NOAA Technical Memorandum NWS WR-231

WASHINGTON STATE TORNADOES

Treste' Huse
Colorado Basin River Forecast Center
Salt Lake City, Utah

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ABSTRACT

This study researches past tornado occurrences in Washington to identify elements conducive for tornado potential. Tornadic events were examined through composites and case study analysis. The composites revealed either southwest or northwest mid- and upper-level flow regimes. Environments more favorable for classic supercell development were implied from the southwest flow cases.

I. INTRODUCTION

Tornadoes in Washington, while rare compared to those east of the Rockies, should not be dismissed as insignificant features of the climate of the state. Tornadoes have been reported in 28 of the last 44 years in Washington; with a total of 53 tornados from 1950 through 1994. Although Washington tornadoes are generally weak, several F3 tornadoes have occurred. The most destructive tornado killed 6 people and injured 300 others in April 1972. This study examines the climatology of tornadoes in Washington and the meteorological conditions associated with these notable events.

II. DATA COLLECTION

NSSFC tornado statistics for Washington provided precise times and locations, path dimensions and severity information for tornadic events. To further assess damage, *Storm Data* were retrieved. Additionally, the surface and upper-level analyses with nearest synoptic times to the events were obtained from a microfilm library at the University of Washington. To gain more insight into similarities of the analyses and their deviation from climatology, composite height fields were produced for 850, 700, 500 and 200 mb; composite sea-level pressure analyses were also generated. All composites were created using the NMC Grid Point Data Set on Compact Disc. These data are available twice daily over a hemispheric domain with a grid resolution of 380 km. Soundings from Quillayute for western Washington and Spokane for eastern Washington were taken from the Radiosonde Data of North America Compact Disc (NOAA/FSL 1993). These soundings were examined and, in certain cases, modified using the interactive Skew T/Hodograph Analysis and Research Program (SHARP). These modifications will be described later.

III. CLIMATOLOGY

Figure 1 illustrates the geographic locations and intensities of tornadoes in Washington. Tornadoes appear to be concentrated in or near Seattle and Spokane (Fig. 2). This apportionment reflects a bias to population centers. The tornadoes in western Washington were mainly observed in the central and southern interior. Thirty four (64 percent) of the tornadoes were reported east of the Cascades even though the population density is less than in western Washington. The frequency of tornadoes was less along the east slopes of the Cascades, increasing significantly over the eastern third of the state. A number of these reports were from areas with population densities of fewer than four persons per square mile. No tornadoes were reported over the Cascade Mountains.

There was a preponderance of F0 and F1 tornadoes in the state with 73 percent of the events in these categories. A higher proportion of Washington tornadoes were classified as F0 and F1 than the 63 percent for the United States as a whole (Fujita 1987). Eleven F2 and three F3 tornadoes have been reported in Washington since 1950. The average path length for tornadoes in Washington was determined to be 1.8 miles. To compare these statistics to path lengths in other areas of the Unites States, Fujita's averages for path lengths by F-scale were obtained. These data show that tornado mean path lengths increase with higher F-scale classifications. A population weighted mean was then constructed using the F-scale classification of the 53 Washington tornadoes and these Fujita averages. This technique revealed an expected mean path length of 3.0 miles, considerably greater than observed. This result indicates that the typical path length for tornadoes in Washington is shorter than for the nation as a whole.

Histograms were constructed showing the frequency of tornadoes by month and hour (Fig. 3). Histograms for eastern Washington were generally similar to national statistics with April and May the most common months for tornado activity. A secondary maximum was indicated July through August. While tornadoes were more evenly distributed by month west of the Cascades, the fewest instances occurred in mid-summer and late winter. This suggests a greater likelihood of tornadoes during transitional seasons in western Washington. However, this is clearly speculation due to the small sample size. The greatest diurnal frequency west of the Cascades is indicated during the late morning and afternoon. The connection between tornado events and solar heating is more evident east of the Cascades where tornadoes tend to peak in the afternoon and early evening.

IV. SYNOPTIC AND LOCAL ENVIRONMENTS

To define the range of synoptic conditions associated with tornadoes in Washington, constant pressure fields were analyzed and composited. The protective barrier afforded by the Cascade Mountains bars the inland penetration of cool maritime air from the Pacific, which promotes stronger diurnal heating as well as a drier climate east of the Cascades. Because of the differing climates, eastern and western Washington were composited separately.

The western Washington composite at 850 mb (Fig. 4a) shows a trough positioned at 130°W with consolidated westerly flow over the state. In contrast, the 850 mb height field for the eastern Washington events (Fig. 4b) indicates a flat ridge extending from the central Pacific into Washington. Both composites at 500 mb (Fig. 5) are characterized by a trough from the southern British Columbia coast to the northern California coast. However, a deeper trough with stronger southwest flow into Washington prevails on the western Washington composites. The standard deviations of the composite values were quite large (not shown) over the eastern Pacific. Due to these significant height variations among the analyses, it was deemed necessary to further classify the tornado events.

A survey of the collected fields revealed that there were two broadly similar synoptic patterns for both eastern and western Washington. The events generally exhibited either northwest or southwest flow at 500 mb. Therefore, the events were subdivided into four classifications based on location and synoptic flow regimes. This process, to some degree, reduced the standard deviation in the near field in the composites. It should be noted that seven cases did not fit in either synoptic flow pattern and these cases were not composited.

The southwest flow cases for western Washington (Fig. 6) are characterized by a deep long-wave trough over the eastern Pacific with strong southwest flow over the state. Difluence is indicated downstream from the upper-level trough axis inferring upward motion over Washington. The synoptic-scale northwest flow regime in western Washington (Fig. 7) consists of a trough extending from British Columbia southwest across Vancouver Island. Northwest winds over Washington are implied to be quite strong at upper levels with significant difluence over Washington at 500 mb.

The southwest flow cases for eastern Washington (Fig. 8) delineate a negatively tilted trough off the Washington coast, typifying short-wave troughs moving northeast. Very strong flow is evident on the backside of the trough. Analogous to the western Washington southwest flow cases, the long-wave pattern places the state in the preferred region of ascent downstream from the trough axis. Finally, for the northwest flow scenarios in eastern Washington (Fig. 9) an 850 mb positively tilted ridge extends from the eastern Pacific northeast across Washington. At 500 mb, a ridge is positioned over the eastern Pacific with a trough centered over Idaho. Northerlies at 850 mb and northwest flow at 500 mb are indicated over the state.

To explore local environments conducive to tornado formation, soundings from Quillayute (for western Washington) and Spokane (for eastern Washington) were examined using the SHARP software package. Due to diurnal heating variations, the soundings were not always indicative of the tornadic environment. This was especially true for western Washington cases given the location of Quillayute on the extreme northwest coast. The afternoon temperatures at Quillayute were usually considerably lower than those across the interior. To provide more representative surface conditions, high temperatures were gathered from a proximity observing site for the day of the tornadic event. If the maximum temperature at the observing site deviated significantly from the initial sounding, the surface temperature of the sounding was modified. Of the 33 soundings available, 22 were modified.

To determine the available buoyant energy in the actual and modified soundings, Convective Available Potential Energy (CAPE) was calculated. CAPE represents the vertically integrated positive area of a parcel rising adiabatically within the ambient environment. Larger temperature differences between the warmer parcel and cooler environment will lead to greater CAPE, updraft strength, and essentially more vigorous convection. Storm-relative helicity was also examined to estimate rotation potential. Storm-relative helicity measures the thunderstorm's potential to develop a rotating updraft as it moves through a vertically sheared environment. It combines the effects of storm motion, inflow strength, and horizontal vorticity. The results are presented in Table 1. The majority of soundings had CAPE values that are considered marginally unstable (between 0 and 1000 J Kg^{-1}). However, several of the modified soundings on both sides of the Cascades were moderately unstable (between 1000 and 2000 J Kg^{-1}). All soundings, with the exception of one, exhibited storm-relative helicity values less than 150 m^2 s^{-2}; which is the approximate threshold indicated for supercell development. Values of CAPE and storm-relative helicity were similar for eastern and western Washington. Interestingly, CAPE and helicity were considerably higher for the southwest flow cases than the northwest cases. This suggests the southwest flow cases provide a more favorable environment for supercell development. However, the classifications consisted of relatively small numbers of soundings, with only four available for the western Washington southwest flow scenario.

V. EVENT DESCRIPTION

The most severe tornadic outbreak occurred during the afternoon of 5 April 1972, with four tornadoes observed in Washington. Two were classified as F3 tornadoes. The most damaging tornado created a nine mile path of destruction in and near Vancouver in extreme southwest Washington. The tornado killed 6 people and injured 300 others, the majority in a shopping center. The other three tornadoes occurred in eastern Washington and touched down in more remote areas demolishing numerous farm buildings.

The general synoptic situation for the event depicted a deep trough located over the eastern Pacific. This placed Washington under a strong, consolidated southwest flow in the mid- and upper-troposphere (Fig. 10), consistent with the southwest flow composites presented earlier.

According to reports, a rapidly moving squall line advanced across Washington during the late morning and afternoon hours of 5 April; the tornadoes were attendant to this squall line. The first tornado initially touched down in north Portland, Oregon, lifted to a funnel cloud as it crossed the Columbia River and then touched down again near Vancouver at 1245 PM PST (2045 UTC). The last tornado was reported in northeast Washington at 6 PM PST (0200 UTC 6 April).

The only radiosonde information available for the event was the 1200 UTC sounding at Spokane. Interestingly, this sounding exhibited an impressive storm-relative helicity value of 281 m^2 s^{-2}; by far the highest of any of the events studied. The hodograph displayed a strong veering wind profile with large wind shear through the lower levels (Fig. 11). The modified CAPE value was 35 J Kg^{-1}. This case study is consistent with the previous suggestion that southwest flow cases are closer to a classic supercell environment.

VI. DISCUSSION

This study examined tornado events in Washington for the past 44 years. The data indicated tornadoes in Washington were less damaging than in other areas of the United States, but Washington's sample size is quite limited. Washington tornadoes also exhibited a shorter path length than those of corresponding intensity across the United States. There was a greater occurrence of tornadoes in eastern Washington than western Washington. The seasonal and diurnal distributions of tornadoes in eastern Washington were similar to national averages, with occurrences highest in the spring. The diurnal maximum was found to be late in the day. Meanwhile, western Washington events tended to peak during transitional seasons and around midday.

Composite maps for selected constant pressure surfaces display either southwest or northwest mid- and upper-level flow regimes for tornadic events. A trough pattern favorable for large-scale ascent was implied from the southwest flow cases. Furthermore, southwest flow is typically characterized by warm advection (although not indicated by the geostrophic shear in the composite) and would generally be considered more prone to thunderstorm outbreaks. Higher CAPE and helicity values for the southwest flow cases also suggest more favorable local environments for classic tornadic activity. The northwest flow cases are indicative of a colder environment and cold advection; conditions not considered conducive for severe storm or supercell development. However, this type of environment is sometimes capable of producing weak tornadoes known as cold-air funnels (Bluestein 1993). In addition, local terrain-induced circulations may contribute to tornado formation in the Puget Sound region. West-northwest flow is the necessary direction for the Puget Sound Convergence Zone to develop (Whitney 1993). This would be a favored region for the generation of antecedent vorticity due to the interaction of low-level wind with topography (Colman 1992).

Several synoptic patterns conducive to tornado formation have been detailed in this study. The patterns found are not dramatically different from typical weather patterns over Washington. However, it is important to note that there are broadly different patterns that can be conducive to tornadic formation across this region. An awareness of the local climate in combination with synoptic pattern recognition can help alert the forecaster to the potential for tornadic activity and lead to a better understanding of these events. With an approaching vigorous short wave and strong instability; operational forecasters need to be aware of the potential for tornadic events. With the installation of WSR-88D radars in the Pacific Northwest, examination of reflectivity and velocity data will provide more insight into mesoscale boundaries more directly associated with tornado occurrences. These will be extremely useful data for better understanding and predicting tornadoes in Washington.

VII. ACKNOWLEDGMENTS

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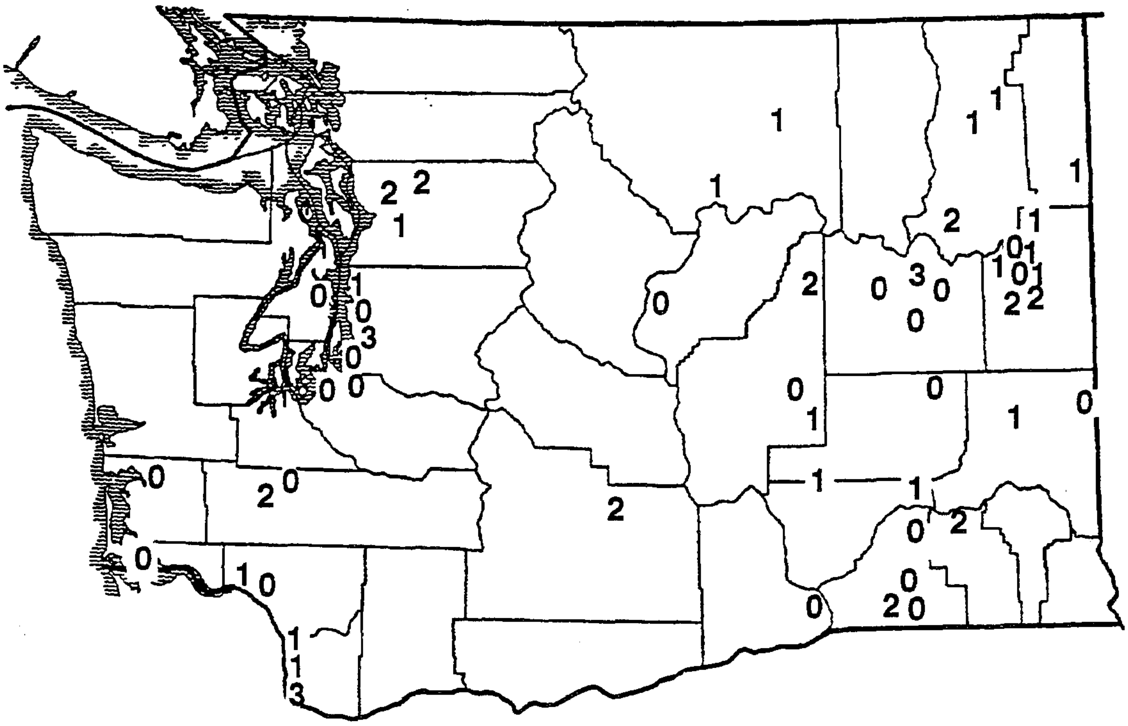


Fig 1. Geographical location and corresponding F-scale intensity of Washington tornadoes from 1950 through 1994.

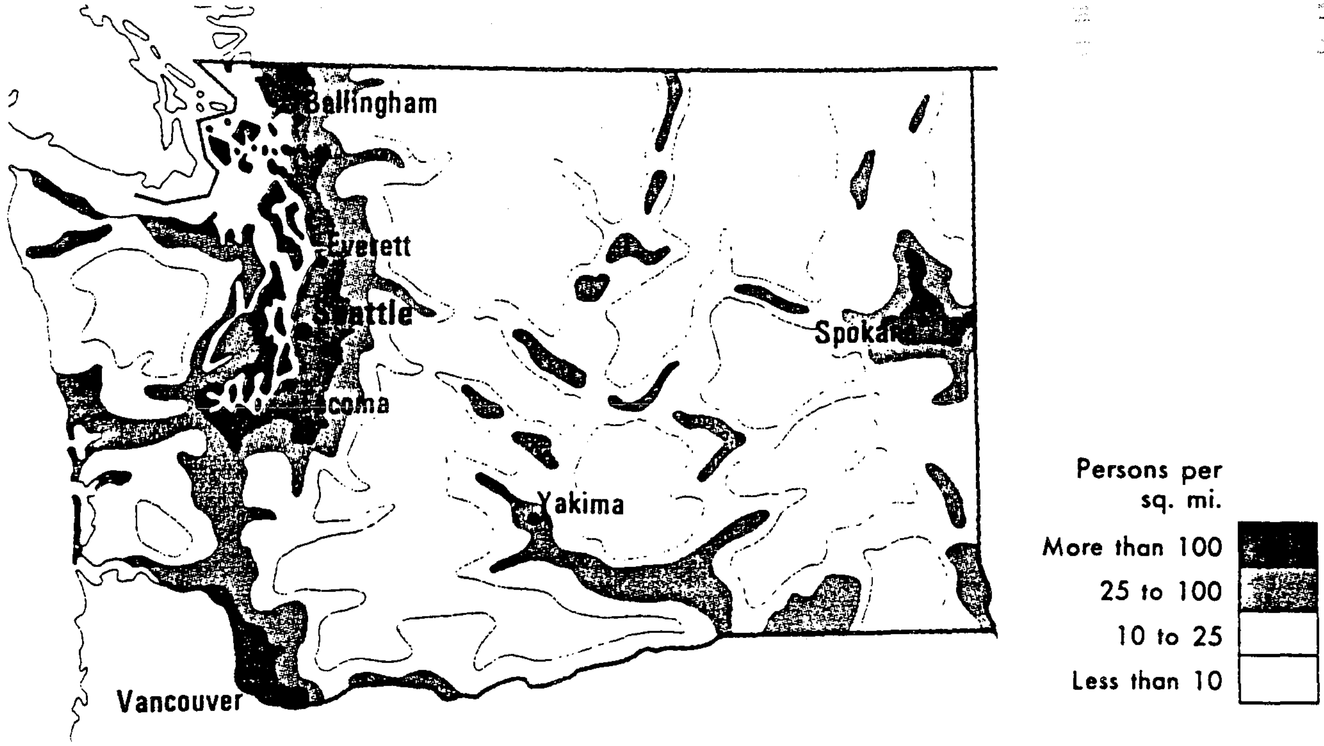


Fig 2. Population density map of Washington based on 1990 U.S. Bureau of Census data (World Book Encyclopedia, 1994).

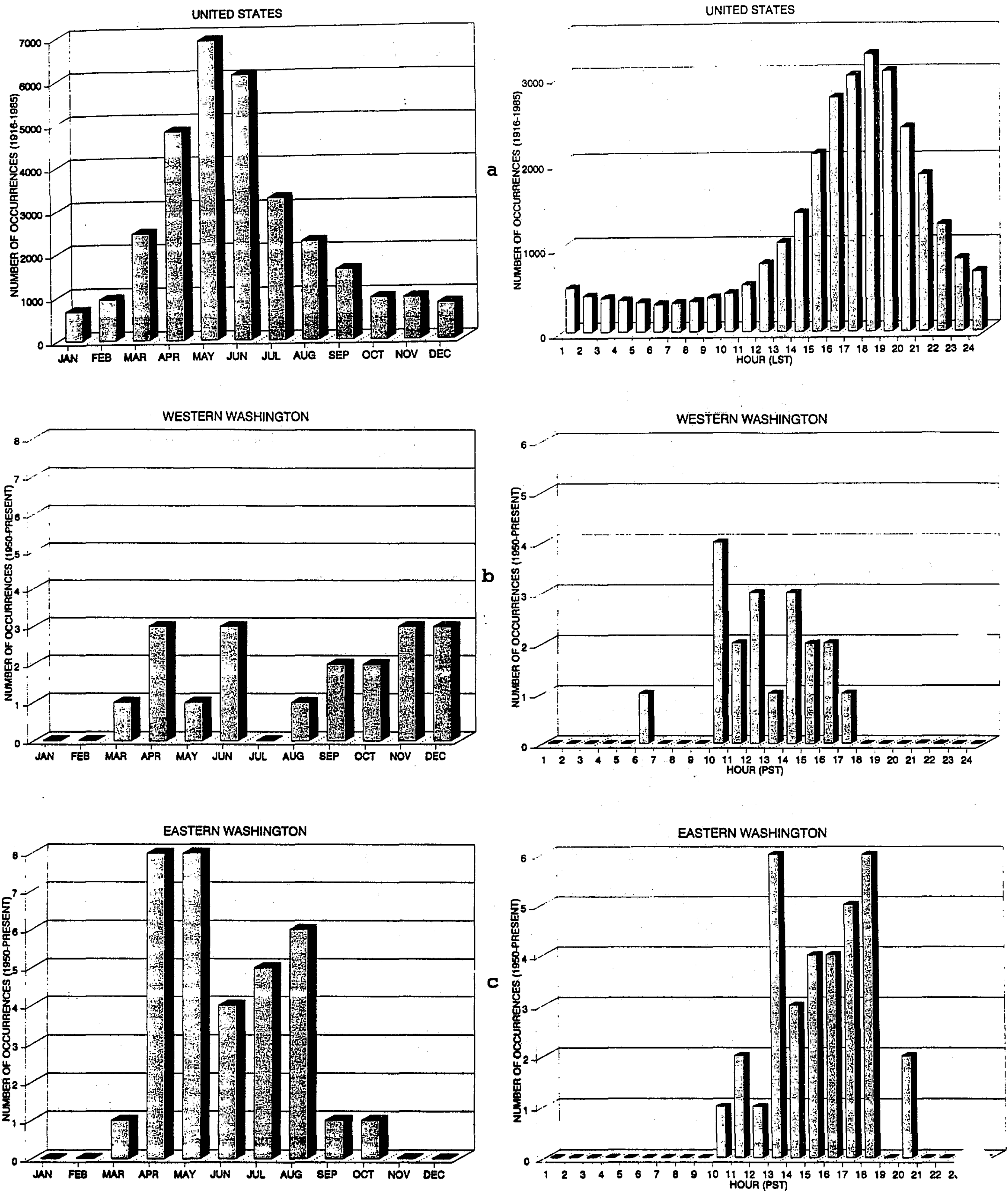
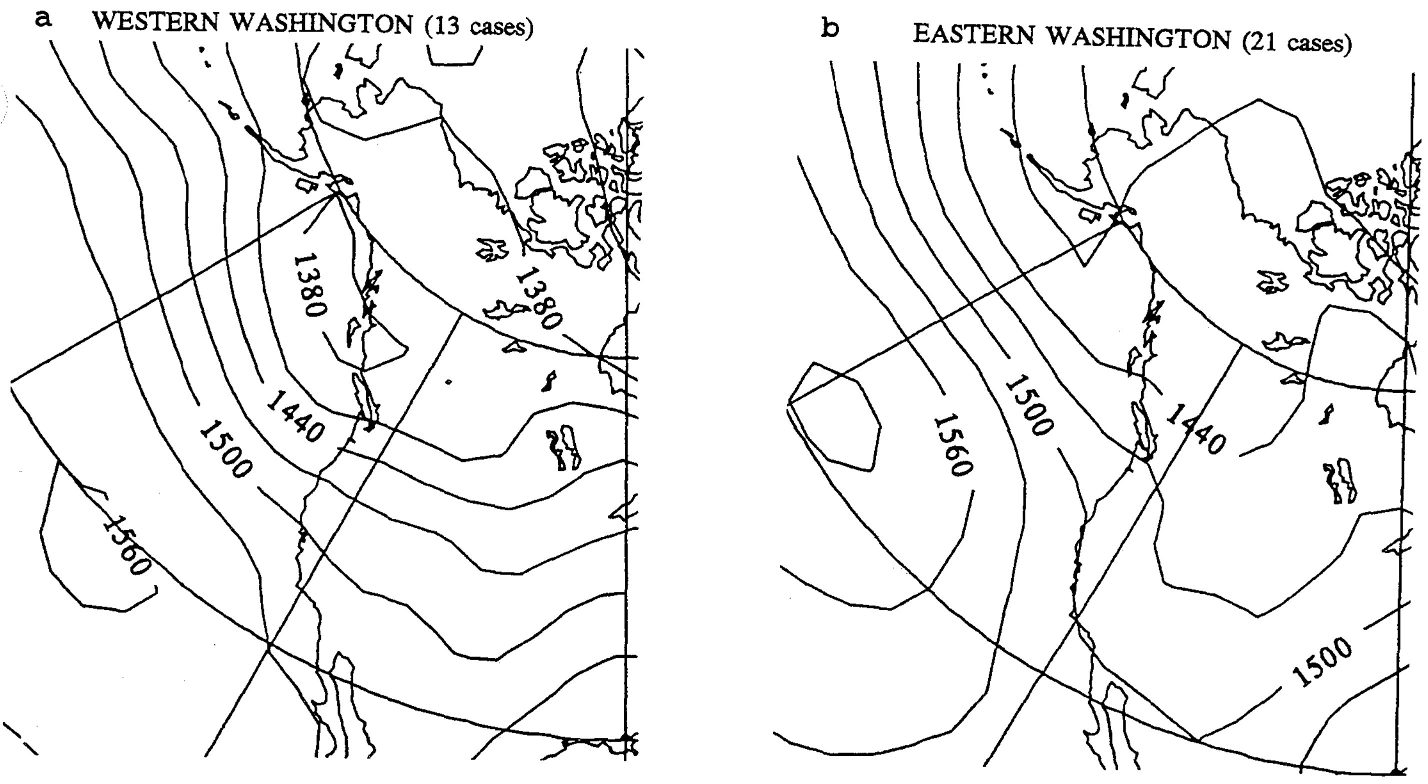


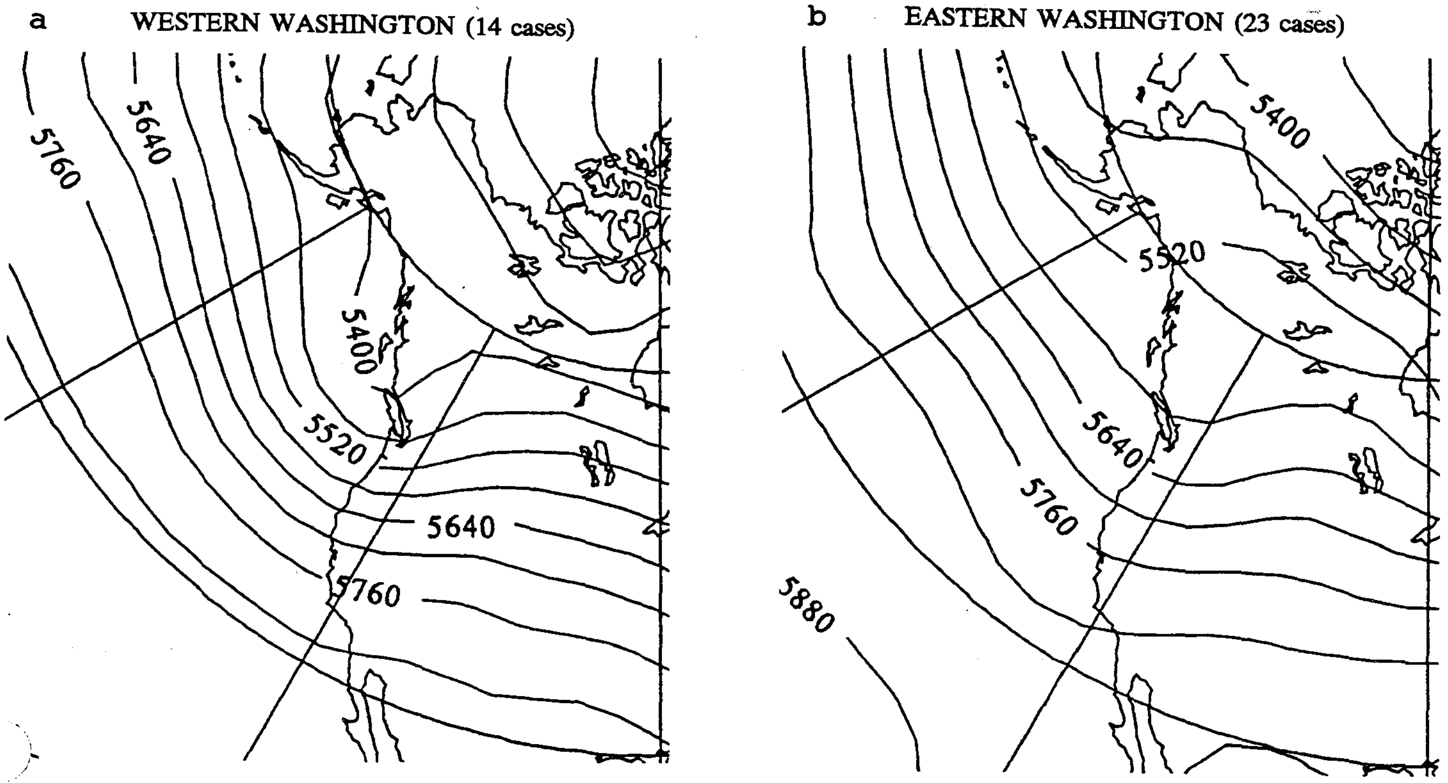
Fig 3. Monthly and Hourly distributions of tornadoes in (a) the United States, (b) western Washington and (c) eastern Washington.



a WESTERN WASHINGTON (13 cases)

b EASTERN WASHINGTON (21 cases)

Fig 4. 850 mb Composites.



a WESTERN WASHINGTON (14 cases)

b EASTERN WASHINGTON (23 cases)

Fig 5. 500 mb Composites.

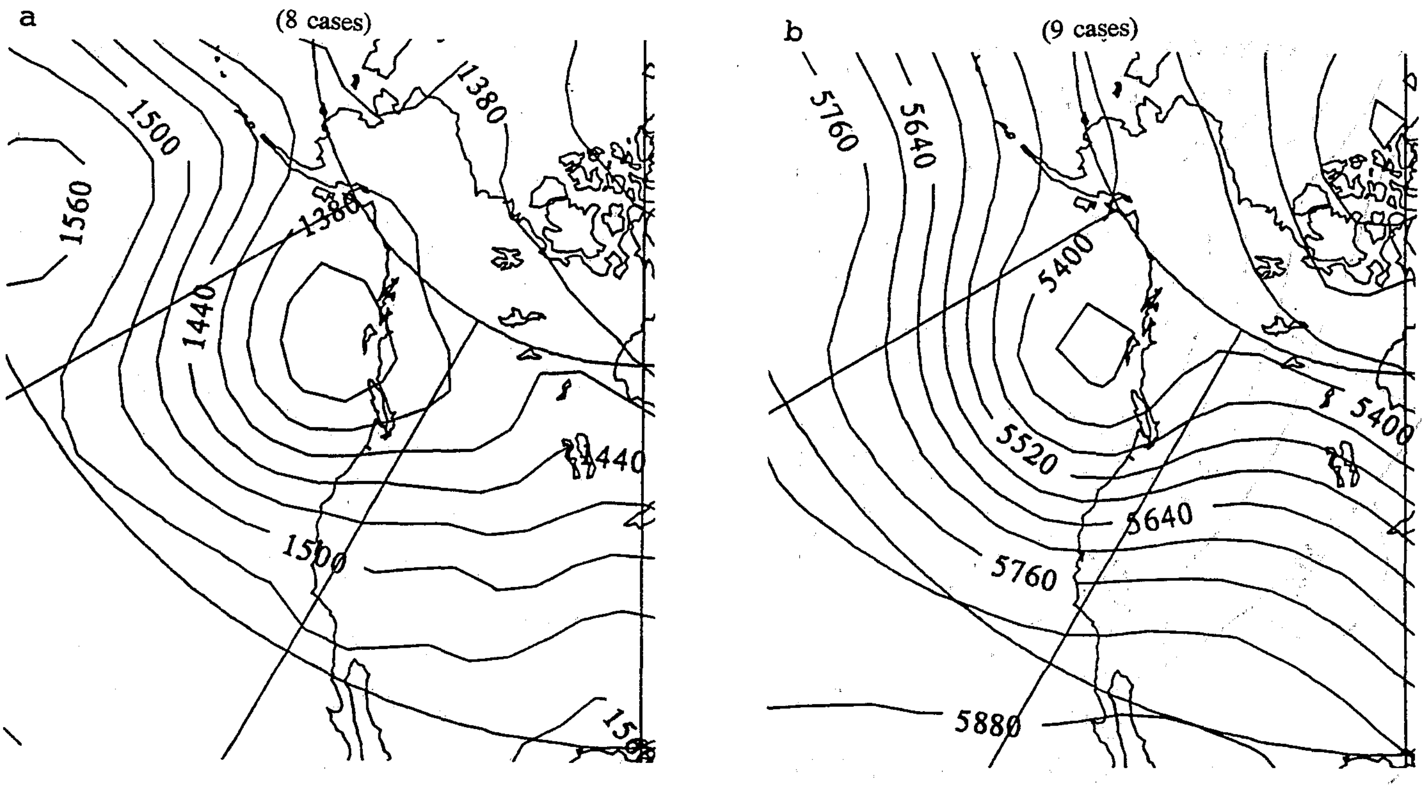


Fig 6. SW flow cases for western Washington at a) 850 mb and b) 500 mb.

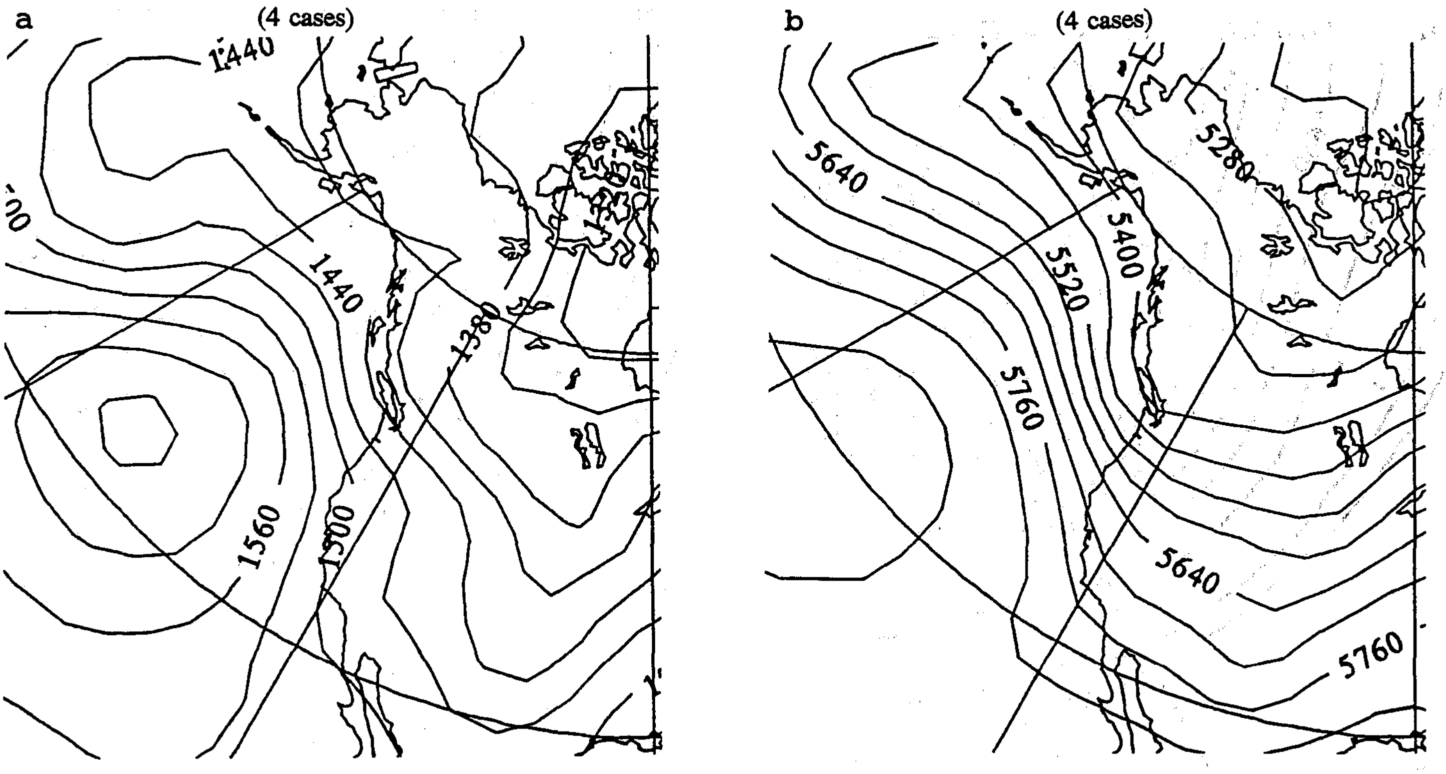


Fig 7. NW flow cases for western Washington at a) 850 mb and b) 500 mb.

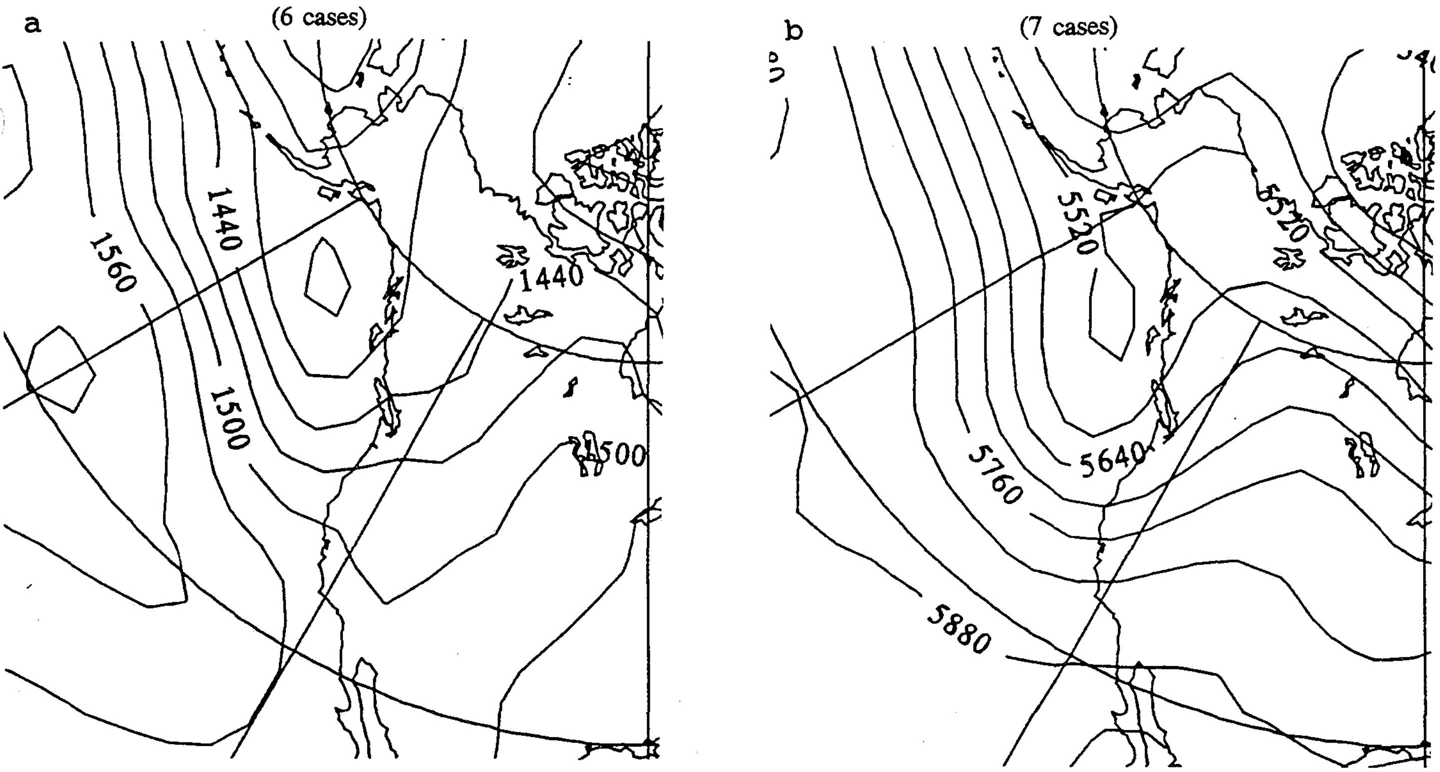


Fig 8. SW flow cases for eastern Washington at a) 850 mb and b) 500 mb.

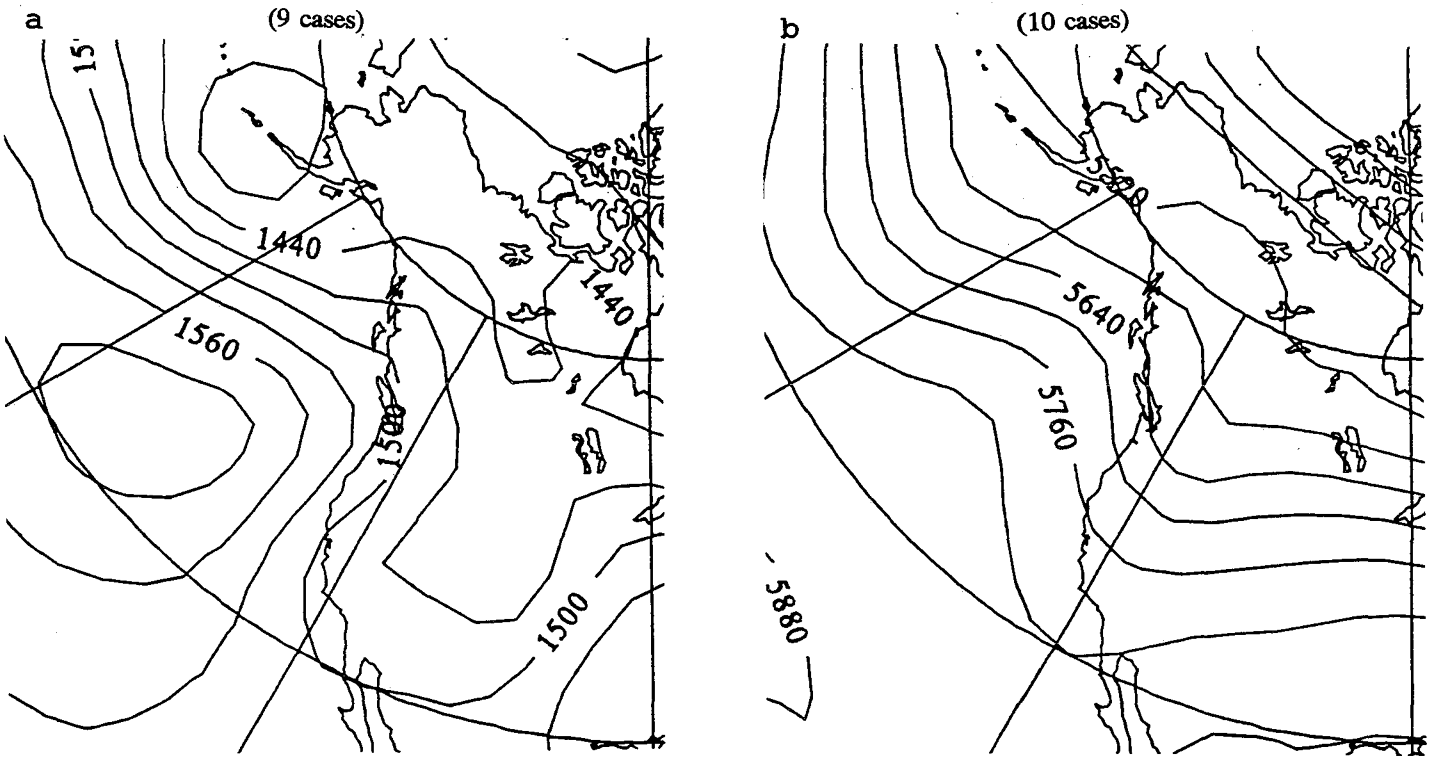


Fig 9. NW flow cases for eastern Washington at a) 850 mb and b) 500 mb.

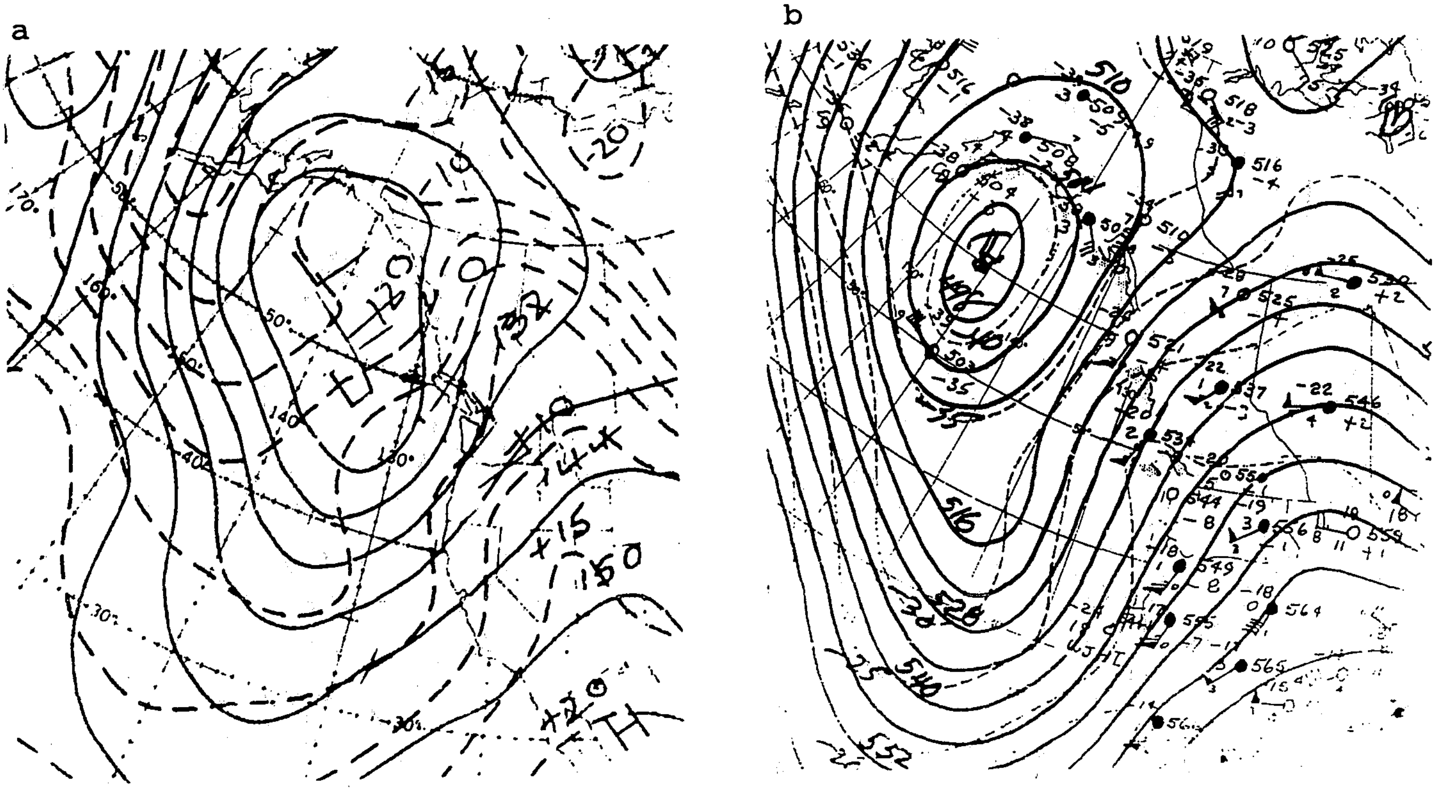


Fig. 10. Analyses of a) 850 mb and b) 500 mb heights for 1200 UTC 5 April 1972.

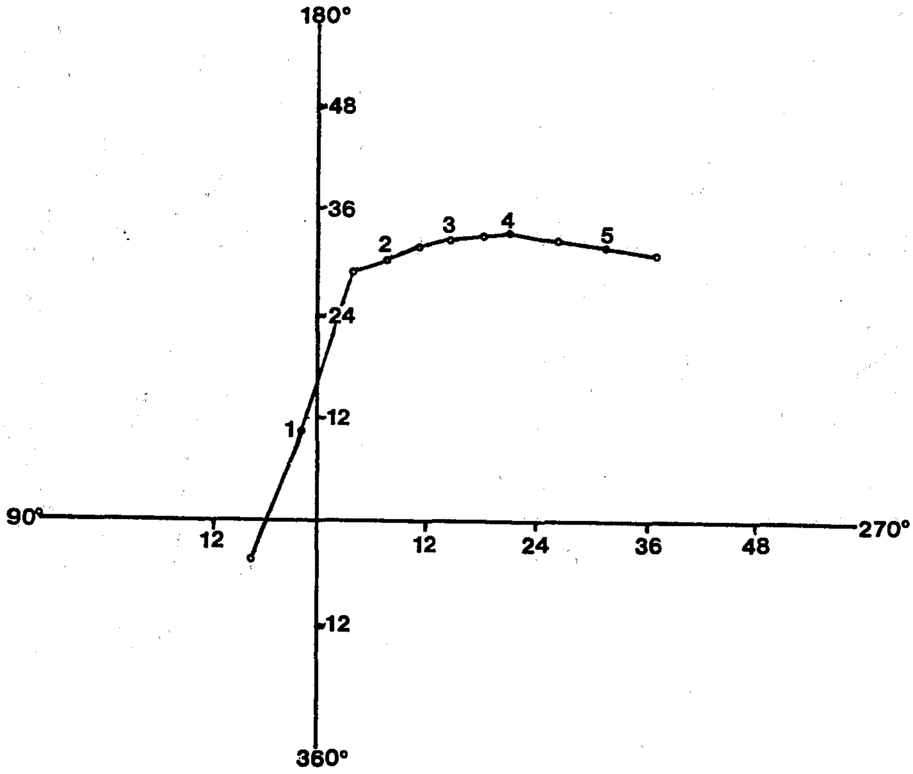


Fig. 11. Hodograph for Spokane 1200 UTC 5 April 1972 sounding (heights are labeled in km).

	Initial CAPE	Modified CAPE	SR Helicity
UIL - all cases	163	780	39
UIL - SW flow cases	104	946	53
UIL - NW flow cases	192	696	32
GEG - all cases	458	790	35
GEG - SW flow cases	616	927	62
GEG - NW flow cases	276	614	7

Table 1. Average values of CAPE and S.R. Helicity for tornadic events using soundings from Quillayute (for western Washington) and Spokane (for eastern Washington).

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