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Synoptic Pattern Typing for Historical Heavy Precipitation Events in Southern California

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Background

Historical heavy precipitation events were defined for the southern California coastal region and synoptic patterns were associated with these events using gridded National Center for Environmental Prediction (NCEP) analyses (formerly the National Marine Center). The purpose of this study was to identify the primary large-scale features associated with heavy precipitation in the southern California coastal region and to document the synoptic climatology of these events.

For simplification, heavy precipitation events were defined for three classifications. The first classification was defined by at least three stations receiving 3.00 inches of liquid equivalent precipitation in one day. The second class was defined by at least three stations receiving 6.00 inches in two consecutive days, and the third class was the same as the second class, but with the added stipulation that at least one station received 10.0 inches in two consecutive days.

Various synoptic patterns were identified and composited with each of these cases. There were five distinct patterns in class I and four in class II. In class III, there were very few events, which were not conducive to identifying patterns. However, the events in class III contain features of the patterns in classes I and II. Most of these synoptic patterns involve a closed upper low off the Pacific Northwest, or British Columbian coast, or an active subtropical jet stream into northern Mexico, southern California, and the Desert Southwest region, with the general amplitude or subtropical moisture advection progressively increasing for classes II and III over class I. A brief attempt was also made to associate historical monthly-standardized teleconnection indices with each of the various synoptic patterns, but with little success. However, there were some modes that appeared stronger within each of the three classes, indicating some potential for further investigation.

The primary synoptic features identified with heavy precipitation in southern California included significant large scale ascent implied by either a deep upper low or trough moving in off the Pacific into the northwest United States or by an active subtropical jet stream bringing shortwave troughs into southern California. Associated with both of these patterns was a sea level pressure pattern favorable for onshore flow with implied orographic precipitation enhancement likely. Subtropical moisture entrainment did not appear necessary in all events in class I, but the amplitude in classes II and III was generally sufficient to imply a tap into subtropical moisture. An injection of continental air into the trough or upper low near the northwest United States appeared to compensate for a lack of subtropical moisture advection in class I and enhance some events in classes II and III. It is also hypothesized that a surface anticyclone over the Central and Southern Plains may have enhanced the upper jet over the southern United States, leading to higher precipitation in the southern California coastal region.

Introduction

Southern California can experience high variability in year-to-year annual precipitation, typically having a significant impact on water resource management, flood control, and wildfire management. Several studies have been undertaken to account for the seasonal variability of precipitation in the California region, especially regarding the role of ENSO in modulating the track of extra-tropical storm tracks in the North Pacific. Mitchell and Blier (1997) found several flow patterns in the 500 h-pa geopotential height and sea level pressure fields associated with wet and dry monthly and seasonal precipitation totals in California. However, their results suggested that an understanding of the circulation patterns associated with California precipitation variability would require analysis on the sub-monthly timescale. Traveling synoptic-scale wave disturbances can bring heavy precipitation to southern California, especially in the mountains adjacent to the coastal plain during the cool season.

This study centered on synoptic weather patterns associated with heavy precipitation in the Southern California coastal region. This region is depicted in the National Climatic Data Center (NCDC) Climatological Data publication as the South Coast Drainage, or area 6. The area covers the mountains and adjoining coastal valleys and plains from around Santa Barbara to San Diego and includes the San Rafael, Santa Ynez, San Gabriel, Santa Ana, San Bernadino, San Jacinto, and Laguna mountains. The purpose was to attempt to gain insight into the general patterns and underlying synoptic-scale mechanisms responsible for producing heavy precipitation and associated flooding on temporal and spatial scales of interest to the California-Nevada River Forecast Center (CNRFC), and also to document the synoptic climatology of such events. The CNRFC is one of 13 River Forecast Centers in the National Weather Service (NWS) and is located in Sacramento, California, with hydrologic forecast responsibility for California, most of Nevada, and a portion of southern Oregon. One of the primary missions of the CNRFC is to provide river and flood forecast and warning guidance for the protection of lives and property within its area of responsibility, although warning responsibility ultimately lies with local Weather Forecast Offices (WFOs). Short-fused flooding is handled almost exclusively by the WFOs and is generally referred to as flash flooding, which is characterized by a rapid response in water levels, typically in smaller creeks, streams, and normally dry washes. Predictability is low with flash flooding, which is loosely defined as flooding occurring on a time scale of less than 6 hours, and is often associated with deep, moist convection. The CNRFC is interested in events that are of a larger scale and that impact major rivers and managed water systems. These larger scale events typically set the stage for flash flooding in California, such as in the cases described by Thompson (2001) and also by Slemmer and Bower (1999).

Thus, precipitation was examined for time scales of 24 to 48 hours, focusing on daily totals for individual stations in southern California. Once the precipitation events were identified, upper-air and sea level pressure patterns were associated with the events using historical gridded NCEP analyses and the results were composited to create "map types." Ferber et al. (1993) used similar techniques to identify synoptic patterns associated with heavy snow over the Puget Sound lowlands.

Methodology

Based on a review of the long-term precipitation records of southern California cooperative stations available from the National Climatic Data Center and limited operational experience of the author, arbitrary values were selected as criteria for identifying "heavy precipitation" for three classes of events. The first class, referred to from this point on as classification I, required at least three stations in the southern

California coastal domain to have all received ≥3.0 inches of liquid equivalent precipitation in one day. The second class, classification II, required at least three stations to have all received≥ 6.0 inches in two consecutive days. The third class, classification III, had the same requirements as classification II, with the added stipulation that at least one of the stations received ≥10.0 inches in two consecutive days. In this manner, it was hoped to generate increasing levels of impact due to heavy precipitation. No attempt was made to account for variations in basin geometry or soil conditions, both of which can affect the impact of a given amount of precipitation.

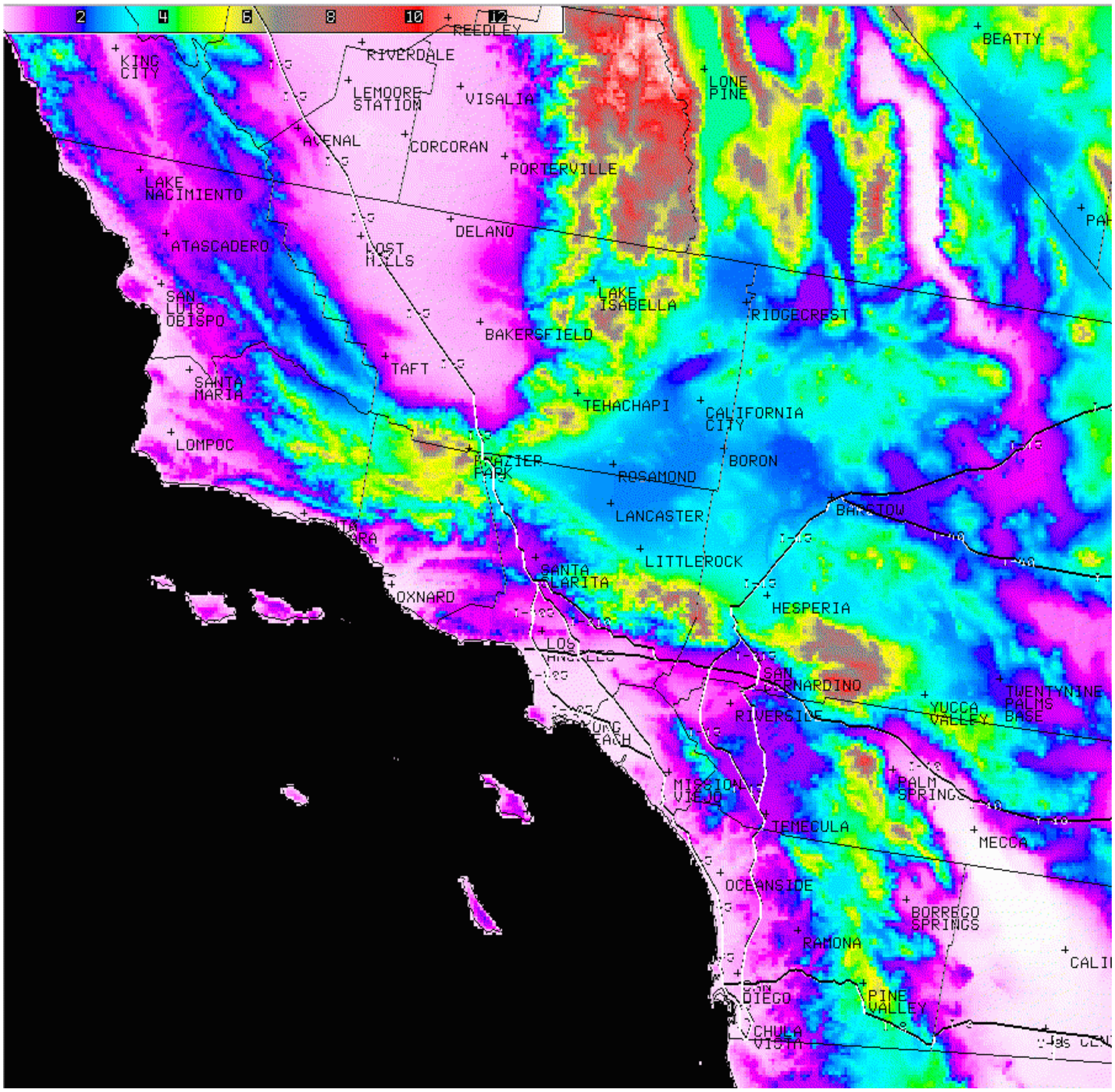

Figure 1-1 - Southern California Topography

Figure 1-1 depicts the orography of southern California, which clearly can, and does, influence precipitation as seen in Figure 1-2.

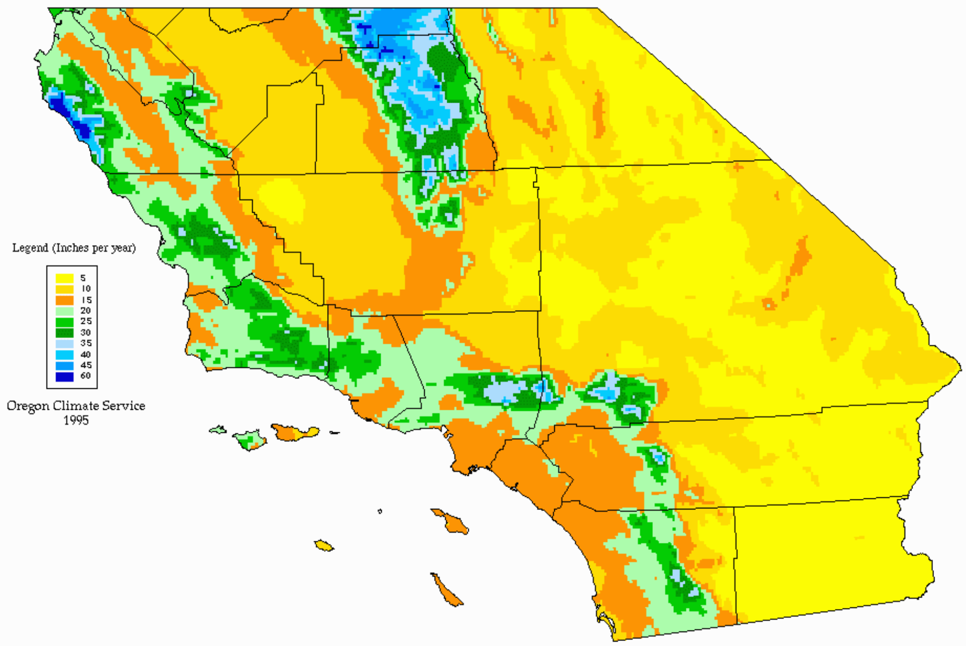

Figure 1-2. Annual Average Precipitation (Inches), Southern California

Period: 1961-1990

A list of the various classifications and types within each classification are shown in Table 1-1, along with the number of events making up each of these groupings.

Table 1-1

Classification I - defined by ≥ 3 stations receiving ≥ 3.00 inches of liquid precipitation in one day
Type 1 (8 cases) - closed upper low off Pacific NW coast
Type 2 (6 cases) - closed upper low off BC coast
Type 3 (5 cases) - strong low latitude upper jet
Type 4 (2 cases) - mid-high latitude blocking from Alaska to the northern Great Basin with undercutting low lattitude jet across the Pacific and into Baja
Type 5 (7 cases) - "coastal slider"
Classification II - defined by ≥ 3 stations receiving ≥ 6.00 inches of liquid precipitation in two consecutive days
Type 1 (5 cases) - closed upper low of Pacific NW coast
Type 2 (2 cases) - closed upper low off BC coast
Type 3 (2 cases) - strong low latitude upper jet
Type 4 (3 cases) - strong low latitude upper jet with significant blocking in the vicinity of Alaska
Classification III - defined by ≥ 3 stations receiving ≥ 6.00 inches of liquid precipitation in two consecutive days with the added stipulation that at least one station received ≥10 inches in two consecutive days
Type 1 (1 case) - similar to classification II Type 1but deeper with stronger low latitude upper flow
Type 2 (1 case) - deep upper low off BC coast plus secondary low latitude upper trough near 30 N 130 W
Type 3 (2 cases) - similar to classification II Type 4 with much lower heights in the low latitudes across the Pacific
Type 4 (1 case) - similar to classification II Type 2 with a much deeper upper low, advection of arctic air into the west side of the upper low, and more energy in the low latitudes with an implied tap into subtropical air

The period of record for station precipitation varied, with data generally available from the 1940's through 1997. Table 1-2 lists the stations used in this study.

Table 1-2

Station	Period of record	Elevation (ft)	Lat	Lon
ALPINE	(1952-1996)	1735	32.50	116.46
ANAHEIM	(1989-1996)	335	33.52	117.51
BIG BEAR LAKE	(1960-1996)	6790	34.15	116.53
BURBANK VALLEY PUMP	(1939-1996)	655	34.11	118.21
CACHUMA LAKE	(1952-1996)	781	34.35	119.59
CAMPO	(1948-1996)	2630	32.37	116.28
CANOGA PARK PIERCE	(1949-1996)	790	34.11	118.34
CHULA VISTA	(1948-1996)	56	32.36	117.06
CULVER CITY	(1935-1996)	55	34.01	118.24
CUYAMACA	(1948-1996)	4640	32.59	116.35
EL CAJON	(1979-1996)	21	32.49	116.58
EL CAPITAN DAM	(1948-1996)	600	32.53	116.49
ELSINORE	(1948-1996)	1285	33.40	117.20
ESCONDIDO NO 2	(1979-1996)	600	33.07	117.06
HEMET	(1948-1996)	1655	33.45	116.57
HENSHAW DAM	(1948-1996)	2700	33.14	116.46
IDLEWILD HWY MNTNCS	(1959-1977)	5380	41.54	123.46
JULIAN CDF	(1949-1996)	4215	33.05	116.36
LAGUNA BEACH	(1928-1996)	35	33.33	117.47
LA MESA	(1948-1996)	530	32.46	117.01
LOMPOC	(1950-1996)	95	34.39	120.27
LONG BEACH WSCMO	(1958-1996)	25	33.49	118.09
LOS ALAMOS	(1948-1996)	565	34.45	120.17
LOS ANGELES WSO ARPT	(1944-1996)	100	33.56	118.24
LOS ANGELES CIVIC CE	(1948-1996)	185	34.03	118.14
MONTEBELLO	(1979-1996)	240	34.02	118.06
MT WILSON NO 2	(1948-1996)	5709	34.14	118.04
NEW CUYAMA FIRE STN	(1974-1996)	2160	34.57	119.41
NEWHALL	(1989-1996)	1765	34.22	118.34
NEWPORT BEACH HARBOR	(1934-1996)	10	33.36	117.53
OCEANSIDE MARINA	(1953-1996)	10	33.13	117.24
OJAI	(1948-1996)	750	34.27	119.41
OXNARD	(1948-1996)	49	34.12	119.11
PALOMAR MOUNTAIN OBS	(1948-1996)	5550	33.21	116.52
PASADENA	(1927-1996)	864	34.09	118.09
RAMONA FIRE DEPT	(1974-1996)	1470	33.01	116.55
REDLANDS	(1927-1996)	1318	34.03	117.11
RIVERSIDE FIRE STA 3	(1927-1996)	840	33.57	117.23
RIVERSIDE CITRUS EXP	(1948-1996)	986	33.58	117.21
SAN BERNARDINO CO HO	(1927-1996)	1140	34.08	117.16
SANDBERG WSMO	(1948-1996)	4517	34.45	118.44
SAN DIEGO WSO AIRPORT	(1927-1996)	13	32.44	117.10
SAN JACINTO R S	(1948-1996)	1560	33.47	116.58
SAN PASQUAL ANIMAL P	(1979-1996)	420	33.05	117.00
SANTA ANA FIRE STATION	(1948-1996)	135	33.45	117.52
SANTA BARBARA	(1927-1996)	5	34.25	119.41
SANTA BARBARA FCWOS	(1941-1995)	9	34.26	119.50
SANTA MARIA WSO ARPT	(1948-1996)	254	34.54	120.27
SANTA MONICA PIER	(1948-1996)	14	34.00	118.30
SANTA PAULA	(1948-1996)	237	34.19	119.09
SUN CITY	(1973-1996)	1420	33.43	117.11
TORRANCE	(1949-1996)	89	33.48	118.20
TUSTIN IRVINE RANCH	(1927-1996)	235	33.44	117.47
U C L A	(1948-1996)	430	34.04	118.27
VISTA 2 NNE	(1957-1996)	510	33.14	117.14

A total of 95 cases were identified which met at least the first level of classification in the period generally ranging from the 1940's to 1997, averaging around two events per year. Virtually all of the cases occurred in the months from November to April, with the exception of one case in September. The majority (75 percent) occurred in the December-January-February time period. Figure 1-3 illustrates the monthly distribution of cases.

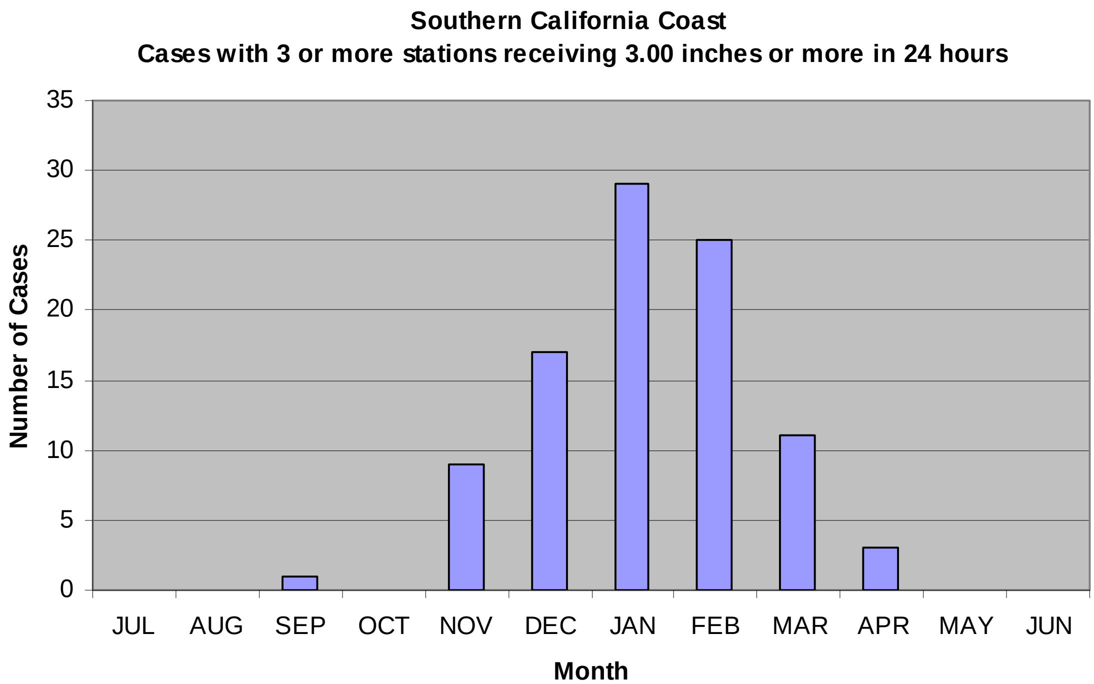

Figure 1-3: This figure represents the monthly distribution of cases where at least 3 stations in southern California received greater that or equal to 3.00 inches of liquid equivalent precipitation in one day. The x-axis depicts the monthly distribution and the y-axis represents the number of cases that occurred.

After identifying these cases, an arbitrary initial time was assigned to each event, which was 1200 UTC of the day where the criteria were met for classification I and 1200 UTC of the first of the two consecutive days where the criteria were met in classifications II and III. This initial time was used to tie each event to the associated 500 and 700 h-pa geopotential height and sea level pressure fields, where available. The NCEP-gridded analyses were available for the Northern Hemisphere from 1946 to 1994 for selected fields. The 500 h-pa geopotential height fields were only available from 1951-1994, bringing the total cases available for synoptic pattern-typing down to 46. Various synoptic patterns were identified and the 500 h-pa geopotential height, 700 h-pa geopotential height, and sea level pressure fields were composited for each pattern, using the DeCep software by LeBlang (2001). This technique will be referred to as map-typing for the remainder of this paper. An attempt was made to associate monthly leading modes with the heavy rain events, using standardized monthly Northern Hemisphere teleconnection indices from the CPC website (ftp://ftp.ncep.noaa.gov/pub/). The DeCep software was also used to identify 500 h-pa geopotential height anomalies and related teleconnections for the events.

Discussion

Using the map-typing approach, it was apparent that several synoptic patterns were associated with heavy rain in southern California. Most of the cases involved a closed upper low or sharp upper trough off the Pacific Northwest or British Columbian coasts, implying broad and vigorous synoptic scale ascent. A deep tropical or subtropical tap did not appear necessary for classification I, although a significant number of events, approximately 25 percent of the total, involved an active subtropical jet or significant southward displacement of the polar jet. Exceptions to this were instances of "coastal sliders" in classification I, which accounted for about 15 percent of the total number of events.

The 700 h-pa geopotential heights and sea level pressure patterns also suggested varying degrees of orographic ascent with the majority of cases in all classifications. There were several events in classifications II and III that appeared to tap into deep subtropical air due to the shear amplitude of the precipitation producing systems. A couple of events in classification III appeared to tap into polar or arctic air, as well as some events in classification I to a lesser extent.

Classification I, type 1, was characterized by a closed upper low off the Pacific Northwest coast, centered near 42° N 135° W, shown in Figure 2-1.

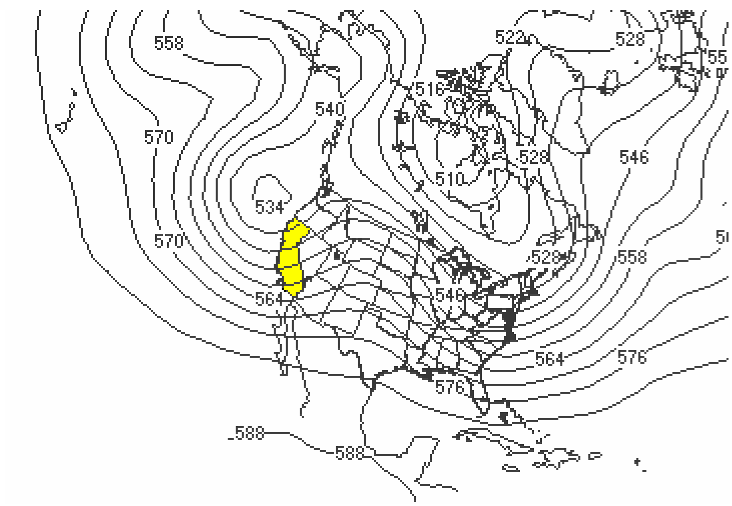

Figure 2-1: Composite of 500 h-pa geopotential heights for classification I type 1

This type was the most common, comprising about 17 percent of the total cases. These systems were vertically stacked with a 700 h-pa trough and a closed sea level pressure low under the upper low, shown in Figures 2-2 and 2-3, respectively.

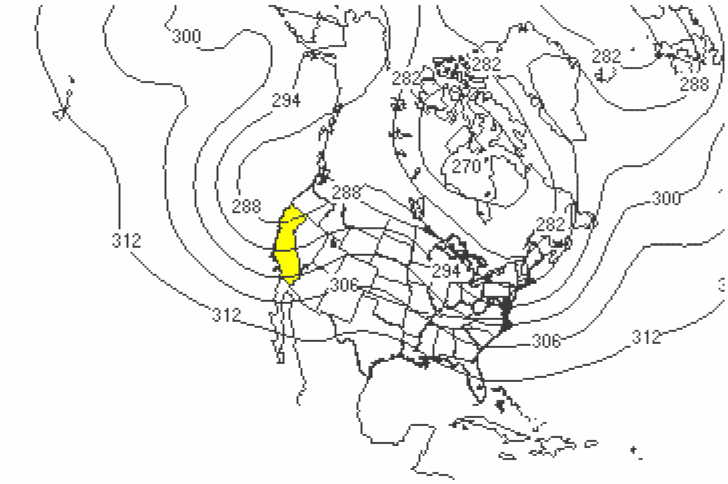

Figure 2-2: Composite of 700 h-pa geopotential heights for classification 1 type 1

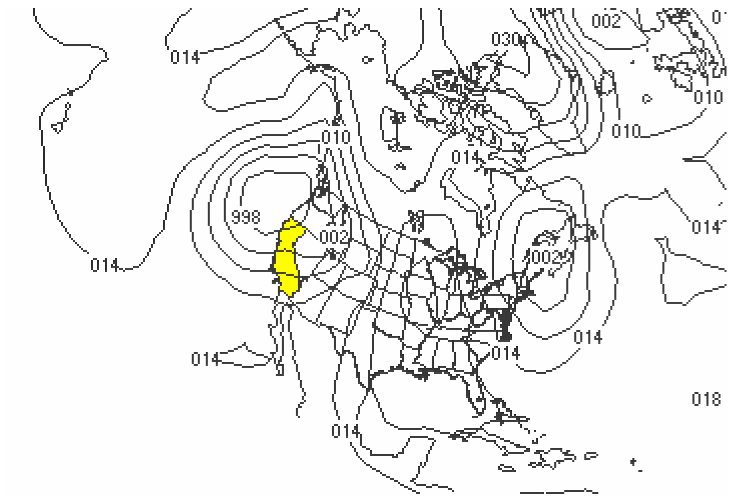

Figure 2-3: Composite of sea level pressure (mb) for classification I type 1

Classification I type 2 was vertically stacked similar to type 1, with the upper low centered farther north near 50° and is shown in Figure 2-4.

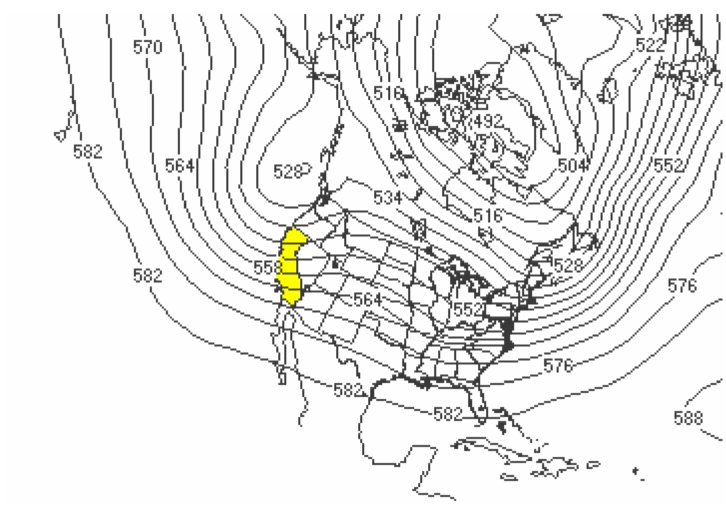

Figure 2-4: Composite of 500 h-pa geopotential heights for classification I type 2

A strong low latitude upper jet was indicated in classification I, type 3, which was also characterized by a weak blocking upper high in the vicinity of Alaska and a negatively-tilted upper trough along the west coast of the United States (Fig. 2-5).

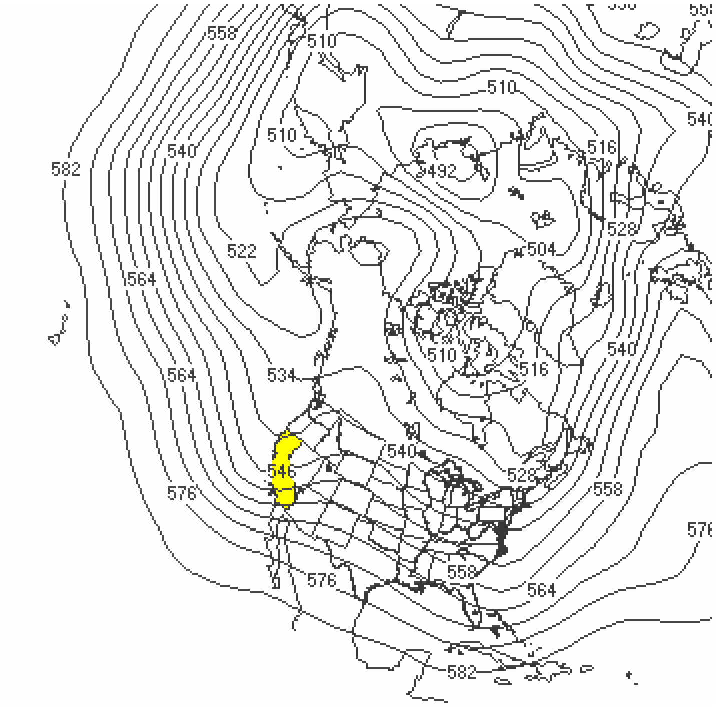

Figure 2-5: Composite of 500 h-pa geopotential heights for classification I type 3

The sea level pressure pattern was weak with this type (Fig. 2-6) but the upper energy appeared to be directed toward southern California more than types 1 and 2.

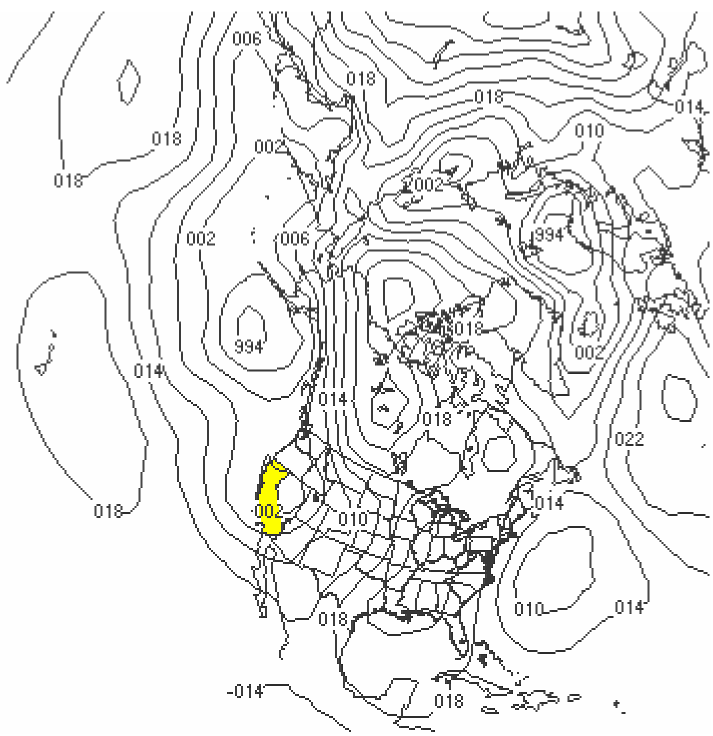

Figure 2-6: Composite of sea level pressure for classification I type 3

A strong low latitude upper jet was indicated in classification I, type 4, similar to type 3, but with strong mid-high latitude blocking from Alaska to the northern Great Basin and an undercutting low latitude upper jet across the Pacific and into Baja (Fig. 2-7).

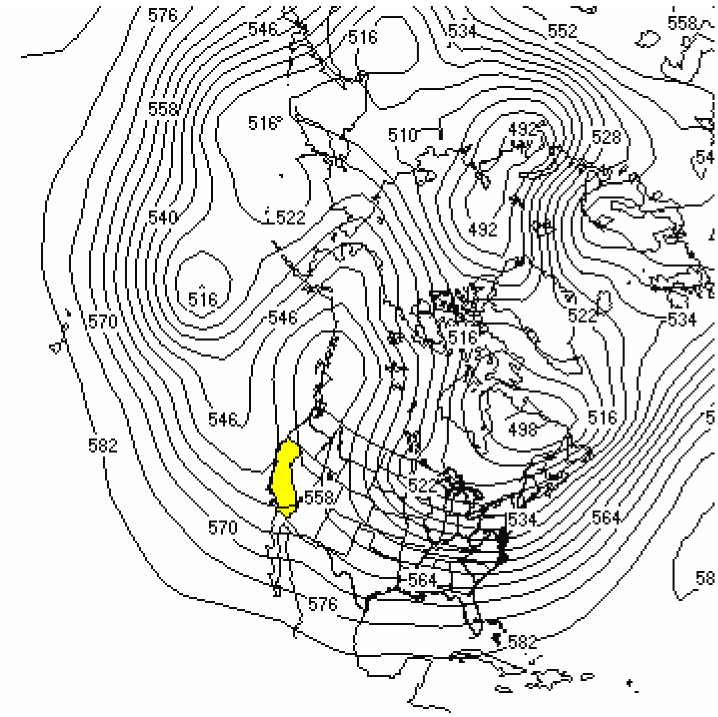

Figure 2-7: Composite of 500 h-pa geopotential heights for classification I type 4

The 700 h-pa geopotential height (Fig. 2-8) and sea level pressure fields (Fig. 2-9) implied decent entrainment of subtropical moisture into southern California, but relatively weak orographics.

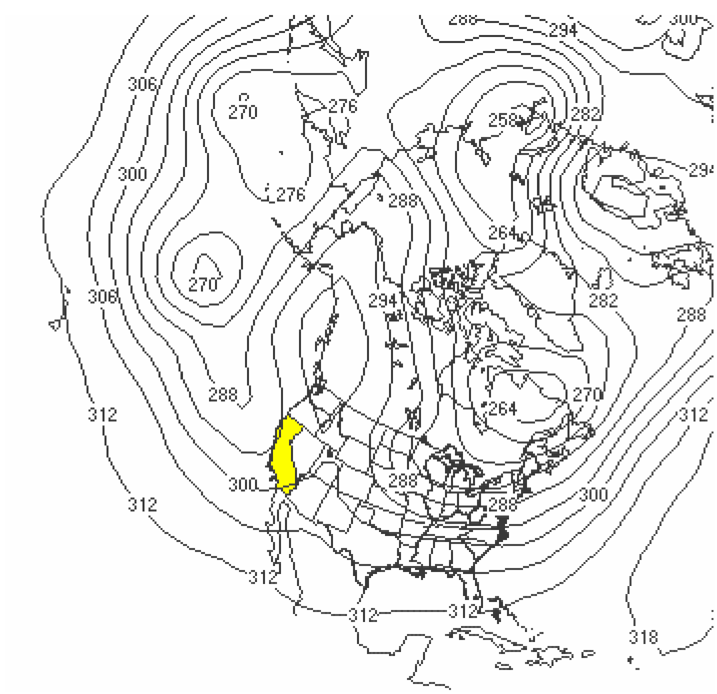

Figure 2-8: Composite of 700 h-pa heights for classification I type 4

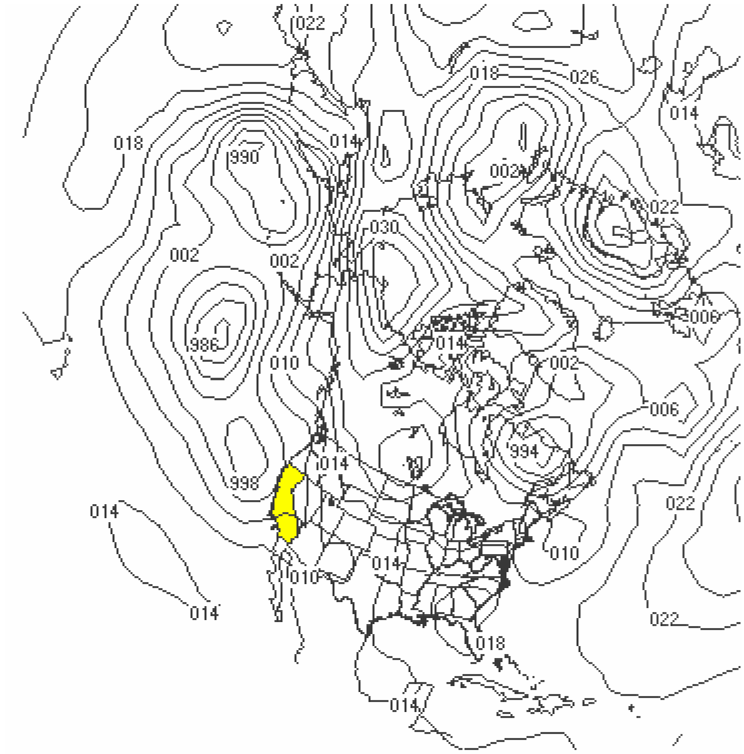

Figure 2-9: Composite of sea level pressure for classification I type 4

Classification I, type 5, differed significantly from all of the other types with a broad upper trough along the west coast of the United States (Fig. 2-10) and a weak sea level pressure low over California and Nevada (Fig. 2-11).

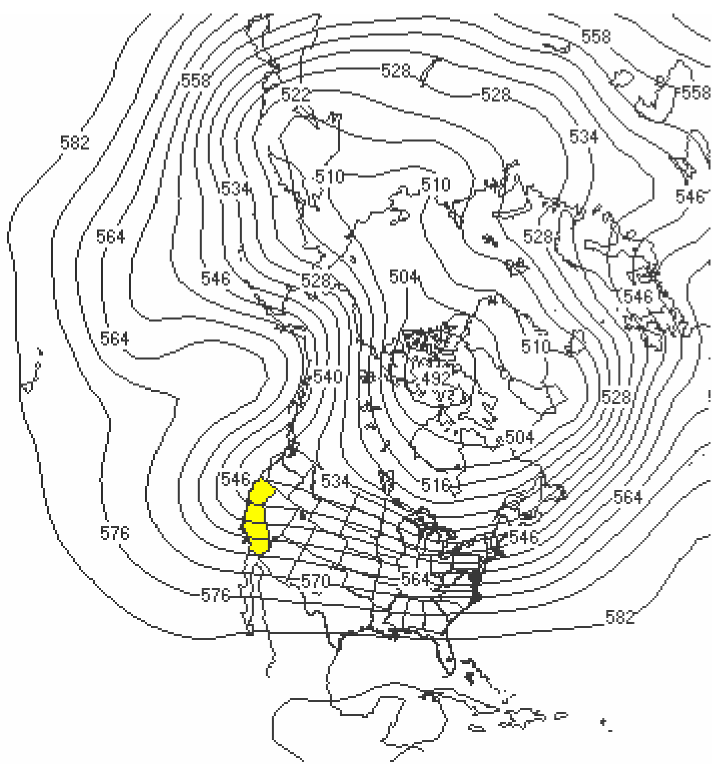

Figure 2-10: Composite of 500 h-pa geopotential heights for classification I type 5

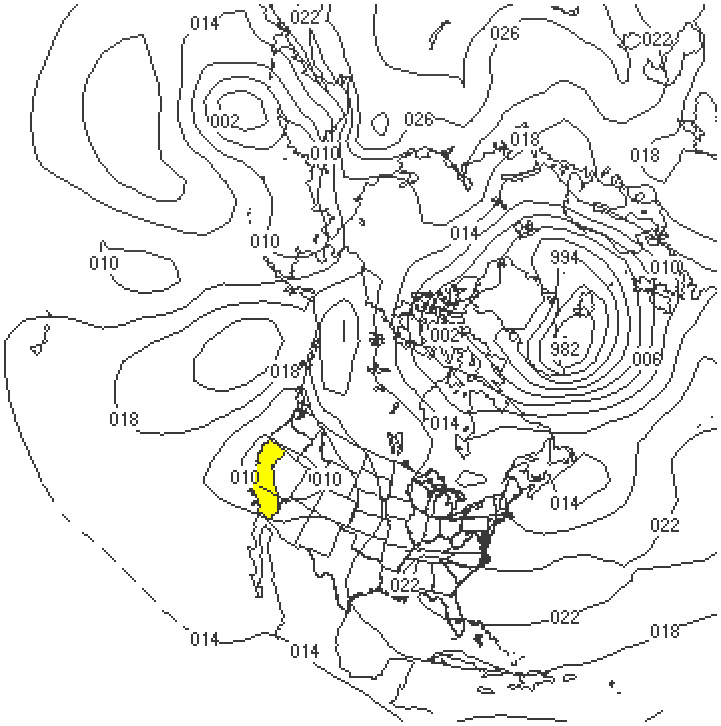

Figure 2-11: Composite of sea level pressure for classification I type 5

The 500 h-pa geopotential height field for classification II, type 1 (Fig. 2-12), was similar to classification I, type 1, with the upper low centered farther south and east (39° N 125° W). Classification II type 2 was quite similar to classification I, type 2, but had lower 500 h-pa heights (Fig. 2-13) across the Pacific and a deeper 700 h-pa trough (Fig. 2-14) and sea level pressure low (Fig. 2-15).

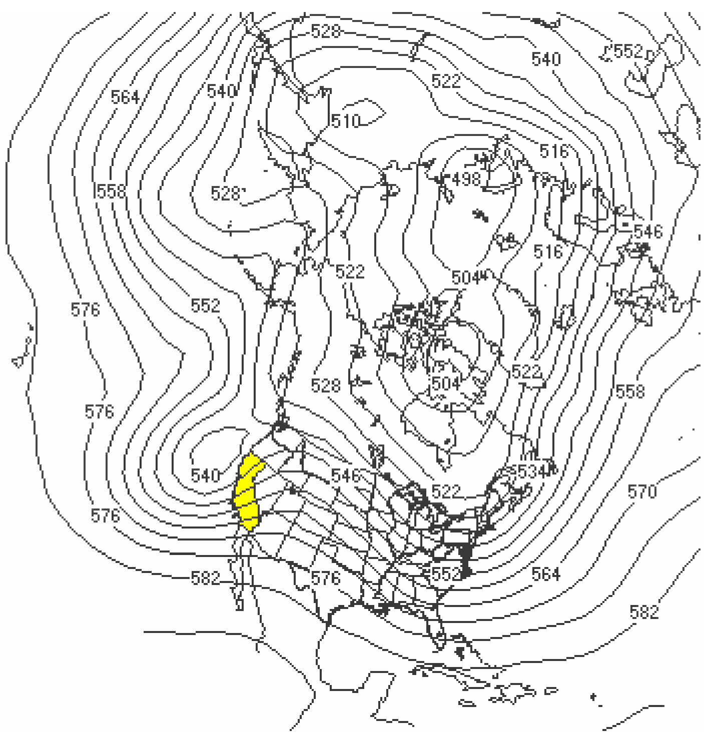

Figure 2-12: Composite of 500 h-pa geopotential heights for classification II type 1

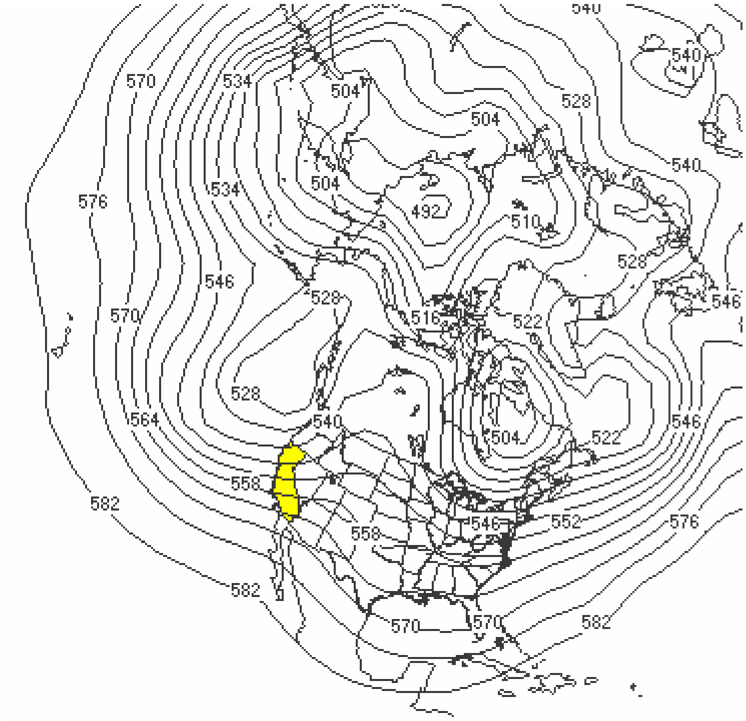

Figure 2-13: Composite of 500 h-pa geopotential heights for classification II type 2

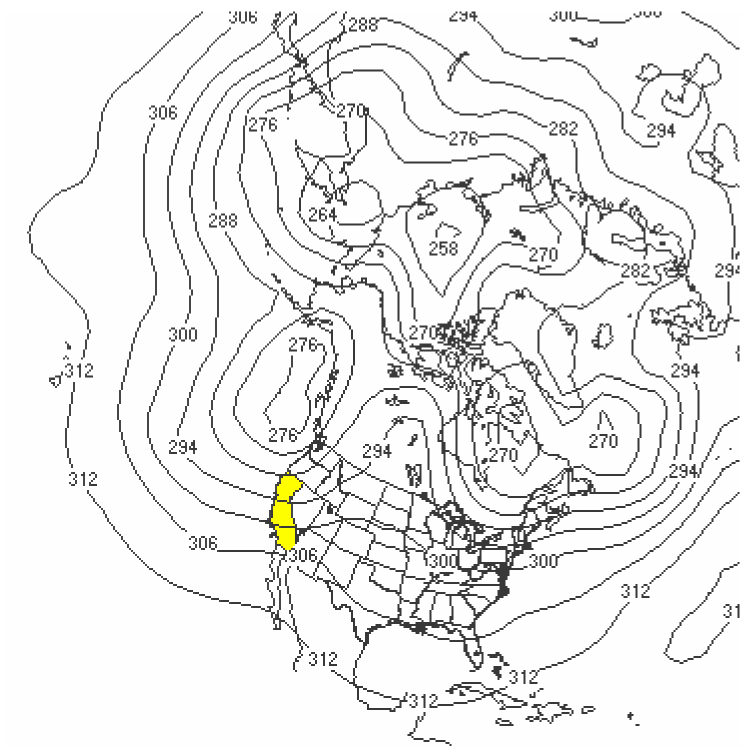

Figure 2-14: Composite of 700 h-pa geopotential heights for classification II type 2

Also of interest was the strong surface anticyclone over the mid-North American continent shown in Figure 2-15, implying an enhanced upper jet over the southern United States and northern Mexico and corresponding to lower 500 h-pa geopotential heights in that region.

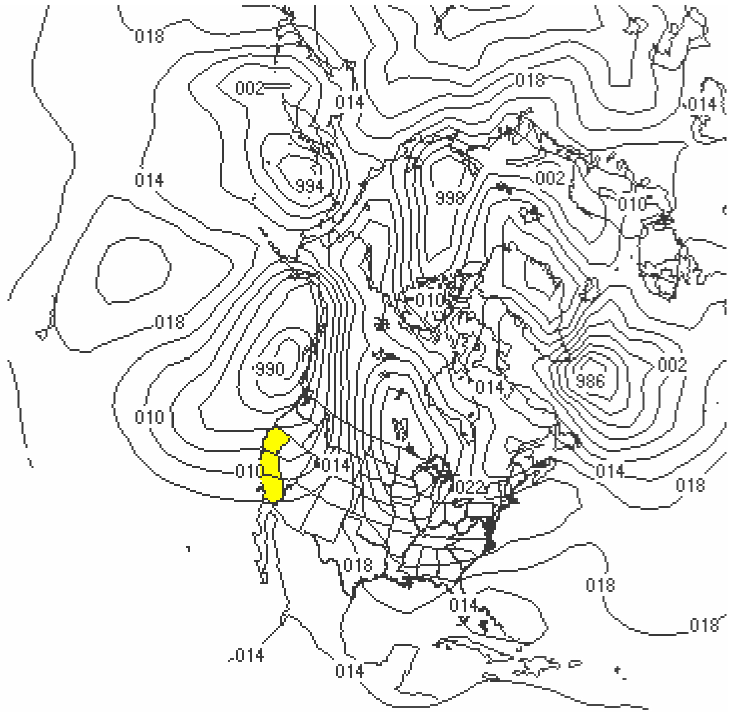

Figure 2-15: Composite of sea level pressure for classification II type 2

This was the only type where this strong surface anticyclone showed up. In classification II, type 3, there was strong low latitude upper flow (Fig. 2-16) with a weak blocking high near Alaska between 160° W and 170° W longitudes. This pattern represents advection of deep subtropical moisture due to the southwest flow and is sometimes colloquially referred to as the "Pineapple Express" by operational NWS forecasters in the western United States. However, there were only 3 cases that represented this map-type, although some other types exhibited similar but less dramatic characteristics.

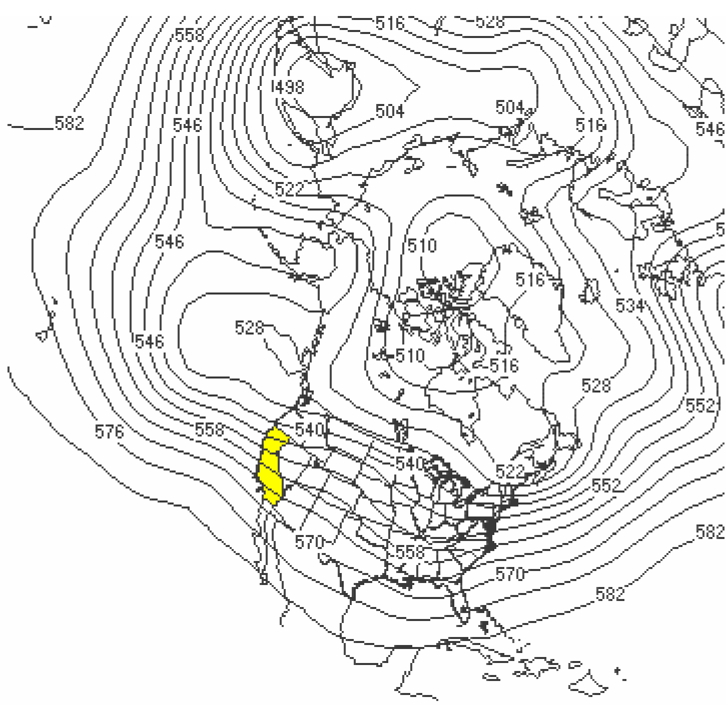

Figure 2-16: Composite of 500 h-pa geopotential heights for classification II type 3

Figures 2-17 and 2-18 show the 700 h-pa geopotential heights and sea level pressure field, respectively. Classification II, type 4, was similar to classification I, type 4, with strong low latitude upper flow undercutting a block (Fig. 2-19).

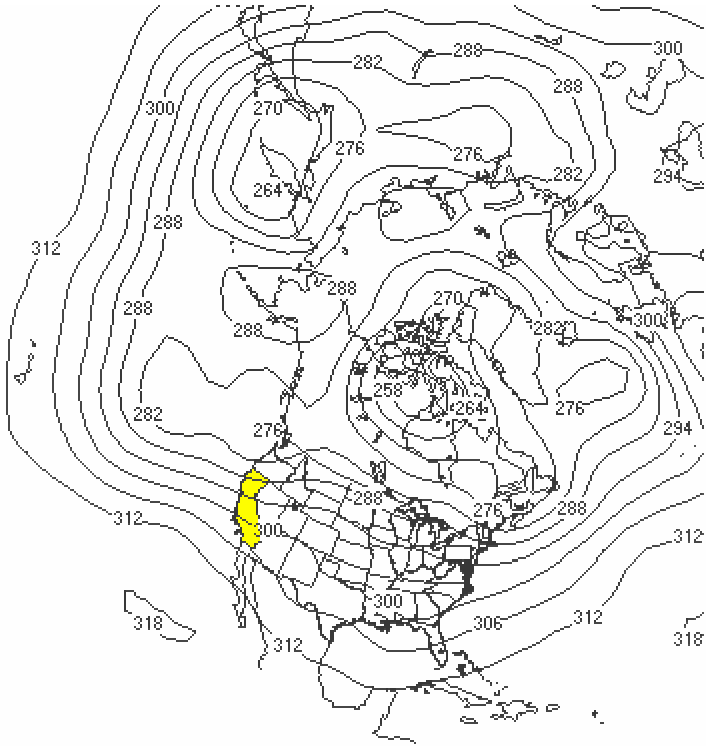

Figure 2-17: Composite of 700 h-pa geopotential heights for classification II type 3

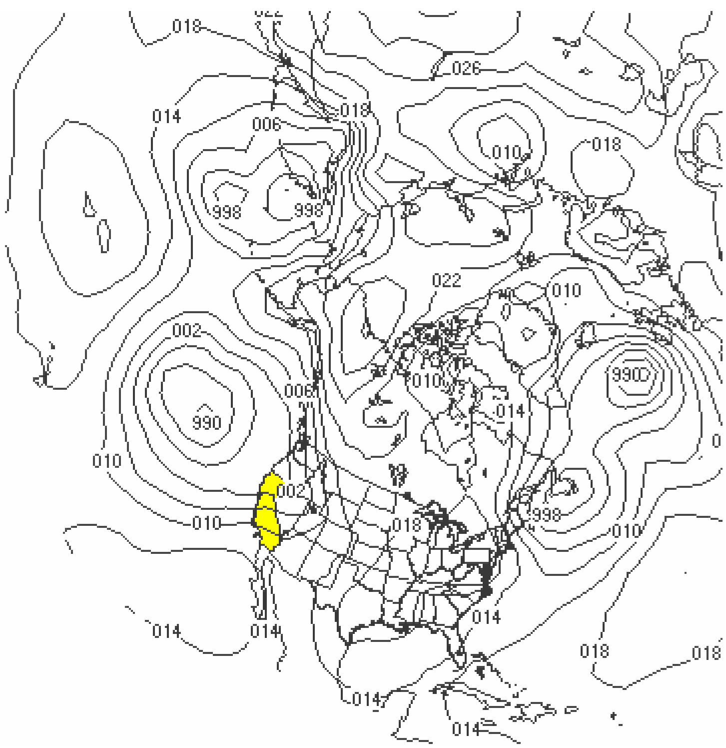

Figure 2-18: Composite for sea level pressure for classification II type 3

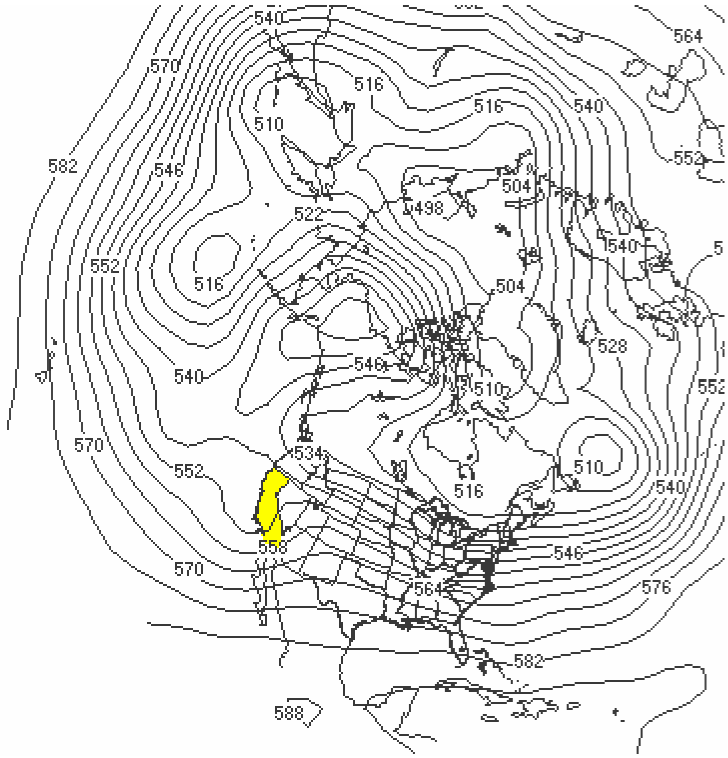

Figure 2-19: Composite of 500 h-pa geopotential heights for classification II type 4

The position of the upper block was located farther west than in classification I, type 4, allowing for more cold air to advect into British Columbia and the Pacific Northwest, as implied in the 700 h-pa geopotential heights (Fig. 2-20) and the sea level pressure field (Fig. 2-21).

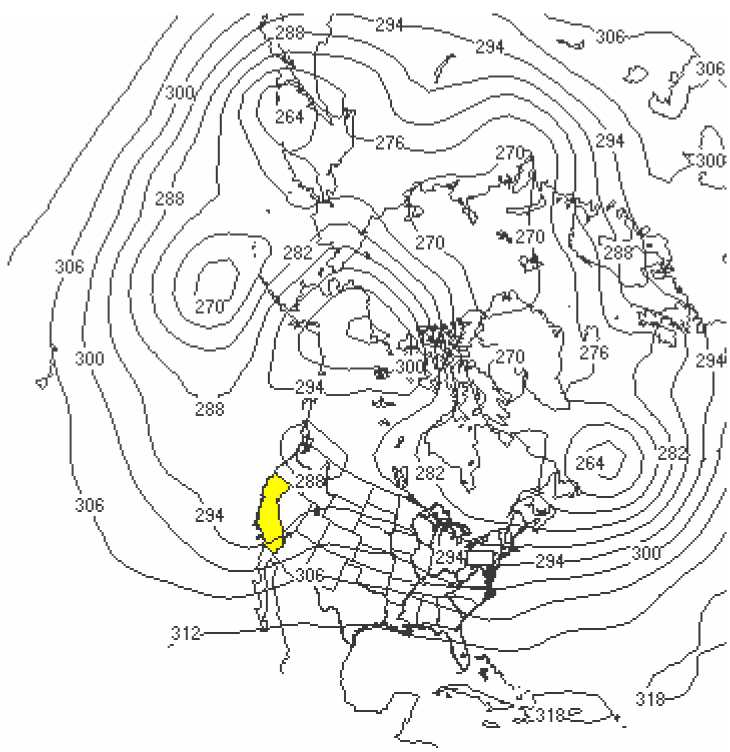

Figure 2-20: Composite of 700 h-pa geopotential heights for classification II type 4

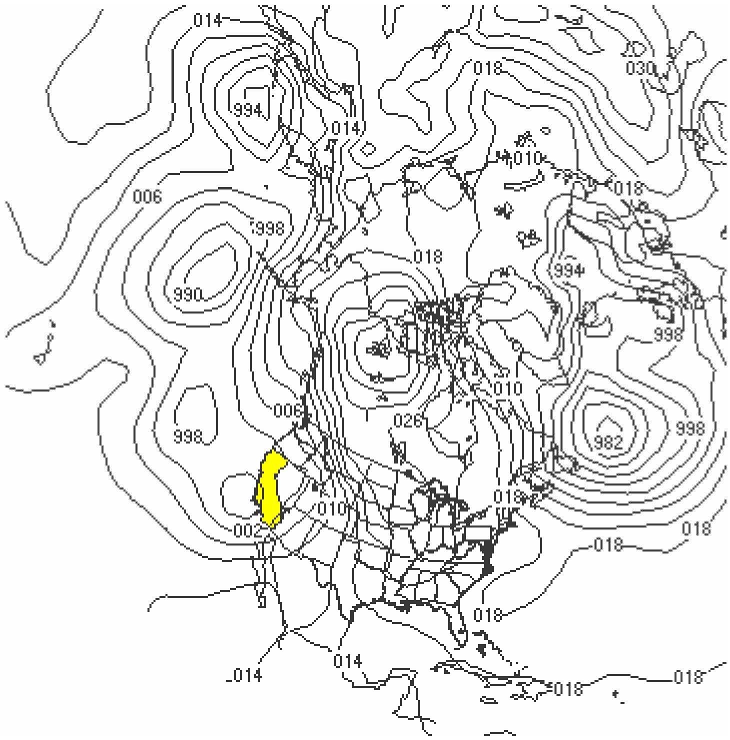

Figure 2-21: Composite of sea level pressure for classification II type 4

The cases comprising classification III were few, which was not conducive to determining synoptic patterns associated with these events. However, it was found that there were common synoptic features between the cases in classification III and those in classes I and II. The difference between these common features included the increased depth of the sea level pressure lows in class III, such as in class III, type 1 (Fig. 2-22).

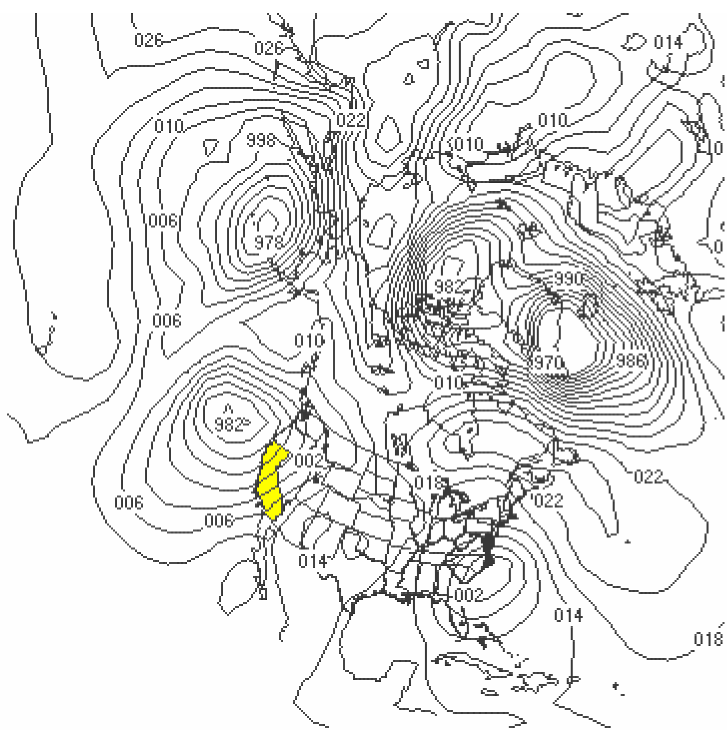

Figure 2-22: Composite of sea level pressure for classification III type 1

Another factor was the southward displacement of the geopotential height fields into the subtropics over the Pacific, as illustrated in the 500 h-pa geopotential heights in class III, type 3 (Fig. 2-23).

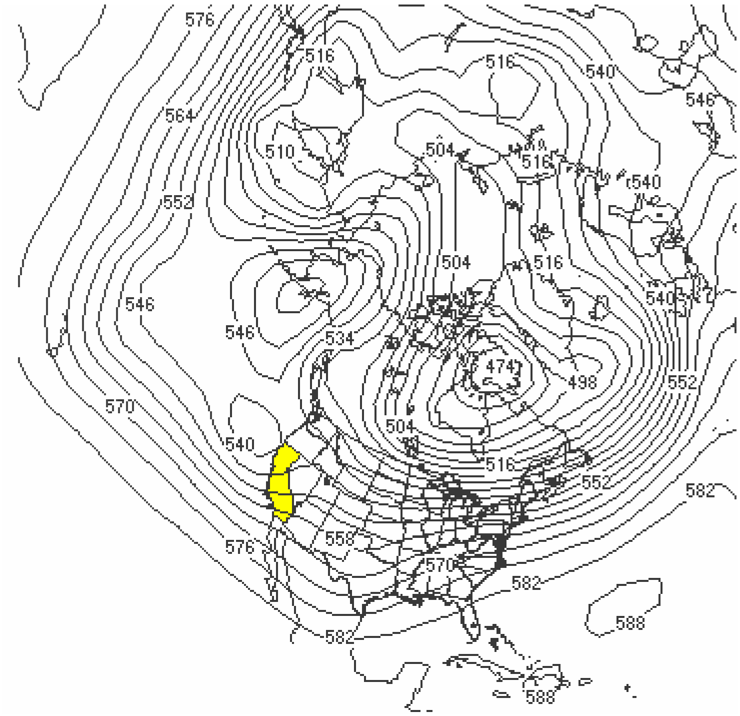

Figure 2-23: Composite of 500 h-pa geopotential heights for classification III type 3

Strong orographic lift was implied in class III, types 1 and 4, as depicted in the 700 h-pa geopotential heights (Figs. 2-24 and 2-25, respectively).

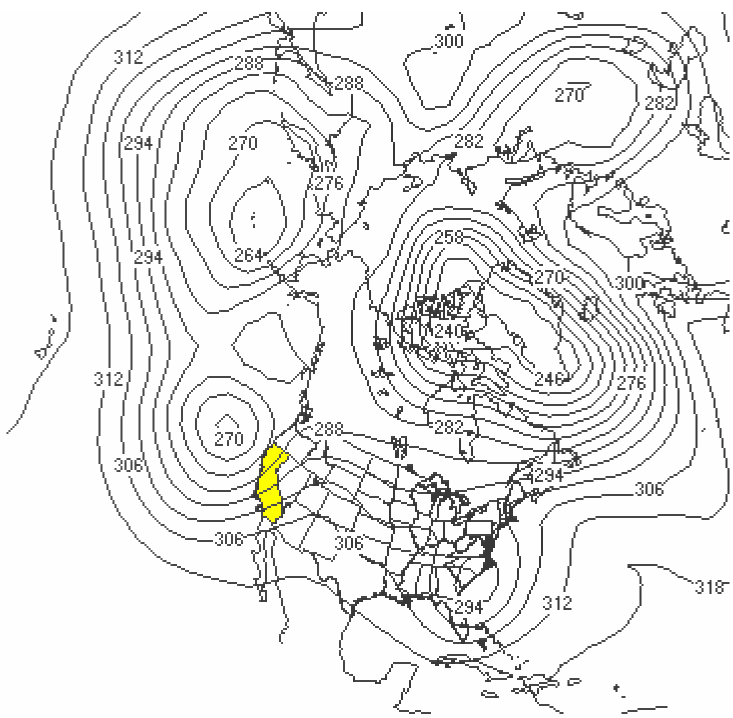

Figure 2-24: Composite of 700 h-pa geopotential heights for classification III type 1

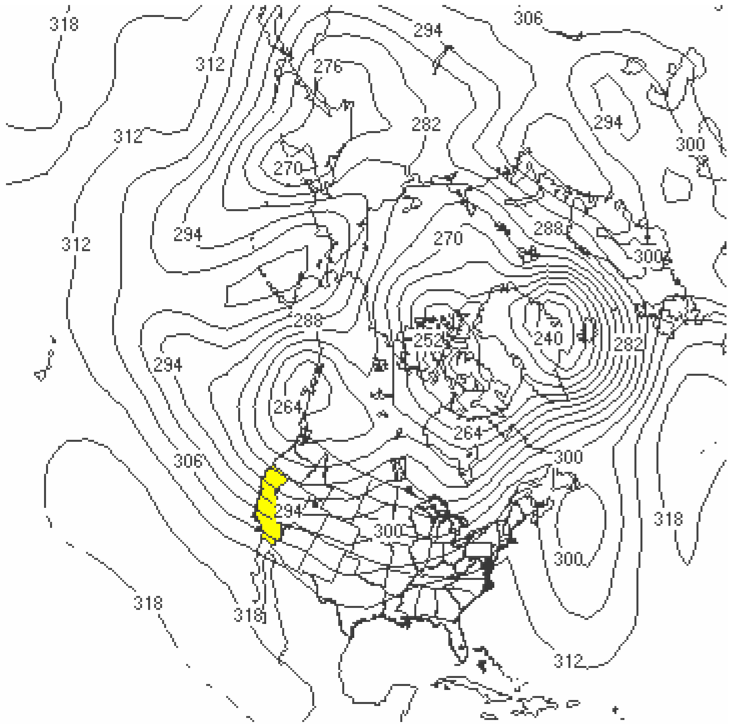

Figure 2-25: Composite of 700 h-pa geopotential heights for classification III type 4

Class III, type 2, differed from the other types in class III and from the types in classes I and II. This event was characterized by a deep upper trough along the British Columbian coast and a secondary upper trough in the subtropical Pacific off the southern California coast near 30° N 130° W (Fig. 2-26).

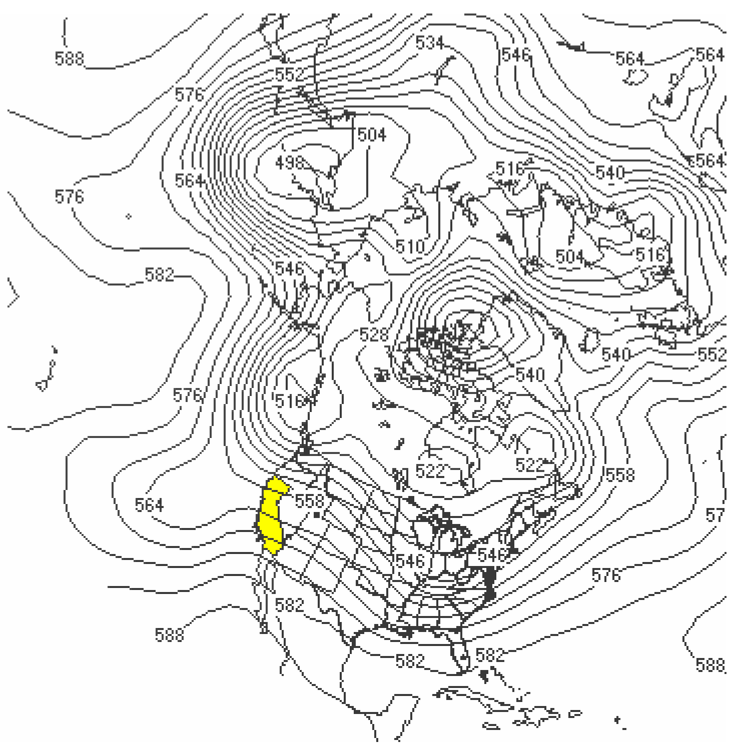

Figure 2-26: Composite of 500 h-pa geopotential heights for classification III type 2

The contributing factors resulting in the magnitude of this event appeared to be significant subtropical moisture advection coupled with an injection of cold continental air from Canada into the upper trough.

The classification and typing applied to the heavy rain events in southern California were useful for identifying the primary synoptic characteristics associated with these events. To further illustrate these primary synoptic characteristics, it was advantageous to lump the classifications and types into groups with common features. In this manner, four super-groups were created.

The first group, referred to from now on as group A, included a vertically stacked closed upper low or deep upper trough off the coast of British Columbia or the Pacific Northwest (Fig. 2-27), with associated W-SW 700 h-pa flow into California (Fig. 2-28).

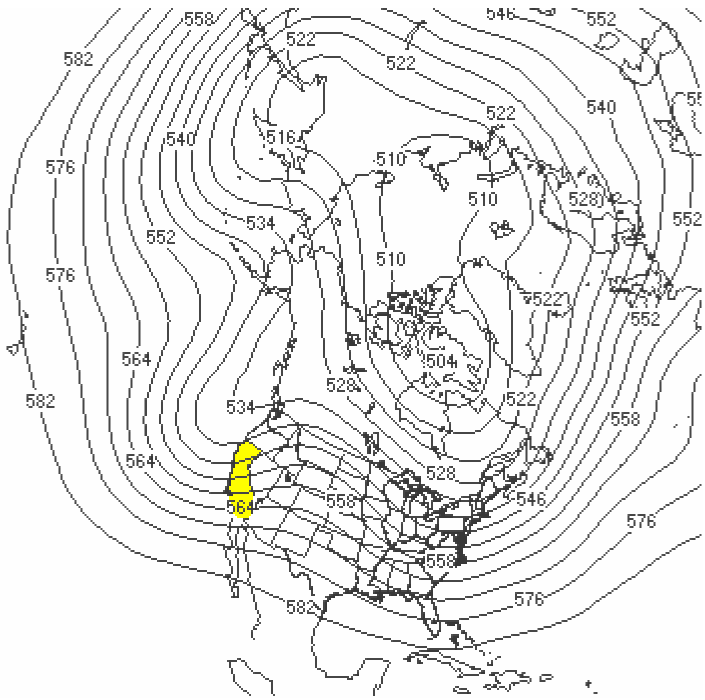

Figure 2-27: Composite of 500 h-pa geopotential heights for group A

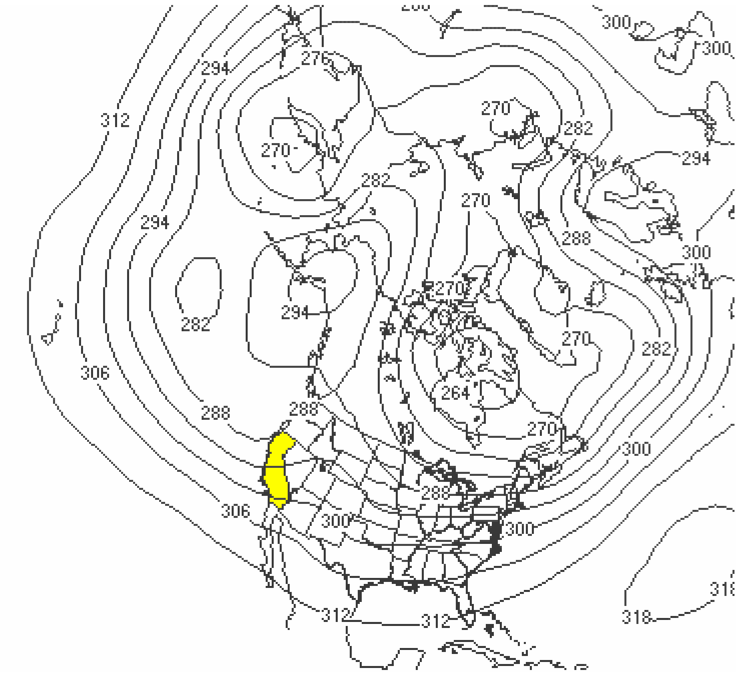

Figure 2-28: Composite of 700 h-pa geopotential heights for group A

A sea level pressure low was found off the British Columbia or Pacific Northwest coast with a gradient implying sly-swly surface winds in southern California (Fig. 2-29). This group was comprised of types 1 and 2 from classifications I and II, as well as types 1, 2 and 4 from classification III.

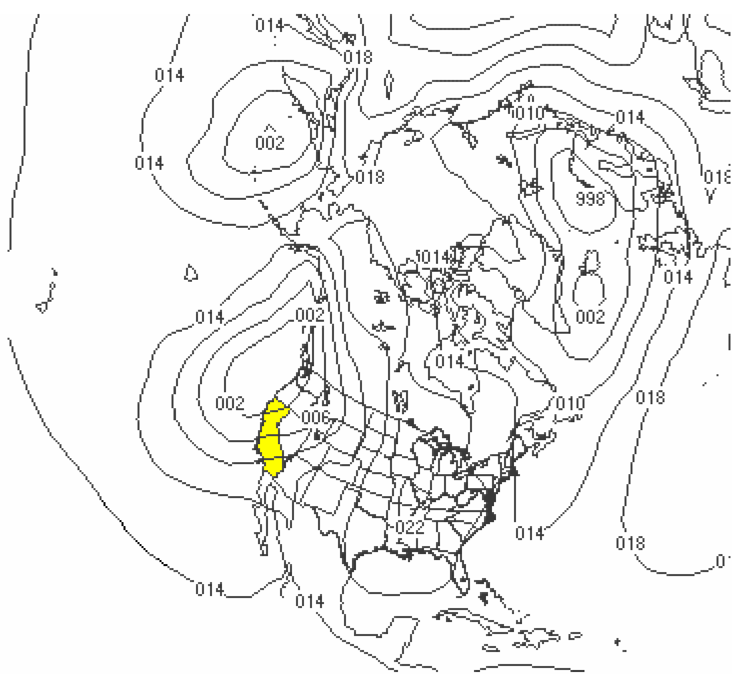

Figure 2-29: Composite of sea level pressure for group A

The second group, referred to from here on as group B, indicated moderate low latitude upper flow across the Pacific, and an embedded "open" wave in the vicinity of southern California (Fig. 2-30).

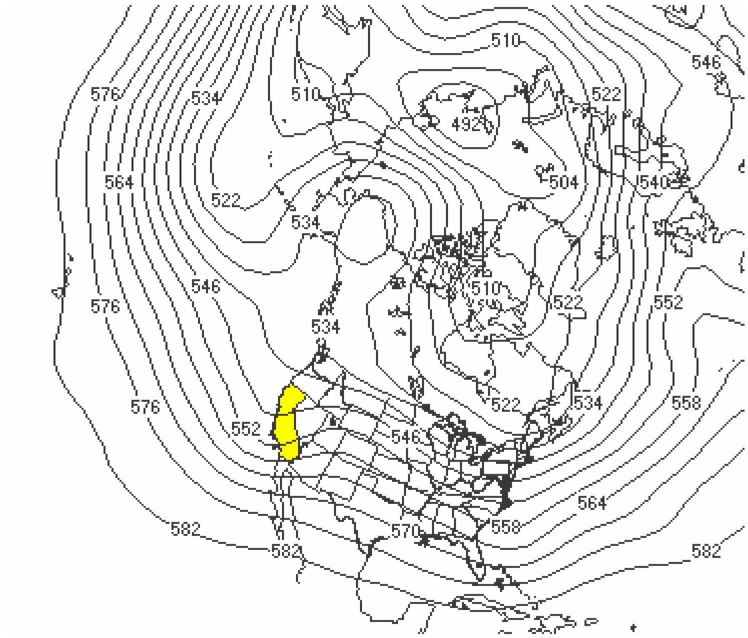

Figure 2-30: Composite of 500 h-pa geopotential heights for group B

These cases had varying degrees of blocking in the flow aloft, anywhere from 120° W to 160° W longitudes and from 40° N to 70° N latitudes. Advection of subtropical moisture was probably significant in these cases, and large scale ascent was likely weaker than the first group mentioned, but was focused farther south. Figures 2-31 and 2-32 show the 700 h-pa geopotential and sea level pressure fields, respectively, with weaker southwest flow aloft and a weaker surface pressure gradient than in group A. This group consisted of type 3 from classifications I and II.

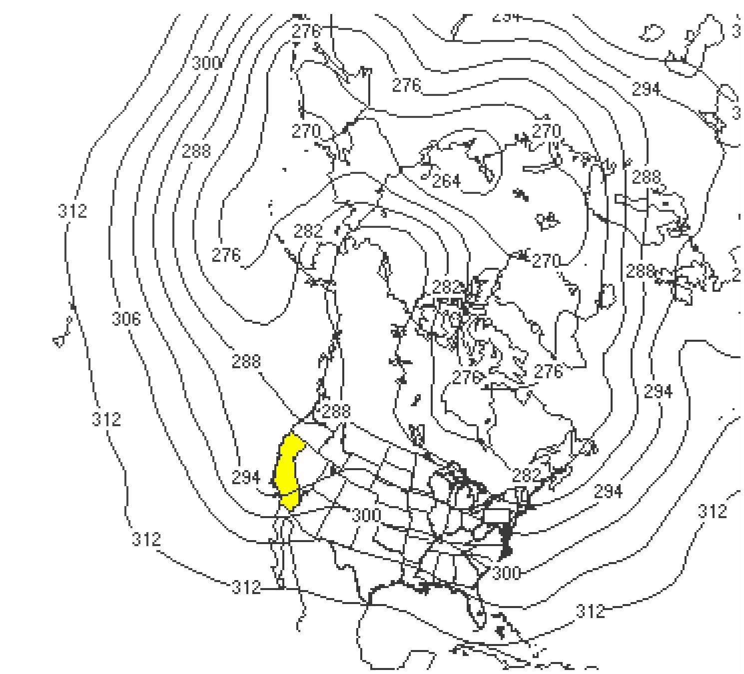

Figure 2-31: Composite of 700 h-pa geopotential heights for group B

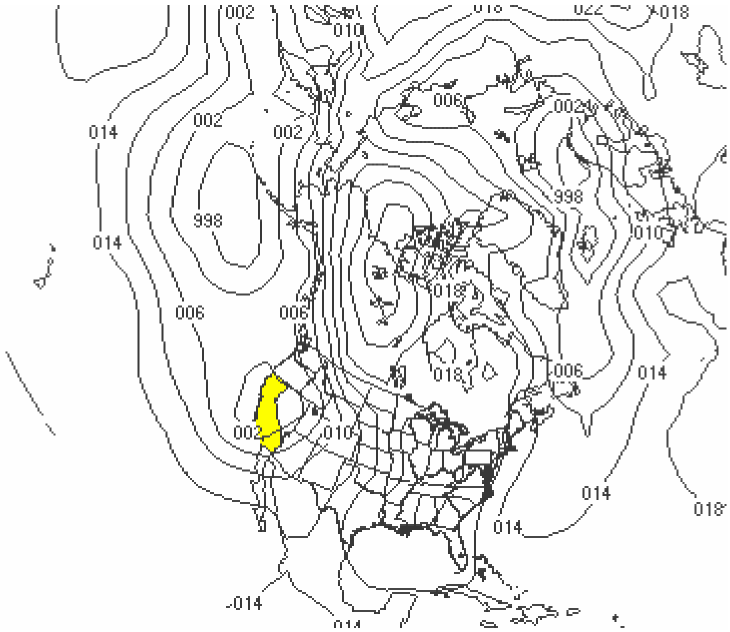

Figure 2-32: Composite of sea level pressure for group B

The third group, group C, was very similar to group B. The differences from group B included stronger low latitude upper flow, with more southwesterly flow and better implied subtropical moisture. Another difference was the westward displacement of the blocking high, centered near 160° W. This allowed southward transport of cold continental air along the west side of the North American Continent, tending to enhance the baroclinic zone and upper jet in the vicinity of California. One other difference was the lower amplitude of the upper flow, implying a series of waves crossing the Pacific. The 500 h-pa geopotential heights are shown in Figure 2-33, the 700 h-pa geopotential heights in Figure 2-34, and sea level pressure in Figure 2-35.

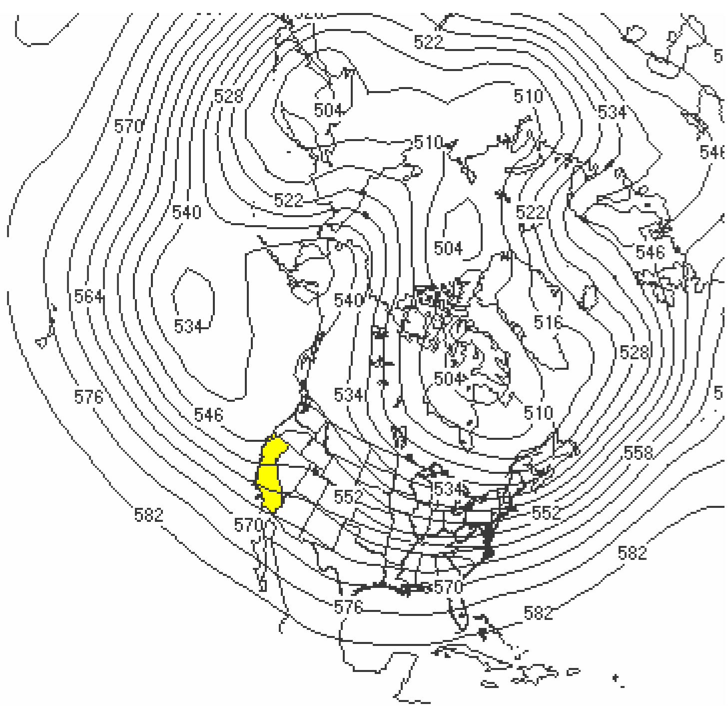

Figure 2-33: Composite of 500 h-pa geopotential heights for group C

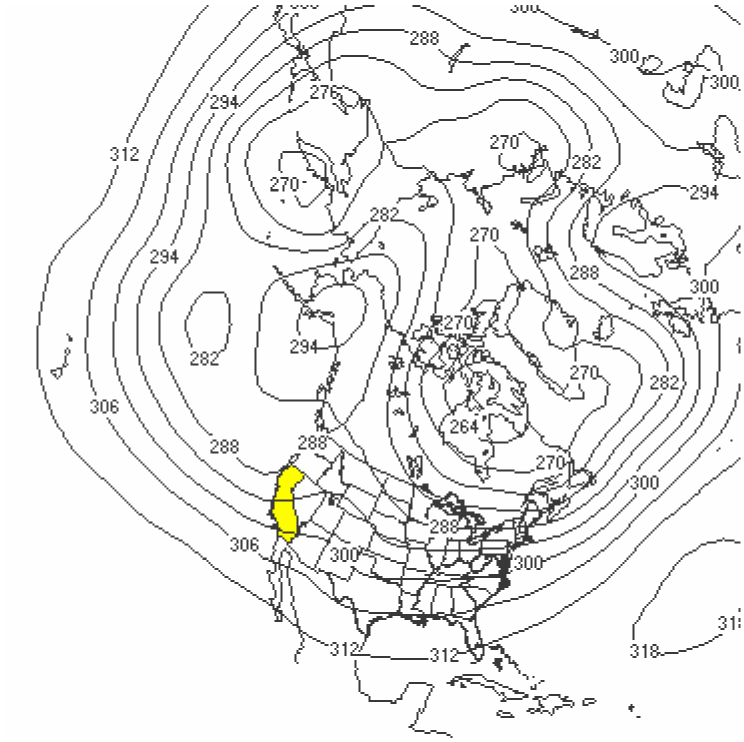

Figure 2-34: Composite of 700 h-pa geopotential heights for group C

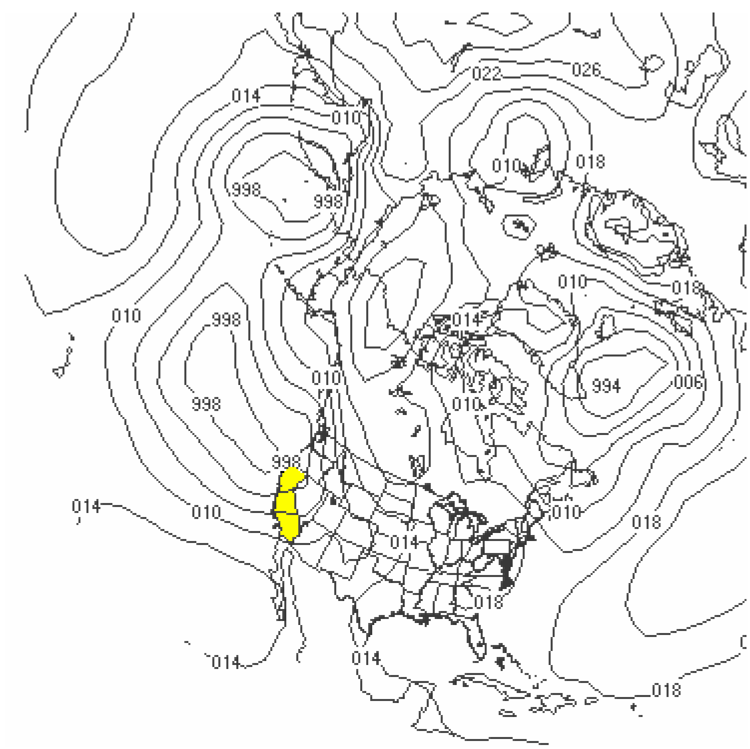

Figure 2-35: Composite of sea level pressure for group C

It is noteworthy that group C was the only group that consisted mostly of classifications II and III (types 4 and 3, respectively), but also including classification I, type 4.

Finally, group D was made up entirely of classification I, type 5 (back to Figs. 2-10, and 2-11). This group was characterized by an open trough aloft whose axis was along the West Coast of the United States as energy moved south along the coast. The 700 h-pa low was found near northern California and a weak sea level pressure low was indicated over California and Nevada. Orographics were weaker with these cases and subtropical moisture advection was absent. The added ingredient appeared to be advection of cold continental-origin air into the west side of the upper trough off the west coast of the United States.

A brief attempt was made to associate monthly leading modes with the heavy rain events, using standardized monthly Northern Hemisphere teleconnection indices from the HPC website. Given the commonalities within each group in groups A-D, these appeared to be the best choices for associating leading modes with heavy rain events. Looking at the higher valued monthly standardized indices, those 1.5 and above, it was found that several modes were more common within each group. Groups A through C all had some degree of the positive phases of the North Pacific and the Pacific/North American teleconnections. Groups B and C indicated some degree of the negative phase of the Eastern Pacific teleconnection. Some other modes were the appearance of the positive phase of the North Atlantic Oscillation in group A and the positive phase of the Polar Eurasian pattern in groups A and B. Please refer to the Climate Prediction Center website for more information on teleconnections:

http://www.cpc.noaa.gov/data/teledoc/nao.shtml

Summary and Conclusions

Some of the main synoptic features associated with heavy precipitation in southern California included a deep upper low or sharp trough near the west coast of the United States, especially in the vicinity of the Pacific Northwest, as well as west to southwest flow at 700 h-pa, and a sea level pressure low from off the West Coast to the Great Basin, implying southerly surface winds. Other features included strong low latitude westerly flow aloft over the Pacific with embedded systems of various amplitudes, and a blocking high in the vicinity of Alaska.

Regarding the frequency of events, there were approximately two heavy precipitation events per year in southern California for the period from 1949 through 1997. Considering just the heavier precipitation events, those in classifications II and III, the frequency dropped to about one every 3 years. Strong El Nino years had at least one heavy precipitation event, but there was no significant correlation between years with frequent events and strong El Nino years.

For the heavier events (those in classifications II and III) the heights tended to be lower over the Pacific with the overall flow displaced further south, and sometimes there were one or more synoptic scale waves in the subtropical latitudes to the west of southern California. The heavier events also tended to have better implied subtropical moisture advection, with the low level flow (700 h-pa and below) typically advecting from the region just north and east of Hawaii. Some of the events analyzed resembled the so-called "Pineapple Connection" referred to by operational forecasters when there is deep tropical moisture advection into the West Coast. Another interesting feature of some of the heavier events was the apparent entrainment of cold continental air into the west side of an upper trough or low near the West Coast. This cold air would tend to destabilize the airmass when passing over the relatively warmer ocean off the West Coast and would also enhance the baroclinicity and, therefore, implicitly enhance the upper jet in the vicinity of Southern California. There were also a few events, all in class

II, type 2, that featured a strong surface anticyclone over the central North American continent, which would also tend to implicitly enhance the upper jet over the southern United States and northern Mexico. This surface anticyclone was the primary difference between class I, type 2, and class II, type 2. Classification I, type 5, comprised approximately 15 percent of the total number of cases and was different than the other patterns. It was characterized by weaker surface pressure gradients than found in the other cases and an absence of subtropical moisture advection, but was the only type in class I that indicated advection of cold continental air into the west side of the upper trough.

The minimum synoptic ingredients for heavy precipitation in the southern California coastal region were a relatively deep upper low or sharp trough off the Pacific Northwest or British Columbian coasts with moderate to strong low level south to southwest flow in southern California. Apparently the upper flow can have lower amplitude, but in those cases, the upper flow will generally be displaced farther south and tend to advect more subtropical moisture into California. There were cases (class I, type 5) where the above mentioned features were present, but were weaker. The compensating factor in those cases appeared to be the injection of cold continental air into the trough off the West Coast. The heavier precipitation events were either deeper with stronger orographics, had stronger low latitude upper flow and implied subtropical moisture advection, or were enhanced by an injection of cold continental air into the trough off the West Coast, or were some combination of all of these factors. There was one event which did not quite fit with the other events that comprised the heavier precipitation cases (classes II and III), which was labeled class III, type 2. The compensating factors for this event appeared to be the entrainment of cold continental air into the upper trough coupled with significant subtropical moisture advection.

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