NOAA Technical Memorandum
NWS WR-126

CLIMATE OF SAN FRANCISCO

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U.S. DEPARTMENT OF COMMERCE | National Oceanic and Atmoshperic Administration | National Weather Service

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I. TOPOGRAPHY

San Francisco is in an area of "exceedingly diversified topography" (McAdie, 1903) that is favorable to numerous microclimates (McAdie, 1913; Gilliam, 1962). Winds are channeled over and around the City of San Francisco by the terrain, resulting in pronounced differences in the weather across relatively short distances (Root, 1960; Null, 1978).The development of the extremely varied California landscape is a consequence of the interaction between of the North American and Pacific tectonic plates (Alt & Hyndman, 1975). The most prominent features, and most important in their effect upon state's climate (Root, 1960), are the Sierra Nevada and Coast ranges, between which lies the Great Valley. All three, generally oriented from northwest to southeast, are parallel to the motion of the North American plate.San Francisco, which is described by approximately a seven mile by seven mile square, sits at the northern end of a peninsula, straddling the Coast Range just south of where it is broken by the Golden Gate. The melting of the ice sheets that covered the North American continent during the Pleistocene caused sea level to rise and flood the structural depression which is now San Francisco Bay (Howard, 1962; Alt & Hyndman, 1991). Outflow from the Sacramento and San Joaquin Rivers, fed by the drainages from the surrounding Sierra Nevada and Coast Range, maintains the breach as the only major outlet to the Pacific. San Francisco's steep topography is the boundary between the Pacific Ocean on the west, San Francisco Bay to the east and the Golden Gate to the north. The highest terrain is toward the south, where the elevations rise to over 900 feet, with Mount Davidson's peak of 938 feet the tallest, followed closely by Mount Sutro at 920 feet and both North and South Twin at 919 feet. In addition to the primary north- northwest to south-southeast ridgeline, a number of significant hills dominate the San Francisco horizon, as spurs off of the main axis. The city's steepness is shown by the fact that the 60 meter elevation contour is generally within one mile of sea level (United States Geological Survey, 1973a, 1973b).Because of the small area that San Francisco covers there are no significant natural drainage basins within the city limits. Those which may have existed historically have long since been constrained to underground culverts and the storm drain system.

CLIMATE

The sharp topography and maritime surroundings of San Francisco combine with the unique California climate to produce a number of extremely varied microclimates within its 46 square miles. California's location in the middle latitudes and on the west coast of the North American continent, places it in the relatively rare Mediterranean (Etesian) type climate (K”ppen type Cs). The only other regions of the earth sharing this climate type are the southwestern tip of Africa, the west coast of Chile, the west coast of Australia, and of course, the region surrounding the Mediterranean Sea (Critchfield, 1966). This type of climate type is generally characterized by moist mild winters and dry summers.

San Francisco's climate is further modified by the location of the City on the northern end of a peninsula, surrounded on three sides by the relatively cool waters of the Pacific Ocean and San Francisco Bay. In addition to the normal cool temperatures of the mid-latitude Pacific Ocean, the water temperatures are modified by the upwelling of cold water along the California coast. This phenomenon is caused by the persistence of the Pacific High and the northwest winds that are constrained by the Coast Range to blow parallel to the coastline. The effects of these winds, the Coriolis Force and resultant sub-surface Ekman Spiral, causes a net transport of surface waters away from the shore. Consequently, as the surface waters drift away from the coast, they are replaced by the upwelling of colder waters from below (Ahrens, 1991).

Summertime in San Francisco is characterized by cool marine air and persistent coastal stratus and fog, with average maximum temperatures between 60øF and 70øF, and minima between 50øF and 55øF. The mornings will typically find the entire city overcast followed by clearing on the warmer bay side, but only partial clearing on the cooler ocean side. The summertime temperature gradient across the city is generally from northwest to southeast, with the warmer readings farthest from the coast and in the wind sheltered valleys east of the Coast Range bisector. These differences are enhanced further by a strong afternoon and evening seabreeze that is a result of the temperature (and consequently pressure) difference between the Pacific Ocean and the interior valleys of California. These westerly winds are channeled through the Golden Gate and lesser breaks in the high terrain of the Coast Range, reaching a maximum during the afternoon with speeds between 20 and 30 miles per hour being typical (Root, 1960).

Rainfall from May through September is relatively rare, with an aggregate of less than an inch, or only about 5 percent of the yearly average total of approximately 21.5 inches. Off- season rains which do occur are usually the result of weak early or late season occluded fronts, or surges of subtropical moisture from the south that result in brief showers or thundershowers spreading into the area. Considerable moisture is due to drizzle when the marine layer deepens sufficiently. This is seldom enough to measure (i.e., less than .01 inch) on any given day, except along the immediate coast.

Winter temperatures in San Francisco are quite temperate, with highs between 55øF and 60øF and lows in the 45øF to 50øF range (Null, 1978). The main source region of wintertime fog in San Francisco is the Great Valley. Radiation fog is formed in the moist regions of the Sacramento River Delta and is advected through Suisun and San Pablo Bays and into San Francisco Bay on cool easterly drainage winds. This type of fog is less common than that of summer, but is typically much denser and has a greater impact upon transportation systems due to greatly reduced visibilities (Root, 1960).

Over 80 percent of San Francisco's seasonal rain falls between November and March, occurring over about 10 days per month. Winter rains on the California coast are primarily due to occluded fronts on a trajectory from the west-northwest, and an occasional cold front from the Gulf of Alaska. These systems are driven southward during the winter as the Pacific High drifts south and westerlies and Polar jetstream dip south of 40øN. Winter thunderstorms occur on the average only twice per season in cold unstable post-frontal airmasses. There is also considerable areal variation of annual precipitation amounts. The isohyet (contours of equal rainfall) analysis developed by Rantz (1971) depicts a maximum (22 " contour) over the higher terrain in the south central portion of San Francisco. This is primarily due to the orographic effects resulting from uplift of the airflow from the Pacific striking the Coast Range. The 20" contour is along the western edge and also across the northeastern quadrant of San Francisco, with the 18" contour just touching the waterfront in the extreme northeast.

Snow is extremely rare in San Francisco, with only 10 documented instances of measurable snow at the official observing site in the past 143 seasons. Snow has fallen on a number of other occasions, but usually only in trace amounts or at the higher elevations. Additionally, some of these occurrences are not true snow events but were the result of either small hail or ice pellets (Pericht, 1988).

Spring and fall are transition periods for San Francisco. These seasons usually produce the most cloud-free days between the overcast days of summertime stratus and the rain laden clouds of winter. San Francisco's hottest days are typically during the spring and fall when high pressure builds into the Pacific Northwest and Great Basin, and dry offshore winds replace the Pacific seabreeze. The three hottest days in San Francisco occurred in September and October (Pericht, 1988).

The occurrence of rainfall during the early spring and fall is infrequent, with only about 5 days per month on the average. While most storms during these periods produce light precipitation, the occasional coupling of polar and subtropical airmasses can produce heavy rainfall events. For example, the "Columbus Day Storm" (October 11, 1962 through October 13, 1962) dropped over five inches of rain on San Francisco (Null, 1978). The diversity of San Francisco's microclimates in general and its rainfall patterns in particular must be considered when utilizing the data from a single site. In a relatively flat region, without the influences of the ocean and topography, there is little discernible change in annual rainfall averages with distance. However, within a distance of only a few miles in San Francisco there can be as much as a 20 percent difference in average annual rainfall (i.e., from 18" to 22").

II. SAN FRANCISCO STATION HISTORY

Weather conditions have been observed in San Francisco since 1847 when the first observations were made at the Presidio of San Francisco. However, the Presidio records were taken only intermittently. It was not until the summer of 1849, when the population of San Francisco increased significantly because of the Gold Rush, that the continuous rainfall record began. Official continous temperature records have been kept from 1871 until present. Measurements of wind, pressure, humidity and sunshine were taken for approximately 102 years, also beginning in 1871, but were discontinued in 1973 when the Weather Bureau Office moved to San Francisco Airport.

The continuous San Francisco rainfall record extends back to August 14, 1849 when Thomas Tennent, a maker of nautical and mathematical instruments, began taking daily measurements shortly after his arrival in San Francisco. Tennent was born a Quaker in Philadelphia in 1822, and apprenticed as an instrument maker. Early in 1849 he made the 95 day journey to California from the east coast via the Panama Canal, walking the final 110 miles from Monterey. While waiting for his instruments to arrive from the East, Thomas Tennent served as a surveyor and also as a miner (Bay of San Francisco: A History, 1892).

When he finally set up his shop, making nautical instruments for the many ships stopping at San Francisco during the Gold Rush, he installed a rain gauge on the roof. This location was on the northeast corner of Union and Dupont (now Grant), and was the first of six locations at which Thomas Tennent would take observations between August 14, 1849 and February 1, 1871. These sites were all confined to a relatively small area in the northeastern quadrant of San Francisco (see Table 1 and Figure 1). He supplied his meteorological data, along with sunrise, sunset, moon and tide tables, to the local newspapers. His meteorological data were eventually published in Tennent's Nautical Almanac beginning in 1868 and continuing until 1890.

Tennent became a prominent San Franciscan and served three terms as a member of the Board of Supervisors. During his tenure as a surveyor he designed the street layout for all of San Francisco west of Larkin Street, and the house numbering system which is still in use (Bay of San Francisco: A History, 1892).

Several other individuals also took weather observations during the Gold Rush. Dr. William O. Ayres took complete weather observations from 1856 until 1868; however, nearly thirty months of data during that period are either missing or were never taken (Loffman, 1975).

Another prominent early San Franciscan, Dr. Henry Gibbons took observations of rainfall and temperatures from 1850 until at least 1880. Like Tennent he sold his data to the newspapers as a Meteorological Table. Gibbons was one of the founders of California Academy of Sciences, a President of the California State Medical Society and a professor at the Medical College of the Pacific (Bay of San Francisco: A History, 1892).

McAdie (1913) also notes that records of rainfall and temperature were taken by Dr. T. M. Logan and Mr. John Pettee. This is the only reference in the literature to these individuals.

On March 1, 1871 the U.S. government took over as the official weather observer for San Francisco when the Army Signal Service began to take the observations. The Signal Service accepted the rainfall data from Thomas Tennent as the "official" early record. This was because of Tennent's expertise as an instrument maker and the fact that he recorded rainfall to the nearest one-hundredth of an inch, while Gibbons measured only to the nearest one-tenth inch (Loffman, 1975). Because of the extreme variability of temperatures, the early temperature records of Tennent, Ayres and Gibbons were not incorporated into the official record (Loffman, 1975). Consequently, the official San Francisco temperature records do not begin until 1871.

From that time to present, the U. S. government has taken weather observations in San Francisco, first as the Signal Service, and then the United States Weather Bureau (later renamed the National Weather Service). Since 1871, the observation site was moved another six times, but has remained in the northeastern quadrant of the city.

The ninth observation site, at the Mills Building, was destroyed by the earthquake and fire on April 18, 1906, and observations were taken at a private residence about 2 miles to the west until October 1, 1906. There is a discrepancy in the records (Null, 1978; Pericht 1988) as to whether observations were taken between April 18 and May 1, 1906. However, records complied by McAdie (1906) indicate rainfall for San Francisco on several dates during that period. This corresponds to data available at several other nearby sites during the same period, and has been incorporated into this research.

In 1936, the observation site was moved to the roof of the Federal Office Building (FOB) on Fulton Street, where it remained until 1983. The forty-seven years at this locale was the longest at any site. In April 1973, the Climatology Office in the Federal Building was closed. Readings from that site, and subsequently Mission Dolores, were transmitted by telephone line to the National Weather Service Office at San Francisco International Airport. Observers discovered that there was a "minor malfunction" in the rain gauge at the FOB from January 1973 to April 1982 (Pericht, 1988). The FOB readings were found to be only about 70% of actual amounts (by comparison to data from surrounding sites). The record was corrected by substituting data from KGO Television, which was only 2 blocks away, and has been accepted by the National Climatic Data Center (NCDC).

The most recent San Francisco rainfall sites are at Mission Dolores and Duboce Park, 1.3 miles south of the FOB then 0.5 miles northwest, where it was moved on April 18, 1983 and June 11, 1997 respectively. These sites are the southernmost of the 13 locations, yet remain within a 1.5 mile radius circle that encompasses all of the aforementioned sites.

The rain gauge that Thomas Tennent used was a six inch square container which funneled into a two inch square receiver, and was capable of holding 4 inches of precipitation (Melnick, 1978). With the establishment of the Signal Service observations in 1871, all observations have been made using a "standard" eight inch circular gauge. Readings from the site were telemetered to the NWS office at San Francisco Airport beginning in 1973.

Acknowledgements: Special thanks to the dedicated people who have faithfully taken and kept the San Francisco weather data for a century and a half.

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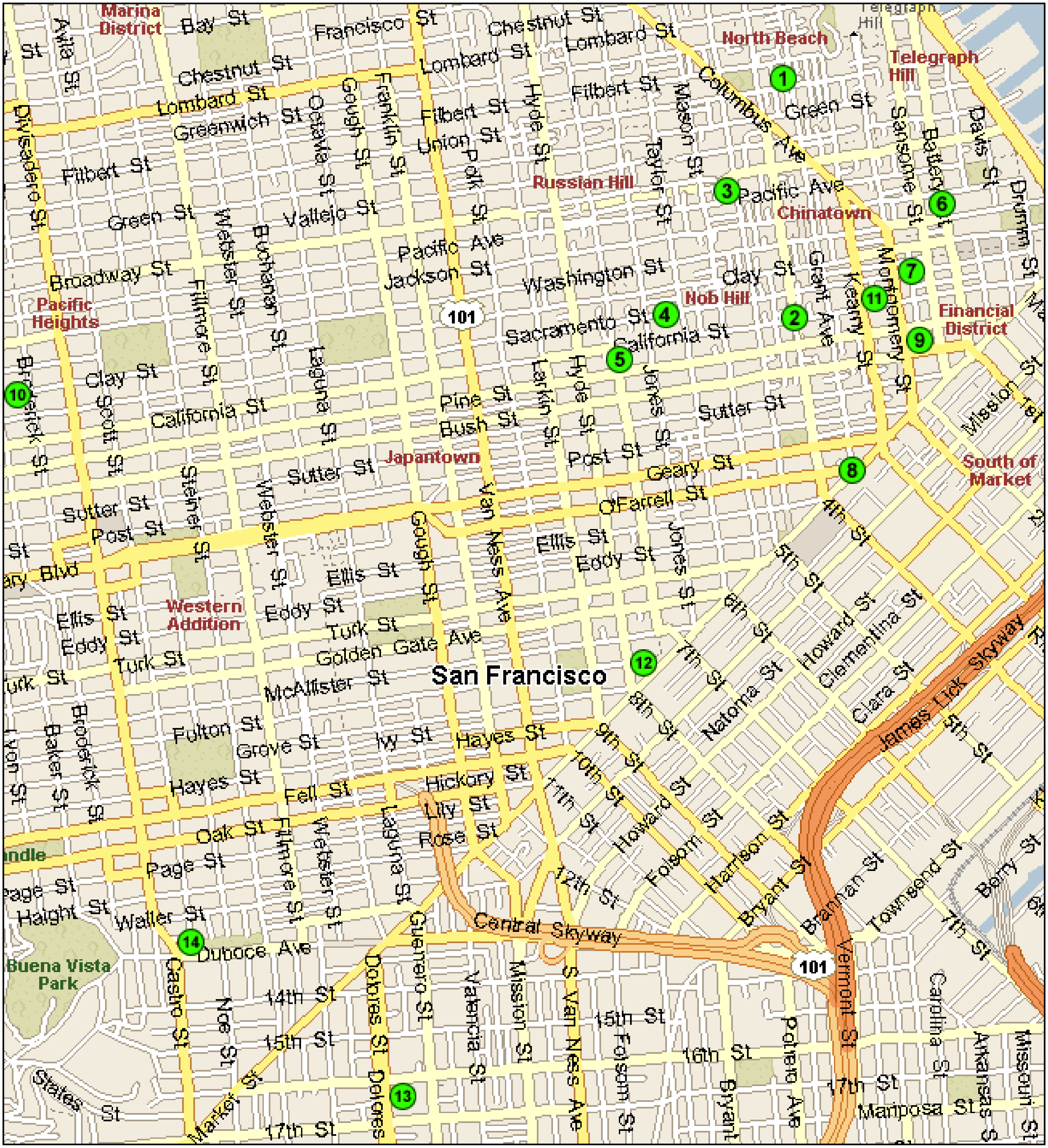
* Note: Due to a malfunctioning raingauge, data for the period of October 1, 1973 through March 10, 1982 has been corrected using rainfall data from the nearby KGO-TV gauge. This site is located at 277 Golden Gate Ave., approxmately 500 feet north of the FederalOfficeBuilding. It had a rooftop exposure with a ten inch tipping bucket gauge located at 125 feet MSL.

Station Locations

	Location	Dist. from	Began	Ended	Elev. ASL
1	NE Corner Union & Dupont (Grant)		8/14/1849	7/1/1851	125'
2	Stockton & California	0.6 mi SSW	7/2/1851	7/1862	175'
3	Powell between Pacific & Broadway	0.3 mi NNW	7/1862	Summer 1863	120'
4	Sacramento between Taylor & Jones	0.4 mi SW	Summer 1863	7/1864	330'
5	Leavenworth between Pine & California	0.2 mi SW	7/1874	7/1866	260'
6	Battery St. between Washington & Jackson	0.9 mi ENE	7/1866	2/1/1871	14'
7	Merchants Exch. Bldg Sac. & Leidesdorff	0.2 mi SW	2/2/1871	9/3/1890	15
8	Phelan Bldg. Market & O'Farrell	0.5 mi SW	9/4/1890	10/31/92	41'
9	Mills Bldg. 220 Montgomery St	0.3 mi	11/1/1892	4/18/1906	25'
10	Residence 3018 Clay St	3.1 mi W	5/1/1906	10/1/1906	257'
11	Merchants Exch. Bldg 465 California St	3.0 mi E	10/1/1906<	5/12/1936	17'
12	Federal Office Bldg* 50 Fulton St	1.0 mi SW	5/13/1936	4/18/1983	102'
13	Mission Dolores 16th & Dolores St	1.3 mi SW	4/18/1983	6/10/1997	75'
14	Duboce Park Duboce & Scott	0.5 mi NW<	6/11/1997	present	175'


San Francisco
Marina District
North Beach
Telegraph Hill
Russian Hill
Chinatown
Nob Hill
Financial District
Pacific Heights
Japantown
South of Market
Western Addition
Buena Vista Park
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Jackson St
Washington St
Clay St
Sacramento St
California St
Pine St
Bush St
Sutter St
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O'Farrell St
Ellis St
Eddy St
Turk St
Golden Gate Ave
McAllister St
Fulton St
Grove St
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Central Skyway
James Lick Skyway