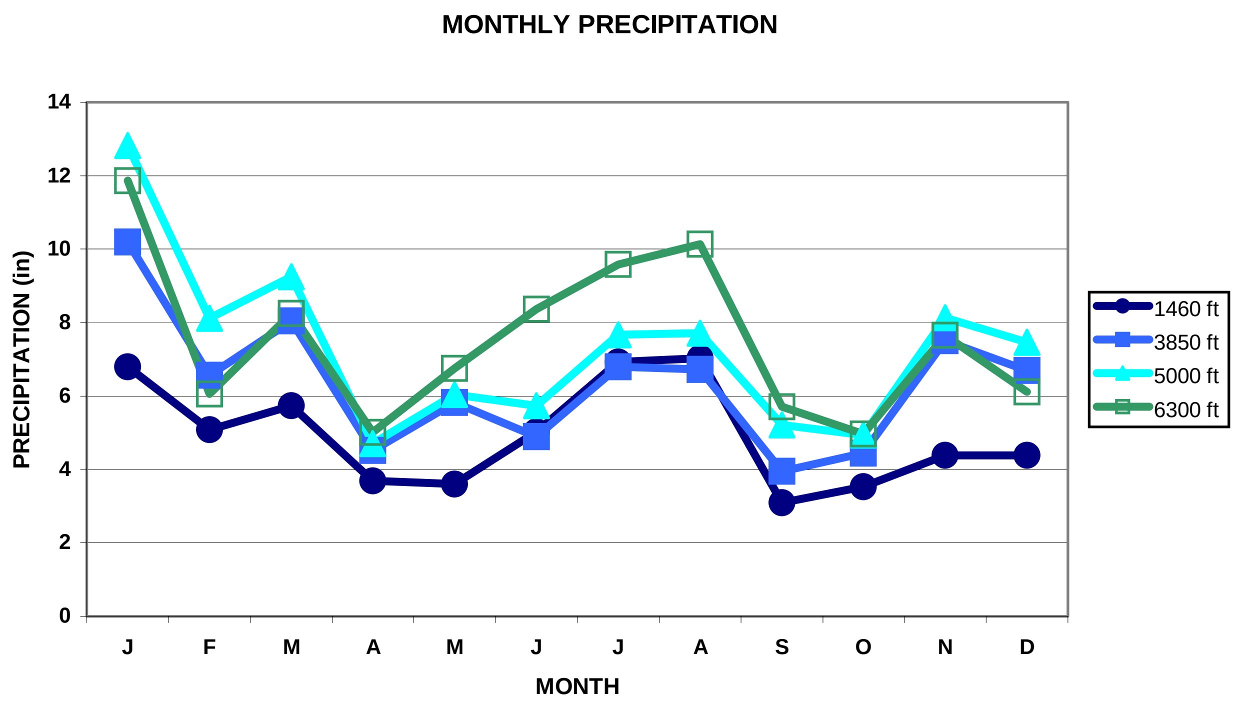


Figure 11. Monthly precipitation (1947-1950) by elevation.

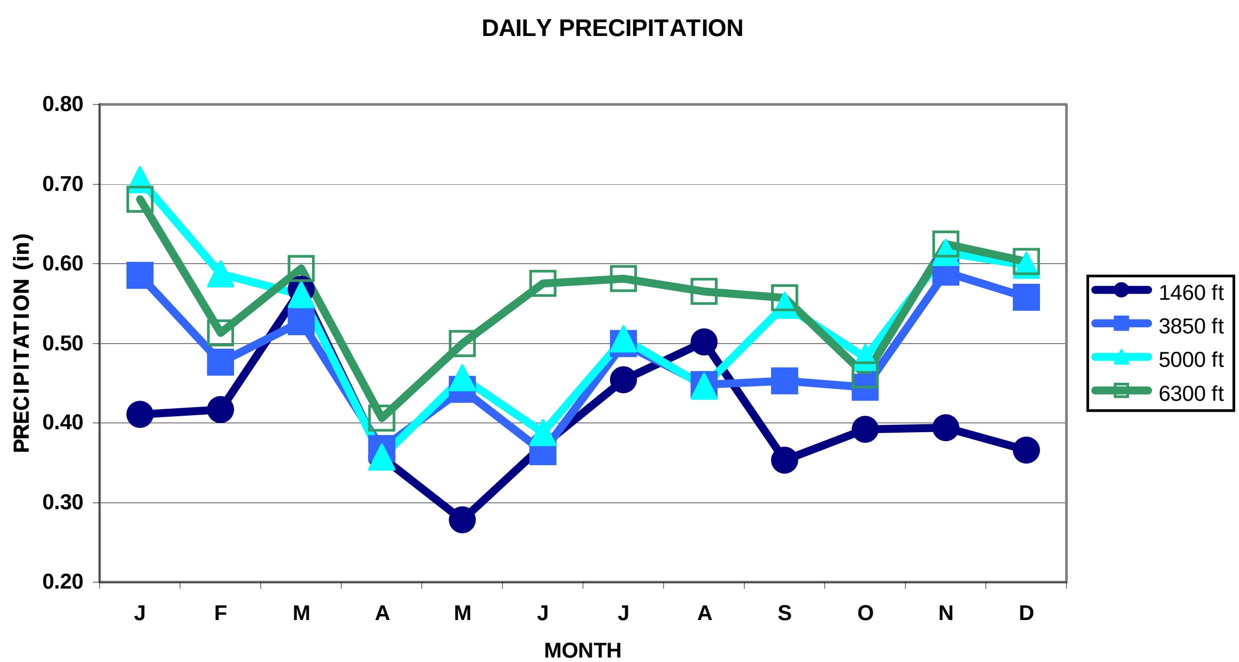


Figure 12. Daily precipitation (1947-1950) by month and elevation.

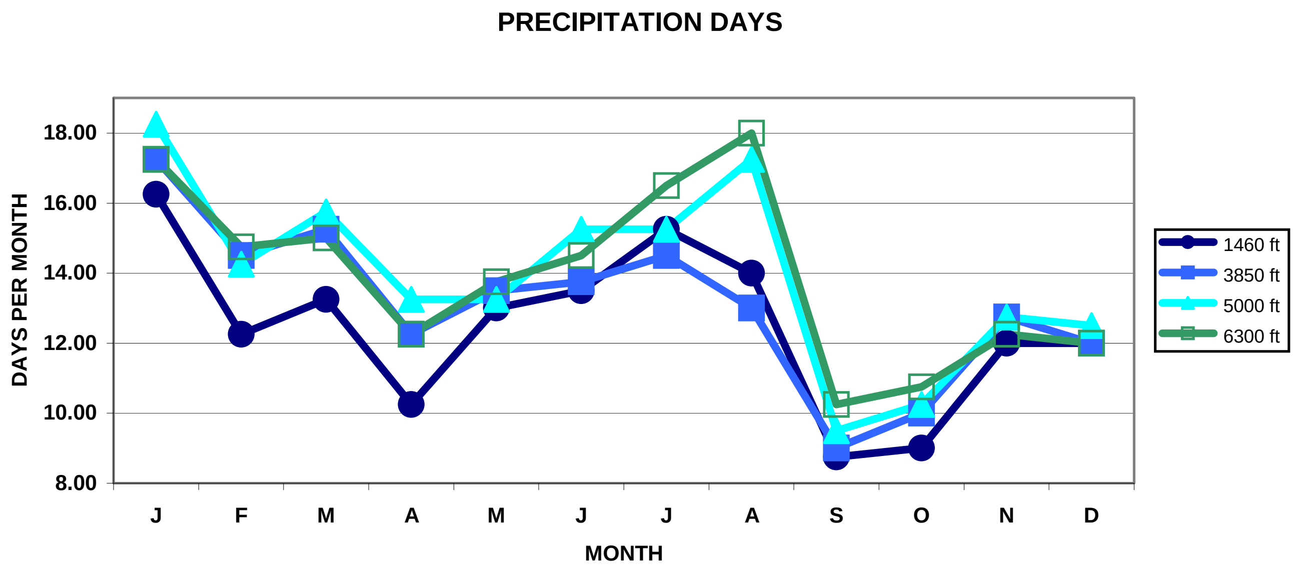


Figure 13. Precipitation days (1947-1950) by month and elevation.

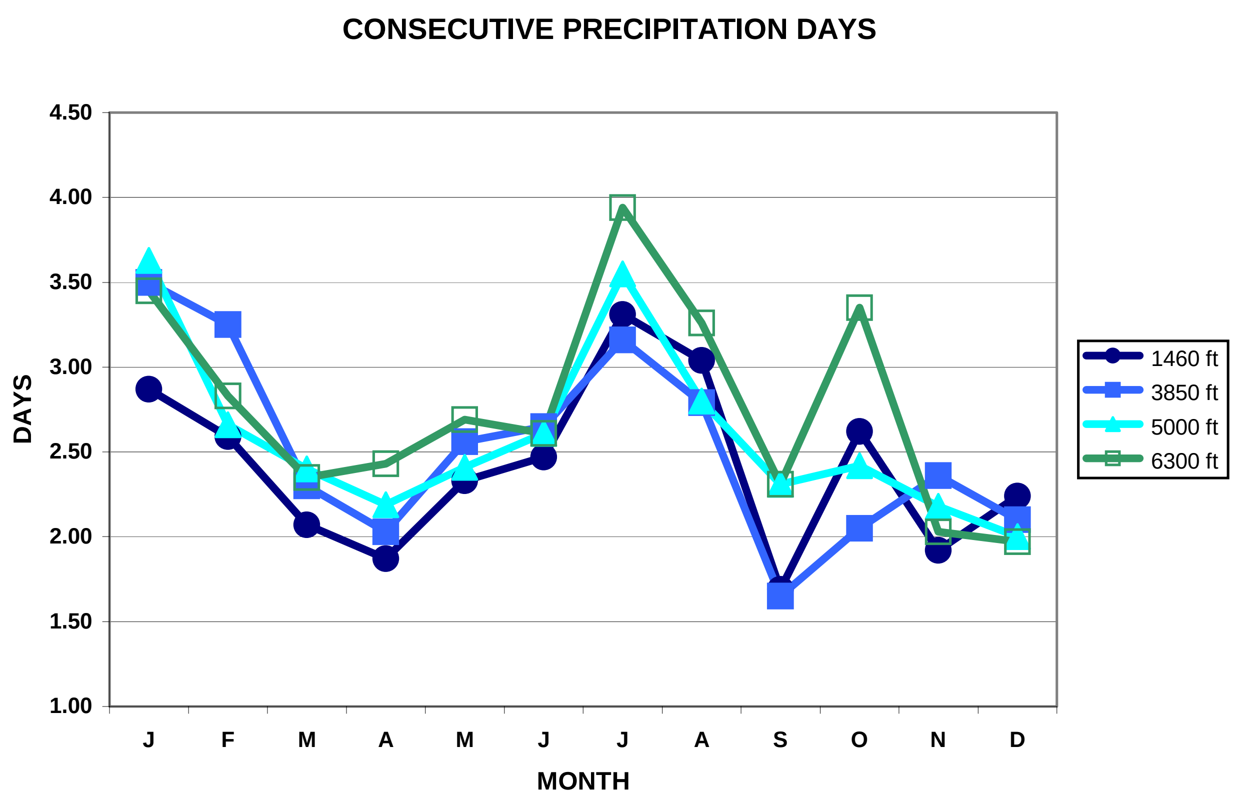


Figure 14. Consecutive precipitation days (1947-1950) by month and elevation.

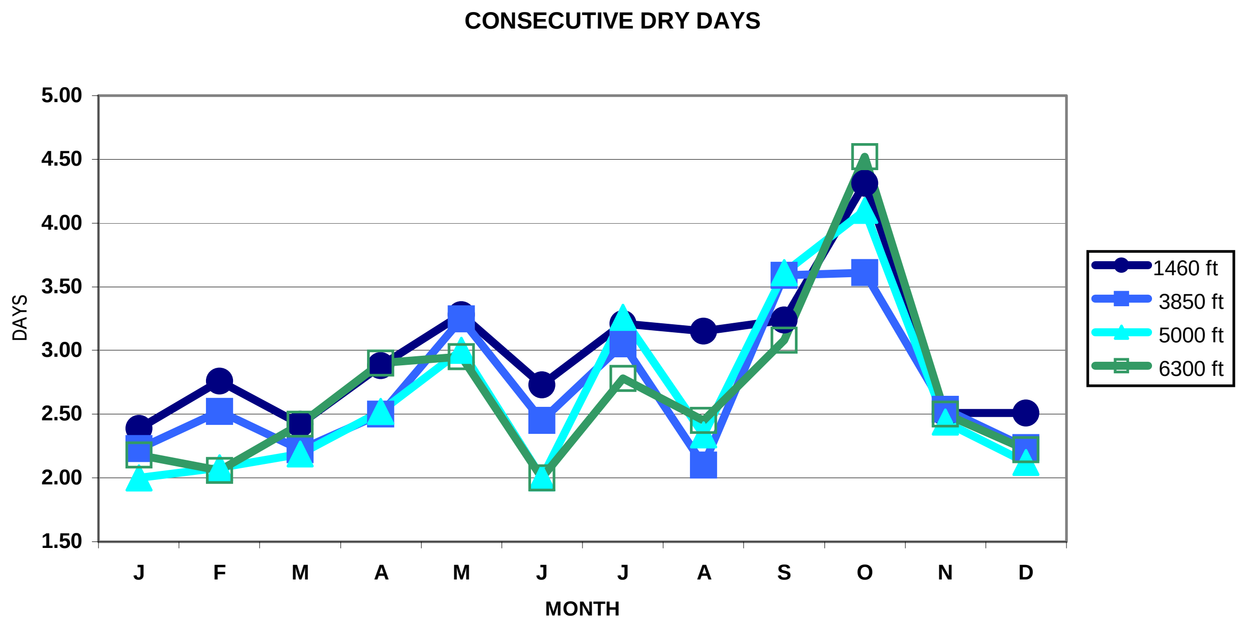


Figure 15. Consecutive dry days (1947-1950) by month and elevation.

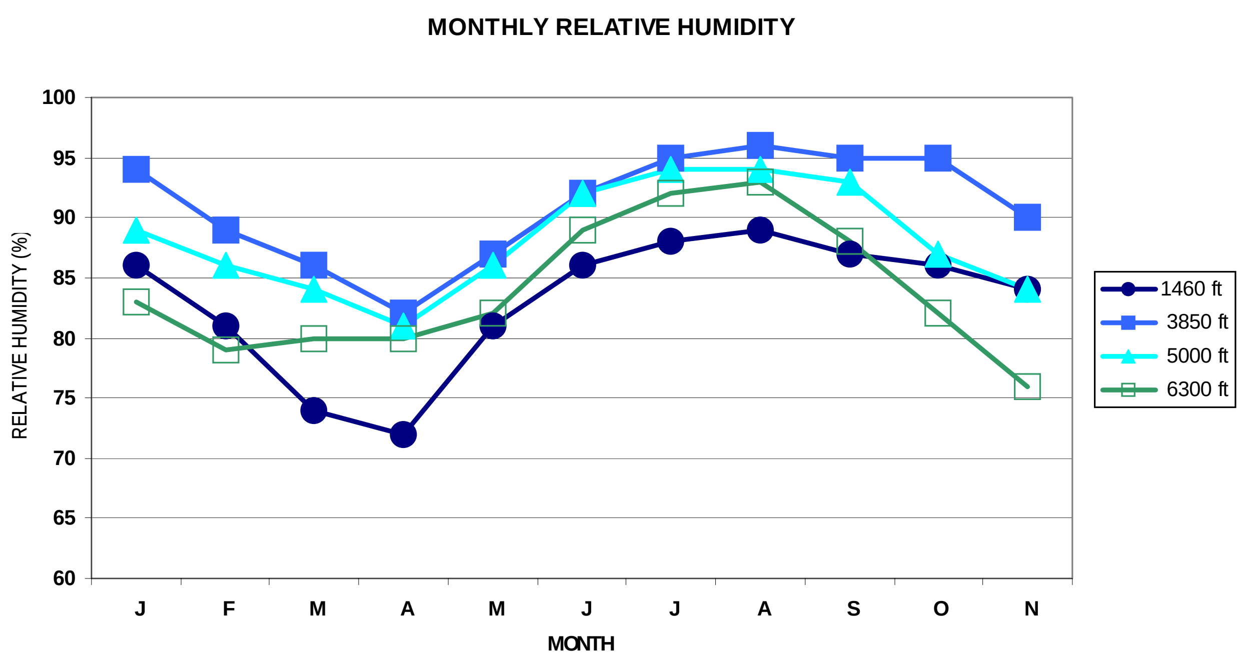


Figure 16. Monthly relative humidity (1947-1950) by elevation.

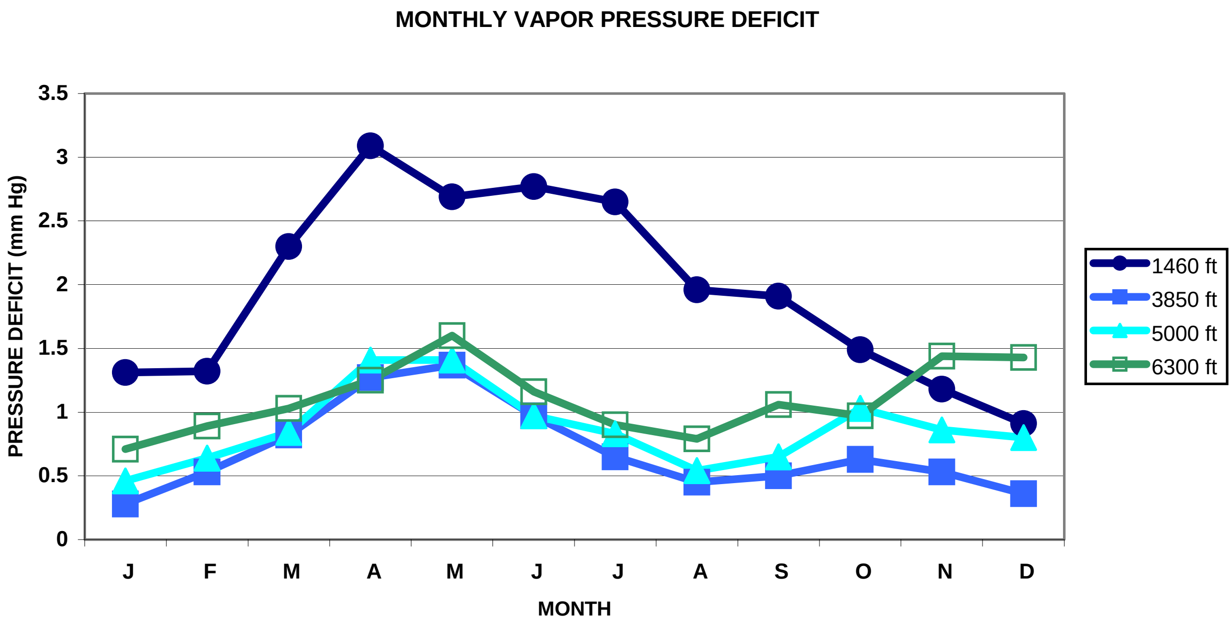
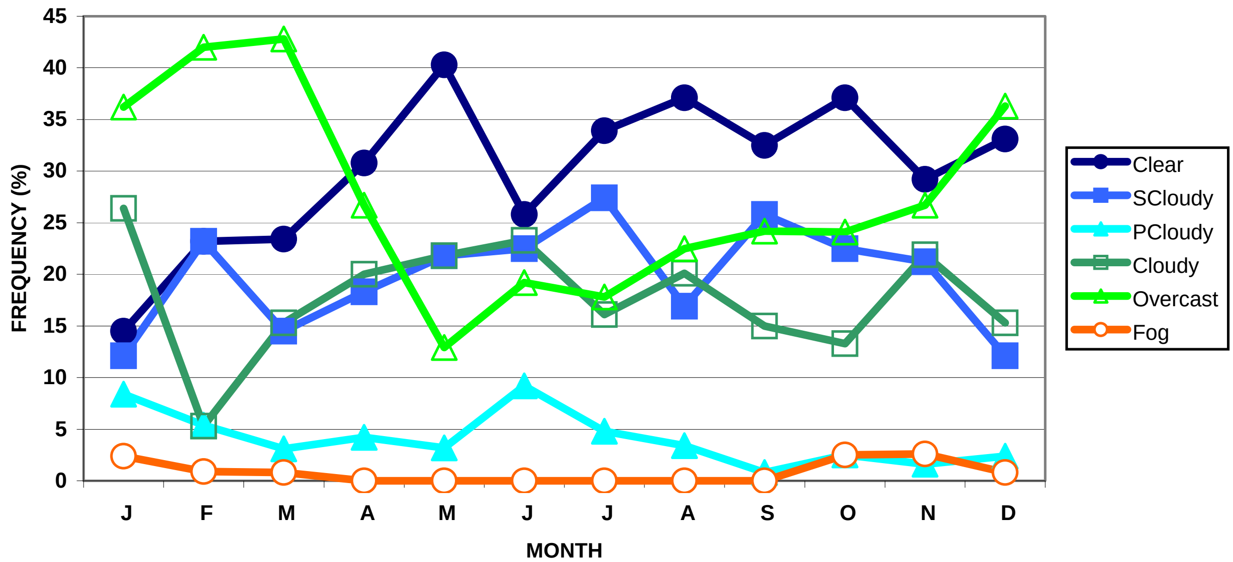
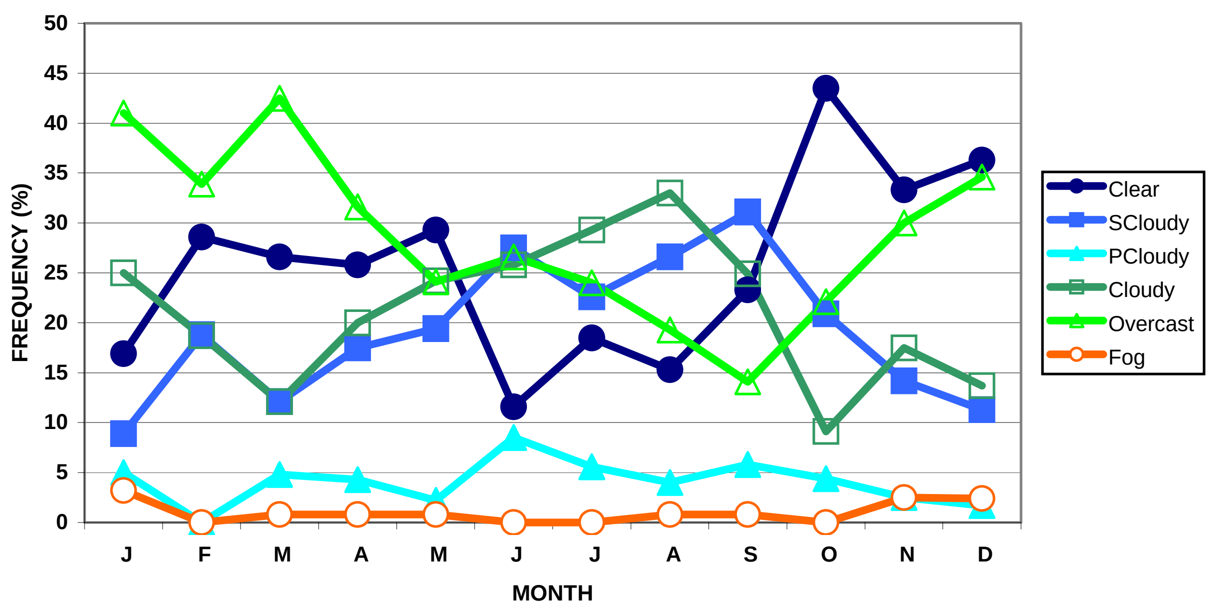


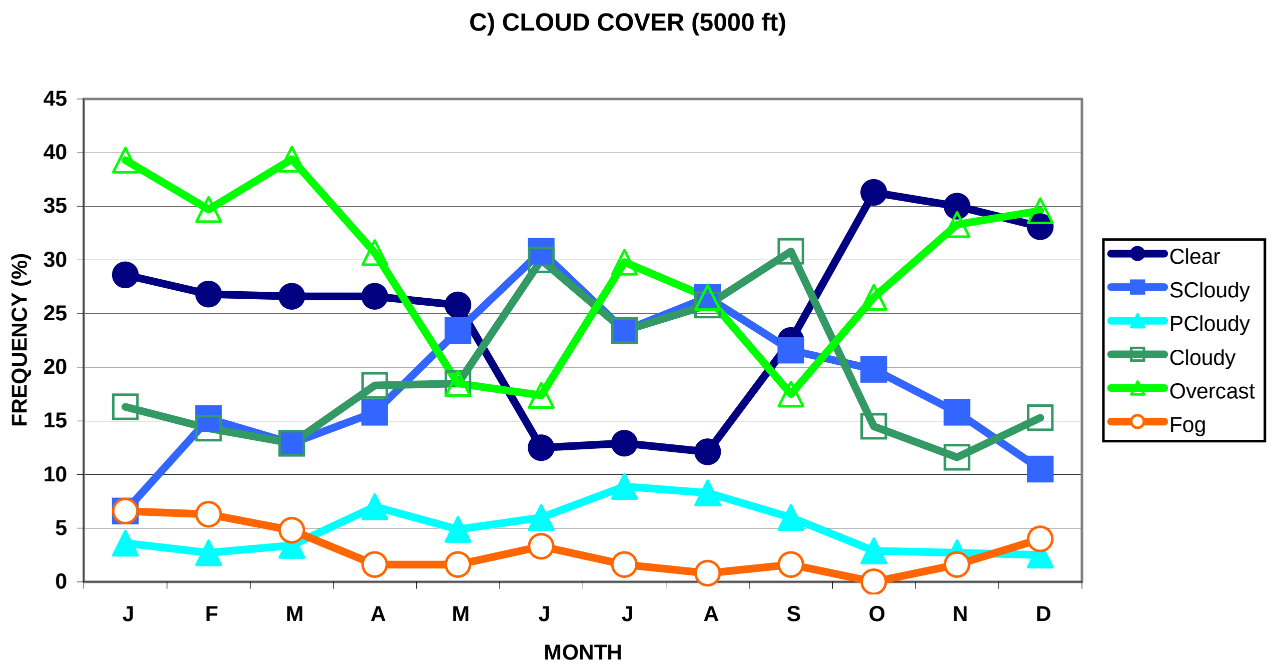
Figure 17. Monthly vapor pressure deficit (1947-1950) by elevation.

A) CLOUD COVER (1460 ft)



B) CLOUD COVER (3850 ft)





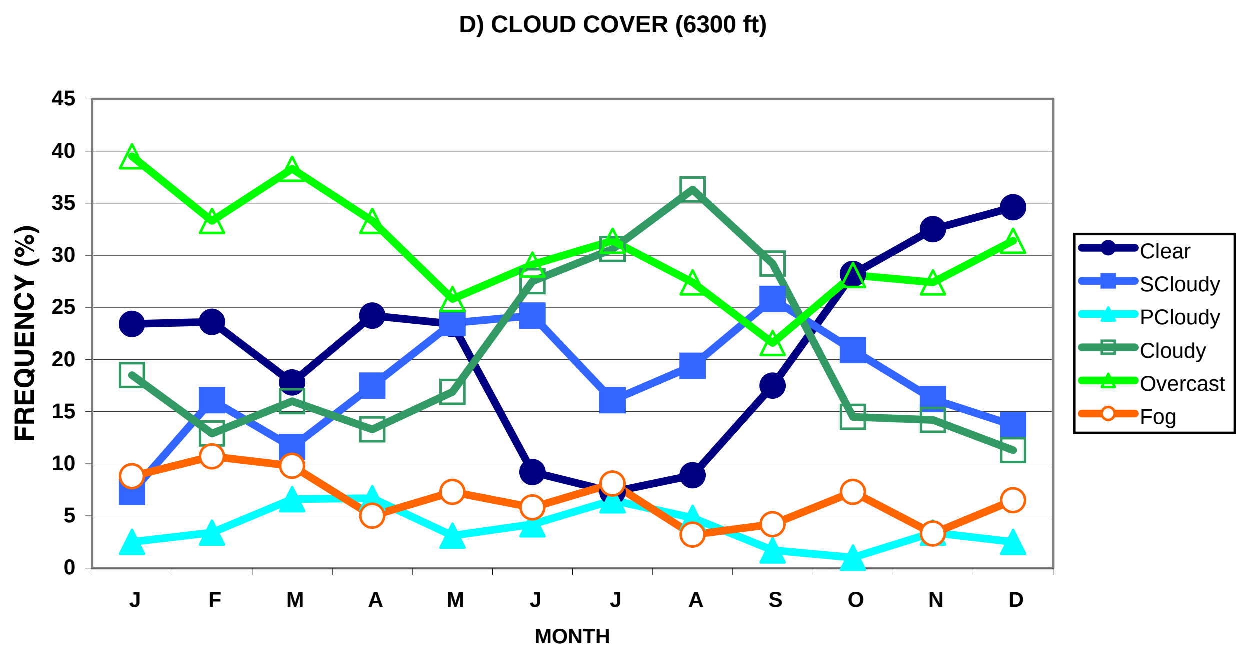
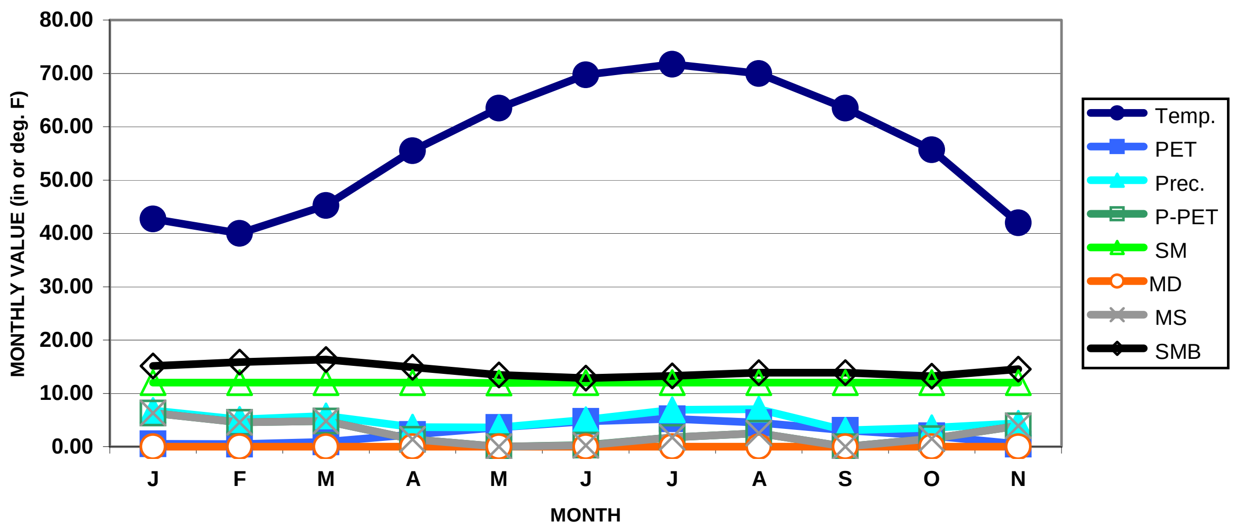
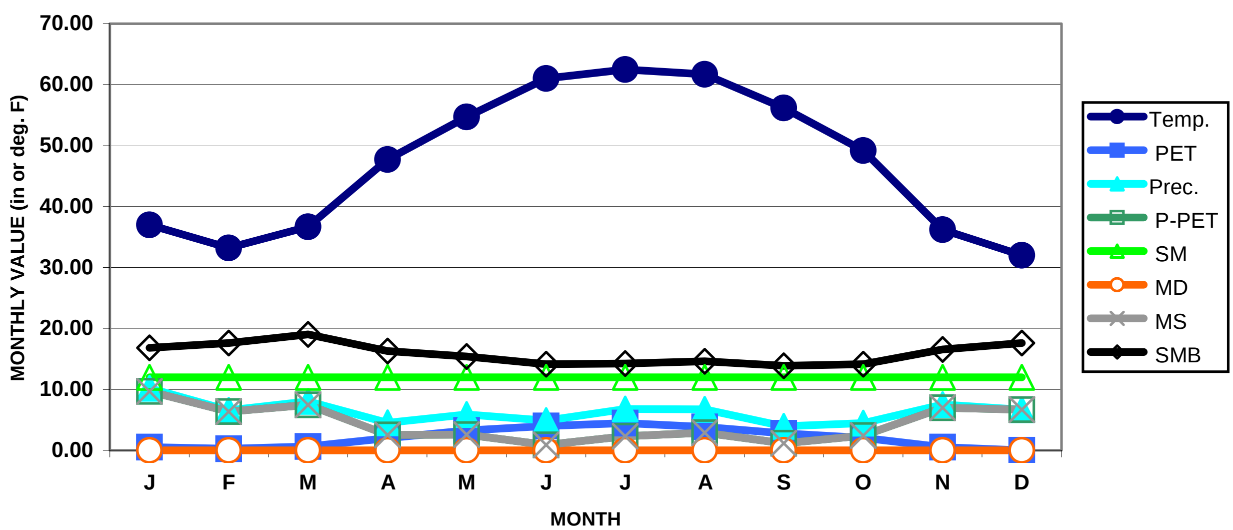


Figure 18. Monthly cloud cover (1947-1950) at A) 1460 ft elevation, B) 3850 ft elevation, C) 5000 ft elevation, and D) 6300 ft elevation.

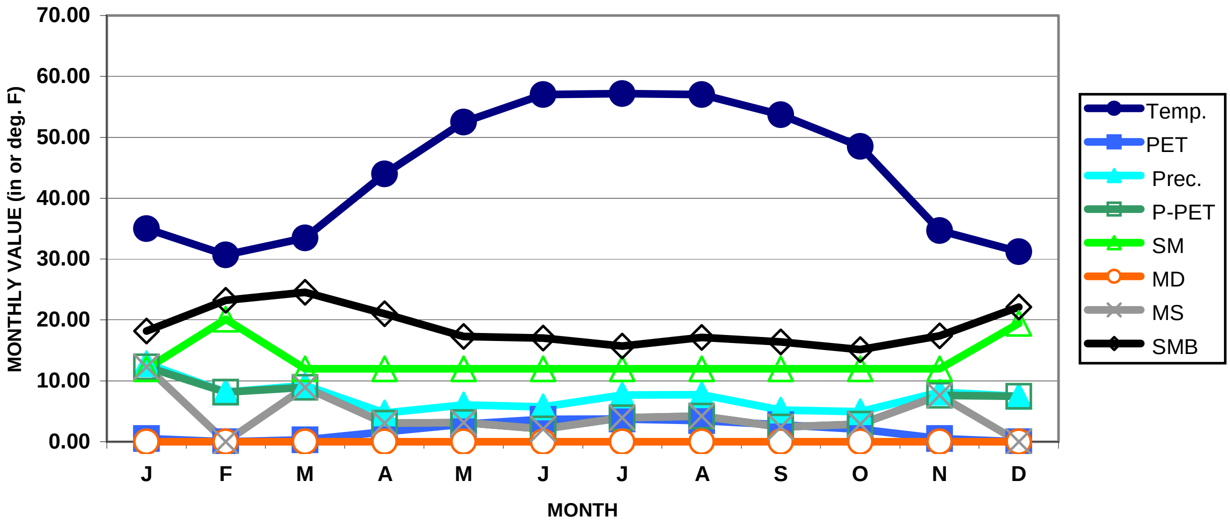
A) ANNUAL SOIL MOISTURE BALANCE (1460 ft, monthly mean)



B) ANNUAL SOIL MOISTURE BALANCE (3850 ft, monthly means)



C) SOIL MOISTURE BALANCE (5000 ft, monthly means)



D) SOIL MOISTURE BALANCE (6300 ft, monthly means)

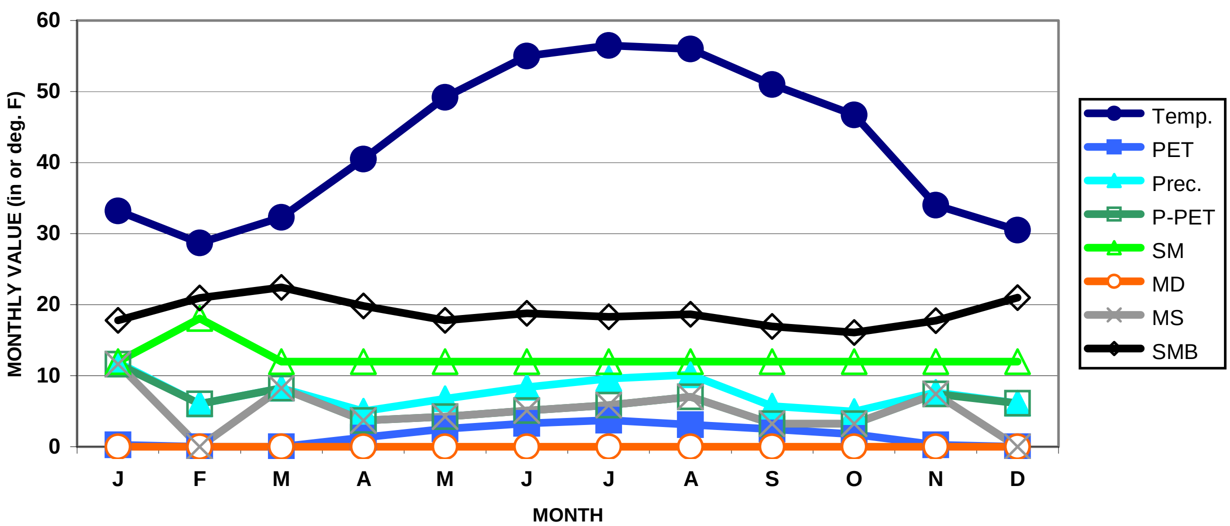
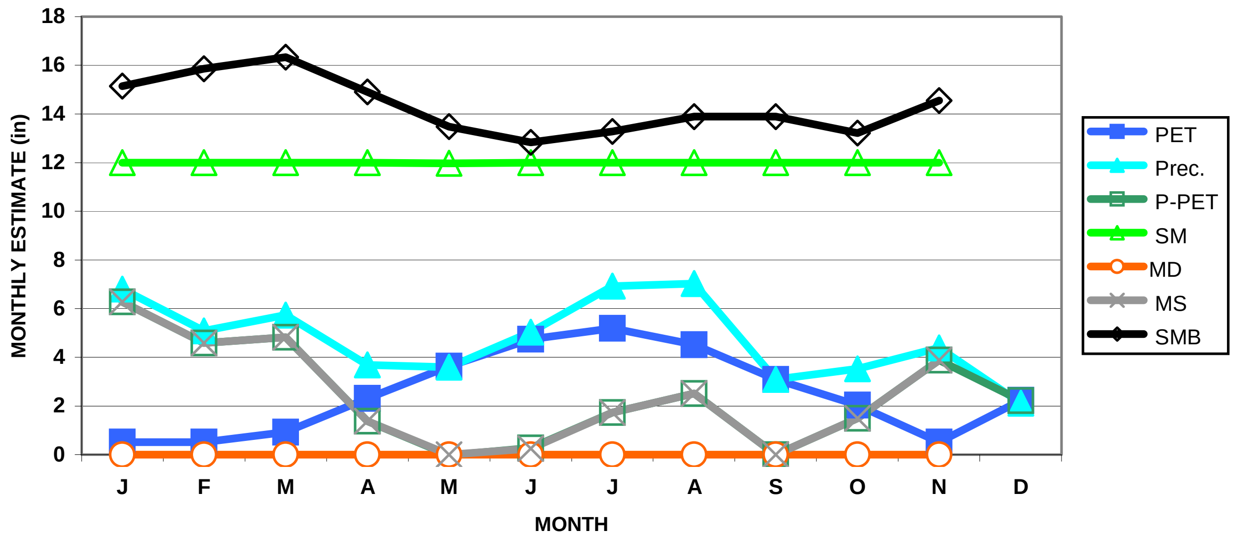
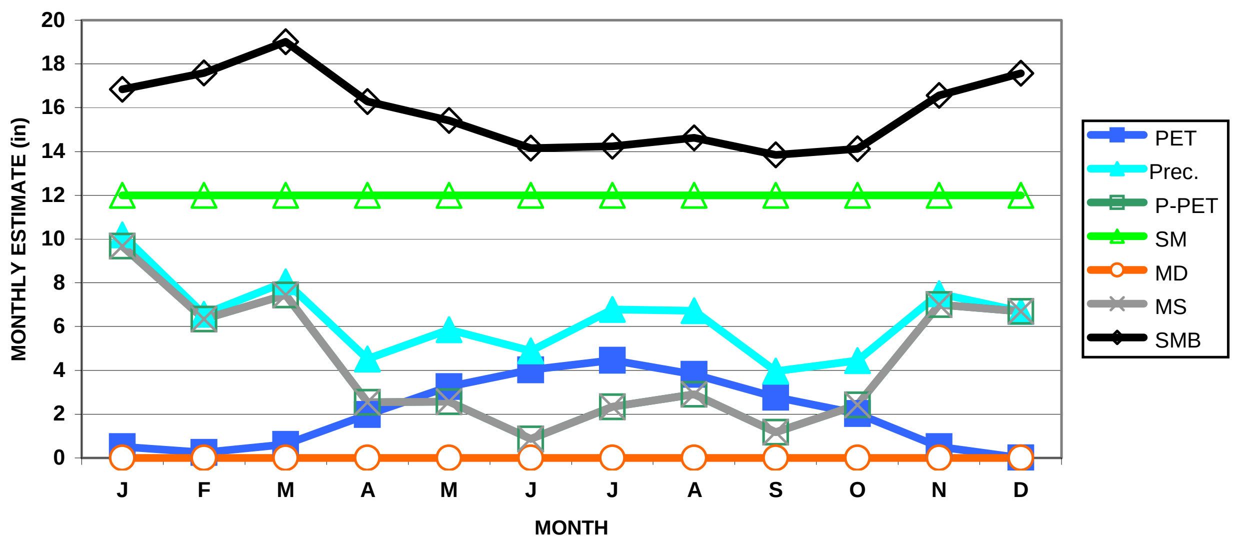


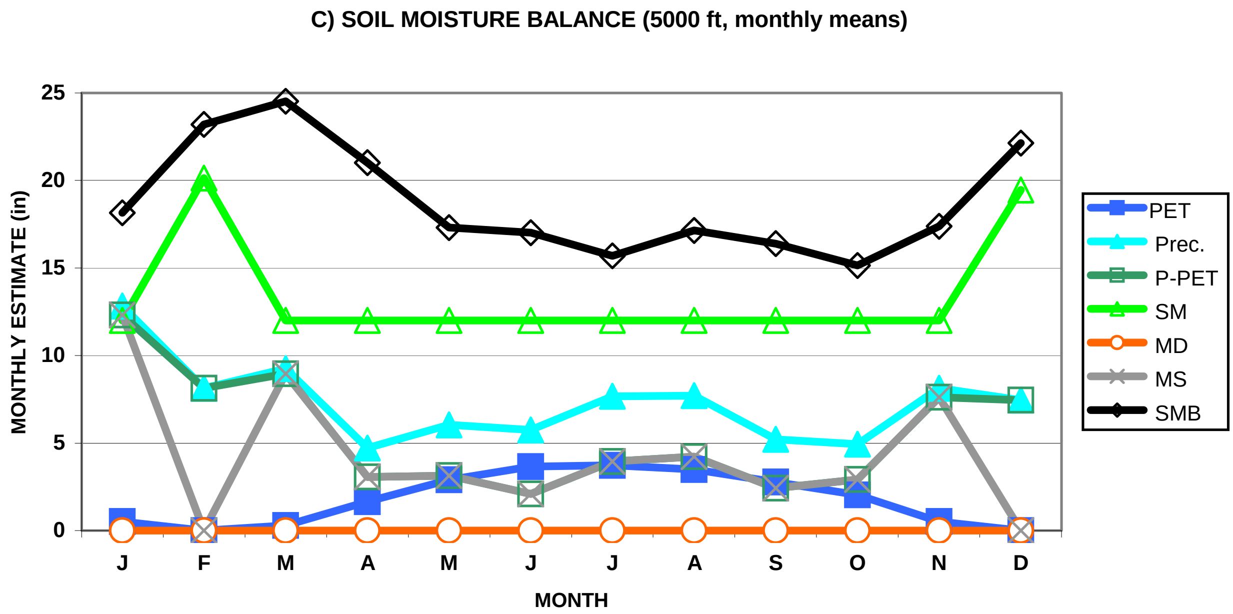
Figure 19. Monthly mean soil moisture (1947-1950) at A) 1460 ft elevation, B) 3850 ft elevation, C) 5000 ft elevation, and D) 6300 ft elevation.

A) ANNUAL SOIL MOISTURE BALANCE (1460 ft, monthly means)



B) ANNUAL SOIL MOISTURE BALANCE (3850 ft, monthly means)





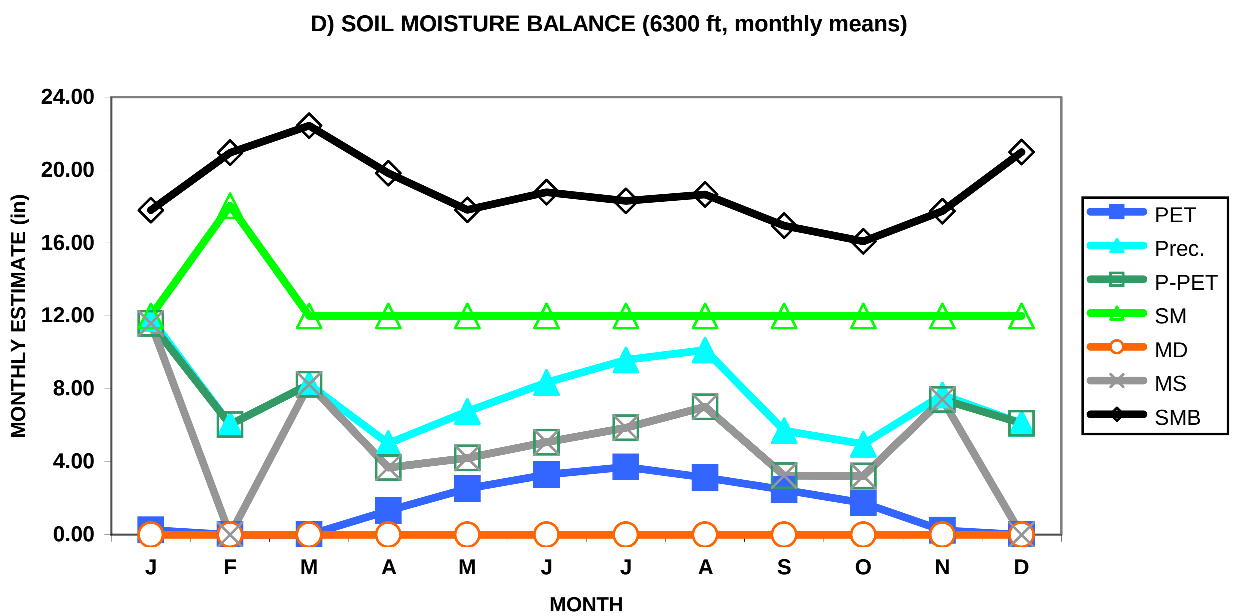
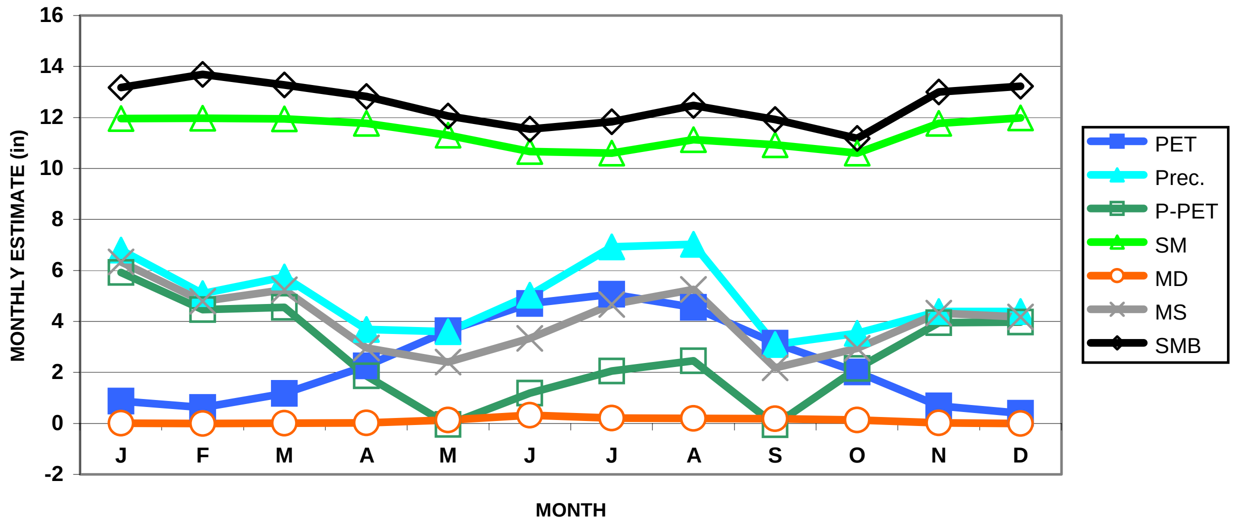
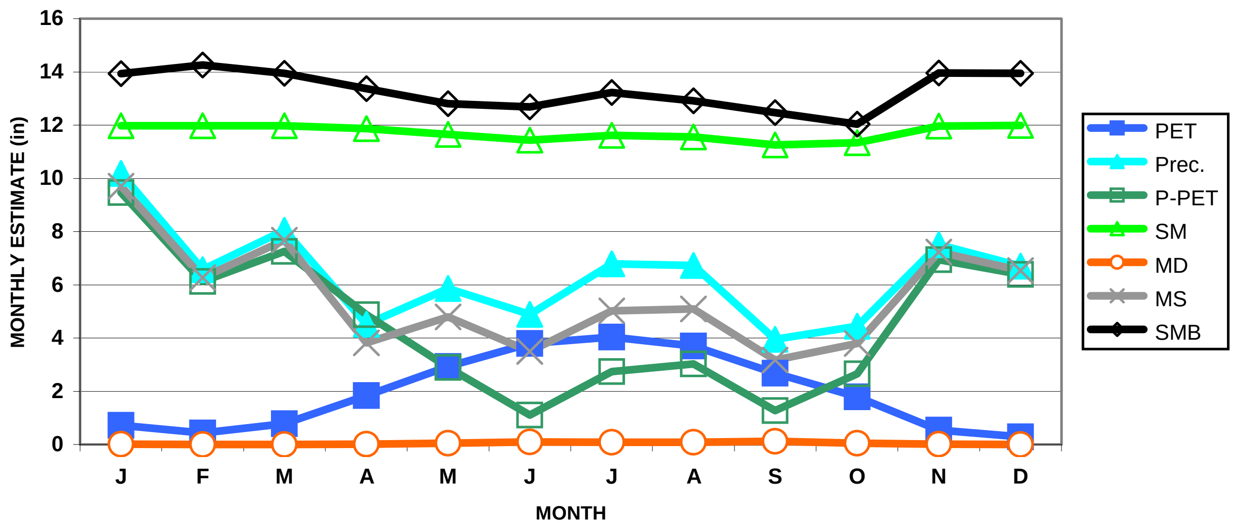


Figure 20. Monthly mean soil moisture balance (1947-1950) at A) 1460 ft elevation, B) 3850 ft elevation, C) 5000 ft elevation, and D) 6300 ft elevation.

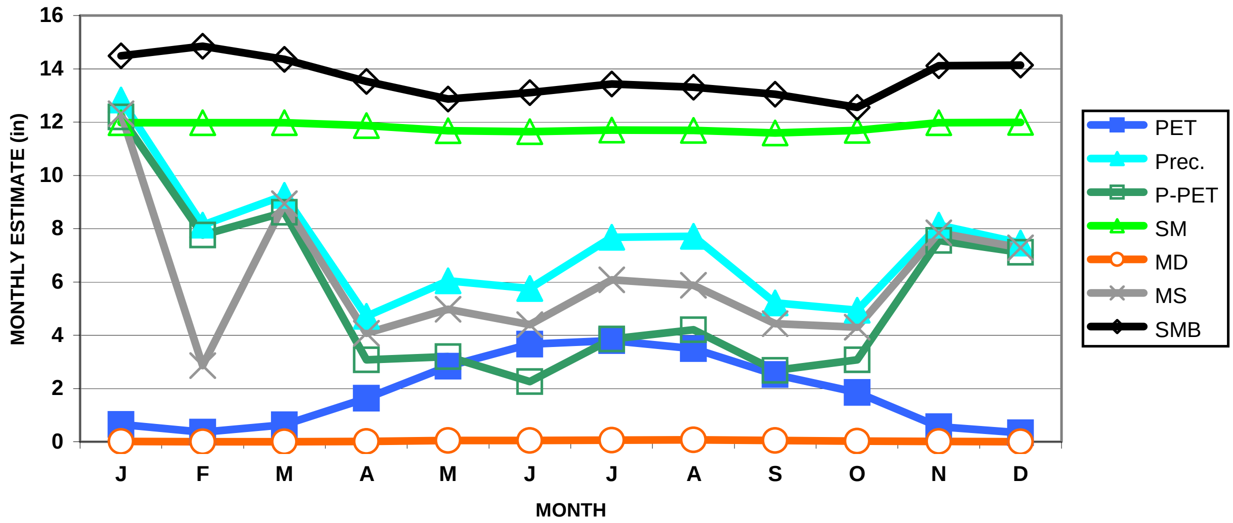
A) SOIL MOISTURE BALANCE (1460 ft, daily means)



B) SOIL MOISTURE BALANCE (3850 ft, daily means)



C) SOIL MOISTURE BALANCE (5000 ft, daily means)



D) SOIL MOISTURE BALANCE (6300 ft, daily means)

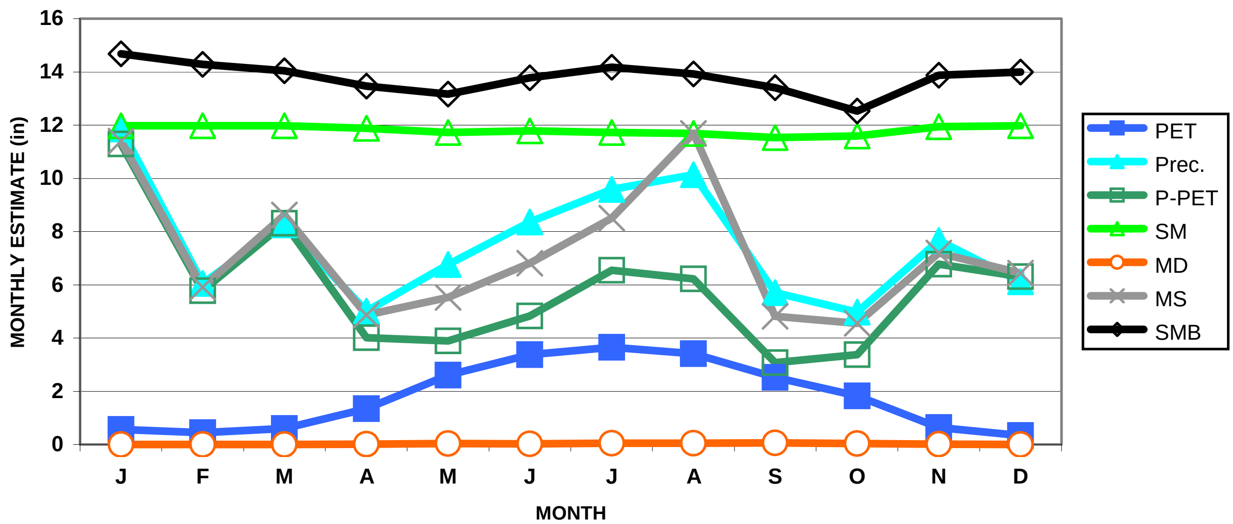


Figure 21. Daily mean soil moisture balance (1947-1950) at A) 1460 ft elevation, B) 3850 ft elevation, C) 5000 ft elevation, and D) 6300 ft elevation.

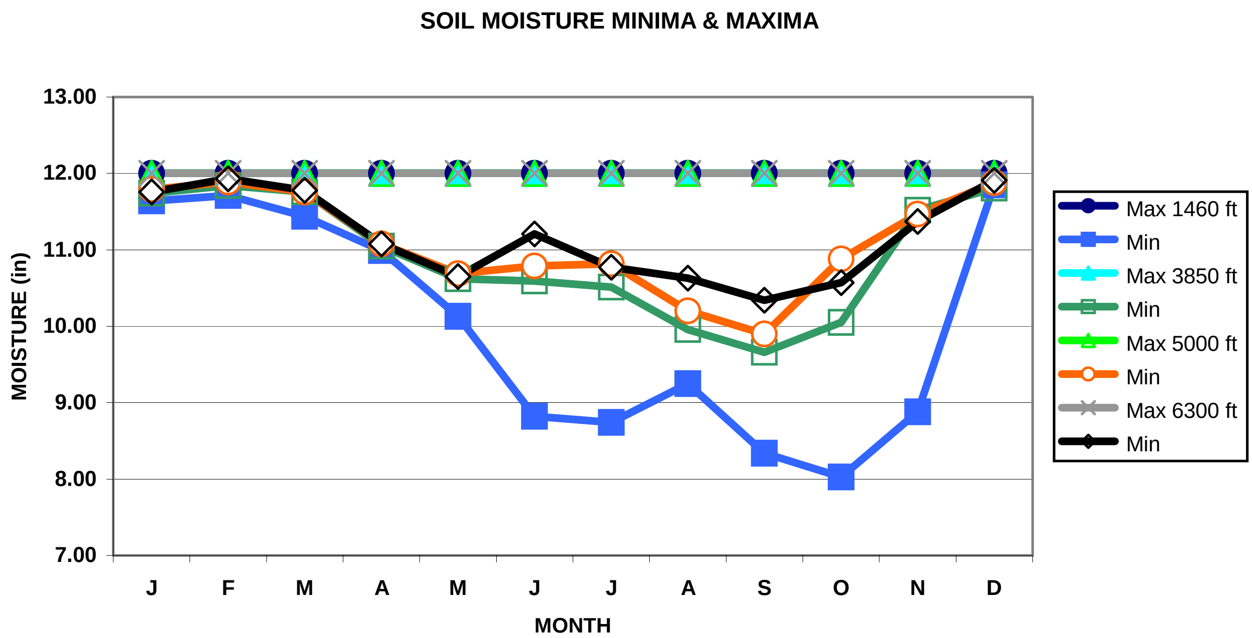


Figure 22. Monthly soil moisture minima and maxima (1947-1950) by elevation.