P51 **A CLIMATOLOGICAL HISTORY OF TORNADOES IN NORTHWEST OREGON AND SOUTHWEST WASHINGTON**

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1. INTRODUCTION

Compared to much of the rest of the continental United States, tornadoes are a relative rarity in the Pacific Northwest. In Southwest Washington and Northwest Oregon there is, however, an extensive enough record of tornadoes to warrant a better historical compilation of the storms than currently exists. The record adds to a better understanding of the conditions under which they occur. The focus of this study is to look at tornadoes that occurred in the National Weather Service (NWS) Portland Forecast Office's area of responsibility (AOR).

While the vast majority of these tornadoes are weak and pose a minimal threat to the local inhabitants, there are a few that have caused substantial property damage and taken several lives. An examination of the conditions under which these tornadoes formed reveals several common environmental characteristics that may help in anticipating future tornadoes.

2. A HISTORY OF TORNADOES IN NORTHWEST OREGON AND SOUTHWEST WASHINGTON

The attached table (Table 1 and 2) is a compilation of 99 known tornadoes in the Portland OAR between October 1876 and December 2015. *Storm Data* (U.S. Dept. of Commerce, 1959-1973), (NOAA, 1974-2015), augmented by the Storm Events Database (NOAA, 1950-2015) accounted for 72 tornadoes in the NWS Portland's AOR. This makes *Storm Data* the most complete, publically available compilation of tornadoes in the Pacific Northwest. All but one of the tornadoes in *Storm Data* has been rated by the National Weather Service using the Fujita Scale (Fujita 1971), or the Enhanced Fujita Scale (Marshall 2004). These are the only ones in the compilation assigned an intensity. *Storm Data* and the Storm Events Database were found to contain inconsistent information on some storms. In compiling this collection, all available sources were considered in determining the date, location and time of touchdown.

Other resources consulted for this study included local National Weather Service documents stored in the Portland office (2016, unpublished data), a previously online compilation by the former Oregon Climate Service (2007), and a compilation by retired National Weather Service employee George Miller (2010, unpublished data). Publications consulted and found to contain relevant information include *Monthly Weather Review* (U.S. War Dept. 1885), (U.S. Dept. of Agriculture 1926-1927), *Climate and Crops* (U.S. Dept. of Agriculture 1897-1904), *Climatological Data* (U.S. Dept. of Agriculture 1918-1940), (U.S. Dept. of Commerce, 1950-1953), *Report of the*

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Portland Oregon (PQR) AOR Tornadoes 1876-2015										
Month	Day	Year	Time (Initial touchdown)	Rating	State	County	(nearest or most affected) City or Landmark	(Beginning) Latitude	(Beginning) Longitude	Primary Information Sources
10	18	1876	1200 LT		OR	Clackamas	Barlow	45°15'	122°43'	N9 (10/19, 10/23)
2	3	1881	1500 LT		OR	Marion	Gervais	45°06'	122°54'	N9 (2/5), N2 (2/5)
9	15	1885	1500 LT		OR	Clatsop	Astoria	46°10'	123°55'	N2 (9/16), MWR
1	19	1887			OR	Lane	Cottage Grove	43°48'	123°04'	N9 (1/20), N4 (1/22)
7	14	1894			OR	Clackamas	Needy	45°10'	122°42'	N2 (7/17), N9 (7/18)
6	14	1897	1500 LT		OR	Tillamook	Bay City	45°31'	123°53'	CCOS
2	26	1904	1045 LT		OR	Multnomah	Portland	45°30'	122°36'	N9 (2/27, 2/28), MWR, CCOS
7	13	1907			OR	Multnomah	Portland	45°31'	122°36'	N9 (7/14)
4	10	1911	1215 LT		OR	Clackamas	Oregon City	45°21'	122°36'	N9 (4/11)
3	26	1916			OR	Clackamas	Wilsonville	45°16'	122°51'	N7 (3/31)
11	26	1918			OR	Lincoln	Newport	44°38'	124°03'	N11 (11/28), CD
11	30	1920	1400 LT		OR	Washington	Beaverton	45°30'	122°46'	N9 (12/1)
11	11	1925	1100 LT		OR	Polk/Marion	Independence/Salem	44°49'	123°12'	N5 (11/12), CD, RCWB, MWR
2	19	1926	1715 LT		OR	Yamhill	McMinnville	45°11'	123°13'	N6 (3/5), RCWB, MWR
5	4	1926	1040 LT		WA	Clark	Vancouver - Minnehaha	45°40'	122°37'	RCWB, MWR
9	27	1926	0600 LT		WA	Pacific	Chinook	46°16'	123°57'	RCWB, MWR
10	12	1934			OR	Columbia	Clatskanie			N8 (10/12)
7	25	1937			OR	Lane	Lowell	43°58'	122°37'	N5 (7/26), CD
7	25	1937			OR	Lane	Rainbow, McKenzie Bridge	44°10'	122°14'	N5 (7/26), CD
9	5	1938	1345 LT		OR	Linn	Brownsville/SE of Halsey	44°20'	123°04'	N9 (9/8)
10	1	1940	1200 LT		OR	Washington	Scholls	45°25'	122°55'	N8 (10/2)
10	4	1946			OR	Clackamas	Canby	45°17'	122°40'	N9 (10/5)
12	23	1949	1100 PST		WA	Pacific	Long Beach	46°21'	124°03'	MWR
10	2	1951	1510 PST		WA	Clark	Cherry Grove	45°47'	122°37'	N9 (10/3), CD
12	6	1951	1540 PST	F1	OR	Lane	3 SW Junction City	44°11'	123°14'	SED
1	20	1953	0800 PST		OR	Benton	Corvallis	44°34'	123°16'	N9 (1/21), CD
10	22	1954	1535 PST	F0	OR	Washington	2 E Hillsboro	45°31'	122°56'	SED
4	12	1957	1200 PST	F1	OR	Clackamas	1 E Sandy	45°24'	122°15'	SED
3	8	1960	1515 PST	F1	OR	Marion	Aumsville	44°50'	122°53'	Storm Data, SED
11	5	1962	1200 PST		OR	Lincoln	Newport	44°38'	124°03'	N10 (11/6)
11	10	1965	1455 PST	F0	OR/WA	Columbia/Cowlitz	Rainier, Longview	46°05'	122°56'	Storm Data, SED
6	23	1966	1630 PST	F0	OR	Washington	6 W Banks	45°38'	123°16'	Storm Data, SED
10	20	1966	1530 PST	F0	OR	Clatsop	Seaside	46°00'	123°55'	Storm Data, SED
3	22	1967	1740 PST		OR	Marion	Butteville (Aurora)	46°16'	122°48'	N1, George Miller
10	3	1967	1305 PST	F1	OR	Clatsop	2 SW Warrenton	46°08'	123°57'	Storm Data, SED
10	13	1968	1300 PST	F0	OR	Washington	3 S Cornelius	45°28'	123°02'	Storm Data, SED
5	25	1971	1555 PST	F0	OR	Yamhill	1.8 mi SSE McMinnville	45°11'	123°11'	Storm Data, SED
4	5	1972	1250 PST	F3	OR/WA	Multnomah/Clark	Vancouver	45°36'	122°38'	Storm Data, SED
12	13	1973	1205 PST		OR	Lincoln	Newport	44°38'	124°03'	N9 (12/14), Storm Data
8	18	1975	1500 PST	F0	OR	Lane	Eugene	44°03'	123°05'	Storm Data, SED
12	12	1975	2120 PST	F1	OR	Tillamook	Tillamook	45°27'	123°51'	Storm Data, SED
8	16	1978	1420 PST	F1	OR	Columbia	Scappoose	45°47'	122°52'	Storm Data, SED
8	20	1978	1700 PST	F0	OR	Yamhill	Amity	45°07'	123°12'	Storm Data
4	18	1984		F0	OR	Yamhill	Woodland Heights (3 S Amity)	45°05'	123°11'	Storm Data, SED
5	14	1984	1500 PST	F0	OR	Lane	3 mi S Junction City	44°10'	123°12'	Storm Data, SED
10	13	1984	1200 PST	F1	WA	Clark	1 N Woodland	45°56'	122°45'	Storm Data, SED
10	26	1984	1230 PST	F0	OR	Marion	2 NW Donald	45°14'	122°53'	Storm Data, SED
11	2	1984	1700 PST	F0	OR	Lincoln	Waldport	44°26'	124°04'	Storm Data
3	28	1985	1630 PST	F1	WA	Cowlitz	Lexington	46°11'	122°54'	Storm Data, SED

Table 1. NWS Portland AOR Tornadoes 1876-2015, part 1. CCOS=Climate and Crops Oregon Section. CD=Climate Data. MWR=Monthly Weather Review. RCWB=Report of the Chief of the Weather Bureau. SED=Storm Events Database. N1=Canby Herald. N2=Daily Astorian. N3=Daily Morning Astorian. N4=Eugene City Guard. N5=Eugene Register Guard. N6=McMinnville Telephone Register. N7=Oregon City Enterprise. N8=Oregon Journal. N9=Oregonian. N10=Statesman Journal. N11=Yaquina Bay News.

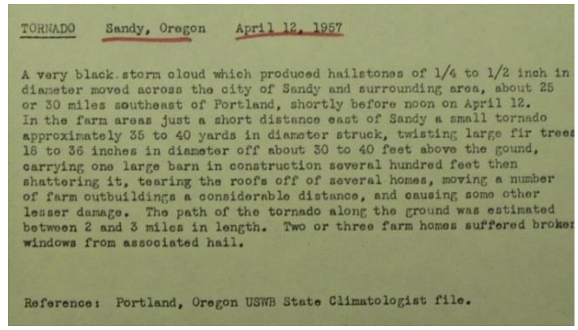
Portland Oregon (PQR) AOR Tornadoes 1876-2015										
Month	Day	Year	Time (Initial touchdown)	Rating	State	County	(nearest or most affected) City or Landmark	(Beginning) Latitude	(Beginning) Longitude	Primary Information Sources
3	28	1985	1630 PST	F1	WA	Cowlitz	Lexington	46°11'	122°54'	Storm Data, SED
6	29	1989	1730 PST	F1	WA	Clark	2 SW LaCenter	45°50'	122°42'	Storm Data, SED
11	24	1989	1630 PST	F1	OR	Lane	Eugene	44°00'	123°05'	Storm Data, SED
12	1	1990	1000 PST	F0	WA	Pacific	South Bend	46°40'	123°48'	Storm Data, SED
4	9	1991	1530 PST	F0	OR	Multnomah	Gresham	45°30'	122°26'	Storm Data, SED
6	13	1991	1100 PST	F0	WA	Pacific	Megler	46°15'	123°51'	Storm Data, SED
11	12	1991	1435 PST	F1	OR	Multnomah	1 N Troutdale	45°33'	122°24'	Storm Data, SED
11	12	1991	1500 PST	F1	OR	Washington	Tualatin	45°23'	122°47'	Storm Data, SED
11	12	1991	1600 PST	F0	OR	Marion	2 SE Silverton	44°59'	122°46'	Storm Data, SED
12	8	1993	1400 PST	F2	OR	Yamhill/Washington	1 N St. Paul	45°15'	122°57'	Storm Data, SED
2	13	1994	0834 PST	F0	OR	Clatsop	1 N Warrenton	46°11'	123°55'	Storm Data, SED
3	22	1994	1440 PST	F0	OR	Linn	Albany	44°38'	123°05'	Storm Data, SED
9	15	1996	1721 PST	F0	OR	Clatsop	3 N Gearhart	46°05'	123°56'	Storm Data, SED
10	24	1996	1400 PST	F0	OR	Lincoln	Cape Foulweather	44°46'	124°04'	Storm Data, SED
12	5	1996	1145 PST	F0	OR	Lane	Eugene	44°04'	123°07'	Storm Data, SED
5	31	1997	1010 PST	F0	OR	Marion	1 E Keizer	45°00'	122°59'	Storm Data, SED
5	31	1997	1645 PST	F0	WA	Clark	Vancouver	45°38'	122°40'	Storm Data, SED
6	1	1997	1137 PST	F0	OR	Benton	6 NW Philomath	44°38'	123°26'	Storm Data, SED
9	15	1997	1030 PST	F0	OR	Polk	5.5 N Rickreall	45°00'	123°13'	Storm Data, SED
9	15	1997	1202 PST	F0	OR	Tillamook	Garibaldi	45°35'	123°55'	Storm Data, SED
9	15	1997	1240 PST	F0	OR	Polk	4 N Rickreall	45°00'	123°13'	Storm Data, SED
9	15	1997	1840 PST	F0	WA	Clark	3 W Yacolt	45°52'	122°29'	Storm Data, SED
9	17	1997	1035 PST	F0	OR	Marion	2 SW Turner	44°49'	122°59'	Storm Data, SED
9	17	1997	1105 PST	F0	OR	Marion	3 N Aumsville	44°53'	122°53'	Storm Data, SED
9	18	1997	0815 PST	F0	OR	Tillamook	1 S Pacific City	45°11'	123°58'	Storm Data, SED
9	18	1997	0830 PST	F0	OR	Tillamook	2 S Neskowin	45°04'	123°59'	Storm Data, SED
1	5	1998	1300 PST	F0	OR	Clatsop	Seaside	46°00'	123°55'	Storm Data, SED
10	3	1998	1430 PST	F0	OR	Marion	Silverton	45°00'	122°48'	Storm Data, SED
10	3	1998	1545 PST	F0	OR	Clackamas	Canby	45°16'	122°42'	Storm Data, SED
12	2	1999	1409 PST	F0	OR	Lane	Creswell	43°55'	123°01'	Storm Data, SED
4	28	2000	1500 PST	F0	OR	Columbia	St. Helens	45°52'	122°49'	Storm Data, SED
5	11	2000	1535 PST	F0	WA	Clark	Battle Ground	45°46'	122°31'	Storm Data, SED
10	9	2000	1815 PST	F1	OR	Clackamas	2 W Molalla	45°09'	122°37'	Storm Data, SED
10	9	2000	1910 PST	F1	OR	Clackamas	3 SE Oregon City	45°19'	122°33'	Storm Data, SED
6	21	2003	0900 PST	F1	OR	Polk	Independence	44°51'	123°11'	Storm Data, SED
5	27	2004	1430 PST	F0	WA	Clark	2 NE La Center	45°52'	122°40'	Storm Data, SED
6	6	2004	1415 PST	F0	OR/WA	Columbia/Cowlitz	Rainier	46°03'	122°53'	Storm Data, SED
6	18	2004	0945 PST	F0	OR	Washington	Sherwood	45°21'	122°51'	Storm Data, SED
9	13	2004	1040 PST	F0	WA	Clark	1 W Ridgefield	45°49'	122°46'	Storm Data, SED
12	16	2006	1500 PST	F0	OR	Marion	8 NE Salem	45°01'	122°53'	Storm Data, SED
9	28	2007	1900 PST	F0	OR	Linn	3 N Lebanon	44°35'	122°54'	Storm Data, SED
1	10	2008	1215 PST	F1	WA	Clark	Vancouver	45°40'	122°45'	Storm Data, SED
6	4	2009	1445 PST	F0	OR	Linn	2 N Peoria	44°29'	123°12'	Storm Data, SED
10	26	2009	1415 PST	F0	OR	Clackamas	2 E Oregon City	45°23'	122°31'	SED
11	6	2009	2130 PST	F0	OR	Lincoln	Roads End (2.5 N Lincoln City)	45°01'	124°01'	Storm Data, SED
12	14	2010	1144 PST	F2	OR	Marion	Aumsville	44°50'	122°52'	Storm Data, SED
3	21	2013	1510 PST	EF0	WA	Clark	2 NE Hockinson	45°45'	122°27'	Storm Data, SED
6	13	2013	1533 PST	EF1	OR	Yamhill	McMinnville	45°13'	123°11'	Storm Data, SED
10	23	2014	1140 PST	EF1	WA	Cowlitz	Longview	46°08'	122°57'	Storm Data, SED
4	14	2015	1505 PST	EF0	OR	Lane	Eugene	44°01'	123°02'	Storm Data, SED
12	10	2015	1115 PST	EF1	WA	Clark	Battle Ground	45°45'	122°34'	Storm Data, SED

Table 2. NWS Portland AOR Tornadoes 1876-2015, part 2. CCOS=Climate and Crops Oregon Section. CD=Climate Data. MWR=Monthly Weather Review. RCWB=Report of the Chief of the Weather Bureau. SED=Storm Events Database. N1=Canby Herald. N2=Daily Astorian. N3=Daily Morning Astorian. N4=Eugene City Guard. N5=Eugene Register Guard. N6=McMinnville Telephone Register. N7=Oregon City Enterprise. N8=Oregon Journal. N9=Oregonian. N10=Statesman Journal. N11=Yaquina Bay News.

Chief of the Weather Bureau (U.S. Dept. of Agriculture 1925-1926), as well as various newspaper accounts. Only tornadoes with documentation found in either formal publications or contemporary accounts were included.

In one instance the *Storm Data* published date of a tornado required correction. *Storm Data* originally reported this tornado as having occurred on 20 August 1978 in Scappoose WA. Articles appearing in the Oregonian on 18 August and 19 August indicated the correct date of the tornado is 16 August. The incorrectly attributed date calls into question another tornado reported on the 20th, in Amity Oregon. No news articles or other original documentation were found for this storm however, so its' recorded date remains 20 August.

The best estimate of latitude and longitude, to the nearest minute, for each touchdown is included. While generally the *Storm Data* location (NOAA 2016) was used when possible, there were a number of tornadoes whose latitude and/or longitude required correction. The corrections were based upon descriptions provided in either Storm Data or other supporting documents. As an example, the Clackamas County Oregon tornado of April 12, 1957 was reported to have touched down near 45.38N, 122.27W. The original description of the storm (Fig. 1) reads "In the farm areas just a short distance east of Sandy a small tornado approximately 35 to 40 yards in diameter struck…" Instead of showing the tornado east of Sandy, the map provided online by the Storm Events Database (Fig. 2) using the published latitude and longitude, incorrectly plots the touchdown location just south of Sandy. In all, 30 corrections to the Storm Data latitude/longitude defined locations are offered.



TORNADO Sandy, Oregon April 12, 1957

A very black storm cloud which produced hailstones of 1/4 to 1/2 inch in diameter moved across the city of Sandy and surrounding area, about 25 or 30 miles southeast of Portland, shortly before noon on April 12. In the farm areas just a short distance east of Sandy a small tornado approximately 35 to 40 yards in diameter struck, twisting large fir trees 18 to 36 inches in diameter off about 30 to 40 feet above the gound, carrying one large barn in construction several hundred feet then shattering it, tearing the roofs off of several homes, moving a number of farm outbuildings a considerable distance, and causing some other lesser damage. The path of the tornado along the ground was estimated between 2 and 3 miles in length. Two or three farm homes suffered broken windows from associated hail.

Reference: Portland, Oregon USWB State Climatologist file.

Fig 1. Oregon State Climatologist report of the Sandy Oregon tornado of 12 April 1957. NWS Portland unpublished records.

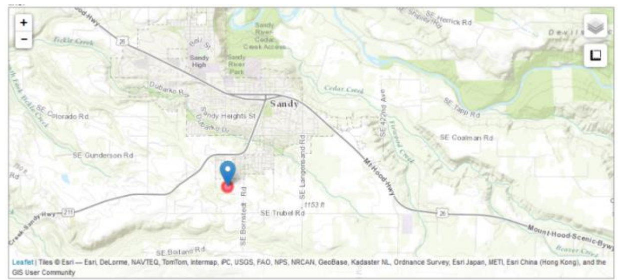


Fig 2. Storm Events Database map showing incorrectly located tornado touchdown location for the Sandy Oregon tornado of 12 April 1957.

Evidence for another five tornadoes between 1951 and 1973 was uncovered. Supporting documentation for these tornadoes included newspaper accounts in the Oregonian and the Statesman Journal, as well as the *Climatological Data* publications for Oregon and Washington. George Miller (2010, unpublished data) brought attention to a tornado near Butteville Oregon on 22 March 1967 (*Canby Herald).* The article speculates on a connection between the tornado and an automobile fatality that occurred approximately 10 minutes prior along the interstate highway about 5.5 km to the south of the known damage path. While it is a possibility that the tornado played some role in the young woman's death, a lack of any eyewitness reports or other direct evidence that the tornado touched down any closer to the accident scene makes it impossible to say with any certainty that the fatality was directly caused by a tornado.

Prior to 1950, United States Weather Bureau annual publications *Report of the Chief of the Weather Bureau* from 1916 to 1934, and *United States Meteorological Yearbook* from 1935 to 1942 included the Weather Bureau's annual compilation of tornado reports nationwide (U.S. Dept. of Commerce, 1942). The lists for the area of interest in southwest Washington and northwest Oregon during this time period however, were quite short with just four tornadoes reported. All four of these reports were made in 1925 to 1926.

Monthly Weather Review also regularly published reports of tornadoes nationwide prior to 1950. Research uncovered two additional tornadoes recorded in this publication, one occurring in Astoria Oregon in 1885 (U.S. War Dept., 1885), the other in Long Beach Washington in 1949 (U.S. Dept. of Commerce, 1949). The government publication *Climate and Crops* contained information on one additional tornado on 14 June 1897, in Bay City Oregon (U.S. Dept. of Agriculture, 1897-1904).

The remaining 12 tornadoes listed are documented solely with newspaper accounts. In recent years, online newspaper search engines have greatly streamlined the process of searching newspaper archives for information. Those consulted in this study included webpages hosted by the University of Oregon Libraries (2015), the University of Washington Libraries (2016), the Washington State Library (2016), Google (2016), the Multnomah County Library (2016), and the Library of Congress (2016).

Documentation for 23 tornadoes was uncovered prior to 1950. Contemporary newspaper accounts verified 19 of these storms. Government and professional publications listed above were used to verify the other four tornadoes. The earliest report of a tornado in the NWS Portland's AOR was on 18 October 1876, in Barlow Oregon (*Oregonian*). Early reports of tornadoes over Southwest Washington were much scarcer. The earliest reliable report of a tornado in Southwest Washington didn't occur until 4 May 1926 (U.S. Dept. of Agriculture, 1925-1926b).

While outside the primary area of interest of this study, reports of a couple of other forgotten but notable tornadoes in present-day Washington were brought to light. The earliest report of a tornado in the Washington Territory came from a news article (*Vancouver Register*), regarding a July 8th 1867 tornado that struck Cowlitz Landing in Lewis County. The town in the article is referred to as Cowlitz, but no such present-day town exists in the area. It is assumed that the name refers to a settlement near the historic Cowlitz Landing, about a mile downstream of Toledo on the Cowlitz River, near 46°28' North latitude, and 122°52' West longitude (Laseke, 1988), (American Road Magazine, 2008).

The earliest report of a tornado fatality in the state of Washington came around midnight on 22 February 1904. The initial report of the tornado and two victims who are known to have ultimately died, were made in the *Morning Oregonian* of 24 February 1904 (*Oregonian*). The victims, David and Mary Kerr (*Port Townsend Leader*), were guests at a local hotel. A third individual was said to be "badly injured and it is doubtful whether he will live." Unfortunately, no follow-up information confirmed whether his injuries were ultimately fatal or not. The tornado struck what was referred to as “the Agency” on the Quinault Reservation, which a year later was named the town of Taholah. With the damage reports concentrated on 1st Avenue, the location of the tornado touchdown can be determined to be near 47°22' North latitude, and 124°17' West longitude.

Only one of the tornadoes in the NWS Portland AOR is known to have caused any fatalities, an F3 that struck Vancouver Washington on 5 April, 1972 (U.S. Dept. of Commerce, 1959-1973). Six people were killed during the event, making it the deadliest tornado in Pacific Northwest history. The Vancouver tornado of 1972 is also the strongest tornado on record for the NWS Portland AOR, and the only known F3.

A significant majority of the tornadoes that were rated on the Fujita (Fujita, T.T., 1971) or Enhanced Fujita (Marshall 2004) scale were weak, classified as F0 or EF0. Forty-nine of the 71 (69%) classified tornadoes were rated as F0 or EF0. Nineteen (27%) were rated as F1 or EF1, two (3%) as F2 or EF2, and one (1%) as F3 or EF3.

3. CLIMATOLOGY OF THE TORNADO DATABASE

3.1 Geographic Distribution

The geographic distribution of tornadoes in Northwest Oregon and Southwest Washington (Fig. 3) favors two regions. The first is the main north-south oriented inland valley encompassing the Willamette Valley and the Lower Columbia between Portland Oregon and Kelso Washington. The second area is the coast.

When compared with the population centers per the 2010 U.S. census (Fig. 4), it is seen that the tornadoes show a strong tendency to be reported in and around urban centers. Using 2000 census data, 48 percent of the tornadoes occurred in an urban area (U.S. Census Bureau, 2016), and 77 percent occurred within three miles of an urban area.

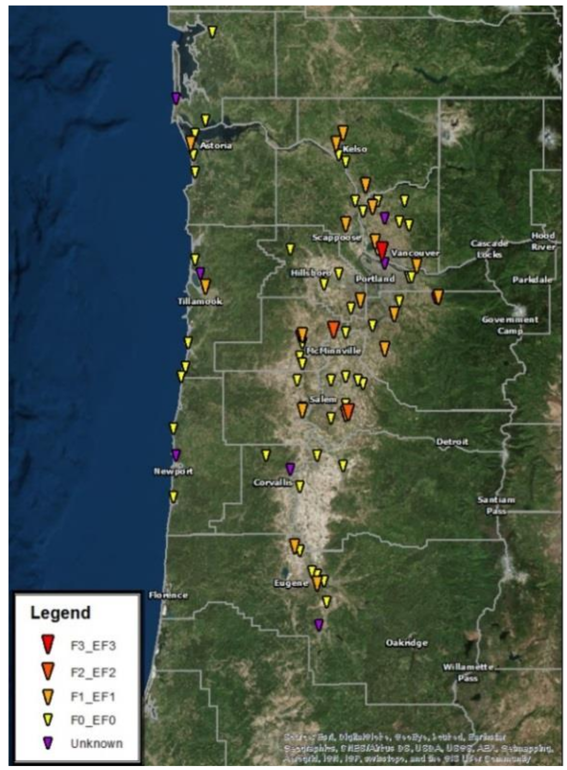


Fig. 3. Plot of all known tornado touchdown locations in the NWS Portland AOR of Southwest Washington and Northwest Oregon between 1876 and 2015.

Fig. 4. Census places designations using the 2010 census. Courtesy USDA Economic Research Service.

While population density likely plays a role on where tornadoes are reported in Northwest Oregon and Southwest Washington, the terrain itself likely plays a major role. The north to south orientation of the primary mountain ranges and valleys can enhance low level helicity. This is especially common at times when the free air wind has a westerly component, and the surface winds are backed by terrain to a more favored southerly direction. A wind rose (Fig. 5) for Salem Oregon, located in the Central Willamette Valley, illustrates just how constricted the prevailing winds can be in the Willamette Valley.

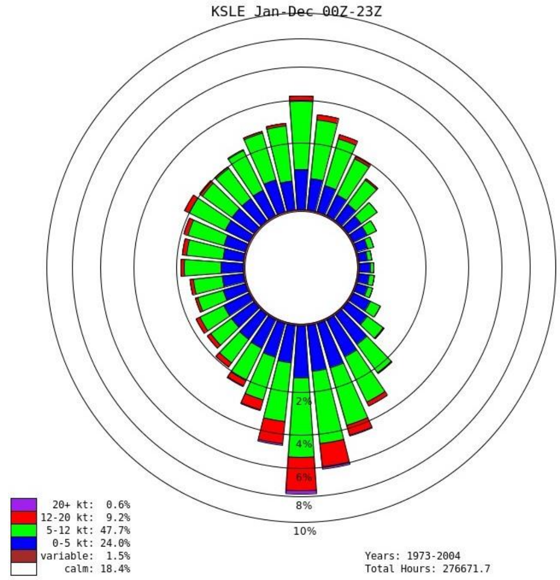


Fig. 5. Wind rose for Salem Oregon airport (KSLE) 1973 to 2004.

3.2 Temporal Distributions

The times of initial touchdown have been reported whenever there was sufficient information to make a reasonable estimate. At first glance it would seem that the time of occurrence would be a straightforward piece of information. However, rarely in the historic accounts when the time is reported, does the account mention the time zone and whether or not daylight saving time is in effect. The history of standard time in time zones, and the use of daylight saving time is complex. Not until 1966 was there any permanent measure of standardization provided nationally, for when daylight saving time would be implemented (U.S. Naval Observatory, 2015). Additionally, Storm Data in its original publication was intended to be reported in local standard time. The Storm Events Database defaults to Central Standard Time (CST). There were several occasions where inconsistencies in time were noted between the two Storm Data listings, as well as occasions where newspaper accounts suggested that the time listed was more likely given in daylight saving time, but not noted as such. With deference generally given to the more organic reports, all storms since 1949 were assigned a time in Pacific Standard Time (PST) with the exception of one, where there was insufficient information available. For storms prior to 1949, the time of occurrence when available was assumed to be in whatever local time (LT) was in use at the time. For a majority of these tornadoes, PST was likely in effect, but could not be determined with any measure of certainty.

A plot of all tornadoes by the local hour of the day (Fig. 6) shows a distinctly diurnal distribution. The most likely time of day is in the afternoon, with the peak hour from 3 pm to 4 pm PST. Only one tornado, occurring on the Oregon coast in December, was noted to occur after dark.

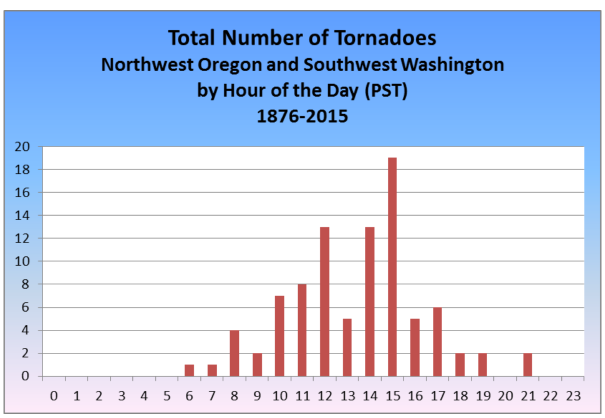


Fig. 6. Total number of reported tornadoes in Southwest Washington and Northwest Oregon by the hours of the day between 1876 and 2015.

Tornadoes in Northwest Oregon and Southwest Washington have occurred in all months of the year. A bimodal distribution is apparent (Fig. 7), with a distinct peak in activity occurring during fall. A secondary peak occurs in the spring.

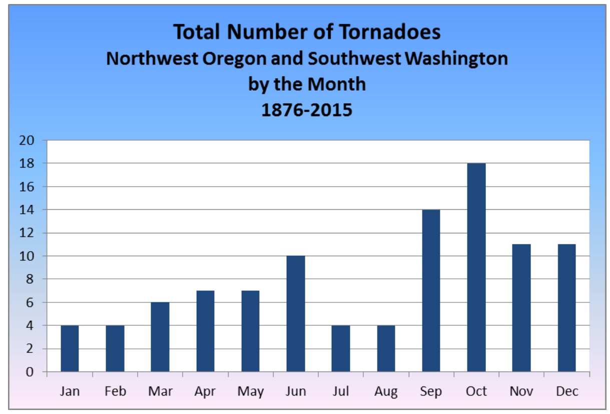


Fig. 7. Total number of reported tornadoes in Southwest Washington and Northwest Oregon by the month between 1876 and 2015.

A general increase in the total number of tornado reports is evident when tornadoes are totaled by decade (Fig. 8). Much of the increase in reported tornado frequency can be accounted for by the increase in population (National Centers for Environmental Information,2016). A graph showing the growth of Oregon since 1870 (Fig. 9) , used as a proxy for the region's population growth, provides some comparison on the rate of population growth to compare with the increase in tornadoes reported.

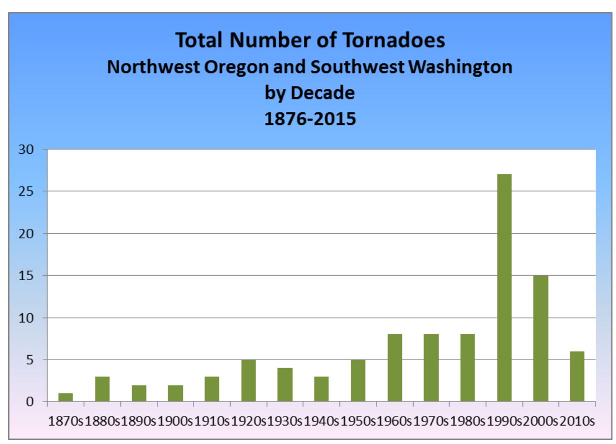


Fig. 8. Total number of reported tornadoes in Southwest Washington and Northwest Oregon by the decade from 1876 to 2015.

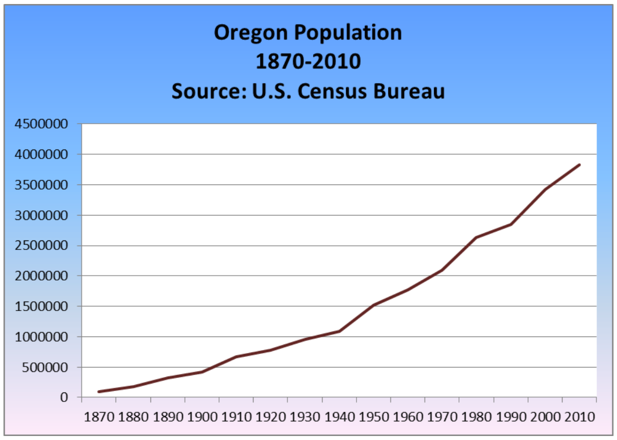


Fig. 9. Oregon population between 1870 and 2010. Source U.S. Census Bureau.

Several other developments over time lend themselves to an increased count in tornadoes; many of them related to population growth. These include increasing saturation in media coverage, the advent of social media, the development of weather radar and the development and refinement of post-storm surveys.

4. F1/EF1 and Stronger Tornadoes

4.1 Temporal Distributions

Twenty tornadoes, all occurring since 1960, have been rated F1/EF1 or higher. Touchdowns plotted by the hour of the day (Fig. 10) show a diurnal distribution, similar to the distribution for all tornadoes, except that the stronger tornadoes show an overall tendency to occur a little earlier in the day. Peak hours occurred between 12 pm and 1pm PST, and 3 pm to 4 pm PST.

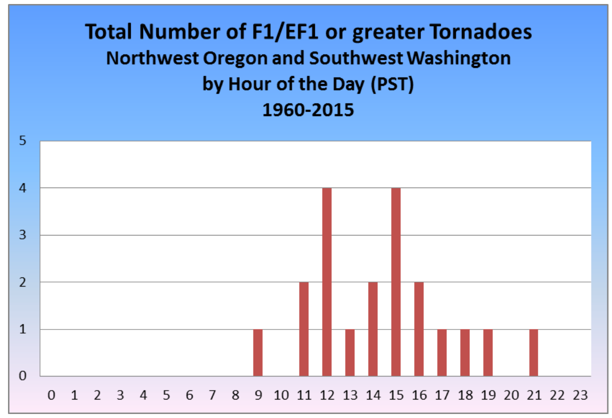


Fig. 10 Total number of reported F1/EF1 or greater tornadoes in Southwest Washington and Northwest Oregon by the hour of the day between 1960 and 2015.

The distribution of F1/EF1 tornadoes through the year, due to the small sample size, is less definitive (Fig 11). While not exclusively so, there is a propensity for the stronger tornadoes to occur in the late fall and early winter.

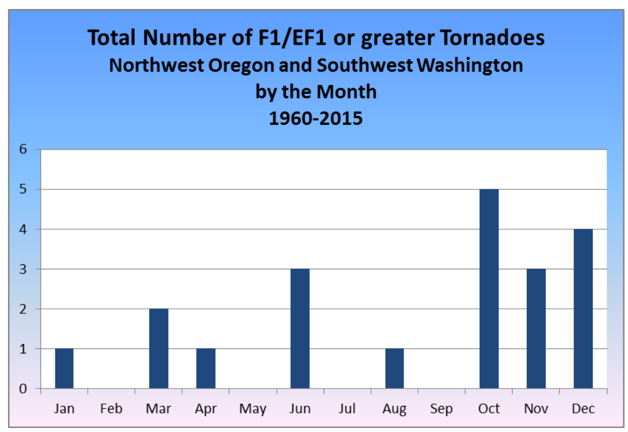


Fig. 11. Total number of reported F1/EF1 or greater tornadoes in Southwest Washington and Northwest Oregon by the month between 1960 and 2015.

4.2 Synoptic Patterns

In looking at the winds aloft, there was a significant amount of variation in the flow at both 300 mb and 700 mb. At both levels though, a composite mean for all F1/EF1 and stronger tornadoes (Fig. 12 and Fig. 13) shows an open trough just off the coast. The 300 mb composite shows a jet core located at the base of the trough with average wind speed in excess of 36 m s^{-1}. In each of the F1/EF1 and stronger cases the tornado occurred either under the core of a 300 mb jet, or to the left of a jet axis. The average distance to the left of the jet axis was 275 km, with a maximum value of 900 km. In eighteen of the twenty cases (90%) the tornado occurred with 500 km of the jet axis.

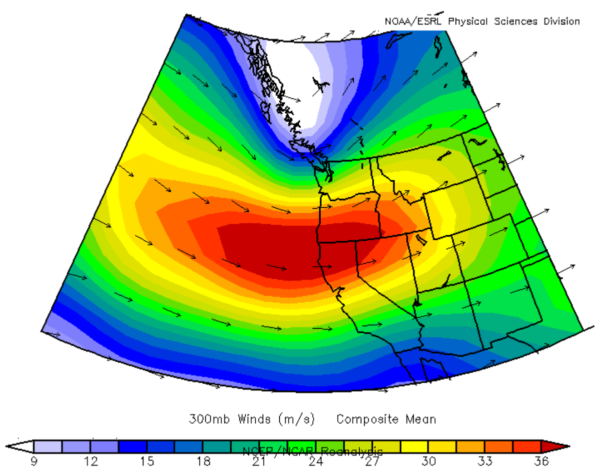


Fig. 12. North American Reanalysis Data Composite for 300 mb wind speed (color fill) and direction (arrows) for the twenty F1/EF1 and greater events.

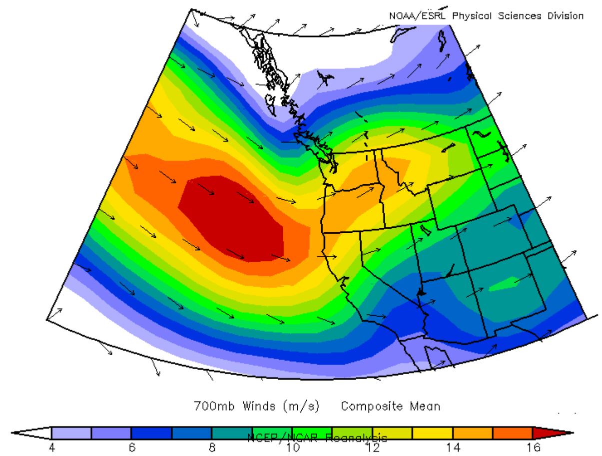


Fig. 13. North American Reanalysis Data Composite for 700 mb wind speed (color fill) and direction (arrows) for the twenty F1/EF1 and greater events.

The composite mean surface pressure pattern for all the F1/EF1 and above cases (Fig. 14) was not dissimilar from the upper air. A north-south oriented trough extended down off the Washington and Oregon coast. Such an orientation maximizes the surface pressure gradients both along the coast, as well as up the lower Columbia and Willamette Valleys between Kelso Washington and Eugene Oregon. Of the 19 F1/EF1 tornado events where a wind was recorded by the Salem (KSLE) sounding at the surface, 16 occurred with a south wind that ranged from 160 degrees to 230 degrees. Backing of near-surface winds, forced by terrain features to a southerly direction, increases low-level shear.

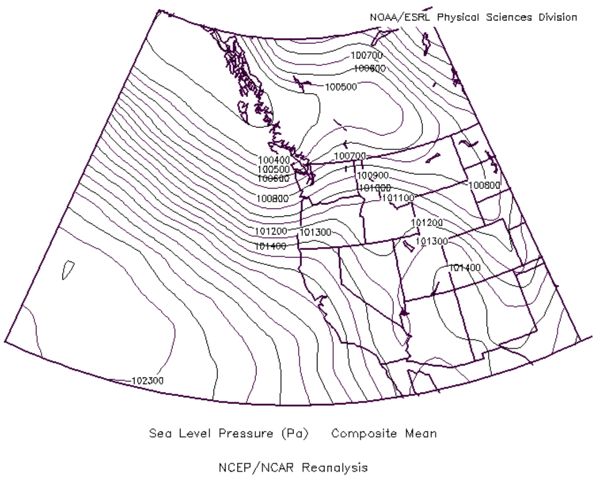


Fig. 14. North American Reanalysis Data Composite for Sea Level Pressure) for the twenty F1/EF1 and greater events.

4.3 Salem Upper Air Soundings

Salem upper air soundings (KSLE), representing the nearest observed upper air information available, were examined for each of the F1/EF1 or greater events. The most representative measurements were selected subjectively from the two soundings closest in time to the event. For some events, 00 UTC soundings were used, for others, 12 UTC soundings. This can result at times in un-even comparisons between events.

The mean KSLE thermal profile for F1/EF1 and greater tornadoes below 500 mb (Fig. 15) indicates on average, just a marginally unstable air mass mainly below 700 mb. Surface pressures for these soundings ranged from 992 mb to 1015 mb, with a mean value of 1003 mb. It is notable that the three lowest surface pressures were associated with the three strongest tornadoes, two F2/EF2s and the one F3. These ranged from 992 mb to 996 mb.

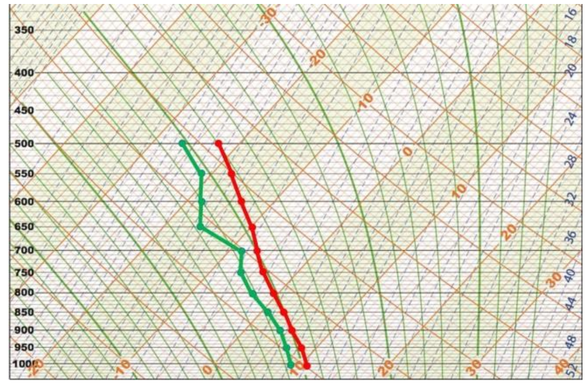


Fig. 15. Mean observed KSLE thermal sounding to 500 mb for the F1/EF1 and greater events.

Mean surface temperatures for the soundings ranged from 1.8^{O} Celsius (C) to 15.6^{O} C, for an average of 10.4^{O} C. Interestingly, when the 00 UTC soundings were separated from the 12 UTC soundings, the mean temperatures varied by just over 1^{O} C, with the 12 UTC soundings averaging 11.1^{O} C, and the 00 UTC soundings averaging 10.0^{O} C. Surface dew points averaged 8.6^{O} C, ranging from a minimum of -0.4^{O} C to a maximum of 13.9^{O} C.

Buoyancy values in the soundings were generally quite modest. Measured values of Convective Available Potential Energy (CAPE) at KSLE averaged 82 J kg^{-1} for all of the F1/EF1 and greater tornadoes. When just the F2/EF2 and F3 tornadoes are considered, the mean value increases to 107 J kg^{-1}. Even the largest measured value for the twenty events was just 216 J kg^{-1}.

Equilibrium levels similarly suggest small storms spawned most of these tornadoes. The mean Equilibrium Level (EL) was 690 mb. For just the F2/EF2 and F3's the mean EL is even lower, at 736 mb. While the lower EL of the stronger tornadoes may at first seem an oddity, when coupled with the higher CAPE values it suggests on average a more vigorous potential updraft than the F1/EF1s, albeit through a shallower layer.

Lazarus and Droegemeier (1990) found that limited thermodynamics could be overcome in a strongly sheared environment, as appears to be the case in many of these F1/EF1 and above tornadoes. The maximum measured 0-3 km helicity values in the SLE soundings for all F1/EF1 and stronger tornado occurrences averaged 252 $m^2 s^{-2}$. When just the F2/EF2 and greater tornadoes were considered, the values jump to 383 $m^2 s^{-2}$. These numbers compare favorably with values found for F2 and F3 tornadoes by Daviess and Johns [1993]. Mean surface winds for the most representative KSLE soundings for the F1/EF1 and greater cases was 8 kt, for F2/EF2 and greater cases was 11 kt. Aloft at 850 mb, mean speeds were 31 kt and 43 kt respectively while at 700 mb mean speeds were 38 kt and 59 kt respectively.

5. AUMSVILLE AND VANCOUVER TORNADOES

Whether it be a coincidence or somehow related to terrain is unknown, but it is notable that of the twenty F1/EF1 or greater tornadoes that have been recorded, two of them have each occurred in the cities of Aumsville Oregon and Vancouver Washington. A side by side comparison of the observed KSLE soundings for the Aumsville tornadoes (Fig. 16) shows as close to what might considered identical conditions as is reasonably possible to expect from two separate soundings; little apparent CAPE in a shallow, marginally unstable air mass, with southerly surface winds quickly increasing to a strong west-southwest flow above 850 mb.

The KSLE soundings for the Vancouver tornadoes (Fig. 17) show many similarities as well. The F3 tornado of 5 April 1972 lacked the more distinct directional low level shear of the 10 January 2008 case, as well as the Aumsville tornadoes. Strong low level speed shear though accounted for the helicity value of 428.

Research into Pacific Northwest tornadoes has been scarce. Hales (Hales, J.E., 1994), in researching the 5 April 1972 Vancouver tornado, concluded that high helicity was a prerequisite for West Coast tornadoes as a result of marginal thermodynamic potential due to the lack of an adjacent warm water body. Hales also found that topographical influences played a critical role in the development of the tornado, due to backing boundary layer winds influenced by the Columbia River Gorge just to the east of Vancouver. Similarly, Elson et al (2008) found the local topography, in the case of the 10 January 2008 Vancouver tornado, helped to both enhance the shear profile and to intensify existing storm circulation through channeled low level flow.

6. SUMMARY

Government records including *Storm Data*, have been augmented with newspaper accounts, to compile a list of 99 tornadoes in northwest Oregon and southwest Washington during the 140 year period from 1876 to 2015. While the majority of these tornadoes were weak, rated as a F0 or EF0, 20 tornadoes since 1960 were classified as F1/EF1 or stronger. Stronger tornadoes, rated F2/EF2 to F3 were quite rare, accounting for just three tornadoes. The only F3 tornado, in Vancouver WA in 1972, has been the only tornado to produce fatalities in the 140 years of records for the NWS Portland AOR.

Tornadoes in the region exhibit a strong tendency to occur during daylight hours. Tornadoes have occurred in all months throughout the year, but a distinct peak in activity occurs during the fall, with October recording the most tornado touchdowns. Topography likely plays a significant role in where tornadoes tend to occur. Geographically, the Willamette Valley and the Lower Columbia Valley between Portland OR and Kelso WA appear to be the most prone to tornadoes, with a secondary preference for tornadoes along the coast.

An analysis of F1/EF1 and stronger tornadoes revealed a strong tendency for the tornadoes to occur under a strong upper level trough, in an area along or within 500 km west of a 300 mb jet axis. KSLE upper air soundings almost exclusively indicated a strongly sheared vertical wind profile, with weak buoyancy over a relatively shallow layer.

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