Contents

List of Tables

List of Figures

Chapter 2

Air Quality Climatology of the WHITEX Study Area

2.1 Introduction

In previous work, Pielke et al.[3] have identified the synoptic meteorological conditions under which the impact of air pollution is most pronounced during wintertime in the western United States. They have shown that the potential for an area to experience air quality degradation is highest under a polar high pressure system. This is because such a system is usually characterized by persistent subsidence (sinking air) and light winds, leading to temperature inversions and poor dispersion. Air quality degradation can be worsened if, as in the study area, complex terrain further inhibits air motion or if there is snow cover on the ground. Radiational cooling from the snow cover would tend to intensify the temperature inversion. Henry and Hidy[1] found similar meteorological conditions contributed to high pollution concentrations during the winter in Salt Lake City, Utah.

During the 6-week WHITEX study period of January 7 through February 18, 1987 one of these polar high pressure stagnation periods existed for a relatively long time—9 days, from February 5 through February 13. In this chapter, the question to be addressed is whether or not this episode was anomalous or if such occurrences are climatologically common.

2.2 February 4 Through February 15, 1987 Weather Maps

The surface and 500 mb flow fields as analyzed by the National Meteorological Center (NMC) at 0500 MST from February 4 through February 15, 1987 are presented in Appendix 8A. Immediately apparent from the analyses is the dominance of a surface polar high, high geopotential heights and warm temperatures at 500 mb. As discussed above, such a weather pattern is associated with synoptic flow stagnation. There is some evidence of a weak trough at 500 mb, and a weak surface low in the eastern portion of the WHITEX area on February 10, which weakened the stagnation pattern, and a stronger trough on February 14 which ended the stagnation event. Also, an upper level trough moved through the area at the beginning of the period (February 4).

2.3 Synoptic Climatology

2.3.1 Southwest United States

The synoptic patterns in the southwest United States were analyzed based on a synoptic classification scheme described in detail in Pielke et al. (1987)[2] and Pielke et al. (1985).[3] In this analysis, the southwest United States was divided into 2.5 degree latitude by 5 degree longitude grid boxes and the synoptic classification was determined once per day at 5:00 am MST for each box. The analysis grid is shown in Figure 2.1. Five possible classifications are shown schematically in Figure 2.2 along with the dispersion characteristics associated with each. The meteorological conditions which generally accompany the first four categories are described in Table 2.1. Note that immediately under a polar high, the synoptic pressure gradient is very weak which, along with the subsidence inversion associated with the high, results in stagnation of the air.

Only four of the categories were observed in the southwest during the winter months (defined as January, February, March, November, December) of 1980-1984. These were:

Category 1: in the warm sector ahead of a cold front
Category 2: in the cold sector ahead of a warm front
Category 3: behind a cold front
Category 4: under a polar high

Figures 2.3, 2.4, 2.5 and 2.6 present the frequency of occurrences of these categories for the southwest United States for these years. As evident in the figures, the WHITEX study area is located in a region of highest occurrences of Category 4 (over 65% of the time during the winter months) and the lowest of Category 3 (less than 19%). Therefore, it appears that the existence of a polar high and the associated high potential for air quality degradation is not only not anomalous, but is the most common weather pattern in this region during the winter months.

2.3.2 The WHITEX Geographic Area

Synoptic Classification Analysis

The five-year synoptic classification scheme described in the preceeding section was shifted forward two years from the years used in the previous section to include the winter periods (November to March) for the years of 1982/83 through 1986/87 for only two grid squares which most closely correspond to the WHITEX study area. These grid squares are shown in Figure 2.1. As expected, the percentage occurrences of the different synoptic categories were very similar to those shown in Figures 2.3, 2.4, 2.5 and 2.6 in this region.

Wind Direction and Speed

Another analysis of meteorological data for February 5–14 was designed to test whether or not the wind speeds and directions which occurred during this time period were unusual.

First the climatological frequencies of occurrence of geostrophic wind direction and speed classes for polar high (Category 4) situations were identified for the "North" and "South" grid boxes. Winds were averaged subjectively over each box for 5:00 am on each day during the winter months of the 1982/83 to 1986/87 time period. Figure 2.7 illustrates the results. The actual surface wind is not usually identical to the geostrophic wind, which is the wind which would be expected in the absence of friction based on the synoptic pressure field. However, the geostrophic wind is more regionally representative than the surface wind because terrain influences and other small scale

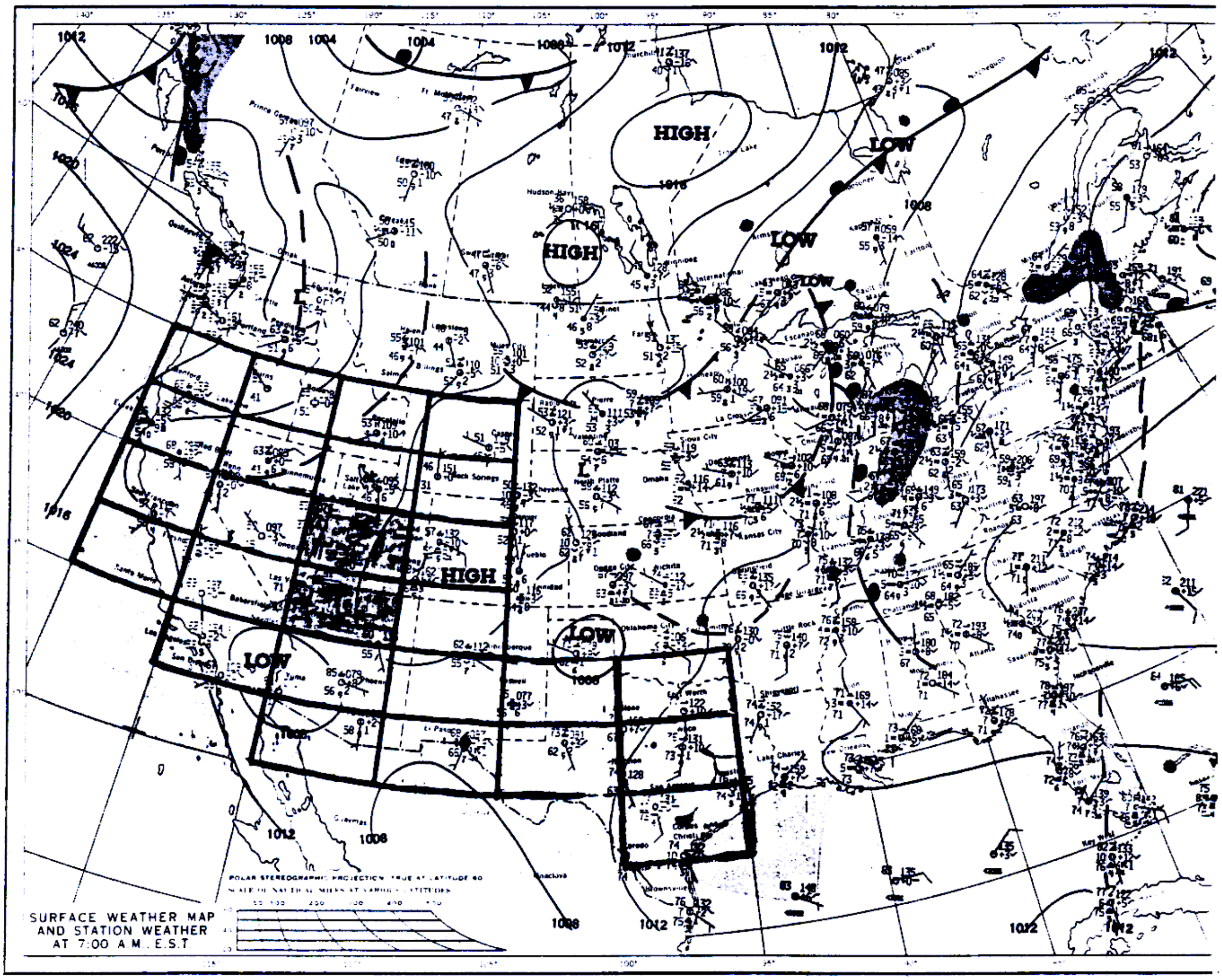

Figure 2.1: Grid used in the 1980-1984 synoptic classification scheme. The two shaded areas are the north and south grid cells corresponding to the WHITEX study area.

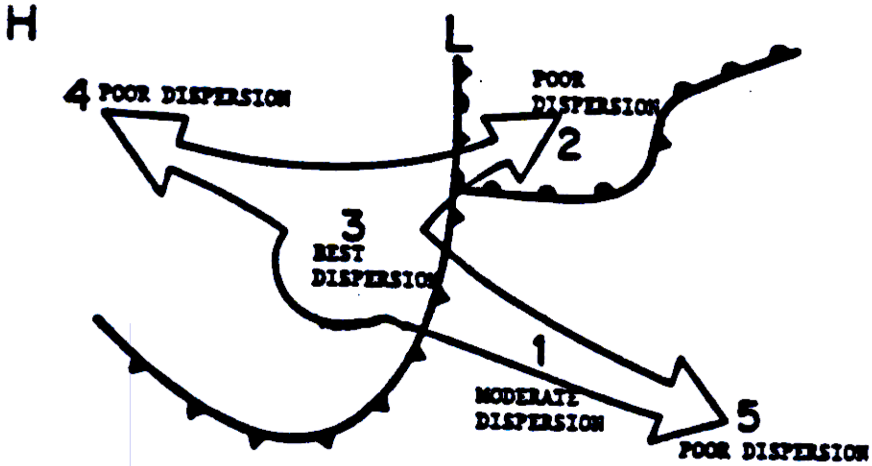

Figure 2.2: Schematic illustration of the relative ability of different synoptic categories to disperse pollutants emitted near the ground.

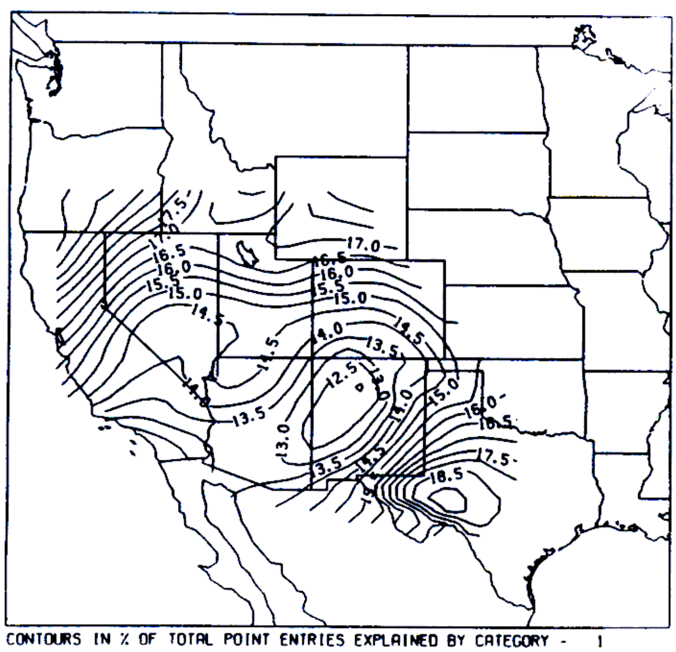

Figure 2.3: Frequency of occurrence of synoptic category 1 (warm sector ahead of a cold front) during the winter months of 1980-1984.

Category Characteristics	Category 1	Category 2	Category 3	Category 4
Category class	mT; in the warm sector of an extratropical cyclone	mT/cP, mT/cA, mP/cA; ahead of the warm front in the region of cyclonic curvature at the surface	cP, cA; behind the cold front in the region of cyclonic curvature to the surface isobars	cP, cA; under a polar high in a region of anticyclonic curvature to the surface
Surface winds	Brisk SW surface winds	Light to moderate SE to ENE surface winds	Strong NE to W surface winds	Light and variable winds
Vertical motion	Weakening synoptic descent as the cold front approaches	Synoptic ascent due to warm advection and positive vorticity advection aloft	Synoptic ascent due to positive vorticity advection aloft (in this region this ascent more than compensates for the descent due to cold advection)	Synoptic descent (due to warm advection and/or negative vorticity advection aloft)
Inversion	Weak synoptic subsidence inversion caps planetary boundary layer	Boundary layer capped by frontal inversion	Deep planetary boundary layer	Synoptic subsidence inversion and/or warm advection aloft create an inversion which caps the planetary boundary layer
Dominant mesoscale systems	Squall lines	Embedded lines of convection	Forced airflow over rough terrain systems; lake effect storms	Mountain-valley flows; land-sea breezes; urban circulations (thermally-forced systems)
Ventilation	Moderate to good ventilation	Poor ventilation of low level (i.e. below frontal inversion) emissions	Excellent ventilation	Night or snow-covered ground: poor ventilation; day: poor to moderate ventilation
Deposition	Dry deposition except wet deposition in showers	Dominated by wet deposition	Dry deposition except in showers	Dry deposition
Dominant transport	Synoptic	Synoptic above inversion	Synoptic	More mesoscale as you approach the center of the polar high

Table 2.1: Overview of meteorological aspects of the four synoptic categories.

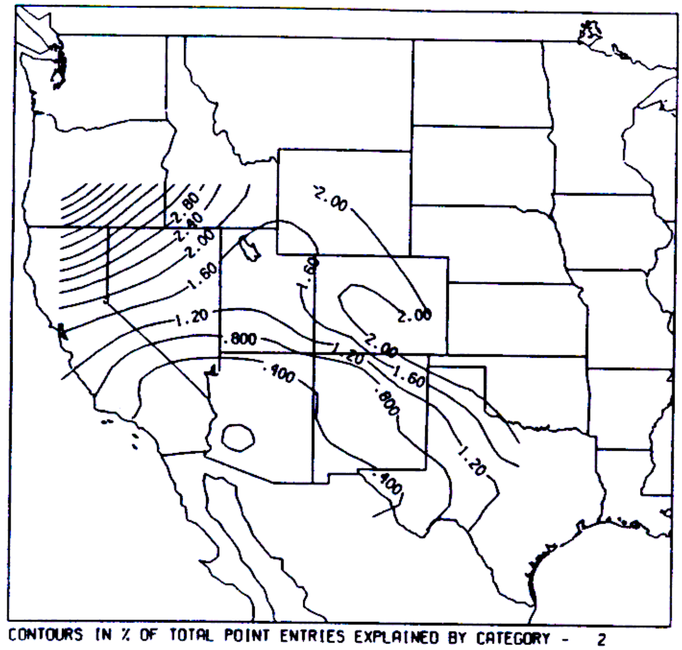

Figure 2.4: Frequency of occurrence of synoptic category 2 (cold sector ahead of a warm front) during the winter months of 1980-1984.

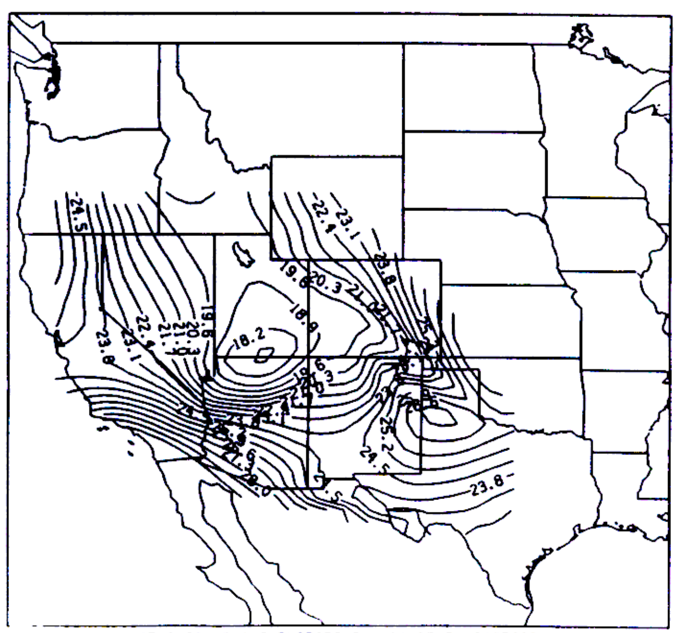

Figure 2.5: Frequency of occurrence of synoptic category 3 (behind a cold front) during the winter months of 1980-1984.

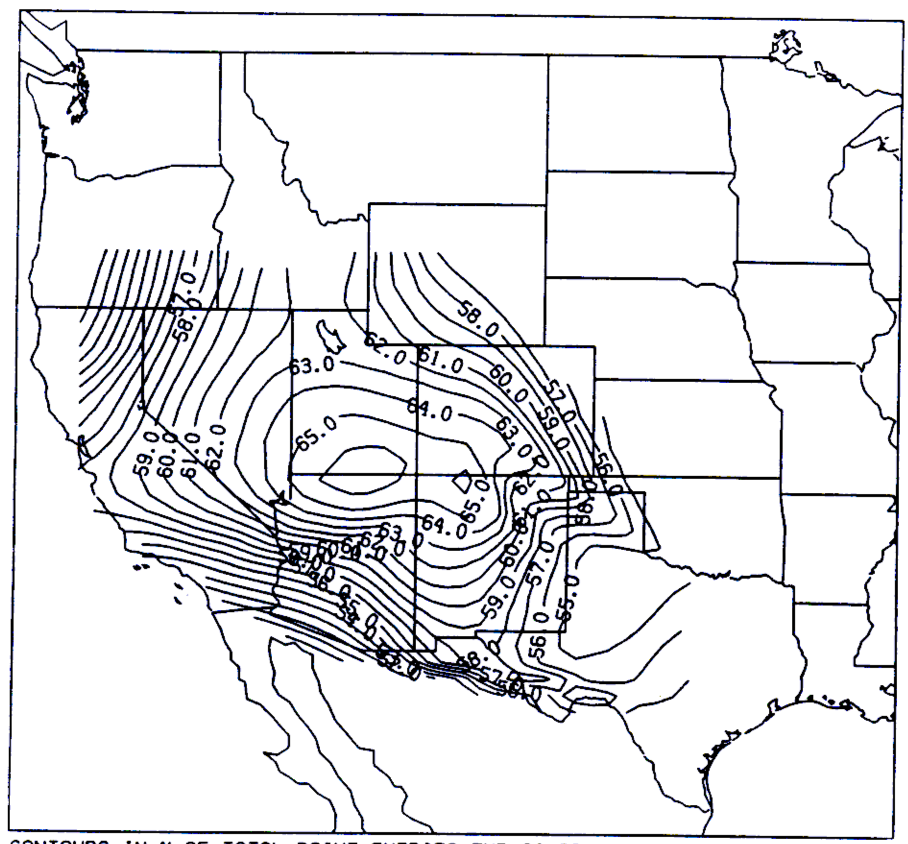

Figure 2.6: Frequency of occurrence of synoptic category 4 (under a polar high) during the winter months of 1980-1984.

Table 2.2: Synoptic climatology for the WHITEX stagnation event of February 5-14, 1987. The table shows the geostrophic wind speed and direction for each of the indicated days along with the climatological percentage of time those classes were observed in the WHITEX area.

Date	geostrophic wind direction at 0500 MST likelihood of occurrence		geostrophic wind speed ($m\ s^{-1}$) at 0500 MST likelihood of occurrence	
	NORTH	SOUTH	NORTH	SOUTH
Feb 5	E (16%)	NE (12%)	2.5-5 (23%)	5-10 (25%)
Feb 6	E (16%)	SE(20%)	5-10 (25%)	5-10 (25%)
Feb 7	SE (20%)	SE (20%)	2.5-5 (23%)	5-10 (25%)
Feb 8	SE (20%)	SE (20%)	5-10 (25%)	5-10 (25%)
Feb 9	SE (23%)	calm (20%)	>10 (29%)	<2.5 (23%)
Feb 10	calm (23%)	SE (20%)	<2.5 (23%)	2.5-5 (23%)
Feb 11	calm (23%)	calm (23%)	<2.5 (23%)	<2.5 (23%)
Feb 12	calm (23%)	calm (23%)	<2.5 (23%)	<2.5 (23%)
Feb 13	SW (6%)	S (8%)	>10 (29%)	5-10 (25%)
Feb 14	N (5%)	N (5%)	>10 (29%)	>10 (29%)

effects on local wind direction and speed are ignored. Unless the pressure gradient is very weak, geostrophic wind usually exerts a strong forcing on the local winds.

The spatially averaged geostrophic wind directions and speeds for 5:00 am for the two grid boxes are given in Table 2.2, along with the climatological percent of time those classes were observed in each box when a polar high was over the grid box. Thus, based on the results shown in Table 2.2, the winds which occurred from February 5 to 14 were not unusual since each of the wind direction and speed classes occurs a significant percentage of the time during similar wintertime synoptic conditions in this geographic area.

Persistence of Synoptic Stagnation

A final, more stringent evaluation is an examination of the persistence of synoptic stagnation. We need to determine if the February 5–14 period corresponded to an anomalously long period of polar high persistence. This analysis was performed for both grid areas in Figure 2.1 separately, although the correlation between the two grid cells should be quite high. Two types of analyses were performed. In the first, if any subportion of a grid cell contained a non-Category 4 region, the persistence event was terminated (these events will be defined as conservative events in Figures 2.8 and 2.9). In the second analysis, if any subportion of a grid cell retained a Category 4 region, the persistence event continued (these events will be defined as non-conservative events in Figures 2.8 and 2.9).

Figures 2.8 and 2.9 represent normalized persistence frequency from the north and south grid cells respectively. Values were normalized by the total number of stagnation events beyond three days in length (three days is the minimum stagnation event considered). The total number of events for the 5-year period was 62 and 54 conservative and non-conservative persistence events respectively, for the north grid cell and 53 and 59 for the south grid cell. Notice the north grid cell has more conservative events and the south grid cell has more non-conservative events. This switch in the number of events between the north and south grid cells can be explained as follows.

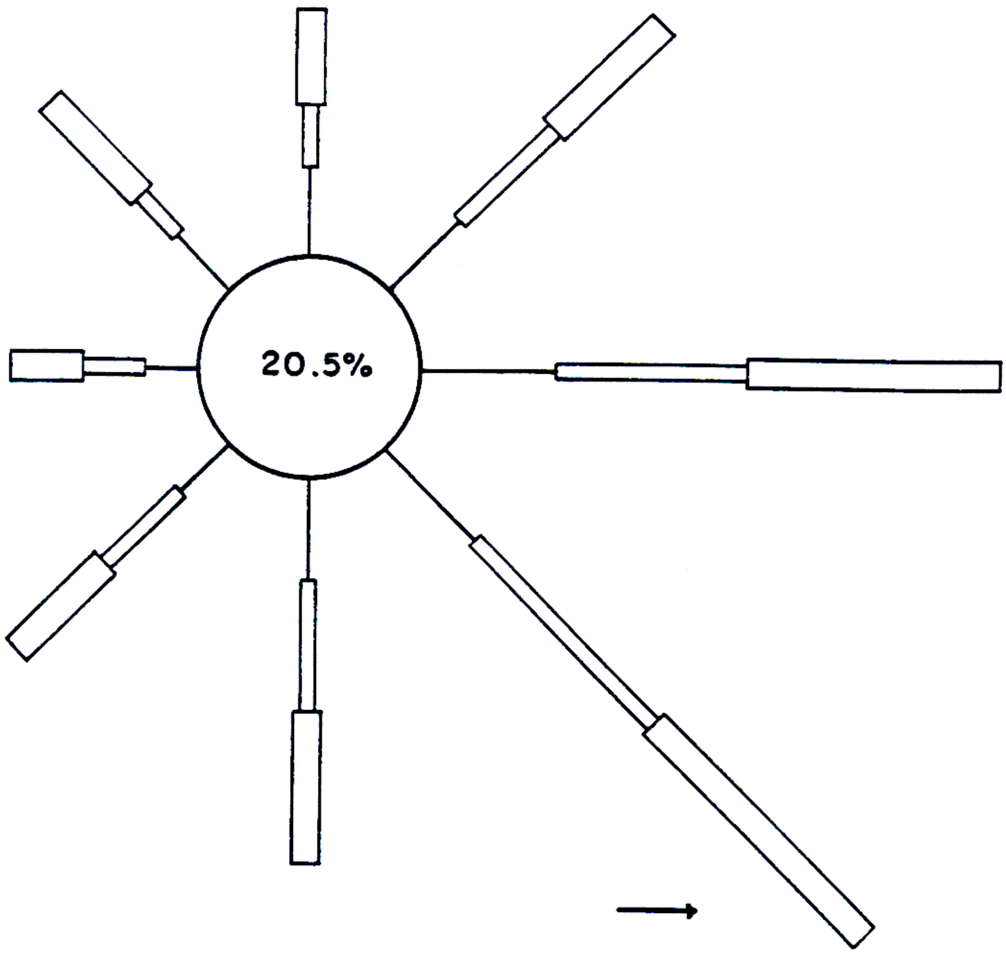

Figure 2.7: Wind rose diagram for polar high conditions for the two cells in Figure 2.1 representing the WHITEX area. Geostrophic wind directions are in octants with the speed indicated by the three levels on any directional stem. The first level represents wind speeds between 2.5 m s^{-1} and 5 m s^{-1}, the second between 5 m s^{-1} and 10 m s^{-1} with the last being speeds greater than 10 m s^{-1}. The percentage of time when calm conditions were present (speeds less than 2.5 m s^{-1}) is shown in the center of the wind rose. The length of the arrow located in the bottom-right represents a 2% frequency in any of the directional wind stems.

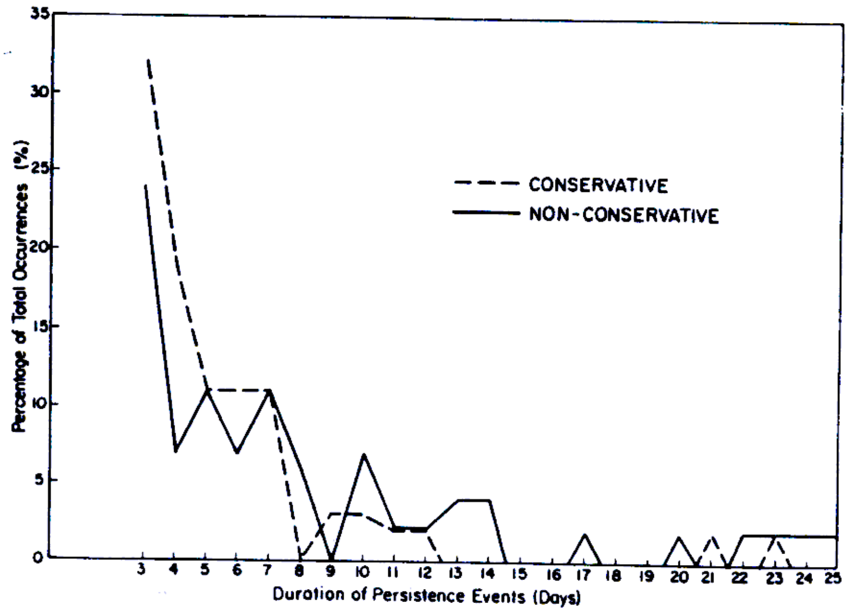

Figure 2.8: Normalized persistence frequency for the northern grid cell.

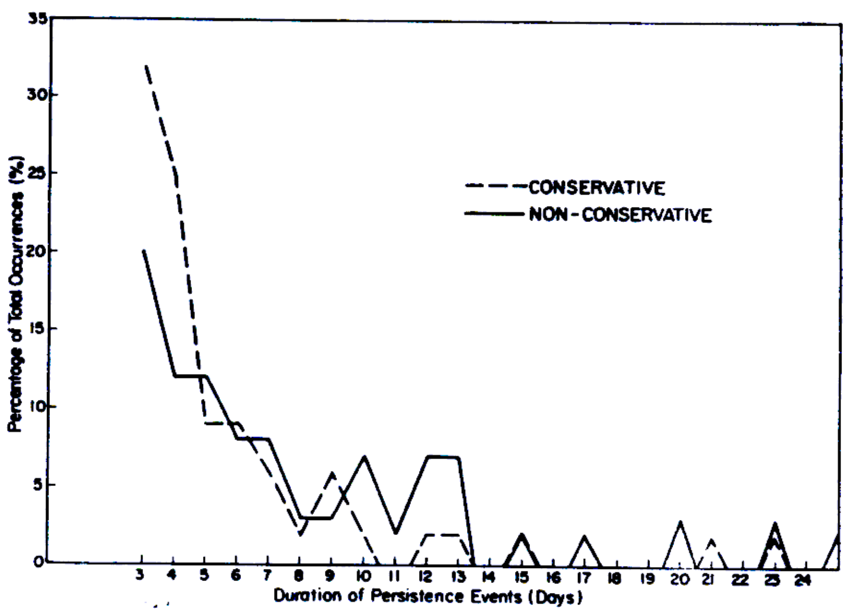

Figure 2.9: Normalized persistence frequency for the southern grid cell.

The first explanation, which is more common in the northern cell, involves the splitting of a non-conservative long persistence event into shorter but more numerous conservative events due to multiple category classifications (i.e. more than one classification per grid cell) within the non-conservative event. The second explanation involves the increase in the number of persistence days using the non-conservative criteria. This happens because persistence events of two days or less in the conservative scheme (which do not count as an event because they are less than three days) can often combine with multiple categoried days (with a partial polar high influence) before or after the conservative event to produce a non-conservative event of three or more days. This was more common in the southern grid cell.

A common feature in both Figures 2.8 and 2.9 is the large difference in the number of short events (events lasting less than 5 days) between the conservative and non-conservative calculations. This switch in the number of events between the north and south grid cells can be explained by the breakup of less frequent non-conservative stagnation periods into shorter more numerous conservative events. These figures tend to produce three separate regions for persistence events:

1) Durations of 3-5 days which account for 42-44% of the non-conservative events and 62-66% of the conservative events.

2) Durations of 6-14 days which account for 43-45% of the non-conservative events and 29-32% of the conservative events.

and

3) Durations greater than 14 days which occur about once a year for the 5 month period considered. This is 4% of the conservative and 12% of the non-conservative events.

The mean length of a stagnation event is approximately 6 days for the conservative method and 8 days for the non-conservative method. Another interesting fact is that the number of days for the north and south grid cells which experience stagnation events of three days or longer is approximately 45% of the total possible wintertime days for the conservative estimate and approximately 60% for the non-conservative estimate. Since the percentage of the time a polar high covers this area for the mentioned 5 month period is about 65%, this indicates that most polar high situations over this region persist for three or more days and that even in the most conservative estimate only 20% of the polar highs observed last for fewer than three days.

2.4 Conclusions

From this synoptic analysis, the number of days in a persistent weather pattern similar to or longer than that observed during the February 5 to February 14, 1987 period of the WHITEX experiment is 16% of the total number of days in a typical winter. This percentage is based on an analysis in Section 2.3.2 in which category 4 situations of 9 days (which is the length of the WHITEX stagnation event in early February based on a conservative persistence calculation) and longer were totaled and compared against the total number of days in the November – March, 1982/83 through 1986/87 time period. Clearly, therefore, the observations were not collected during an anomalous event but appear to be quite representative of a synoptic stagnation event in southern Utah and northern Arizona with this length of stagnation episode generally occurring an average of one or two times per winter.

References

[1]Henry, R.C. and Hidy, G.M. (1982) Multivariate Analysis of Particulate Sulfate and Other Air Quality Variables by Principal Components - II. Salt Lake City, Utah and St. Louis, Missouri. *Atmospheric Environment*, Vol. 16, pp. 929-943.

[2]Pielke, R.A., Garstang, M., Lindsey, C., and Gusdorf, J. (1987) Use of a Synoptic Classification Scheme to Define Seasons. *Theor. Appl. Climatol.*, Vol. 38, 57-68.

[3]Pielke, R.A., Segal, M., Arritt, R.W., Yu, C-H, and McNider (1985) Influence of Distant as Opposed to Local Pollution Transport on Wilderness Air Quality. Presented at the National Wilderness Research Conference.