The Spatial Location and Temporal Frequency of Storm Fronts Along The Pacific Coast Between 35 and 55 Degrees North Latitude during the Period 1973-1994

by

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Introduction

The purpose of this paper is to provide a regional perspective of winter storm activity on the Pacific Northwest coastline from 1973 to 1994. This paper will further existing research on winter storm climates by examining the spatial and temporal connectivity of extreme climate forcing events. This information can be used to better understand the relatedness of coastal erosion to seasonal and larger magnitude interannual climatic forcing episodes.

Increasing population densities combined with occasionally severe erosion have led to a series of studies on sediment movement along the Oregon and Washington coastlines (Komar, et al 1976, Komar 1986, Jackson and Rosenfeld 1987, Zhang 1991, Assail 1992, Booth 1992). Each of the studies have added further information to a growing body of knowledge. The dominance of the winter months on sediment movement in Oregon was established by Komar (Komar Et. al 1976). They found that increased wave heights and energy in November and December moved beach sand offshore (Komar Et. al 1976, p.106-107). The offshore sand movement allows wave energy to travel farther up the beach without being dissipated, leading to higher sea-cliff and property erosion from mid December to February (Komar Et. al 1976, p.107, 110).

The pace of research increased during and after the strong 1982-1983 El-Nino Southern Oscillation (ENSO) event.

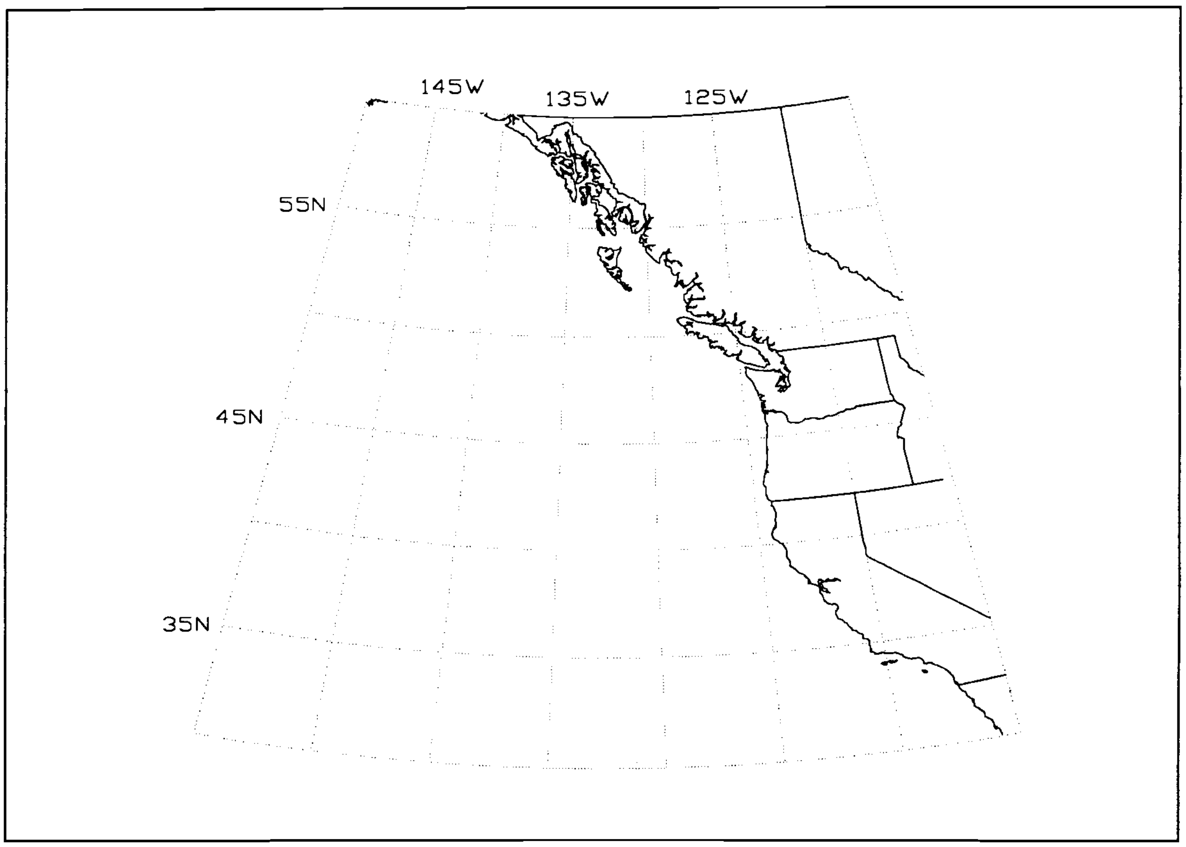
During this ENSO event, Komar detailed Erosional differences within different portions of a littoral cell. In particular, erosion was most severe along the southern portion of littoral cells while areas in the northern portion of littoral cells saw mild erosion, or in some cases, beach build up (Komar 1986, p.6). The northward sand movement during the 1982-1983 ENSO event led to severe erosion along the seaward side of Alsea Spit Waldport, Oregon (Komar 1986). In September of 1985, erosion again began on Alsea Spit (Komar 1986). The erosion appeared to be caused by the exposure of the tip of Alsea Spit to almost direct wave attack (Jackson and Rosenfeld 1987, p.57). This erosion created a wide, but shallow inlet in an area which formally had a deep, narrow inlet (Jackson and Rosenfeld 1987, p. 57). This led to erosion on portions of the coastline which had formerly been protected by the spit. The upswing in erosion was followed by a return of the inlet to its original condition (Jackson and Rosenfeld 1987, p. 58).

The lack of significant climatic forcing events at the time of the erosion lead Dr. Philip Jackson to facilitate a series of graduate research papers on climatic forcing events along the Oregon and Washington coastlines. (Zhang 1991, Assail 1992, Booth 1992). Each of the papers has addressed a particular aspect of how climatic forcing is related to erosion and sediment transport. Zhang looked at the winter weather patterns for three stations along the

Oregon Coast over a ten year period (Zhang 1991). Assail compared Zhang's weather data with significant wave events as recorded in Newport, Oregon (Assail 1992). Finally Booth analyzed the winter wave climates at Bandon, Oregon and Gray's Harbor, Washington and spatially and temporally compared them with weather data gathered at Astoria and Newport, Oregon (Booth 1992).

Study Area

The study area was made up of the Continental and Oceanic regions between 55 and 35 degrees north latitude and 120 to 150 degrees west longitude (map 1).



Map 1: Study Area

Research Questions:

1) What are the characteristics of storm location and frequency that distinguish interannual forcing events, (ENSO periods) for the northwest Pacific Coast?

2) Are there differences in the spatial and temporal characteristics of storm events, (location and frequency), between interannual forcing periods and annual average periods?

3) Are there specific month to month storm variations that influence winter period climatic forcing?

4) What patterns of forcing emerge from periods of consecutive storm days? Are these patterns most characteristic of ENSO periods?

Methodology

Data Acquisition

The main dataset used in the completion of this project was the Daily Weather maps weekly series produced by the National Oceanic and Atmospheric Administration (NOAA). Winter maps (winter being defined as the months of November, December, January and February) were used to determine the location of storm fronts within the study area. In each case, the source map information corresponded to conditions at 7:00 AM Pacific time. In order to map storm fronts, a general basemap was prepared using the microcam software program. The world basemap, an Azimuth Equal Area projection, was loaded into autocad where the break and erase commands were used to eliminate all unnecessary portions of the map. All significant winter storm fronts from January 1973 until February 1994 were then mapped. The beginning and ending years of the study corresponded to the availability of the necessary weather maps.

Significant Storms

Previous research has suggested that coastal erosion has more to do with specific high intensity forcing events rather than day to day weather activity (Peterson et al 1990, Booth 1992). This observation was used in order help limit the number of storm days examined. Significant storms are defined as cyclonic disturbances with atmospheric pressure less than 1000 Mb. This designation was chosen as a threshold value because it represents days with weather station observations of intense winter storm activity on the Oregon Coast. During the research time period, 750 out of the possible 2584 winter days (approximately 30 percent) had at least one storm that made the threshold. Since the number of storms per day were not limited, some days included more than one frontal event.

Basemap Preparation

Once the pressure threshold was established, a regional basemap was prepared for use with each division of the dataset. The original basemap generalized 15 degrees between latitude and longitude lines. Using intermediate distance markers, the study area was divided into a grid of 5 degrees latitude and 5 degrees longitude. To facilitate comparison and preserve map readability, each winter season was portrayed by eight separate maps. The semi-monthly divisions were used for each year of the study with the exception of leap years. In leap years an extra day was assigned to the first February map.

Mapping Procedure

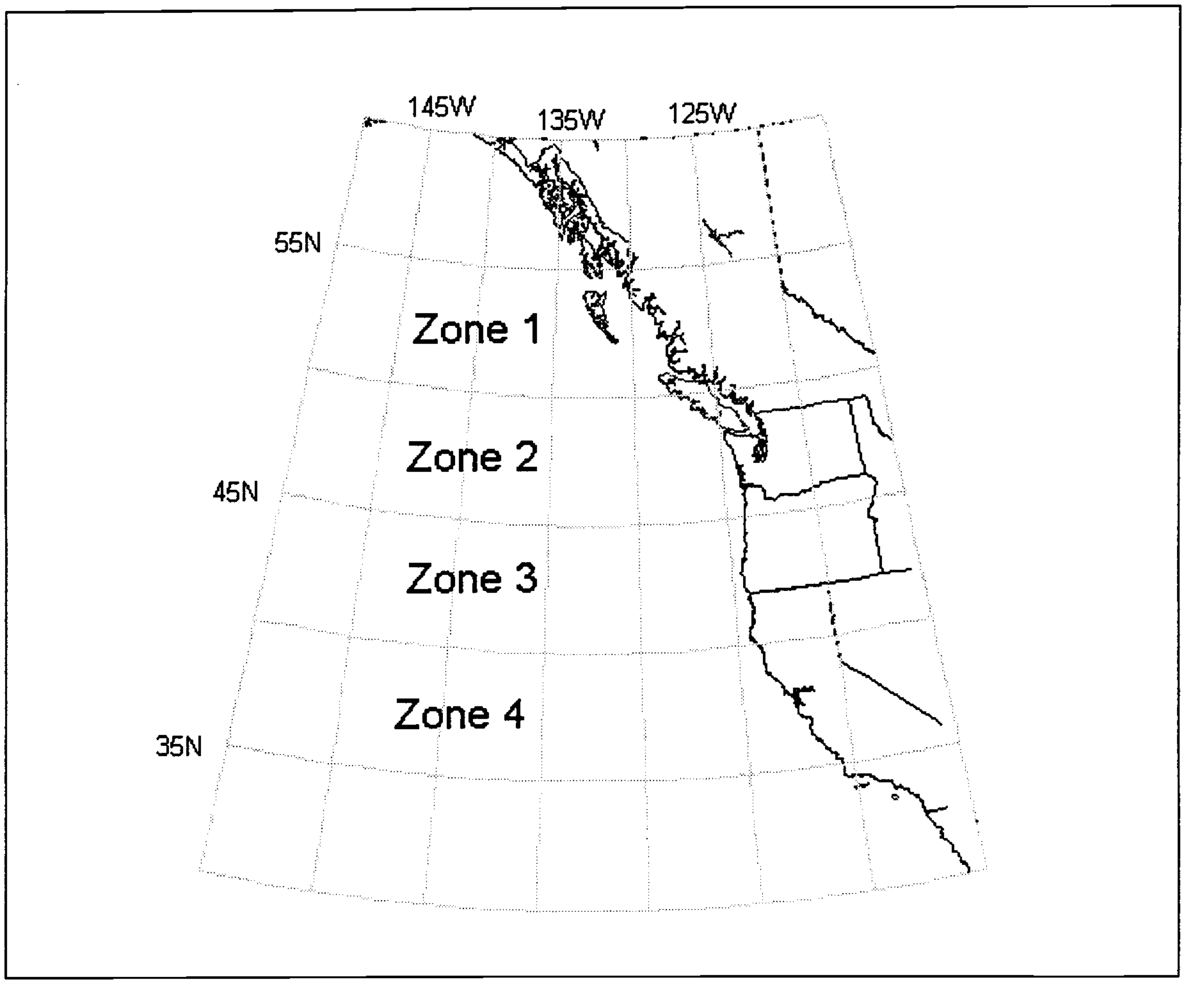
Cyclonic storms which met the necessary pressure threshold were mapped by matching several points on the frontal zones with corresponding points on the basemap. The line created by joining these points closely approximates the shape of the front. The scale and projection difference of the basemap allowed the addition of information gathered from more than one map(NOAA includes three separate weather maps for each day in its weekly weather map series). Although the storm end points are correct using the line approximation method, portions of the front may be off by upwards of 5 degrees of longitude and 1 degree of latitude, due to the specific curvature of the Azimuth Equal Area map projection. Most of the potential longitudinal error is isolated in the areas between 50 and 55 degrees latitude.

Data Manipulation

A number of different methods of data manipulation were undertaken in order to complete the research. The first step undertaken after the completion of mapping the storms was the determination of calendar year storm frequency. The total number of storms recorded each year were summed and placed in an Excel spread sheet. The spread sheet was then graphed using Excel in order to determine storm frequency by year. The same process was repeated in order to determine the storm frequency by winter season (November to February). Once the general yearly storm patterns were determined, the number of storms occuring in each month of the study were calculated. The data was entered into a spread sheet where the storm total for each of the four winter months was graphed against itself over the entire study period. The four resulting graphs contain comparisons of the monthly storm total over the entire study period.

Zone Creation

The next step in the study was to review each storm in order to determine the geographic area of occurrence. The study area was separated into four distinct zones each based on 5 degrees of latitude (map 2). Each of the zones contained 30 degrees of longitude (120-150 degrees west). Zones were numbered from north to south beginning at 55 degrees north latitude and running to 35 degrees north latitude. (Zone 1; from 55 to 50; zone 2 from 50 to 45; zone 3 from 45 to 40; and zone 4 from 40 to 35 degrees north latitude). Upon completion of the zone designations, each storm was recorded by its date, main zone tracks, total zones covered and travel direction. Main zone refers to any zone or zones in which the specified storm front crossed



Map 2: Storm Zones

over 75 percent of the total area. Since several storms crossed 2 or more zones, main zone designation was not limited to one zone. Storms which did not cross more than 75 percent of any zone were counted as part of their main zone of residence. Although infrequent, storms which covered more than five degrees of longitude in a specific zone had the zone counted as one of its main areas. Total zones refers to any zones a specific storm front may have crossed. The direction category was a description of the general direction in which a storm was pointed. Several of the geographically larger storms were characterized as complex frontal interconnections, where no clear direction of movement was noted.

Graphing by Zones

Following the completion of zone assignments the number of storms which fell into each of the ten possible zone categories were added up and placed in a spread sheet. The graphing function of Excel was used in order to create ten separate graphs. These graphs compared the frequency of storms in a particular zone or zone combination in yearly intervals over the study period. Storm frequency was determined in monthly intervals for each of the 10 possible zone combinations by entering the frequency figures by month. Graphs were created which looked at specific zone and zone combinations over the entire study period.

Storm Connectivity

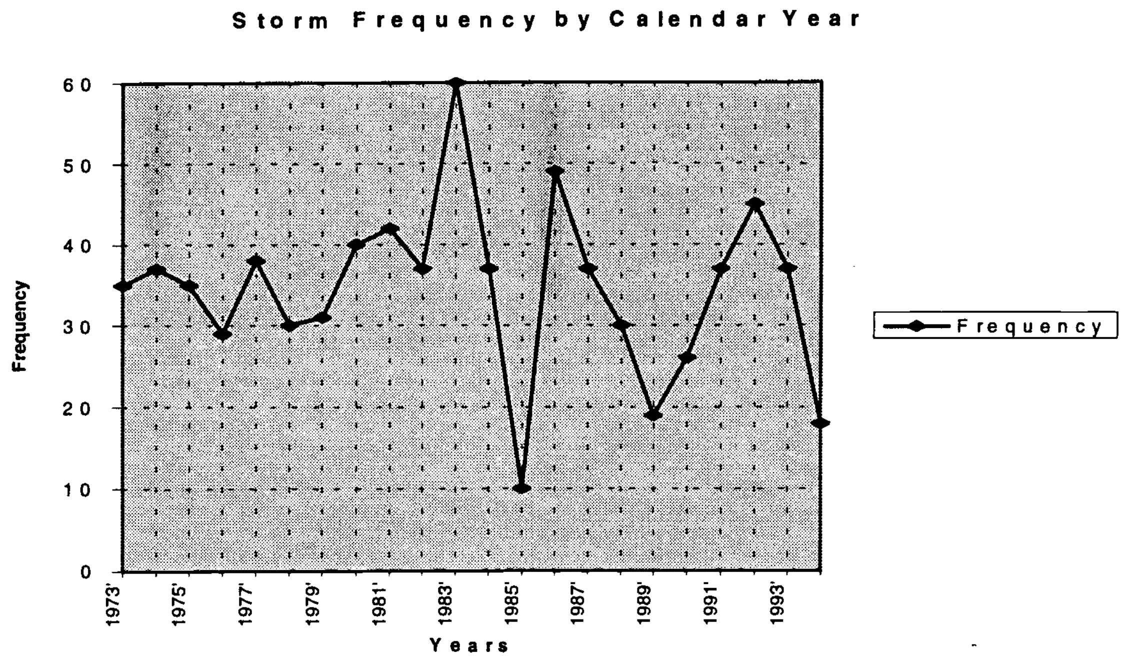
Once the frequency graphs were completed, the first step in determining storm connectivity was undertaken. This was completed by writing down every period of time where two or more consecutive days had met the pressure threshold. This information was partitioned and recorded by months in order to use it in determining geographical connectivity. The second step in ascertaining storm connectivity was determining any period of four or more consecutive days in which storms occurred in the same zone.

Discussion

1) What are the characteristics of storm location and frequency that distinguish interannual forcing events, (ENSO periods) for the northwest Pacific Coast?

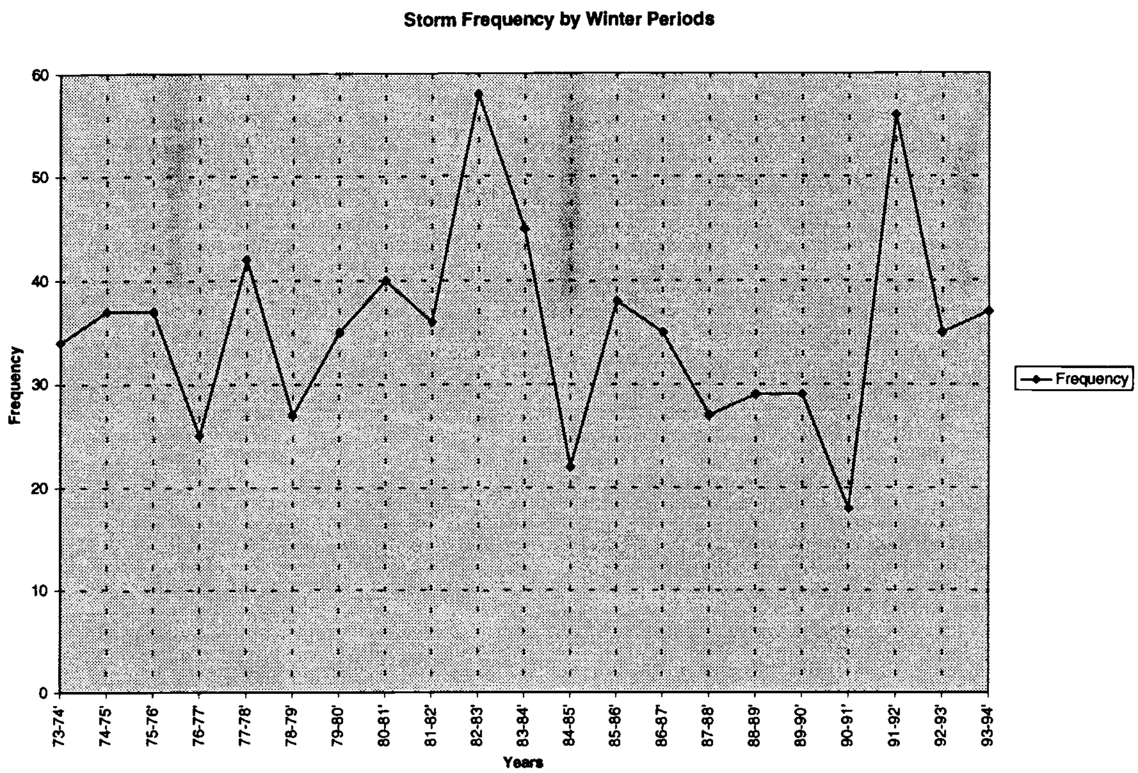
Storm Frequency

While general temporal characteristics including increased storm frequency during the El-Nino Southern Oscillation (ENSO) have long been assumed, they have not been previously quantified for the Pacific Northwest. The graph of storm frequency by calendar year (graph 1) exhibited three separate individual peaks in storm frequency. Two of these peaks, 1982-1983 and 1991-1993 correlated with generally agreed upon ENSO years. The 1976 ENSO period did not appear as anything more than an average storm year. The third peak, the 1986 peak, was not expected. When the graph was replotted looking at storm years instead of calendar years (graph 2), the 1986 peak



Graph 1: Calendar Year Storm Frequency

dropped out, leaving only the major peaks associated with ENSO years 1982-83 and 1991-93. The January, February 1986 storm peaks were connected to the low peaks of November and December 1985.



Graph 2: Coastwide Storm Frequency by Winter Periods

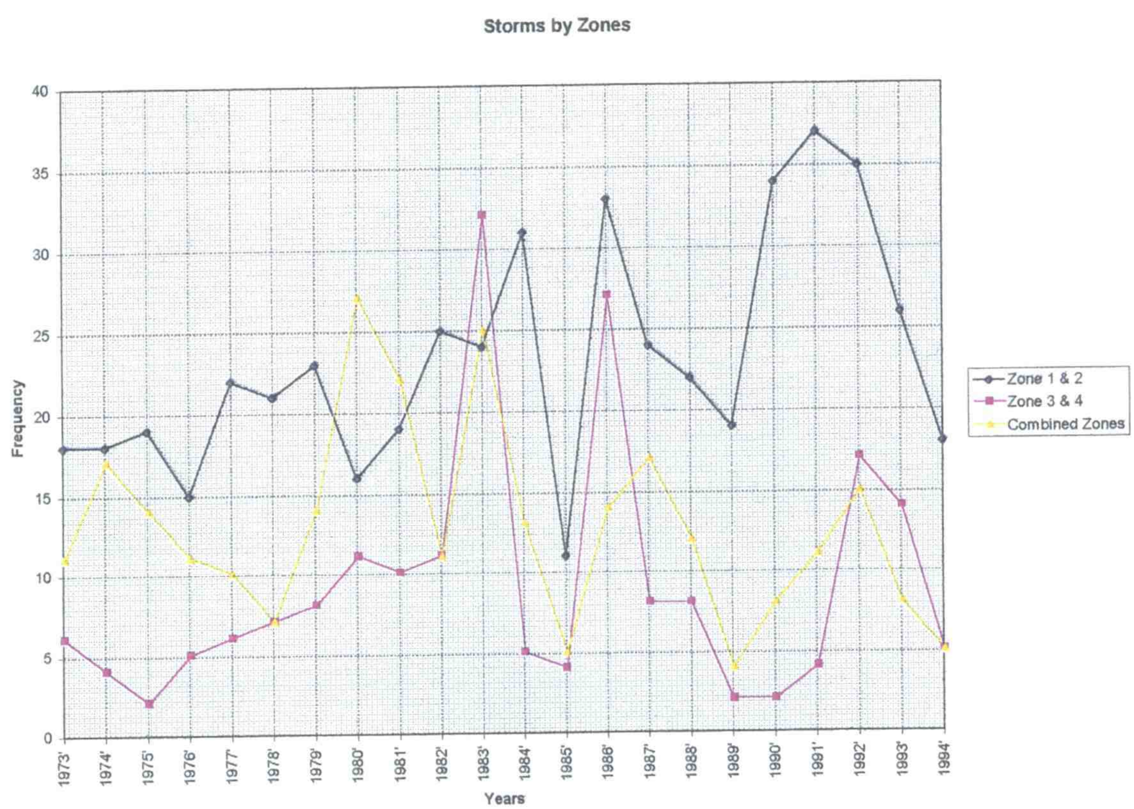
While the study period contained only three documented ENSO events the peaks on graph 2 support the assumptions in earlier work (Peterson Et al 1992 and Booth 1992) that ENSO events contain more potential climatic forcing events than other years. While the overall frequency argument is suggestive, storm frequency by month exhibits less of a pattern.

2) Are there differences in the spatial and temporal characteristics of storm events, (location and frequency), between interannual forcing periods and annual average periods?

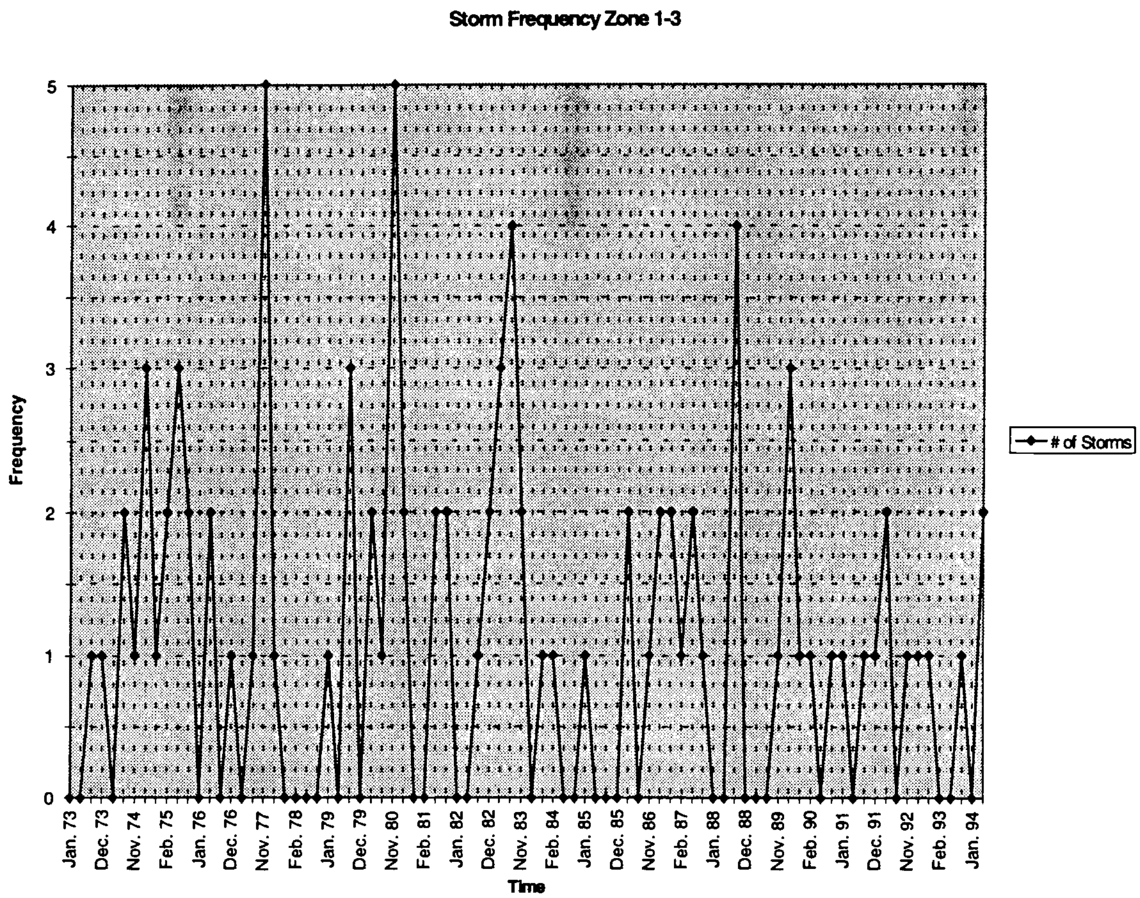
Storm Location

The graphs on storm location (graphs 3-13) were created to exhibit the spatial and temporal features of coastal storms. Ten of the graphs (4-13) represent all the actual combinations of the 4 major zones which are based on 5 degrees of latitude. Examples of this include graph 4 which includes all storms which cover the total area between 55 and 40 degrees north latitude and graph 6 which includes all storms which only covers the area between 55 and 50 degrees north latitude. The data were displayed monthly rather than seasonally to provide greater resolution for the spatial patterns. Graph 3 is a composite graph of seasonal storm locations.

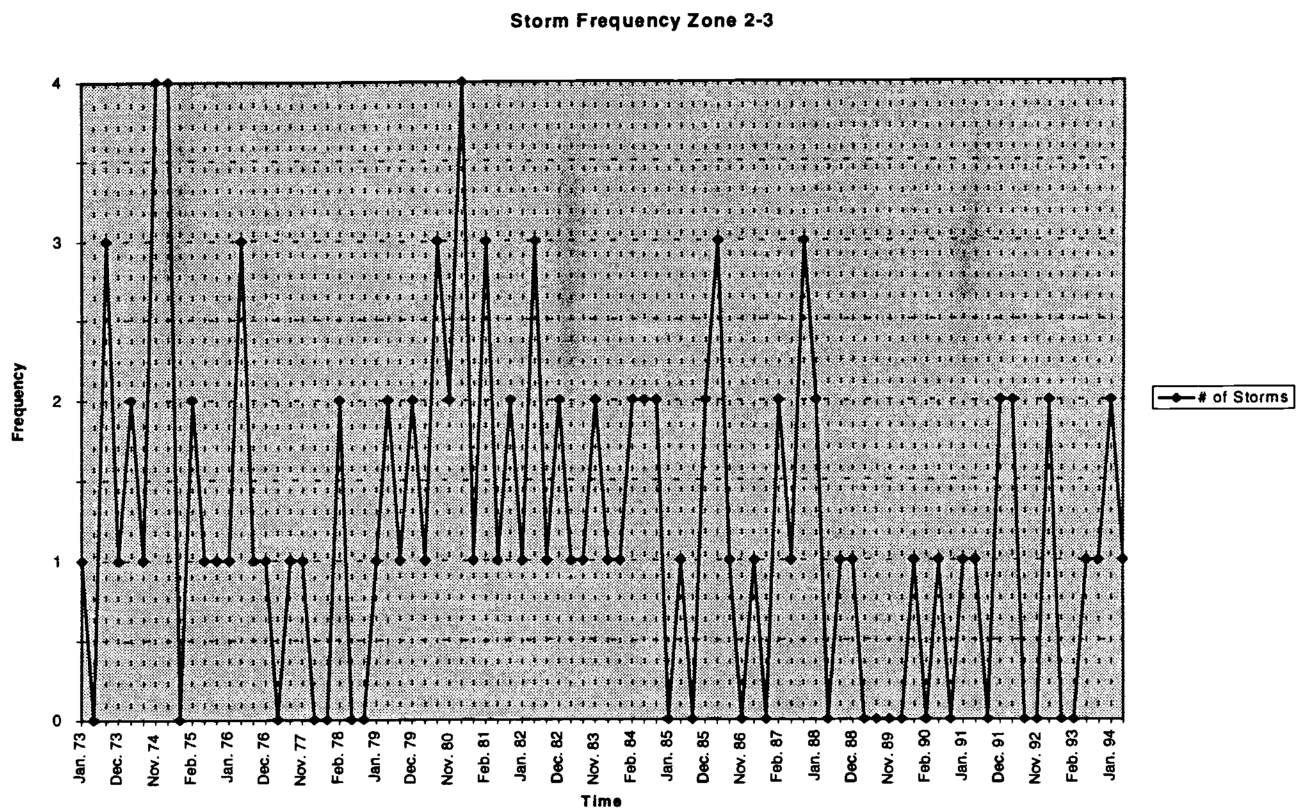
Throughout the research period most of the storm systems were observed in the northern two zones (poleward of 45 degrees north latitude). Importantly, this observation is true of most non-ENSO years. This supports earlier, time limited findings (Peterson Et al 1992) that observed fronts crossing north of 40 degrees latitude. Exceptions to this finding were observed in 1980 and 1981, where storms were randomly distributed throughout the combined zone category (graph 3). The combined zone category includes storm fronts which overlapped both sides of 45 degrees north latitude. Both 1980 and 1981 had large numbers of storms in zone 1-3 and zone 2-3 (see Graph 4 and 5). It was these combination storms (20 in 1980 and 15 in 1981) which led Peterson et. al (1992) to conclude that the average storm track affected the coastal zone primarily north of 40 degrees latitude.



Graph 3: Storm Frequency by Zone Combinations



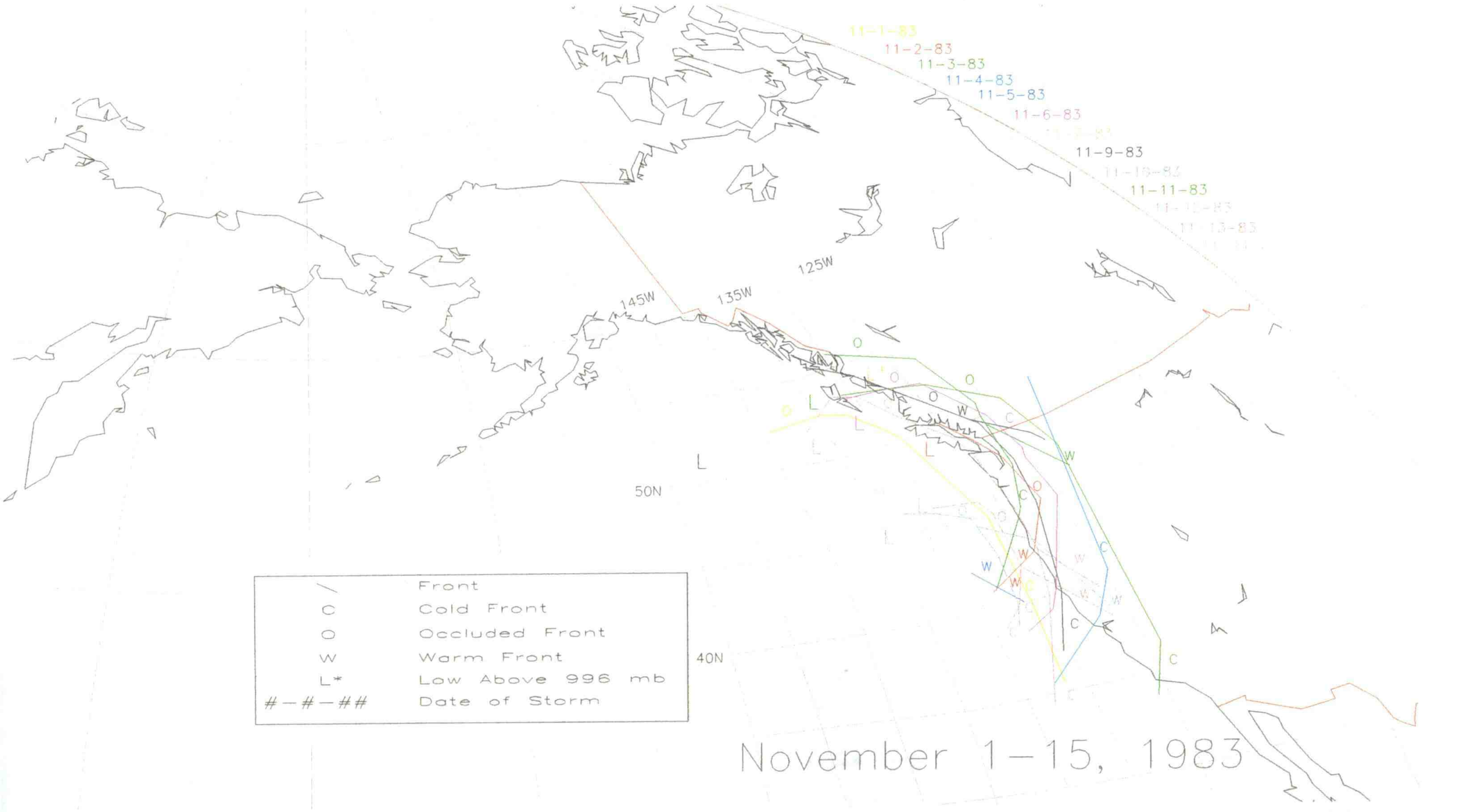
Graph 4: Storm Frequency Zones 1-3



Graph 5: Storm Frequency Zone 2-3

This study finds that during these years most storms affected areas north of 45 degrees latitude. Graph 3 also shows that during the 1982-83 ENSO event more storms occurred in zones 3 and 4 than occurred in zones 1 and 2. These 1983 storm pattern illustrated in map 3, November 1983 characterize a complexity and magnitude of storm events not observed elsewhere in the temporal record from 1973 to 1994.

Map 3: Storm Pattern Focused on Zones 3 and 4



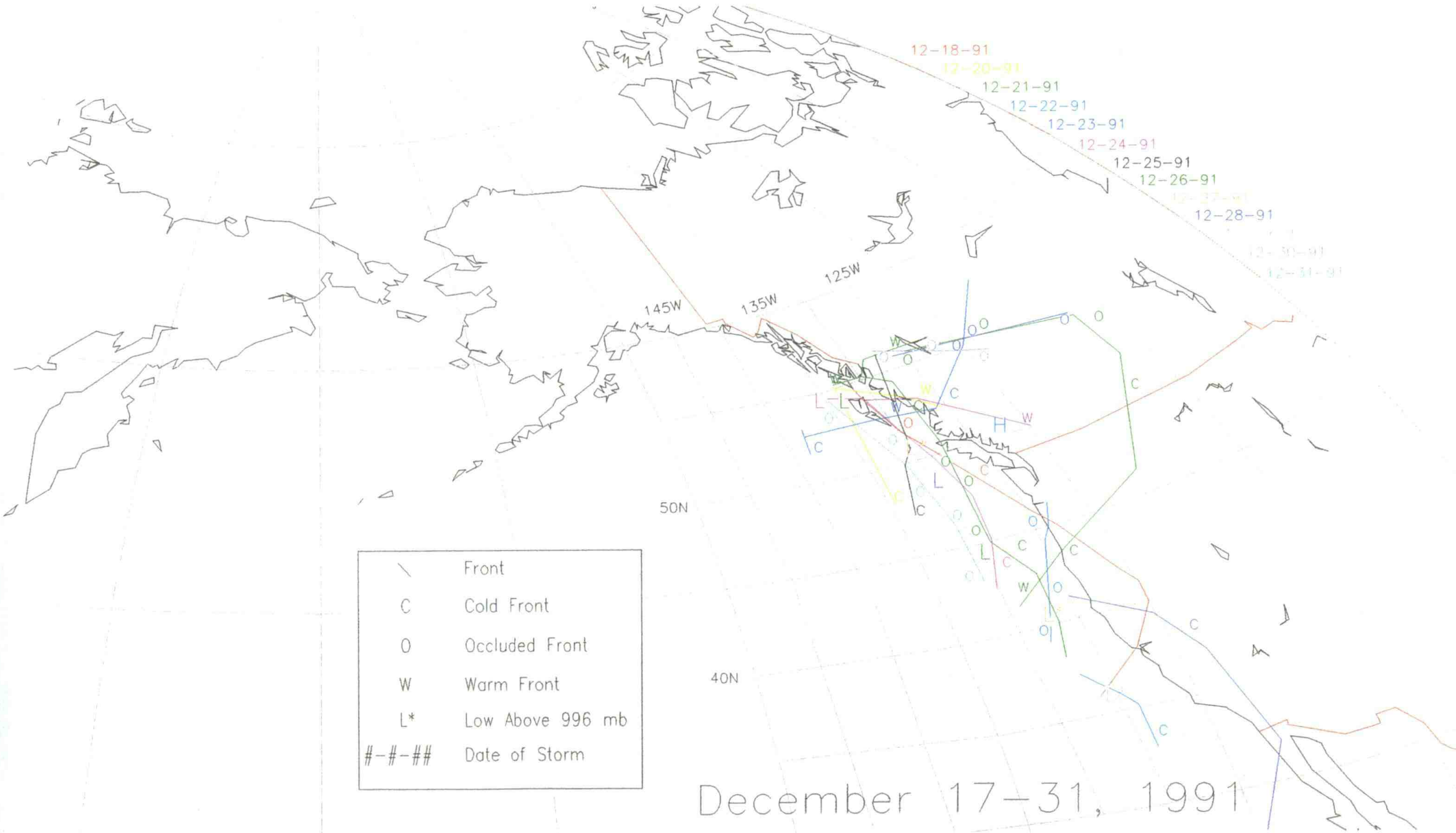
Sixteen more storms hit zones 3 and 4 during this season than the second highest seasonal total (1986). In comparison, the early 1990's ENSO event, which was characterized by a similar storm frequency, directed almost all of its energy into higher latitude zones 1 and 2 (Graph 3, map 4).

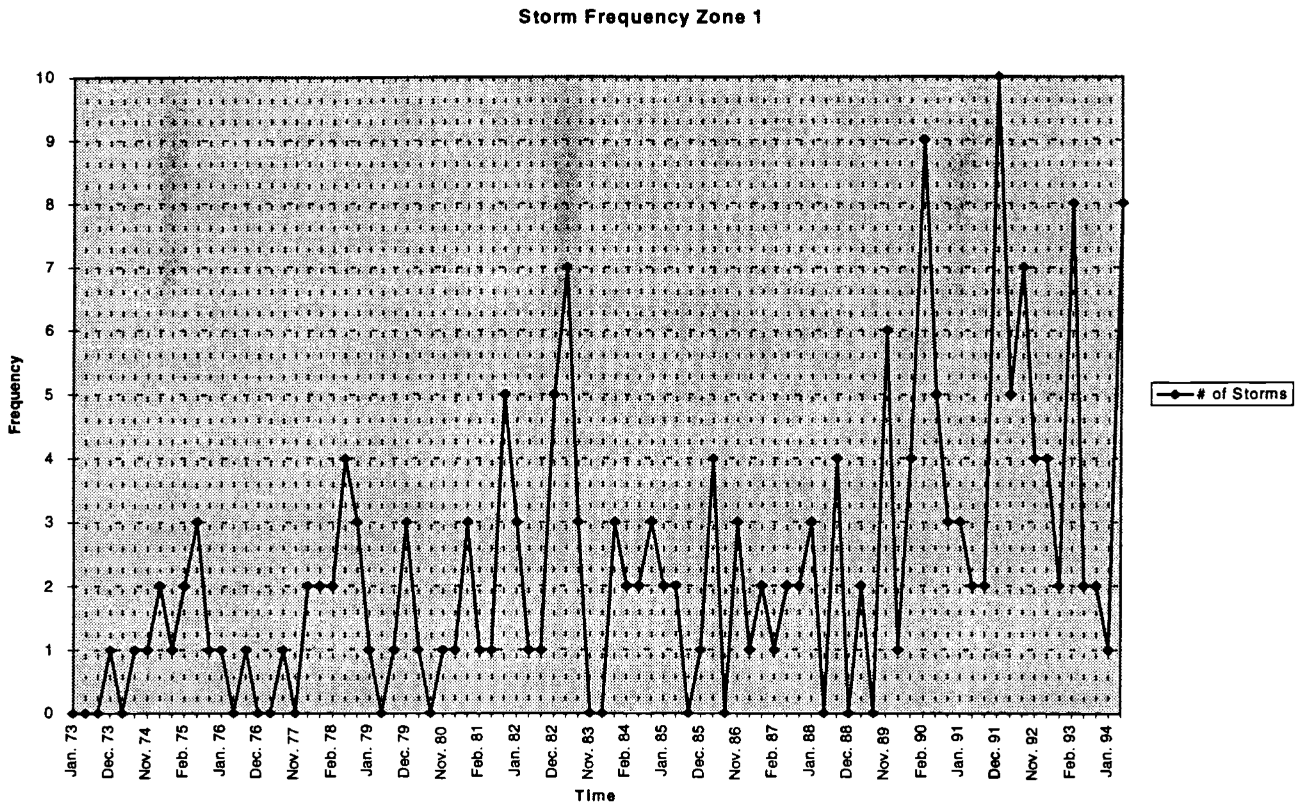
Several of the individual graphs exhibited a peak which was considerably higher than other peaks. In half of the graphs (4, 6, 7, 8 and 9) the peaks were focused in ENSO years. The peak in zone 1 (graph 6) and zones 1-2 (graph 7) centered on the 1991-1992 ENSO event while the 1977 ENSO event equaled the dominant peak in zones 1-3 (graph 4). The 1982-1984 ENSO was the dominant peak in zones 2-4 (graph 8) and zones 3-4 (graph 9).

Of the graphs that exhibited high readings in non-ENSO years, only graphs 10 (zone 3) and 11 (zone 4) exhibited any temporal patterns. In both graphs the peak frequencies occurred in early 1986. This, coupled with February 1986 having the second highest peak on graph 13 (zone 2), points to a large number of potential climatic forcing events in a short temporal period. The other two graphs, 14 (zones 1-4) and 5 (zones 2-3), were homogenous between years. The homogeneity had more to do with low storm frequencies rather than any actual pattern.

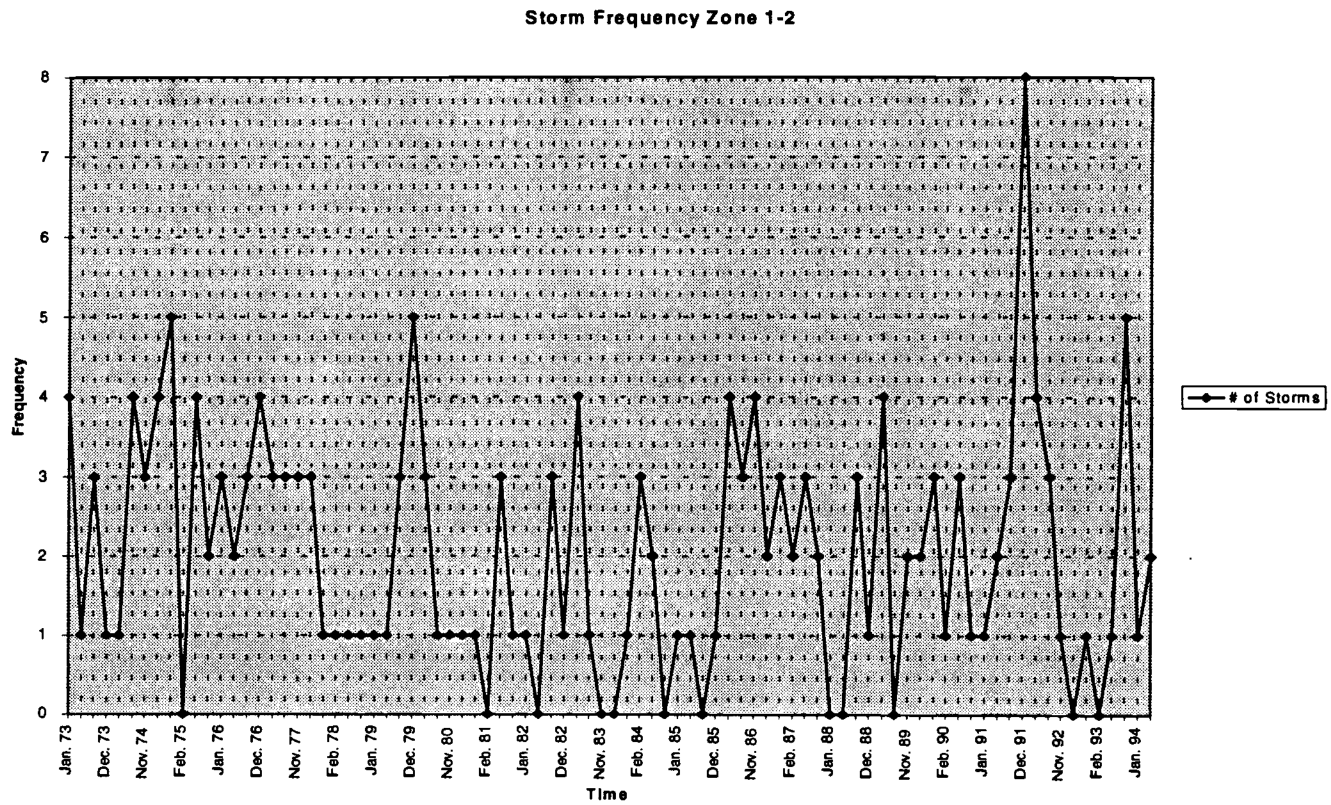
The difference between ENSO and non-ENSO years is visually represented by maps displaying the projected position of cyclonic storm tracks (maps 5 and 6). The storm

Map 4: Storms Focused on Zone 1

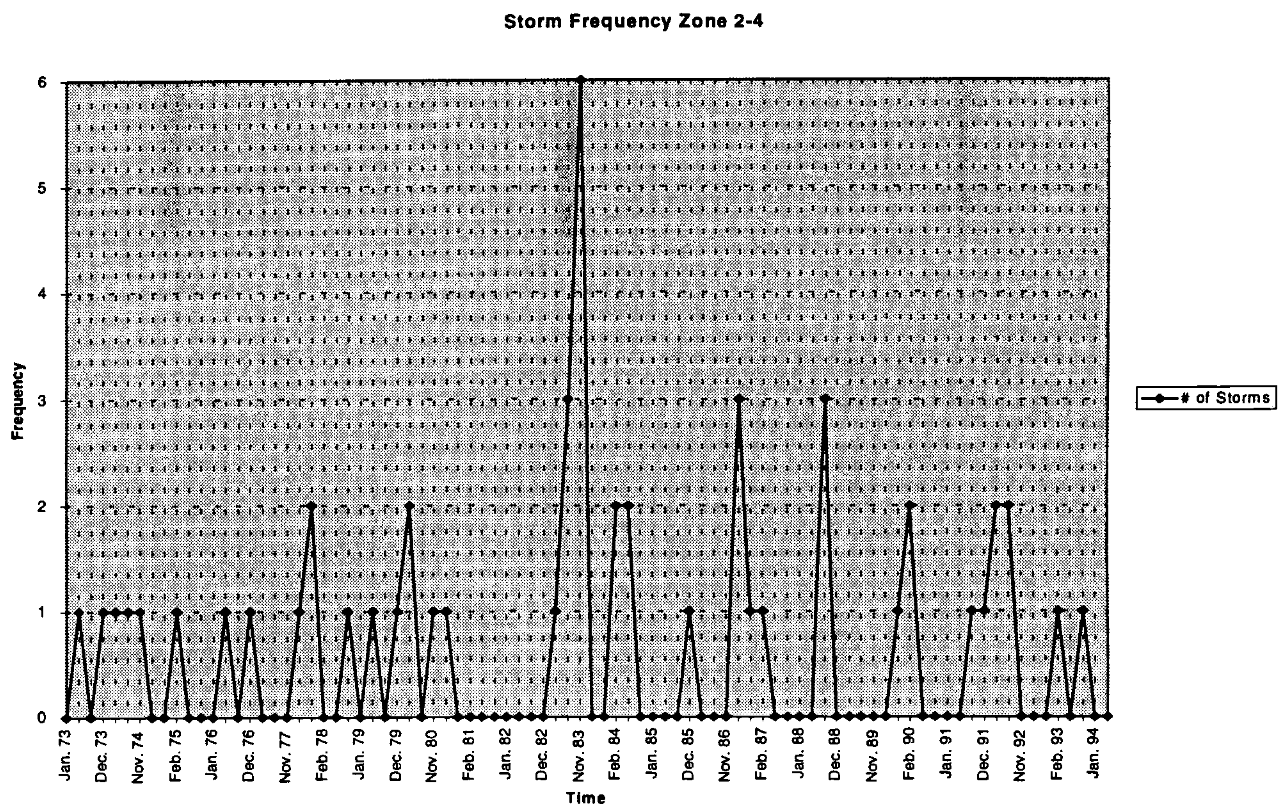




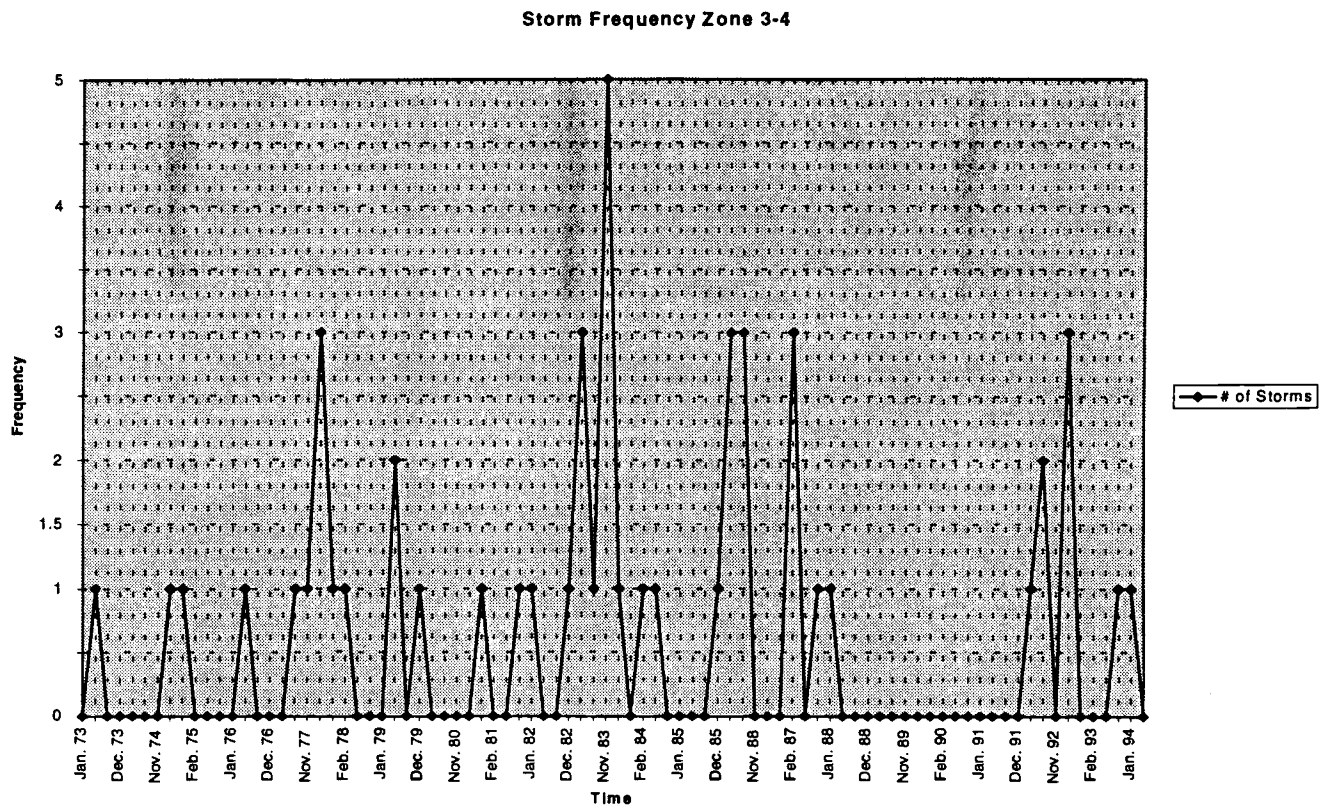
Graph 6: Storm Frequency Zone 1



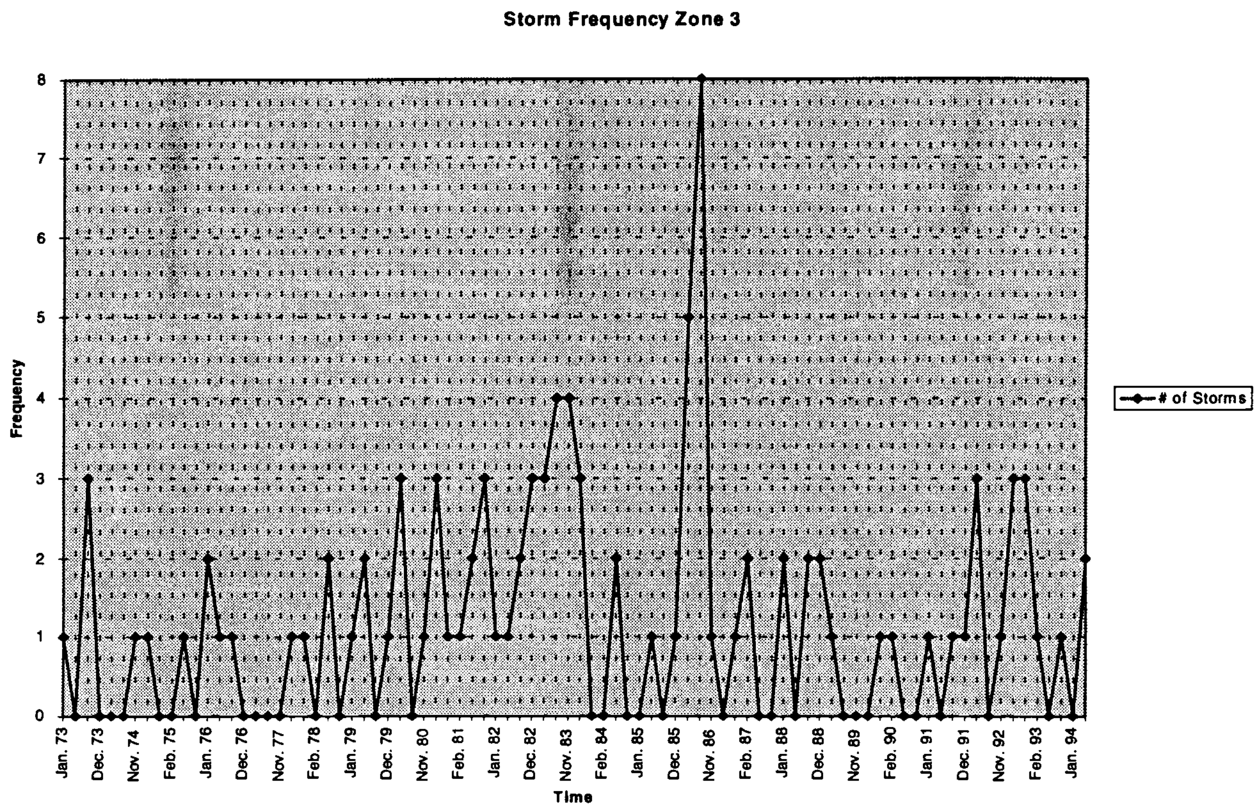
Graph 7: Storm Frequency Zones 1-2



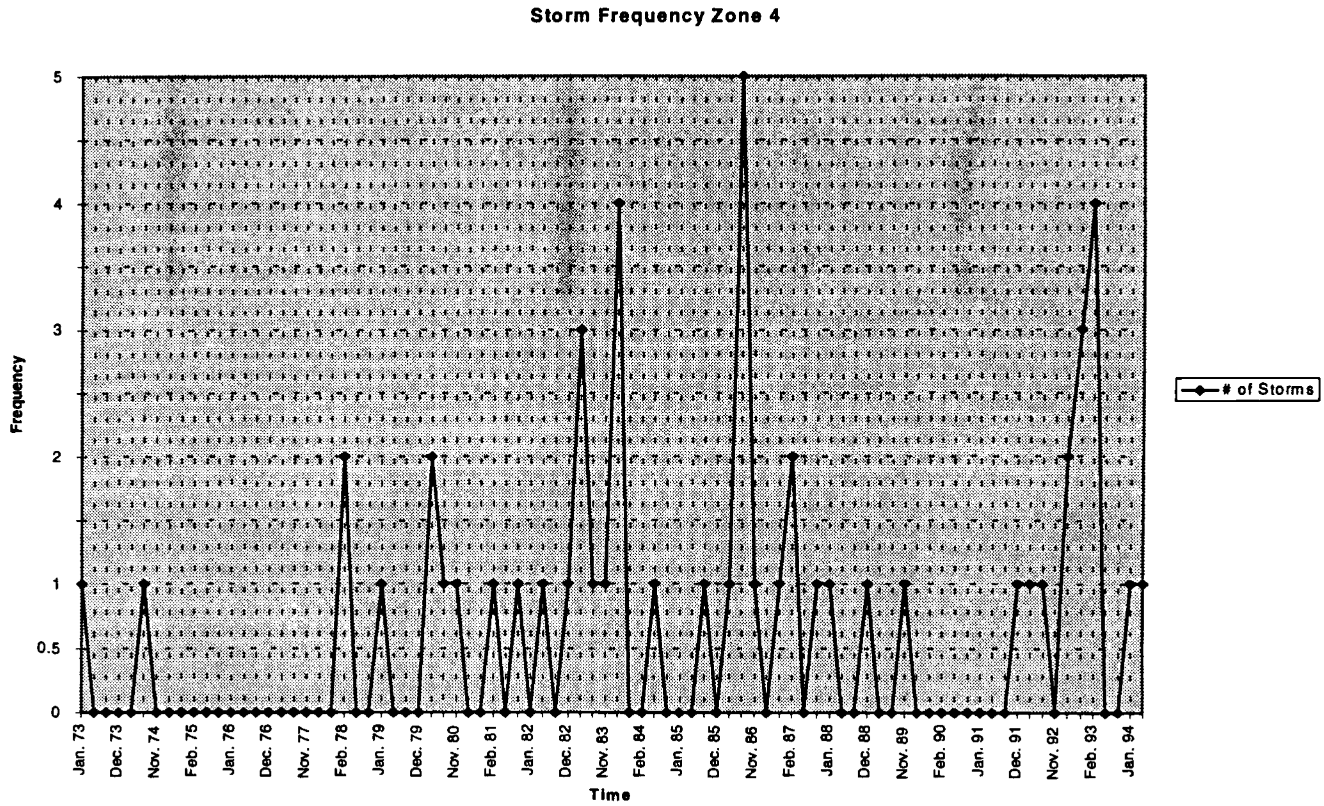
Graph 8: Storm Frequency Zones 2-4



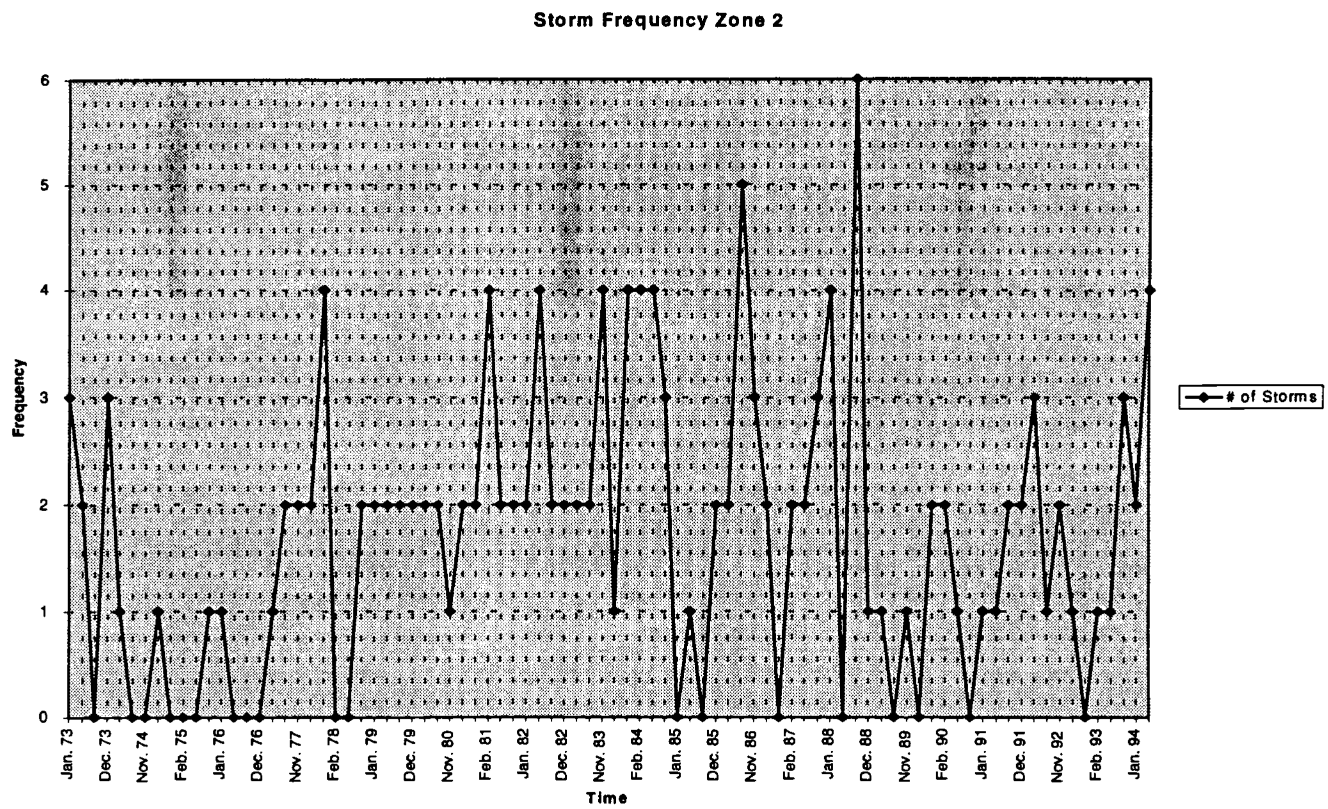
Graph 9: Storm Frequency Zones 3-4



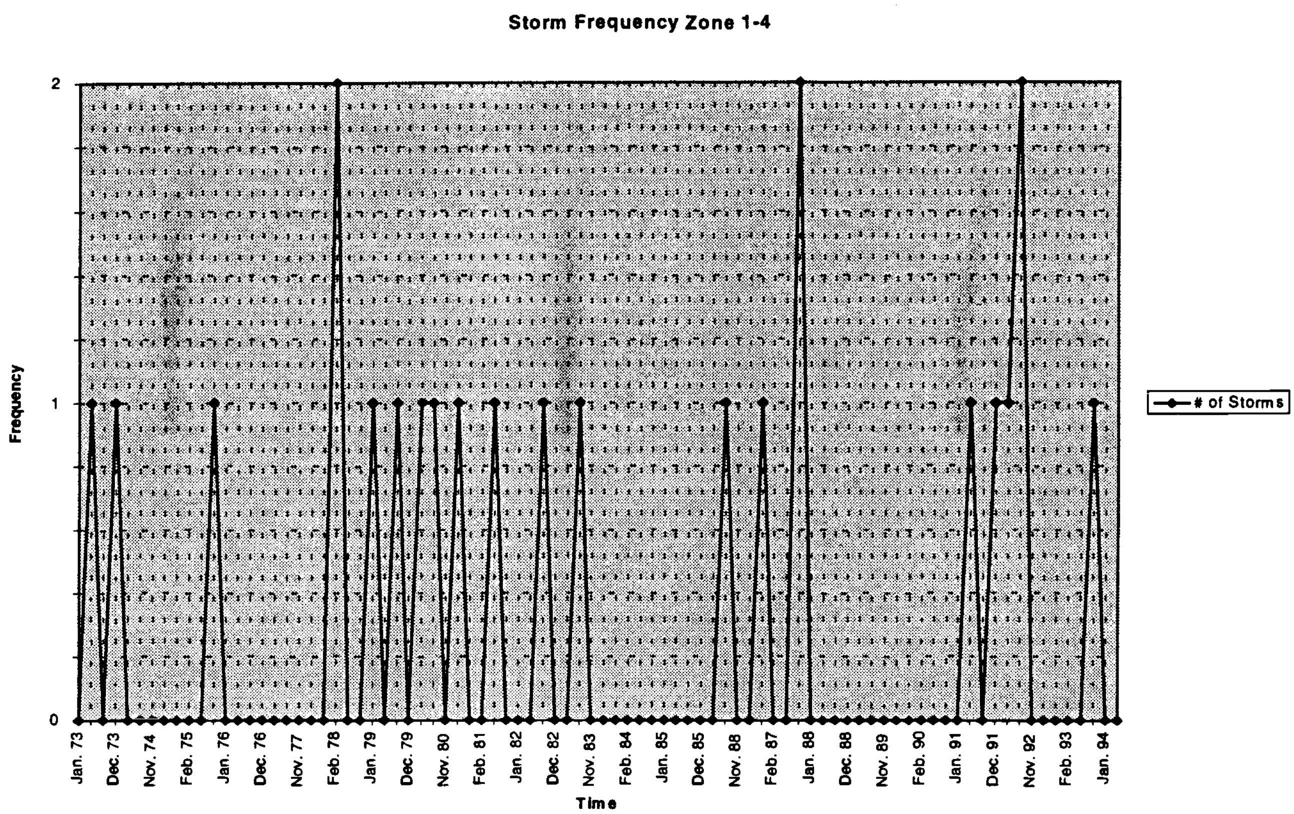
Graph 10: Storm Frequency Zone 3



Graph 11: Storm Frequency Zone 4



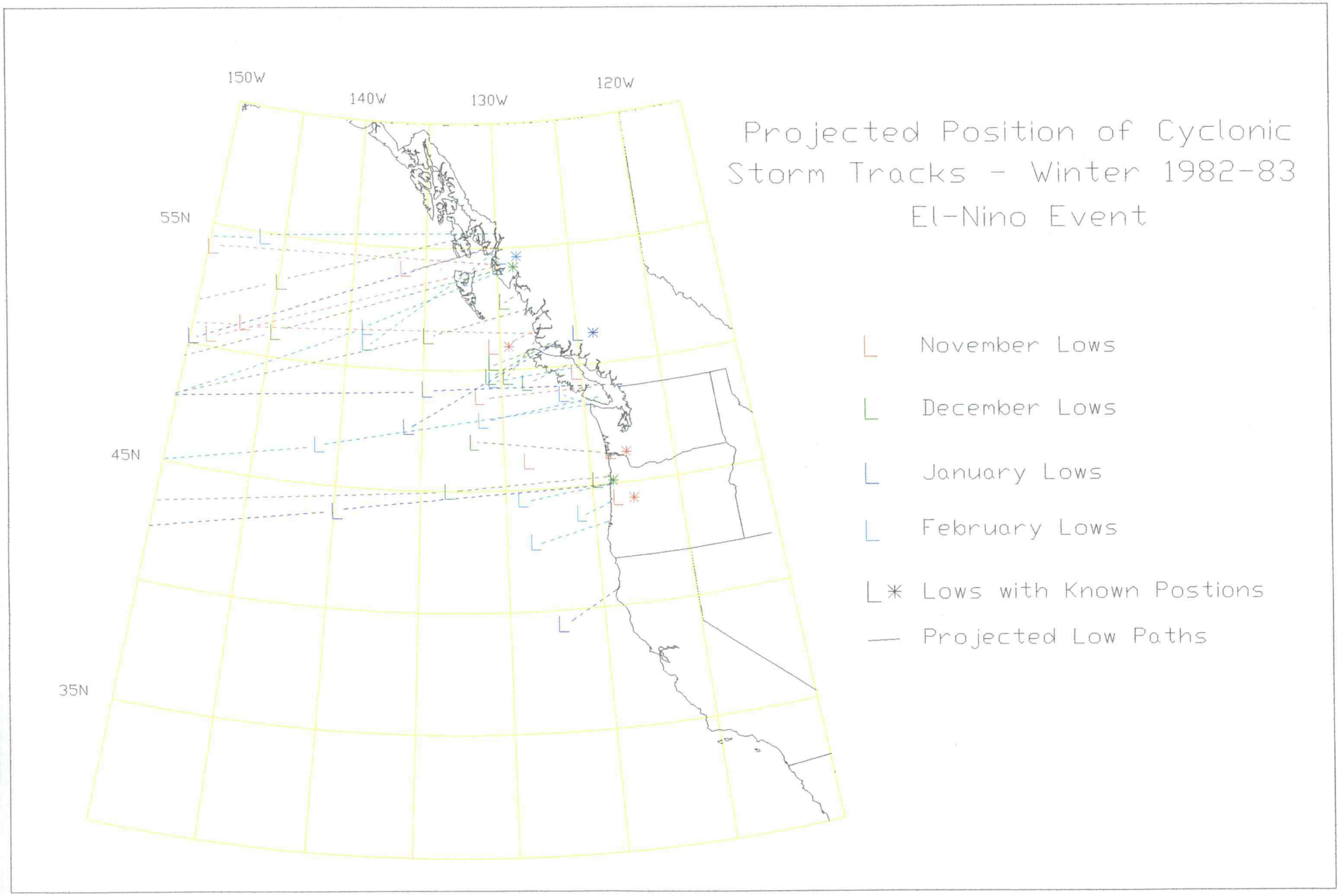
Graph 12: Storm Frequency Zone 2



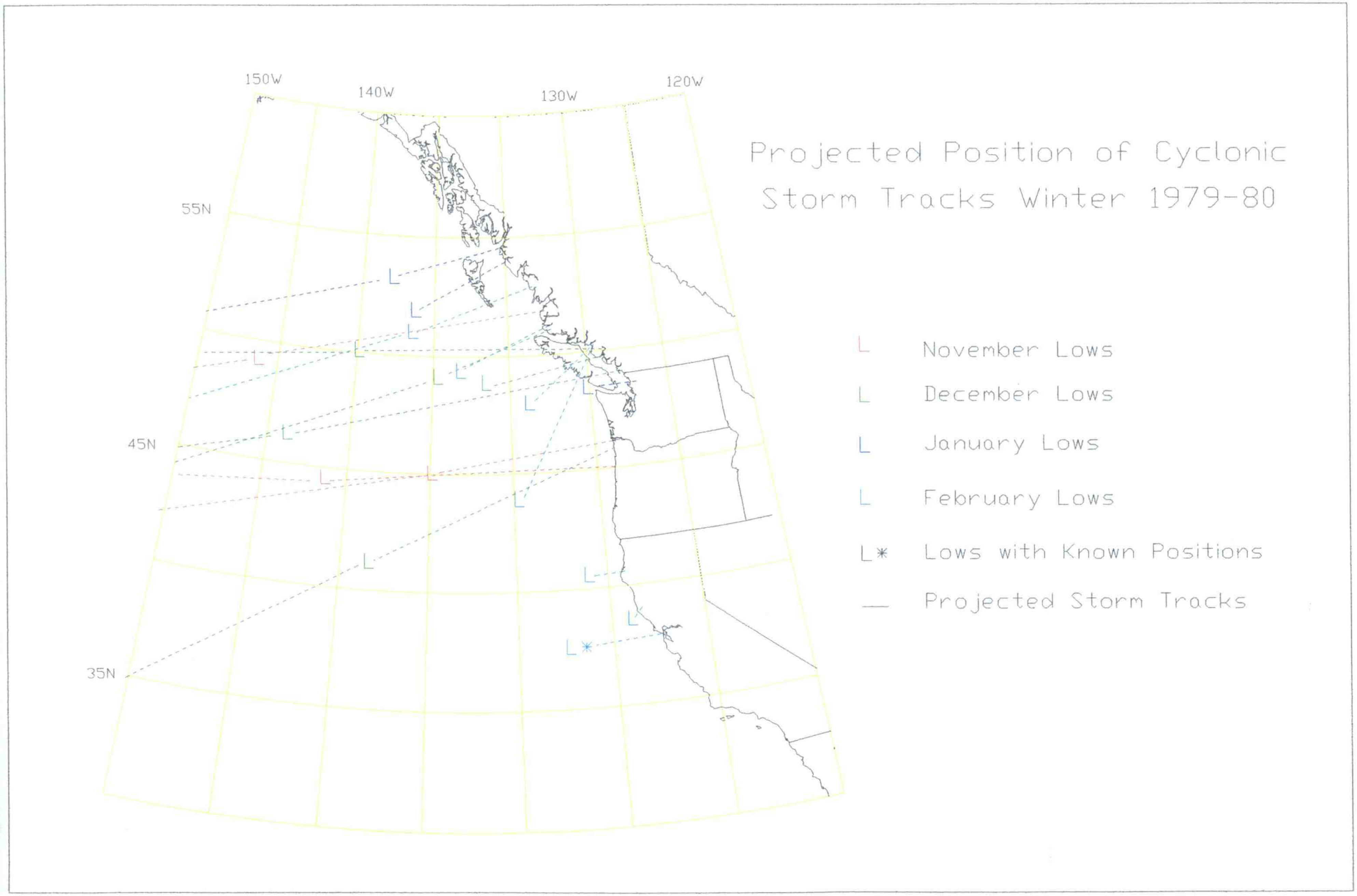
Graph 13: Storm Frequency Zones 1-4

track visible in the winter 1982-83 (map 5) shows both the increased storm frequency and the higher percentage of lows off the Pacific Northwest coast when compared to the non-ENSO year of 1979-80 (map 6).

Map 5: 1982-83 Projected Storm Tracks



Map 6: 1979-80 Projected Storm Tracks

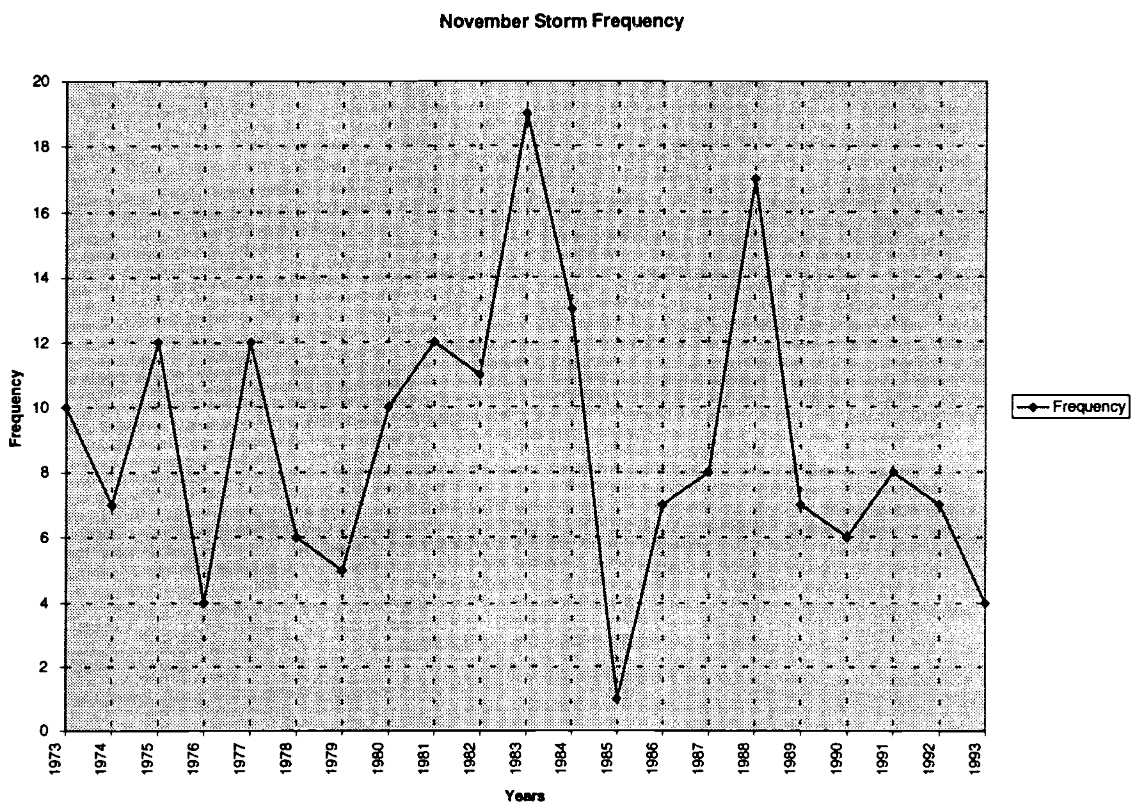


3) Are there specific month to month storm variations that influence winter period climatic forcing?

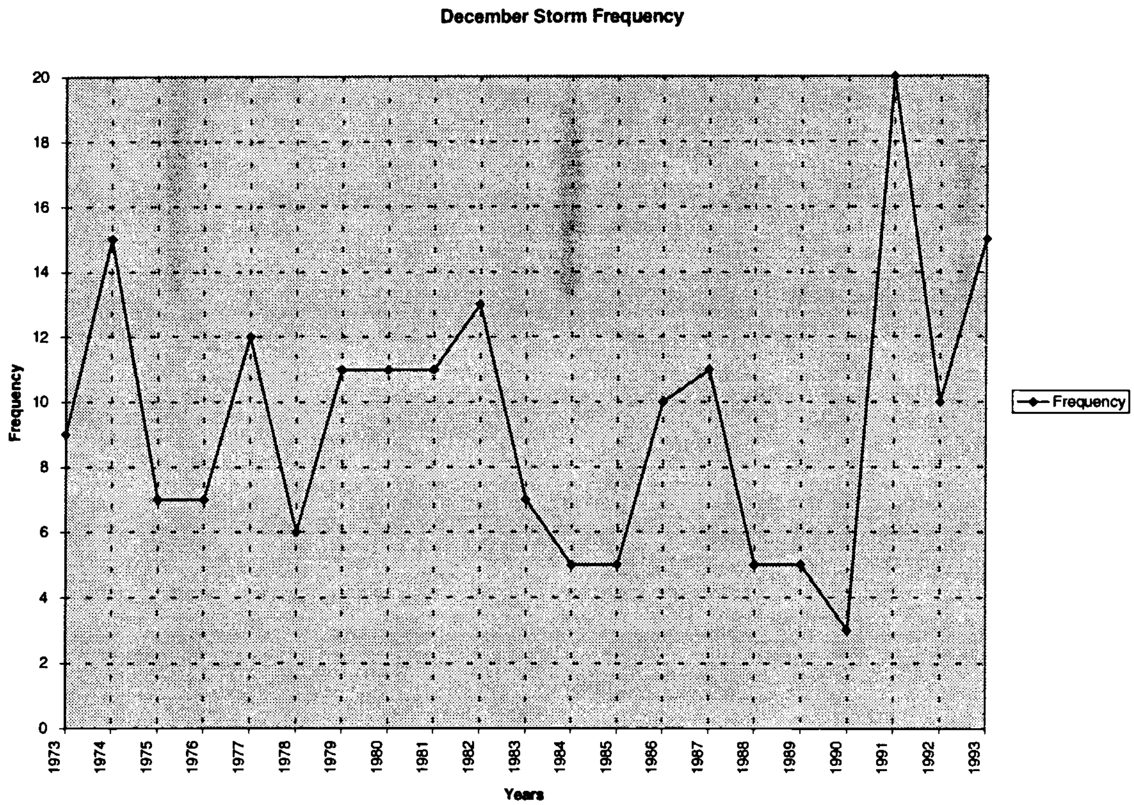
Monthly Storm Frequency

The monthly storm frequency graphs (graphs 14-17) exhibit several instances where individual months displayed greater than expected storm frequency even in non-ENSO years. An obvious example of this occurs on graph 14, November Storm Frequency. In this graph, the second highest November storm total is associated with 1988. This was a non-ENSO year, but November 1988 showed significantly more threshold storms than the ENSO years of 1976 and 1991. December storm frequency (Graph 15), nearly always a high frequency storm month, exhibited very high storm frequency in the non-ENSO year of 1974. Most of the non-ENSO years exhibit a low frequency or inconsistent monthly pattern of storms. The exception is seen in both graphs (16 and 17). These graphs show that the high frequency pattern visible in January 1986 (graph 16) continued into February 1986 (graph 17). During the 1985-1986 storm season 32 of 38 threshold storms occurred in January and February. In comparison January and February of 1987 contained 18 of 35 threshold storms. Future research at a finer temporal scale will be needed in order to further access the relative importance of temporally concise storm periods similar to the 1986 storm pattern on climatic forcing.

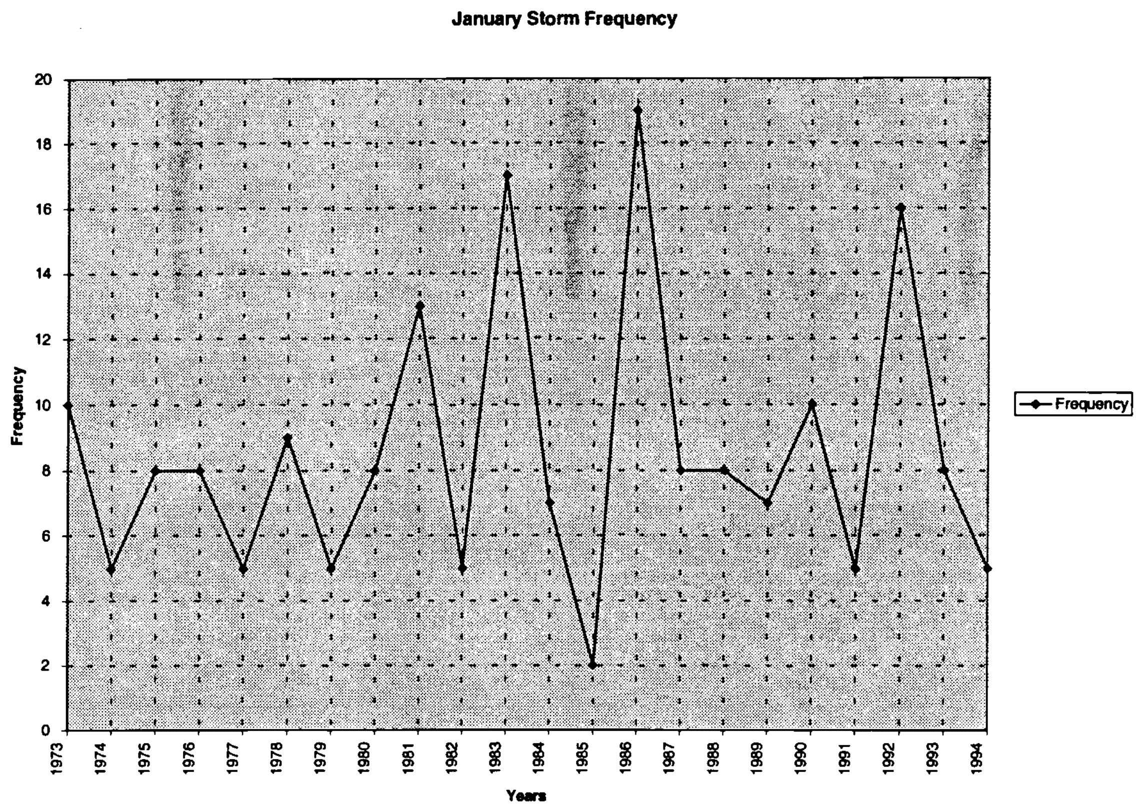
While ENSO years generally show high frequency in each winter month, they also exhibit great amounts of variability. Different ENSO events focused their climatic forcing events in different times of the year. The 1982-83 event exhibited a gradual increase in storm frequency beginning in November 1982 and peaking in November 1983. The 1991-92 ENSO event peaked quickly in December of 1991 and gradually decreased through the remainder of the winter.



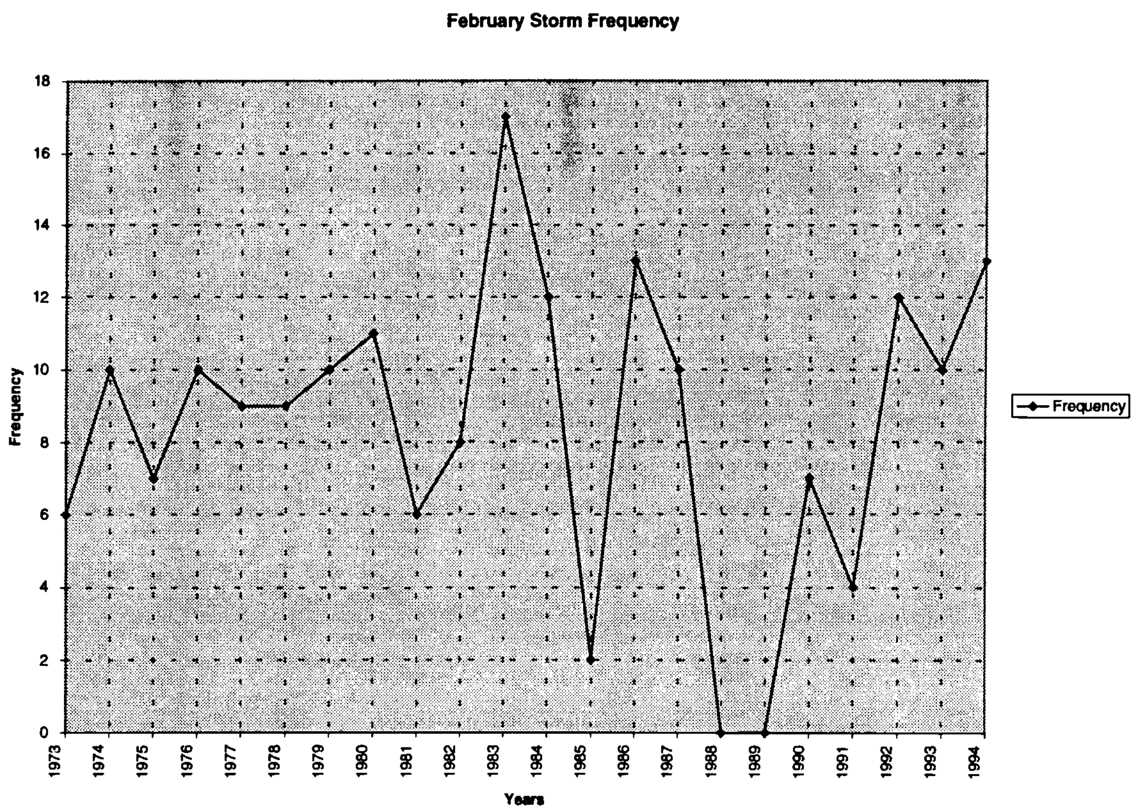
Graphs 14: November Storm Frequency



Graph 15: December Storm Frequency



Graph 16: January Storm Frequency



Graph 17: February Storm Frequency

4) What patterns of forcing emerge from periods of consecutive storm days? Are these patterns most characteristic of ENSO periods?

General Storm Connectivity

Storm connectivity refers to storms which occur on consecutive days. In some years storm tracks appear to be more spatially random than others. Table 1 looks at the general connectivity of storms across the entire study area, while table 2 looks consecutive storms occuring in the same zone. The amount of general connectivity varies considerably over the years (table 1). Very little connectivity is visible in the early years of the study. A quick glance at table 1 reveals that a large portion of the connected storms events were limited to two days. A general increase in storm connectivity began to occur in the early 1980's. January 1981 clearly shows this upswing in both the occurrence of connected days and the length of each occurrence. The pattern of relatively high connectivity continued until 1985 when it dwindled down to nearly nothing. The first two months of 1986 exhibited a great deal of connectivity. The remainder of the 1980's saw general connectivity gradually decline with the exception of November 1988. While this month exhibited relatively high general storm connectivity, it did not exhibit any zonal storm connectivity (Table 2). The early 1990's were characterized with increasing levels of connectivity. The

Month-Year	Days	Month-Year	Days
Jan-73	14-15, 17-18	Jan-83	6-8, 16-18, 22-30
Feb-73	14-16	Feb-83	11-14, 16-20, 22-25
Nov-73	11-13	Nov-83	1-6, 9-17, 19-20
Dec-73	5-6, 11-12, 19-21	Dec-83	8-12
Jan-74	14-15	Jan-84	3-4, 22-23
Feb-74	13-15, 17-18, 28- March 1	Feb-84	9-13, 19-20, 26-28
Nov-74	5-6, 20-22	Nov-84	1-3, 6-7, 22-24
Dec-74	2-3, 6-7, 26-27	Dec-84	11-12
Jan-75	30-31	Dec-85	2-5
Feb-75	18-19	Jan-86	1-2, 7-10, 12-13, 15-16, 21-23, 29- Feb 3
Nov-75	2-3, 6-7, 11-15	Feb-86	13-19, 23-25
Dec-75	3-4, 21-22	Nov-86	18-20, 25-27
Jan-76	4-5, 10-11, 27-28	Dec-86	18-20, 24-28, 31- Jan 1
Feb-76	16-17, 21-23	Jan-87	29- Feb 2
Dec-76	24-25	Feb-87	4-5, 10-13, 15-16
Jan-77	14-16	Nov-87	9-11, 30- Dec 6
Feb-77	18-21	Dec-87	8-10
Nov-77	11-15	Jan-88	8-11, 13-14
Dec-77	10-15, 21-23	Nov-88	1-2, 5-7, 9-13, 21-23
Jan-78	4-5, 7-9	Dec-88	20-22
Feb-78	4-7, 11-12	Jan-89	30-31
Nov-78	1-2, 6-7	Nov-89	8-9
Dec-78	13-14	Dec-89	1-4
Jan-79	14-16	Jan-90	4-9, 30- Feb 5
Feb-79	13-15, 17-18, 24-25	Nov-90	12-13
Nov-79	21-22	Dec-90	3-4
Dec-79	16-21, 23-24	Jan-91	11-14, 31-Feb. 2
Jan-80	9-13	Nov-91	11-12, 15-17, 19-20
Feb-80	31-3, 17-19, 27-28	Dec-91	4-9, 11-12, 20-26, 30- Jan 6
Nov-80	3-7, 26-27	Jan-92	8-10, 25-28, 30- Feb 3
Dec-80	2-4, 13-14, 24-25, 28-29	Feb-92	9-15
Jan-81	7-10, 15-19, 21-22, 26-27	Dec-92	5-10, 28-29
Feb-81	13-16, 18-19	Jan-93	7-8, 19-21, 30-31
Nov-81	10-12, 14-15, 19-21, 22-30	Feb-93	3-6, 8-9, 19-20, 27-28
Dec-81	13-15	Nov-93	2-3, 29- Dec 4
Jan-82	16-17, 25-27	Dec-93	6-13, 30- Jan 2
Feb-82	15-16, 18-19, 26-28	Jan-94	23-24
Nov-82	3-4, 16-19, 25-29	Feb-94	12-18, 25- March 2
Dec-82	2-3, 13-18, 20-22		

Table 1: Consecutive Days Under the 1000 Mb Threshold

connectivity reached a peak in December 1991. 1992 marked a dramatic decrease in connectivity. The decrease ended in December of 1992 after which time general connectivity increased. The increase peaked in February of 1993. February 1994 is representative of the end of the study period where fewer connected events lasted for longer time intervals.

As expected from the frequency of storms (graph 2), ENSO years had more general connectivity than normal winters. While each of the ENSO periods exhibited high general storm connectivity, the non-ENSO winters varied greatly. This can best be seen by looking at the winter of 1985-86. November and December of 1985 had limited storm frequency resulting in each month having only one period of general connectivity. The far higher storm frequencies in January and February of 1986 led to multiple periods of general connectivity.

Zonal Storm Connectivity

Zonal storm connectivity is defined here as either 1) storm fronts which occurred in the same zone on four or more consecutive days, or 2) consecutive storm fronts passing through the same zone in a four day period. The 1970's were characterized by only one zonally connected storm sequence. This occurred in November of 1977. In general, storm sequences in the 1970's were limited to only a few days,

Month-Year	Dates	Zone	Days
Nov-77	11-15	2	5
Jan-80	9-12	2	4
Nov-80	3-7	1-2	5
Jan-81	15-19	2	5
Nov/Dec-81	29-5	2	7
Nov-82	25-29	2	5
Jan-83	22-26	1	5
Nov-83	1-6, 9-13	3/3	6/5
Dec-83	9-12	3	4
Jan/Feb-86	29-3; 29-3	4/3	6/5 of 6
Feb-86	14-19	3	6
Nov/Dec-87	30-4	3	5
Jan/Feb-90	30-5	1	7
Dec-91	4-9; 23-26	1-2/1	6/4
Dec/Jan-92	30-3	1	5
Jan/Feb-92	30-3	1	5
Feb-92	9-15	1	7
Nov/Dec-93	29-4	2	6
Feb-94	12-16	1	5

Table 2: Time Periods with Four or More Consecutive Storm Days in the Same Zone

precluding many chances for a four day zonal sequence. In the record only 5 events meet the minimum connectivity requirement (Table 1). This corresponds to only twenty percent ratio of zonal storm connectivity to general storm connectivity. In comparison the ratio for the 1980's and the 1990's are 43 percent (12/28) and 50 percent (8/16) respectively. The 1990's appear to be on course to have a higher number of connected storms than the 1980's, but almost all of the zonally connected storms have been in zone 1. The 1980's also began with nine zonally connected storms in the first four years. The remainder of the decade saw only four zonally connected storms.

Zonal storm connectivity helps to illustrate the energy focused on a geographic area of the coast. Of particular importance are several periods of connectivity that affected particular zones. Between January 1981 and November 1982 a series of storms raked zone 2 (45 degrees to 50 degrees north latitude). November and December of 1983 exhibited storm connectivity which focused on zone 3 (40 degrees to 45 degrees north latitude). This same zonal connectivity occurred in January and February 1986. A similar pattern was visible in zone 1 (50 degrees to 55 degrees north latitude) in connection with the 1991-1993 ENSO event.

While most of the zonally connected storms occurred in moderate to severe ENSO years, a large number of events occurred outside of ENSO years. The zonal connectivity in non-ENSO years appears to be concentrated into specific time periods. Table 2 clearly shows concentrations of zonal connectivity in 1980-81, 1986 and 1990. Further research will need to be undertaken to try and determine if these temporal patterns occur outside the study period.

Conclusion

Spatial and temporal analysis of the Pacific coast line of the United States and Canada between 55 degrees north latitude and 35 degrees north latitude supports many of the observations and theories previously presented by Jackson and Rosenfeld 1987, and Komar 1986.

Temporally, a general increase in storm frequency appears to occur in moderate to severe ENSO years. The weak ENSO year of 1976 suggests that weak ENSO events may not differ much from non-ENSO years. The relatively high frequencies associated with January and February 1986 suggest the possibility that coastal erosion can be induced by temporal patterns too short to be readily seen using storm year intervals.

Moderate to severe ENSO events appear to have a greater than average storm connectivity. This connectivity combined with the higher than normal temporal frequency focuses a great deal of storm energy on the coastline. Different ENSO events appear to focus on different portions of the coastline. Most zonal connectivity is focused on the area north of 45 degrees latitude. With one exception (Nov-Dec 1987), only the severe ENSO event of 1982-1983 and early 1986 exhibited zonal connectivity south of 45 degrees latitude. January and February of 1986 appear different than other non-ENSO years. This brief time period comes closer to the moderate to severe ENSO events of 1982-1983 and 1991-1993. The major difference between early 1986 and the ENSO years is the duration of the activity, not the apparent severity of the event.

Moderate to severe ENSO events stand out from other storm years. The increase in temporal frequency (graph 2) and zonal connectivity of storms (table 2) makes the years readily visible when plotted. The temporal frequency appears to be scattered throughout the entire storm year, with only the month of January (graph 16) exhibiting more frequency than non-ENSO Januarys. Spatially, ENSO events exhibit greater connectivity, but do not appear to focus on one particular portion of the study coastline (table 2).

End Notes

Assail, N. Daniela. 1992. Comparative Analysis of Winter Storm Episodes and Significant Wave Events: Newport, Oregon 1982-1990. M.S. Research Paper, Department of Geosciences, Oregon State University, Corvallis, Oregon.

Booth, Benjamin J. 1992. A Spatiotemporal Analysis of the Correspondence of Wave Climates and Weather Events on the Washington and Oregon Coasts: Winters 1980-81 Through 1989-1990. M.S. Research Paper, Department of Geosciences, Oregon State University, Corvallis, Oregon.

EarthInfo. 1992. NCDC Surface Airways. CD-ROM

Jackson, P.L., C.L. Rosenfeld 1987. Erosional Changes at Alsea Spit, Waldport, Oregon. Oregon Geology, 49(5):55-59.

Komar, Paul D. 1986. The 1982-83 El Nino and Erosion on the Coast of Oregon. Shore and Beach, 54:3-12.

Komar, P.D., W. Quinn, C. Creech, C.C. Rea, and J.R. Lizarraga-Arciniega 1976. Wave Conditions and Beach Erosion on the Oregon Coast. Ore Bin, 38(7):103-112.

Peterson, C.D., M. Hansen, G. Briggs, R. Yeager, I.A. Saul and P.L. Jackson, C.L. Rosenfeld, G. White, B. Booth, H. Zhang, D. Assail and T.A. Terich. 1992. Regional Sediment Dynamics and Shoreline Instability in Littoral Cells of the Pacific Northwest. The National Coastal Resources Research and Development Institute. Portland, Oregon.

Peterson, C.D., P.L. Jackson, C.L. Rosenfeld and A.J. Kimerling 1990. Littoral Cell Response to Interannual Climatic Forcing 1983-87 on the Central Oregon Coast, USA. Journal of Coastal Research, 6:87-110.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration. 1973-1994. Daily Weather Maps, Weekly Series. Washington D.C.

Zhang, Hongyun. 1991. Characteristics of Oregon Coast Winter Storm Events from 1981-1990. M.S. Research Paper, Department of Geosciences, Oregon State University, Corvallis, Oregon.