# Climatology of the Seasonal Precipitation Maximum in the Western United States

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**ABSTRACT**: The western United States is characterized by heterogeneous patterns of seasonal precipitation regimes due to the hierarchy of climatic controls that operate at different spatial scales. A climatology of intermonthly precipitation changes, using data from more than 4,000 stations including high-elevation sites, illustrate how different climatic controls explain the spatial distribution of the seasonal precipitation maximum. These results indicate that smaller-scale climatic controls must be considered along with larger-scale ones to explain patterns of spatial climate heterogeneity over mountainous areas. The results also offer important implications for scholars interested in assessing spatial climatic variations of the western United States at different timescales.

## Introduction

Precipitation of the western United States varies spatially because of numerous smaller-scale climatic controls embedded within larger-scale controls, primarily as a result of the rugged physiography in the region (Bryson and Hare 1974; Hirschboeck 1991). The distribution of the seasonal precipitation maximum exhibits complex patterns, with different seasonal maxima intermixed in some areas (Pyke 1972; Tang and Reiter 1984). Several scholars have examined spatial variations of precipitation over the region and assessed the climatic controls responsible for these variations (*eg*, Tang and Reiter 1984). These studies were able to infer how larger-scale climatic controls explain spatial precipitation variation; however, their surface data networks were too sparse to examine smaller-scale climatic controls. Their data networks also included few high-elevation sites; that is problematic for interpreting spatial precipitation variations in the western United States.

This study presents a precipitation climatology of the western United States and adjacent Canada and Mexico, using a spatially dense network of stations to detect spatial variations at both large and small scales. The study area includes the states west of the Mississippi River to cover a diverse range of spatial climatic scales and controls. Data consist of averaged modern climatic normals of monthly precipitation from more than 4,000 stations (Figure 1).

Precipitation data came from four sources: World WeatherDisc Associates (1990), Atmospheric Environmental Service (1982) of Canada, Willmott *et al* (1981), and the Soil Conservation Service (1988). The Soil Conservation Service network contains data from high-elevation stations, which are useful for delineating smaller-scale climatic features in mountainous

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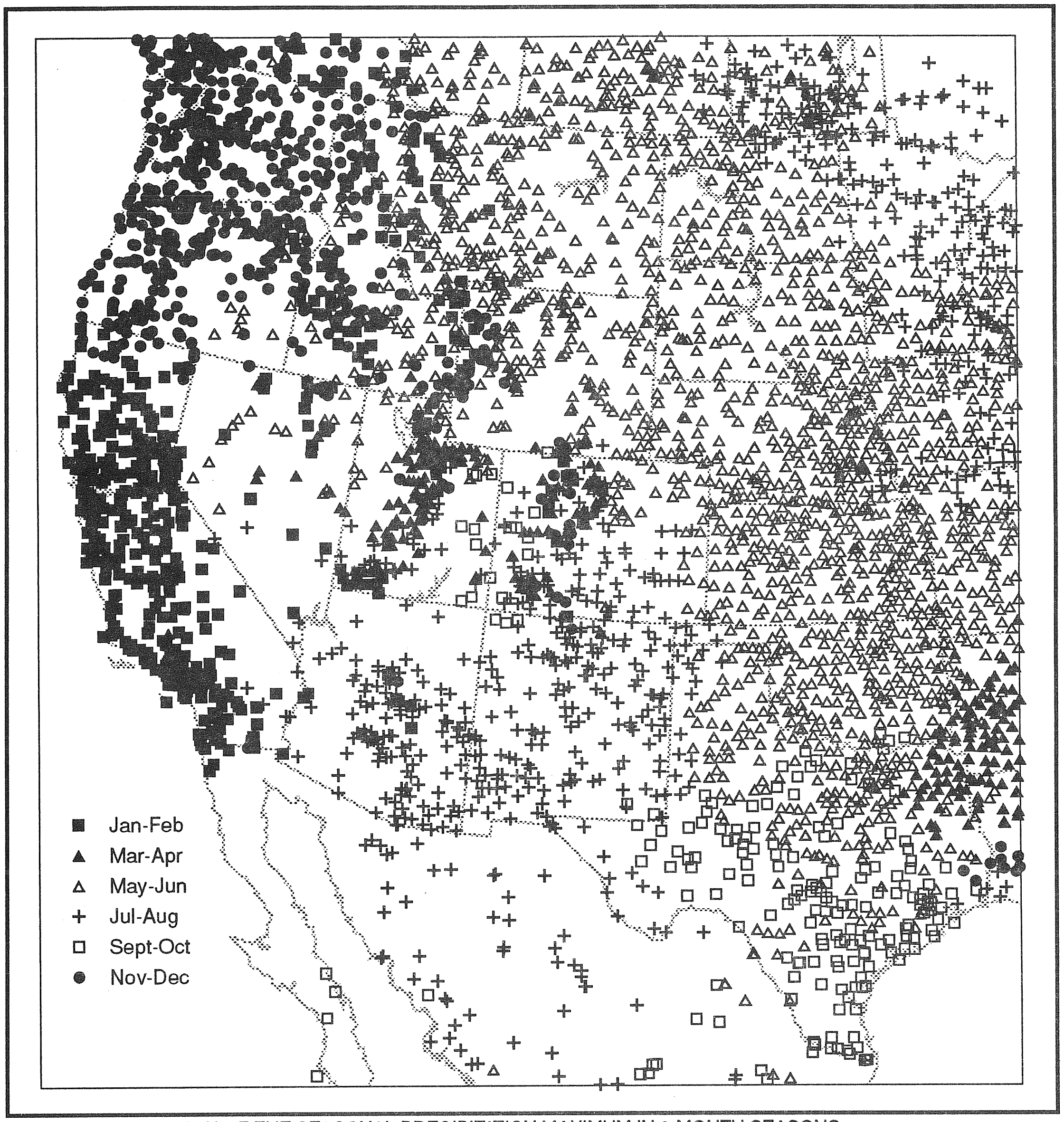


Figure 1. DISTRIBUTION OF THE SEASONAL PRECIPITATION MAXIMUM IN 2-MONTH SEASONS

terrain. Monthly precipitation data from World WeatherDisc and Atmospheric Environmental Service are 1951-1980 normals; that period represents a useful climatic normal because it excludes the widespread droughts of the 1930s and 1980s, which may present misleading representations of climatic normals (Mock 1991). Some of the climatic normals of periods from the datasets by Willmott *et al* (1981) and the Soil Conservation Service vary due to the data being relatively scarce and discontinuous, particularly for the latter dataset. The shorter records, however, span at least 10 years and are not believed to be a severe constraint when combined with longer networks of climatic data for delineating smaller-scale precipitation variations.

## Seasonal Precipitation Maximum Regimes

In anticipation of the seasonal analyses of the hierarchy of different spatial climatic controls on precipitation variations, a map indicating regimes of the seasonal precipitation maximum was generated. This map was constructed by mapping the time of year of the precipitation maximum for each station in 2-month seasons (Figure 1). This classification provided a clear analysis of different precipitation regimes as they relate to different climatic controls. The map shows both large-scale and small-scale patterns. Some homogeneous areas are evident. These are the November/December and January/February regimes of the Pacific coast; the May/June regime over most of the Great Plains; the July/August regime over Arizona, southeastern California, New Mexico, and northwestern Mexico; the November/December and March/April regimes in east Texas; and the September/October regime in southeastern Texas and southern Baja California.

Spatial heterogeneity of seasonal precipitation regimes, however, is clearly evident over the mountainous areas. A small region of a September/October regime over southwestern Colorado and southeastern Utah is evident, but other areas in Utah, western Colorado, southeastern Oregon, and Nevada show a mixture of precipitation regimes. Spatial heterogeneity is also evident in western Montana and eastern Idaho, but there it involves a less complex mixture of regimes than for the Utah/Colorado region to the south.

## Construction of Intermonthly Precipitation Maps

To examine the climatic controls that cause patterns of spatial heterogeneity of the seasonal precipitation maximum, the author constructed intermonthly maps for selected seasons. Each map summarizes intermonthly trends for 2 months simultaneously for a particular season, showing the relative changing areal extent of precipitation variations. Maps were constructed with symbols indicating the sign of intermonthly trends for each station. For example, a symbol in the analysis of intermonthly trends for summer precipitation could indicate decreased precipitation from June to July as well as from July to August. The months summarized in this paper are December/January (winter), March/April (spring), July/August (summer), and September/October (fall).

## December/January Intermonthly Precipitation Trends

The summary of December/January trends shows a number of distinctive patterns at both larger and smaller scales (Figure 2). Large-scale controls include the southward progression of the jet stream (Pyke 1972). This migration explains precipitation increases in December and decreases in January (*DecI, JanD*) for parts of Washington and Oregon and

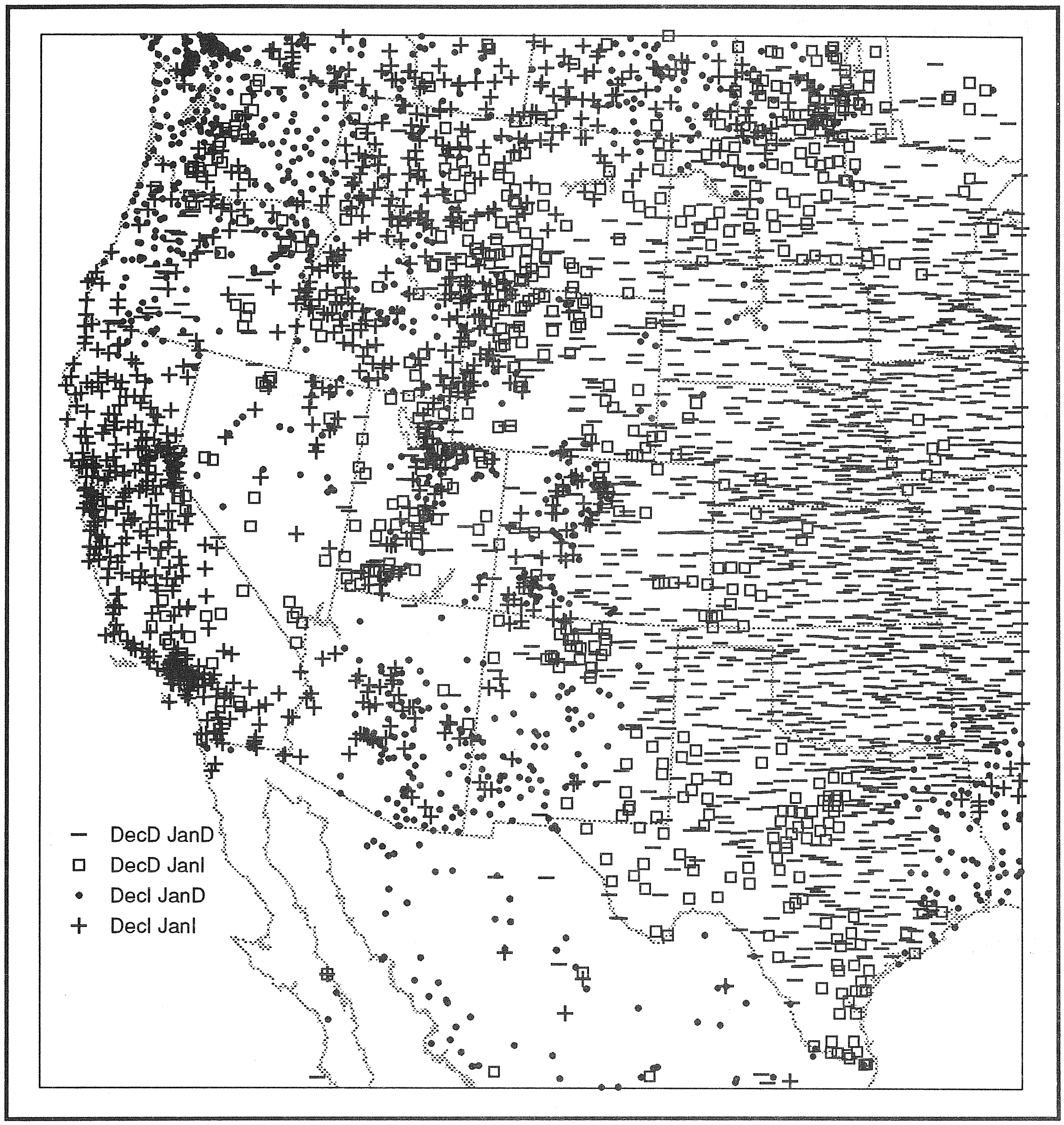


Figure 2. INTERMONTHLY PRECIPITATION TRENDS FOR DECEMBER/JANUARY

increases in both December and January (*DecI, JanI*) for most of California. The establishment of the PNA (Pacific North American teleconnection) pattern explains December decreases and January decreases (*DecD, JanD*) over most of the Great Plains as northwesterly flow is more frequent. It also explains precipitation increases over southern Canada and the northern Great Plains from increased leeside cyclogenesis in Alberta (Whittaker and Horn 1982).

Smaller-scale climatic controls explain why some areas show patterns of heterogeneity in the precipitation changes. Low-elevation pathways explain the distribution of precipitation increases for both December and January (*DecI, JanI*) for the Snake River Plain, western Wyoming, and upper Colorado River Valley, as Pacific air is advected inland (Bryson and Hare 1974). Conversely, because of their high elevation, some sites in the northern Cascades experience decreases of precipitation for both December and January (*DecD, JanD*), because they are less exposed to moisture sources and situations for orographic precipitation enhancement. Some stations in the American Southwest show precipitation increases in December and decreases in January (*DecI, JanD*). The increases in December correspond to what Tang and Reiter (1984) termed as the "Plateau Monsoon of Winter." They suggested that although the plateau is generally dry during winter, some axes of precipitation enhancement occur in the Great Basin and Colorado, between the Great Basin and Four Corner highs. Some high-elevation sites are more susceptible to receiving precipitation from strong mid-level westerly and southwesterly flow than are broad interior valleys, which would experience dry, rain-shadow-like conditions. Convergence zones may explain localized areas of intermonthly precipitation variation in Washington and Oregon. Similarly, cyclogenesis in the southern Rockies and Gulf of Mexico, as well as their influences on the spatial distribution of the low-level jet, explain precipitation variation for locations in eastern Texas.

## March/April Intermonthly Precipitation Trends

Precipitation trends for March/April also exhibit both large- and small-scale variations. The Great Plains show a homogeneous response of precipitation increases for March and April (*MarI, AprI*) (Figure 3). Although several climatic controls influence precipitation in the Great Plains, most of them involve the same large-scale pattern of increased troughing into the western United States that cause leeside cyclogenesis in the Rocky Mountains (Whittaker and Horn 1982). Southern Texas shows a region of precipitation decreases for March as a result of frequent occurrences of this troughing pattern. Increases in April are due to the increased moisture advected from the Gulf of Mexico.

Most of Washington, Oregon, California, the Snake River Plain, western Wyoming, and western Mexico exhibit precipitation decreases for both months (*MarD, AprD*) due to a strengthened and expanded Pacific subtropical high, and a weakened Aleutian low. However, some locations in Oregon and Washington have increases for March and decreases for April. The causal mechanisms are still not clear, but they likely involve topographic influences, increased convective activity at lower elevations, and/or some aspect of precipitation recycling (Pyke 1972). An area of March increases and April decreases (*MarI, AprD*) in Arizona and the Four Corners region represent the influence from Great Basin cyclogenesis and the subtropical jet stream.

Stations in the mountainous regions of Utah, Colorado, Arizona, Nevada, and New Mexico illustrate a pattern of spatial heterogeneity. Some stations west of the Continental Divide in Colorado exhibit more of a wet Great Plains-type regime as a result of topographic gaps and south- or east-facing slopes. Some low-elevation stations in Utah, Nevada, and Arizona lie in the rainshadow of moist air masses from the Gulf of California and the Pacific Ocean, thus indicating precipitation decreases

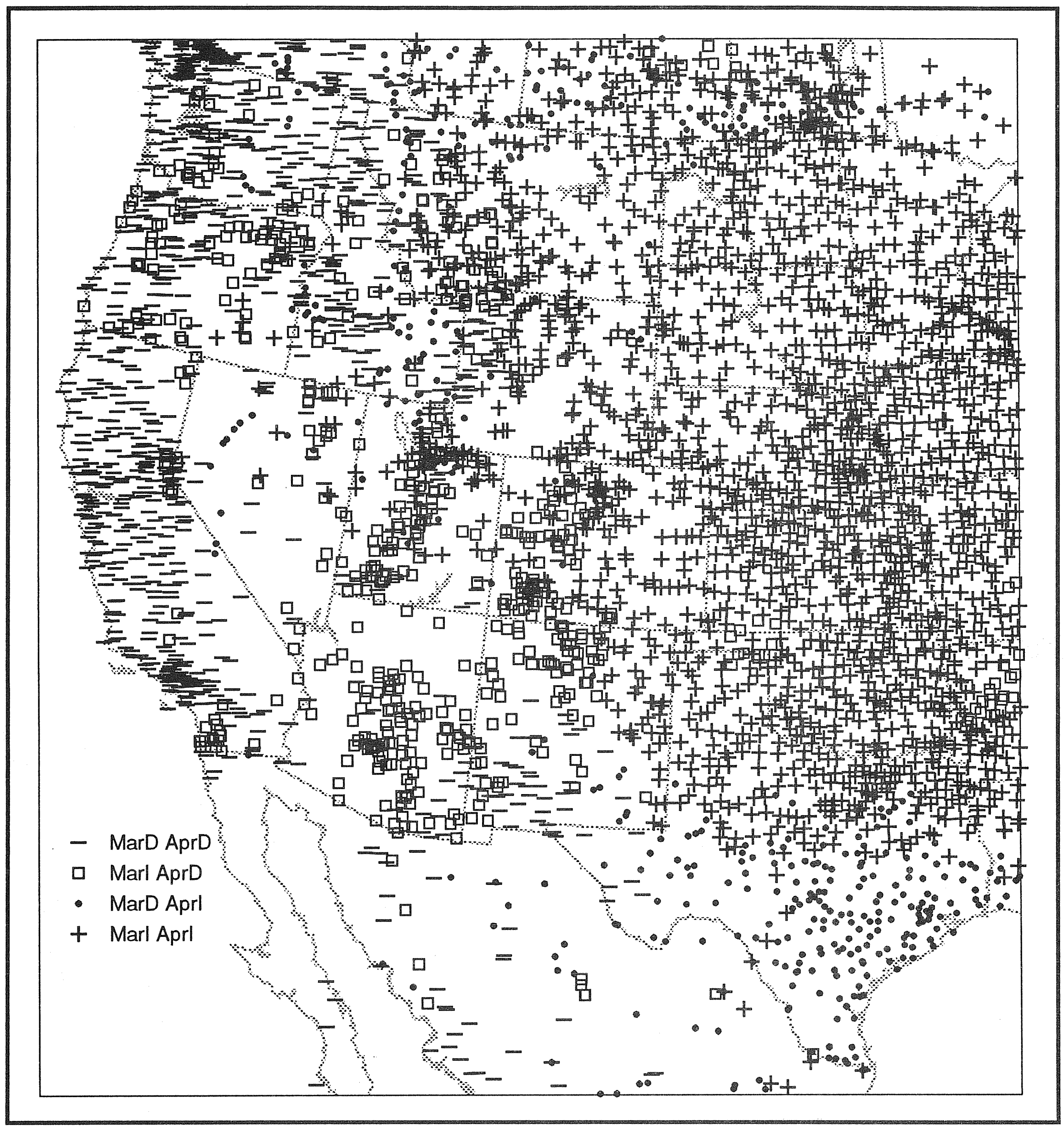


Figure 3. INTERMONTHLY PRECIPITATION TRENDS FOR MARCH/APRIL

for both March and April. The assessments of climatic controls on precipitation for the Four Corners states, the Great Basin, and parts of the Pacific Northwest are site-specific for many cases.

## July/August Intermonthly Precipitation Trends

The map of July/August intermonthly trends shows that precipitation decreases in northern Great Plains are fairly homogeneous (*JulD, AugD*), with August precipitation increases to the north and east (*JulD, AugI*) responding to Alberta lows and high thunderstorm frequency respectively (Figure 4). However, conditions in the Great Plains are still relatively wet during summer, largely due to the formation of mesoscale convective systems (Hirschboeck 1991). An upper-level subtropical ridge, which explains the summer monsoon in the American Southwest (Carleton 1987), does not cause a homogeneous distribution of precipitation de-

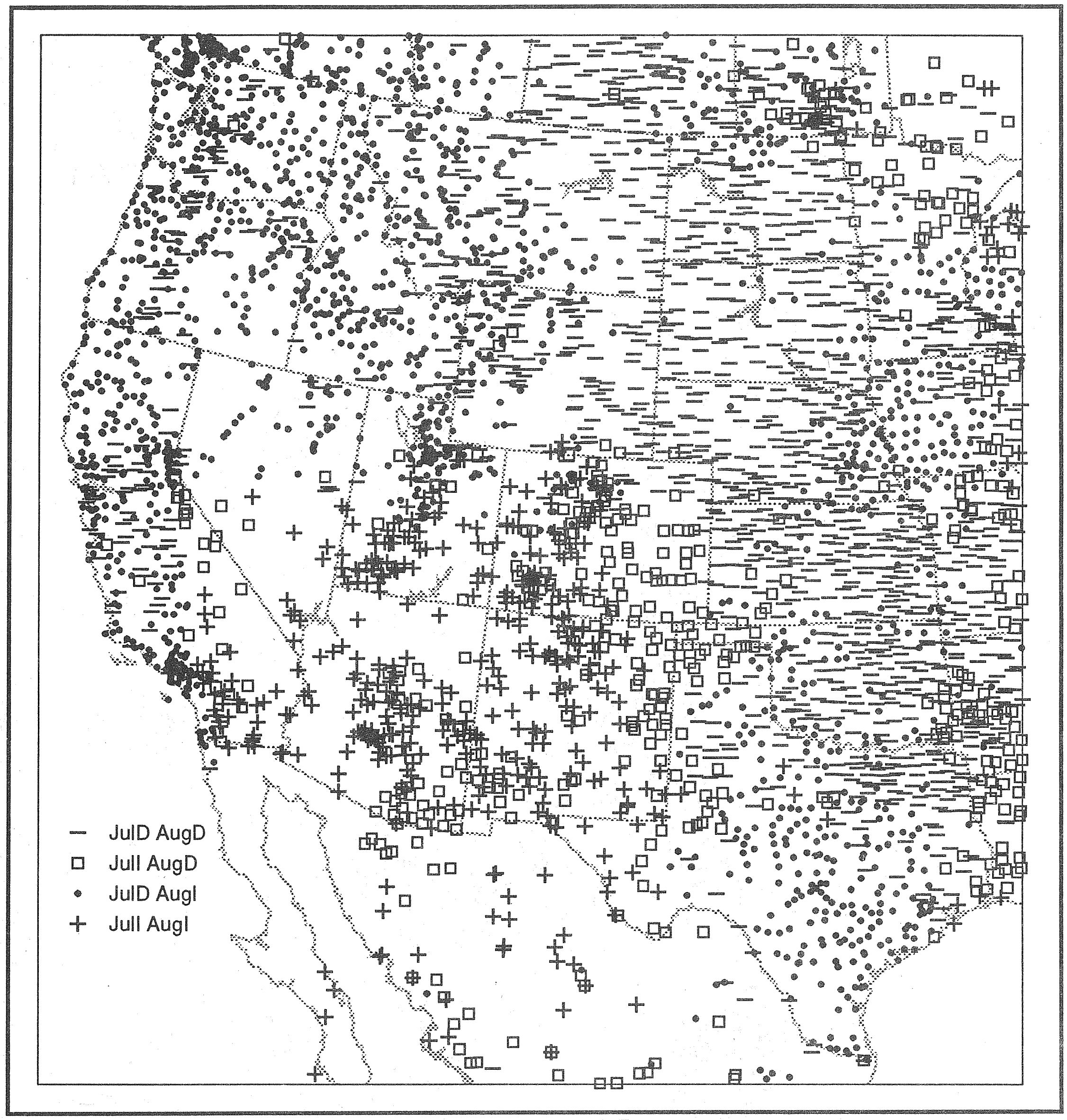


Figure 4. INTERMONTHLY PRECIPITATION TRENDS FOR JULY/AUGUST

creases in the southern Great Plains because of effects from the tropical upper-tropospheric trough and tropical storms from the east in August. A westward shift of the summer monsoon is apparent, with July increases and August decreases (*JulI, AugD*) over the southern Plains, and increases for both months (*JulI, AugI*) for much of the Southwest, consistent with implications by Tang and Reiter (1984). Stations that deviate from the westward shift have their climatic regimes controlled by topography.

Most stations in the Pacific Northwest experience July decreases due to the strong Pacific subtropical high and August increases due to a relatively higher frequency of upper-level disturbances as compared with July (*JulD, AugI*). However, the Cascades and some high-elevation areas in Idaho and Montana show precipitation decreases for both July and August. As compared with surface frontal systems, upper-level disturbances usually bring relatively more precipitation to lower elevations than to higher ones (Schermerhorn 1967). The upward motion in upper-level disturbances relates with vorticity aspects that do not deal with orographic aspects. A peculiar area of July increases and August decreases (*JulI, AugD*) is evident along the eastern Sierra Nevada. The August decreases are the result of lower-level divergence, which is indirectly related to topographic influences and the thermal trough (Hill 1993).

## September/October Intermonthly Trends

The map for September/October (Figure 5) illustrates stations with precipitation increases for both September and October (*SepI, OctI*) over most of the Pacific states and interior Pacific Northwest. The increases reflect the influence from mid-latitude cyclones originating in the Gulf of Alaska. Topography plays an important role on the spatial extent, with the Snake River Plain, Cascade Range, and Sierra Nevada having the

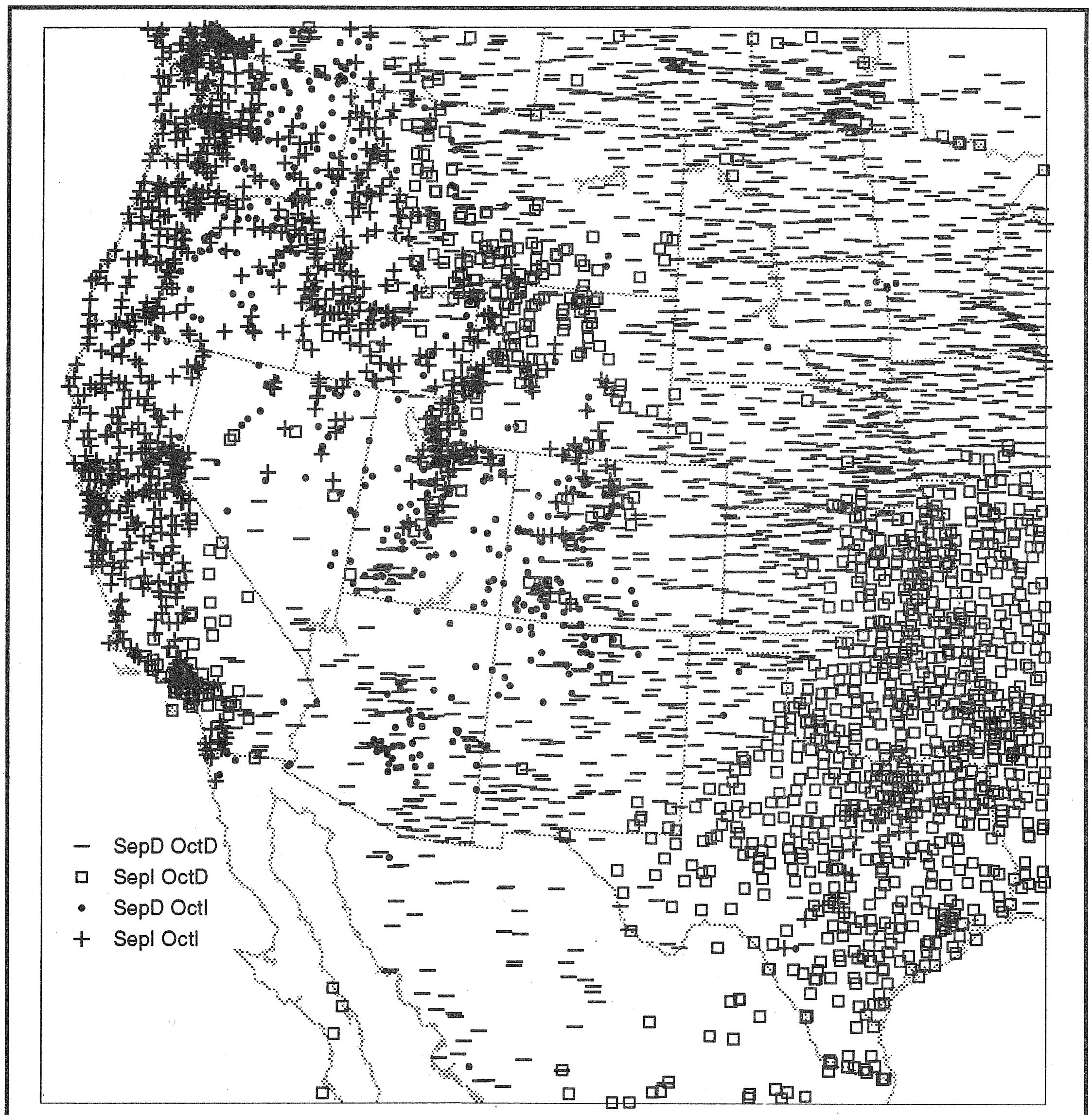


Figure 5. INTERMONTHLY PRECIPITATION TRENDS FOR SEPTEMBER/OCTOBER.

largest increases (Bryson and Hare 1974). Some large increases for both months are also located over the Wasatch Range in northern Utah, in northern Nevada, and in western Colorado, but they may reflect the influence of cutoff lows (Hirschboeck 1991). Some stations with precipitation increases for September and precipitation decreases for October (*SepI, OctD*) scattered over Nevada, Utah, and Colorado also reflect the influence of cutoff lows. Locations with precipitation increases for September and decreases for October in Baja California and the southeastern Great Plains indicate the effects from easterly disturbances and tropical storms. Most stations over the American Southwest exhibit precipitation decreases for both months (*SepD, OctD*) in Arizona, New Mexico, northwestern Mexico, and southeastern California, illustrating the final dissipation of the summer monsoon (Tang and Reiter 1984). Similar decreases are also evident throughout the northern and central Great Plains due to modified Pacific airstreams penetrating far inland (Bryson and Hare 1974). These airstreams reduce convective activity, limit the spatial extent of the low-level jet, and reduce the frequency of mesoscale convective systems.

## Conclusions

Climatological analyses of intermonthly precipitation trends for four seasons clearly illustrates that a number of climatic controls interact with one another to jointly explain spatial climate variation. Intermonthly maps show that larger-scale climatic controls, such as the polar jet stream, the Pacific subtropical high, and the subtropical ridge, play important roles on spatial variation of climate in the region. They do not, however, explain all the patterns in some mountainous areas where smaller-scale climatic controls are the rule rather than the exception. Smaller-scale climatic controls, such as physiography and the thermal trough, also play important roles in explaining spatial precipitation variation. For example, these smaller-scale controls explain why some stations in the mountainous areas of Utah and Colorado have winter precipitation maxima while other nearby stations have spring and summer maxima.

Results from this study provide several applications regarding research on climatic change for the western United States. A knowledge of precipitation responses at a variety of spatial scales to particular large-scale circulation patterns can improve spatial resolution for forecasting seasonal precipitation anomalies (*eg*, from ENSO events), parameterization of general circulation models, and refinement of lateral boundary conditions for high-resolution mesoscale models. Such an understanding can also aid in analyses of floods (Hirschboeck 1991) and late-Quaternary paleoclimates (Mock 1994) in the region. Improvement of spatial and temporal records of high-elevation sites will aid in future analyses of the hierarchy of climatic controls and the heterogeneous precipitation responses that characterize the climate of the western United States.

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