Table 8.2: High measurements of S from the NPS network monitor at Hopi Point for winter months before June 1986.

Start Time	End Time	S (ng m^{-3})
November 1, 1983 1200 LST	November 4, 1983 1200 LST	771
March 29, 1986 0000 LST	April 1, 1986 0000 LST	597
January 22, 1985 1200 LST	January 25, 1985 1200 LST	583
November 5, 1983 0000 LST	November 8, 1983 0000 LST	539
November 23, 1982 1200 LST	November 26, 1982 1200 LST	527
March 1, 1986 0000 LST	March 4, 1986 0100 LST	500

January 3, 1987

The low concentration on this date of 48 ng m^{-3} can be explained by the passage of a strong cold front the day before. The S reading on December 31, 1986 was only 93 ng m^{-3}. It is also unlikely that there was a local buildup at NGS before the front came through the area. Photographs 8-37 and 8-38 show skies which are mostly cloud free.

8.4 High Sulfur Events During 1982 – 1986

There were 159 3-day averaged S concentrations measured between January 1982 and March, 1986 at Hopi Point during the months of November, December, January, February, and March.

Since the sampling period was so long, high measurements of S could be due to high concentrations on one, two, or all three of the days in the averaging period. Therefore, although this section will follow the format of the two previous sections, all three days during the sampling time will have to be used in determining causes of the high S reading at Hopi Point.

Table 8.2 shows the high S events which will be discussed in this section. Values of S 500 ng m^{-3} or higher were considered high.

8.4.1 November 1 to November 4, 1983

A high S concentration of 771 ng m^{-3} was measured at Hopi Point for this 72 hour sampling period beginning November 1, 1987 at 12 noon LST. There are two possible explanations for the high S reading for this period, but both are related to a seven day persistent polar high event starting on October 25 and ending November 1. One possible scenario involves arguments similar to the WHITEX stagnation event of February 9 to February 14, 1987 discussed in section 7.2.1 where mesoscale forcing was the dominant transport mechanism. This mechanism can be supported for the November 1 to November 4 case because light and moderately light synoptic winds were evident for four days beginning on October 31. This synoptic pattern indicates mesoscale transport of pollutants (mechanism 2). The other possible scenario involves mechanism 1 and is due to the presence of an upper level trough centered on the southern border of central Arizona on November 2 and November 3. Although the strongest pressure gradient is located to the south of the WHITEX area and moderately strong easterly geostrophic winds existed over the WHITEX area during these two days, this upper level trough might still have had some influence on the high S concentration. Therefore, for this case, mechanism 2 seems to provide the best explanation for the high S value with mechanism 1 playing a more minor role. No photographs were available for this measurement period.

8.4.2 March 29 to April 1, 1986

The S concentration was 597 ng m^{-3}. A persistent light geostrophic wind polar high event began on March 19 and lasted until March 31. The days between March 20 and March 30 indicate light geostrophic flow interrupted by a weak frontal system on March 25. The synoptic pressure gradient associated with the three-day event was very weak. These conditions imply mesoscale transport with the source of the pollution being local. This episode is similar to the February 9-14, 1987 WHITEX episode (mechanism 2) except for the longer stagnation period which would be a reason for the higher S reading. There were some low clouds with extremely hazy conditions on all three days (see Photographs 8-24 through 8-26).

8.4.3 January 22 to January 25, 1985

The mean S concentration was 583 ng m^{-3} during this time period. A very well-defined polar high stagnation event started on January 11 and ended January 20 followed by a weak surface low development to the south of the area associated with an upper level trough. The resultant pressure gradient produced moderately strong to strong northeasterly geostrophic winds during the measurement period. The long duration of the polar high coupled with sustained strong geostrophic easterly winds on January 21 and January 22 and then northeasterly winds on January 24 produced the high S concentration at Hopi Point. Transport is similar to mechanism 1. There were low clouds and very poor visibility throughout the measurement period (see Photograph 8-21).

8.4.4 November 5 to November 7, 1983

The S concentration of 539 ng m^{-3} during this time can be linked to mesoscale transport in the region. A polar high was present most of the time over the area starting October 25 and continuing until the last day of the measurement period, November 7, when a strong surface front moved through. All but four of these fourteen days had light geostrophic winds. There was a surface low to the south of the region centered in Mexico from October 30 until November 4, but this feature was quite weak and appeared to have little impact on the area. Thus the weak synoptic conditions prior to and during this time suggest mesoscale transport of the pollutants from NGS in a manner similar to WHITEX mechanism 2. Photographs taken on this day (8-17 and 8-18) show cloudless skies and a layered haze on the horizon.

8.4.5 November 23 to November 26, 1982

Mean S during this sample period was 527 ng m^{-3}. This is a case in which local buildup of pollutants was probably not a factor. On November 19, a moderately strong surface front passed through the area. This was followed by two days of light geostrophic flow on November 20 and November 21. The next day, November 22, a surface front was situated north of the area with moderately strong west and southwest geostrophic winds. This front passed through on the next day leaving post-frontal conditions with strong easterly flow. On November 24 and November 25 an upper level low centered around Baja generated strong southeasterly winds over the area. This suggests that the high S concentration occurred because of long range transport with the source(s) probably being the smelters of southern Arizona or Mexico. No photographs were available for this time period.

8.4.6 March 1 to March 3, 1986

The S measured at Hopi Point for this period was 500 ng m^{-3}. Synoptic conditions prior to this measurement period show the existence of a polar high stagnation event lasting from February 21 to February 27. Synoptic conditions from February 28 until the end of the measurement period indicate the development of an upper level trough and surface low to the south. Geostrophic wind directions and speeds varied through the measurement period with moderately strong geostrophic southeasterly flow on March 1, light easterly flow on March 2, and strong northeasterly geostrophic flow on March 3. The strong northeasterly winds on March 3 would be expected to produce the highest values of S at Hopi Point during this measurement time. Due to the persistence of the polar high prior to the measurement period (7 days) and the extremely high concentration of S measured, synoptic transport of local pollutants from the east during the two other measurement days could have also had an impact. There were a few low level clouds in the area but no clouds on the rims or within the canyon walls (see Photographs 8-22 and 8-23). Transport mechanism is similar to WHITEX mechanism 1.

8.5 Summary of Historic Episodes

Sixteen extreme (13 high and 3 low) wintertime fine sulfur episodes which occurred at Hopi Point between 1982 and 1987 were examined. In general, the types of synoptic conditions which were associated with these episodes were very similar to those which occurred during the WHITEX study. The three types of synoptic conditions which were associated with high sulfate during WHITEX were also associated with high wintertime fine sulfur concentrations in other years. Examining the historic data can give some indication of how climatologically common each of these scenarios is. Mechanism 1, a persistent polar high followed by northeasterly synoptic transport was associated with 8 (62%) of the 13 wintertime high sulfate episodes in the NPS network data base. Mechanism 2, persistent light wind polar high with surface winds dominated by mesoscale flow up and down terrain causing "sloshing" of pollutants between Hopi Point and NGS, was associated with 3 (23%) of these episodes. There were 2 (15%) cases when long range transport from sources south and southeast of Hopi Point probably contributed to high sulfate concentrations there. An additional mechanism which is common in the summer months but not during WHITEX, was long range transport from southern California (see Figure 8.11).

As with the WHITEX data, the low sulfate concentrations were associated with prefrontal conditions and/or high wind speeds, especially if the wind direction was from westerly or southerly directions.

8.6 Overall Summary and Conclusions

Three different synoptic flow mechanisms have been shown to be associated with high wintertime sulfate concentrations at Hopi Point. These are:

1. A light geostrophic wind polar high which allows local buildup of sulfur concentrations around NGS, followed by moderate to strong northeasterly winds which then transport the polluted air mass towards Hopi Point. The longer the polar high persists, the greater the sulfur concentration is likely to be.

2. A strong persistent (longer than 2 days) polar high with weak geostrophic winds such that the surface wind flow is dominated by mesoscale terrain influenced flow which causes pollutants to "slosh" up and down the canyon between NGS and Hopi Point.

3. Long range transport from distant sources to the south or southeast.

Of the three mechanisms, the first is the most common, accounting for 10 (67%) of the 15 high wintertime sulfur episodes analyzed in this report during the years 1982–1987. The second is the next most common, responsible for approximately 3.5 (23%) of the high sulfur episodes, and the third is the least common, attributable to only 2.5 (17%) of the episodes analyzed.

These three mechanisms can be illustrated by four figures. Figure 8.7 represents a polar high with light synoptic geostrophic winds (mechanism 2). This synoptic condition, when present in the area, is expected to cause a local buildup of pollutants to the northeast of Hopi Point around the Navajo Generating Station. The local pollutants at NGS will continue to build due to trapping of the airmass under a strong subsidence inversion which acts as a lid to suppress vertical mixing. With reduced vertical mixing, pollutants can remain below the inversion where wind speeds are light and are not transported to higher levels in the troposphere where wind speeds are greater and venting is more efficient.

Mechanism 1 could occur with either of 2 weather patterns. Figure 8.8 shows a polar high with strong (> 10 ms^{-1}) synoptic geostrophic flow as indicated by the strong gradient of the isobars (lines of constant pressure). When a Great Basin high is centered to the northwest of the area, geostrophic winds out of the northeast are generated. One reason for a polar high to have strong rather than light winds would be the approach of a short wave frontal system from the west which will produce an increase in the pressure gradient as the high strengthens in response to the approaching short wave trough. This scenario is illustrated in Figure 8.8. Another common way of generating the strong pressure gradient in a polar high pressure is the development of a synoptic low pressure system to the southeast of the region. This development is associated with a middle and upper tropospheric trough moving across the southwest United States. This type of feature is common in the region and is illustrated in Figure 8.9. Both of these scenarios will produce strong northeasterly geostrophic winds which, if occurring after a few days of persistent polar high conditions, will move some of the locally built up pollutants from NGS to the southwest towards Hopi Point.

Figure 8.10 shows a strong upper level low centered around Baja California. This system, in contrast to the low centered over north central Mexico as in Figure 8.9, is positioned to the southwest of the WHITEX study area. This low pressure system is characterized by less stable lower tropospheric thermodynamic conditions and strong southeast geostrophic winds over much of the southwestern United States. These strong southeast winds are partly due to the upper level low and partly due to the pressure gradient around the polar high, centered in this example, in eastern Nebraska. Both synoptic conditions will produce strong southeast transport with the upper level low being more likely to produce long range transport due to the expected relatively deep mixing layer. This scenario is the most likely scenario for long range transport to the WHITEX study area during the winter months (mechanism 3). Prefrontal conditions, which might also be postulated to produce long range transport from the Los Angeles Basin due to the associated strong southwest geostrophic winds, seem instead to serve more as a local flushing mechanism, venting out pollutants trapped in the complex terrain.

Despite the need to further work on a predictive tool for haze and sulfate forecasting, the analysis presented in this chapter, along with the climatological analysis in Chapter 2 and the tracer evidence presented in Chapter 6, demonstrate that the dominant source for the peak values of sulfate observed at Hopi Point during the winter is the Navajo Generating Station and not a distant source such as the Los Angeles Basin or southern Arizona.

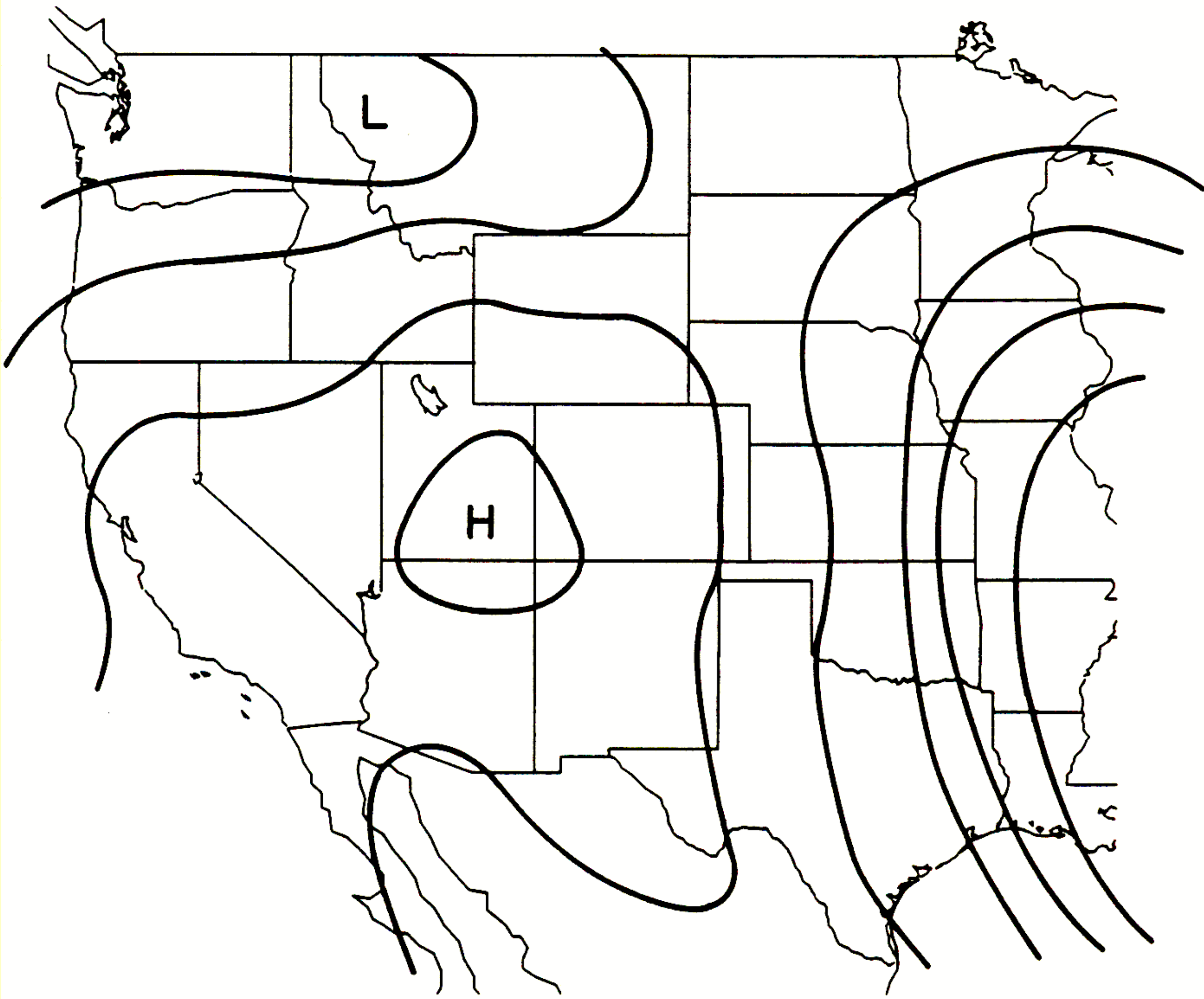

Figure 8.7: Light geostrophic synoptic wind - polar high.

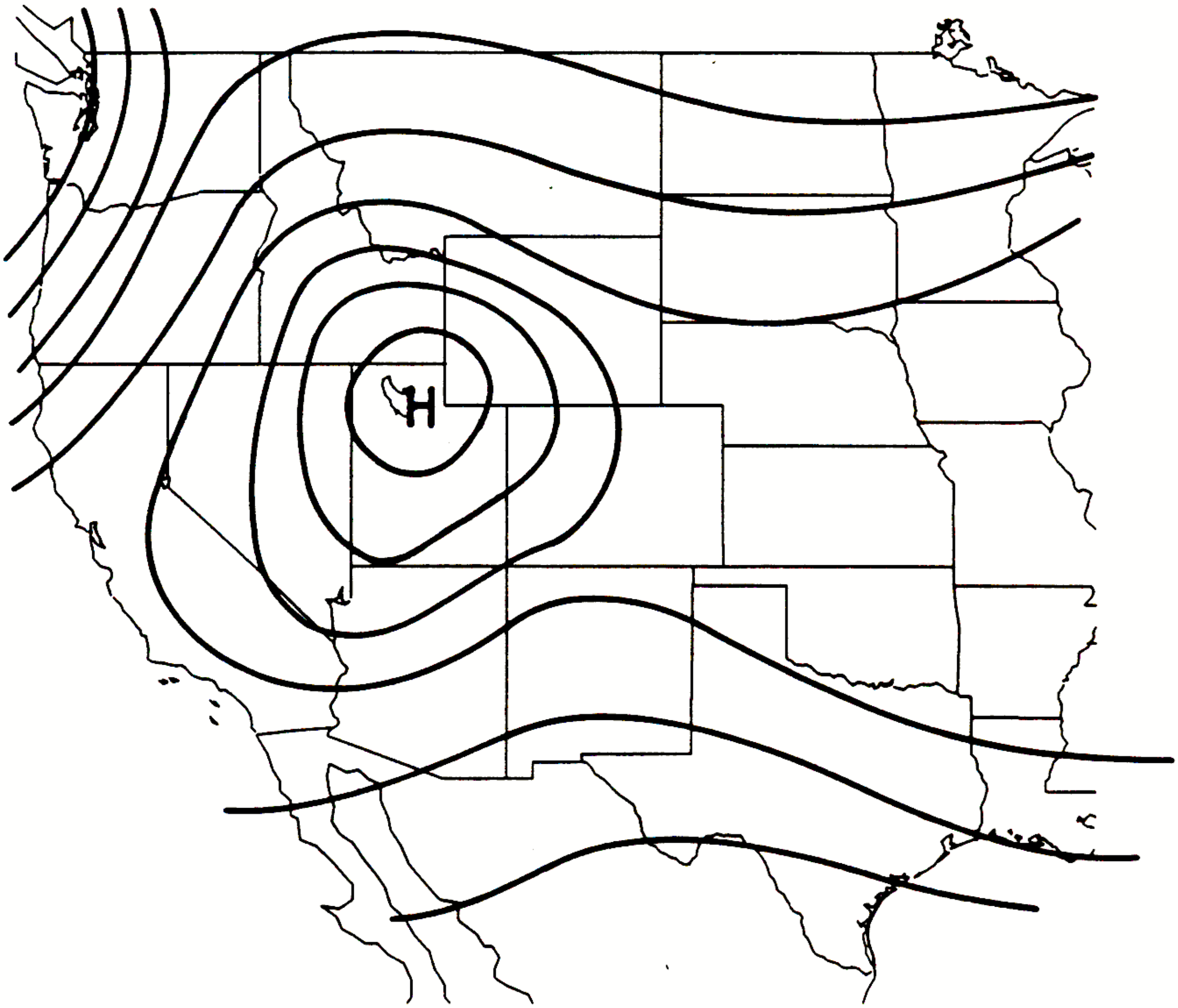

Figure 8.8: Strong geostrophic wind - polar high.

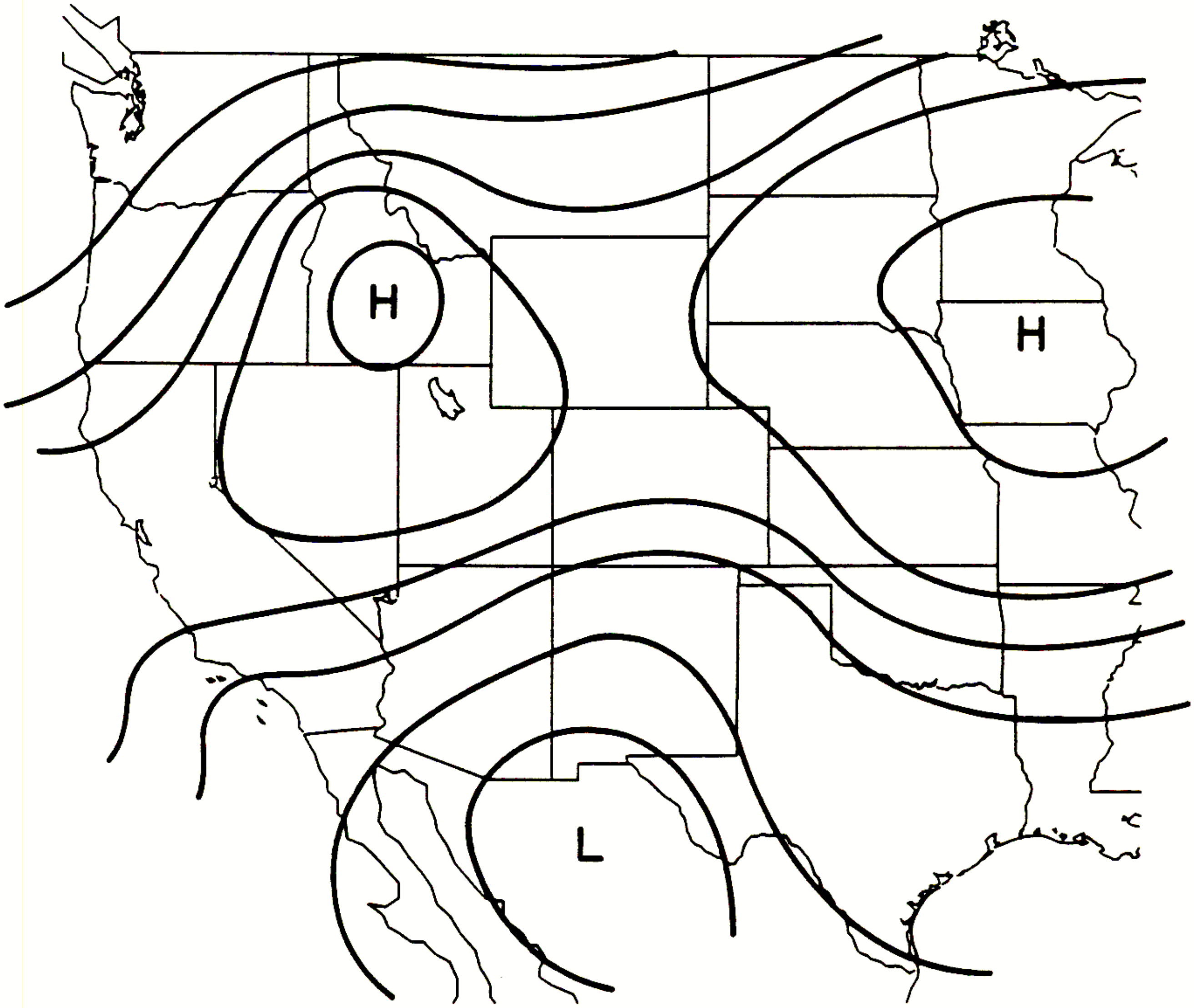

Figure 8.9: Upper level trough.

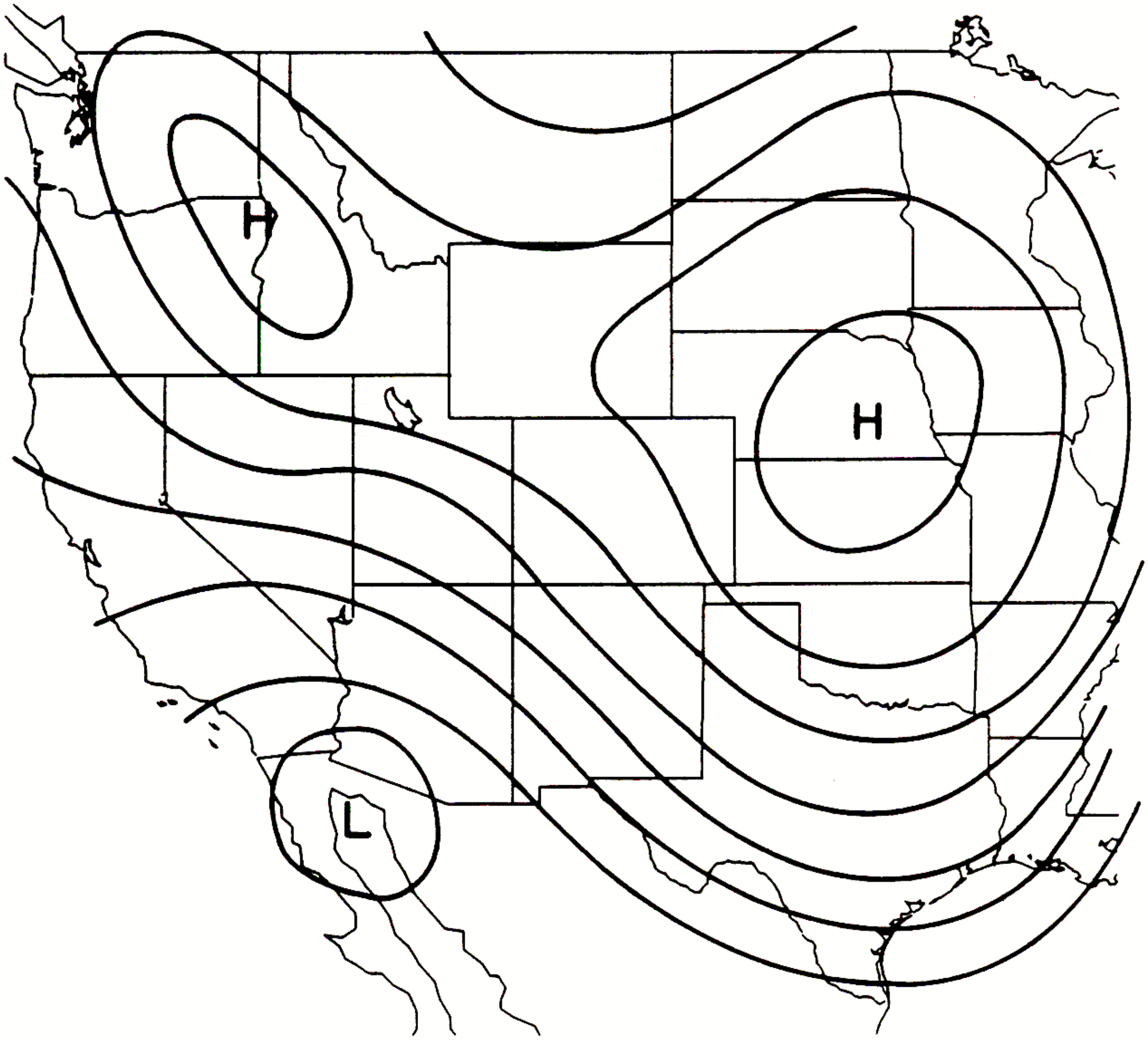

Figure 8.10: Long range transport from southern Arizona.

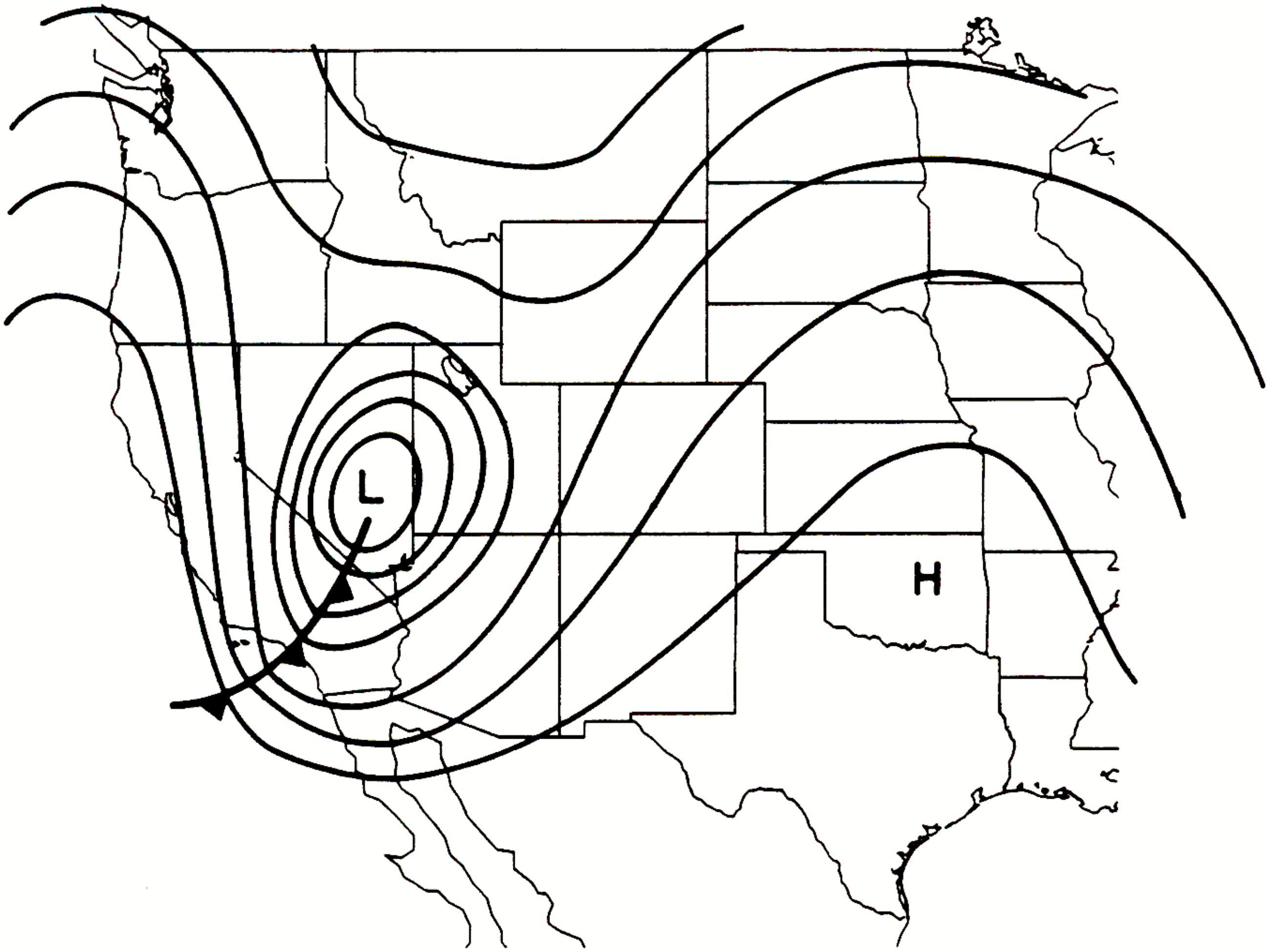

Figure 8.11: Long range transport from southern California.