



A comparison of three automated precipitation simulation models : ANUSPLIN, MTCLIM-3D, and PRISM

by Sara Teresa Stillman

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Earth Sciences

Montana State University

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Abstract:

A comparison of the ANUSPLIN, MTCLIM-3D, and PRISM model performance is needed to assist users with appropriate model selection and elucidate potential differences. The models employ different techniques to develop gridded precipitation surfaces from published climate station (point) data and digital elevation models (DEMs) using the same monthly and annual data sets to determine whether the predicted precipitation surfaces are hydrologically reasonable over a region which contains a diverse physiography and produces a wide range of precipitation regimes. Mean monthly and annual precipitation estimates were prepared for the Bozeman, Billings, Ashton, and White Sulphur Springs 1 x, 2° topographic quadrangles in southwestern Montana and the Cody quadrangle in Wyoming for the 1961-90 data period. Input data included monthly precipitation data from 258 weather stations and a 0.5 km square-grid DEM derived from the appropriate 3 arc-second USGS DEMs with ANUDEM.

The models generated statistically similar results. The mean annual precipitation predictions for the 20 (randomly selected) withheld stations were accepted as statistically similar to the observed data at the 0.05 significance level. ANUSPLIN produced slightly higher mean annual estimates (5.6% and 4.0% higher than MTCLIM-3D and PRISM, respectively), and tended to overestimate precipitation at the 20 withheld stations. This model also generated slightly higher mean absolute errors (MAE) compared to the other two models which tended to underestimate precipitation at the 20 withheld stations. The largest differences between the model predictions occur in high elevation areas (e.g. Absarokas, Tetons) where a lack of climate stations and highly variable precipitation patterns complicate the interpolation process. Similar results suggest model selection should be based on ease of use and efficiency.

The MTCLIM-3D mean values are higher in winter and early spring while PRISM predictions are greater in the late spring-summer months and ANUSPLIN generally has the lowest predictions overall although the differences are minimal. The predictions fell in the same 25 mm classes in over 80% of the DEM cells in 28 out of 36 monthly surface comparisons. The largest differences occurred in the late fall and winter. The largest MAE and bias estimates were generated for all three models in these months. In addition, predictions were different from the observed data at the 20 withheld stations at the 0.05 significance level in November for ANUSPLIN and MTCLIM-3D, December for ANUSPLIN and PRISM, and February for ANUSPLIN. Relatively low agreement between the summed monthly surface and annual surface values for all three models demonstrate the importance of incorporating snow course data.' The models require less climate knowledge compared to the hand-contouring method and provide error estimates as well as precipitation estimates that can be accessed directly by modem geographic information systems. Increased numbers of climate stations in high elevations and more precise measurements of station locations and elevations would improve model predictions in the northern Rocky Mountains.

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MONTANA STATE UNIVERSITY-BOZEMAN
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Date 5/18/96

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ABSTRACT

A comparison of the ANUSPLIN, MTCLIM-3D, and PRISM model performance is needed to assist users with appropriate model selection and elucidate potential differences. The models employ different techniques to develop gridded precipitation surfaces from published climate station (point) data and digital elevation models (DEMs) using the same monthly and annual data sets to determine whether the predicted precipitation surfaces are hydrologically reasonable over a region which contains a diverse physiography and produces a wide range of precipitation regimes. Mean monthly and annual precipitation estimates were prepared for the Bozeman, Billings, Ashton, and White Sulphur Springs 1 x 2° topographic quadrangles in southwestern Montana and the Cody quadrangle in Wyoming for the 1961-90 data period. Input data included monthly precipitation data from 258 weather stations and a 0.5 km square-grid DEM derived from the appropriate 3 arc-second USGS DEMs with ANUDEM.

The models generated statistically similar results. The mean annual precipitation predictions for the 20 (randomly selected) withheld stations were accepted as statistically similar to the observed data at the 0.05 significance level. ANUSPLIN produced slightly higher mean annual estimates (5.6% and 4.0% higher than MTCLIM-3D and PRISM, respectively), and tended to overestimate precipitation at the 20 withheld stations. This model also generated slightly higher mean absolute errors (MAE) compared to the other two models which tended to underestimate precipitation at the 20 withheld stations. The largest differences between the model predictions occur in high elevation areas (e.g. Absarokas, Tetons) where a lack of climate stations and highly variable precipitation patterns complicate the interpolation process. Similar results suggest model selection should be based on ease of use and efficiency.

The MTCLIM-3D mean values are higher in winter and early spring while PRISM predictions are greater in the late spring-summer months and ANUSPLIN generally has the lowest predictions overall although the differences are minimal. The predictions fell in the same 25 mm classes in over 80% of the DEM cells in 28 out of 36 monthly surface comparisons. The largest differences occurred in the late fall and winter. The largest MAE and bias estimates were generated for all three models in these months. In addition, predictions were different from the observed data at the 20 withheld stations at the 0.05 significance level in November for ANUSPLIN and MTCLIM-3D, December for ANUSPLIN and PRISM, and February for ANUSPLIN. Relatively low agreement between the summed monthly surface and annual surface values for all three models demonstrate the importance of incorporating snow course data.

The models require less climate knowledge compared to the hand-contouring method and provide error estimates as well as precipitation estimates that can be accessed directly by modern geographic information systems. Increased numbers of climate stations in high elevations and more precise measurements of station locations and elevations would improve model predictions in the northern Rocky Mountains.

CHAPTER 1

INTRODUCTION

Scope and Purpose

Estimates of the amount and spatial distribution of rainfall data provide critical inputs for regional resource assessments and environmental modeling applications. Average monthly and annual precipitation data are required to evaluate potential land uses, water supply, drought hazards, and fire risk. Many silviculture, insect and disease, and hydrological models also need spatially variable precipitation estimates as inputs (eg: Lebel et al. 1987; Running et al. 1987; Hungerford et al. 1989; Caprio et al. 1990; Nielsen et al. 1990; Phillips et al. 1992; Wilson et al. 1993). Precipitation variability is a critical factor for determining the water budget of a region, particularly in the western United States where a large percentage of the total available water may be contained in the snowpack at high elevations and spatial variability can be extremely large over very small distances (<5 km) (Johnson and Hanson 1995). Knowledge of precipitation distribution can also assist in reservoir placement (Giorgi et al. 1992), irrigation, and overall watershed management (Basist et al. 1994).

Unfortunately, precipitation is assumed to be uniform for most applications due to low data density and computational and statistical difficulties associated with extrapolation (Anderson 1973; Johnson and Hanson 1995). Interpolation of precipitation data to unmeasured locations is particularly difficult in complex mountainous regions and

at the mountain-plains interface where highly variable spatial patterns of precipitation are produced (Peck and Brown 1962; Doesken et al. 1989; Daly and Neilson 1992; Phillips et al. 1992). Common obstacles include acquisition of a complete and continuous data set of rainfall measurements, determination of accurate and appropriate precipitation/elevation lapse rates, incorporation of orographic effects, selection of the appropriate grid resolution, and accounting for the additional data complexity caused by the large temporal and spatial variation in the distribution of rainfall.

The overall goal of this project is to compare the performance of three models using the same monthly and annual data sets to determine whether the predicted precipitation surfaces are hydrologically reasonable over a region which contains a diverse physiography and produces a wide range of precipitation regimes. The models are ANUSPLIN (Hutchinson 1989a, 1995, 1996), MTCLIM-3D (Running and Thornton 1996), and PRISM (Daly et al. 1994; Daly and Taylor 1996). These models employ different techniques to develop gridded precipitation surfaces from point data, and several model runs were performed to:

- (1) Determine if the models generate the same mean annual precipitation surfaces using climate station records and 3-arc-second DEMs for the Bozeman, Billings, Ashton, and White Sulphur Springs 1 x 2° quadrangles in southwest Montana and the Cody quadrangle in Wyoming. A randomly selected subset of the climate station data will be withheld from these model runs and the predicted values will be compared with measured values to assess model performance.
- (2) Determine if the models generate the same mean monthly precipitation surfaces

using monthly climate station records. The same subset of data withheld in Objective 1 will be withheld from these model runs and used to evaluate model performance.

- (3) Determine if the models generate the same mean annual precipitation surfaces as the professionally hand-drawn 1961-1990 precipitation contour maps produced by Phillip Farnes (USDA Soil Conservation Service (SCS) 1977). No data will be withheld for these model runs. Because the "true" average annual precipitation at many locations is not known for Montana (or any other state), the veracity of a computer-generated map is best assessed with respect to a tested and widely used reference map (Custer et al. 1996).

These answers are needed because it is essential that models designed for similar purposes be compared to other models and tested against observed measurements prior to producing baseline data for land and resource management decisions.

Spatial Interpolation Techniques Used in Climatology

Climatological work examining spatial variability of precipitation has taken one of two approaches: (1) a statistical approach where precipitation is distributed by use of spatial interpolation methods; or (2) a physically-based modeling approach in which precipitation is "dynamically" or deterministically simulated (Johnson and Hanson 1995). Dynamic models often lack the finer spatial-scale resolution required for estimating precipitation in mountainous regions and require substantial computer resources for long-term simulations. Statistical methods that use topographic variables as predictors can

effectively estimate the spatial distribution of mean annual precipitation in mountainous regions (Spreen 1947; Hutchinson 1973; Danard 1976; Vidal and Varas 1982; Basist et al. 1994). The remainder of the focus in this study will therefore be on statistical models.

A large number of spatial interpolation methods have been proposed for estimation of precipitation in unsampled areas from measured data (Creutin and Obled 1982; Tabios and Salas 1985; Hutchinson 1991c; Phillips et al. 1992; Dingman 1994). These techniques incorporate not only different statistical methods, but also vary in terms of computational complexity, data requirements, determination of lapse rates, and their ability to incorporate additional variables. As a result, very different estimates may be derived for the same location on different computer-generated maps. The commonly used techniques have been classified as local interpolation, moving average interpolation, spline, and kriging methods (Moore and Hutchinson 1991).

Local Interpolation Methods

Local interpolation methods include the use of triangulation, simple bivariate analysis, trend surface analysis, and similar methods that fit a polynomial equation or another simple function to a subregion to create a surface, with its complexity adjusted by changing the order of the polynomial (Shaw and Lynn 1972; Akima 1978). The resulting surfaces can suffer from somewhat arbitrary restrictions on their form and can be sensitive to the position of the data points because irregularly spaced and spurious effects may be generated away from the data points (Hutchinson and Bischof 1983). These techniques are quite complex to implement in more than two dimensions and do

not lend themselves easily to the smoothing of noisy data (Moore and Hutchinson 1991). These methods can also be implemented and used to fit the data very closely, whether or not the fit is justified in terms of the amount of noise associated with the data (Hutchinson and Bischof 1983). In addition, these techniques show persistent patterns in residuals from trend surfaces of different degrees, especially in regions of extrapolation (Edwards 1972; Shulze 1976; Hughes 1982; Hutchinson and Bischof 1983;).

Moving Average Interpolation Methods

Weighted interpolation or moving average methods use a moving window technique which requires a subjective choice of a weighting function defined in terms of a user-specified radius of influence beyond which data points are ignored (Goodin et al. 1979; Lancaster 1979). Linear regression is employed to develop estimates for each grid cell. The degree of data smoothing depends on the choice of weighting function. These methods also tend to fit the data very closely (Hutchinson and Bischof 1983). In addition, the choice of an optimum radius of influence can present a problem when the density of data points varies greatly across the data network. The selection of the appropriate digital elevation model (DEM) resolution is also very important (Hutchinson 1989b). The modeling purpose should determine the grid spacing of the DEM data which directly affects the degree of topographic generalization. Studies have shown that regional means do not change with generalization; however, the regional variances change significantly for different types of terrain (Dubayah et al. 1989; Dubayah 1990; Dubayah and van Katwijk 1992).

The original MT-CLIM model (Running et al. 1987; Hungerford et al. 1989) applied an inverse distance weighting technique to extrapolate meteorological variables from a point of measurement to the site of interest, making corrections for differences in elevation, slope and aspect, based on a user-specified domain-wide lapse rate for the precipitation-elevation (P/E) relationship. Inverse distance weighting assigns each grid cell a value by summing the product of the nearest data values (within a radius of influence) and the inverse of some power of the distance between the grid cell and the nearest base station. MT-CLIM was developed for forest ecosystem modeling applications and used daily observations. Studies ranging in spatial scale from point simulations (Running and Coughlan 1988; Running 1994) to single watershed simulations (Band et al. 1991; Band et al. 1993; White and Running 1994) and regional simulations over areas of 1-2000 km² (Running and Nemani 1991; Nemani et al. 1993) have demonstrated the successful application of the basic MT-CLIM logic.

A modified form of this logic is used in MTCLIM-3D to generate long-term average climate surfaces. A slightly more sophisticated spatial smoothing algorithm than the algorithm used in the version of MTCLIM-3D described by Thornton et al. (1996) is used to select the appropriate degree of smoothing for the DEM required for final map production (Thornton 1996, pers. comm.).

MTCLIM-3D uses the spatial convolution of a truncated Gaussian filter with a DEM and an unlimited number of stations as the interpolation framework to generate surfaces for temperature, precipitation, humidity, and incoming shortwave radiation over large regions. The convolution of the filter with the DEM results produces a list of

weights associated with observations for each grid cell. The truncation distance from the cell center, R_p , is varied as a smooth function of the local station density through the iterative estimation of local station density at each prediction point. The interpolation method for a given set of observations and a given prediction grid is defined by four parameters: I , the observation location; N , the average number of observations to be included at each point; a , a unitless shape parameter; and R_p . Additional inputs required to run MTCLIM-3D include a DEM, precipitation means with large gaps filled with data from nearby stations using linear regression or another method, and station elevations and locations. Output accuracy is estimated by monthly and annual mean absolute errors and standard errors of estimation. MTCLIM-3D was applied to the state of Montana on a 1-km resolution grid and produced mean absolute errors of 11.83 cm yr^{-1} or 20% measured as a proportion of total annual precipitation (Running and Thornton 1996).

Daly et al. (1994) have implemented an alternative moving average method in the PRISM model to generate gridded estimates of monthly and annual precipitation. The model is similar to MTCLIM-3D in that it generates a meteorological database for ecological models that integrate the role of microclimate in key forest processes such as forest evapotranspiration and photosynthesis over large areas. This topoclimatological model automatically computes climate surfaces in order to provide high resolution, terrain-sensitive daily climate data. The three main components of the conceptual framework of PRISM include the evaluation of the effects of elevation on precipitation, the determination of the spatial scales at which orographic effects are observed, and the inclusion of the effects of complex terrain on the spatial patterns of orographic regimes.

Inputs include a DEM, monthly and annual precipitation means, and user-specified minimum and maximum radii of influence, minimum and maximum slopes for the regression function, and the minimum number of stations required for the precipitation/orographic elevation (P/OE) calculation. These values can be determined for each application or left as default values (Daly and Neilson 1992).

PRISM was applied to northern Oregon and the entire western United States and produced a minimal increase in bias (4.5% versus 3.5%) and absolute errors (17% versus 16%) when applied to the larger region (Daly and Neilson 1992). High residual errors from stations in northern Oregon were attributed to either high precipitation variability on the leeward side of major mountain barriers, the altered P/E lapse rate below the crest, or the poor spatial resolution of the 5-minute DEM. Furthermore, P/OE regression functions developed from stations in relatively dry valley bottoms for regions spanning hundreds of meters of elevation may have lead to an underestimation of precipitation at the mountain crests (Daly and Neilson 1992). The Oregon Department of Water Resources uses PRISM to develop water supply forecasts and the model is currently being used by the USDA-Natural Resources Conservation Service (NRCS) (formerly the Soil Conservation Service (SCS)) to develop mean annual precipitation maps for the conterminous United States (Daly and Taylor 1996).

Splines

Splining has been developed primarily by Wahba (1980), Wahba and Wendelberger (1980) and implemented by Hutchinson (1991a, 1995). The method is

related to certain forms of optimum objective analysis proposed by Gandin (1965) and described in Goodin et al. (1979) and Wahba (1990). A summary of the basic methodology of thin plate splines, focusing on climate interpolation, can be found in Hutchinson (1991a, 1995).

The ANUSPLIN suite of programs (Hutchinson and Bischof 1983; Hutchinson 1989a, 1991a, 1991b) employ a multi-dimensional Laplacian partial thin plate smoothing spline technique and exemplify this type of approach. Tri-variate thin plate splines allow for spatially variable dependence on elevation which is suitable for applications across large heterogeneous areas (Hutchinson 1991c, Hutchinson et al. 1993). ANUSPLIN is a contouring routine which fits spline surfaces to spatial data with the degree of smoothing determined by minimizing the predictive error of the surface with generalized cross validation (GCV). The method is self-validating so that an optimal smoothing parameter is derived as each data point is removed. The degree of smoothing represents a trade-off between data infidelity, as measured by the mean square residual from the data points weighted according to variance estimates, and surface roughness, as measured by the total curvature of the fitted spline. This approach has been implemented in several Australian applications (Hutchinson and Bischof 1983; Hutchinson and Johnson 1991; Hutchinson 1995), and both the prestandardized and non-diagonal error covariance models of ANUSPLIN were recently applied to 34 years of annual rainfall data in southeastern Australia. The predicted mean rainfalls were 907 mm and 914 mm with estimated standard errors of 38 mm (4% of the areal mean) and 26 mm (3% of the areal mean) respectively (Hutchinson 1995).

Kriging

Kriging and a number of more sophisticated geostatistical interpolation techniques that incorporate various dependencies on topography have been developed (Chua and Bras 1982; Hevesi et al. 1992; Phillips et al. 1992; Daly et al. 1994). Kriging is a geostatistical method in which a semi-variogram model that best fits the data is developed to arrive at optimum station weights for interpolation (Daly et al. 1994). Whereas thin plate splines are defined by minimizing the roughness of the interpolated surface with a prescribed residual from the data, kriged surfaces are defined by minimizing the variance of the error of estimation which normally depends on the preliminary semi-variogram analysis (Hutchinson and Gessler 1994). Due to the dependence on the accuracy of the fitted semi-variogram model to determine the minimum error properties of kriging, it is not immediately apparent whether kriging is a more accurate interpolator than splines (Hutchinson and Gessler 1994). The derivation of the semi-variogram in kriging is discussed in Armstrong (1984), Davis (1987), Russo and Jury (1987), Laslett and McBratney (1990), and Cressie (1991), and recent comparisons with splines are presented in Hutchinson et al. (1993), Hutchinson and Gessler (1994), Laslett (1994), and Hutchinson (1996). The formal equivalence with splines is discussed in Matheron (1981), Dubrule (1983, 1984), Watson (1984), and Wahba (1990).

Although kriging extends easily to larger data sets, its "main limitation is that it depends critically on first estimating a spatial covariance function or variogram. The method is hampered by ad hoc assumptions about the form that the variogram should

take and the computational difficulties in assessing the merit of different functional forms" (Hutchinson 1991b, p. 106-7). The main advantage of splines is the lack of a requirement for prior estimation of a spatial autocorrelated covariance structure which can be difficult to estimate and validate (Hutchinson 1995). Daly et al. (1994) point out that kriging implicitly relies on the data to directly represent the spatial variability of the actual precipitation field. If the variability is not representative (which will often be the case in complex terrain), the accuracy of the resulting interpolated field will be questionable. Although the modified kriging techniques such as elevationally detrended kriging or cokriging show more topographically-related spatial patterns in complex terrain, these methods can only be applied to areas characterized by a strong overall P/E relationship. Furthermore, multiple semi-variograms may be needed to estimate precipitation at various time periods because of variations in the relative importance of different precipitation sources.

Study Area Description

A robust test of a model's predictive capabilities is provided by the generation of precipitation surfaces for a region which incorporates the Rocky Mountains and northern Great Plains which display a large variety of precipitation regimes. The Bozeman, Billings, Ashton, and White Sulphur Springs U.S.G.S. 3-arc-second quadrangles in southwest Montana and the Cody Wyoming quadrangle cover 47,328 km² and contain numerous national forests (NF) and parks, including all of Yellowstone National Park (YNP), as well as several wilderness areas. Split by the Continental Divide, the region

includes multiple watersheds and mountain ranges, rangeland, cropland, and intermontane plains and valleys (Figure 1). The elevations (as recorded on the DEMs) range from 2840 m above sea level northeast of Billings to 4197 m above sea level (Grand Teton, WY).

The amount of precipitation that is received depends on the orientation of nearby mountain ranges, elevation, rainshadows, the storm direction, intensity, and time of year. Annual precipitation across the study area is as high as 152.1 cm (Black Bear, 2484 m) on the Yellowstone Plateau, 130.8 cm in the Madison Range (Carrot Basin, 2743 m) and 148.9 cm at Fisher Creek (2774 m) in the Beartooth/Absaroka mountains, and as low as 17.0 cm (Basin, 1170 m) in the plains region near Greybull WY and 30.0 cm at Canyon Ferry Dam (1119 m) in the northeast corner.

The disparate precipitation distribution between valley and mountainous areas is exemplified in the Gallatin Range where the valley stations, Ennis (1510 m) and Jack Creek (2027 m), receive 32.4 cm and 36.8 cm, respectively, and the Sentinel Creek (2530 m) and Bear Basin (2484 m) mountain stations receive 91.4 cm and 116.8 cm, respectively. The Bridger Bowl summit station (2210 m) receives 136.6 cm annually whereas the Bozeman 12NE station at the base (1814 m) receives 89.2 cm and stations on the eastern side of the Crazy Mountains, Melville (1635 m) and Wilsall (1539 m), receive only 42.4 cm and 39.2 cm, respectively due to the rainshadow effect. The rainshadow effect, in which the intensity of a storm dissipates as it rises over a mountain range, is further illustrated when the snowfall in the Madison Drainage (60-67 cm) is compared to that of the Gallatin Drainage (44-49 cm).

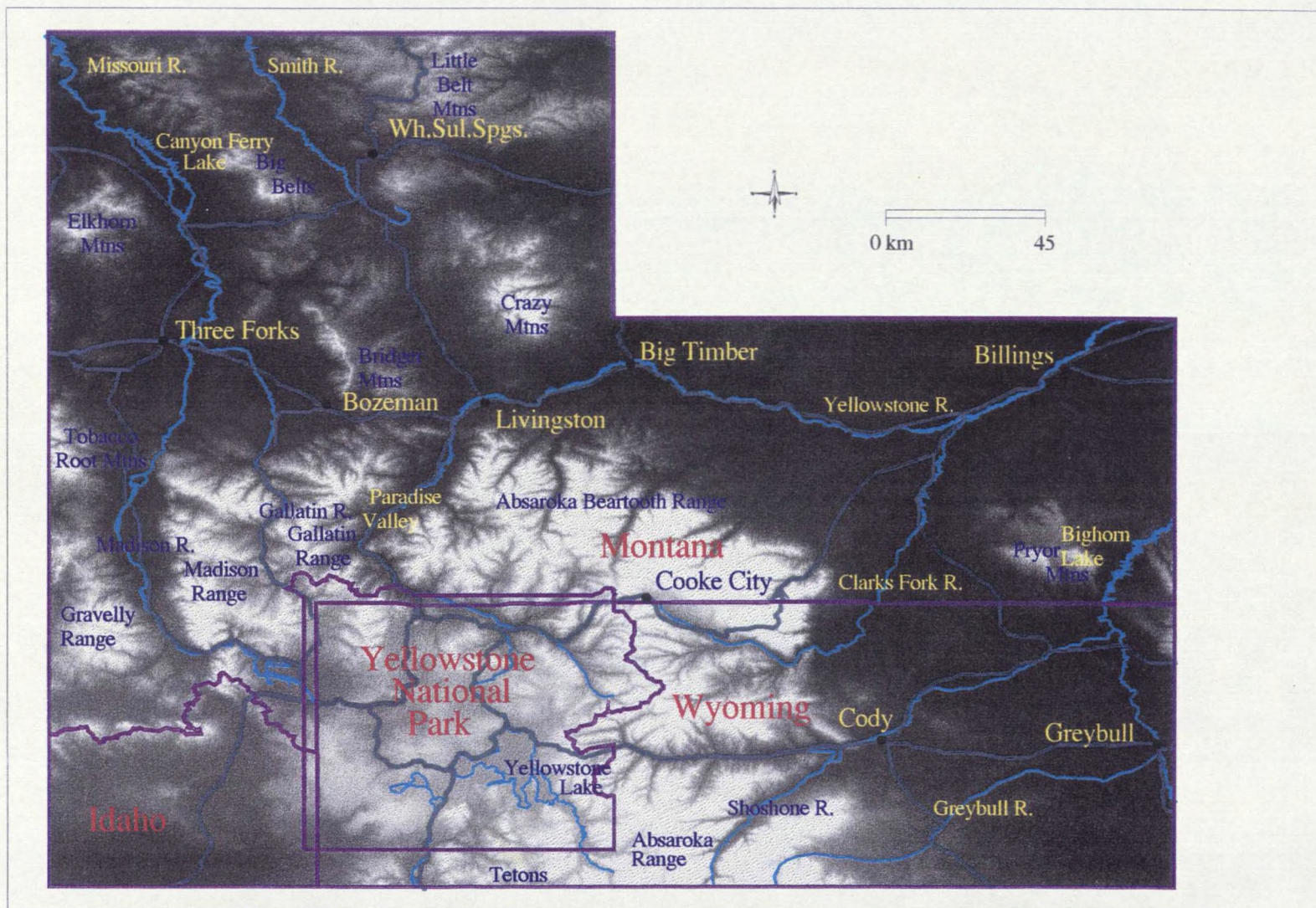


Figure 1. Study area location map: White Sulphur Springs, Bozeman, Billings, Ashton, MT and Cody, WY map quadrangles.

At high elevations, the spring component (April-June) of the annual precipitation is much smaller than the winter component (October-March) and the summer/fall component (July-September) is generally only about 10 to 20% of the annual precipitation (Farnes 1995). On the Yellowstone Plateau, Black Bear receives 67% of its annual precipitation in the winter, 21% in the spring, and 12% in the summer/fall period whereas the Bridger Range summit station receives 52% in the winter, 32% in the spring, and 16% in the summer/fall period. Lower elevations, usually occupied valley areas, in drainages east of the Continental Divide receive the majority of their annual precipitation in the spring (Greybull, 1155 m, receives 43% in spring, 31% in winter, and 26% in the summer/fall period) while the majority of annual precipitation for lower elevations west of the Divide such as Ashton, ID (1603 m) occurs in the winter (55%) followed by the spring period (28%). However, at some lower elevation stations such as Townsend (1170 m), the summer-fall component (35%) is greater than the six-month winter accumulation (25%) due to severe summer thunderstorms caused by convective air movement (Farnes 1995).

In the fall, Arctic incursions combine with the Aleutian Low to deliver dense, cold air and snowfall and displace the calm summertime North Pacific high pressure systems. By December, precipitation from the Aleutian Low covers the Little Belts, Bridger, and Crazy Mountains with snow while the Great Basin high pressure systems from Idaho and Utah bring snow to the Yellowstone Plateau, Gravelly, Tobacco Root, Madison, and Gallatin Ranges. Throughout the spring, the Aleutian Low dissipates, reducing the amount of precipitation drastically by June for the majority of stations and

creating weak westerlies. By July, the Aleutian Low has been completely replaced by the North Pacific High cutting off the moist air from the southwest and dramatically reducing precipitation. Precipitation remains low in the early fall months as the high pressure systems settle over the mountains and plains regions.

CHAPTER 2

METHODS AND DATA SOURCES

Climate Station Data

Precipitation means with at least 5 years of data within the 1961-1990 period for National Weather Service (NWS), U. S. Department of Agriculture (USDA)-Natural Resources Conservation Service (NRCS) SNOTEL (Snow Survey Telemetry) and snow course stations were used as inputs (Table 1). The spatial distribution of stations is shown in Figure 2. Stations located within a 0.5 decimal degrees latitude and longitude buffer surrounding the study area were used to account for edge effects (Table 1). Inputs provided by the author for each model consist of climate station latitude, longitude, elevation, and one annual and twelve monthly precipitation means per station (Appendix 1). Standard deviations and monthly means were calculated for months with at least five years of data. Annual means were calculated for years with at least five complete years (twelve months) of data. A digital file containing station locations (DMS) and elevations (feet) was created and measurements were converted to decimal degrees and kilometers depending on the model's required input format.

The NWS precipitation data for climate stations in Montana was extracted from the Lightning! Environmental Database Manager produced by J.D. Software Developers, Inc. (1995). The "redbook standard" used in the Lightning! database requires at least 75%

Table 1. Number of climate stations by type.

Time Period	NWS Stations		SNOTEL Stations		Snow Course Stations	
	Study Area	Buffer Region	Study Area	Buffer Region	Study Area	Buffer Region
January	71	51	57	22	--	--
February	70	51	57	22	--	--
March	71	51	57	22	--	--
April	72	51	57	22	--	--
May	71	51	57	22	--	--
June	73	50	57	22	--	--
July	73	51	57	22	--	--
August	72	51	57	22	--	--
Sept.	72	51	57	22	--	--
October	72	51	57	22	--	--
November	71	51	57	22	--	--
December	71	51	57	22	--	--
Annual	73	58	57	22	38	12

of the days in each month to have recorded precipitation data. NWS precipitation data for stations in Wyoming and Idaho, the SNOTEL data, and the snow course data were captured via modem from the NRCS Centralized Database System (CDBS) in Portland, Oregon.

NWS climate stations are primarily located in valley and plains locations (Figure 2). Snow depth is included in the NWS precipitation measurements; however, the lack of windscreens can cause measurement errors as large as 50% primarily in the eastern plains regions (Dingman 1994). Therefore, the inclusion of SNOTEL and snow course climate

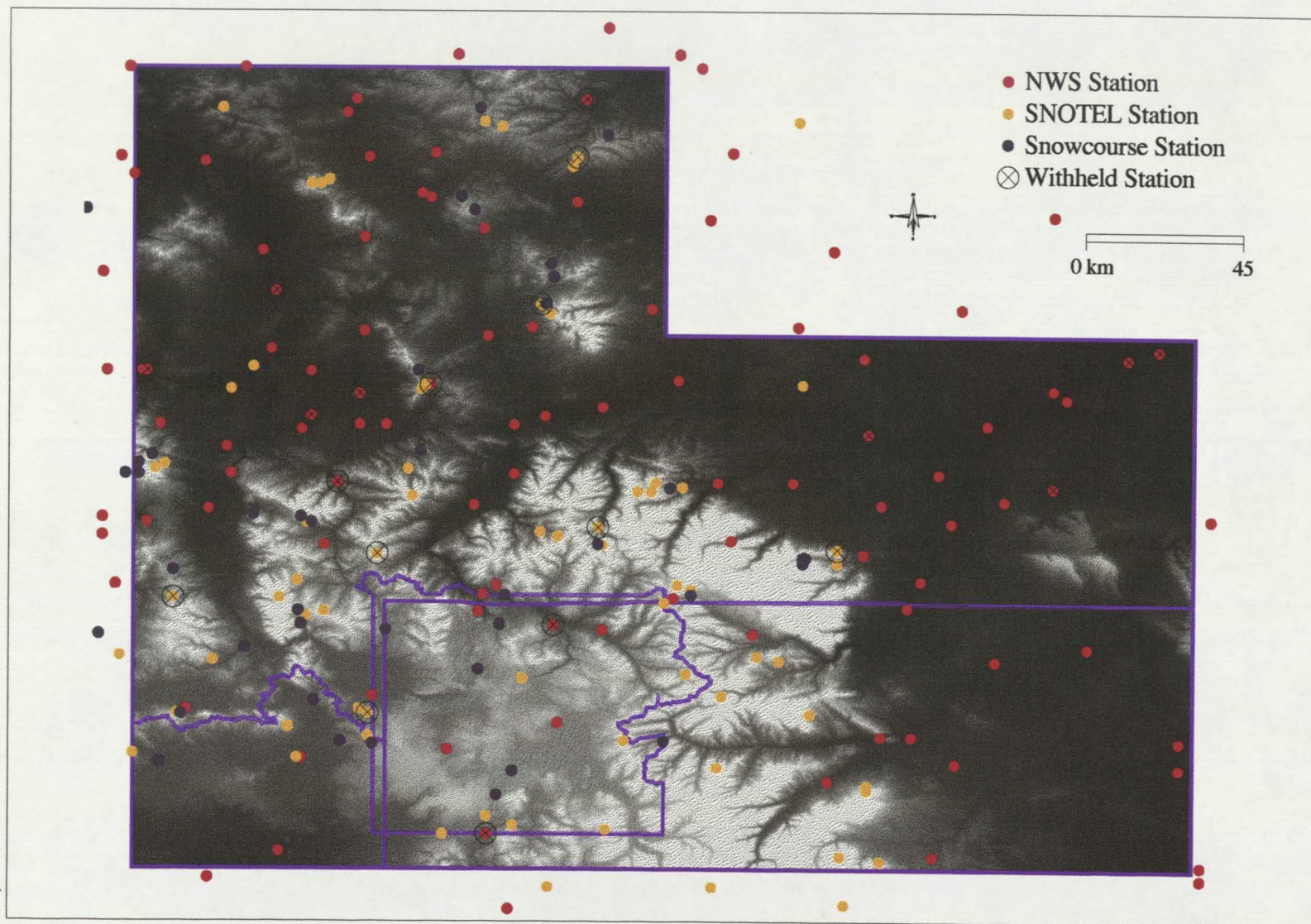


Figure 2. Climate station location map.

stations which are mostly located in mountainous regions is essential to maximize the spatial distribution of climate stations and improve model predictions.

SNOTEL is a network of automated radiotelemetry remote data collection sites for obtaining snow water equivalent, precipitation, air temperature, and other hydrologic measurements throughout the western United States. There are 79 SNOTEL stations within the study area and surrounding buffer (Table 1) (Farnes 1995). The Federal, State, and private cooperative snow course survey program directed by the USDA-NRCS measures the extent and water content of the mountain snow cover.

The addition of snow course measurements to a data set can double or triple a database for mountain areas in most western states (Farnes 1995). The NRCS April 1st snow course snow water equivalents (SWEs) were converted to annual precipitation values by Phillip Farnes using site-specific algorithms correlating SWE and annual precipitation at SNOTEL sites for specific mountain ranges. (Farnes 1971, 1995). The April 1st SWEs were multiplied by 0.91 for the standard federal cutter or 0.94 for the sharpened cutter to correct for overmeasurement with snow tubes (Farnes et al. 1983) and stations in ID and WY were adjusted for canopy cover, if any, at the sites (Farnes 1971, McCaughey et al. 1995). Farnes and Shafer (1975) estimated canopy cover for sites without previously recorded SCS Snow Survey Unit measurements (Custer et al. 1996).

Data quality assessment is as important as the factors which influence precipitation distribution. Data values must be evaluated for reasonableness both to assess data input error (Hutchinson 1989a) and to evaluate the effectiveness of the prediction technique in the mountains and at the mountains-plains interface. Data entry, measurement, or

conversion errors in published data sets can severely skew precipitation estimates (Hutchinson 1989a). The data were exhaustively checked for locational and precipitation errors, outliers, and completeness of record to minimize inaccurate model predictions.

Station locations and elevations were double-checked for conversion and input errors several times. Some of these errors were identified with ANUSPLIN which prints ordered lists of outliers from the fitted spline surface where potentially erroneous data, particularly those data with errors in geographic position or elevation, exist (Hutchinson 1995, pers. comm.). Errors in precipitation totals were revealed by comparing the values between nearby stations and stations at approximately equivalent elevations. Large calculated standard deviations also indicated errors in the original data sets in some instances, and other errors were identified when the recorded station elevations were compared with DEM elevations (as discussed in next section).

Digital Elevation Model Data

The success of many interpolation methods depends on the spatial scale of the input DEM. PRISM, for example, uses the DEM to delineate topographic facets and other terrain characteristics. Spatial "shifting" of precipitation accumulation downwind of terrain features (i.e crest-line blow-over or leeside enhancement on ridgelines and downwind of mountains) may occur when a fine-grid DEM is used (Daly 1995, pers. comm.).

The USGS 3-arc-second (1:250,000-scale) DEMs for the five quadrangles were obtained from the USGS DEM FTP site via the Internet. The DEMs were edgematched

and joined in the ARC/INFO (Environmental Systems Research Institute, Inc., Redlands, California) GRID module to create a single DEM with 245,542 cells (469 rows by 660 columns, 0.0063-decimal degrees cellsize, minus the upper right corner). This DEM was converted into an ARC/INFO point coverage with the gridpoint command and projected into an equal area lattice with a Lambert Conformal Conic projection. This step was required because ARC/INFO works with square grids and changing the projection in the GRID module would have added an additional and unwanted spatial interpolation.

An ASCII file with the latitude, longitude, and elevation for each coverage point was generated for input into ANUDEM, a program that interpolates source data to a user-specified square-grid (Hutchinson 1989b). The user-directive file for input into ANUDEM contains elevation and location bounds, an RMS residual (0.08), a centering option (1), a drainage enforcement option (0), a roughness penalty tradeoff (0.25), the desired output grid spacing (500 m), and several input/output file parameters. ANUDEM output the 0.5 km grid in ASCII format which was converted back to an ARC/INFO point coverage and then to a lattice with 0.5 km spacing. This lattice was used in the MTCLIM-3D model. This lattice was also reprojected to a geographic projection and converted to a 21.6-arc-second lattice in ARC/INFO for use in the ANUSPLIN (LAPGRD program) and PRISM models.

The discrepancies between recorded station and DEM elevations and their impact on ANUSPLIN model predictions observed by Custer et al. (1996) demonstrate that model performance is tied closely to the accurate description of station locations. However, recorded station locations are given only to the nearest arc-minute and it is not

known if this location is a truncated or rounded minute. The specification of station locations to ± 1 arc-minute corresponds to a potential error of 3.7 km for latitude and 2.5 km for longitude (at 47° N) (Thornton et al. 1996), and may cause problems during model development when recorded station elevations are used in conjunction with DEM elevations (Custer et al. 1996). An average absolute difference between the smoothed 21.6-arc-second DEM and the recorded climate station elevations of 81.35 m with a standard deviation of 119.10 m demonstrated the need to check and, in some instances, modify the locations of the climate stations and elevations in this study.

The scatterplot reproduced in Figure 3 shows the differences between the recorded station elevations and those extracted from the DEMs at the recorded station locations. These discrepancies (as measured by the magnitude of the deviation from the 45° line) tend to increase with elevation, although the two most prominent outliers denote mid-elevation SNOTEL stations with incorrect station elevations (Figure 3). Two methods were examined prior to the final model runs in an attempt to minimize these discrepancies. One method used a 3 by 3 cell window search (each cell is 21.6 arc-seconds on a side) centered on the station location to select the cell with the most similar elevation to the station elevation and the second method (used here) utilized a similar technique developed by Chris Daly. Daly's subroutine, INTRP35, subdivides the ± 1 arc-minute area into 100 cells, estimates an elevation value for each cell with a $1/r^2$ interpolation from the four surrounding DEM cell centers (where r is the radial distance), and selects the cell with the most similar elevation (Daly 1995, pers. comm.). The new elevations and corresponding geographical locations found with Daly's routine were used

in place of the recorded station locations and elevations. The average absolute difference and standard deviation were reduced to 19.68 m and 77.97 m, respectively. Figure 4 shows the improved match between the new elevations and the DEM elevations at the revised station locations, and why recorded station locations and elevations were replaced with those selected with Daly's routine for the model runs described in the next section.

Model Runs

Fourteen runs of each model were required to answer the three questions described in the opening chapter. One set of runs used the revised climate station data set (minus 20 withheld stations) and smoothed DEM data to estimate mean annual precipitation across the study area (Objective 1). The next series of runs (12 runs per model) used the monthly climate station data to estimate mean monthly precipitation across the study area (Objective 2). The final set of runs used the complete station data and smoothed DEM to estimate mean annual precipitation across the study area. The results from this last set of model runs represent the best possible model performance and they were generated so comparisons could be made with the 1961-1990 precipitation contour maps prepared by Philip Farnes (Objective 3). The following subsections describe the tasks that must be performed to run each model. The PRISM and MTCLIM-3D model runs were performed by Chris Daly at the University of Oregon and Peter Thornton at the University of Montana, respectively. The ANUSPLIN model runs were performed by the author at Montana State University.

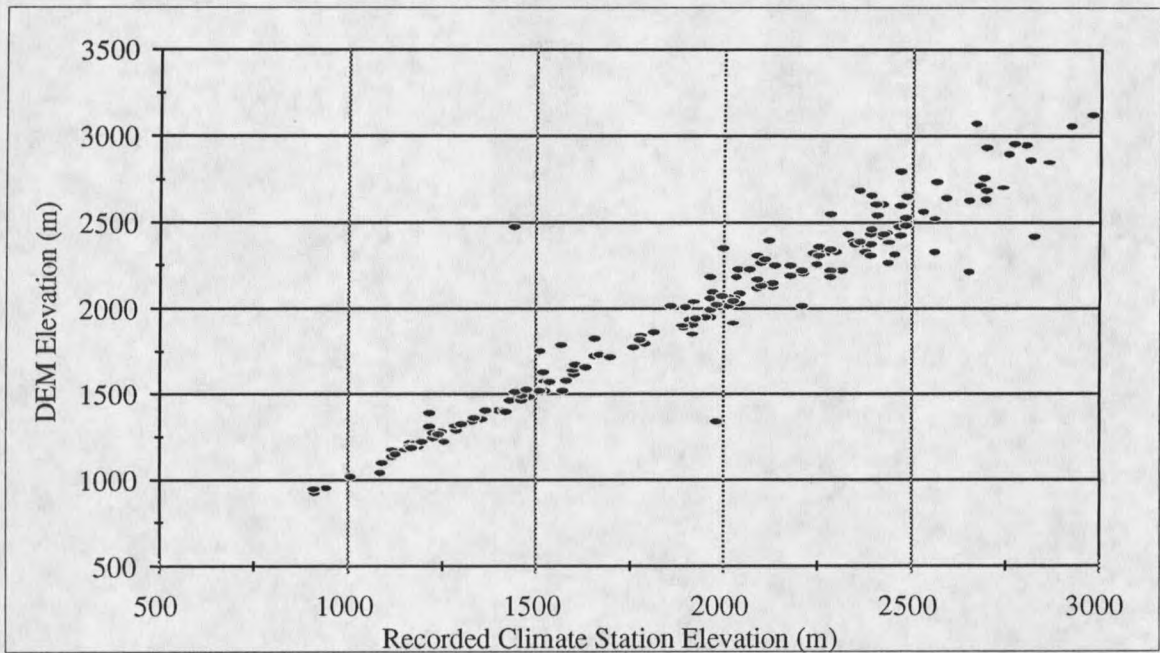


Figure 3. Scatterplot comparing recorded climate station elevations and DEM elevations at recorded station locations.

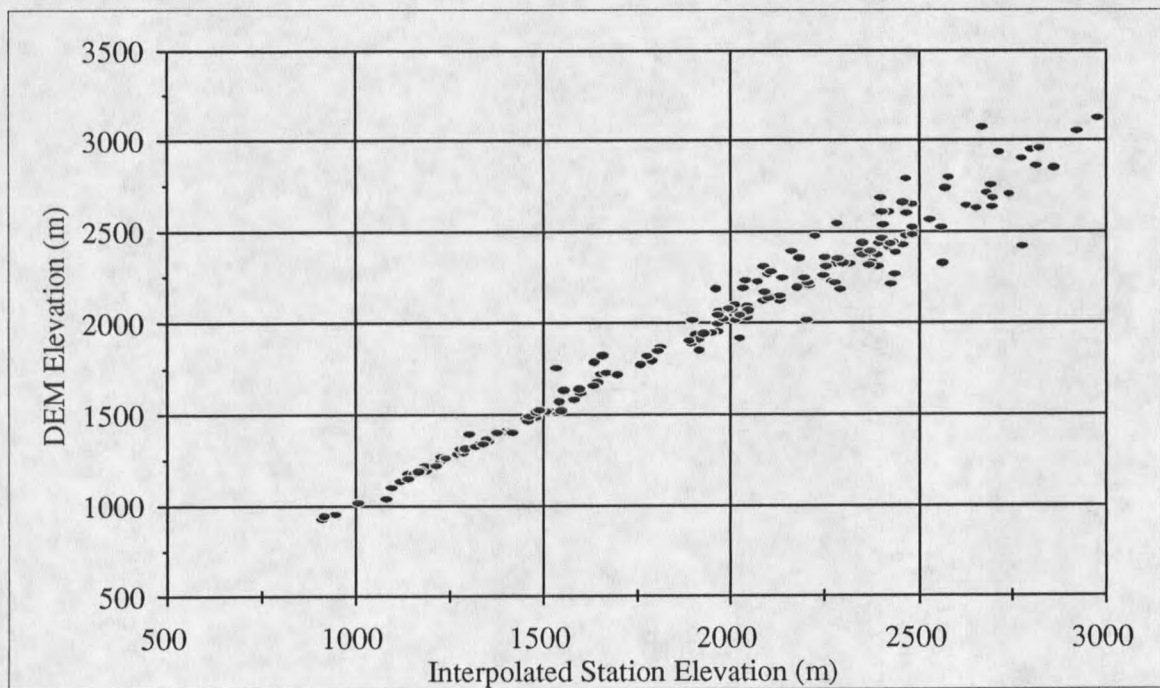


Figure 4. Scatterplot comparing revised station elevations and DEM elevations at revised station locations.

ANUSPLIN

The ANUSPLIN model runs utilized two separate programs. The first step involved executing a FORTRAN program called SPLINA fourteen times to calculate the precipitation distribution surfaces using partial thin plate smoothing splines for each of the monthly and annual climate data sets. SPLINA was used because there are less than 350 climate stations per data set; SPLINB is used for larger data sets (Hutchinson 1989a). The second stage required the execution of a second FORTRAN program called LAPGRD that used the SPLINA output surface coefficient file and the DEM data to interpolate mean monthly and annual precipitation across a geographic and elevation gradient.

The SPLINA runs required two input files. The first user-directive file contained the number of independent spline variables, elevation and location bounds, error standard deviation estimates, and input/output file parameters. The second ASCII file contained the monthly or annual precipitation means (cm), and the station locations (decimal degrees, multiplied by -1), elevations (km) (both derived from Daly's INTRP35 routine), and weights (determined by the sample variance divided by the number of years of record to account for the precipitation variance across the network of the study area) (see Hutchinson 1995 for details). Stations with a greater number of years of record receive a higher weight. SPLINA lets the precipitation/elevation (P/E) lapse rate associated with the fitted surface vary with both geographical position and elevation in response to local conditions rather than being fixed at a constant average value similar to MTCLIM-3D and PRISM.

SPLINA generated numerous diagnostics in addition to an ASCII file containing the surface coefficients summarizing the relationship(s) between mean precipitation, latitude/longitude and elevation, and a list of the 100 largest residuals (which was used in some preliminary model runs to identify input data errors). These surface diagnostics include a generalized cross validation (GCV) estimate, a mean square error (MSE) of the smoothed data values, a mean square residual (MSR), a mean relative error variance (VAR) estimate, their square roots (RTGCV, RTMSE, RTMSR, and RTVAR), and the signal. These diagnostics are generated because the SPLINA error structure allows for departures of observed rainfall means from standard period means to account for missing records and to account for deficiencies in the representation of mean rainfall as a smooth function of position and elevation (Hutchinson 1995).

These diagnostics were used to evaluate model performance and may require brief descriptions. The GCV is a measure of the predictive error of the fitted surface, calculated by removing each data point in turn and summing the square of the discrepancy of each omitted data point from a surface fitted to all the other data points. The MSR is a measure of data infidelity between observed and predicted values weighted according to variance estimates. The VAR is an assessment of the spatial variability of the true mean rainfall field or the amount of noise associated with the data. Large inconsistencies across the network would lead to larger RTVARs and GCVs than expected. The signal is defined as the trace of the influence matrix or the number of points needed to adequately describe the spatial distribution of the annual rainfall. The number of points needed to generate a surface is generally not more than about half of the number of data points in the

data set. This result ensures that there is a certain amount of redundancy in the data.

The LAPGRD program runs required three input files: the surface coefficients file output from SPLINA, the DEM in ASCII format, and a user-directive file containing elevation and location bounds, grid cell size, special value options for cells with no data, and input/output file parameters. LAPGRD combines the surface coefficients with the DEM to estimate precipitation values at each DEM grid node. This program generated a series of ASCII files with precipitation estimates tied to grid cells that were transferred to ARC/INFO for further analyses and the generation of maps.

MTCLIM-3D

The MTCLIM-3D model runs were performed by Peter Thornton at the University of Montana. The fourteen climate station data files (12 monthly and one annual data set with 20 withheld stations and a complete annual data set) and smoothed DEM file were prepared at MSU and transferred across the Internet. The results were sent back to the author using the same transfer medium.

MTCLIM-3D is comprised of two subroutines. Subroutine A is a two-step spatial filtering process which determines a station's weight based on the distance from the point of prediction (grid cell) and modifies the weight based on the topographically weighted density of stations near that point. This subroutine requires a DEM, an ASCII file with station locations and monthly and annual precipitation means (cm), the number of station density iterations (3), a user-specified initial filter truncation radius (100 km), a unitless Gaussian shape parameter (8), the average number of stations to be used for making

predictions (30), and a maximum value for P/E regression slopes (0.45) as inputs. The spatial domain is divided into proximal polygons (either Voronoi or Dirichlet) such that each grid cell is associated with a single station based on a nearness algorithm (Running and Thornton 1996).

The second step of the spatial filtering process selects the stations to include in the interpolation for each cell and assigns appropriate weights using a linearly ramped 7×7 (3.5 x 3.5 km) filter kernel. The circular kernel, defined on a regular grid of the same resolution as the DEM, is weighted by the truncated Gaussian filter where the weights are greatest at the center and decrease radially outward until at a certain radius, the weight is zero. Initially, each grid cell is assigned a value defined by the radius of the circular kernel, the distance from the center of the cell to the center of the kernel, and a shape parameter. A station will be included in a cell's "list" if any part of its proximal polygon lies within the non-zero region of the kernel. Station weights are defined as the sum of the kernel weightings for each grid cell within the proximal polygon. If part of the kernel extends outside the domain which is common at the edges, weights are summed over all included stations at a point and normalized to that sum, forcing the normalized sum of weights for all stations at a given point to 1.0. As a result, the method favors stations that are near the point of prediction and weights are distributed in proportion to the local density of stations.

Subroutine B employs a linearly ramped window smoothing algorithm to estimate the P/E relationship and uses a linear regression function to derive precipitation predictions. For monthly and annual precipitation means, a semi-logarithmic

transformation is applied. The relationship is developed with a linear formulation for daily estimates as described in Running and Thornton (1996). This subroutine requires the width of the smoothing window (3.5 km) and the sum of the station weights in each cell's list as inputs. The final gridded precipitation predictions are generated from the DEM smoothed with the same filter kernel. MTCLIM-3D outputs monthly and annual average errors, descriptive grid statistics for withheld station predictions, and mean absolute error (MAE) and bias in cms of annual/monthly total precipitation and percent of observed total precipitation (Running and Thornton 1996) in addition to the final map products.

PRISM

The PRISM runs were performed by Chris Daly at Oregon State University. The input data were prepared by the author and transferred to OSU across the Internet. The results were sent back to the author using the same medium.

Three programs comprise PRISM: 1) FACET, which generates arrays of topographic facets from the DEM; 2) PRISM, which assimilates the DEM, facet grids, and station data to estimate precipitation; and 3) GRAD, an optional postprocessor to the grids (Daly et al. 1994).

The FACET program produces six facet grids at successively larger spatial scales by smoothing the unsmoothed (original) DEM (level 1 facet) to regularly increasing resolutions (levels 2 through 5) until the resolution specified by the user for the maximum cutoff diameter for filtering (1.0°) is reached (level 6). Next, FACET employs the INTRP35 routine to search within a user-specified radius (i.e. 1 arc-minute of latitude and

longitude) for a better match between each station elevation and the DEM or orographic elevations. Finally, FACET delineates contiguous groups of cells or facets within the same user-defined radius which have a relatively constant slope. The MINSTA module is employed to select additional stations by searching smoother grids if facets are composed of less than two DEM cells. The topographic facets are best delineated with a DEM resolution that closely matches the smallest orographic scale supported by the data, thereby reducing the number of facets delineated at scales too small to be resolved by the data and overaggregation of orographically important facets (Daly and Taylor 1996).

The topographic facet grids, DEM, and an ASCII file with monthly and annual precipitation means (cm) are input into the PRISM program. PRISM searches within the input maximum radius of influence (maxrad, in grid cells) and within vertical distance of influence limits (m) for stations to include in the P/E regression function at each grid cell. The minimum number of stations (minsta) on each facet should match the topographic facet scale with the density and representativeness of the station data. The optimal combination of maxrad (158) and minsta (12) values for the incomplete annual and monthly data sets were determined by PSTAT, a statistical version of PRISM, to produce both a low mean absolute error in cross-validation for all stations and a low mean absolute error for predicting the 20 deleted stations. The combination for the complete annual data set which produced the lowest cross-validation error was chosen (maxrad 168, minsta 4). The limited vertical cell search (the PRISM defaults, 500 to 1500 m from the grid cell, were used for all runs) allows PRISM to be more sensitive to vertical changes in the P/E slope. Searching too far upwards in semi-arid areas where high-elevation precipitation

may be several times larger than low-elevation precipitation can cause a high P/E slope bias by including very wet stations (Daly 1995, pers. comm.). Because the P/E slope is closely tied to the mean precipitation (i.e., slope is greater in wet areas and smaller in dry areas), a normalized slope is much more stable over a wide range of precipitation regimes than is its unnormalized counterpart.

If the slope of the P/E regression falls outside specified bounds (b_{1min} 0.1, b_{1max} 1.7 (1/km)), which also vary with DEM resolution, PRISM begins to delete stations from the regression data set for the grid cell, starting with the lowest weighted station, until either the slope falls within the valid range, or a specified minimum number of stations is left ($isubfac$). If the P/E regression slope cannot be moved into compliance through station deletion, a default slope ($db1$) in layer 1 is substituted. The value of $db1$ (0.7 for all runs) varies with the resolution of the DEM, usually higher for coarse grids because they exhibit less elevational variability than fine grids and thus less elevation change per unit precipitation change (Daly 1995, pers. comm.).

The weighting coefficients can then be determined for each station in a cell's regression function based on the maximum distance weighting exponent (2.0) and importance factor (0.8), an elevation weighting exponent (1.0) and importance factor (0.2), and a maximum facet weighting exponent (1.0). If the variability of precipitation values exceeds a user-specified amount (0.05 or 5%), PRISM begins to drop stations with outstanding precipitation values until either the variability is at or below the maximum or the minimum number of stations left on the facet ($minsta$) is reached. This procedure attempts to control for situations in which the facet groupings have erroneously mixed

stations from different precipitation regimes. This problem arises when sharp changes in precipitation regime occur at scales smaller than the facet grid can resolve (Daly 1995, pers. comm.).

The precipitation prediction for each cell is a proportion of the cell's P/E regression slope. PRISM calculates 95% prediction intervals for the estimates (Daly and Neilson 1992) and outputs a gridded precipitation distribution map with MAE and bias estimated in cm of annual/monthly total precipitation and percent of observed total precipitation.

GRAD is a postprocessor which makes vertical extrapolation adjustments when possible to eliminate sharp discontinuities between cell estimates (Daly et al. 1994). GRAD ensures that between-cell gradients of predicted precipitation follow the same rules as were applied for the P/E slopes in the regression functions in PRISM. If the slope between two cells falls outside the limits, GRAD smooths the gradient to fall within the minimum and maximum allowable slopes. This procedure is repeated for every grid cell on the prediction grid until all cell pairs pass the gradient test. Two lower limits to the gradients, the percentage gradient (%/grid cell) and the absolute gradient in precipitation (mm/grid cell) below which GRAD does not do any postprocessing were set to the PRISM defaults of 10% and 10 mm. A cell-to-cell change of 10 mm or 10% or more, whichever applies, is considered "in the noise level" and is changed by GRAD in order to avoid both very small and very large precipitation amounts. GRAD outputs the final gridded precipitation predictions and mean error estimates (Daly 1995, pers. comm.).

Model Evaluation

The withheld data were used to evaluate model performance in three ways:

- (1) A difference of means test or matched pairs t test was performed to evaluate whether or not the mean difference between the observed values and model predictions was significantly different than zero at the 0.05 significance level for the 20 withheld data points. The requirements and assumptions for the test were met in all cases.
- (2) The mean absolute error (MAE), the average absolute difference between observations and predictions at the 20 withheld station locations was computed. Large MAE values indicate larger discrepancies between predicted and observed values at the 20 withheld stations.
- (3) The bias, or sum of the actual differences divided by the number of stations, was computed. Large bias estimates indicate systematic (high/low) discrepancies between predicted and observed values at 20 withheld stations.

The model predictions were also checked to evaluate whether or not they generated the same spatial patterns of precipitation across the entire study area. This analysis was necessary because the final maps may have similar statistical properties and yet predict different spatial patterns. These patterns were checked by generating a series of difference maps (grids) using grid subtraction in the ARC/INFO GRID module to identify regions where model predictions varied. Monthly precipitation was divided into 25 mm (1") classes and annual precipitation was divided into 100 mm (4") and 200 mm (8") classes to compute percent agreement between different sets of predictions.

Comparison of Complete Annual Model Surfaces with Hand-Drawn Maps

Each model was implemented with the complete annual climate station data set and compared with the unpublished hand-drawn 1961-90 annual average precipitation contour maps. Five 1:250,000 hand-drawn maps were digitized in PC ARC/INFO, edgematched, and joined to produce a single ARC/INFO contour-line coverage. The contour maps were converted to polygon coverages in which each polygon was assigned a value that represented the midpoint between the two contour values. For example, if the two bounding contours were 6 inches and 8 inches of precipitation the polygon was assigned a precipitation value of 7 inches. If the two bounding contours were 30 inches and 40 inches a value of 35 inches was assigned. The contour interval on the hand-drawn maps is 2 inches from 0 to 20 inches of precipitation (generally plains regions) and 10 inches between 20 and 80 inches of precipitation (mountainous regions). The difference in interval arises because useful contour-based portrayals of precipitation in low elevation areas are unreadable when carried into mountainous areas with high precipitation and large precipitation gradients. The coverage was converted to a square-grid with precipitation in mm, changed to a geographic projection from a Universal Transverse Mercator (UTM) projection, and resampled to a cellsize of 0.0063 dd (196,093 cells) to facilitate the comparisons with the model predictions.

Farne's 1941-70 maps are currently used by the State of Montana for annual precipitation estimates. The unpublished 1961-90 maps have been created for the study area with the same climate station data set used in this study. These maps also incorporate Farne's extensive knowledge of regional weather behavior. These maps were used by

Custer et al. (1996) in a pilot study to evaluate the feasibility and performance of the ANUSPLIN model. Another series of difference grids was created to illustrate the contrast between the hand-drawn map and annual surfaces generated with the ANUSPLIN, MTCLIM-3D, and PRISM models.

CHAPTER 3

RESULTS

Annual Predictions

Table 2 summarizes the mean annual precipitation predicted by the three models on a cell-by-cell basis using the 0.5 km DEM and climate station data (minus the 20 stations withheld for model evaluation). ANUSPLIN predicted slightly larger precipitation amounts on average across the entire study area (5.6% and 4.0% higher than MTCLIM-3D and PRISM, respectively), although PRISM and to a larger extent, MTCLIM-3D, predicted much higher values in some cells (Figure 5). The coefficient of variation removes the influence of the magnitude of the mean and indicates the relative variability of ANUSPLIN surface predictions is approximately equivalent to the other models (Table 2). The histogram reproduced in Figure 6 shows how ANUSPLIN predicted moderate to high precipitation quantities in more cells than the other two models. Values on the X-axis represent the midpoints of the class intervals.

The three models produce similar maps at first glance (Figure 5). The spatial pattern is very closely tied to major topographic features in all three instances. Lower precipitation values, represented by yellow and red, found chiefly in the southeastern plains and Canyon Ferry Lake area, effectively delineate the series of river valleys in the study area, such as the Madison, Smith, and Shoshone forks. The extent of the

Table 2. Mean annual precipitation predictions for individual cells (mm).

Cell value(s)	ANUSPLIN	MTCLIM-3D	PRISM
Minimum	154	199	170
Maximum	1582	1668	2243
Mean	607.8	574.6	582.9
Std. Dev.	298.4	266.7	288.1
Coeff. of Var.	0.49	0.46	0.49

Yellowstone River is easily traced from its source in Yellowstone National Park, up Paradise Valley, and east to the study area boundary. All models produce high predictions, shown in dark blue and purple, in the Madison range. Large ANUSPLIN predictions also occur in the Tetons to the south and Little Belts in the north. Peak values on the MTCLIM-3D and PRISM maps are found in the Beartooth and Bridger mountains. PRISM also predicted large values in the Gallatin, Bridger, and Teton ranges. The MTCLIM-3D values are slightly lower in the Teton and southern Absaroka mountains south(east) of YNP. The differences between the three models emphasize the need to examine model performance and the magnitude and pattern of these differences more closely.

The results summarized in Table 3 show that the mean annual precipitation values predicted for the 20 withheld stations with the three models were not significantly different from the reported station quantities. The test is based on a new variable representing the differences between the precipitation predicted with the different models and the measurements by climate station and testing whether the mean difference was significantly different from zero at the 0.05 significance level. ANUSPLIN has the highest MAE values

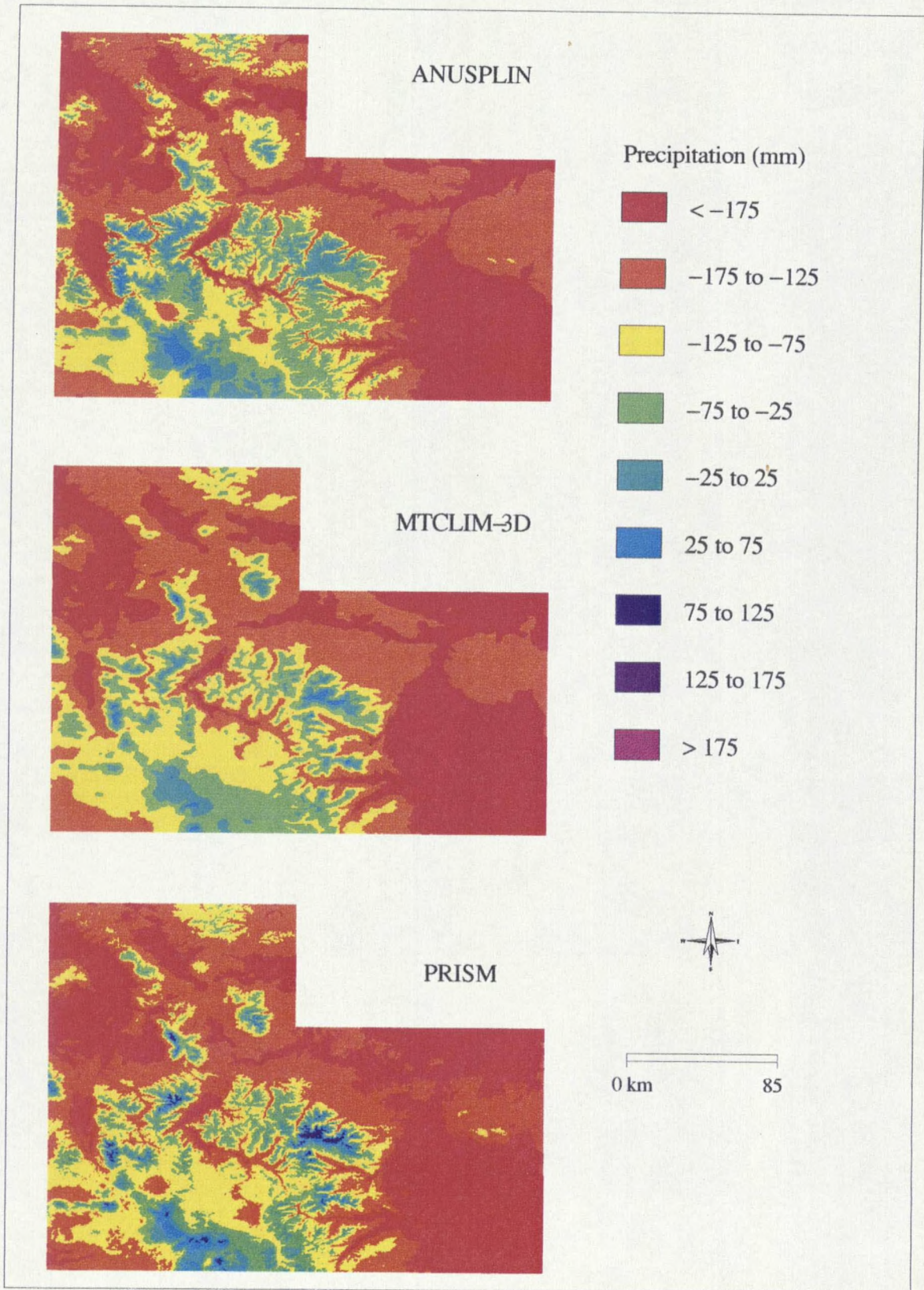


Figure 5. Mean annual precipitation maps generated with three models.

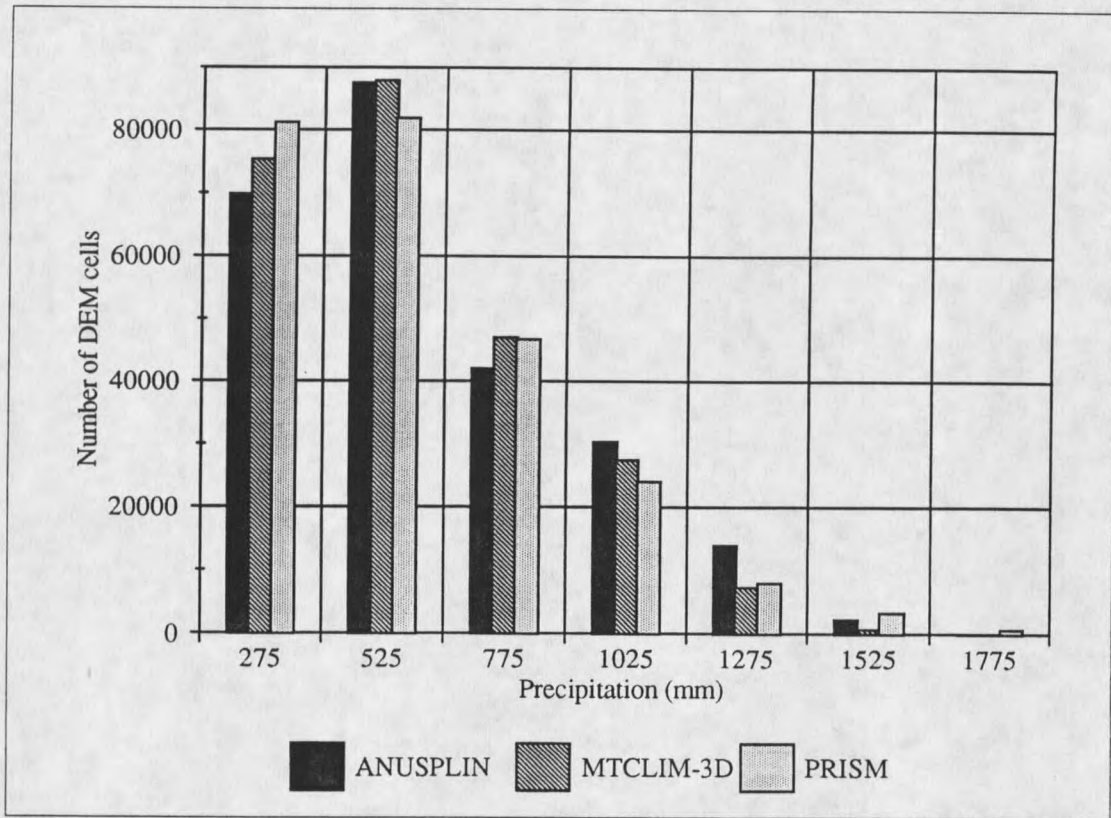


Figure 6. Graph showing number of DEM cells falling in mean annual precipitation classes reported in Figure 5 by model.

Table 3. T test results comparing ANUSPLIN, MTCLIM-3D, and PRISM mean annual predictions with 30 year means at 20 withheld climate stations.

Model Run	Mean annual difference (mm)	Standard error	T	Prob > T
ANUSPLIN	22.25	38.347	0.580	0.569
MTCLIM-3D	-4.75	28.119	-0.169	0.868
PRISM	-25.50	20.951	-1.217	0.239

for the 20 withheld stations followed by MTCLIM-3D and PRISM (Table 4). The bias estimates indicate that PRISM and to a lesser extent, MTCLIM-3D, underestimates precipitation compared to the climate station measurements while ANUSPLIN tends to overestimate mean annual precipitation.

The results summarized in Tables 2 and 3 indicate that the models could not be distinguished in terms of their performance using comparisons with observed data at withheld stations and typical statistical measures. The model predictions were also compared with one another to assess whether or not they generated similar spatial patterns. The model predictions were divided into 100 and 200 mm increments for this purpose in ARC/INFO and cells were designated equivalent in pairwise comparisons of the models if their predicted values fell in the same class. Table 5 indicates that approximately 60% of the cells fall in the same 100 mm class and that the percent agreement increased to 80% when 200 mm class intervals were used.

Difference grids were produced with the grid subtraction tools in the ARC/INFO GRID module to identify the existence of spatial similarities and differences between model predictions (Figure 7). ANUSPLIN predicts higher precipitation than the other models (based on orange and red colors displayed in top and bottom maps; Figure 7) in the Madison range, the mountains on both sides of the Paradise Valley, in the Little Belt mountains to the north, and south of the Continental Divide (following ID/MT state border). MTCLIM-3D predicted higher values compared to ANUSPLIN (blue colors in top map; Figure 7) and PRISM (red colors in middle map; Figure 7) in the vicinity of Yellowstone Lake and along the eastern margins of the Absaroka Beartooth Range.

Table 4. Mean absolute errors (MAE) and bias measurements for 20 withheld climate stations.

	ANUSPLIN	MTCLIM-3D	PRISM
MAE (mm)	119.8	88.7	47.2
MAE (%)	17.2	13.2	6.7
Bias (mm)	22.3	-10.7	-25.5
Bias (%)	1.7	-0.49	-3.5

Table 5. Percent agreement between ANUSPLIN, MTCLIM-3D, and PRISM model predictions within 100 mm and 200 mm.

Model pairs	Class interval used	
	100 mm	200 mm
MTCLIM-3D-ANUSPLIN	59	82
MTCLIM-3D-PRISM	62	84
PRISM-ANUSPLIN	57	79

MTCLIM-3D predictions also exceed the ANUSPLIN and PRISM predictions in the Madison Valley and Elkhorn Mountains, respectively. PRISM predicts higher precipitation in the Shoshone and Greybull River regions and in almost all mountain ranges, particularly in the Big Belt mountains northwest of Canyon Ferry Lake, on the Beartooth Plateau, and in the northern Tetons. The tendency for the largest variations between model predictions to be concentrated in the Absarokas, on the Yellowstone Plateau, and in the Tetons can be attributed to a lack of climate stations at high elevations (Figure 2).

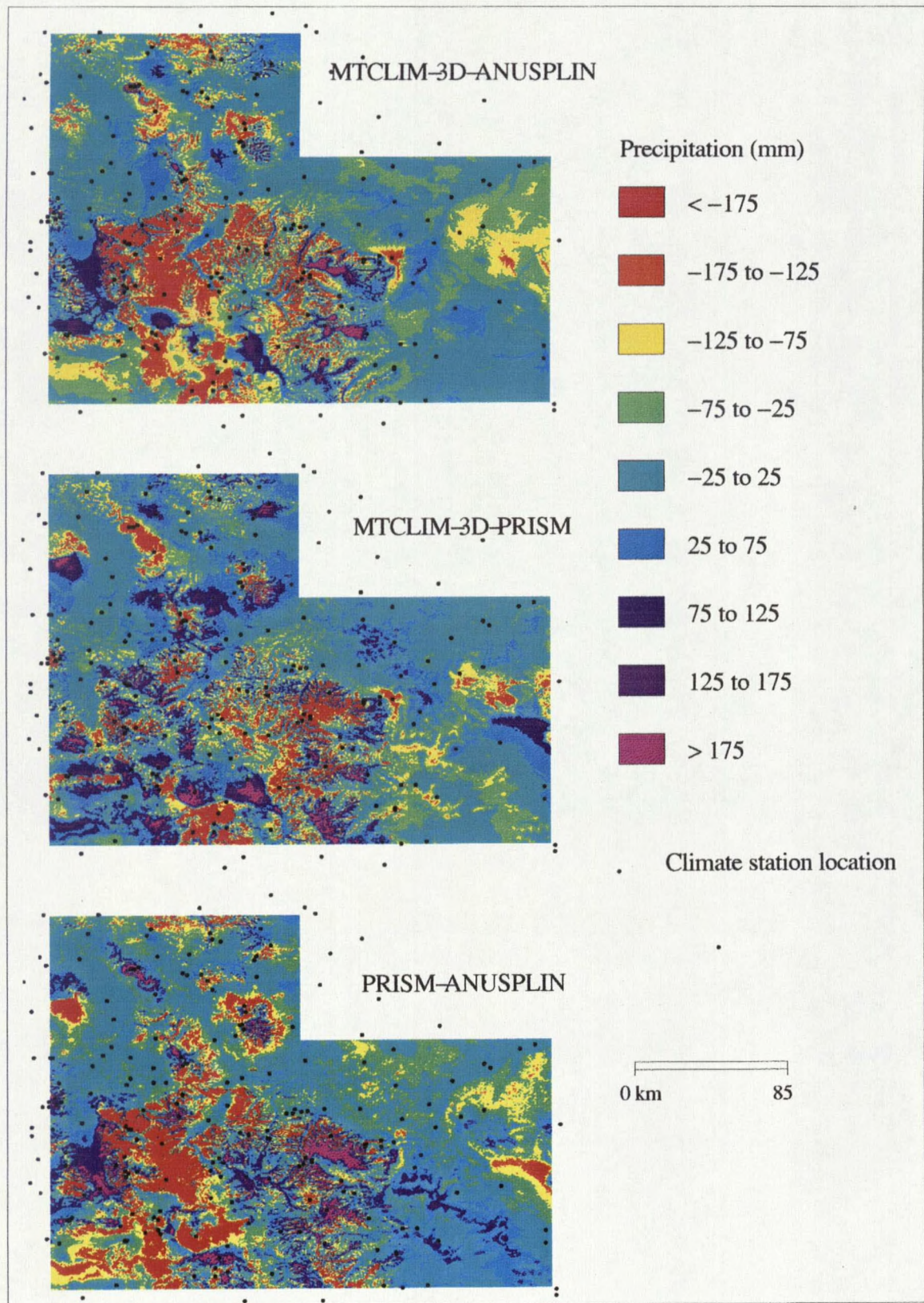


Figure 7. Maps showing differences between mean annual precipitation predictions with different pairs of models and station locations.

Monthly Predictions

Many applications and users of spatially distributed precipitation data need monthly as opposed to annual estimates which warrants an examination of model performance using monthly data. Diverse trends arise on monthly surfaces because snow dominates winter season precipitation, rain dominates summer season precipitation, and the fall and spring precipitation favors rain at lower elevations and snow at higher elevations.

Table 6 summarizes mean monthly precipitation predicted by the three models on a cell-by-cell basis using the 0.5 km DEM and climate station data (minus the 20 stations withheld for model evaluation and snow course stations). The three models predicted the most precipitation in May and June and to a lesser extent in April. The MTCLIM-3D mean values are higher in winter and early spring while PRISM predictions are greater in the late spring-summer months and ANUSPLIN generally has the lowest predictions overall although the differences are not very large. Both MTCLIM-3D and PRISM exhibit noteworthy differences (in tens or hundreds of mm) for cells with the highest predictions. MTCLIM-3D has the highest maximum values in the winter-spring (Figures 8 and 9), PRISM in the summer-fall (Figures 10 and 11), while ANUSPLIN generated the lowest maxima every month. There is little difference in the minimum values although MTCLIM-3D values are consistently higher than the other models.

The presence of primarily snowfall measurements makes spatial interpolation of precipitation values more difficult in the fall and winter months causing increased variation between model predictions, illustrated by the 57% and 44% increases in the

Table 6. Mean monthly precipitation for individual cells (mm).

Cell value (s)	Months											
	J	F	M	A	M	J	J	A	S	O	N	D
ANUSPLIN												
Minimum	5	2	3	13	31	27	11	15	5	8	8	3
Maximum	103	102	149	149	167	110	71	64	90	96	90	109
Mean	35.1	31.9	47.0	55.9	76.8	62.6	38.4	37.6	46.6	38.6	33.3	35.7
Std. Dev.	22.8	23.8	29.1	25.7	23.9	15.5	12.0	10.2	13.7	17.8	17.3	24.8
Co. of Var.	0.65	0.75	0.62	0.46	0.31	0.25	0.31	0.27	0.29	0.46	0.52	0.69
MTCLIM-3D												
Minimum	7	4	7	14	35	29	16	16	16	11	11	6
Maximum	408	356	383	243	326	162	83	78	113	153	177	421
Mean	46.1	38.5	52.0	55.2	77.2	64.4	40.1	37.7	46.1	38.3	37.5	44.8
Std. Dev.	42.1	37.3	42.0	28.2	26.8	17.2	12.8	10.5	13.3	10.5	23.6	41.9
Co. of Var.	0.91	0.97	0.81	0.51	0.35	0.27	0.32	0.28	0.29	0.27	0.63	0.94
PRISM												
Minimum	6	3	5	13	22	26	11	15	20	10	6	5
Maximum	272	199	243	201	237	216	109	110	143	137	226	229
Mean	42.7	35.6	48.2	52.8	77.2	65.9	41.2	39.0	47.6	38.3	43.9	40.9
Std. Dev.	36.8	32.0	33.5	26.0	24.5	17.9	13.7	11.7	14.1	17.3	35.6	34.9
Co. of Var.	0.86	0.90	0.70	0.49	0.32	0.27	0.33	0.30	0.30	0.45	0.81	0.85

coefficient of variation (CV) estimates in November for the MTCLIM-3D and PRISM surfaces, respectively (Table 6). Higher CV values throughout the winter months indicate high prediction variability relative to the magnitude of precipitation.

A matched pairs t test was performed to test whether the observed and predicted values for the 20 withheld stations were significantly different. The results are listed in

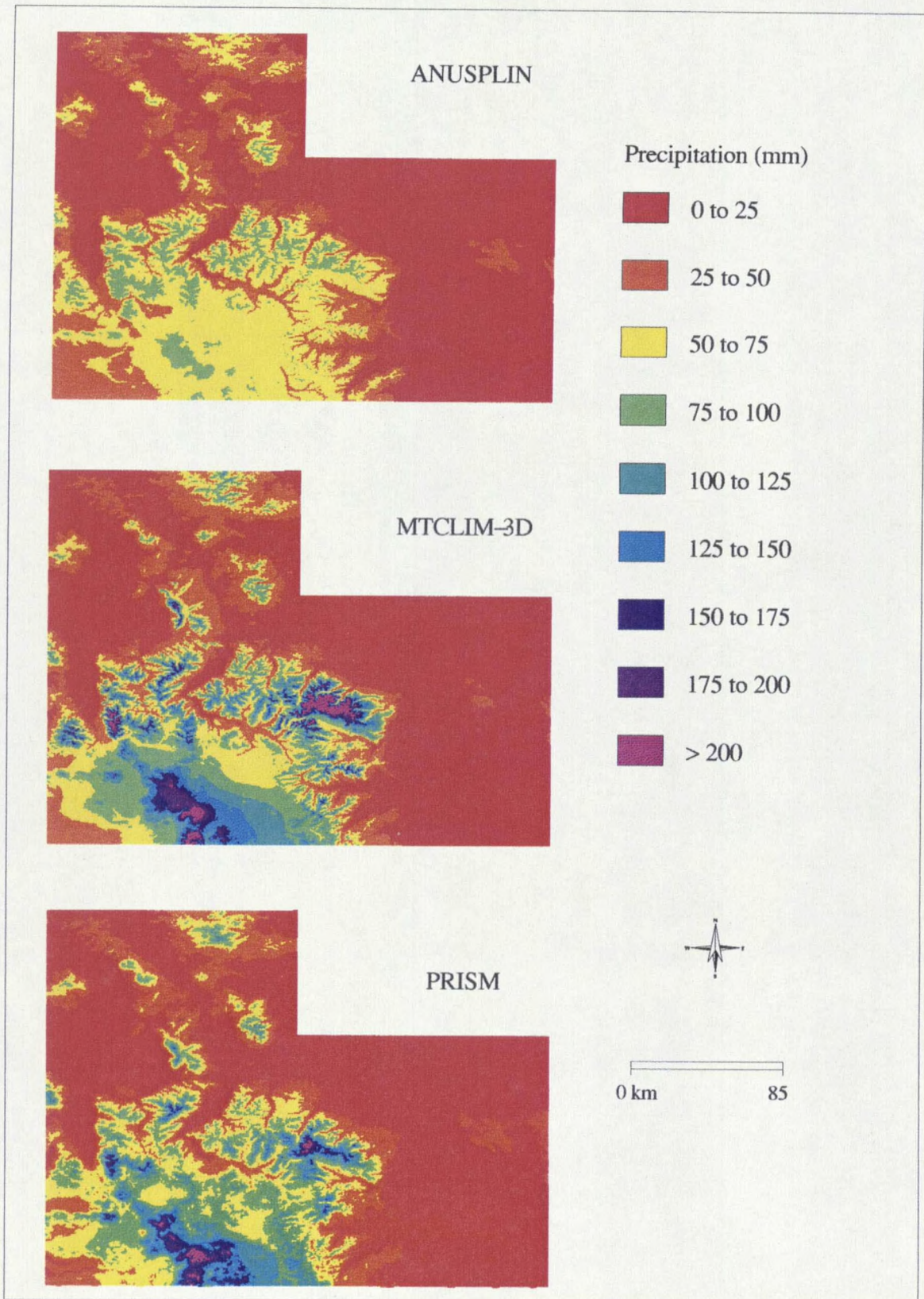


Figure 8. Mean January precipitation maps generated with three models.

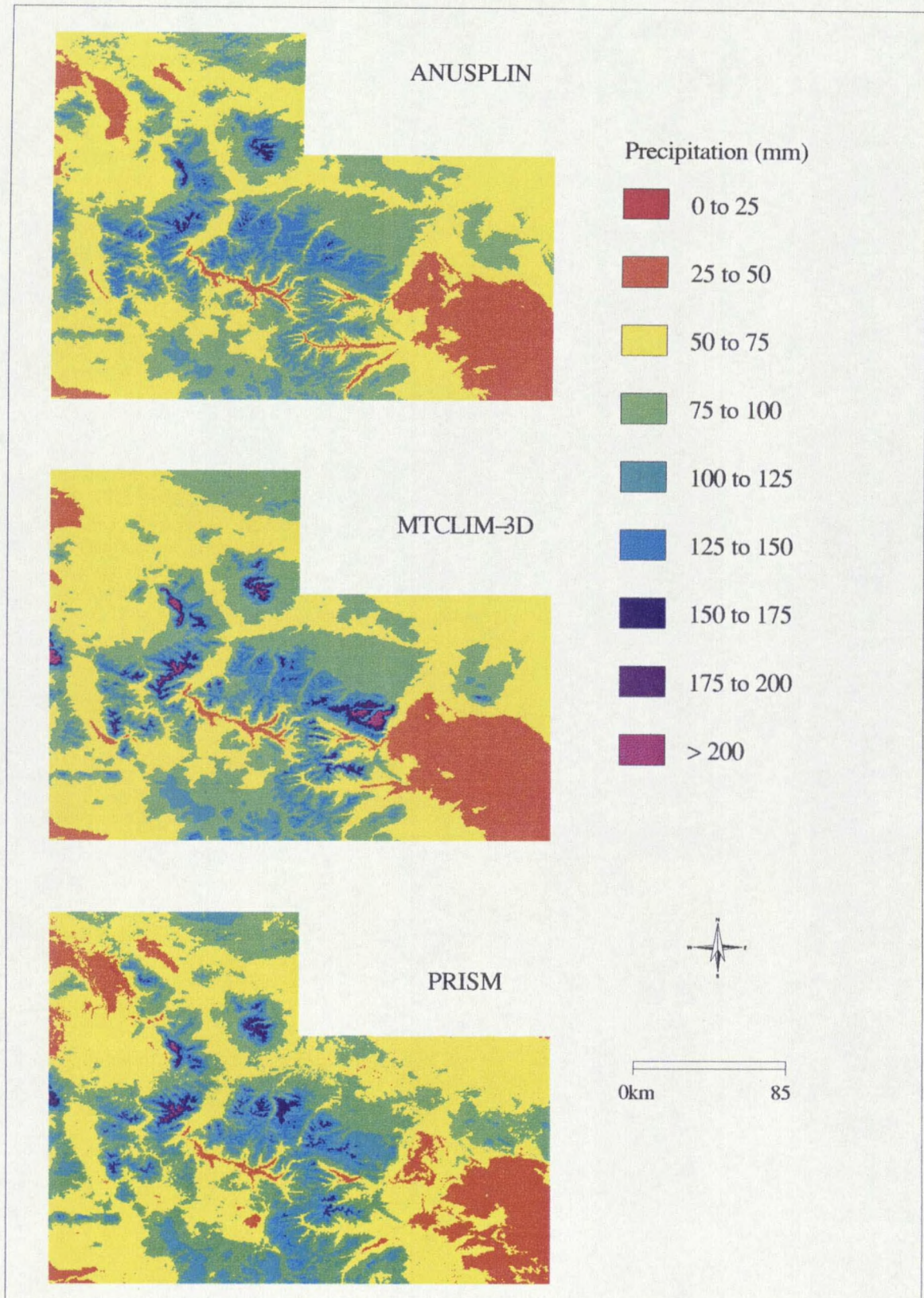


Figure 9. Mean May precipitation maps generated with three models.

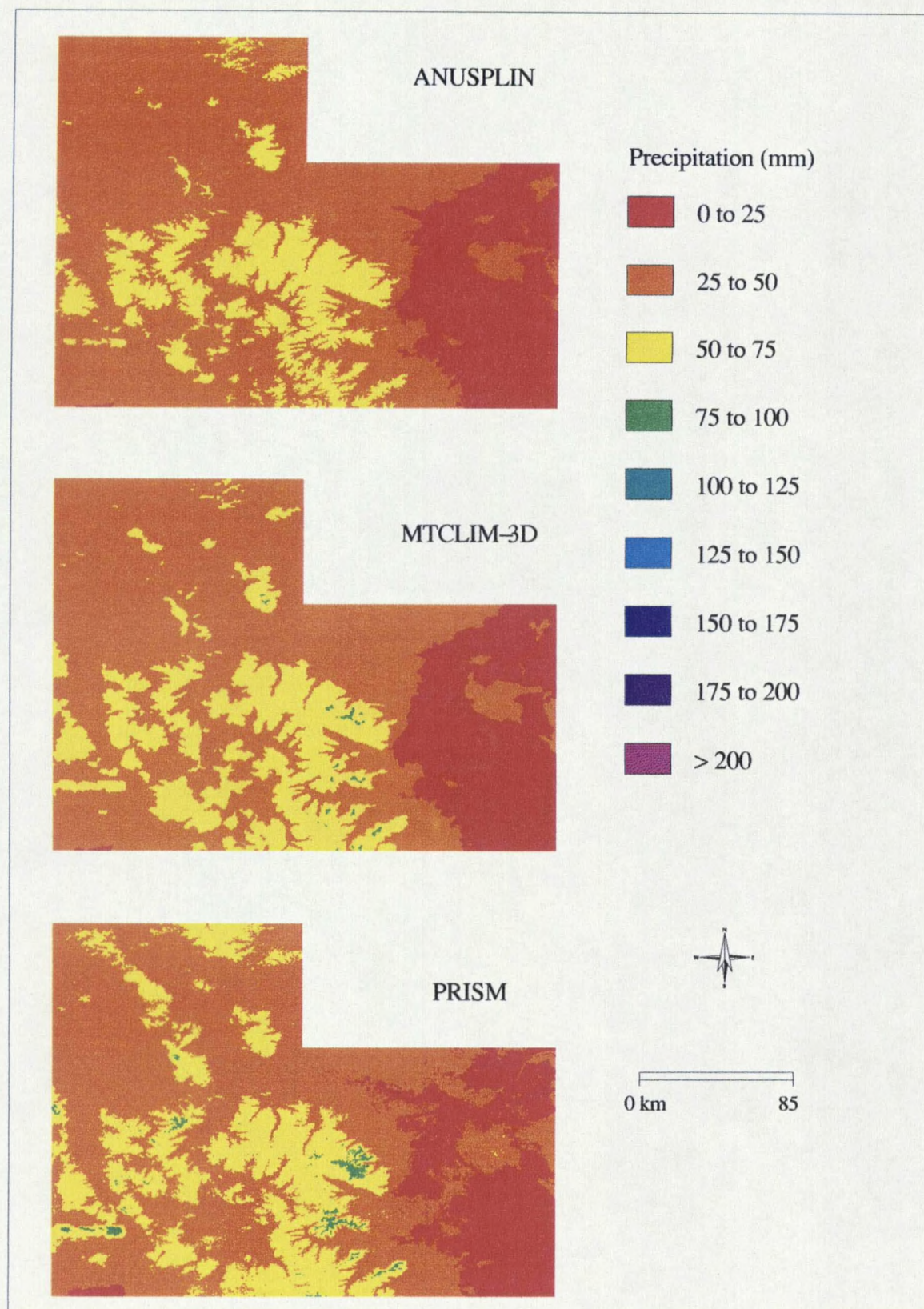


Figure 10. Mean July precipitation maps generated with three models.

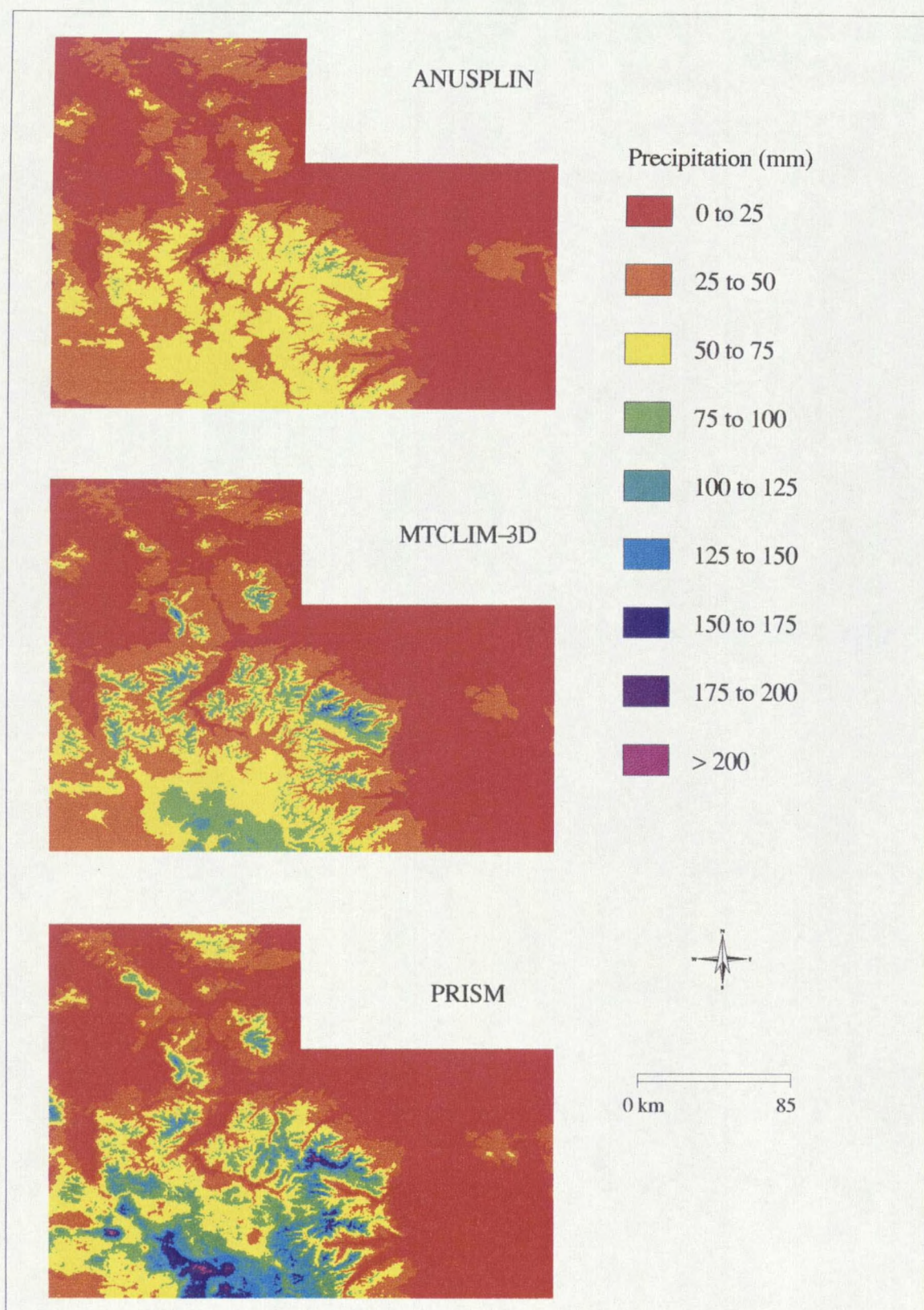


Figure 11. Mean November precipitation maps generated with three models.

Tables 7, 8, and 9. The null hypothesis was rejected (indicating the differences between predicted and observed values were different than zero at the 0.05 significance level) in February, November, and December for ANUSPLIN (Table 7), November for MTCLIM-3D (Table 8), and in December for PRISM (Table 9). These months have high MAE estimates for the 20 withheld station locations indicating (once again) larger discrepancies between predicted and observed values (Table 10). ANUSPLIN exhibits the highest bias estimates in months where the null hypothesis was rejected followed by MTCLIM-3D and PRISM. The ANUSPLIN and PRISM monthly predictions tend to be negatively biased, indicating systematic underprediction at the 20 station locations, and the MTCLIM-3D bias estimates indicate overprediction. The lowest MAE and bias estimates occur in the late summer and early fall months.

Difference grids were produced once again with the grid subtraction tools in the ARC/INFO GRID module to identify the existence of spatial similarities and differences between these sets of model predictions. A reclassification was then performed on each difference grid and cells within 25 mm (1") were designated equivalent in pairwise comparisons of the models if their predicted values fell in the same class (Table 11). Late fall and winter months display the least agreement between models. Only 75% of the cells were classified in the same 25 mm classes on the January MTCLIM-3D-ANUSPLIN difference grid (Figure 12). This is most likely due to poor snow measurements at NWS sites, a dearth of stations at higher elevations, and the increase in the complexity of the spatial patterns of precipitation in these months. The MTCLIM-3D and PRISM predictions in January are more than 87.5 mm greater than ANUSPLIN on the Beartooth

Table 7. T test results comparing ANUSPLIN mean monthly predictions with 30 year means at 20 withheld stations.

Month	Mean precipitation difference (mm)	Standard Error	T	Prob. > T
January	-3.50	3.53	-0.992	0.334
February	-6.30	3.13	-2.015	0.058
March	-6.35	3.99	-1.591	0.128
April	-0.30	4.20	-0.071	0.944
May	-5.35	3.29	-1.626	0.121
June	-2.85	2.92	-0.976	0.341
July	-0.85	1.14	-0.745	0.465
August	-2.75	1.67	-1.648	0.116
September	-3.15	2.52	-1.252	0.226
October	-0.75	2.03	-0.370	0.716
November	-11.65	3.64	-3.196	0.005
December	-8.60	3.59	-2.393	0.027

Table 8. T test results comparing MTCLIM-3D mean monthly predictions with 30 year means at 20 withheld stations.

Month	Mean precipitation difference (mm)	Standard error	T	Prob > T
January	0.60	3.52	0.170	0.867
February	-0.10	2.73	-0.037	0.971
March	2.05	3.21	0.638	0.531
April	0.35	3.50	0.100	0.921
May	-9.15	5.59	-1.637	0.118
June	-0.95	3.36	-0.282	0.781
July	-0.20	1.20	-0.166	0.870
August	-1.95	1.59	-1.228	0.235
September	-3.30	2.49	-1.325	0.201
October	-0.90	1.60	-0.563	0.580
November	-7.75	3.07	-2.526	0.021
December	-0.65	3.35	-0.194	0.848

Table 9. T test results comparing PRISM mean monthly predictions with 30 year means at 20 withheld stations.

Month	Mean precipitation difference (mm)	Standard error	T	Prob. > T
January	0.05	3.76	0.013	0.989
February	-3.55	2.14	-1.660	0.113
March	-4.65	3.28	-1.418	0.172
April	-2.70	3.57	-0.757	0.458
May	-4.60	2.76	-1.669	0.112
June	-0.25	3.92	-0.064	0.950
July	0.00	1.43	0.00	1.000
August	-2.25	1.78	-1.265	0.221
September	-1.70	2.13	-0.799	0.434
October	-1.45	1.60	-0.908	0.375
November	-3.35	1.77	-1.896	0.073
December	-5.55	2.34	-2.371	0.029

Table 10. Monthly surface mean absolute errors (MAE) and bias estimates.

ANUSPLIN	J	F	M	A	M	J	J	A	S	O	N	D
MAE (mm)	14.9	10.2	13.1	12.2	11.1	10.3	4.1	5.9	7.1	6.2	13.0	12.4
MAE (%)	25.1	26.1	22.6	20.6	12.8	13.7	9.9	13.3	11.6	15.2	23.9	25.5
Bias (mm)	-10.4	-6.3	-6.3	-0.3	-5.3	-2.9	-0.9	-2.7	-3.2	-0.7	-11.7	-8.7
Bias (%)	-11.5	-11.5	-10.8	0.0	-6.0	-2.9	-2.0	-5.1	-4.2	-0.2	-19.3	-16.0
MTCLIM-3D	J	F	M	A	M	J	J	A	S	O	N	D
MAE (mm)	11.0	10.2	11.9	13.2	10.6	12.3	4.6	5.8	6.9	6.1	10.2	10.7
MAE (%)	23.9	27.9	20.7	22.7	12.0	16.5	11.1	13.3	11.5	14.2	18.5	23.2
Bias (mm)	1.0	2.1	0.4	2.0	-2.3	0.5	0.4	-1.3	-2.4	-0.9	-8.1	-1.2
Bias (%)	6.7	7.0	0.3	6.6	-2.2	2.3	1.8	-1.6	-2.4	0.7	10.6	-2.6
PRISM	J	F	M	A	M	J	J	A	S	O	N	D
MAE (mm)	8.4	7.0	9.8	9.2	8.3	12.2	5.1	5.0	5.6	4.9	5.1	8.3
-MAE (%)	14.9	21.2	16.9	14.7	9.6	16.1	12.8	11.1	9.2	11.2	10.5	17.1
Bias (mm)	-5.0	-3.5	-4.7	-2.7	-4.6	-0.2	0.1	-2.2	-1.7	-1.5	-3.4	-5.6
Bias (%)	-4.1	-3.4	-5.2	-0.2	-4.5	0.7	0.0	-4.5	-2.0	-1.2	-6.8	-9.9

Plateau and in the northern Tetons (Figure 12).

Summer months were the most similar due to low rainfall (Table 11) and a stronger dependence on geographic position and/or elevation. The May surfaces exhibit very high agreement shown by the large areas of light green and yellow in Figure 13. Differences greater than ± 37.5 mm between model predictions are restricted to mountainous regions, and the largest differences occur on the Beartooth Plateau and in the Bridger and Tobacco Root mountains. MTCLIM-3D predicted higher values on the Beartooth Pass and in the Tobacco Root, Gallatin, and Bridger ranges than PRISM and ANUSPLIN (Figure 13). The large areas of light green and yellow on the July difference

Table 11. Percent agreement between ANUSPLIN, MTCLIM-3D, and PRISM model predictions within 25 mm.

Model pairs	Months											
	J	F	M	A	M	J	J	A	S	O	N	D
PRISM-ANUSPLIN	76	80	79	83	84	88	95	97	96	95	71	79
MTCLIM-3D-ANUSPLIN	75	80	80	88	92	95	99	100	99	97	89	78
PRISM-MTCLIM-3D	81	84	79	81	82	92	99	98	96	95	75	82

grids demonstrates the extremely high levels of agreement between models in the summer months (Table 11, Figure 14).

Agreement values drop again in November to 71% for ANUSPLIN and PRISM, 89% for ANUSPLIN and MTCLIM-3D, and 75% agreement for MTCLIM-3D and PRISM (Table 11). PRISM predicts higher precipitation in November on the Yellowstone Plateau, in the northern Tetons, and especially in the Absaroka mountains where PRISM predicts up to 156 mm and 141 mm more than ANUSPLIN and MTCLIM-3D, respectively (Figure 15).

Table 12 compares the mean annual precipitation in the study area predicted with the three models using the sum of the monthly estimates and the annual climate data. The ANUSPLIN, MTCLIM-3D, and PRISM monthly predictions were 10.9% lower, 1.7% lower, and 0.6% higher, respectively. The larger variation reported for ANUSPLIN may be attributed to the change in user-specified input standard deviation values from 1 for the annual ANUSPLIN runs to -1 for the monthly ANUSPLIN runs.

Difference grids were created using the grid subtraction tools in the ARC/INFO

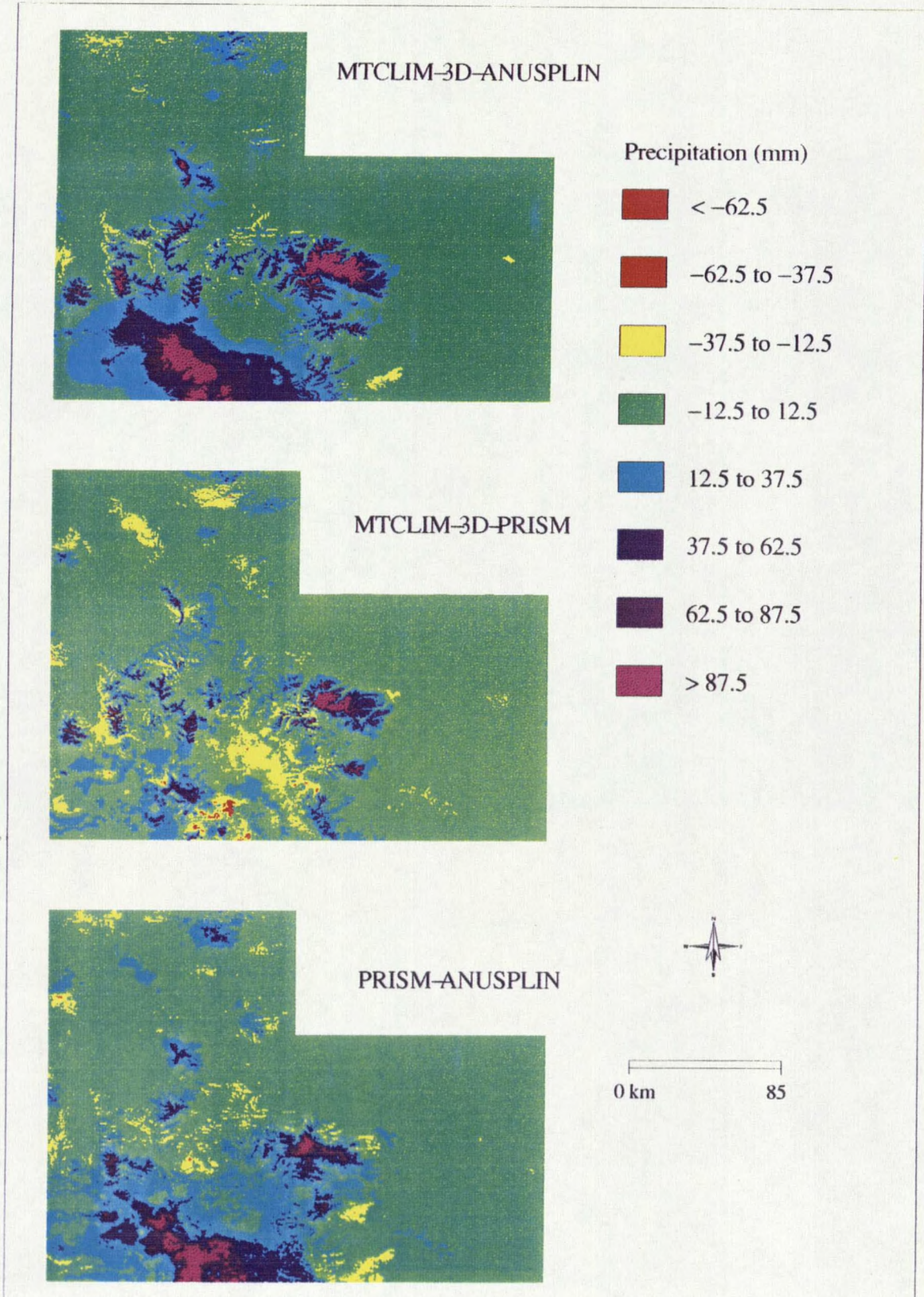


Figure 12. Maps showing differences between mean January precipitation predictions with different pairs of models.

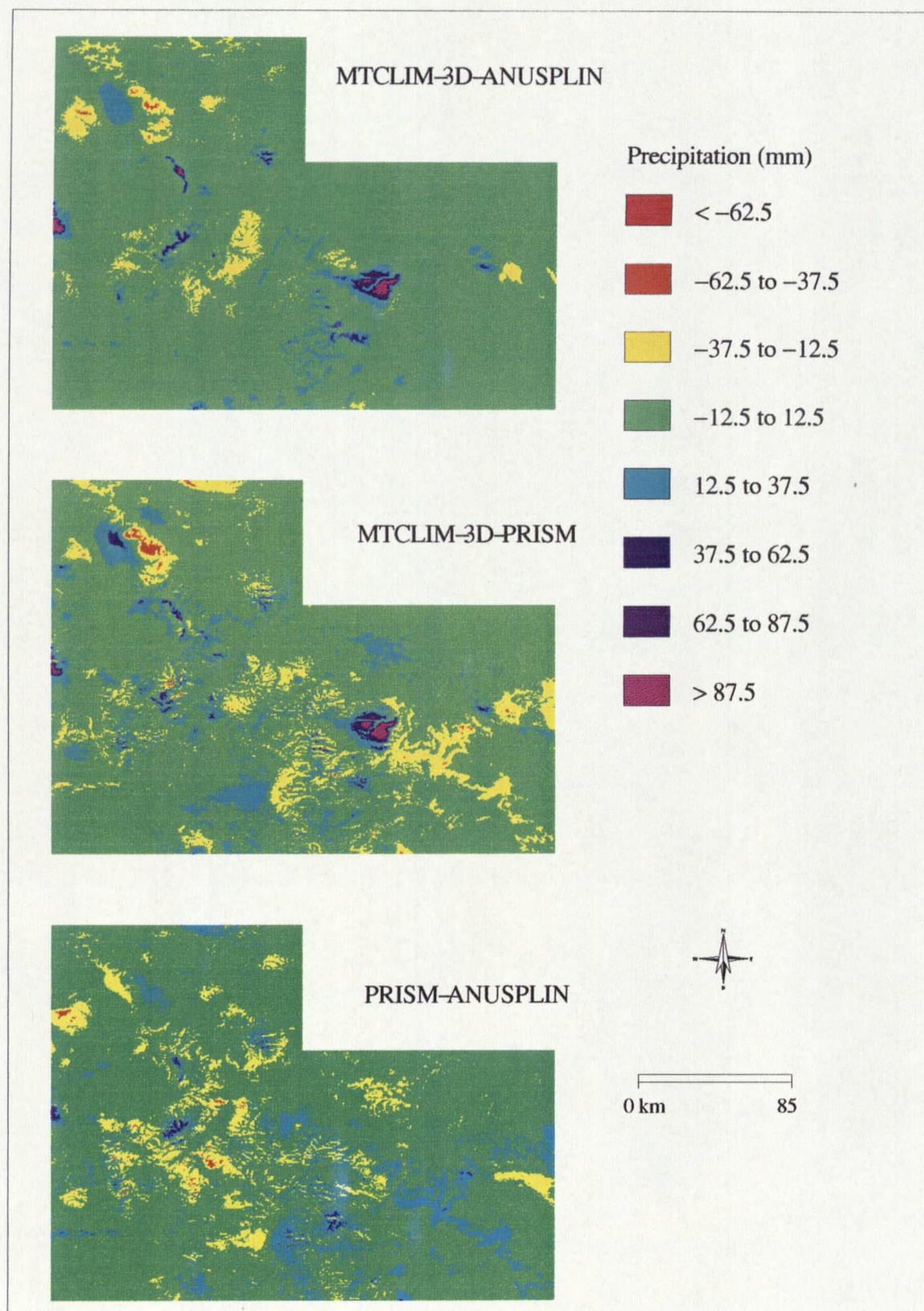


Figure 13. Maps showing differences between mean May precipitation predictions with different pairs of models.

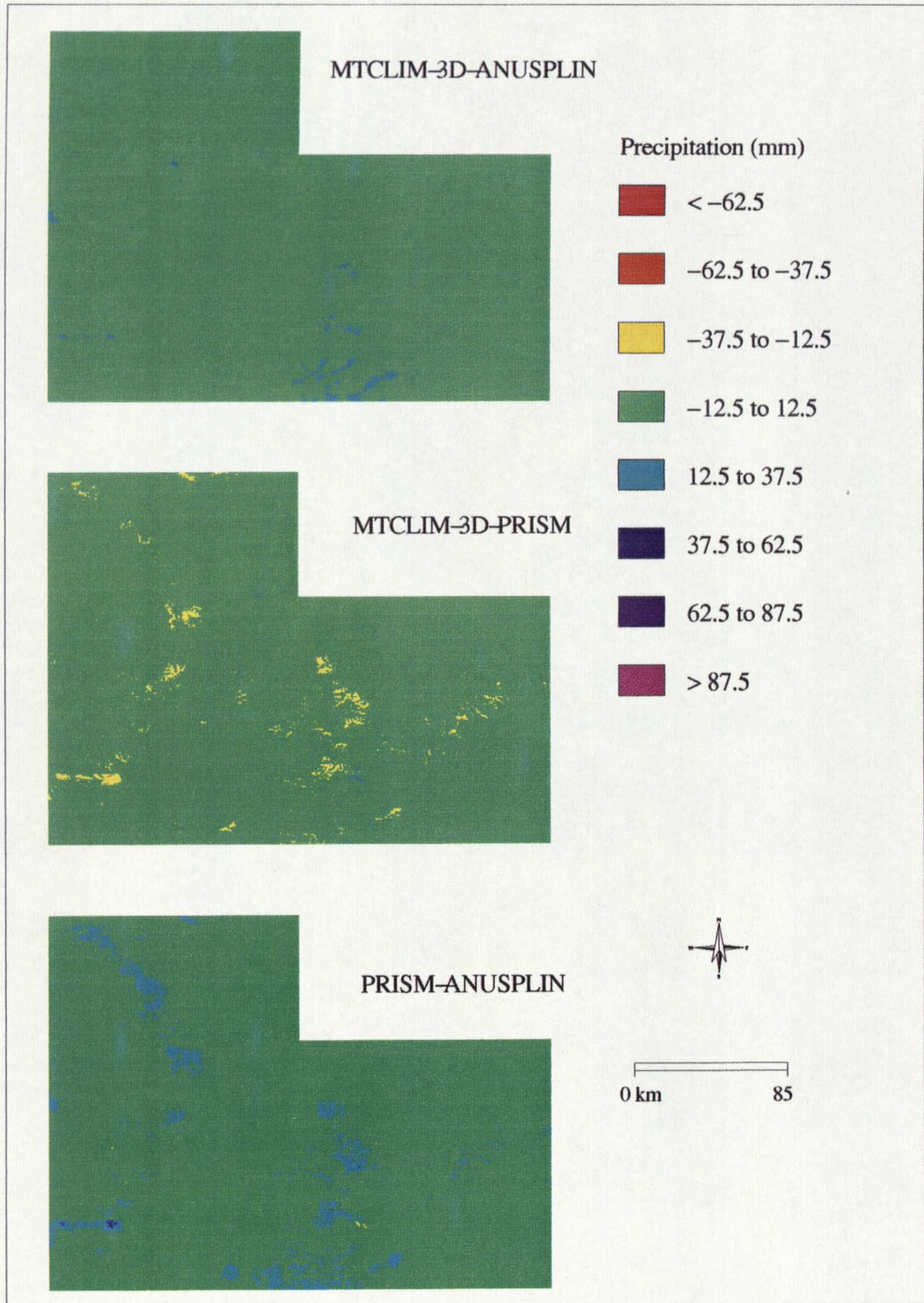


Figure 14. Maps showing differences between mean July precipitation predictions with different pairs of models.

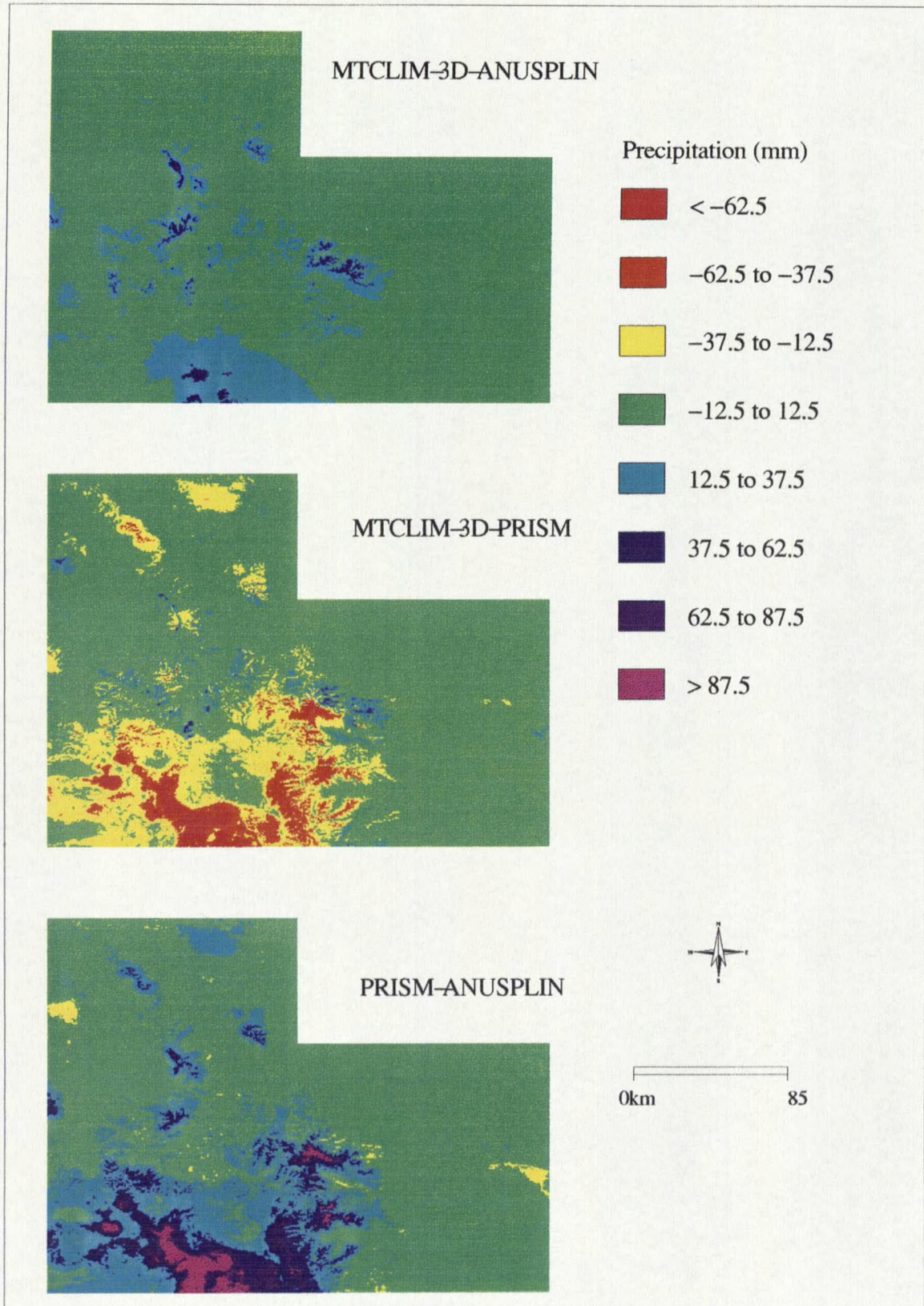


Figure 15. Maps showing differences between mean November precipitation predictions with different pairs of models.

Table 12. Mean annual precipitation predicted with three models using annual and summed monthly climate station data.

Model prediction using	Monthly data (Table 6)	Annual data (Table 2)
ANUSPLIN	540.3	606.2
MTCLIM-3D	573.3	582.9
PRISM	577.9	574.3

GRID module and the agreement values in Table 13 reflect the percentage of cells which fall within 100 mm and 200 mm of each other. MTCLIM-3D shows the most agreement between cells for both intervals (73% and 87%, respectively) followed by ANUSPLIN (61% and 77%) and PRISM (48% and 78%). The difference maps reproduced in Figure 16 are instructive because they demonstrate: (1) that the ANUSPLIN and PRISM annual predictions exceeded the summed monthly values in most high elevation areas; (2) the MTCLIM-3D annual run predicted more precipitation in some areas (Gallatin Range, Crazy Mountains) and less in other areas (Beartooth Plateau, Tobacco Root Mountains) compared with the summed monthly values.

Comparisons with Hand-Drawn Maps

The model predictions were also compared with the 1961-1990 professionally hand-drawn contour maps prepared by Philip Farnes for the NRCS which incorporate his extensive expertise in precipitation measurements in the region. The map reproduced in the bottom half of Figure 17 is the digitized contour map which was converted to a single polygon coverage in which each polygon was assigned a value that represented the

Table 13. Percent agreement between annual and summed monthly model predictions using 100 mm and 200 mm class intervals.

Model	Class interval used	
	100 mm	200 mm
ANUSPLIN	61	77
MTCLIM-3D	73	87
PRISM	48	78

midpoint between the two contour values. This coverage was converted into an ARC/INFO grid, changed from a UTM projection to a geographic projection, and resampled to the same cellsize (0.0063 dd) as the model lattices (see top half of Figure 17). The spatial extent of the Farnes map is smaller than the study area region as the entire study region has yet not been hand-drawn and therefore fewer cells (193,046 versus 245,542) were used in the comparison between the Farnes and model maps.

The model runs used for this part of the study incorporated all of the climate station data, including the snow course data and 20 previously withheld stations. The results represent the best possible model predictions for the study area. Farnes' method produced larger mean annual precipitation values than ANUSPLIN (1.6%), MTCLIM-3D (4.4%), and PRISM (2.4%) (Table 14) with a higher distribution of cells in the low and high class intervals (Figure 18). This may be due to overgeneralization of precipitation estimates on the hand-drawn maps and the lack of stations at high elevations. The larger CV value indicates slightly greater relative variability in predictions for the Farnes surface compared with the model surfaces.

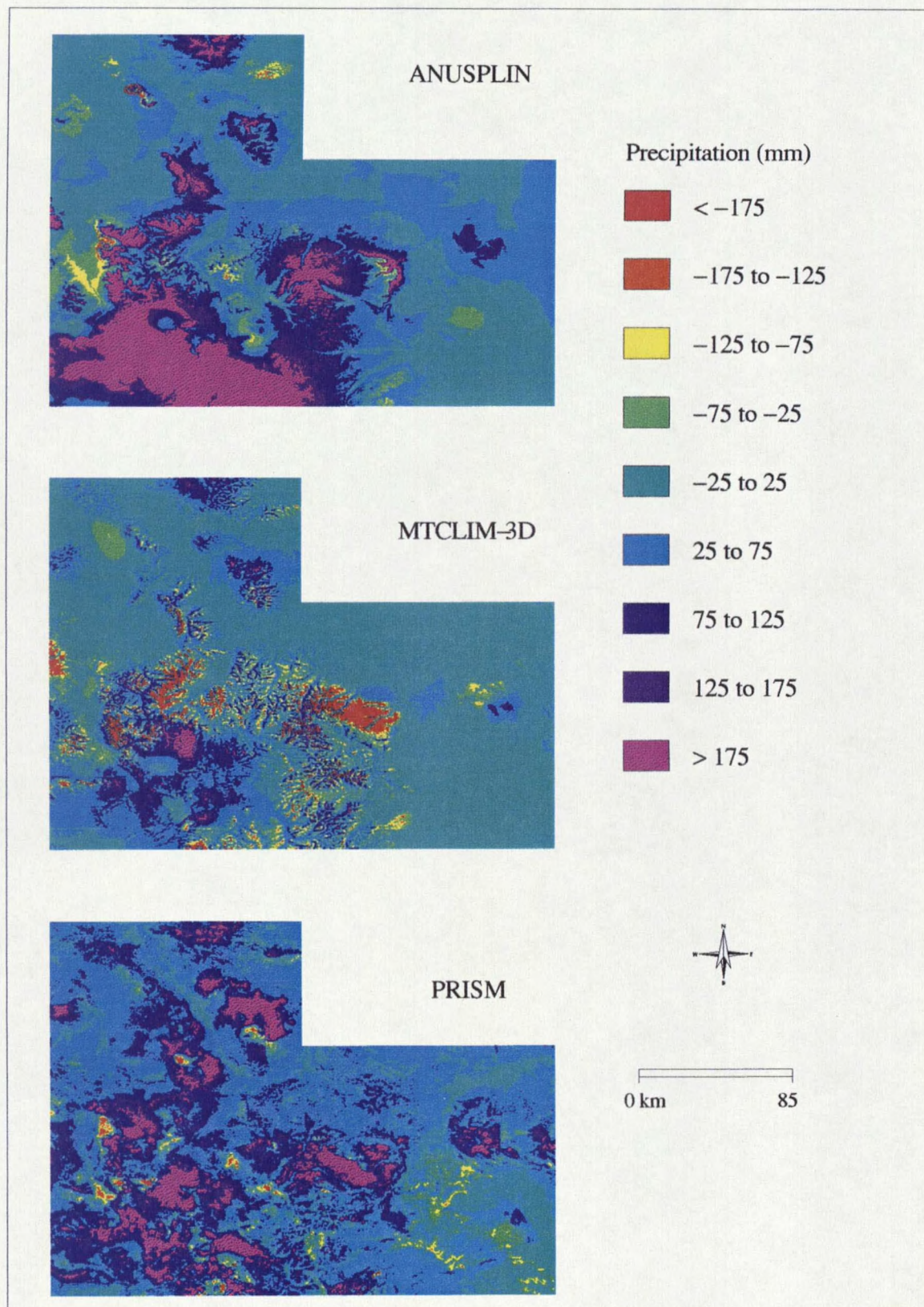


Figure 16. Maps showing differences between mean annual precipitation predictions generated with annual data and summed monthly data.

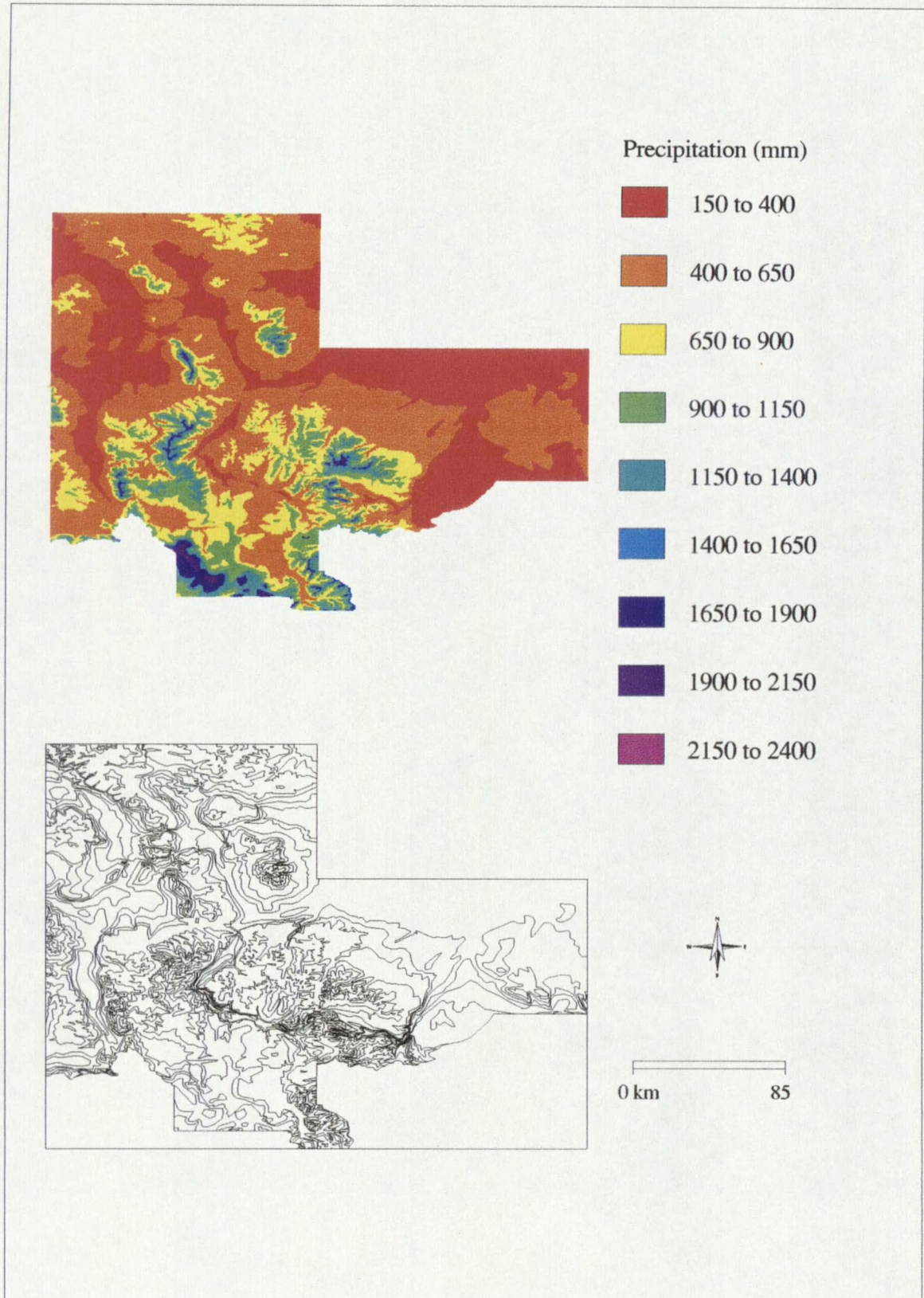


Figure 17. Mean annual precipitation maps produced by Philip Farnes.

Table 14. Mean annual precipitation predictions for individual cells (mm).

Cell value(s)	ANUSPLIN	MTCLIM-3D	PRISM	FARNES
Minimum	199	228	180	178
Maximum	1572	2031	2196	1905
Mean	629.9	613.0	625.3	640.0
Std. Dev.	278.1	276.2	285.4	320.6
Coeff. of Var.	0.44	0.45	0.46	0.50

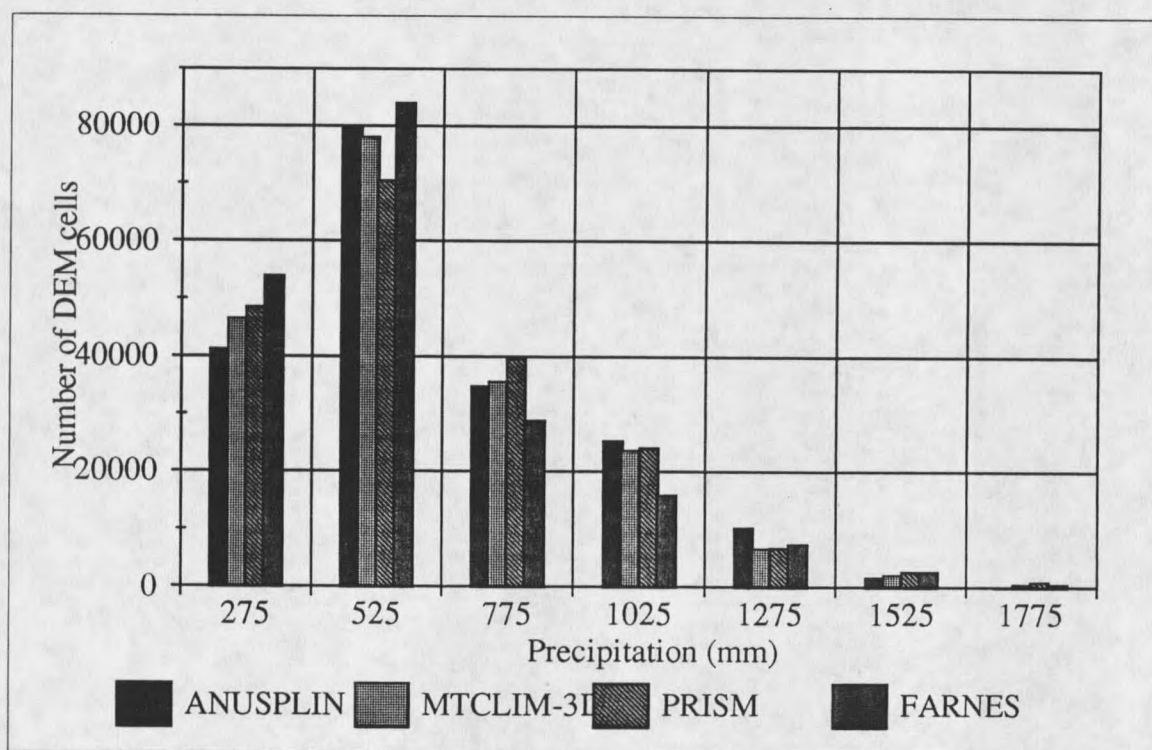


Figure 18. Graph showing number of DEM cells falling in mean annual precipitation classes for the three models and Farnes map within the Farnes map extent.

Difference grids were produced with the grid subtraction tools in the ARC/INFO GRID module to identify the existence of spatial similarities and differences between the Farnes and the three sets of annual model predictions (Figure 19). The grids were divided into 100 and 200 mm increments for this purpose in ARC/INFO and cells were designated equivalent in pairwise comparisons if their predicted values fell in the same class. The Farnes/model comparisons did not fare as well as the model comparisons reported earlier. More than 50% and 33% of the cells reported different values using 100 mm and 200 mm interval, respectively (Table 15). The Farnes map predicted higher precipitation than all of the models on all mountain peaks, especially in the Teton, Madison, and Beartooth ranges. The models all exhibited higher values than the Farnes map in the same regions, including the Pryor and Bighorn ranges to the east, in the Yellowstone Lake drainage, in the Absaroka mountains east of Paradise Valley, and south of the Beartooth Pass. The similarity in the spatial pattern of the differences between each of the models and the Farnes map demonstrates the high degree of similarity between the model predictions relative to the Farnes map. However, the use of 5 cm contours from 0 to 760 cm and 25 cm contours on the Farnes map probably contributed to this result, and explains why the Farnes map generated both a higher mean annual precipitation estimate and a larger number of cells in the two lower class intervals reported in Figure 18.

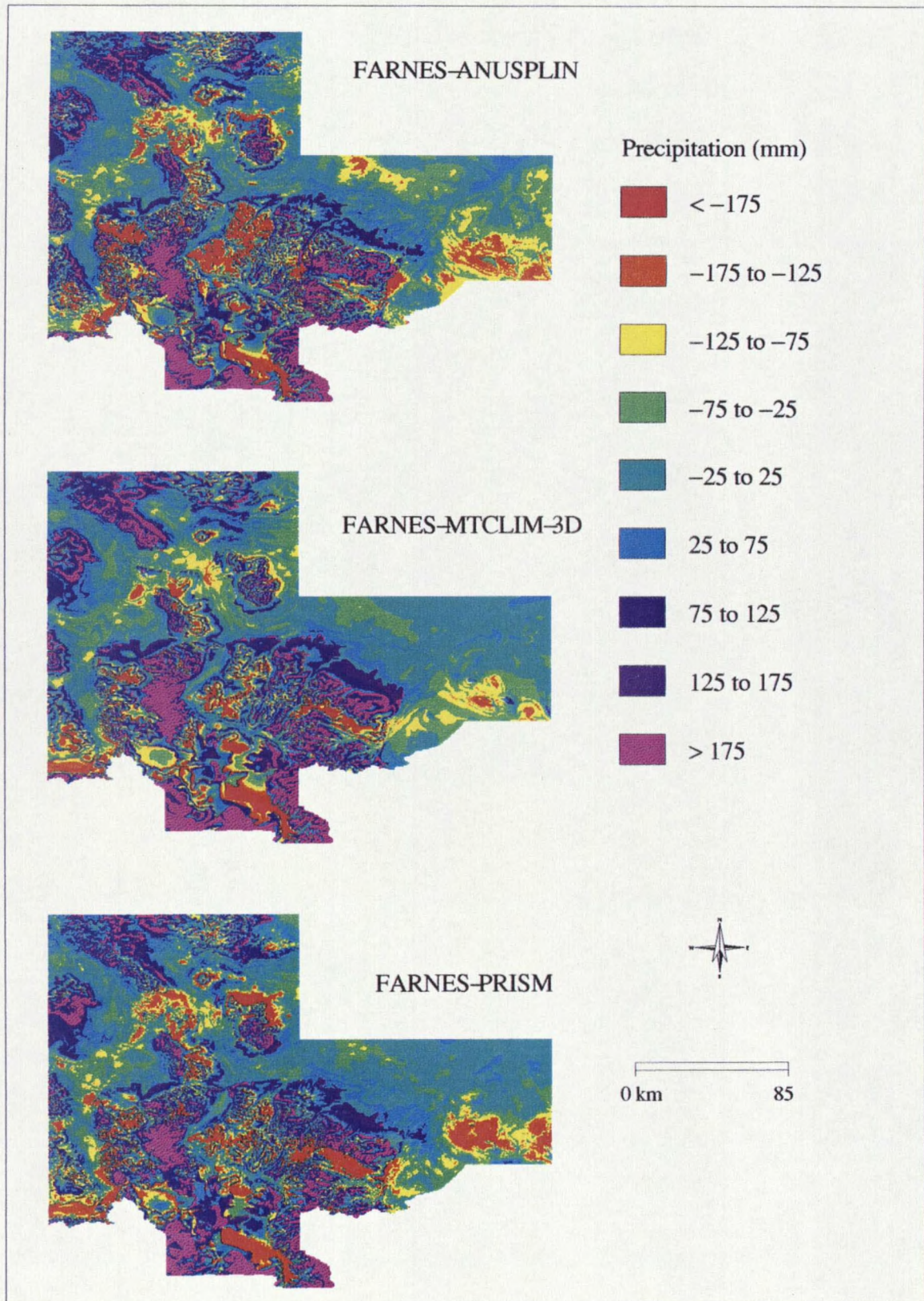


Figure 19. Maps showing differences between Farnes and model mean annual precipitation predictions.

Table 15. Percent agreement between ANUSPLIN, MTCLIM-3D, PRISM, and Farnes model predictions based on 100 mm and 200 mm class intervals.

Model pairs	Class interval used	
	Within 100 mm	Within 200 mm
MTCLIM-3D-ANUSPLIN	66	87
MTCLIM-3D-PRISM	64	84
PRISM-ANUSPLIN	63	84
FARNES-MTCLIM-3D	47	69
FARNES-PRISM	46	67
FARNES-ANUSPLIN	44	68

CHAPTER 4

CONCLUSIONS

The mean rainfall field is not known because precipitation measurements are not ground-truthed and therefore absolute predictive errors cannot be assessed. The goal of this study was to determine whether the models could be distinguished in terms of their performance using typical statistical measures comparing predicted and observed data at 20 withheld stations, analysis of variation in spatial pattern, and comparisons with hand-drawn contour maps.

The three methods generate statistically similar annual results. The ANUSPLIN annual mean is only slightly larger than the other models, and the mean annual precipitation predictions for the 20 withheld stations were accepted as statistically similar to the observed data at the 0.05 significance level. In addition, the predicted mean annual precipitation fell within the same 200 mm (8") classes in at least 80% of the cells when pairs of models were compared (Table 5). The spatial precipitation patterns from all three models define the location of large scale topographic features, including the western plains regions, major river valleys and drainages, the Continental Divide, and mountainous regions (Figure 5). The largest variations in model predictions occur in the mountains where a lack of climate stations and highly variable precipitation patterns complicate the interpolation process.

The level of agreement between monthly surfaces predicted by the models was measured by the percent agreement between cells and varied with season. The precipitation predictions fell in the same 25 mm classes in over 80% of the DEM cells in 28 out of 36 monthly surface comparisons, including all of the spring, summer, and early fall months (Table 11). Agreement was poor in the late fall and winter months. The ANUSPLIN predictions were significantly different from the observed data for the 20 withheld stations in November,

December, and February at the 0.05 level of significance (Table 7). The MTCLIM-3D and PRISM predictions were significantly different from the observed data at the 0.05 level of significance in November and December, respectively (Tables 8 and 9). All three sets of mean monthly precipitation predictions generated for the 20 withheld stations exhibited high MAE and bias estimates in these months as well (Table 10).

The lack of data in regions such as the Beartooth/Absaroka, Tetons and the Yellowstone Plateau, causes a substantial amount of variability in precipitation over short distances and produces highly variable interpolation results. This may be a large problem for hydrological modeling applications at catchment and larger scales. The addition of the April 1 snow course SWE measurements is designed to supplement the NWS and SNOTEL climate data and improve the spatial coverage of stations at high elevations. Although the monthly data are different than the annual totals due to the way missing data values must be handled during data set development, the extreme differences at high elevations and low agreement between the summed monthly and annual surface values for all three models (77%, 87%, and 77% agreement using 200 mm classes for ANUSPLIN, MTCLIM-3D and PRISM, respectively (Table 13, Figure 16)) demonstrate the importance of including the snow course data in the annual data set.

Because annual precipitation means cannot be distinguished and predicted station values at withheld climate stations are similar, other criteria are needed to select a model. Two important factors to consider in an automated model comparison are whether the models are available for implementation by users other than the model creators and the degree of user intervention required to produce optimal runs of the model. ANUSPLIN was run by a novice user (the author) following a manual. The MTCLIM-3D and PRISM models required data sets to be formatted and transferred to the University of Montana and Oregon State University, respectively, for execution. The selection of user-defined parameter values, specific to the topographic region, require inputs based on the expertise of the model creators. In this regard,

it could be argued that the ANUSPLIN method is superior because it is available for public use and input parameters are easily specified by the user. These apparent advantages are partially offset by the need to generate station weights and required user intervention in the late fall and early spring months where the transition from rain to snow and vice-versa at varying elevations generated larger surface errors. The change in input standard deviations improved the predictions although ANUSPLIN still performed slightly worse than the other models in both the comparison of mean annual values with the sum of the monthly precipitation values and the comparison of the predicted versus observed values at the 20 withheld station locations for the late fall and early spring periods.

The models may offer significant advantages over Farnes' (manual) method in terms of speed, reproducibility, and lower expectations in terms of pre-existing climate expertise. None of these models required extensive knowledge of local conditions and all three models provided statistical measures of model performance (MAE, bias estimates) as well as precipitation surfaces. Manual techniques usually involve preparation of contours (isolines) and it is difficult to interpolate between these isolines over large areas. Automated interpolation models produce unique cell values over a continuous surface which are much easier to use in modern geographic information systems. It is important to note, however, that the incorporation of Farnes' extensive knowledge in the creation of the hand-drawn maps may have produced a more accurate annual result. Future models should strive to include parameters which reflect climatic processes.

The most variation in model predictions occurred in regions without climate stations. Increased climate station density is needed particularly in mountainous areas to produce improved estimates of precipitation in the Rocky Mountains. It is necessary/desirable to check input data extensively prior to starting the interpolation routine to assure reasonable model performance. Even slight errors in station location, elevation and precipitation values within the data set can have large impacts on the results. GPS measurements should be taken at

climate stations to reduce errors in the recorded locations and elevations. Modellers must be aware of both climate station and DEM errors and their potential impact on precipitation estimates. A closer examination of climate patterns at the mesoscale particularly on the monthly surfaces could improve the current models and/or suggest additional factors that could be used to predict precipitation patterns in the northern Rocky Mountains.

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APPENDIX

Climate Station Data

Climate station data. NWS stations are denoted by four digits, SNOTEL stations begin with a character, and snow course stations have four digits split with a character. Withheld stations are marked with an asterisk. Mean monthly and annual precipitation, standard deviation and number of years of record are listed.

Station Name	Stn. #	Long.	Lat.	Elev. (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
ALDER	0100	112.12	45.32	1560.500	0.47 0.219 16	0.40 0.255 13	0.61 0.458 15	0.88 0.735 15	1.51 0.697 18	2.00 1.138 18	1.37 0.760 17	1.11 0.677 17	1.30 0.829 16	0.94 0.671 15	0.64 0.474 15	0.40 0.283 16	11.25 2.654 11
ALDER 17S	0110	112.07	45.07	1782.993	0.32 0.245 30	0.23 0.245 30	0.68 0.520 30	0.92 0.671 30	2.17 0.995 30	2.44 1.162 30	1.55 1.054 30	1.46 0.648 30	1.50 0.964 30	0.97 0.520 30	0.65 0.387 30	0.38 0.245 30	13.27 2.483 30
ALDER RUBY DAM	0115	112.12	45.25	1612.313	0.35 0.268 9	0.44 0.332 10	1.03 0.480 10	1.05 0.520 9	2.25 1.162 10	2.08 1.025 10	1.75 1.162 10	1.62 0.854 10	1.20 0.686 10	0.85 0.742 10	0.77 0.728 10	0.51 0.490 10	13.40 4.203 8
ALTA 1 NNW	0140	111.03	43.78	1959.768	2.05 0.866 30	1.60 0.842 30	1.62 0.688 30	2.09 1.072 30	3.10 1.611 30	2.36 1.408 30	1.59 0.975 30	1.54 1.006 30	1.97 1.328 30	1.84 1.138 30	2.02 1.014 30	1.90 1.091 30	23.68 4.332 30
ANCENEY	0202	111.37	45.65	1450.777	0.89 0.839 8	0.33 0.148 11	1.19 0.645 13	1.85 0.696 11	2.54 0.845 14	2.73 1.580 13	1.44 0.936 12	1.11 0.684 12	1.42 0.785 11	1.36 0.716 9	1.05 0.714 10	0.49 0.205 7	16.59 2.669 5
ASHTON	0470	111.45	44.07	1603.170	2.29 1.075 30	1.82 1.037 30	1.57 0.718 30	1.54 0.753 30	2.26 1.283 30	1.96 1.256 30	0.99 0.696 30	1.12 0.891 30	1.36 0.861 30	1.36 0.985 30	2.13 1.036 30	2.23 1.271 30	20.63 4.314 30
ASTER CREEK	10E08	110.63	44.28	2362.085													42 13.102 30
AUGUSTA	0364	112.38	47.48	1240.475	0.52 0.300 30	0.42 0.346 30	0.65 0.458 30	1.07 0.775 30	2.34 1.459 30	2.40 1.913 30	1.25 0.964 30	1.41 1.109 30	1.30 1.149 30	0.69 0.853 28	0.45 0.341 29	0.55 0.387 30	12.97 3.727 28
AUSTIN 1W	0375	112.27	46.65	1523.926	1.11 0.742 29	0.77 0.417 29	0.98 0.424 30	1.29 0.702 29	2.25 1.455 29	2.15 1.228 29	1.37 1.297 29	1.34 0.948 29	1.56 1.183 28	0.91 0.702 29	0.91 0.424 30	1.16 0.648 30	15.43 3.123 26
BALD RIDGE	10C05	110.45	46.12	2285.888													6.495 30
BALLANTINE*	0432	108.13	45.95	914.355	0.59 0.458 30	0.41 0.417 29	0.80 0.458 30	1.62 1.068 30	2.58 1.529 30	2.39 1.849 30	0.99 0.614 29	1.20 0.916 30	1.63 1.162 30	1.01 0.794 30	0.70 0.539 29	1.28 3.571 30	14.46 3.550 28
BARBER	0466	109.37	46.32	1136.849	0.54 0.435 27	0.33 0.341 29	0.51 0.424 30	0.91 0.671 30	2.23 1.225 30	2.35 1.758 30	1.31 0.735 30	1.34 0.900 30	1.14 0.849 30	0.89 0.590 29	0.49 0.381 29	0.42 0.346 30	12.87 2.475 25
BASE CAMP	S292	110.43	43.93	2142.639	3.78 2.167 10	3.88 3.347 10	2.99 1.802 10	2.68 1.250 10	2.96 0.857 10	1.74 1.125 9	1.72 1.143 9	0.98 0.830 9	1.66 0.955 9	1.86 1.038 10	4.76 2.063 10	3.34 1.759 10	30.84 7.323 9

Climate station data continued.

Station Name	Stn. #	Long.	Lat.	Elev. (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
BASIN	0515	112.27	46.27	1633.648	1.27	0.49	0.77	0.99	1.91	2.71	1.46	1.31	1.22	0.74	0.68	0.95	
					0.837	0.300	0.335	0.710	0.949	1.069	0.616	0.629	1.109	0.700	0.424	0.934	***
					10	10	7	9	9	9	10	9	10	10	9	8	
BASIN	0540	108.05	44.38	1169.461	0.25	0.13	0.29	0.75	1.24	1.04	0.45	0.60	0.84	0.50	0.26	0.30	6.71
					0.193	0.167	0.258	0.560	0.882	0.913	0.322	0.558	0.618	0.606	0.225	0.347	1.455
					30	30	30	30	30	30	29	30	30	30	29	29	29
BEAR BASIN	11D09	111.37	45.32	2483.999													46
																	9.986
																	30
BEARTOOTH LAKE	S400	109.57	44.78	2826.882	3.48	2.91	2.97	2.84	3.67	2.39	1.98	1.59	1.53	1.79	3.11	3.28	31.54
					1.922	1.744	1.713	1.272	1.187	0.996	1.127	0.867	1.077	0.986	1.083	1.791	5.030
					10	10	10	10	10	10	10	10	10	10	10	10	10
BEAVER CREEK	MI38	111.35	44.95	2392.563	2.92	2.93	3.23	2.43	2.83	1.88	1.80	1.48	2.05	1.78	3.45	2.63	29.43
					1.102	1.853	1.104	1.120	0.882	0.736	1.318	0.643	1.620	1.461	1.174	1.067	5.940
					6	6	6	6	6	6	6	6	6	6	6	6	6
BELFRY 4 SSW	0617	109.03	45.08	1188.662	0.42	0.10	0.31	0.66	1.12	1.66	0.45	0.74	1.25	0.63	0.53	0.39	7.85
					0.452	0.182	0.257	0.470	0.502	1.379	0.410	0.790	0.955	0.684	0.514	0.480	2.217
					12	11	11	13	12	11	12	12	12	11	10	7	
BELGRADE AIRPORT*	0622	111.15	45.78	1356.599	0.64	0.49	1.05	1.22	2.46	2.45	1.12	1.27	1.52	1.17	0.83	0.59	14.81
					0.458	0.387	0.735	0.625	1.175	1.449	0.900	0.714	0.900	0.735	0.490	0.300	2.278
					30	30	30	30	30	30	30	30	30	30	30	30	30
BERRY MEADOW	12C07	112.27	46.18	2133.496													24
																	5.564
																	30
BIG SKY SCS	MH17	111.42	45.30	2346.845	2.31	1.97	2.77	2.79	4.19	3.82	2.12	2.04	2.73	2.17	2.24	2.46	31.61
					1.104	1.144	1.372	1.185	1.352	1.961	1.369	1.189	1.820	1.213	0.949	1.496	6.790
					30	30	30	30	30	30	30	30	30	30	30	30	30
BIG TIMBER	0780	109.95	45.83	1249.619	0.66	0.40	0.87	1.41	2.92	2.61	1.22	1.20	1.47	1.34	0.75	0.61	15.10
					0.511	0.387	0.614	0.978	1.559	1.929	0.933	0.883	0.949	0.917	0.490	0.520	3.148
					29	30	29	29	30	30	30	30	30	30	30	30	27
BILLINGS WATER	0802	108.48	45.77	943.920	0.64	0.51	0.76	1.48	2.50	2.28	0.89	1.11	1.39	1.12	0.63	0.58	13.45
					0.502	0.458	0.424	1.039	1.679	1.818	0.812	0.933	1.095	0.980	0.381	0.387	2.825
					28	30	30	30	30	28	30	30	30	30	29	30	26
BILLINGS WSO AP	0807	108.53	45.80	1087.169	0.90	0.64	1.16	1.75	2.57	1.99	0.94	1.01	1.36	1.14	0.84	0.80	15.00
					0.671	0.424	0.490	1.095	1.643	1.530	0.714	0.775	0.995	0.883	0.520	0.548	3.421
					30	30	30	30	30	30	30	30	30	30	30	30	30
BLACK BEAR	MI35	111.12	44.50	2483.999	9.01	6.85	7.72	4.73	4.01	3.74	2.02	2.27	2.81	3.42	6.46	6.84	59.88
					4.733	3.044	3.904	1.998	1.423	2.203	1.010	1.909	1.900	1.952	3.119	3.369	11.718
					23	23	23	23	23	23	23	23	23	23	23	23	23
BLACK CANYON	11E18	111.10	44.47	2426.090													54
																	14.050
																	28

Climate station data continued.

Station Name	Stn. #	Long.	Lat.	Elev. (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
BLACK MOUNTAIN	0778	107.72	43.65	1717.464	0.53	0.50	1.02	1.75	2.16	1.78	0.79	0.85	1.12	1.24	0.65	0.66	13.11
					0.417	0.336	0.538	1.182	1.468	1.341	0.698	0.855	0.992	0.993	0.476	0.444	3.690
BLACKWATER	S402	109.80	44.38	2980.799	27	27	27	27	27	27	27	27	26	26	27	26	24
					2.92	3.24	3.36	3.82	3.93	3.02	2.45	1.95	2.21	2.43	4.29	3.22	36.21
					1.745	2.489	1.607	1.111	1.234	2.341	1.264	2.071	1.362	0.958	1.456	2.069	6.553
BONE SPRINGS	S295	107.58	44.68	2849.741	10	10	10	10	10	10	10	11	11	10	10	10	10
					2.53	2.28	3.35	2.96	4.31	2.94	2.13	1.98	2.87	2.17	2.18	2.46	32.16
					1.063	1.147	1.059	1.233	1.928	1.162	1.327	1.062	1.368	1.015	0.694	1.035	3.976
BOTS SOTS	09D14	109.48	45.17	2362.085	11	11	11	11	11	11	11	11	11	11	11	11	11
																	25
																	6.070
																	30
BOULDER	1008	112.12	46.23	1494.666	0.60	0.35	0.59	0.82	1.86	1.94	1.39	1.35	1.17	0.55	0.51	0.52	11.64
					0.424	0.245	0.300	0.520	1.204	1.107	0.917	1.117	0.794	0.520	0.381	0.346	2.705
					30	30	30	30	29	29	29	29	30	30	29	30	27
BOULDER MOUNTAIN	MG01	111.30	46.57	2423.042	3.41	3.45	4.45	3.76	4.81	3.19	2.45	1.69	2.79	2.49	3.61	3.76	39.86
					1.318	1.308	1.035	1.137	2.718	1.347	1.946	0.847	2.152	1.577	1.273	2.252	7.938
					14	14	14	14	14	14	14	14	14	14	14	14	14
BOX CANYON*	MD31	110.25	45.28	2042.060	1.93	1.73	2.32	2.02	3.62	2.08	1.94	1.44	1.81	1.50	2.17	2.04	24.60
					0.785	0.683	0.824	0.939	1.910	0.583	1.068	0.885	1.514	0.753	0.748	0.825	3.206
					14	14	14	14	14	14	14	14	14	14	14	14	14
BOZEMAN MSU	1044	111.05	45.67	1480.037	0.87	0.67	1.42	1.87	3.18	2.86	1.35	1.50	1.95	1.63	1.19	0.74	19.17
					0.424	0.387	0.693	0.714	1.342	1.427	0.849	0.794	1.216	0.933	0.671	0.387	3.130
					30	30	30	30	30	30	30	30	29	29	30	30	28
BOZEMAN 6W EXP FM	1047	111.15	45.67	1455.349	0.56	0.51	1.14	1.52	2.76	2.65	1.43	1.35	1.73	1.44	0.92	0.59	16.57
					0.268	0.379	0.559	0.727	1.278	1.359	0.967	0.657	0.955	0.790	0.474	0.316	2.529
					24	24	24	23	24	24	24	24	24	24	25	25	23
BOZEMAN 12NE*	1050	110.88	45.82	1813.472	2.81	2.02	2.71	3.22	4.58	4.24	2.10	2.47	3.23	2.69	2.59	2.47	35.12
					1.319	0.812	1.175	1.273	1.578	1.749	1.470	1.578	1.897	1.625	1.149	1.109	6.153
					30	30	30	30	30	30	30	30	30	30	30	30	30
BRANHAM LAKES	11D14	111.98	45.52	2697.348													48
																	10.224
																	30
BRASS MONKEY	MD29	110.05	45.42	2758.305	2.62	2.49	3.83	4.58	3.91	3.20	1.92	1.91	2.00	3.06	2.17	3.14	34.84
					1.659	1.548	0.881	1.948	2.483	1.672	1.246	0.899	1.030	1.890	1.283	1.432	6.060
					8	8	8	8	8	8	8	8	8	8	8	8	8
BRIDGER	1102	108.92	45.30	1121.609	0.80	0.54	1.06	1.71	2.42	1.85	0.62	0.83	1.43	1.08	0.68	0.61	13.61
					0.548	0.387	0.755	1.109	1.418	1.470	0.637	0.671	1.200	0.868	0.511	0.387	2.593
					30	30	30	30	30	30	29	30	30	29	29	30	27
BRIDGER BOWL	MD15	110.92	45.80	2209.692	5.17	4.30	5.57	5.44	6.47	5.28	2.31	2.88	3.46	3.74	4.31	4.82	53.77
					2.526	1.749	2.088	2.168	2.125	2.299	1.584	1.862	2.450	2.347	1.730	2.623	8.993
					30	30	30	30	30	30	30	30	30	30	30	30	30

Climate station data continued.

Station Name	Stn. #	Long.	Lat.	Elev. (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
BROADVIEW	1149	108.88	46.10	1182.566	0.51	0.40	0.74	1.22	2.74	2.22	1.27	1.24	1.37	0.93	0.52	0.38	13.67
					0.417	0.341	0.424	0.980	1.530	1.818	0.849	0.917	1.039	0.671	0.381	0.341	3.156
					29	29	30	30	30	29	30	30	30	30	29	29	25
BUFFALO BILL DAM	1175	109.18	44.50	1571.472	0.40	0.33	0.65	1.46	2.17	1.83	0.93	0.76	1.21	0.73	0.51	0.33	11.32
					0.446	0.332	0.449	1.256	1.729	1.202	0.762	0.525	1.007	0.607	0.307	0.297	2.736
					30	30	30	30	30	30	30	30	30	30	30	30	30
BURGESS JUNCTION	S297	107.53	44.78	2401.707	1.54	1.59	3.03	3.12	3.20	2.27	1.97	0.95	2.31	2.15	1.75	1.83	25.70
					0.424	0.686	1.005	2.090	1.847	1.063	1.709	0.500	0.735	1.049	0.574	1.127	3.108
					10	10	10	10	10	10	10	10	10	10	10	10	10
BURROUGHS CREEK	S298	109.67	43.70	2666.870	3.23	2.58	2.57	2.57	3.03	1.67	1.56	1.68	2.22	1.58	3.38	2.76	28.79
					1.883	2.575	1.152	0.958	0.857	0.923	1.166	0.868	1.297	0.777	1.267	1.638	4.524
					11	11	11	11	11	11	11	11	11	11	11	11	11
BUTTE FAA AAP	1318	112.50	45.95	1.688510	0.55	0.37	0.76	0.92	1.86	2.15	1.27	1.31	1.25	0.69	0.52	0.44	12.10
					0.423	0.226	0.339	0.564	1.029	1.348	1.072	0.736	0.867	0.633	0.285	0.242	2.887
					30	30	30	30	30	30	30	30	30	30	30	30	30
CALL ROAD	11D07	111.85	45.12	2438.281													30
																	30
																	6.238
CAMP CREEK	12E03	112.23	44.45	2005.486													30
																	24
																	10.212
CAMP SENIA	09D01	109.47	45.17	2404.755													30
																	26
																	9.303
																	30
CANYON	S299	110.53	44.72	2465.712	2.95	2.15	2.29	1.92	2.63	2.57	1.81	2.12	2.31	1.83	2.51	2.60	27.70
					1.571	1.314	1.311	1.033	1.172	1.753	1.129	1.431	1.458	1.413	1.023	1.294	4.778
					30	30	30	30	30	30	30	30	30	30	30	30	30
CANYON CREEK	1450	112.25	46.82	1313.624	0.55	0.39	0.41	1.11	1.75	2.55	1.33	1.18	0.85	0.73	0.47	0.54	12.83
					0.465	0.268	0.300	0.940	1.159	1.207	1.083	0.967	0.759	0.883	0.212	0.470	5.558
					18	18	18	17	16	16	17	17	16	15	15	17	10
CANYON FERRY DAM	1470	111.73	46.65	1119.171	0.54	0.33	0.57	0.95	1.93	1.93	1.34	1.30	1.21	0.66	0.48	0.55	11.80
					0.458	0.245	0.387	0.548	1.123	1.039	1.054	0.900	0.883	0.574	0.300	0.346	3.161
					30	30	30	30	30	30	30	30	30	30	30	30	30
CARDWELL*	1500	111.95	45.87	1301.432	0.43	0.42	1.17	1.28	2.53	1.84	1.32	1.22	1.60	0.70	0.54	0.41	13.29
					0.465	0.310	0.438	0.876	1.559	0.876	0.967	0.675	1.057	0.559	0.302	0.361	2.430
					12	12	12	12	13	13	13	13	13	13	13	13	12
CARROT BASIN	MI29	111.28	44.97	2743.066	5.19	4.28	5.91	4.45	5.16	5.21	2.66	2.61	3.50	3.15	4.53	4.86	51.51
					2.110	1.845	2.256	1.905	2.007	3.162	1.297	2.061	2.308	1.594	1.802	2.078	10.388
					24	24	24	24	24	24	24	24	24	24	24	24	24
CARTER CREEK	12D04	112.45	45.13	2255.410													20
																	7.070
																	30

Climate station data continued.

Station Name	Stn. #	Long.	Lat.	Elev. (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
CARTER MOUNTAIN	X026	109.23	44.32	2423.042	1.13	0.95	1.93	3.46	2.97	2.13	1.56	1.39	1.84	1.53	1.33	0.97	21.29
					1.260	0.695	0.708	2.422	1.313	1.145	1.034	1.132	1.415	1.135	0.572	0.694	4.031
CASCADE 5 S	1552	111.72	47.22	1033.222	23	23	23	23	23	23	23	24	24	23	23	23	23
					0.63	0.48	1.11	1.53	2.95	2.45	1.41	1.58	1.62	0.91	0.61	0.65	15.92
					0.346	0.300	0.671	1.010	1.697	1.568	1.162	1.296	1.342	0.980	0.387	0.424	4.058
CASCADE 20 SSE	1557	111.58	47.00	1402.012	30	30	30	30	30	30	30	30	30	30	30	30	30
					0.57	0.38	0.80	1.21	2.82	2.64	1.36	1.41	1.68	0.92	0.50	0.58	14.86
					0.424	0.245	0.387	0.714	1.741	1.568	1.068	0.980	1.175	0.866	0.346	0.424	3.822
CASHE CREEK	MH23	111.38	45.08	2377.324	30	30	30	30	30	30	30	30	30	30	30	30	30
					2.35	1.91	2.54	1.96	2.82	2.81	1.73	1.70	2.06	1.61	2.03	2.36	25.90
					1.091	0.869	1.023	0.969	1.091	1.462	0.996	1.078	1.106	0.800	0.835	1.104	4.459
CHESSMAN RES	12C05	112.18	46.47	1889.668	24	24	24	24	24	24	24	24	24	24	24	24	24
																	20
																	9.542
																	30
CHRISTENSEN RANCH	MM06	112.45	45.18	1828.711	0.46	0.49	1.02	1.36	2.63	2.05	1.58	1.48	1.50	1.00	0.48	0.54	14.66
					0.272	0.351	0.338	0.769	1.833	1.181	1.180	1.009	1.042	0.731	0.311	0.468	3.274
					19	19	19	19	19	20	20	20	20	19	19	19	19
CLARK 7NE	1775	109.08	44.98	1228.284	0.29	0.19	0.48	0.59	1.30	1.52	0.84	0.75	0.90	0.55	0.29	0.21	8.02
					0.274	0.203	1.306	0.516	0.802	1.048	0.518	0.676	0.691	0.564	0.261	0.244	2.302
					29	29	30	30	29	30	30	30	30	30	30	29	28
CLOVER MEADOW*	MH08	111.85	45.02	2682.109	3.49	2.87	3.94	3.63	4.06	2.83	2.41	2.32	2.61	2.16	2.68	3.23	36.22
					1.671	1.136	1.558	1.901	1.374	1.409	1.604	1.058	1.446	1.272	1.085	1.828	6.114
					19	19	19	19	19	19	19	19	19	19	19	19	19
CODY	1840	109.07	44.50	1520.878	0.37	0.22	0.42	0.94	1.88	1.56	0.99	0.83	1.12	0.64	0.44	0.28	9.64
					0.492	0.249	0.247	0.628	1.069	0.929	0.737	0.654	0.856	0.607	0.298	0.289	2.317
					29	29	29	29	29	29	30	30	30	29	29	29	29
CODY 12SE	1850	108.90	44.40	1599.512	0.40	0.22	0.54	0.98	2.01	1.95	0.99	0.93	1.10	0.56	0.45	0.35	10.54
					0.495	0.262	0.427	0.876	1.463	1.248	0.725	0.839	0.987	0.621	0.308	0.367	2.688
					27	29	29	28	30	30	30	30	30	29	29	29	26
CODY 21SW	1855	109.38	44.33	1779.945	0.43	0.40	0.79	1.47	1.86	1.62	1.26	0.94	1.36	0.96	0.64	0.52	12.21
					0.381	0.378	0.608	1.132	1.418	0.935	0.848	0.788	1.134	0.854	0.410	0.408	2.609
					30	30	30	30	30	30	30	30	30	30	30	30	30
COLE CREEK*	TX16	109.35	45.20	2392.563	2.48	2.08	4.36	5.25	5.77	4.10	1.93	2.16	3.62	2.74	2.44	1.97	38.88
					1.543	1.135	1.951	3.145	2.735	2.867	1.103	1.484	2.670	1.651	1.379	1.122	6.567
					30	30	30	30	30	30	30	30	30	30	30	30	30
COLLEY CREEK	MD30	110.47	45.27	1920.146	1.65	1.36	1.97	1.65	3.43	2.23	1.79	1.36	2.06	1.51	1.60	1.78	22.39
					0.986	0.662	0.509	0.898	1.675	0.936	0.823	0.673	1.564	0.968	0.618	1.211	3.339
					15	15	15	15	15	15	15	15	15	15	15	15	15
COLUMBUS*	1938	109.23	45.63	1092.655	0.66	0.50	0.93	1.53	3.02	2.04	1.10	1.09	1.46	1.14	0.66	0.59	14.64
					0.580	0.529	0.548	1.010	1.568	1.706	1.025	0.812	1.162	0.883	0.424	0.473	3.677
					28	28	30	30	30	30	30	30	30	30	30	28	26

Climate station data continued.

Station Name	Stn. #	Long.	Lat.	Elev. (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Nov	Dec	Annual	
COOKE CITY 2 W	1995	109.97	45.02	2273.697	2.46 1.419 19	1.86 1.186 19	1.93 0.993 21	1.69 0.780 21	2.66 1.344 21	2.67 1.210 19	2.10 1.045 21	2.18 1.187 22	2.10 1.352 21	1.41 0.767 21	2.17 0.792 19	2.31 1.265 20	25.82 3.647 14
COOKE STATION	09D07	109.90	45.03	2483.999													37 9.811
COPPER MOUNTAIN	12C09	112.42	46.02	2346.845													29 27 5.548
COULTER CREEK	S404	110.57	44.17	2139.592	4.76 2.110 10	4.92 3.257 10	3.70 2.066 10	3.32 0.935 10	3.34 0.992 10	2.12 1.176 10	2.08 1.024 10	1.78 1.602 10	2.33 1.567 10	2.47 1.372 10	4.84 2.115 10	4.31 2.460 10	39.97 9.895 10
CRAB CREEK	S428	112.00	44.43	2090.826	2.38 0.858 9	2.59 1.200 9	3.96 1.907 9	2.57 1.839 9	2.66 0.890 9	2.30 1.438 9	2.42 1.548 9	1.64 1.475 9	1.70 1.348 9	1.73 1.321 9	3.86 2.446 9	2.69 1.805 9	30.49 9.263 9
CRANDALL CREEK RS	2135	109.67	44.88	2045.108	1.57 0.988 20	0.97 0.584 20	1.01 0.651 20	1.14 0.862 20	1.58 0.700 20	1.85 0.694 20	1.20 0.764 20	1.30 0.846 20	1.57 0.824 20	1.09 0.862 20	0.83 0.543 20	1.24 0.810 20	15.36 2.568 20
CREVICE MOUNTAIN	10D05	110.60	45.03	2560.195													27 7.308
CRYSTAL LAKE	TW01	109.50	46.80	1843.950	2.78 1.017 23	1.89 0.711 23	3.20 1.689 23	3.90 1.510 23	5.86 3.082 23	4.94 2.759 23	2.45 1.966 23	2.70 2.057 23	2.96 1.894 23	2.90 1.640 23	1.97 0.994 23	2.61 1.845 23	38.16 5.225 23
DAISY PEAK*	MC15	110.33	46.67	2316.367	1.17 0.788 13	1.28 0.737 13	1.97 0.677 13	2.38 1.018 13	3.57 1.767 13	2.64 1.142 13	1.91 1.278 13	1.43 0.936 14	1.60 1.135 13	1.02 0.645 13	1.18 0.607 13	1.69 0.740 13	21.72 4.474 13
DEADMAN CREEK	MC09	110.68	46.80	1965.864	2.80 1.538 24	1.85 0.833 24	2.33 0.985 24	2.22 0.783 24	3.03 1.447 24	2.94 1.486 24	1.95 1.258 24	1.86 1.174 24	1.74 1.171 24	1.47 1.082 24	2.16 0.857 24	2.69 1.297 24	27.03 4.542 24
DEEP CREEK PASS 2	2272	111.13	46.37	1658.031	1.15 0.410 12	1.33 0.525 12	1.85 0.438 12	1.82 0.812 12	3.18 1.676 12	2.31 1.154 12	1.91 1.333 12	1.58 0.841 12	1.85 1.249 13	1.13 0.635 13	1.27 0.442 13	1.30 0.535 13	20.49 4.001 12
DENTON 1 NNE	2347	109.95	47.33	1103.322	0.60 0.548 30	0.38 0.245 30	0.63 0.381 29	1.02 0.590 29	3.06 1.737 29	2.65 1.274 29	1.74 1.251 29	1.64 1.251 29	1.48 1.228 29	0.90 0.614 29	0.46 0.295 29	0.60 0.511 29	15.16 3.427 29
DIVIDE	MN07	112.05	44.80	2377.324	2.44 0.102 19	2.00 0.038 19	3.02 0.094 19	2.42 0.101 19	3.18 0.148 19	2.85 0.116 19	1.74 0.140 19	1.62 0.057 19	2.06 0.127 19	1.58 0.079 19	1.94 0.061 19	2.17 0.083 19	27.05 1.838 19
DRIGGS	2676	111.12	43.73	1864.066	1.43 0.821 30	0.96 0.619 30	1.13 0.749 30	1.30 0.877 30	2.00 0.912 28	1.86 1.517 28	1.25 0.915 28	1.15 0.871 28	1.48 1.198 28	1.17 0.836 30	1.26 0.609 30	1.36 0.796 30	16.33 4.153 28

Climate station data continued.

Station Name	Stn. #	Long.	Lat.	Elev. (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
DUBOIS EXP STN	2707	112.20	44.25	1661.079	0.72	0.66	0.86	1.02	1.68	1.81	1.11	1.07	1.11	0.78	1.23	0.93	12.72
					0.493	0.542	0.514	0.867	1.139	1.025	0.893	0.890	0.769	0.616	0.741	0.556	3.165
DUBOIS	2715	109.63	43.57	2108.199	30	30	29	30	30	30	30	30	29	30	29	29	27
					0.30	0.26	0.44	1.06	1.38	1.47	0.89	0.87	1.11	0.58	0.40	0.27	8.88
					0.391	0.337	0.256	0.772	0.864	1.158	0.608	0.636	0.940	0.544	0.337	0.326	2.395
EAGLE CREEK	10C13	110.42	46.22	2133.496	29	30	30	30	30	30	29	29	30	30	30	30	28
																	36
																	8.232
EAST ENTRANCE	09E05	110.00	44.48	2121.304													30
																	23
																	7.479
EDGAR 9 SE	2661	108.72	45.38	1219.141	0.94	0.68	1.25	3.27	3.17	3.58	0.83	1.44	2.18	1.43	0.90	0.77	20.88
					0.488	0.427	0.853	1.852	1.672	3.852	0.559	1.239	1.676	1.223	0.378	0.361	4.344
ELK PEAK	10C07	110.72	46.47	2438.281	14	14	14	14	13	11	13	13	13	13	13	13	11
																	38
																	8.007
ELLISTON	2738	112.43	46.57	1546.785	1.11	0.63	0.85	1.35	1.96	2.71	1.12	1.42	1.42	1.10	0.75	0.91	30
					0.665	0.391	0.283	0.855	0.793	1.491	0.921	0.867	0.894	0.963	0.379	0.473	15.53
					17	17	16	17	17	16	16	16	16	16	16	16	16
EMIGRANT	2778	110.72	45.37	1523.926	0.65	0.35	0.50	0.75	2.02	2.02	1.45	1.03	1.49	0.90	0.73	0.53	12.77
					0.456	0.237	0.473	0.424	0.734	0.832	0.861	0.615	1.268	0.648	0.435	0.324	1.598
					8	8	7	6	7	7	7	6	6	6	7	7	5
ENNIS	2793	111.72	45.35	1509.601	0.36	0.38	0.76	1.17	2.08	2.41	1.31	1.36	1.38	0.94	0.65	0.40	13.10
					0.245	0.295	0.451	0.600	0.980	1.054	0.812	0.794	0.831	0.574	0.346	0.245	2.419
					30	29	29	30	30	30	30	30	30	30	30	30	28
EVENING STAR	S405	109.78	44.65	2804.023	4.16	4.51	3.91	4.44	4.94	3.45	2.85	2.03	2.78	2.76	5.14	4.25	44.50
					2.271	2.716	1.827	1.653	1.833	2.585	1.843	1.275	2.034	1.218	2.086	2.144	8.028
					10	10	10	10	10	10	10	11	11	10	10	10	10
FISHER CREEK	TX06	109.95	45.07	2773.545	8.59	6.11	6.64	5.00	4.77	3.86	2.71	2.36	2.91	3.28	5.99	6.39	58.62
					4.375	2.631	3.480	2.234	2.018	1.579	1.312	1.542	1.688	1.545	2.529	2.632	10.803
					24	24	24	24	24	24	24	24	24	24	24	24	24
FISHTAIL	2996	109.52	45.45	1371.533	0.67	0.63	1.18	1.94	3.62	2.79	1.44	1.29	1.85	1.49	0.90	0.69	18.50
					0.520	0.490	0.714	1.273	1.865	1.990	1.162	0.917	1.396	1.136	0.548	0.490	3.826
					30	30	30	30	30	30	30	30	30	30	30	30	30
FOREST LAKE	10C14	110.43	46.27	1950.625													34
																	7.792
																	30

Climate station data continued.

Station Name	Stn. #	Long.	Lat.	Elev. (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
FORT LOGAN	3157	111.12	46.67	1432.490	0.35	0.22	0.51	0.68	1.71	2.03	1.32	1.32	1.22	0.61	0.37	0.33	10.71
					0.300	0.173	0.300	0.424	0.837	1.149	0.978	0.917	0.775	0.458	0.241	0.245	2.488
					30	30	30	30	28	30	30	30	30	30	29	30	28
FOUR MILE	MH12	111.88	45.52	2103.017	1.80	1.42	2.70	3.19	3.84	3.32	1.77	1.69	1.97	1.93	2.25	1.87	27.86
					0.633	0.791	0.917	1.348	1.546	1.524	1.119	0.899	1.180	1.108	1.169	0.904	4.104
					24	24	24	24	25	25	25	25	24	24	24	24	24
FROHNER MEADOWS	ML13	112.20	46.45	1975.008	2.27	1.56	2.48	2.45	3.20	2.69	1.44	1.83	2.03	1.81	1.78	2.13	25.67
					1.252	0.647	0.803	1.422	2.147	1.474	1.289	1.168	1.470	1.205	0.731	1.053	4.895
					23	23	23	23	23	23	23	23	23	23	23	23	23
GALLATIN GTY10SSW*3366		111.23	45.45	1670.222	1.00	0.92	1.92	2.53	3.86	3.08	1.49	1.77	2.28	2.01	1.31	1.02	22.65
					0.520	0.545	0.930	1.274	1.690	1.506	0.917	1.063	1.651	1.020	0.677	0.648	2.976
					27	27	27	28	28	28	28	29	29	26	27	28	24
GALLATIN GTY 26S	3368	111.25	45.23	1874.476	0.86		0.86	1.22	2.01	1.95	1.26	1.27	2.36	0.74	0.82	0.60	
					0.265	***	0.332	0.610	0.701	0.652	0.725	0.583	1.098	0.453	0.212	0.292	***
					5		5	6	6	5	5	5	5	5	5	5	
GALLATIN GTY26SSW	3372	111.28	45.22	2011.582	1.71	1.12	1.75	1.51	2.61	3.15	1.85	1.77	2.08	1.64	1.50	1.85	22.45
					0.690	0.505	0.867	0.727	1.193	0.980	0.984	0.922	1.002	0.702	0.597	0.845	0.451
					17	17	16	16	16	16	17	17	17	17	17	17	16
GARDINER	3378	110.68	45.03	1607.742	0.43	0.20	0.48	0.57	1.62	1.48	1.20	1.05	1.03	0.76	0.59	0.47	10.40
					0.435	0.228	0.490	0.285	0.690	0.758	0.697	0.802	0.790	0.548	0.354	0.438	1.849
					27	26	24	27	28	25	27	28	26	25	24	18	
GIBSON 2 NE	3486	109.50	46.03	1325.815	0.42	0.40	0.90	1.41	2.86	2.36	1.29	1.44	1.66	1.08	0.66	0.43	14.72
					0.341	0.381	0.702	0.834	1.514	1.711	0.868	1.036	1.022	0.702	0.520	0.341	3.122
					29	29	29	29	29	29	29	29	29	29	30	29	27
GRANITE PASS	X015	107.50	44.63	2773.545	3.14	2.00	2.64	3.12	3.33	3.02	1.90	1.53	2.26	2.59	2.04	2.26	29.71
					1.282	0.885	0.768	0.844	1.662	1.676	1.491	1.576	1.157	0.870	0.968	0.863	4.719
					9	9	9	9	9	9	9	10	10	9	9	9	9
GRASSHOPPER	10C02	110.77	46.52	2133.496													29
																	7.765
																	30
GRASSY LAKE	S302	110.83	44.13	2214.264	7.53	5.74	5.34	4.38	4.36	3.34	1.88	2.09	2.66	3.07	6.33	6.96	53.55
					3.479	2.480	2.453	1.560	1.775	2.160	1.341	1.651	1.675	1.827	2.880	3.261	10.449
					28	28	28	28	28	28	27	27	29	28	28	28	26
GREAT FALLS WSCMO	3751	111.37	47.48	1116.428	0.91	0.57	1.10	1.41	2.52	2.39	1.24	1.54	1.24	0.78	0.66	0.85	15.21
					0.520	0.346	0.574	1.109	1.296	1.396	0.917	1.342	0.900	0.671	0.458	0.490	3.425
					30	30	30	30	30	30	30	30	30	30	30	30	30
GREYBULL	4080	108.05	44.48	1155.136	0.45	0.34	0.36	0.71	1.38	1.15	0.48	0.59	0.84	0.45	0.37	0.36	7.67
					0.678	0.403	0.636	0.572	1.269	0.845	0.355	0.528	0.659	0.543	0.310	0.378	2.417
					29	29	29	29	29	29	29	29	29	29	30	29	25
HARDIN	3915	107.60	45.72	885.401	0.59	0.38	0.51	1.37	1.98	1.93	0.87	0.88	1.42	1.03	0.52	0.49	12.70
					0.603	0.410	0.402	0.940	1.315	1.579	0.545	0.716	1.057	0.028	0.361	0.346	7.322
					28	28	27	26	27	29	27	27	26	27	26	24	22

Climate station data continued.

Station Name	Stn. #	Long.	Lat.	Elev. (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
HARLOWTON	3939	109.83	46.43	1261.810	0.50	0.42	0.66	0.96	2.46	2.73	1.49	1.52	1.25	1.03	0.53	0.46	12.70
					0.458	0.387	0.520	0.648	1.225	1.568	1.054	1.082	0.817	0.856	0.346	0.387	7.291
					30	30	30	30	30	30	30	30	29	30	30	30	29
HAYMAKER	10C11	110.22	46.75	2453.520													32
																	7.682
																	30
HEBGEN DAM*	4038	111.33	44.87	1977.751	3.33	2.49	2.68	1.96	2.61	3.26	1.94	2.05	2.13	1.60	2.74	3.27	30.37
					1.539	1.109	1.661	1.342	1.068	1.606	1.090	1.386	1.273	0.978	1.123	1.549	1.165
					30	30	30	30	30	30	29	30	30	29	30	30	28
HELENA 6 N	4050	112.05	46.67	1158.183	0.48	0.20	0.32	0.75	1.39	1.78	1.04	1.25	0.97	0.52	0.32	0.45	9.49
					0.390	0.138	0.276	0.689	0.767	1.145	0.835	0.859	0.827	0.643	0.232	0.402	3.329
					19	19	19	19	19	19	17	18	18	18	18	18	17
HELENA WSO AP	4055	112.00	46.60	1186.528	0.63	0.41	0.73	0.99	1.78	1.87	1.10	1.29	1.15	0.60	0.48	0.59	11.62
					0.548	0.300	0.387	0.671	1.225	1.010	1.025	0.980	0.917	0.574	0.300	0.346	3.175
					30	30	30	30	30	30	30	30	30	30	30	30	30
HOBSON	4193	109.87	47.00	1243.523	0.81	0.40	0.72	0.98	2.90	2.80	1.33	1.32	1.12	0.89	0.64	0.63	15.00
					0.580	0.268	0.429	0.580	1.840	1.445	0.967	1.094	0.817	0.547	0.363	0.455	3.095
					24	24	23	24	24	24	24	23	23	23	22	23	21
HOLTER DAM	4241	112.02	47.00	1062.786	0.44	0.29	0.51	1.14	2.23	1.91	1.34	1.30	1.29	0.58	0.37	0.42	11.71
					0.300	0.173	0.245	0.714	1.308	1.263	1.039	1.054	1.025	0.671	0.245	0.346	3.027
					30	30	30	30	30	29	30	30	30	30	30	30	29
HOOD MOUNTAIN	10D03	110.97	45.48	2011.584													29
																	7.909
																	30
HUNTLEY EXP STN*	4345	108.25	45.92	911.308	0.63	0.47	0.81	1.55	2.44	2.26	0.95	1.25	1.55	0.99	0.65	0.64	14.18
					0.458	0.424	0.600	0.980	1.386	1.549	0.671	0.883	1.187	0.735	0.520	0.458	3.250
					30	30	30	30	30	30	30	30	30	30	30	30	30
IDAHO FALLS FAAAP	4457	112.07	43.52	1441.634	0.81	0.76	0.81	1.01	1.39	1.24	0.62	0.70	0.86	0.82	0.99	0.85	10.85
					0.456	0.577	0.426	0.750	0.907	0.858	0.524	0.592	0.742	0.630	0.634	0.491	2.577
					30	30	30	30	30	30	30	30	30	30	30	30	30
INDEPENDENCE	10D06	110.25	45.22	2392.563													36
																	9.196
																	30
IRISH ROCK	S407	109.33	44.05	2925.937	0.78	1.24	1.69	2.49	2.70	1.96	1.99	1.23	1.71	1.23	1.47	1.13	19.62
					0.563	1.312	0.606	1.305	1.365	0.769	0.936	0.483	0.897	1.004	0.835	0.587	2.446
					10	10	10	10	10	10	10	10	10	10	10	10	10
ISLAND PARK	4598	111.37	44.42	1917.098	4.00	3.12	2.75	2.25	2.30	2.70	1.54	1.70	1.93	1.80	2.93	3.56	31.70
					2.520	1.579	1.670	1.176	1.263	1.585	1.096	1.296	1.159	1.221	1.619	2.167	6.513
					29	29	30	29	28	29	29	28	28	29	28	29	26
ISLAND PARK SNOT	S332	111.38	44.42	1917.098	3.29	3.29	3.32	2.16	2.54	2.01	1.91	1.31	1.42	1.76	3.99	3.22	30.22
					1.504	1.462	1.413	1.274	0.843	1.511	1.084	0.774	1.032	1.315	1.634	1.764	8.250
					9	9	9	9	9	9	9	9	9	9	9	9	9

Climate station data continued.

Station Name	Stn. #	Long.	Lat.	Elev. (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
JACK CREEK	11D05	111.55	45.33	2026.821													14.5 4.069 23
JARDINE	4462	110.63	45.07	1965.864	1.93	1.25	0.81	1.22	1.92	3.07	1.56	1.28	1.88	1.17	1.32	1.80	20.16
					1.806	0.592	0.502	0.378	0.782	2.550	1.453	1.164	1.330	0.820	0.812	1.915	7.941
JOHNSON PARK	MC12	110.35	46.63	1965.864	14	13	14	13	13	12	12	12	13	14	12	13	10
					1.24	1.20	1.98	1.98	3.29	2.56	1.84	1.30	1.39	0.89	1.09	1.68	20.48
					0.899	0.645	0.817	0.711	1.445	1.147	1.290	0.902	1.074	0.559	0.527	0.996	4.560
JOLIET	4506	108.97	45.48	1127.705	13	13	13	13	13	13	13	14	14	13	13	13	13
					0.75	0.60	1.21	1.92	3.27	2.05	0.96	1.17	1.67	1.33	0.73	0.67	16.71
					0.511	0.410	0.755	1.200	2.071	1.549	0.671	0.964	1.263	0.949	0.424	0.424	3.257
JUDITH GAP	4538	109.75	46.68	1429.442	29	28	30	30	30	30	30	30	29	30	30	30	27
					0.78	0.51	0.79	1.22	3.00	2.91	1.88	1.64	1.29	0.85	0.46	0.51	15.50
					0.636	0.341	0.548	0.831	1.849	1.578	1.109	1.149	0.866	0.539	0.381	0.529	3.849
KILGORE	11E12	111.90	44.40	1926.242	27	29	30	30	30	30	30	30	30	29	29	28	23
																	26
																	8.770
KINGS HILL	10C01	110.70	46.85	2285.888													30
																	40
																	10.501
																	30
KINGS HILL	4663	110.70	46.83	2227.979	***	***	***	***	3.03		2.96	1.53					
									1.353	***	1.268	0.569	***	***	***	***	***
									5		6	6					
KIRWIN	S462	109.32	43.87	2910.698	1.61	1.79	2.09	2.41	2.82	2.27	3.11	1.86	2.73	1.53	2.29	1.29	25.80
					1.289	2.098	0.491	1.231	0.957	0.772	1.553	0.795	1.582	0.826	1.196	0.827	4.297
					10	10	10	10	10	10	10	10	10	10	10	10	10
LAKE CREEK	11E22	111.58	44.83	1859.189													15.50
																	4.560
																	30
LAKE YELLOWSTONE	5345	110.40	44.55	2368.180	1.99	1.47	1.57	1.35	1.84	2.12	1.58	1.83	1.87	1.32	1.74	1.73	20.42
					1.187	1.032	0.882	0.683	0.981	1.224	1.057	1.055	1.107	1.086	0.844	0.975	3.758
					30	30	30	30	30	30	30	30	30	30	30	30	30
LAKEVIEW	4820	111.80	44.60	2045.108	1.41	0.88	1.79	1.57	2.33	3.05	1.75	1.63	1.93	1.28	1.40	1.36	20.36
					1.514	0.722	1.396	0.964	1.439	1.568	1.364	0.980	1.480	0.917	0.883	0.976	4.294
					29	29	30	30	30	30	30	30	30	30	30	28	27
LAKEVIEW CANYON	11E04	111.82	44.58	2112.161													27
																	10.50
																	30

Climate station data continued.

Station Name	Stn. #	Long.	Lat.	Elev. (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
LAKEVIEW RIDGE	MI03	111.83	44.58	2255.410	2.62	1.76	3.08	2.50	3.49	4.43	2.37	2.29	2.70	2.09	2.57	2.37	32.26
					2.289	1.323	2.169	1.456	2.047	2.667	1.743	1.512	2.233	1.468	1.555	1.537	6.497
					30	30	30	30	30	30	30	30	30	30	30	30	30
LAMAR RANGER STN	5355	110.23	44.90	1971.960	1.08	0.79	0.70	0.92	1.41	2.04	1.38	1.53	1.69	1.01	0.90	1.12	14.56
					0.571	0.597	0.448	0.696	0.688	1.028	0.595	0.797	1.149	0.568	0.369	0.626	2.640
					20	20	20	20	20	20	20	20	20	20	20	20	20
LAUREL	4894	108.78	45.67	1008.839	0.80	0.48	0.99	1.60	2.79	2.07	1.01	1.17	1.76	1.14	0.70	0.75	15.05
					0.524	0.443	0.592	1.127	1.676	1.636	0.854	1.049	1.640	0.978	0.456	0.535	3.221
					25	28	27	27	27	25	27	25	28	29	26	26	19
LENNEP 6 WSW	4954	110.68	46.40	1792.137	1.01	0.71	0.97	1.09	2.42	2.61	1.62	1.47	1.47	1.12	0.90	0.88	16.28
					0.693	0.387	0.575	0.693	1.212	1.396	0.995	0.812	0.933	0.812	0.490	0.600	3.113
					30	30	30	30	30	30	30	30	30	30	30	30	30
LEWIS LAKE DIVIDE	S097	110.67	44.20	2392.563	8.73	6.26	6.16	4.49	3.66	3.15	1.74	2.01	2.33	2.94	7.06	7.17	55.71
					4.269	3.156	3.016	1.731	1.488	1.754	0.999	1.442	1.541	1.800	3.547	3.772	12.241
					27	27	27	27	27	27	27	27	27	27	27	27	27
LICK CREEK	MD13	110.97	45.50	2090.826	2.55	2.22	3.74	4.08	4.77	3.60	1.75	2.12	2.48	2.52	2.40	2.48	34.60
					0.968	1.062	1.445	1.922	1.813	1.530	1.154	1.106	1.268	1.352	0.874	1.194	5.270
					26	26	26	26	26	26	26	26	26	26	26	26	26
LITTLE PARK	11D10	111.33	45.30	2255.410													37
																	9.013
																	30
LITTLE WARM	S305	109.75	43.50	2855.837	2.18	1.76	2.40	2.93	2.91	1.80	1.93	1.59	2.26	1.73	2.63	2.03	26.14
					1.217	1.679	1.020	1.173	0.760	1.069	1.179	0.872	1.379	1.105	0.949	1.068	4.453
					11	11	11	11	11	11	11	11	11	11	11	11	11
LIVINGSTON	5076	110.57	45.67	1368.485	0.89	0.47	1.07	1.34	2.66	2.37	1.33	1.14	1.60	1.41	0.93	0.48	15.99
					0.497	0.424	0.680	0.950	1.390	0.950	0.827	0.657	0.965	0.861	0.707	0.308	3.027
					19	20	21	21	21	21	19	18	19	19	20	19	15
LIVINGSTON 12 S	5080	110.57	45.48	1484.304	0.70	0.48	1.06	1.29	2.96	2.55	1.51	1.58	1.91	1.38	0.91	0.66	16.92
					0.424	0.245	0.735	0.831	1.285	1.109	0.866	0.831	1.095	0.817	0.511	0.458	2.672
					30	30	30	30	30	30	30	30	30	29	29	30	28
LIVINGSTON FAA AP	5086	110.45	45.70	1418.165	0.61	0.45	0.88	1.44	2.90	2.46	1.38	1.39	1.69	1.27	0.76	0.45	15.69
					0.574	0.424	0.458	0.849	1.418	1.162	0.900	0.883	0.933	0.775	0.574	0.245	2.939
					30	30	30	30	30	30	30	30	30	30	30	30	30
LOVELL	5770	108.40	44.83	1169.461	0.24	0.15	0.26	0.61	1.38	1.22	0.67	0.75	0.81	0.52	0.26	0.23	7.16
					0.228	0.193	0.243	0.490	0.947	0.954	0.532	0.599	0.714	0.548	0.198	0.221	1.761
					30	30	30	30	30	30	30	30	30	30	30	30	30
LOWER TWIN	MH11	111.92	45.50	2407.802	3.05	2.90	4.43	4.38	5.64	3.95	2.48	2.39	2.66	2.74	3.56	3.26	41.44
					1.324	1.436	1.305	1.817	2.021	1.694	1.648	1.433	1.813	1.665	1.714	1.567	5.837
					14	14	14	14	14	14	14	14	14	14	14	14	14

Climate station data continued.

Station Name	Stn. #	Long.	Lat.	Elev. (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
LOWER WILLOW CK	MQ35	111.33	46.57	1444.681	0.73	0.70	0.70	0.83	0.74	1.07	1.19	1.93	1.55	1.19	1.22	1.13	12.99
					0.664	0.458	0.324	0.597	0.458	0.502	0.632	1.221	1.168	0.939	0.928	0.869	3.448
LUCKY DOG	11E14	111.22	44.48	2090.826	21	21	21	21	21	21	21	21	21	21	21	21	21
																	42
																	11.165
LUPINE CREEK	10E01	110.62	44.92	2249.314													30
																	27
																	8.310
																	30
MADISON PLATEAU*	MI31	111.12	44.58	2362.085	5.67	4.37	5.01	3.08	3.54	2.91	1.64	1.88	2.18	2.40	4.32	4.60	41.59
					3.208	1.865	2.618	1.627	2.074	1.559	0.892	1.391	1.535	1.505	2.356	2.375	7.854
					23	23	23	23	23	23	23	23	23	23	23	23	23
MANHATTAN	5351	111.33	45.87	1289.241	0.60	0.43	0.86	1.02	2.22	2.43	1.11	1.08	1.45	0.91	0.69	0.47	13.04
					0.363	0.297	0.574	0.455	1.062	0.994	0.785	0.632	0.914	0.615	0.435	0.290	2.474
					22	22	22	23	23	23	22	21	22	21	21	21	18
MARQUETTE CREEK	S464	109.23	44.30	2669.918	0.88	1.33	2.17	3.41	3.70	2.41	2.24	1.52	2.45	1.65	1.73	1.24	24.52
					0.405	0.720	0.738	2.113	1.402	1.361	1.035	0.836	1.557	1.200	0.806	0.878	3.823
					10	10	10	10	10	10	10	11	11	10	10	10	10
MARTINSDALE 3 NNW	5387	110.33	46.50	1462.969	0.59	0.31	0.67	0.92	2.43	2.18	1.63	1.47	1.31	0.71	0.50	0.50	13.23
					0.502	0.290	0.510	0.735	1.616	1.082	0.854	0.949	0.851	0.451	0.335	0.381	2.609
					28	28	26	30	30	30	27	30	29	29	28	29	23
MARYSVILLE 3	5405	112.30	46.75	1639.744	1.98	1.20	1.31	2.07	3.04	3.49	1.13	1.04	1.79	1.15	1.30	1.78	21.81
					1.022	0.363	0.378	0.593	1.723	1.688	0.734	0.778	1.509	0.792	0.520	1.281	3.901
					11	11	11	11	11	11	11	11	11	11	9	10	9
MAYNARD CREEK	MD18	110.90	45.82	1892.716	3.69	2.76	3.60	4.00	5.40	4.95	2.44	2.73	3.51	3.06	3.40	3.21	42.70
					1.744	0.971	1.188	1.539	1.729	2.017	1.766	1.886	2.191	2.001	1.597	1.389	7.710
					30	30	30	30	30	30	30	30	30	30	30	30	30
MCLEOD 12 SSW	5540	110.23	45.50	1597.074	***	***	***	***	***	***	1.82	2.50	1.87	1.48	1.18	***	***
											0.319	2.087	0.964	0.861	0.675	***	***
											6	7	7	7	6	***	***
MELVILLE 4 W	5603	110.05	46.10	1635.172	0.67	0.47	1.10	1.45	2.88	2.90	1.68	1.65	1.53	1.00	0.82	0.53	16.69
					0.648	0.387	0.648	0.883	1.559	1.881	1.136	1.162	1.054	0.755	0.600	0.346	3.503
					30	30	30	30	30	30	30	30	30	30	30	30	30
MENARD 3 NE	5608	111.13	46.02	1540.079	0.65	0.51	0.96	1.07	2.35	2.57	1.26	1.43	1.64	1.05	0.77	0.66	15.18
					0.410	0.290	0.473	0.493	1.207	1.180	0.868	0.742	1.117	0.722	0.381	0.443	3.054
					28	28	28	27	27	29	29	29	29	29	29	28	25
MIDDLE MILL CK	11D15	111.98	45.48	2392.563													34
																	8.299
																	30
MILL CREEK	MD19	110.40	45.25	2285.888	1.95	1.50	2.50	2.22	4.02	2.56	2.17	1.68	2.08	1.64	1.84	2.18	26.35
					1.030	0.694	0.633	0.919	1.761	0.778	1.046	0.893	1.727	1.089	0.752	1.329	2.790
					17	17	17	17	17	17	17	17	17	17	17	17	17

Climate station data continued.

Station Name	Stn. #	Long.	Lat.	Elev. (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
MILLEGAN 14 SE	5712	111.17	46.88	1514.782	0.65	0.72	1.37	1.39	2.52	1.62	1.81	1.86	1.82	0.82	0.63	0.76	15.23
					0.310	0.417	0.346	0.610	1.079	0.797	1.530	1.180	1.256	0.597	0.365	0.279	1.000
					6-	6	6	6	6	6	6	7	6	7	7	6	5
MOCN EXP STN	5761	109.95	47.05	1310.576	0.66	0.50	0.87	1.24	3.14	3.07	1.78	1.74	1.46	0.91	0.59	0.59	16.54
					0.458	0.346	0.424	0.614	1.625	1.319	1.082	1.149	1.109	0.600	0.346	0.424	3.258
					30	30	30	29	30	30	30	30	30	30	30	30	29
MONIDA	5811	112.32	44.57	2067.967	0.90	0.86	1.07	1.05	1.61	2.07	1.19	1.29	1.25	0.84	0.77	0.95	13.88
					0.600	0.831	0.755	0.866	1.054	1.249	1.285	0.900	0.933	0.762	0.443	0.785	3.455
					30	30	30	30	30	30	30	30	30	29	28	28	27
MONUMENT PEAK	MD12	110.23	45.22	2697.348	3.39	3.21	3.62	2.97	4.47	2.91	2.21	1.99	2.22	2.29	3.64	3.81	36.72
					1.373	1.927	1.545	1.058	1.650	1.079	1.193	1.237	1.607	1.120	1.352	2.094	6.276
					14	14	14	14	14	14	14	14	14	14	14	14	14
MOOSE	6428	110.72	43.67	1971.960	2.57	1.92	1.55	1.44	1.89	1.76	1.20	1.34	1.45	1.26	2.23	2.48	21.25
					1.222	1.025	1.035	0.755	1.036	0.911	0.831	0.954	1.037	0.744	1.174	1.597	4.552
					30	30	29	30	30	30	30	29	30	30	30	30	28
MORAN	6440	110.58	43.85	2069.491	3.28	2.27	2.00	1.88	2.06	1.61	1.22	1.21	1.59	1.48	2.79	2.91	24.30
					1.488	1.375	1.200	0.819	0.817	0.788	0.906	0.705	1.052	0.918	1.457	1.884	4.872
					30	30	30	30	30	30	30	30	30	30	30	30	30
MOULTON RES	ML20	112.50	46.08	2042.060	1.26	1.32	1.79	1.97	2.85	2.12	1.73	1.37	1.57	1.21	0.95	1.30	19.44
					0.660	0.674	0.601	1.118	2.018	1.392	1.368	0.779	1.236	0.678	0.638	0.823	6.155
					14	14	14	14	14	14	14	14	14	14	14	14	14
MYSTIC LAKE	5961	109.75	45.23	1998.781	1.43	1.23	2.06	2.72	3.69	2.98	2.21	1.90	2.26	1.80	1.55	1.26	25.11
					0.917	0.755	1.025	1.616	1.688	1.396	0.933	0.995	1.249	1.162	0.831	0.775	4.271
					30	30	30	30	30	30	30	30	30	30	30	30	30
NEIHART 8 NNW	6008	110.78	47.05	1594.026	1.09	0.68	1.43	1.59	3.67	3.09	1.87	2.05	2.06	1.40	1.02	1.19	21.36
					0.567	0.392	0.711	0.871	2.560	1.569	1.249	1.428	1.333	0.790	0.537	1.051	4.629
					23	22	23	23	23	23	24	24	24	24	24	24	22
NEW WORLD	10D01	110.92	45.57	2103.017													36
																	6.708
																	30
NORRIS 3 ENE	6153	111.65	45.58	1462.969	0.43	0.37	1.15	1.56	2.87	2.70	1.07	1.11	2.00	1.55	0.85	0.29	15.79
					0.447	0.346	0.910	0.859	1.371	1.673	0.735	0.600	1.559	0.906	0.548	0.268	3.165
					20	20	18	18	20	20	20	20	19	20	20	18	16
NORRIS BASIN	10E19	110.70	44.75	2301.128													32
																	9.063
																	30
NORRIS MADISON PH	6157	111.63	45.48	1446.205	0.56	0.47	1.31	1.71	3.17	2.77	1.52	1.53	1.77	1.35	0.91	0.57	17.69
					0.346	0.458	0.714	0.794	1.568	1.319	1.149	0.755	1.090	0.849	0.600	0.387	3.042
					30	30	30	30	30	30	30	30	29	30	30	30	29
NORTH MEADOW	11D03	111.93	45.55	2285.888													29
																	29
																	6.731
																	30

Climate station data continued.

Station Name	Stn. #	Long.	Lat.	Elev. (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
NORTHEAST ENT	MD07	110.00	45.00	2240.171	2.53	1.84	1.71	2.00	2.66	2.57	2.10	1.90	2.23	1.53	2.18	2.10	25.35
					1.417	0.818	0.859	1.458	1.166	1.071	1.027	1.058	1.369	0.860	0.910	1.098	4.516
NOTCH	12E06	112.13	44.88	2590.674	30	30	30	30	30	30	30	30	30	30	30	30	30
																	32
																	8.425
NYE 5 NE	6190	109.80	45.45	1478.208	0.56	0.79	1.55	2.07	2.71	2.54	2.04	1.30	1.83	1.23	0.81	0.67	18.30
					0.329	0.474	0.805	1.280	1.134	1.114	1.321	0.768	1.407	0.812	0.574	0.424	3.354
OLD FAITHFUL	6845	110.82	44.45	2255.410	9	9	9	9	9	9	9	10	10	10	10	10	9
					2.76	2.06	2.34	1.96	2.49	3.01	1.85	1.96	2.29	1.75	2.80	2.76	28.04
					1.666	1.107	1.314	1.151	1.026	1.607	1.038	1.494	1.573	1.217	1.599	1.677	6.217
OWL CREEK	S465	109.02	43.67	2735.447	30	30	30	30	30	30	30	30	30	30	30	30	30
					0.76	0.84	1.62	1.85	2.52	1.87	1.88	1.06	1.59	1.03	0.94	0.72	16.79
					0.445	0.849	0.889	1.279	1.286	1.069	1.302	0.572	1.284	0.673	0.497	0.358	2.683
PARKER PEAK	S409	109.92	44.73	2864.980	10	10	10	10	10	10	10	10	11	10	10	10	10
					2.69	2.82	2.79	3.13	3.92	3.04	2.09	1.65	2.27	2.33	3.15	2.44	31.84
					1.801	1.221	1.394	0.973	1.196	1.581	1.356	0.854	1.638	1.354	1.189	1.066	6.460
PHILLIPS BENCH	S100	110.92	43.52	2499.238	10	10	10	10	10	10	10	11	11	10	10	10	10
					5.16	4.66	5.31	3.42	3.68	1.90	1.42	1.28	2.40	2.12	5.08	5.43	43.35
					2.088	3.572	1.871	1.459	1.552	1.476	1.098	0.822	1.470	1.149	3.160	3.341	9.401
PICKET PIN LOWER	TX13	109.93	45.43	1889.668	11	13	14	14	12	14	12	11	11	12	13	11	8
					1.34	1.08	2.24	2.68	3.78	1.91	1.67	1.43	1.48	1.73	1.73	1.25	22.34
					0.626	0.439	0.754	1.433	1.909	0.986	1.150	0.857	0.913	1.012	0.881	0.617	3.615
PICKET PIN MIDDL	09D12	109.98	45.43	2209.692	18	18	18	18	18	18	18	18	18	18	18	18	18
																	30
																	14.604
PICKET PIN UPPER	MD28	110.03	45.45	2468.760	2.46	1.99	3.96	4.29	6.21	3.28	2.27	2.06	2.11	2.80	2.88	2.39	36.70
					1.073	0.876	1.223	1.923	3.065	1.414	1.262	1.052	1.350	1.398	1.285	0.998	4.838
PICKFOOT CREEK	MG02	111.27	46.58	2026.821	18	18	18	18	18	18	18	18	18	18	18	18	18
					2.18	2.24	3.16	2.77	4.02	2.71	2.21	1.50	2.45	1.85	2.78	2.65	30.79
					1.102	0.800	0.798	0.988	2.643	1.231	1.764	0.884	1.730	1.041	0.944	1.332	4.873
PIKES GULCH	MG03	111.67	46.85	1917.098	13	13	13	13	13	14	14	14	14	13	13	13	13
					1.06	1.22	2.00	1.92	2.54	2.09	2.18	1.49	2.27	1.18	1.60	1.32	21.85
					0.548	0.588	0.922	0.738	1.120	1.242	1.915	1.160	1.374	0.741	0.506	0.691	6.219
PLACER BASIN	MD24	110.10	45.42	2691.253	8	8	8	7	8	8	8	8	7	8	8	8	7
					2.52	2.20	4.11	3.59	6.45	2.89	2.34	2.07	2.31	2.68	3.14	2.48	36.77
					1.150	1.038	1.217	1.541	3.913	0.925	1.353	1.216	1.445	1.096	1.194	1.161	4.645
PONY	6655	111.90	45.67	1699.177	14	14	14	14	14	14	14	14	14	14	14	14	14
					0.64	0.62	1.42	1.78	3.07	2.43	1.35	1.41	1.98	1.16	1.00	0.69	17.50
					0.456	0.410	0.615	0.885	1.468	1.723	1.155	0.933	1.605	0.735	0.710	0.367	4.217
					26	28	27	27	28	28	29	29	28	27	28	27	20

Climate station data continued.

Station Name	Stn. #	Long.	Lat.	Elev. (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
PIPESTONE PASS	12D01	112.45	45.85	2194.453													21 5.176 30
PORCUPINE*	MC03	110.47	46.12	1981.103	1.76 0.825 15	1.78 0.661 15	2.65 1.097 15	2.46 1.323 15	4.10 1.886 15	2.74 1.524 15	1.61 0.966 15	1.86 1.036 15	2.55 1.785 15	2.00 1.350 15	2.02 0.694 15	1.77 0.872 15	27.28 3.911 15
POTOMAGETON PARK	11E21	111.37	44.92	2179.214													31 8.238 30
POWELL	7388	108.75	44.78	1331.911	0.23 0.241 30	0.14 0.190 30	0.21 0.176 30	0.52 0.453 30	1.49 0.925 30	1.29 1.006 30	0.80 0.560 30	0.67 0.472 30	0.87 0.708 30	0.40 0.427 30	0.22 0.190 30	0.18 0.225 30	7.04 1.378 30
PRYOR*	6747	108.38	45.43	1219.141	0.77 0.473 28	0.63 0.387 30	1.12 0.574 30	2.05 1.459 30	3.31 2.135 30	2.37 1.758 30	1.14 1.054 30	1.20 0.995 30	1.73 1.490 30	1.40 1.097 28	0.82 0.482 29	0.66 0.473 28	17.37 3.816 26
RAPELJE 4 S	6862	109.25	45.92	1257.239	0.69 0.548 30	0.58 0.574 30	1.08 0.690 28	1.31 0.933 30	2.80 1.485 29	2.35 1.723 30	1.33 0.993 29	1.31 1.136 30	1.45 0.980 30	1.17 0.866 30	0.76 0.548 30	0.59 0.458 30	15.46 3.608 28
RAYNESFORD	6900	110.73	47.28	1286.193	0.69 0.445 9	0.39 0.297 8	0.50 0.544 8	1.17 0.639 8	3.36 1.587 9	4.25 1.979 9	1.43 0.832 9	1.43 1.000 9	1.89 1.863 8	1.23 0.913 7	0.69 0.335 7	0.86 0.961 6	17.63 4.076 5
RAYNESFORD 2 NNW	6902	110.75	47.30	1286.193	0.83 0.510 20	0.70 0.374 20	1.26 0.566 20	1.44 0.872 20	3.14 1.769 21	2.48 1.336 21	1.62 1.113 21	1.85 1.359 21	1.76 1.195 21	1.18 0.680 21	0.77 0.410 21	0.91 0.458 21	17.93 3.876 20
RED LODGE	6918	109.25	45.18	1699.177	1.66 1.082 30	1.28 0.755 30	2.59 1.319 30	3.40 2.177 30	4.01 2.049 30	2.89 1.897 30	1.38 0.849 30	1.47 1.123 30	2.46 1.817 30	1.80 1.095 30	1.56 0.900 30	1.35 0.831 30	25.83 4.579 30
RIMINI 4 NE	7055	112.17	46.55	1432.490	0.96 0.701 6	1.04 0.595 6	1.57 0.508 6	1.65 0.496 6	2.46 1.263 6	2.43 *** 5	2.18 2.362 6	2.18 1.547 7	2.18 1.721 7	0.95 0.680 7	1.23 0.685 7	0.90 0.374 7	*** *** ***
ROBERTS 1 N	7128	109.18	45.37	1423.347	0.67 0.520 30	0.48 0.346 30	0.95 0.482 29	1.55 1.167 29	3.26 1.726 28	2.14 1.561 28	0.96 0.690 28	1.16 0.869 28	1.69 1.394 29	1.21 1.010 30	0.65 0.424 30	0.52 0.346 30	15.25 3.454 28
ROCK CREEK MEAD*	MH21	111.08	45.18	2487.047	2.34 1.035 15	2.15 0.861 15	2.97 1.201 15	2.17 0.978 15	4.13 1.488 15	3.19 1.434 15	1.79 1.103 15	1.61 0.834 15	2.41 1.699 15	2.41 2.439 15	2.43 1.269 15	2.38 1.185 15	29.97 5.904 15
ROCKER PEAK	ML11	112.25	46.37	2438.281	3.20 1.546 23	2.22 0.799 23	3.44 0.826 23	3.54 1.759 23	4.01 2.290 23	2.76 1.406 23	1.68 1.186 23	2.17 1.502 23	2.30 1.475 23	1.89 1.450 23	2.19 0.915 23	2.91 1.282 23	32.33 5.543 23
ROGERS PASS 6 NNE	7159	112.32	47.17	1353.246	0.96 0.806 25	0.67 0.418 25	1.44 0.954 26	1.80 1.280 26	3.19 1.885 24	2.84 2.057 23	1.48 1.478 26	1.84 1.604 26	1.83 1.770 27	1.02 1.052 27	0.75 0.465 27	1.13 0.900 27	18.99 4.673 21

Climate station data continued.

Station Name	Stn. #	Long.	Lat.	Elev. (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Dec	Annual	
ROUNDUP	7214	108.53	46.45	983.542	0.44	0.36	0.58	1.03	2.39	2.20	1.30	1.32	1.32	0.89	0.32	0.41	12.81
					0.458	0.387	0.574	0.614	1.470	1.670	1.109	0.978	1.039	0.849	0.295	0.381	3.520
					30	30	30	29	30	30	30	29	30	30	29	29	27
ST. ANTHONY 1 WNW	8022	111.72	43.97	1508.686	1.23	0.92	0.93	1.15	1.67	1.57	0.89	0.80	1.07	0.98	1.37	1.37	14.12
					0.578	0.670	0.487	0.819	1.212	1.112	0.820	0.844	0.748	0.808	0.731	0.740	3.298
					29	29	28	29	29	29	28	29	29	29	29	29	27
SACAJAWEA	10D10	110.93	45.87	1996.343													34
																	8.436
SENTINEL CREEK	11E20	111.38	44.97	2529.717													30
																	36
																	8.610
SHELL	8124	107.77	44.53	2710.824	0.60	0.36	0.58	0.99	1.56	1.74	0.70	0.69	1.28	0.81	0.52	0.53	30
					0.476	0.269	0.370	0.887	1.126	1.421	0.486	0.743	0.941	0.800	0.232	0.482	10.30
					23	23	24	25	24	23	23	24	25	24	26	25	2.843
SHOWER FALLS	MD16	110.95	45.40	2468.760	4.54	3.89	5.69	5.60	6.53	5.30	2.76	2.49	3.73	3.50	3.92	4.00	16
					1.834	1.209	1.726	1.978	2.273	2.069	1.308	1.348	2.077	2.001	1.317	1.831	51.95
					26	26	26	26	26	26	26	26	26	26	26	26	7.492
SILVER RUN	TX18	109.35	45.15	2020.725	0.99	1.11	2.05	2.15	3.94	2.04	1.28	1.38	1.65	1.41	1.28	1.08	20.37
					0.437	0.490	0.895	1.666	2.622	0.920	0.712	0.665	1.486	0.800	0.540	0.571	2.994
					15	15	15	15	15	15	15	15	15	15	15	15	15
SIMMS 1 NE	7618	111.92	47.50	1094.179	0.23	0.33	0.65	0.96	1.71	1.39	1.75	2.42	1.34	0.50	0.30	0.46	
					0.190	0.245	0.339	0.629	0.634	0.452	1.192	2.096	1.045	0.313	0.141	0.232	***
					6	6	5	6	6	6	6	6	7	7	5	6	
SMUGGLER MINE	12D05	112.03	45.48	2121.304													27
																	6.525
																	30
SNAKE RIVER*	8315	110.67	44.13	2109.113	4.02	2.98	2.54	2.22	2.51	2.63	1.60	1.77	1.98	2.08	3.34	3.82	31.50
					1.868	1.625	1.010	1.011	1.059	1.543	0.976	0.953	1.231	1.128	1.361	2.286	5.591
					30	30	30	30	30	30	30	30	30	30	30	30	30
SOUTH FK SHIELD	MC08	110.43	46.08	2468.760	3.08	3.48	5.06	4.52	5.88	4.07	2.28	2.56	3.02	2.71	3.48	3.18	43.30
					1.218	0.866	1.309	1.697	1.830	2.256	1.282	1.373	1.821	1.747	1.205	1.459	7.157
					12	12	12	12	12	12	12	12	12	12	12	12	12
SPRINGDALE	7800	110.23	45.73	1286.498	0.45	0.32	0.75	1.18	2.62	2.23	1.16	1.06	1.56	1.22	0.64	0.40	13.89
					0.346	0.241	0.482	0.883	1.622	1.490	0.671	0.742	0.868	0.785	0.490	0.341	2.841
					30	29	29	26	28	30	30	29	29	28	30	29	23
SPUR PARK	MC06	110.62	46.78	2468.760	4.80	3.42	4.14	3.56	4.24	3.44	2.39	2.37	2.07	2.38	3.20	4.58	40.58
					2.426	1.310	1.258	1.184	1.839	1.416	1.373	1.440	1.420	1.521	1.225	2.088	7.164
					24	24	24	24	24	24	24	24	24	24	24	24	24
STANFORD	7864	110.22	47.15	1481.256	0.72	0.48	0.88	1.37	3.08	3.00	1.78	1.72	1.50	0.90	0.56	0.63	15.79
					0.522	0.379	0.535	0.962	1.643	1.469	1.406	1.270	1.032	0.625	0.371	0.402	3.069
					21	24	26	25	25	26	26	26	26	26	23	18	15

Climate station data continued.

Station Name	Stn. #	Long.	Lat.	Elev. (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
STEMPLE PASS	12C01	112.48	46.88	2011.582													30 8.159
SUN RIVER 4 S	8021	111.73	47.48	1097.226	0.49	0.32	0.68	1.04	2.17	2.21	1.39	1.43	1.08	0.66	0.48	0.47	12.70
					0.295	0.241	0.482	0.834	1.123	1.520	0.995	1.308	0.834	0.729	0.387	0.295	13.775
SUNSHINE 2 ENE	8758	108.98	44.05	1964.035	29	29	29	29	30	30	30	30	29	28	30	29	25
					0.37	0.36	0.99	1.77	2.59	2.42	1.46	1.27	1.45	0.92	0.60	0.47	14.84
					0.387	0.304	0.641	1.136	1.696	1.356	1.084	0.993	1.210	0.800	0.460	0.456	2.607
SYLVAN LAKE	S310	110.15	44.48	2566.291	30	29	30	30	30	30	30	30	30	30	30	30	29
					3.10	3.32	3.09	3.45	4.70	2.34	2.16	1.66	2.45	2.78	4.47	3.46	36.59
					1.356	2.480	1.263	1.223	1.989	1.381	1.031	0.895	1.795	1.959	1.521	1.651	7.550
TAYLOR PEAKS	MH13	111.45	45.02	2590.674	10	10	10	10	10	10	10	11	11	10	10	10	
					4.77	3.36	4.67	3.71	4.28	5.15	2.22	2.56	3.38	2.70	3.35	4.28	44.44
					1.771	1.422	1.740	1.443	1.620	2.404	1.261	1.542	1.755	1.320	1.156	1.705	7.819
TEN MILE LOWER	12C02	112.28	46.45	2011.582	24	24	24	24	24	24	24	24	24	24	24	24	24
																	23
																	5.532
TEN MILE MIDDLE	12C03	112.30	46.43	20725.39													30
																	33
																	7.193
TEN MILE UPPER	12C04	112.28	46.42	2438.281													30
																	36
																	8.533
TEPEE CREEK	MI24	111.70	44.78	2438.281	2.72	2.37	3.23	2.67	2.84	2.40	2.08	1.70	1.98	1.54	2.73	2.72	30
					1.470	1.232	1.571	1.633	1.315	1.390	1.432	1.129	1.400	1.123	1.313	1.264	28.98
					19	19	19	19	19	19	19	19	19	19	19	19	19
THERMOPOLIS 2	8880	108.22	43.65	1341.055	0.45	0.62	0.90	1.62	2.37	1.66	0.71	0.71	1.17	1.12	0.65	0.56	12.54
					0.279	1.295	0.607	0.948	2.004	1.331	0.528	0.585	1.154	0.858	0.544	0.427	3.800
					30	30	30	30	30	30	30	30	30	30	30	30	30
THREE FORKS	MH20	111.55	45.88	1241.999	0.40	0.45	0.91	1.17	2.89	2.21	1.36	1.35	1.79	0.86	0.51	0.40	14.40
					0.350	0.267	0.511	0.595	2.404	0.857	0.677	0.606	0.914	0.649	0.258	0.253	2.517
					13	13	13	12	12	12	12	12	12	13	13	13	12
THUMB DIVIDE	10E07	110.57	44.37	2432.185													44
																	14.653
																	30
TIMBER CREEK	X025	109.18	44.03	2423.042	0.78	0.80	1.90	2.95	3.77	2.08	1.70	1.62	1.98	1.23	1.17	0.73	20.77
					0.728	0.775	1.328	1.864	2.434	1.103	1.247	1.038	1.640	0.869	0.721	0.527	3.988
					24	24	24	24	24	24	24	25	25	24	24	24	24
TIMBERLINE CK	09D04	109.48	45.15	2697.348													33
																	8.762
																	30

Climate station data continued.

Station Name	Stn. #	Long.	Lat.	Elev. (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
TOGWOTEE PASS	S311	110.05	43.75	2919.842	5.16	3.86	4.14	4.24	4.04	2.62	1.73	1.83	2.49	2.37	4.35	4.61	41.53
					2.414	1.844	1.632	1.525	1.454	1.443	1.023	1.077	1.405	1.172	1.928	3.085	6.502
					30	30	30	30	30	30	30	30	30	30	30	30	30
TOSTON 1 W*	8314	111.47	46.17	1197.806	0.44	0.18	0.75	0.88	2.02	2.24	1.22	1.27	1.32	0.79	0.57	0.41	12.20
					0.276	0.134	0.569	0.424	1.032	1.058	0.849	0.794	0.906	0.561	0.374	0.338	2.588
					19	18	18	20	19	20	20	21	20	21	20	19	18
TOWER FALLS*	9025	110.42	44.92	1909.784	1.34	0.87	1.04	1.05	1.84	2.16	1.79	1.57	1.60	1.20	1.22	1.25	16.94
					0.710	0.527	0.578	0.563	0.918	1.043	0.858	0.894	1.108	0.759	0.577	0.724	3.142
					30	30	30	30	30	30	30	30	30	30	30	30	30
TOWNSEND	8324	111.52	46.32	1170.375	0.44	0.28	0.64	0.76	1.75	2.01	1.33	1.33	1.24	0.67	0.42	0.40	11.21
					0.346	0.241	0.346	0.424	0.980	1.068	0.964	0.693	0.917	0.548	0.346	0.300	2.709
					30	29	30	30	30	30	30	30	30	30	30	30	29
TRIDENT	8363	111.48	45.95	1230.113	0.39	0.28	0.67	0.99	2.17	2.16	1.25	1.18	1.43	0.79	0.56	0.26	12.03
					0.346	0.346	0.451	0.574	1.149	1.082	0.812	0.625	1.025	0.520	0.387	0.245	2.809
					30	30	29	30	30	30	30	30	30	30	30	30	29
TROUT CREEK	S471	109.45	44.58	2560.195	0.73	2.02	1.93	2.20	3.23	2.58	1.44	1.32	3.20	1.54	2.53	1.60	24.68
					0.423	2.324	0.413	1.640	1.929	1.172	0.445	0.646	2.623	0.399	0.956	1.664	6.797
					6	6	6	6	6	6	5	5	6	7	6	6	5
TWENTY ONE MILE	11E06	111.05	44.90	2179.214													41
																	13.601
																	30
TWIN BRIDGES	8430	112.32	45.55	1409.631	0.21	0.18	0.48	0.78	1.69	1.90	1.10	1.12	1.12	0.55	0.42	0.23	9.83
					0.173	0.173	0.300	0.458	0.883	1.155	0.762	0.714	0.831	0.387	0.346	0.173	2.335
					30	30	30	30	30	29	29	30	30	30	30	30	29
TWO OCEAN PLATEAU	S410	110.22	44.15	2816.215	4.67	4.72	4.82	4.45	4.58	2.66	2.60	1.43	2.58	2.70	5.70	4.80	45.71
					2.762	3.423	2.121	1.845	1.411	1.182	1.549	0.686	1.457	1.515	1.995	2.428	9.348
					10	10	10	10	10	10	10	10	10	10	10	10	10
ULM 8 SE TRULY	8455	111.43	47.35	1017.982	0.79	0.57	1.07	1.69	2.53	3.72	1.57	1.12	1.33	0.85	0.52	0.86	17.39
					0.481	0.457	0.432	1.134	1.351	1.970	0.906	1.030	1.164	0.767	0.346	0.663	5.362
					11	11	11	13	11	10	10	10	12	12	10	11	5
UTICA 11 WSW*	8495	110.30	46.88	1523.926	0.69	0.53	0.90	1.12	3.01	3.10	1.64	1.86	1.46	0.91	0.73	0.67	16.63
					0.548	0.361	0.510	0.665	1.846	1.466	0.791	1.095	1.061	0.570	0.387	0.447	2.931
					25	26	26	26	26	25	25	25	25	25	25	25	24
VALLEY VIEW	11E08	111.32	44.63	2035.965													35
																	11.363
																	30
VIRGINIA	8597	111.95	45.30	1759.525	0.66	0.54	1.07	1.37	2.52	2.66	1.72	1.56	1.53	1.15	1.04	0.66	16.47
					0.387	0.346	0.600	0.693	1.187	1.187	1.039	0.735	1.025	0.755	0.648	0.387	2.711
					30	30	30	30	30	30	30	30	30	30	30	30	30
WEST YELLOWSTONE	8857	111.10	44.65	2030.783	2.18	1.60	1.65	1.57	2.02	2.38	1.67	1.59	1.75	1.32	2.10	2.13	22.86
					1.308	0.869	0.868	0.947	0.883	1.136	0.980	1.212	1.167	0.917	1.352	1.180	3.607
					30	28	29	28	30	30	30	30	29	30	29	29	24

Climate station data continued.

Station Name	Stn. #	Long.	Lat.	Elev. (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
WHISKEY CREEK	MI30	111.15	44.60	2072.539	4.48	3.46	4.07	2.56	2.56	2.97	1.85	1.91	2.18	2.18	3.42	4.00	35.63
					2.561	1.479	2.100	1.470	0.906	1.413	1.105	1.345	1.473	1.310	1.867	2.111	6.608
WHITE ELEPHANT	S427	111.42	44.53	2349.893	23	23	23	23	23	23	23	23	23	23	23	23	23
					4.99	5.03	6.44	3.82	3.67	2.96	3.02	1.80	2.04	2.56	7.04	4.61	47.99
					2.587	2.900	2.710	2.362	1.362	2.463	1.893	1.124	1.602	1.807	3.517	2.582	13.169
WHITE MILL	TX08	109.90	45.05	2651.631	9	9	9	9	9	9	9	9	9	9	9	9	9
					6.45	4.48	4.88	3.85	4.01	3.23	2.41	2.28	2.53	2.68	4.85	5.06	46.72
					3.559	1.926	2.261	1.576	1.759	1.382	1.257	1.328	1.546	1.422	1.935	2.252	7.977
WHITEHALL	8910	112.10	45.87	1328.863	24	24	24	24	24	24	24	24	24	24	24	24	24
					0.28	0.19	0.53	0.79	1.58	2.47	0.96	1.07	1.04	0.82	0.43	0.26	9.89
					0.187	0.265	0.324	0.620	0.355	1.274	0.522	0.917	0.705	0.632	0.418	0.134	1.658
WHITEHALL AVIATION	8914	111.97	45.87	1304.480	7	7	7	7	7	7	7	7	7	7	7	6	6
					0.43	0.16	0.56	0.90	1.65	2.00	1.17	1.22	1.45	0.89	0.55	0.27	11.23
					0.316	0.141	0.300	0.574	0.640	1.054	0.866	0.583	0.849	0.648	0.316	0.148	2.396
WHITE SUL SPRGS	8927	110.92	46.53	1572.691	10	10	10	10	10	10	10	10	10	10	10	11	10
					0.91	0.48	0.66	0.78	2.05	2.38	1.43	1.45	1.40	0.93	0.70	0.60	13.81
					0.849	0.838	0.537	0.537	0.782	1.244	0.827	1.004	0.949	0.643	0.538	0.568	3.658
WHITE SUL SPRGS2	8930	110.88	46.52	1584.883	18	18	18	18	18	18	18	18	18	18	17	17	17
					0.36	0.46	0.91	1.03	2.09	1.96	1.92	1.09	1.32	0.94	0.41	0.42	12.06
					0.245	0.310	0.492	0.574	1.468	0.956	1.802	0.629	0.923	0.663	0.257	0.228	1.982
WHITE SUL SPRGS10	8933	110.87	46.68	1658.031	12	12	11	11	11	11	7	11	12	11	11	13	6
					1.02	0.64	0.93	0.87	2.45	2.73	1.56	1.61	1.39	0.84	0.84	0.95	15.22
					0.657	0.345	0.585	0.465	1.241	1.390	0.917	1.035	0.860	0.721	0.458	0.632	1.356
WHITE SUL SPRGS	8936	111.20	46.83	1338.007	18	17	19	18	20	21	21	21	20	20	21	19	13
					0.81	0.46	0.97	1.17	2.64	2.65	1.72	1.34	1.52	1.10	0.70	0.73	16.34
					0.414	0.355	0.553	0.684	1.660	1.271	1.122	1.018	1.123	0.997	0.529	0.457	4.212
WILLOW CREEK PC	MH27	111.63	45.80	1981.103	19	18	17	18	17	16	17	17	18	14	14	19	10
					0.48	0.28	0.84	1.37	2.88	1.70	1.58	1.86	1.43	0.54	0.50	0.42	13.88
					0.808	0.311	0.568	0.669	1.001	0.340	1.353	1.029	1.127	0.937	0.469	0.512	2.173
WILSALL	9018	110.67	46.00	1539.165	5	5	5	5	5	5	5	5	5	5	5	5	5
					0.59	0.44	1.08	1.04	2.63	2.79	1.32	1.45	1.66	1.09	0.99	0.55	15.42
					0.379	0.392	0.669	0.577	1.013	1.414	0.310	0.687	0.947	0.669	0.383	0.458	2.824
WILSALL 8 ENE	9023	110.50	46.03	1778.421	8	7	8	9	9	9	8	8	8	8	7	7	7
					0.92	0.78	1.49	1.80	3.43	3.21	1.69	1.82	2.01	1.50	1.08	0.90	20.78
					0.490	0.346	0.693	0.794	1.386	1.625	0.851	1.010	1.273	0.933	0.458	0.458	3.652
WOLVERINE	S475	109.65	44.80	2331.606	30	30	30	30	30	30	29	30	30	30	30	30	29
					2.03	2.38	1.72	2.55	3.08	1.88	2.25	1.74	1.58	1.56	2.52	2.33	25.62
					1.249	1.466	1.025	1.109	1.030	1.140	1.396	0.678	1.269	0.592	1.114	1.140	4.662
					10	10	10	10	10	10	10	10	10	10	10	10	10

Climate station data continued.

Station Name	Stn. #	Long.	Lat.	Elev. (m)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
WORLAND	9770	107.97	44.02	1237.428	0.26	0.18	0.30	0.82	1.39	1.13	0.44	0.62	0.77	0.67	0.27	0.25	7.12
					0.220	0.168	0.207	0.485	1.117	0.818	0.395	0.680	0.673	0.655	0.190	0.214	2.073
WORLAND FAA	9785	107.97	43.97	1271.564	25	25	25	25	25	25	24	24	24	25	24	25	24
					0.26	0.20	0.39	0.83	1.50	1.13	0.47	0.66	0.77	0.59	0.34	0.27	7.40
					0.232	0.171	0.267	0.548	1.005	0.802	0.399	0.618	0.630	0.539	0.268	0.213	1.745
YELLOWSTONE PARK	9905	110.70	44.97	1898.811	30	30	30	30	30	30	30	30	30	30	30	30	30
					1.14	0.72	1.01	1.00	1.93	1.93	1.53	1.60	1.42	0.96	1.13	1.03	15.39
					0.973	0.447	0.634	0.559	0.831	0.886	0.821	0.947	0.928	0.664	0.516	0.710	3.136
YELLOWTAIL DAM	9240	107.93	45.32	1007.315	30	30	30	30	30	30	30	30	30	30	30	30	30
					1.01	0.75	1.37	2.49	3.32	2.59	1.19	1.18	1.86	1.59	1.02	0.88	19.27
					0.529	0.443	0.669	1.818	2.123	2.036	1.183	0.947	1.097	1.296	0.555	0.590	3.674
YOUNTS PEAK	S411	109.82	43.93	2544.956	28	28	28	28	28	28	28	28	28	28	28	29	28
					2.84	2.44	2.75	2.50	3.07	2.24	2.49	1.91	2.87	1.85	3.28	2.75	30.69
					1.957	2.464	1.145	0.825	1.233	2.131	1.327	0.436	1.908	1.136	1.315	1.449	6.563
					10	10	10	10	10	10	10	10	11	10	10	10	10

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