Chapter 2
Weather and Climate of Portland

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The climate of Oregon has always been the subject of much discussion, and it is the persistence of precipitation that elicits the most comment, both rational and irrational. A common perception is that the state is suited only to salamanders, waterfowl, and crayfish. In the words of Ken Kesey (1963, p. 5), Oregonians ". . . have lived and worked and logged in the wet so long that they are no longer capable of distinguishing it from the dry." In rebuttal, other Oregonians retort with a certain amount of smugness that the state as a whole receives less annual precipitation than most other states. The average yearly precipitation in the United States is about 29 inches; in Oregon it is only 27 inches, less than states like Pennsylvania (42 inches), Michigan (30 inches), and many others. This, of course, is a statistical abstraction, given the contrast between wet western Oregon and dry eastern Oregon as defined by the crest of the Cascade Mountains. Residents also delight in pointing out that Portland's official value for annual precipitation of 37.4 inches is less than New York City (50 inches), Houston (46 inches), Atlanta (48 inches), and many other American cities not known for extremes in climate. However, regardless of the interpretation of the data, the fact is that compared to most of the nation Portland experiences an extremely large number of rainy days (152 per year), of overcast skies (ranging from 88 percent cloud cover in December to 42 percent in July), and of reduced solar radiation. Rainfall is of low intensity, but it is the succession of overcast, dreary days in the winter that establishes a reputation that is irrefutable.

Richard Maxwell Brown (1980) presented a delightful historical perspective on the subject in an article entitled "Bless the Rain." Early visitors to the Willamette Valley found the long rainy season to be oppressive, and the image of incessant rainfall became a handicap in attempts to attract settlers. To counter this view, promoters placed emphasis on the overall climate and in the 1890's developed what Brown called the "ideology of climate," containing the following propositions:

1. Although rainfall is prolific, it falls gently and does not generally inhibit outdoor work and activity.
2. The total amount of yearly rainfall is about average for the United States and only seems excessive because it is distributed over a longer rainy season than elsewhere.
3. Even when the long fall-to-spring rainy season is taken into account, there are two notable compensating factors: the warm weather in comparison to the subfreezing temperature and blizzards of the central and eastern United States, and the delightfully dry and sunny but not excessively hot summers.
4. The regularity and dependability of temperature and rain is such that -- in stark contrast to other parts of the country -- crops never fail west of the Cascades.
5. The climate is unexcelled for the

personal health of the individual, who benefits in terms of comfort and longevity.

6. When, for comparative purposes, the Northwest climate is viewed in a scope beyond this country, that climate is most analogous to those of England, France and Japan -- "all regions inhabited by healthy and progressive peoples" -- and is therefore not merely the finest climate in the United States but one of the best in the world (Brown, 1980, p. 27).

Given this thoroughly optimistic summary, it is a wonder that our climate must still be defended. To many Portland residents the climate is, indeed, ideal. To others, the lengthy winters are the price one must pay for short, idyllic summers. For most of us the reality lies somewhere in between.

GENERAL CLIMATOLOGY

The climate of Portland -- relatively wet, mild winters and clear, dry summers -- can be classified as a modified west coast marine type; relevant statistics are presented in Table 2.1. A mid-latitude location (45 degrees North) accounts for seasonal contrasts of temperature and precipitation, and the long rainy season is primarily the result of the prevailing westerlies. Precipitation is associated with cyclonic storms embedded in the westerly flow of maritime airstreams and exhibits a well-defined annual cycle (Figure 2.1). The annual march of precipitation is representative of conditions common to the entire west coast of North America (Trewartha, 1981, p. 298): 1) there is a conspicuous single maximum in the annual profile of precipitation which occurs in the winter; 2) a marked single minimum occurs in the summer; and 3) the month of maximum precipitation is a function of latitude, occurring later with decreasing latitude.

All three of these features are closely associated with the seasonal migration of the North Pacific subtropical high pressure cell and of the jet stream and associated cyclonic storms which flank the anticyclone on its northward side (Figure 2.2). The minimum coincides with the summer season when the subtropical anticyclone extends its influence farthest poleward, displacing the jet and the major storm tracks to the north. The single maximum coincides with the retreat southward of the high and the advance toward lower latitudes of the jet stream and storm belts. Approximately 88 percent of the annual precipitation in Portland occurs in the months October through May, 9 percent in June and September, while only 3 percent comes in July and August. Precipitation is mostly rain with an average of only five days per year that receive measurable snow. Seldom do more than 2 - 3 inches of snowfall accumulate, and it generally lasts only a day or so. The greatest official measurement of snowfall in 24 hours was six inches in January, 1950, part of a monthly total of 41.4 inches, also a record. Snow has been recorded in every month of the year in Portland except July.

Although latitude is the dominant control of climate in Portland, topography and distance from the Pacific Ocean also play significant roles. Located 65 miles inland, the city lies in the Willamette Valley midway between the Coast Range and the higher Cascade Range to the east (Figure 2.3). The Coast Range is both a buffer protecting Portland from the full impact of Pacific storms and a modifier of incoming air masses. Marine air is cooled as it moves inland and over the Coast Range, resulting in more than 150 inches of annual precipitation in the mountains west of Portland. Therefore, air that descends into the

Table 2.1: *Climatic summary for Portland, Oregon, 1941-1985. Data are for the National Weather Service station located six miles north-northeast of downtown Portland on the Columbia River. Elevation is 21 feet above sea level. Normals are based on the 1951-1980 record; extremes are for the entire period of record (solar radiation data are from Western SUN, 1980, p. 16; all other data are from NOAA, 1986).*

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual Average
Solar Radiation (BTU/FT2-Day)													
Total Horizontal Insolation	310	554	895	1308	1663	1773	2037	1674	1217	724	388	260	1067
Direct Beam Normal Incidence	952	1302	1583	2159	2603	2494	3111	2825	2413	1746	1143	698	1960
Percent of Possible Sunshine	27	37	47	53	58	55	70	66	61	42	29	22	47
Percent of Mean Cloud Cover	84	83	81	77	72	68	47	52	56	72	82	87	72
Temperature (Degrees F)													
Normals													
Daily Maximum	44.3	50.4	54.5	60.2	66.9	72.7	79.5	78.6	74.2	63.9	52.3	46.4	62.0
Daily Minimum	33.5	36.0	37.4	40.6	46.4	52.2	55.8	55.8	51.1	44.6	38.6	35.4	44.0
Monthly	38.9	43.2	46.0	50.4	56.7	62.5	67.7	67.2	62.7	54.3	45.5	40.9	53.0
Extremes													
Record High	62	70	80	87	100	100	107	107	101	90	73	64	
Year	1964	1984	1947	1957	1983	1982	1965	1981	1944	1980	1975	1980	
Record Low	−2	−3	19	29	29	39	43	44	34	26	13	6	
Year	1950	1950	1955	1955	1954	1966	1955	1980	1965	1971	1985	1964	
Precipitation (inches)													
Water Equivalent													
Normal	6.2	3.9	3.6	2.3	2.1	1.5	0.5	1.1	1.6	3.1	5.2	6.4	37.4
Maximum Monthly	12.8	9.5	7.5	4.7	4.6	4.1	2.7	4.5	4.0	8.0	11.6	11.1	
Year	1953	1949	1957	1955	1945	1984	1983	1968	1982	1947	1942	1968	
Minimum Monthly	0.1	0.8	1.1	0.5	0.5	T	0.0	T	T	0.4	0.8	1.4	
Year	1985	1964	1965	1956	1982	1951	1967	1970	1975	1978	1976	1976	
Maximum in 24 Hours	2.6	2.0	1.8	1.5	1.5	1.8	1.1	1.5	2.4	2.2	2.6	2.6	
Year	1974	1982	1943	1962	1968	1958	1978	1977	1982	1941	1973	1977	
Snow, Ice pellets													
Maximum Monthly	41.4	13.2	12.9	T	0.6	T	—	T	T	0.2	8.2	15.7	
Year	1950	1949	1951	1985	1953	1981	—	—	1949	1950	1977	1964	
Maximum in 24 Hours	10.6	3.2	7.7	T	0.5	T	—	—	T	0.2	7.4	8.0	
Year	1950	1962	1951	1985	1953	1981	—	—	1949	1950	1977	1964	
Wind													
Mean Speed (mph)	10.0	9.1	8.3	74	7.0	7.1	7.6	7.1	6.5	6.5	8.7	9.6	7.9
Prevailing Direction	ESE	ESE	ESE	NW	NW	NW	NW	NW	ESE	ESE	ESE	ESE	ESE

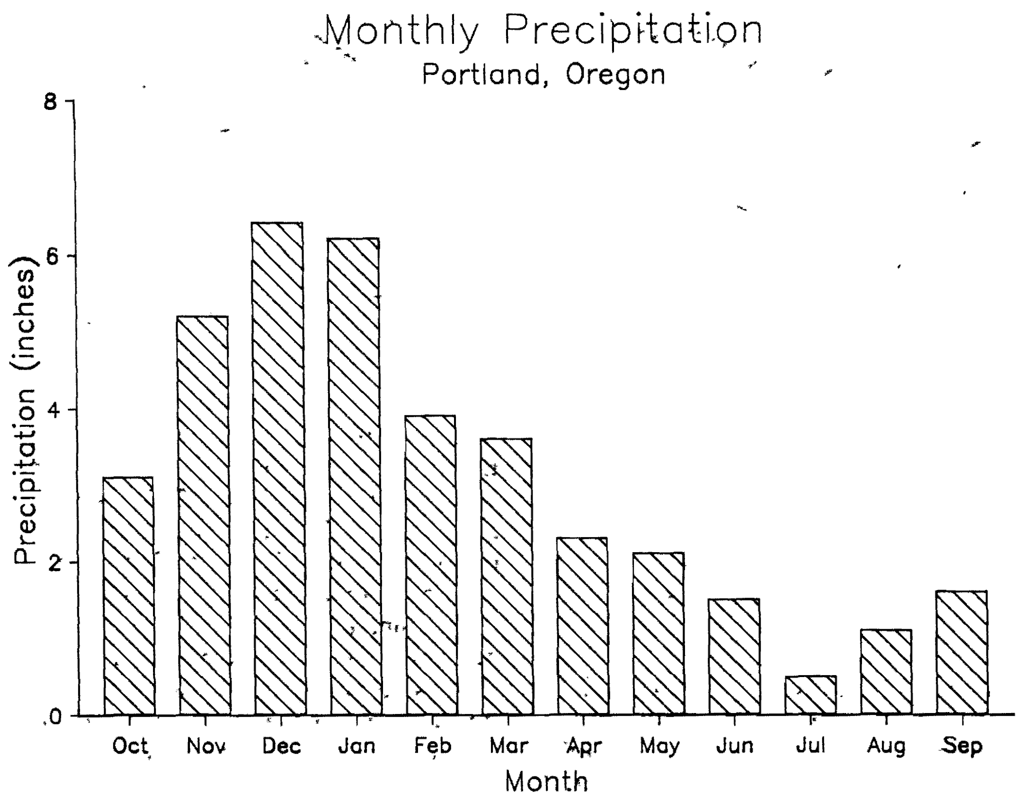

Figure 2.1: Annual march of precipitation, Portland, for the normal period 1951-1980. Data are presented according to the Water Year, October through September (from NOAA, 1986).

Willamette Valley is drier and yields less precipitation than it would in the absence of this topographic barrier. In summer, the Coast Range effectively prevents penetration of cool, marine air into the valley.

The Cascades provide an even steeper slope for orographic uplift of the moisture-laden westerly winds. The crest of the Range varies from 5,000 to 10,000 feet, and is a significant east-west precipitation divide shielding the interior Columbia Plateau from the moderating influence of the Pacific Ocean. Furthermore, the Cascade Range is an effective barrier to continental air masses that form over the interior. As a result, extreme winter and summer temperatures that characterize areas 100 to 200 miles to the east rarely occur in Portland.

The marine influence in western Oregon reduces the amplitude of the annual temperature cycle below that of continental locations. Thus the wet winter season is marked by relatively mild temperatures; the mean temperature of the coldest month, January, is 38.9°F. Also typical of a marine type of climate, the diurnal range is small in the winter when cloudy skies prevail, with a mean daily maximum in January of 44.3°F and a mean daily minimum of 33.5°F.

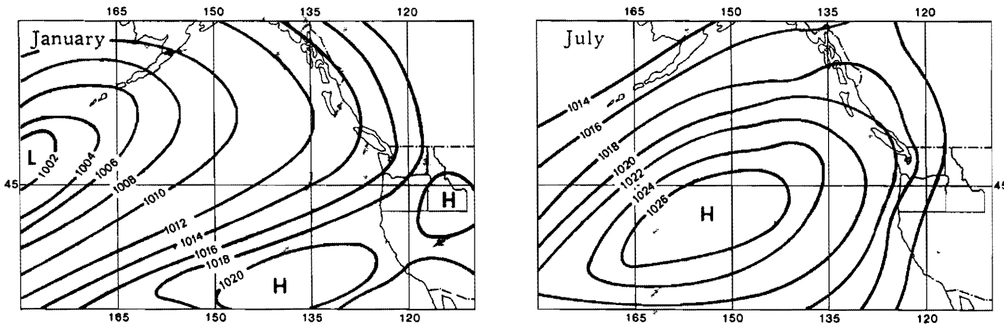

Figure 2.2: Generalized air pressure and wind conditions for the eastern Pacific Ocean and western United States, January and July, depicting dominant seasonal modes of atmospheric circulation that influence the climate of Portland (Jackson, 1985, p.49).

Summer produces some of the most pleasant weather in North America, with mild temperatures and very little precipitation. In July, the warmest month, the mean temperature is 67.7°F, with a larger diurnal range than in winter attributable to clear skies (daily maximum = 79.5°F; daily minimum = 55.8°F). Temperatures below 0°F are very rare in Portland. The lowest on record is -3°F which occurred in February 1950. Temperatures above 100°F are also infrequent; the maximum of 107°F was recorded in July, 1965. Temperatures above 90°F are attained every year, but seldom persist for more than a few days. Hence, a long growing season combined with ample moisture supports prosperous agricultural activity in the rural areas surrounding Portland and is an important underlying factor in Portland's reputation as the Rose City.

Climatic normals, or averages, represent a series of constantly fluctuating values of the basic climatic elements. Calendar year 1985 offers a good illustration of the fact that climate is more than just an average of the elements which comprise it (Figure 2.4). This was a year in which many new records were established for daily maximum and minimum temperatures, a response to the dominance of continental air masses over the more moderate marine air masses for extended periods of time. July was one of the warmest months of the century, with a monthly mean of 74.1°F (normal = 67.7°F). The mean daily temperature on 30 of the 31 days exceeded the norm and for 11 days the daily maximum was above 90°F, an unusually long spell of hot weather.

Conversely, the year began and ended with well below normal winter temperatures. January and February were extremely cold due to the anchoring of a high pressure ridge over the Pacific Northwest, permitting the influence of a continental air mass with clear skies. November 1985 was the coldest November on record, in spite of several warm days at the beginning of the month. During one 10 day sequence there were eight days in which the temperature remained constantly below freezing, an unusually prolonged cold spell for Portland. The monthly mean of 37.3°F was 8.2°F below normal. After a few relatively balmy days in December, there followed another remarkable se-

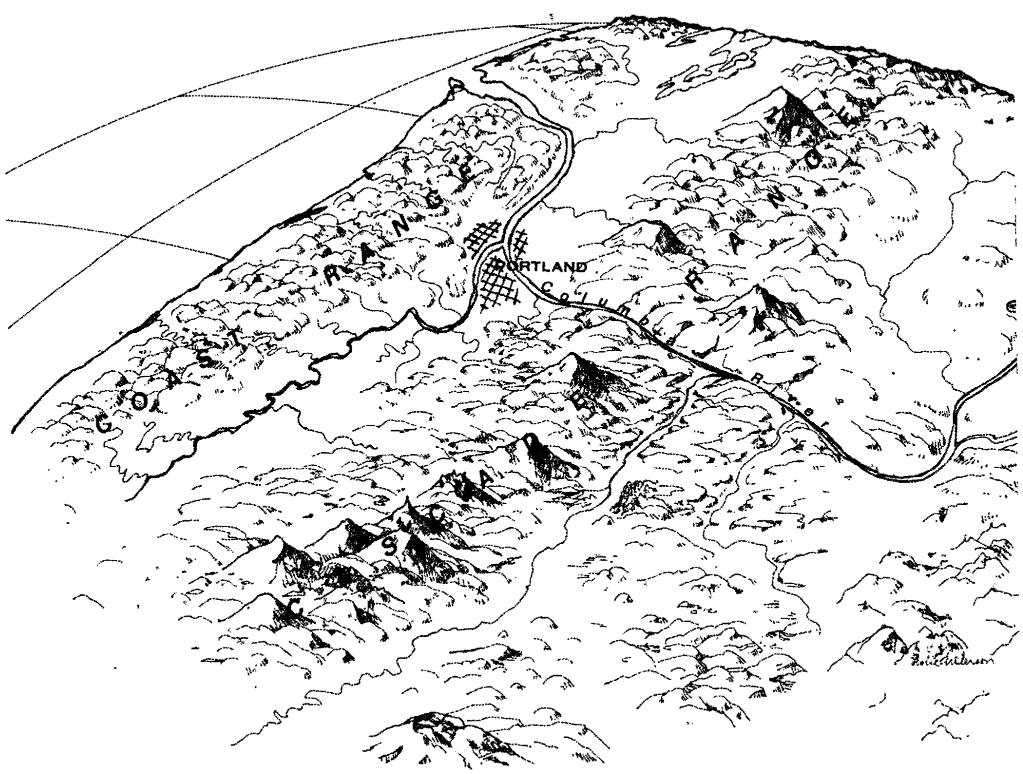

Figure 2.3: Regional setting of Portland, illustrating the major topographic controls on climate. Drawing is not to scale.

quence of cold weather extending to the end of the month. Fortunately the area was released from this icy grip on New Year's Day, 1986, with the arrival of a marine air mass that raised the temperature to a high of 51°F.

EXTREME METEOROLOGICAL EVENTS

The Portland area, indeed the entire Pacific Northwest, is generally immune from the effects of severe storms which so often create havoc in other parts of the world. For example, the combination of climatic controls is not conducive to the formation of hurricanes and tornadoes. From 1953 to 1976 only 23 tornadoes were reported in Oregon and 24 in Washington, and most of these were east of the Cascades. These numbers pale in comparison to the 1,326 tornadoes reported in Oklahoma during the same period (Ahrens, 1985, p. 406). Severe thunderstorms, while common east of the Cascades, are also rare in the Willamette Valley. Air mass thunderstorms require vigorous convective uplift in a humid atmosphere, a situation uncommon in Portland where the warm, sunny summer days that would promote convective activity are also days in which a dry air mass dominates the region. Likewise, forced lifting along a frontal boundary is rarely rapid enough to

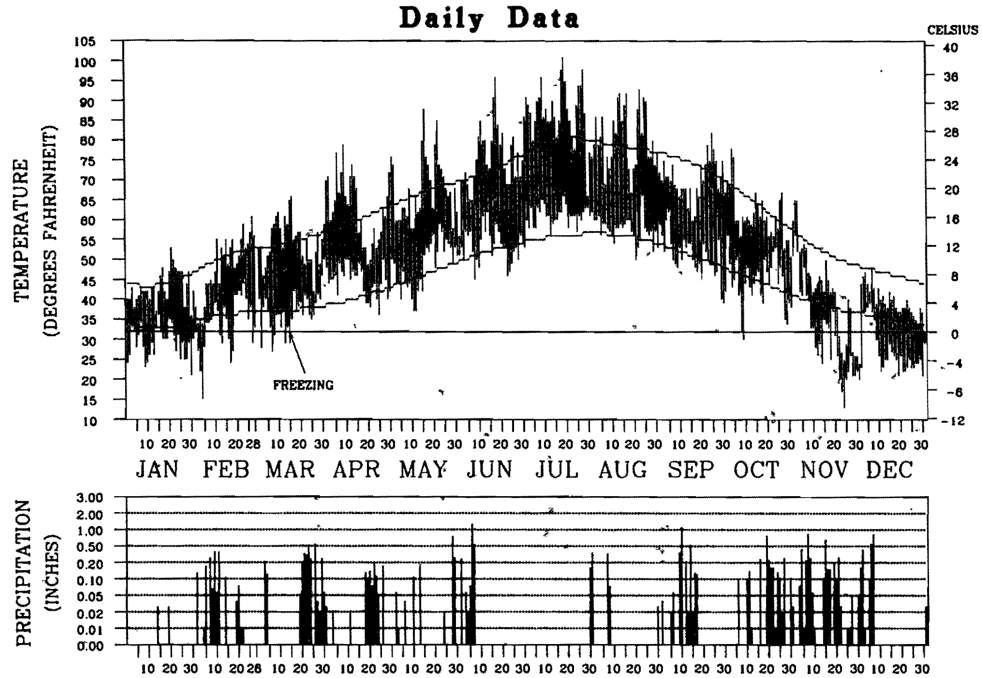

Figure 2.4: Annual march of daily temperature and precipitation in Portland for Calendar Year 1985. Data are for National Weather Service station (NOAA, 1986, p. 1).

spawn thunderstorms. The National Weather Service reports an average of only 7.1 thunderstorms per year in Portland, the majority occurring from April to August (NOAA, 1986).

Extreme meteorological events in the Portland area are generally restricted to two types -- 1) mid-latitude cyclones which on occasion are very severe; and 2) winds and precipitation influenced by the Columbia River Gorge. In the minds of most long-time residents of northwest Oregon, the single most frightening meteorological event of this century was the famous Columbus Day Storm of October 12, 1962, one of the most vigorous and destructive of its type ever recorded along the west coast (Lucia, 1963; Lynott and Cameron, 1966). In many places new records of extreme winds were established and damage was in the millions of dollars. Contrary to popular reports in the press, this was not a hurricane or tropical storm, but a mid-latitude cyclonic storm unusual for its severity and its early season occurrence. Wind gusts on Mount Hebo in the northern Oregon Coast Range at 3,000 feet elevation were estimated at 170 miles-per-hour. In downtown Portland gusts of 116 miles-per-hour were recorded at the Morrison Street Bridge, exceeding any previous records for the metropolitan area (Harper, 1962).

The storm of November 13, 1981, was a similar event that howled up the Oregon coast, generated by an intense low pressure cell. Ninety mile-per-hour winds, flooding, and widespread devastation in Brookings and Coos Bay were

reported from the south and central coast. It swept into Portland shortly after midnight with hurricane-force winds that ripped roofs from buildings and tore a supertanker from its Swan Island mooring. Power lines and radio towers were toppled, trees uprooted, motor homes crumpled, and aircraft upended. Throughout Oregon the storm took 11 lives and caused $33 million in damage (Cody, 1985, p.7).

Infrequent severe storms of this type highlight the difficulty of weather forecasting in Portland and the Pacific Northwest. Despite major technological advances that have made weather prediction a science instead of a mysterious attempt at outguessing the gods, meteorologists claim that the Northwest remains one of the trickier regions in the country to forecast (Read, 1983). A primary reason is the paucity of surface observations over the Pacific Ocean. Forecasters thus look to satellite photographs for information. These give immediate data on the higher levels of the atmosphere, but only limited surface information can be obtained from them. Furthermore, satellite photos are not detailed enough for local forecasts which are so often confounded by the complex influences of local topography.

Another source of headaches and sleepless nights for local forecasters, and a compelling example of the influence of topography on climate, both on the local and regional scale, is the Columbia River Gorge. This remarkable transverse valley is a topographic feature of unparalleled natural grandeur sculptured by the Columbia River (Figure 2.3). It offers a low-elevation passage through the Cascades, thus permitting a transition from the marine type climate of western Oregon to the continental type of the interior (Lynott, 1966). In response to prevailing regional pressure gradients the majority of air movement through the Gorge is from the west to east allowing marine air to modify temperatures east of the Cascades in both summer and winter.

The Gorge has been described as a giant wind funnel. Westerly winds can become quite strong, and are often observed as far east as Pendleton. However, it is the less frequent but normally more violent east winds, induced by a reversal of the regional pressure gradient, that are of particular concern to Portland. These may occur at any time of the year, but are most common in the winter when a cold-core anticyclone located over the interior blocks storm movement through the Pacific Northwest. Polar air nocturnally cools and deepens east of the Cascades in the Columbia and Snake River Basins, forming a large pool of cold air. The Cascade Mountains form a natural barrier that traps this cold air mass, and the only escape is through the Columbia River Gorge, the Frazier River Valley in British Columbia, and to a lesser extent the low passes in the Cascades (Baker and Hewson, 1978).

Occasionally, cold air in the Great Plains spills over the Rockies into the interior basins and intensifies this east wind surge. It is a synoptic pattern that typically persists for several days and has been known to last for several weeks, sustaining strong easterly flow through the Gorge into the Portland metropolitan area (Cameron and Carpenter, 1936). For this reason Portland is generally windier and colder than nearby cities to the north and south. The record low temperature of -3°F recorded in February 1950 was due to the influence of these easterly winds. Freezing rain is another hazard that area residents are exposed to because of proximity to the Gorge. If high pressure to the east coincides with a fall of air

pressure along, the coast as a frontal system approaches, the regional pressure gradient is increased and the flow of east winds through the Gorge accelerated. A shallow layer of cold air clings to the surface and temperatures remain very cold in Portland. As the moisture-laden air from the Pacific moves inland it rides aloft over this cold layer, a combination of events that produces freezing rain, or as it is commonly termed in Portland, a "silver thaw." One such event occurred in early January, 1979, as the first rains from an approaching Pacific storm fell into a frigid surface layer and coated all surfaces with clear ice. Electric power, communications, transportation, and all normal work routine broke down in most of Portland, most dramatically in the eastern part of the city near the west end of the Gorge (Decker, 1979).

In this kind of synoptic situation all kinds of precipitation can occur in northwest Oregon, depending on the temperature balance as controlled by elevation, distance from the sea, and proximity to the Gorge. It is a unique, and devastating, mix of topography and climate that makes the beautiful Columbia River Highway, paradoxically, the most treacherous stretch of highway in the country. While other regions in the country experience ice storms, the topography ensures that the Columbia River Gorge and those areas exposed at either end of it will be subjected to more onslaughts than most. Several years may go by without such an event, but it may also occur with alarming frequency in the space of a few years. Within the metropolitan area itself the severity of such storms and the pattern of minimum temperatures due to the Gorge winds will vary dramatically. While the east side of town may be buffeted by cold Gorge winds and freezing rain, the Tualatin Valley to the lee of the West Hills may be relatively balmy. East wind events in the summer cause a different sort of problem, importing high temperatures and low humidities to northwest Oregon and southwest Washington. At these times, residents of the area watch for the return of more moderate marine air and forest managers take special precautions against forest fires. Most of the historically great forest fires in Oregon and Washington, notably the great Tillamook Burn of the 1930's, were driven by hot, dry east winds (Johnson and Dart, 1981).

SPATIAL PATTERNS

The unique setting and the complex topography within the Portland metropolitan area generates a fascinating mosaic of microclimates, patterns of climatic elements that are as complex as those for any metropolitan area in the country. Precipitation patterns are well documented thanks to data collected from the Portland Mesoscale Precipitation Network, a network managed by the Bonneville Power Administration and operational since the late 1960's. Winter storms traverse the area on prevailing west to southwest winds, distributing precipitation in a pattern highly correlated with topography. The spatial distribution is essentially repeatable from storm to storm throughout the rainy season. This topographic control is apparent in the pattern of annual precipitation, yet not all valleys are equally dry, nor are similar elevations in the hills equally wet (Figure 2.5).

The least surprising aspect of the annual pattern is the west to east precipitation gradient, a steady decrease down the east slope of the Coast Range and a steady increase up the west slope of the Cascade foothills. Elevated areas within the valley, e.g. the Chehalem

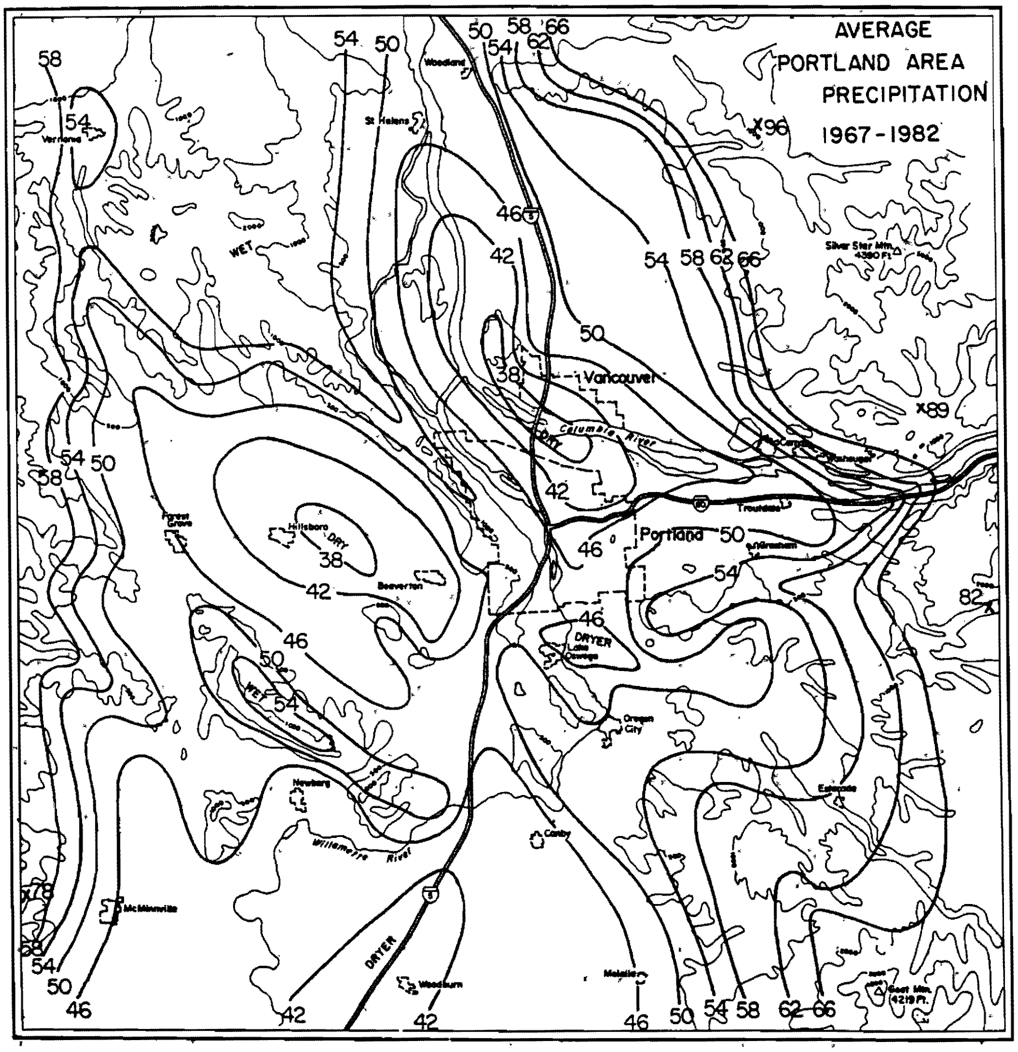

Figure 2.5: Average annual precipitation, in inches, for the Portland metropolitan area (1968-1982). Relatively wetter and drier areas are marked (Wantz, et al, 1983, p. 13).

Mountains southwest of the city and the West Hills which flank downtown, receive greater amounts of 54 inches per year. Immediately downwind of the Chehalem Mountains lies the Tualatin Valley, where the 15-year average rainfall is as little as 38 inches in a large area between Beaverton and Hillsboro. This valley may be the driest area in northwest Oregon. The other "dry" area has been recognized for years because the Portland National Weather Service Office lies at its eastern edge. This is a long, narrow rain shadow along the Columbia River lying to the lee of the West Hills. The 15-year average rainfall at the Portland National Weather Service Office is 38.7 inches (compared to 37.4 inches, the climatic "normal"

from Table 2.1). It would be difficult to find a more unrepresentative location for the city's official precipitation measurements (Wantz, et al, 1983).

The West Hills rise more than 1,000 feet above the surrounding lowlands and receive over 47 inches of orographically enhanced precipitation, 25 percent more than the adjacent Tualatin Valley. The increased amounts of precipitation in the West Hills are significant to local residents in the winter when monthly mean temperatures at the 1,000 foot level average 5°F lower than at the National Weather Service Office. Annual snowfall here averages about 24 inches, nearly three times the average in the lower valley areas. Residents of the West Hills are occasionally surprised by a six inch snowfall that severely hampers travel across the steeper terrain, while suburban areas at lower elevations nearby may have no snow whatever.

Temperature data from this mesoscale network are a fairly recent addition and are collected at a smaller number of stations. The major control on the spatial pattern of temperature in the metropolitan area is elevation. Thus, outlying areas are cooler than is the city center adjacent to the Willamette River. However, due to the combined influences of land use, cold air drainage, and proximity to the Columbia River Gorge, a consistent temperature-elevation relationship does not exist. Low-lying areas frequently have exceptionally cold nights, and east side locations tend to be colder than at similar elevations on the west side.

The interaction of temperature, atmospheric moisture, and topography dictates the pattern of fog in the metropolitan area, a climatic element for which few data exist. The National Weather Service reports an average of 33.6 days per year during which heavy fog restricts visibility to 1/4 mile or less (NOAA, 1986). But such "point" data do not tell the real story of the spatial patterns of fog in an area where the topography is so varied. The National Weather Service Office is located in east Portland on the Columbia River, adjacent to the Portland International Airport. It is a site well-exposed to easterly Columbia Gorge winds which effectively dissipate fog that may persist in other parts of the metropolitan area. Therefore, data from this station are not representative. Happily, the location of the airport is such that it is not subject to frequent closures due to fog and reduced visibility, a problem of greater magnitude at other cities in the Pacific Northwest, for example Medford in southern Oregon and Sea-Tac Airport in Seattle.

The combination of cold air drainage and high moisture content in river valleys makes them susceptible to radiation fog, which occurs frequently when regional high pressure dominates the area, a common occurrence at any time of the year. At times the low-lying areas are completely shrouded while the hills remain bathed in sunlight. Radiation fogs tend to form upward from the ground as the night progresses and are usually deepest around sunrise. A shallow layer will usually dissipate or "burn off" by afternoon. Advection fog is more of a winter season phenomenon, formed when relatively warm, moist air moves over colder surfaces. It is enhanced by upslope air flow, so the higher elevations in Portland are more likely to be fogged in.

Another significant environmental element directly related to the complex interaction between climate and topography is air pollution. Unfortunately, the combination of these controls in Portland precludes the efficient dispersal of pollutants. The valley setting, with

mountains on either side, inhibits horizontal dispersion, especially in the summer when winds are light and generally from the north. Pollutants cannot escape vertically when mixing is reduced by inversions that exist under the influence of high pressure, a situation common in all seasons. In fact, throughout the valleys of western Oregon there is a higher frequency of inversions than in most places in the country. In Portland, the average height of the mixed layer is 3,000 feet, and about 10 percent of the time the mixing height is below 1,500 feet, well below the crests of the flanking mountains (DEQ, 1986). Thus there is a heavy build-up of pollution with a corresponding reduction in visibility. This is both a public health issue and an aesthetic one. Many area residents gauge air quality by their ability to view two of the region's volcanic landmarks -- Mount Hood, 60 miles to the east of downtown, and Mount St. Helens, an equal distance to the north. Stagnant air, trapped under an inversion, becomes increasingly polluted until the weather changes to bring in a strong regional flow that permits vertical and/or horizontal mixing.

CLIMATE IN THE PAST

One aspect of the temporal variability of climate is the annual cycle; another is the variability over longer time scales. Unfortunately, observations of temperature and precipitation in Portland have been recorded for barely more than a century. For the longer period, prior to the advent of instrumental records in the 19th century, the climate of Portland can be discussed only in general terms of the climate history of the Pacific Northwest. A coarse outline for climate of the last 25,000 years in the Pacific Northwest has begun to emerge thanks to the work of several investigators, most recently Heusser (1983) and Barnosky (1984). In these studies paleoecologic data have been used to interpret precipitation and temperature for the late Pleistocene and early Holocene, and they have shown that the region has experienced a great range in climatic conditions, variations in temperature and precipitation that certainly exceed anything noted in the past few centuries.

For the past 1,000 years the accuracy and number of paleoclimatic indicators is greatly increased. Three such indicators yielding a wealth of information about climate throughout the American West are tree rings, lake level fluctuations, and the movements of mountain glaciers. No information specific to the Portland metropolitan area is available, but the broad-scale studies are spiced with interesting implications. Perhaps the most significant finding is that the climate of the mid-20th century is anomalous when viewed in an historical context. Bradley (1976), for example, noted that warm-moist conditions prevalent in the 1941-1970 period have not occurred since the 14th century. Furthermore, there is a growing body of evidence that, for the globe as a whole, the extreme inter-annual variability of climate since about 1970 is more in keeping with climatic behavior over the past several centuries; the middle decades of the 20th century were unusual because of low inter-annual variability. Extreme events in the 1970's such as severe winters in the central and eastern United States and drought in the west have certainly done nothing to refute this finding (Diaz and Quayle, 1978; Shelton, 1977).

Nevertheless, it is only for the period of instrumental observations that precise statements can be made about the climatic history of Portland. Data collection

commenced in 1871 at a downtown station, which became the official U. S. Weather Bureau station when that agency was established in 1892. Service continued uninterrupted until 1973. Coincident with the closure of this station was the addition of the downtown KGW-TV station to the cooperative climatological network. Thus, a nearly homogeneous record of temperature and precipitation is available since 1871.

These data can be analyzed in the context of climate variability for the northern hemisphere and for the Pacific Northwest. Mean annual temperature in Portland shows a steady increase from 1872 through the mid-1940's (Figure 2.6). Studies of instrumental records from throughout the northern hemisphere document the much discussed general warming trend from about 1850 to the 1940's (Mitchell, 1961; 1963), attributable in part to increased levels of carbon dioxide in the atmosphere. After about 1940 there was a reversal of this trend and general cooling into the 1970's, primarily at middle and high latitudes (Jones, Wigley, and Kelly, 1982). Causes of this cooling episode are likely multiple, including solar variability (Willett, 1974;

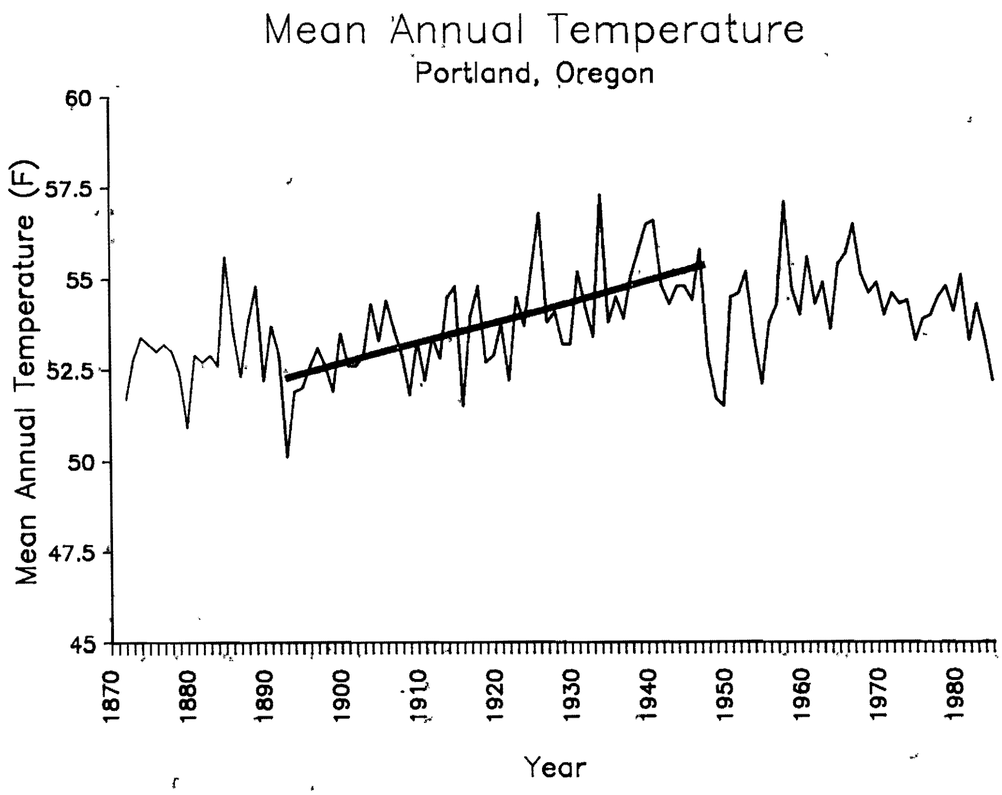

Figure 2.6: Time series of mean annual temperature, Portland, 1872-1985. Data are from downtown station through 1972 and Portland KGW-TV beginning in 1973.

Agee, 1980) and volcanic activity (Oliver, 1976). However, temperature and precipitation anomalies on a regional basis do not necessarily reflect the hemispheric trend. For example, much of the western half of the United States experienced a slight warming while the rest of the nation experienced the cooling documented for the northern hemisphere as a whole (Wahl and Lawson, 1970).

In Portland there is no clear evidence of either progressive warming or cooling since the 1940's. However, the analysis of temperature changes over time is complicated by many factors, not the least of which is the influence of human activity. Due to changes in the heat balance associated with urbanization, cities tend to be warmer than the surrounding countryside. Likewise, the growth of a large city like Portland may account for warming noted during the first half of the century.

Precipitation data are less sensitive to the effects of urbanization (Figure 2.7). The decade of the 1870's and the early 1880's were extremely wet; in Water Year 1883 Portland received an incredible 71.8 inches of precipitation. Annual amounts declined steadily through the 1920's and early 1930's, a time of widespread drought in North America, and then increased steadily through the 1960's. The decade of the 1970's is marked by extreme year-to-year variability, a finding consistent with the global climate as discussed above.

CLIMATE OF THE FUTURE

Although it is impossible to forecast future climate with any confidence, scientists have rapidly increased their understanding of short-term anomalies in temperature and precipitation. Year-to-year variability of climate in the Pacific Northwest is due to fluctuations in the jet stream; i.e. changes in location of mean ridges and troughs in the windflow in the middle and upper troposphere. The location and intensity of these features appears to be critically influenced by sea-surface temperature anomalies, and investigations for the North Pacific and the North Atlantic Oceans have demonstrated interactions with the atmospheric circulation on a near-hemispheric scale (Namias, 1969). For example, an extensive, relatively warm pool of surface water in the north-central Pacific in the winter of 1971-72 contributed to a northward displacement of the westerly jet stream together with a compensating southward displacement over the western United States, bringing in cold air (Figure 2.8). This pattern contrasts with that of the 1960's when anomalous cold sea-surface temperatures persisted in the central Pacific with warmer water to the west, leading to frequent storm development in the intervening zone of strong temperature gradients. The associated upper airflow produced a ridge of high pressure over the American West with warm winters in California and the Pacific Northwest (Barry and Chorley, 1982).

The most famous drought of the American West in recent memory was that of 1976-77. For much of the Pacific Northwest this was the driest winter on record (Bates, 1978). Portland, for example, received 27.6 inches at the downtown station, 65 percent of the long-term normal. Namias (1978) demonstrated the cause linked to sea-surface temperatures. In the autumn of 1976 to February, 1977, warmer water and a strong upper-air ridge persisted near the west coast. Cooler waters and a persistent trough were located toward the central Pacific. In other words, it was a more extreme example of the

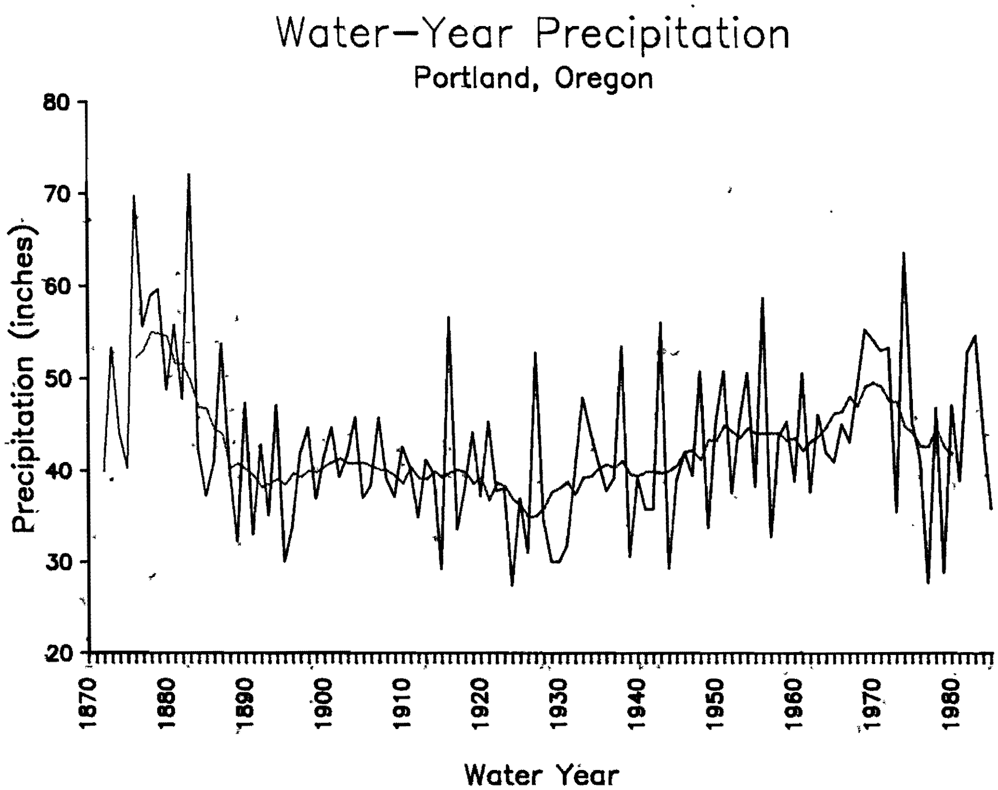

Figure 2.7: Time series of annual precipitation, Portland, 1872-1985. Data are from downtown station through 1972 and Portland KGW-TV beginning in 1973. Annual totals are for the Water Year (October through September).

situation presented in Figure 2.8 for the 1960's.

In recent years the concept of atmospheric teleconnections as related to sea-surface temperature patterns has taken on a new dimension with recognition of the ocean-atmosphere phenomenon called El Nino-Southern Oscillation (ENSO) which occurs in the equatorial Pacific Ocean. ENSO is identified as a weakening in the normal gradient between high pressure centered in the central Pacific off the coast of South America and low pressure in the Indian Ocean near Australia (Rasmusson, 1985). Recent research has clearly demonstrated that there are world-wide effects derived from an ENSO event. A decrease in the pressure gradient results in displacement of the normally occurring weather systems in the middle latitudes, and is termed the Pacific North American (PNA) Teleconnection. The shift in normal circulation in the eastern north Pacific and over the continental United States has been observed to result in associated shifts in storm tracks and temperature patterns. Lough and Fritts (1985) showed that during an ENSO event precipitation, particularly in the winter, tends to be less than normal over the Pacific Northwest due to a southern displacement of the usual storm track. In addition, temperatures

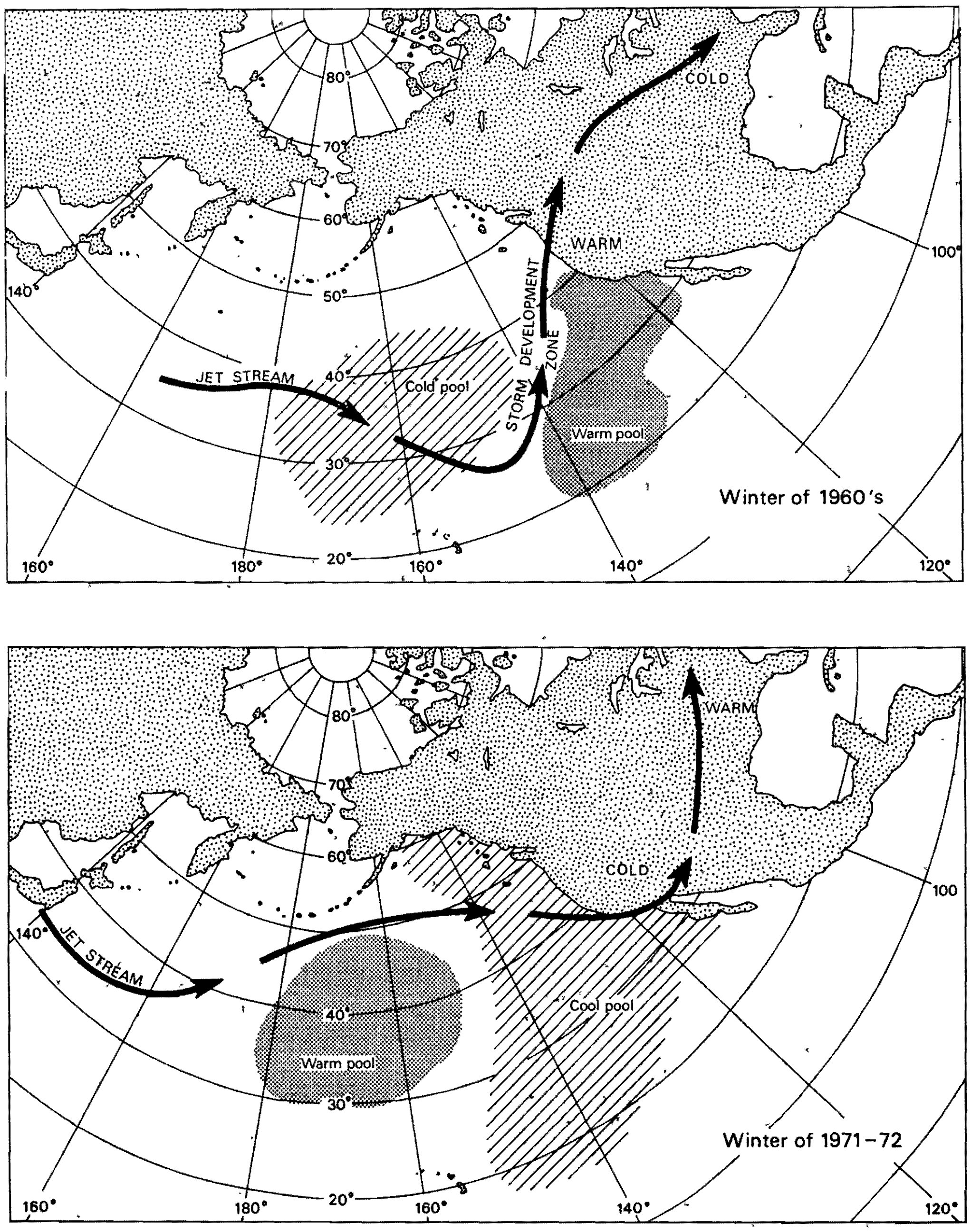

Figure 2.8: Generalized relationships between ocean-surface temperatures, jet stream tracks, and land temperatures over the North Pacific and North America during average winter conditions in the 1960's, and the winter of 1971-72 (Barry and Chorley, 1982, pp. 192-193).

tend to be warmer than normal over the Pacific Northwest.

Only a few years ago distant events such as a warming in the equatorial oceans would have appeared to hold little relevance for the weather and climate of Portland. Although these atmospheric teleconnections are not yet adequately defined for reliable monthly and seasonal forecasting, it is a field in which knowledge is accumulating rapidly. Yet, in spite of advances in our understanding of climate – in its controlling mechanisms and in its natural variability -- the "ideology of climate" for Portland and the Pacific Northwest is still relevant. Rainfall in Portland is, indeed, prolific; but the mild winters and the pleasant summers blend with a beautiful and accessible physical and cultural environment to enhance a lifestyle valued by local residents.

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