AN ABSTRACT OF THE THESIS OF

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Title: Meteorological Reconstruction of the Lewis and Clark Expedition

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Meriwether Lewis and William Clark explored the lands from Missouri northward and westward to the Pacific Northwest during the years 1804 to 1806. They kept records of the weather they encountered along their trip. These weather records were analyzed to: 1) describe the weather they encountered, 2) determine if their data fit within the range of today's observations, and 3) suggest possible explanations to account for any differences in their data.

Lewis and Clark's weather data were obtained from their journals, and the National Weather Service's weather data were obtained from the National Climatic Data Center and the Climate Prediction Center. The weather data analysis focused on Lewis and Clark's two main stops on the trip, Fort Mandan and Fort Clatsop. Through analysis of the wind direction provided by Lewis and Clark at both locations, hypothetical weather maps were constructed in order to explain the weather they

encountered more thoroughly. Lewis and Clark's temperature and precipitation data were compared to the National Weather Service's temperature and precipitation data visually through the construction of box plot diagrams.

It was found that Lewis and Clark's weather at Fort Mandan did not deviate greatly from modern observations. December 1804 and January 1805 were found to be a few degrees Fahrenheit on the colder end of the modern range of temperatures. The number of days with precipitation was somewhat higher in March and April 1805 than it is today, but these values were not outside the range of modern data. It was also found that Lewis and Clark's time in the Pacific Northwest could have been one of the rainiest on record. Further analysis by studying tree rings or cyclic climate episodes may further support these findings.

Meteorological Reconstruction of the Lewis and Clark Expedition

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Chapter 1

Introduction

Background

During the years 1804 through 1806, Meriwether Lewis and William Clark explored lands from Missouri northward and westward to the coast of the Pacific Northwest (Fig. 1-1). During their trip, they recorded information about the geography of the newly acquired territory, as well as information about the ethnology, zoology, botany, mineralogy, astronomy, hydrology, and weather phenomena (Lewis, 1959). My focus will be on describing the weather experienced by the expedition. Lewis and Clark gathered data on temperature, sky condition, wind direction, and river depth, which they recorded in monthly tables (Lewis, 1959), and this data have not been studied extensively. In their journals separate from the data tables, they also added weather remarks, such as increases in snow depth, etc.

Previous Work

Some work has been done regarding the weather of the Lewis and Clark Expedition. Large (1986) mentioned that the 1804-1805 winter Lewis and Clark experienced in North Dakota might have been colder than modern temperature data over the last 30 years, but he did not analyze and discuss this through their entire journey. Large (1986) also mentioned how stormy Lewis and Clark's stay was in the Pacific Northwest, and he showed a weather map of a mid-latitude cyclone

Figure 1-1: Map of Lewis and Clark's Route.

comparable to one that Lewis and Clark may have experienced while staying in the Pacific Northwest.

Bluemle (1999) made other comments on the weather Lewis and Clark experienced in North Dakota. His focus was mainly on the geology that Lewis and Clark encountered, but he did quote from the journals on how harsh the winter of 1804-1805 was in North Dakota. Bluemle (1999: 17) also mentions that there was one instance in which Clark wrote "...a verry Cold morning the Thmt. Stood at 45°[F] below 0...about 8 oClock P.M. the thermometer fell to 74°[F] below the freezing pointe" that did not seem to make any sense. The reason is a temperature of 74°F below the freezing point would actually equate to a 3°F rise in temperature. However, it seems as if Clark paraphrased too much. From the journals, it is noted that the high temperature on this day (17 December 1804) was 28°F below zero (Lewis, 1959). Therefore, Clark probably experienced the following: a temperature of 45°F below zero in the morning, rising to 28°F below zero in the late-afternoon hours, and then falling back to 74°F below the freezing point by 8 p.m.

Purposes

As previously mentioned, my focus will be on describing the weather Lewis and Clark experienced. Using Lewis and Clark's data and analogs derived from modern data available from the United States National Weather Service, I will concentrate on three things: 1) describing the weather Lewis and Clark encountered during their journey, 2) determining if the Lewis and Clark temperature data fits within the range of modern observations, and 3) suggesting possible explanations if the Lewis and Clark data differs from modern observations.

Weather Description

Lewis and Clark's weather records, especially wind direction, were analyzed in order to deduce where low pressure systems, high pressure systems, and fronts were at the time. From this, weather maps were constructed for the times when Lewis and Clark were at Fort Mandan and at Fort Clatsop in order to visually explain the weather occurring at the time and why it was occurring (i.e. was a mid-latitude cyclone moving by?).

Lewis and Clark's Data vs. Today's Observations

Lewis and Clark's temperature and precipitation data at Fort Mandan were compared with modern temperature and precipitation data recorded at the National Weather Service site at Bismarck, North Dakota. For Fort Clatsop, Lewis and Clark's precipitation data were compared with modern precipitation data recorded at the National Weather Service site at Astoria, Oregon. Temperature data at Fort Clatsop were not compared, since Lewis and Clark's last thermometer broke prior to their arrival at Fort Clatsop. This fact will be further addressed in chapter 2. By doing these differentiations, it can be determined whether or not Lewis and Clark's data fits within the range of today's observations.

Possible Explanations for Difference in Lewis and Clark's Data

The Little Ice Age: Ice ages (or glaciations) are times in history when the Earth can be thought of as being in an icehouse mode with polar climates and continental glaciers expanding toward the equator. The Little Ice Age was a period of time from approximately A.D. 1550 to 1850 when average global temperatures were lower and continental glaciers expanded (Crowley and North, 1991). It was smaller in terms of its overall coverage area and length of time as compared to other ice ages in Earth's history. Nonetheless, it is an import factor to consider, since the Lewis and Clark journey occurred during a time when Little Ice Age climate patterns were active. Given the expanse of polar climates during ice ages, it can be concluded that the polar jet stream would have pushed closer toward the equator.

The polar jet stream is a fast moving air stream located in the upper atmosphere, and can be thought of as a boundary between the cold air to the north and the warm air to the south (Ahrens, 2000). This strong difference in temperature, creates a strong difference in pressure per the Ideal Gas Law. The Ideal Gas Law is given by:

$$P = \rho RT$$

Equation 1-1: Ideal Gas Law (Cotton and Anthes, 1989)

where P is the pressure, ρ is the density, R is the ideal gas constant, and T is the temperature. Basic algebra states that if one side of the equation is adjusted, then the other side of the equation must be adjusted by the same amount or the equality will no longer exist. Thus, strong temperature contrasts give rise to strong pressure contrasts all other factors being equal. Wind comes from the horizontal differences in air pressure. And the stronger the difference in air pressure, the stronger the wind becomes (Cotton and Anthes, 1989). Therefore, the polar jet stream can be thought of as a boundary between the cold air to the north and the warm air to the south. If the polar regions expand equatorward, then the polar jet stream also must migrate to the south.

The polar jet stream provides a strong influence on storm tracks (Cotton and Anthes, 1989). In other words, the mid-latitude cyclones will follow the track of the polar jet stream. If the jet stream is farther equatorward, then the majority of the storm systems will also be closer to the equator. This is why taking into account the Little Ice Age is so important. Not only should the average global temperatures have been cooler, but the actual track of the polar jet stream should have forced the mid-latitude cyclones to go farther equatorward (Figs. 1-2 and 1-3). This is significant because instead of a given area experiencing warm and dry conditions on the southern side of the polar jet stream, the same area may experience cooler and wetter conditions if the polar jet stream dives far enough south. This type of modification in the track of the polar jet stream could easily come about with the influence of the Little Ice Age.

El Niño of 1804: Another important work is that of Quinn et al. (1987), who backtracked El Niño over the past four and a half centuries. They noted from the study of ancient annual records of the Nile River at Alexandria that 1804 was a moderate El Niño year. This moderate El Niño would then be in effect during the

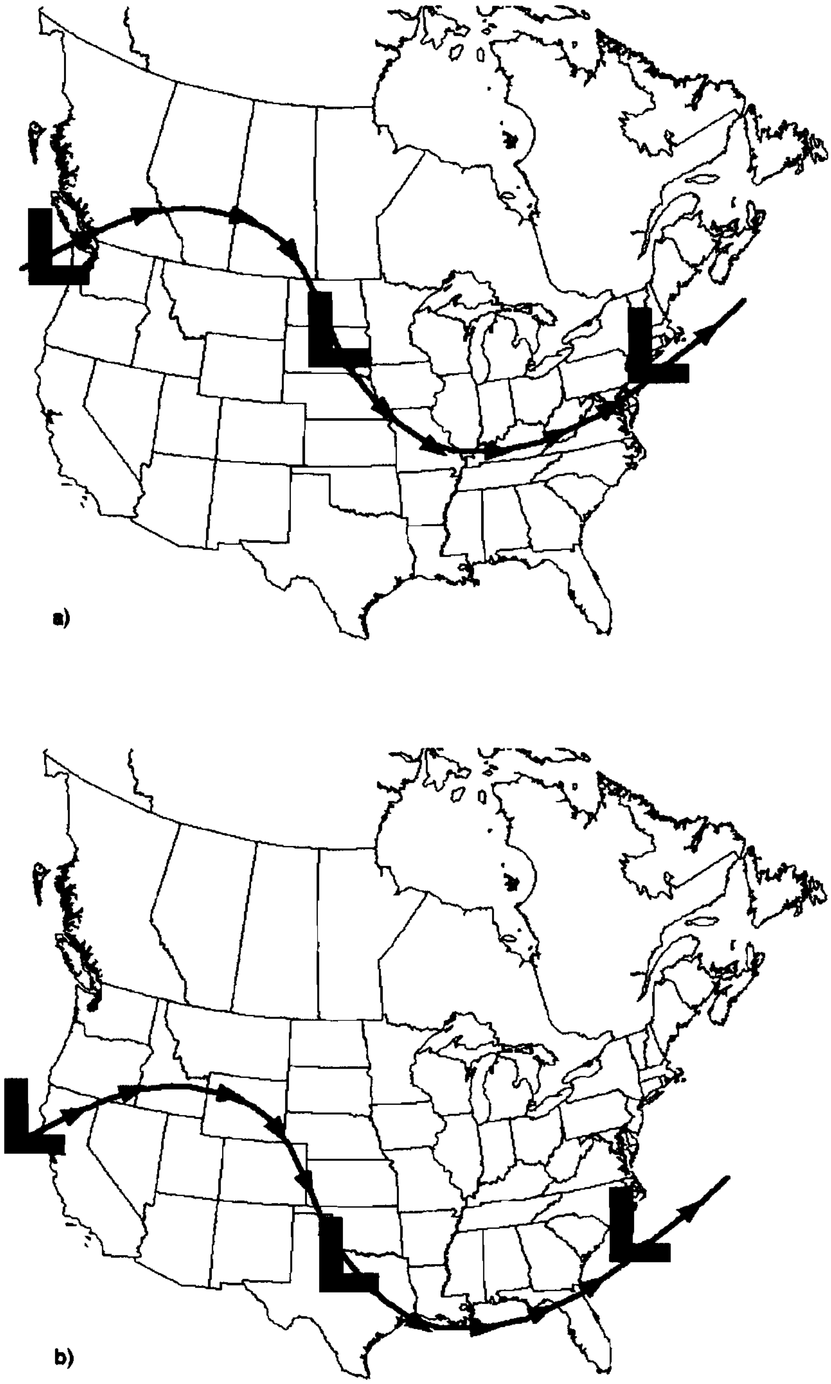


Figure 1-2: Jet Stream Tracks in Meridional Flow.

a) shows a typical jet stream unaltered by the Little Ice Age, **b)** shows how this same jet stream would take a track farther south due to the expanse of polar climates in the Little Ice Age

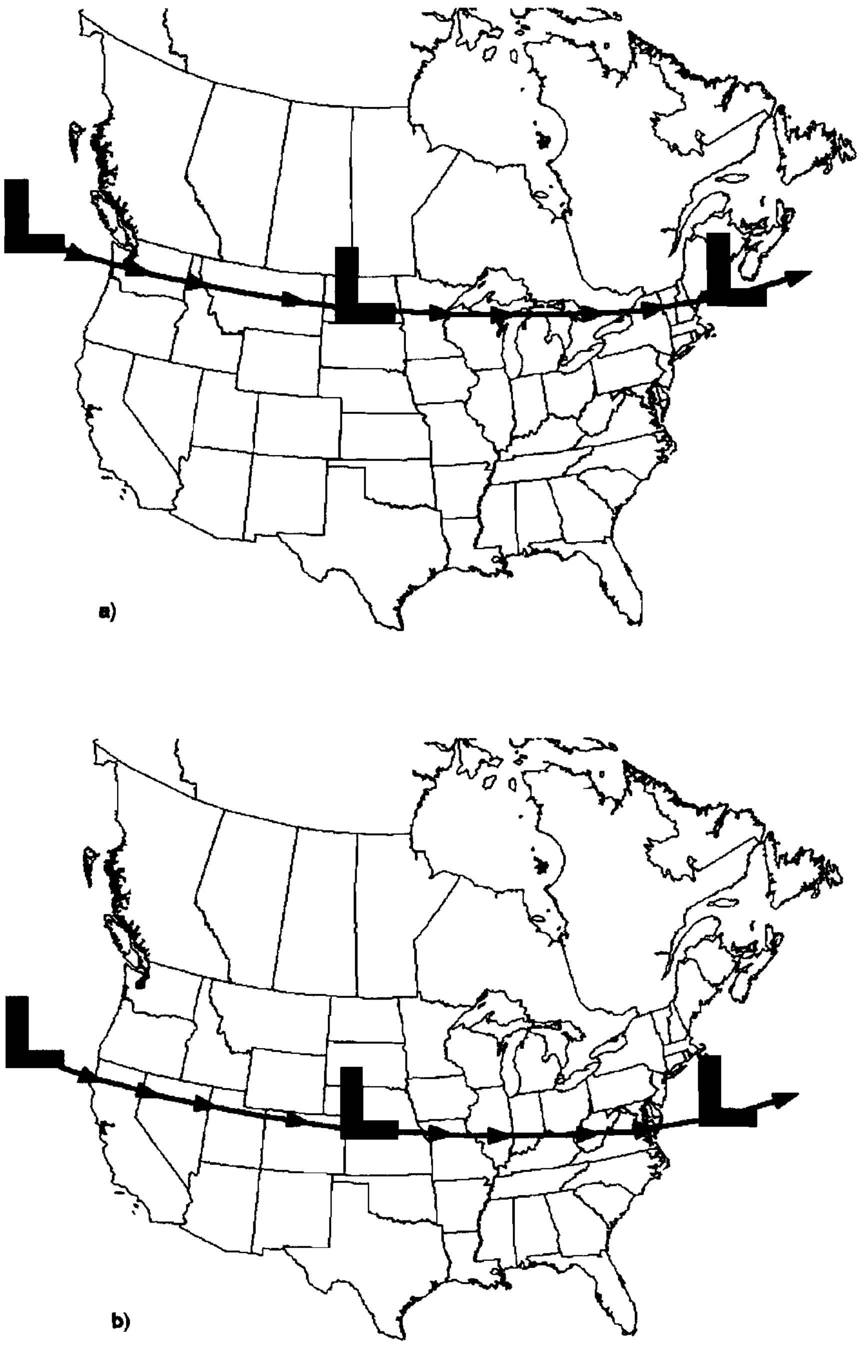


Figure 1-3: Jet Stream Tracks in Zonal Flow.

a) shows a typical jet stream unaltered by the Little Ice Age, **b)** shows how this same jet stream would take a track farther south due to the expanse of polar climates in the Little Ice Age

Lewis and Clark journey from St. Louis, Missouri to Fort Mandan (near present day Bismarck), North Dakota. This would include the months of May through December 1804. El Niño is defined as warmer than normal ocean water off the coast of Peru and Ecuador (Lamb, 1982). It is not a storm, but instead it influences the weather patterns to change by intensifying the subtropical jet stream and forcing the polar jet stream farther northward. The end result is that some areas will experience enhanced rainfall along with cooler temperatures, while other areas experience drought and warmer temperatures. Studies of past El Niño events have led to findings of certain associated weather patterns. An analysis of El Niño maps gathered from the Climate Prediction Center (Climate Prediction Center, 2001) reveals that for Lewis and Clark's journey from St. Louis to Fort Mandan, temperatures should have been near modern normal to warm, and precipitation should have been near modern normal with a brief burst of wetness from September through November.

The Little Ice Age, El Niño, and Lewis and Clark: It must be remembered, however, that both the Little Ice Age and the supposed El Niño of 1804 occurred simultaneously during Lewis and Clark's journey from St. Louis to Fort Mandan. Therefore, the effects of the two must be added together and the result should be something near what Lewis and Clark experienced through their journey from St. Louis to Fort Mandan. In other words, it would not be surprising to see Lewis and Clark's data representing somewhat cooler temperatures and somewhat heavier precipitation than today's observations in the northern Plains. By January 1805, the impact of the El Niño event should have been done, and Lewis and Clark's data should support the tail end of the Little Ice Age only. In other words, their data should indicate cooler temperatures than today's observations and the number of days with snow should have been a bit greater.

Chapter 2

Methodology

Moving vs. Stationary Points

Lewis and Clark's weather records are moving point measurements of short duration and the National Weather Service's weather records are stationary point measurements of long duration. Comparing moving point measurements of short duration to stationary point measurements of long duration is difficult. There are a couple of exceptions in the Lewis and Clark data, however, that allow them to be compared to the National Weather Service data more readily. These two exceptions are the weather data collected at Fort Mandan, North Dakota and Fort Clatsop (near present day Astoria), Oregon. Lewis and Clark spent several months at both forts, and this is enough time to allow some meaningful comparison between the data collected at the forts and modern National Weather Service data. For elsewhere on the journey, comparisons have been limited to discussion about types of weather Lewis and Clark encountered.

Lewis and Clark Data

The Thermometers

Through their journey, Lewis and Clark made careful weather observations in tabular format and included remarks as necessary (Lewis, 1959). Lewis and Clark used three mercury thermometers on their trip. When one thermometer broke, they took out another and continued recording data. Their data do present some significant problems that must be addressed before they can be compared with modern data. First, the accuracy of their thermometers is questionable. By performing experiments with the thermometers, Lewis was able to attain an error of plus or minus 8 degrees Fahrenheit (Lewis, 1959). Lewis tested this with "...water and Snow mixed for the friezing point, and boiling water for the point marked boiling water." (Lewis, 1959: 166). While, water does not boil at 212°F and freeze at 32°F everywhere on Earth due to pressure differences, this potential inaccuracy still must be remembered when comparing their temperature data to the National Weather Service's. Another very important note to make was that on the 6th of September 1805, Lewis and Clark broke their last thermometer, when the box it was in struck a tree in the Rocky Mountains (Lewis, 1959). Because of this, temperature data could not be obtained along the entire journey, but they did continue making observations of the wind and the state of the weather (Lewis, 1959). Therefore, while I have compared Lewis and Clark's temperature and precipitation findings at Fort Mandan to the National Weather Serivce's temperature and precipitation data at Bismarck, I could only compare the precipitation findings of Lewis and Clark at Fort Clatsop to the precipitation data at Astoria (no temperature data could be compared).

Temperature Collecting

Another factor to take into account was the fact that the National Weather Service takes temperature readings at 5 to 6 feet above the ground in covered louvered white structures (Ahrens, 2000). There is no mention by Lewis or Clark as to what height above the ground they recorded the temperature. There is also no indication as to whether Lewis and Clark were standing in direct sunlight when the temperature was measured or standing in a shaded area.

The Question of High and Low Temperature

Another uncertainty with the temperature data was whether or not Lewis and Clark actually recorded the high and the low temperature for a 24-hour period. Lewis and Clark made temperature observations twice a day (Lewis, 1959). One was at sunrise and the other was at 4 o'clock in the afternoon. Normally this is when the low temperature and the high temperature for the day occur respectively. The reason why this occurs is due to Earth's heat budget. Shortwave radiation comes in from the Sun through the day. This shotwave radiation is absorbed into the ground if nothing else is in the way (clouds, etc.). Planets do not create light, but instead absorb it and readmit it (Carroll and Ostlie, 1996). The Earth will send the radiation it receives from the Sun back out into the atmosphere as infrared radiation (heat energy) some 4 hours later. Due to this lag time, incoming radiation from the Sun overbalances the outgoing radiation from the Earth. Therefore, an energy surplus is achieved and the temperature rises. After 4 p.m., the outgoing radiation exceeds the incoming radiation, an energy deficit occurs, and the temperature falls. Thus, while the most intense solar radiation is at 12 noon, the high temperature for the day usually does not occur until around 4 p.m. Also on normal occasions, the low temperature for the day will occur around sunrise. This happens because the Earth continuously radiates the heat into outer space at night. Therefore, the surface will continue to cool off until it becomes warmed by the rise of the Sun.

One complication are days in which the high temperature will occur in the morning, and temperatures will then fall during the afternoon. This can happen from cold air advection behind a cold front. Cold air advection is the horizontal movement of cold air into an area resulting in a temperature fall (Ahrens, 2000). In this case, the cold front would come through around midday, and colder air would continue to move into the area through the afternoon causing the temperature to fall. Therefore, the high temperature for this day would occur just before the passage of the cold front, and the 4 p.m. temperature will not be the high temperature at all. In fact the 4 p.m. temperature, may be colder than the temperature at sunrise. Another example would be a situation where the low temperature may not occur at sunrise, but may occur around midnight with warm air advection continuing through the night and bringing in warmer air. Warm air advection is the horizontal movement of warm air into an area resulting in a temperature rise (Ahrens, 2000). Yet another way for the low temperature to occur at a time different than normal would be to have strong cold air advection through the day and have the temperature still be falling during the time when the National Weather Service records the last reading for the 24-hour period (at 11 p.m.).

The way to overcome the uncertainty of high temperature and low temperature readings is to analyze the data they gathered, noting any changes in wind direction and minor increases in temperature through the day, and see if it is reasonable or not. For example, a 25°F temperature difference between sunrise and 4 p.m. is reasonable for most of the Great Plains. However, a 3°F temperature difference between sunrise and 4 p.m. accompanied by a shift in the wind direction would indicate anomalous conditions for the day. If the high temperature and low temperature for the day appear to be anomalous, then that particular day's data was rejected, as the sunrise and 4 p.m. temperatures would not be comparable to the National Weather Service's high and low temperatures.

National Weather Service Data

Information on where Lewis and Clark were and when they were there was obtained from Lewis (1953). From this, I was able to deduce when they were at present day Bismarck, North Dakota and at present day Astoria, Oregon for statistical comparison between their data and the National Weather Service's data to be valid. Daily highs, lows, and precipitation amounts for Bismarck during the years 1948 through 1999 and daily precipitation amounts for Astoria during the years 1953 through 1998 were collected from the National Climatic Data Center (National Climatic Data Center, 2001). Seasonal mean temperatures and precipitation for El Niño events during the years 1895 through 1997 were collected from the Climate Prediction Center (Climate Prediction Center, 2001).

Weather Description

By using data recorded by Lewis and Clark in their journals, I have been able to describe the weather they encountered. Furthermore, during the time they were stopped at Fort Mandan and Fort Clatsop, I have been able to take the analysis one step further and reconstruct hypothetical weather maps showing where the low pressure systems, high pressure systems, cold fronts, and warm fronts were at the time. The way this mid-latitude cyclone reconstruction was done was by using a law in meteorology called Buys Ballot's Law. It is a basic but very powerful law in meteorology that states if you stand with your back to the wind in the Northern Hemisphere, then low pressure will be on your left and high pressure will be on your right (Ahrens, 2000). This is shown visually in Fig. 2-1. This method can be used as a first approximation, and then by taking into account storm system movement, temperature, and the associated weather Lewis and Clark experienced, a reasonable hypothetical weather map can be constructed. Unfortunately because Lewis and Clark broke their last thermometer prior to their arrival at Fort Clatsop, I was unable to construct possible locations of cold fronts and warm fronts while they were there. However, I was still able to show where low pressure systems were in relation to Fort Clatsop, since Lewis and Clark still noted the wind direction and the associated weather.

Lewis and Clark's Data vs. National Weather Service's Data

Box plots provide a convenient method to visually compare data from multiple populations. These diagrams break the data up into sections to show where the most common results are concentrated (Moore, 1995). A sample box plot is shown in Fig. 2-2. To construct a box plot diagram, all the similar data are placed in order from top to bottom. The middle 50% is placed in a box with the upper and lower 25% placed out of the box above it and below it respectively. From this box plot

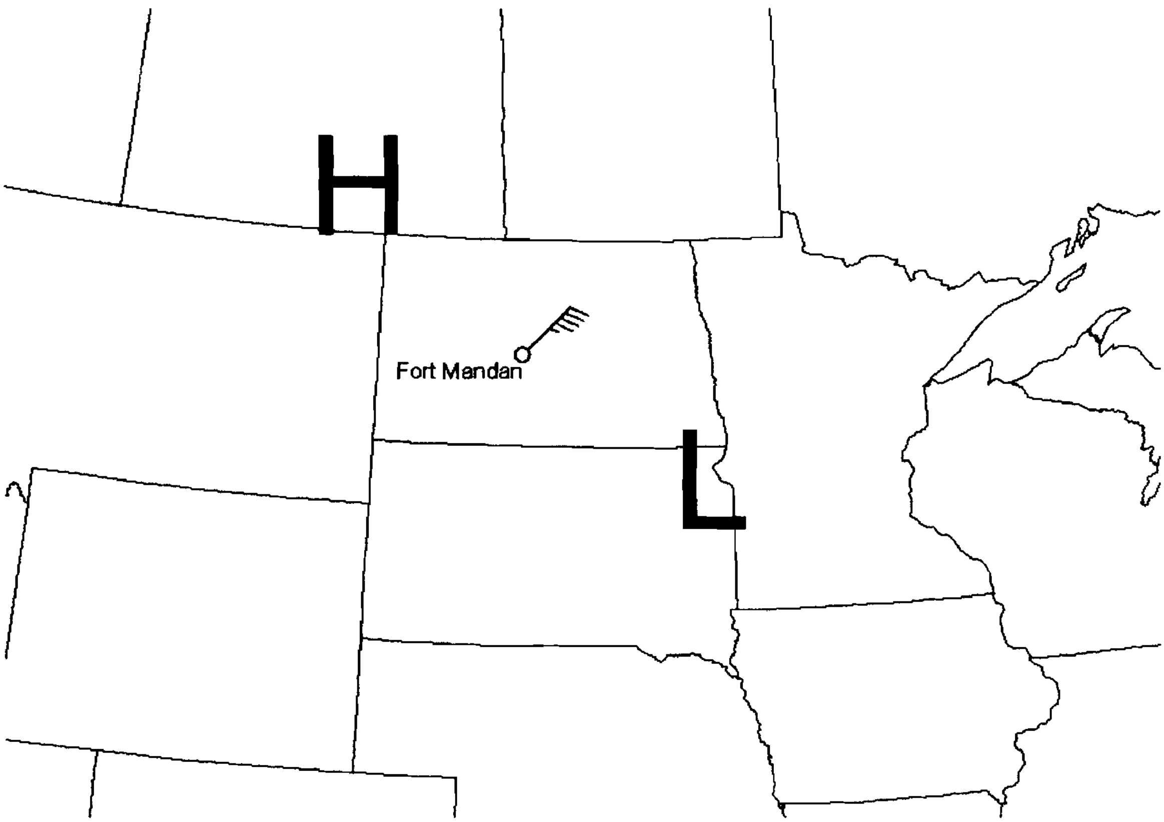


Figure 2-1: An Example of Buys Ballot's Law.

Standing with your back to the northeast wind depicted by the standard wind symbol, means to a first approximation low pressure should be off to the southeast (to the left with your back to the wind) of Fort Mandan and high pressure should be off to the northwest (to the right with your back to the wind) of Fort Mandan.

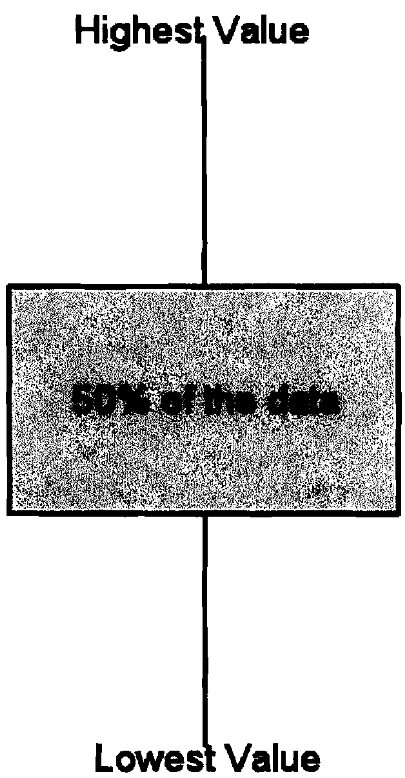


Figure 2-2: An Example of a Box Plot Diagram.

Fifty percent of the values are located in the gray box, while the upper and lower twenty five percent of the values lie outside the box between the highest value and the lowest value respectively.

diagram construction, datasets can be compared visually to see if one is similar to the other or to see if one deviates from the other.

Chapter 3

Data and Analysis

Weather From St. Louis, Missouri to Chamberlain, South Dakota

Lewis and Clark did not make many observations of the weather as they traveled from St. Louis, Missouri up the Missouri River to Chamberlain, South Dakota. However, one piece of information stands out. It is in regard to some damage that was observed on 29 July 1804. In the journals, Clark noted the following: "...passed much falling timber apparently the ravages of a Dreddfull harican which had passed oblequeley across the river from N.W. to S.E. about twelve months Since, many trees were broken off near the ground the trunks of which were sound and four feet in Diameter," (Lewis, 1953: 14). Clark was definitely on the right track in attributing the damage to high winds. However, his "harican" (or hurricane) is a tropical system, and is therefore not a likely suspect. Instead more reasonable suspects would be a tornado or straight-line winds. There is insufficient evidence to deduce the actual culprit. Given that Clark mentioned a direction of northwest to southeast that would tend to indicate that the trees might have been lying from northwest to southeast. If that it was the case, then the cause was likely straight-line wind, as a tornado would not usually lay the trees out in the same direction. Specifically, it could have been a squall line, a line of strong to severe thunderstorms, which often produce winds strong enough to knock down the trees. It could also have been a downburst from an isolated severe thunderstorm.

Weather From Chamberlain, South Dakota to Fort Mandan, North Dakota

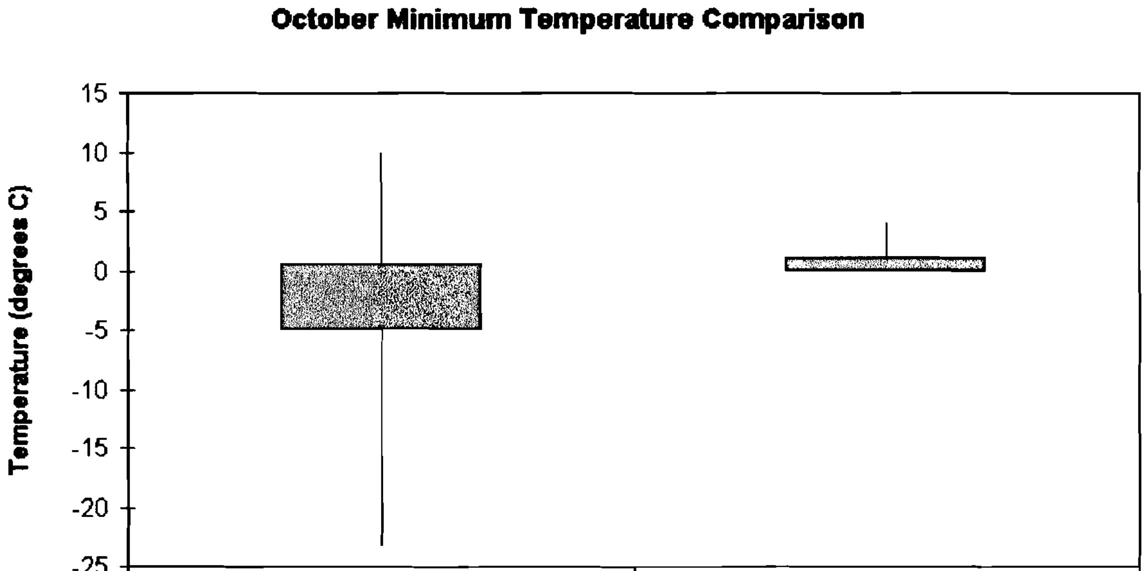
Warm afternoon temperature readings in the 80s were observed during the periods of 21-24 September 1805 and 27-28 September 1805 (Lewis, 1959). Rain was noted on the following days: 30 September, 3-4 October, 9-10 October, 13 October, and 14 October (Lewis, 1959). The first snowfall event encountered took place on the 21st of October with temperatures in the 30s all day (Lewis, 1959). Normally during this time of year, weather systems will move through every few days. The pattern of weather noted in the journals does support weather systems moving through every few days. In this regard, the weather patterns Lewis and Clark experienced during this time were similar to today's.

Weather At Fort Mandan, North Dakota

27 October 1804 – 31 October 1804

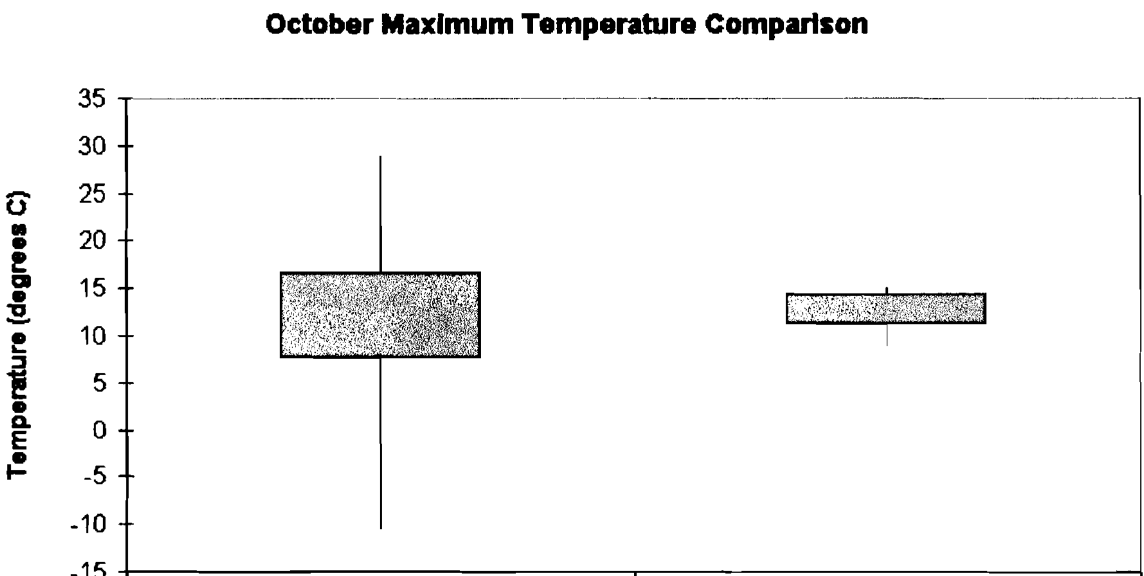
Lewis and Clark arrived in Fort Mandan on 27 October 1804. No major weather systems were noted through the remainder of the month. Temperatures were primarily in the 50s during the afternoon with the exception of the 31st, which had a 4 p.m. temperature of 48 (Lewis, 1959).

Lewis and Clark recorded minimum temperature readings during that time on the upper range of those commonly observed today (Fig. 3-1). The maximum temperature readings recorded by Lewis and Clark during that time were similar to today's readings (Fig. 3-2). Lewis and Clark did not experience any precipitation during the last few days of October, which would not be an unusual occurrence in



	National Weather Service	Lewis and Clark
75th	0.6	1.1
Max	10	3.9
Min	-23.3	0
25th	-5	0

Figure 3-1: Comparison of the National Weather Service's minimum temperatures to Lewis and Clark's minimum temperatures.



	National Weather Service	Lewis and Clark
75th	16.7	14.4
Max	28.9	15
Min	-10.6	8.9
25th	7.5	11.1

Figure 3-2: Comparison of the National Weather Service's maximum temperatures to Lewis and Clark's maximum temperatures.

the northern Great Plains (Fig. 3-3). Lewis and Clark's data and the National Weather Service's data were compared for only a few days in October. Thus, the results presented do not represent the full month of October, but rather the last few days on the month.

November 1804

No major storm systems impacted the area through the 24th of November. One might hypothesize that the conditions noted in the journal through the 24th of November could have arisen by surface low pressure systems constantly passing to the south of Fort Mandan. However, this is unlikely given that there were times where temperatures in the afternoon reached the low 60s (Lewis, 1959). Surface low pressure systems passing to the south of Fort Mandan would indicate cool air was over the area constantly, and this was not the case. Instead a more reasonable hypothesis is that a stationary front was aligned northwest to southeast across North Dakota. Every few days, a shortwave trough would move along the front causing the front to waffle back and forth across the state. A shortwave trough is an upper level disturbance that contains upward motion, clouds, and precipitation on its eastern side (Ahrens, 2000). For the most part, these shortwave troughs lacked moisture to generate precipitation. Therefore, all Lewis and Clark noted was an increase in the cloud cover (Lewis, 1959). There was one shortwave trough, however, that did have enough moisture to produce some snow from the 13th through the 15th (Lewis, 1959). This scenario of a stationary front with occasional shortwave troughs moving across, depicted in Fig. 3-4, would allow for the

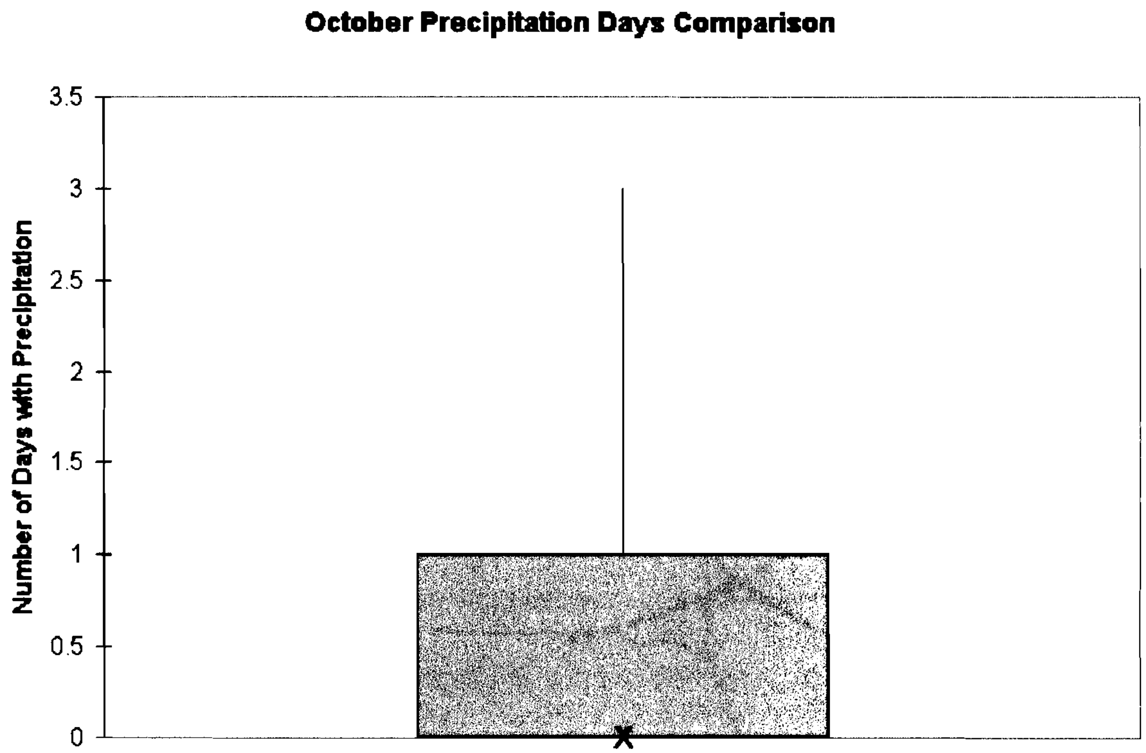


Figure 3-3: Comparison of the National Weather Service's number of days with precipitation to Lewis and Clark's number of days with precipitation. The box plot in the figure depicts the National Weather Service's range of days with precipitation. The "X" in the figure depicts the number of days Lewis and Clark experienced precipitation.

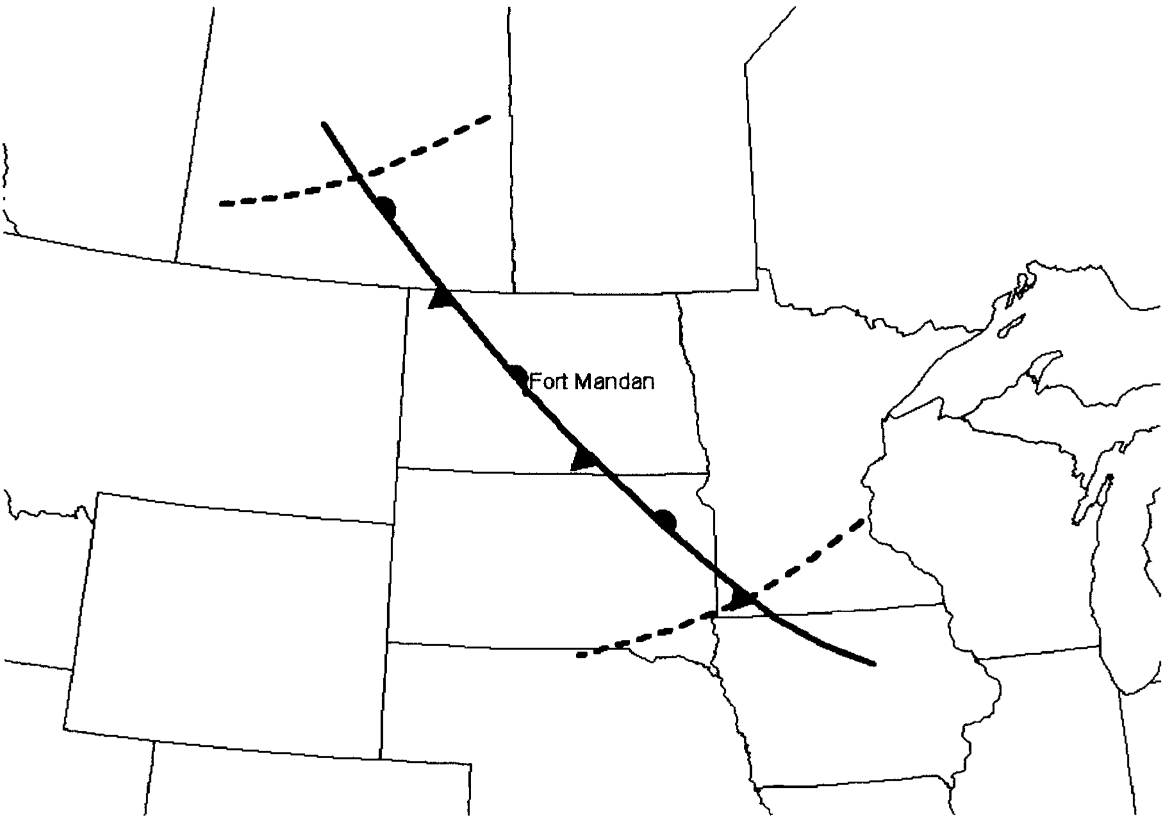


Figure 3-4: Hypothetical Weather Map 1 November – 24 November 1804. The solid line with alternating semicircles and triangles is a stationary front. The dashed lines represent shortwave troughs moving along the front. This pattern would allow the stationary front to move back and forth across Fort Mandan. When the stationary front was north and east of Fort Mandan, temperatures were warmer and when the stationary front was south and west of Fort Mandan, temperatures were colder.

conditions noted in the journals. Another frontal system moved into the area on the 25 November 1804. Fig. 3-5 shows the frontal system moving across Fort Mandan. Given that the temperature was 2 degrees colder at 4 p.m. than it was at sunrise when a southwest wind was observed (Lewis, 1959), it is very probable that the cold front reached Fort Mandan (Fig. 3-5) at 4 p.m. This cold front decreased temperatures into the teens and 20s°F (Lewis, 1959). The first strong winter storm developed on the 27th (Fig. 3-6) and affected the expedition on the 28th (Fig. 3-7) and the morning of the 29th (Fig. 3-8). By 4 p.m. on the 29th, eight inches of snow was on the ground (Lewis, 1959) as high pressure developed (Fig. 3-9).

Lewis and Clark's temperature records compared to the National Weather Service's were similar to those presented for the last few days of October (Figs. 3-10 and 3-11). Lewis and Clark's minimum temperatures were in the upper range of those commonly observed today, but the maximum temperatures were similar to modern measurements. The number of days Lewis and Clark experienced precipitation also fits well within the realm of today's observations (Fig. 3-12).

December 1804

Another winter storm developed on the 5th of December (Fig. 3-13). Snow and excessive amounts of wind were reported by the expedition (Lewis, 1959). The winter storm moved out on the area on the 6th of December, as a strong Arctic high pressure system moved in (Fig. 3-14). No snowfall amounts were reported in the journals. However, given the amount of time Lewis and Clark observed snowfall, it would not have been surprising if they received several inches of snow from such a

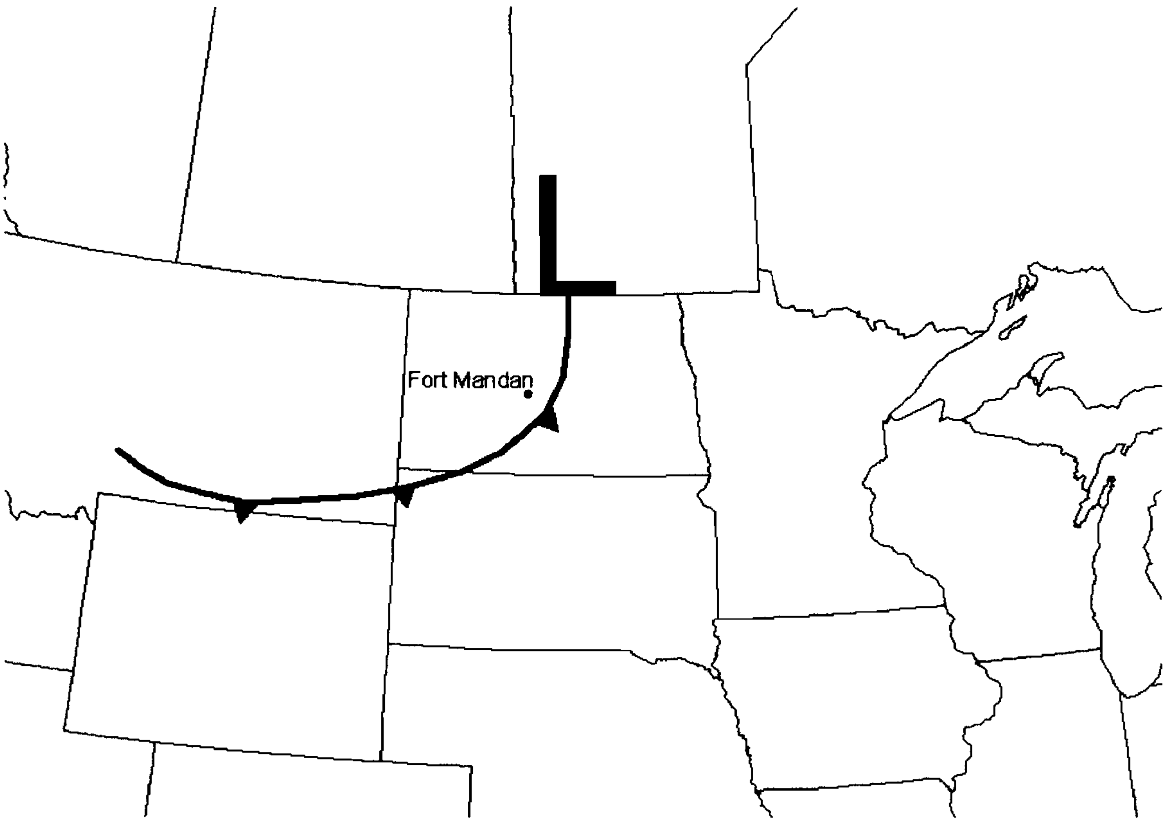


Figure 3-5: Hypothetical Weather Map 25 November 1804. A cold front noted by the solid line with triangles moves across Fort Mandan by 4 p.m.

Figure 3-6: Hypothetical Weather Map 27 November 1804. The solid line with alternating triangles and semicircles is a stationary front. At this time, a winter storm was developing to the south of the expedition. The center of the winter storm at the surface was developing over South Dakota.

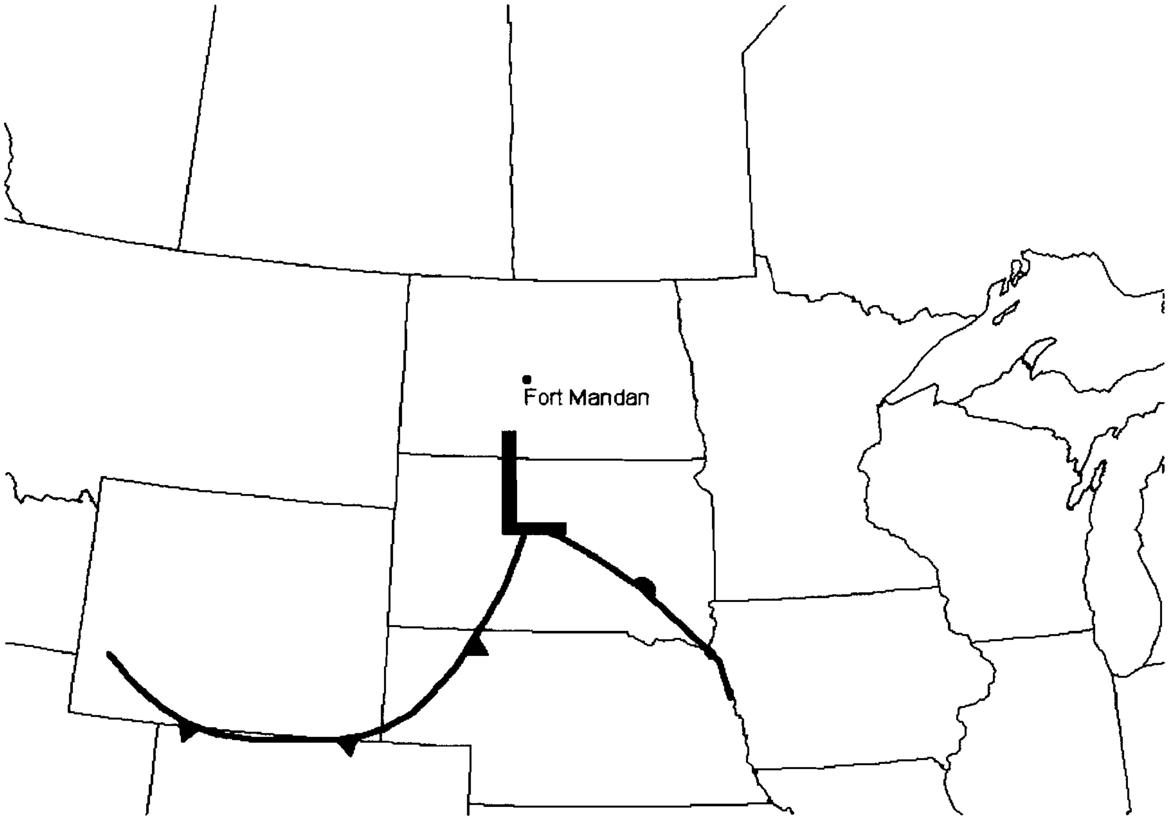


Figure 3-7: Hypothetical Weather Map 28 November 1804. The solid line with triangles is a cold front and the solid line with semicircles is a warm front. The center of the winter storm moved eastward across South Dakota. Snow fell all day at Fort Mandan.

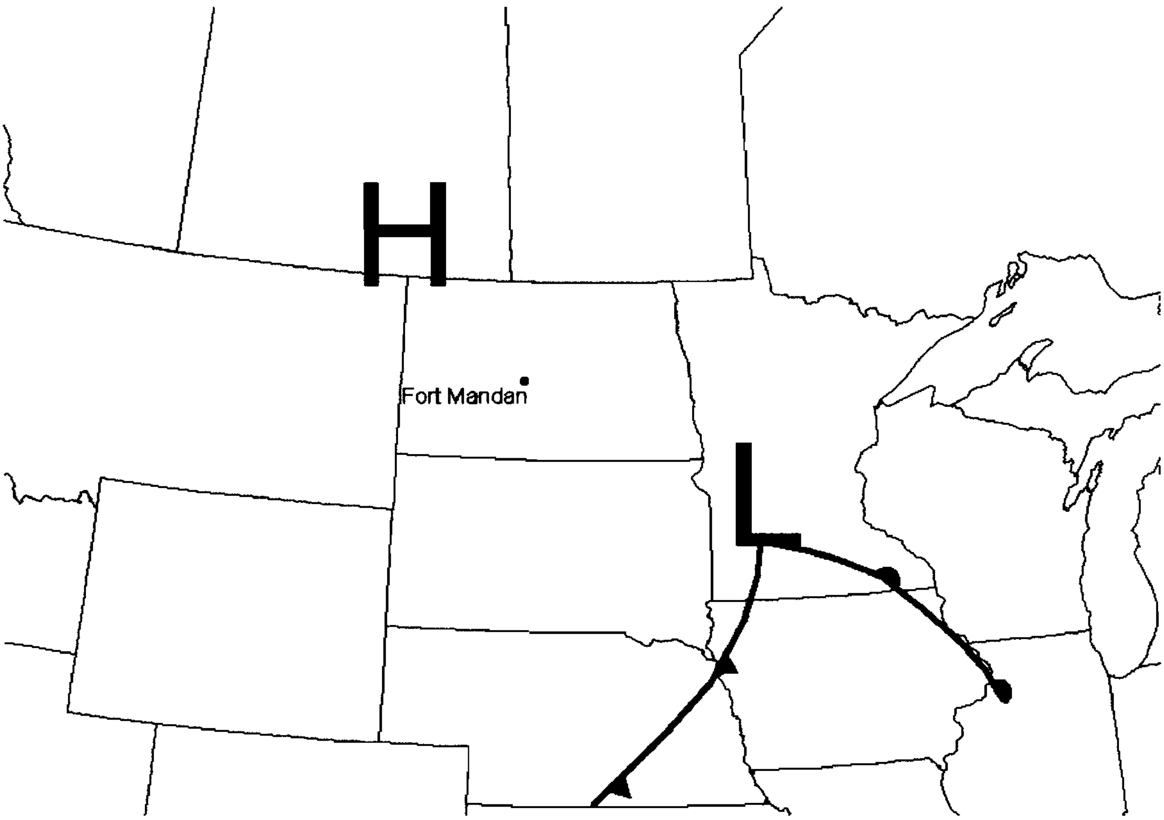
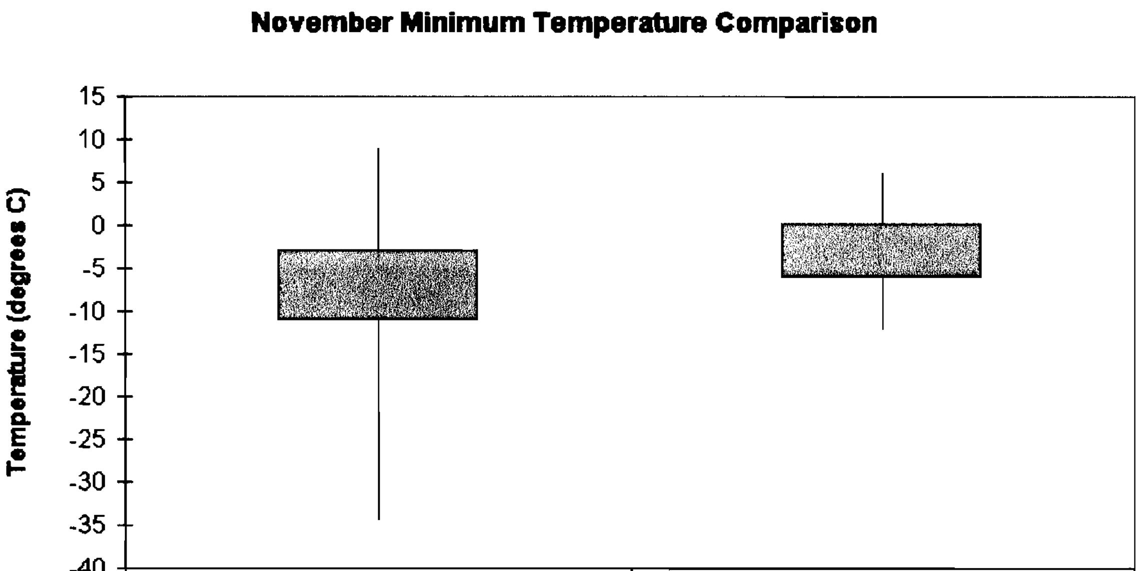


Figure 3-8: Hypothetical Weather Map Sunrise, 29 November 1804. The solid line with triangles is a cold front and the solid line with semicircles is a warm front. The center of the winter storm was moving away from Fort Mandan. Snow ended during the morning hours.

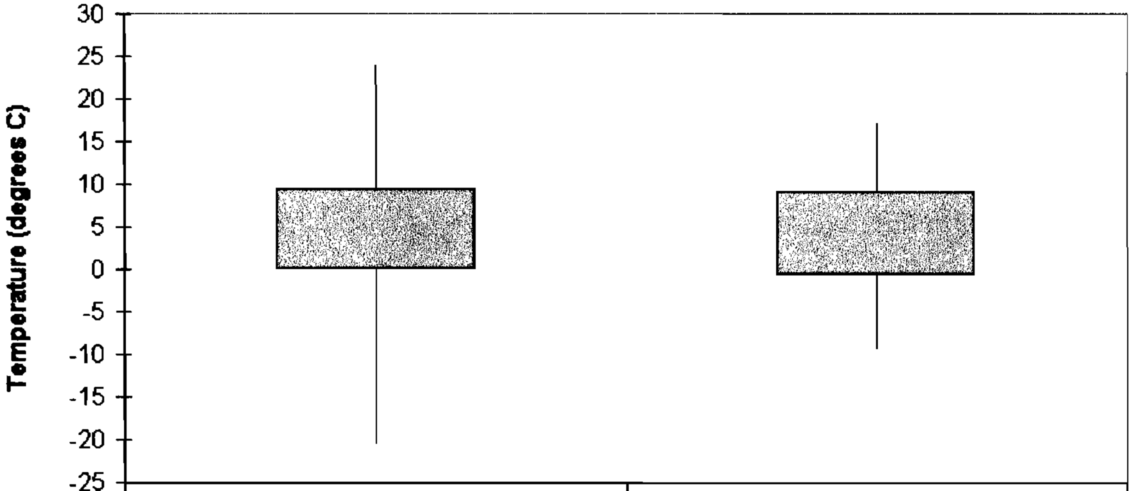
Figure 3-9: Hypothetical Weather Map 4 p.m., 29 November 1804. High pressure moved into the area and brought fair conditions.



	National Weather Service	Lewis and Clark
75th	-2.925	0.15
Max	8.9	6.1
Min	-34.4	-12.2
25th	-11.1	-6.15

Figure 3-10: Comparison of the National Weather Service's minimum temperatures to Lewis and Clark's minimum temperatures.

November Maximum Temperature Comparison



	National Weather Service	Lewis and Clark
75th	9.4	9.025
Max	23.9	17.2
Min	-20.6	-9.4
25th	0	-0.725

Figure 3-11: Comparison of the National Weather Service's maximum temperatures to Lewis and Clark's maximum temperatures.

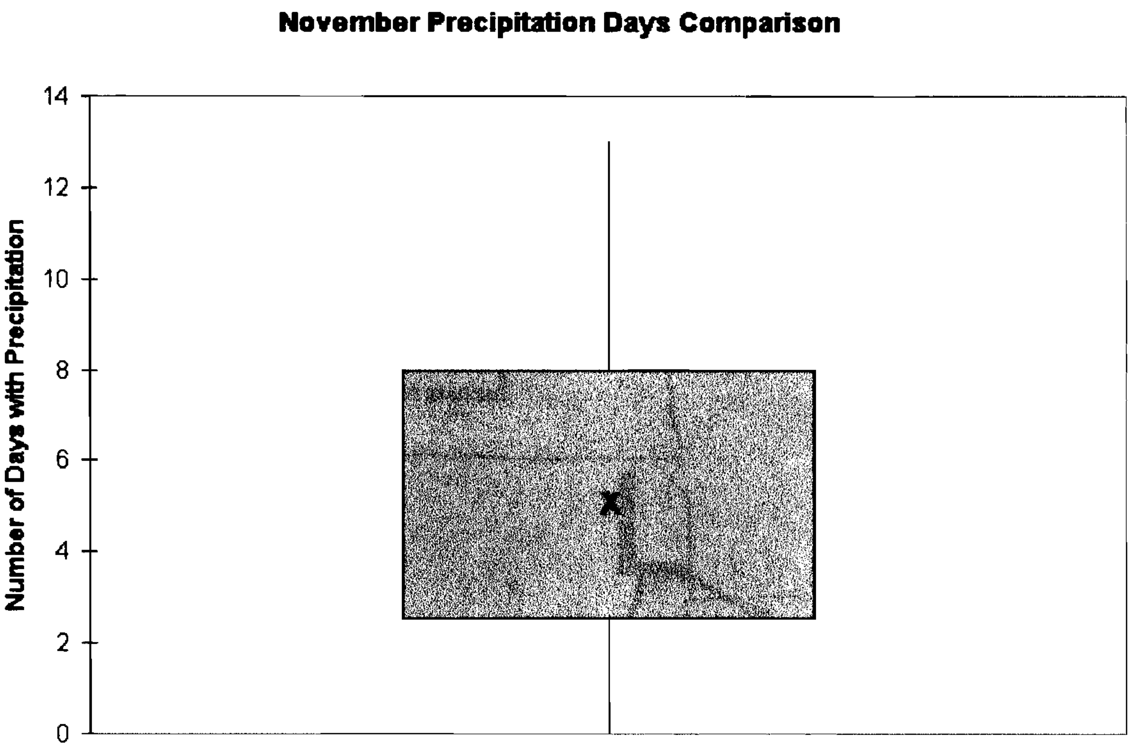


Figure 3-12: Comparison of the National Weather Service's number of days with precipitation to Lewis and Clark's number of days with precipitation. The box plot in the figure depicts the National Weather Service's range of days with precipitation. The "X" in the figure depicts the number of days Lewis and Clark experienced precipitation.

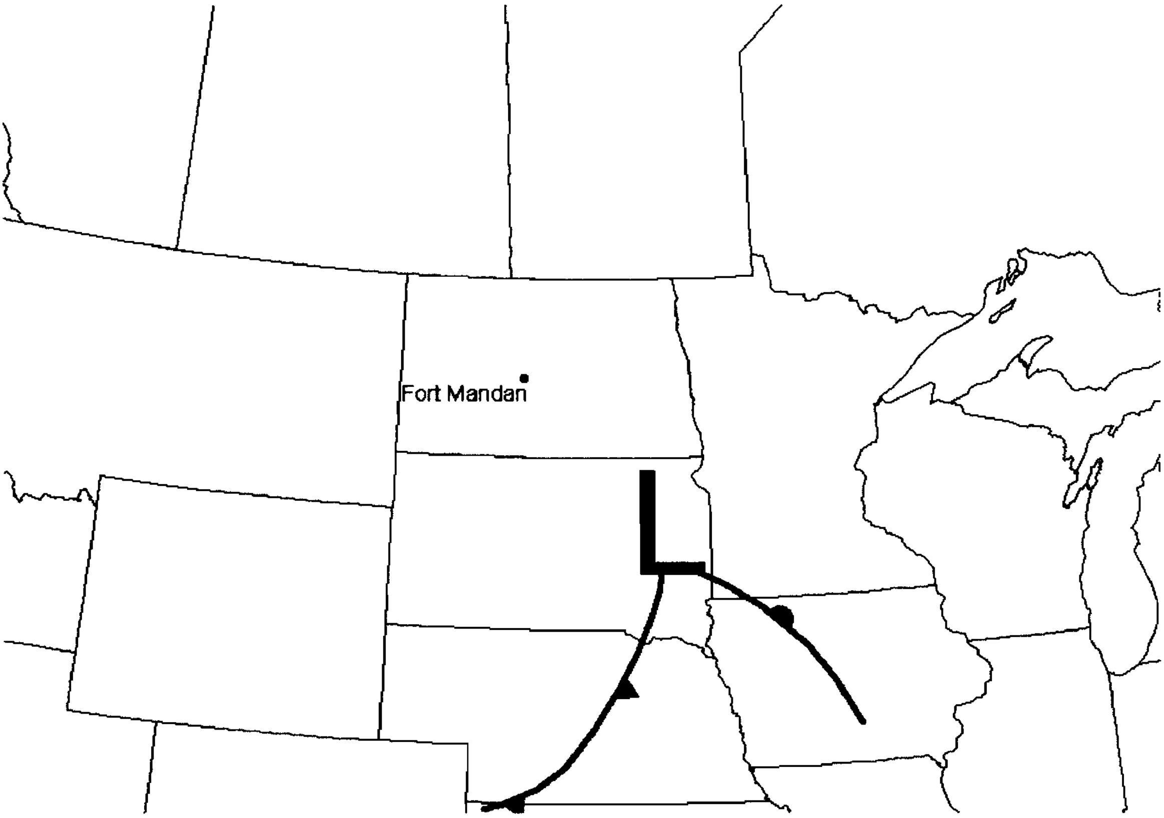


Figure 3-13: Hypothetical Weather Map 5 December 1804. The solid line with triangles is a cold front and the solid line with semicircles is a warm front. The center of the winter storm developed in South Dakota and brought another round of snow to Fort Mandan.

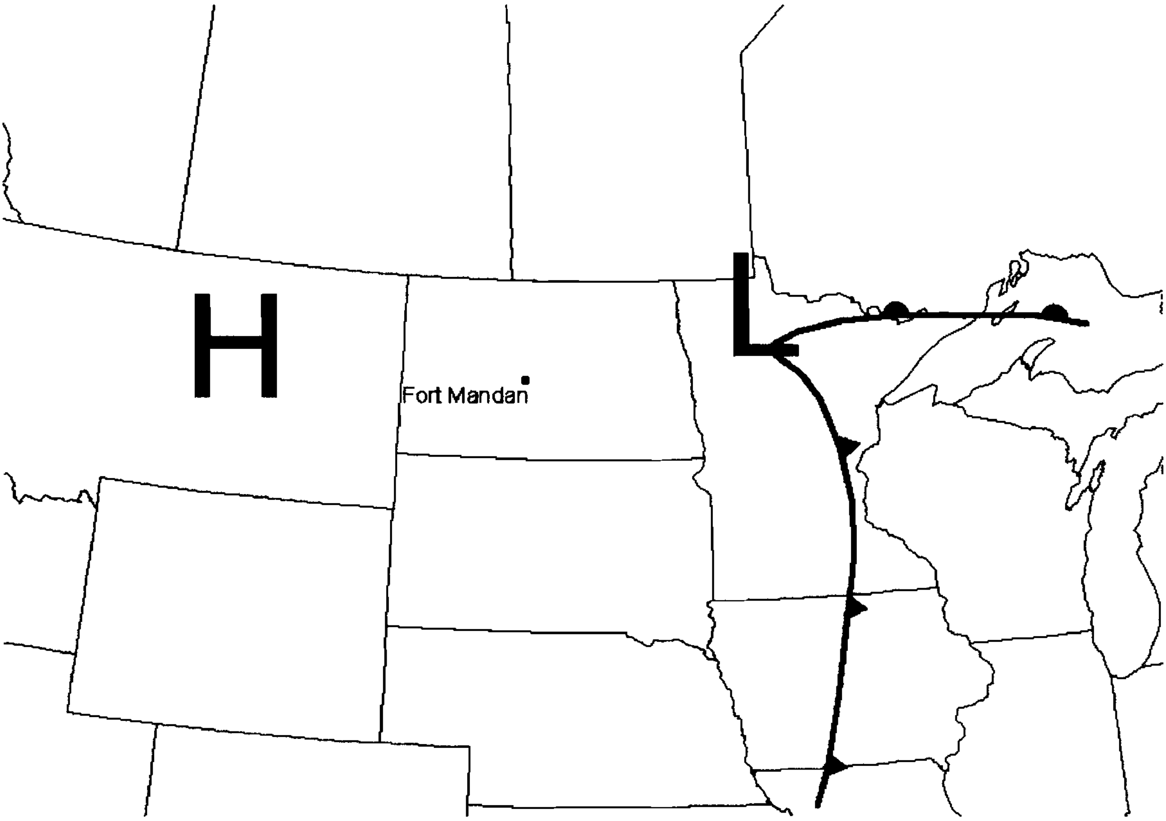


Figure 3-14: Hypothetical Weather Map 6 December 1804. The solid line with triangles is a cold front and the solid line with semicircles is a warm front. The center of the winter storm was moving northeastward away from Fort Mandan as high pressure moved in from the west. Snow ended by the afternoon.

storm system. Under the strong Arctic high pressure, the expedition recorded its first below 0°F temperature reading on the 7th of December (Lewis, 1959). Another storm system developed by late in the day on the 14th of December (Fig. 3-15) and departed by the end of the day on the 15th of December (Fig. 3-16). According to the journals, ½ inch of snow fell. Given that Lewis and Clark observed snow late on the 14th and all day on the 15th and that only ½ inch of snow fall, it is very probable that this storm system was starved for moisture. After the storm system departed, an exceptionally strong Arctic high pressure system moved in. This was the first massive outbreak of Arctic air that Lewis and Clark experienced. The temperature at sunrise on the 17th of December was –43°F (Lewis, 1959). In fact, according to the journals, after an afternoon high around –28°F, the temperature then dropped to –42°F by the evening hours (Lewis, 1959).

An increase in temperature occurred by the 20th. On that day the afternoon temperature rose to 37°F (Lewis, 1959). However, this warming trend was brief, as the next storm system arrived by the 24th of December (Fig. 3-17). According to the journals, the snowfall on this day was "verry considerable" (Lewis, 1959: 181), but no numeric value of how much snow fell was noted. Cold air then moved into area. Although this air was not as cold as the previous Arctic outbreak, it was still Arctic in nature with –20°F recorded at sunrise on the 30th.

Temperatures observed by Lewis and Clark became more variable during December 1804 (Fig. 3-18). Some of these temperatures were colder than those commonly observed today, but temperatures this low are not unheard of nowadays. The maximum temperatures recorded by Lewis and Clark do appear to be on the

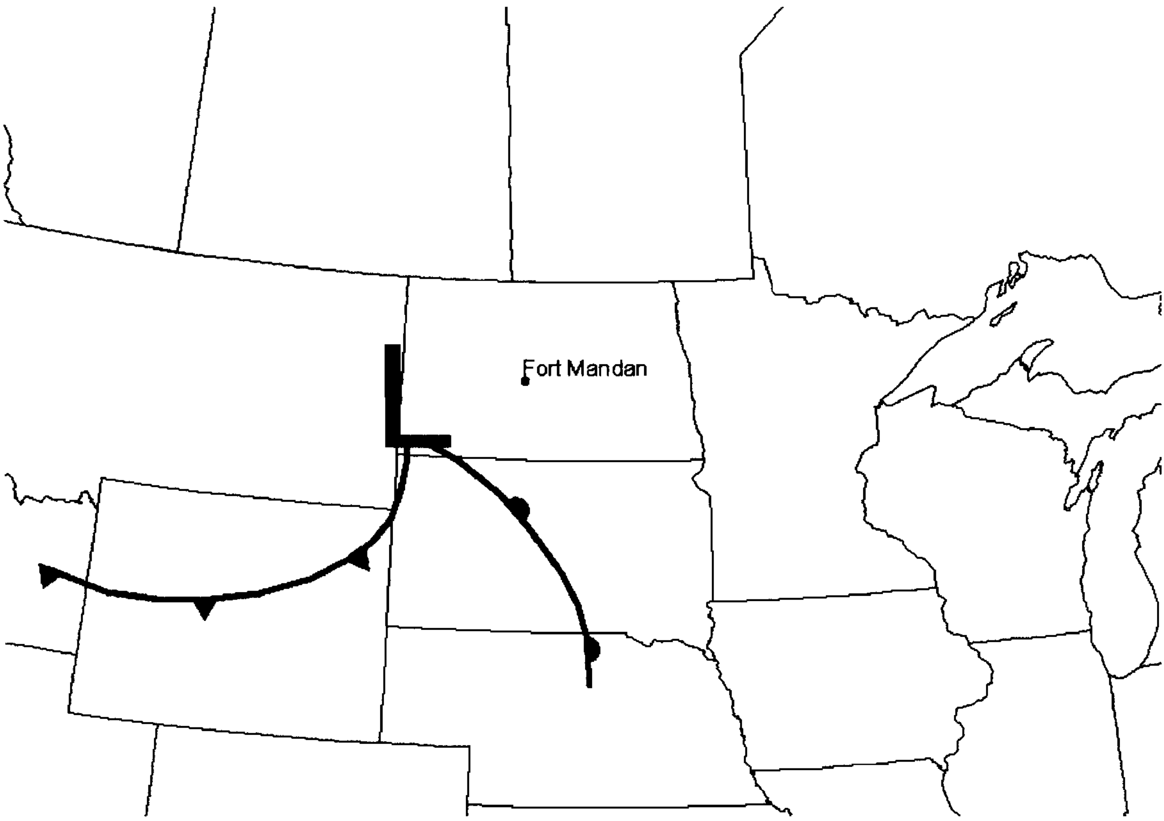


Figure 3-15: Hypothetical Weather Map 14 December 1804. The solid line with triangles is a cold front and the solid line with semicircles is a warm front. The center of the winter storm developed in Montana and moved southeastward. Snow moved into Fort Mandan by the afternoon.

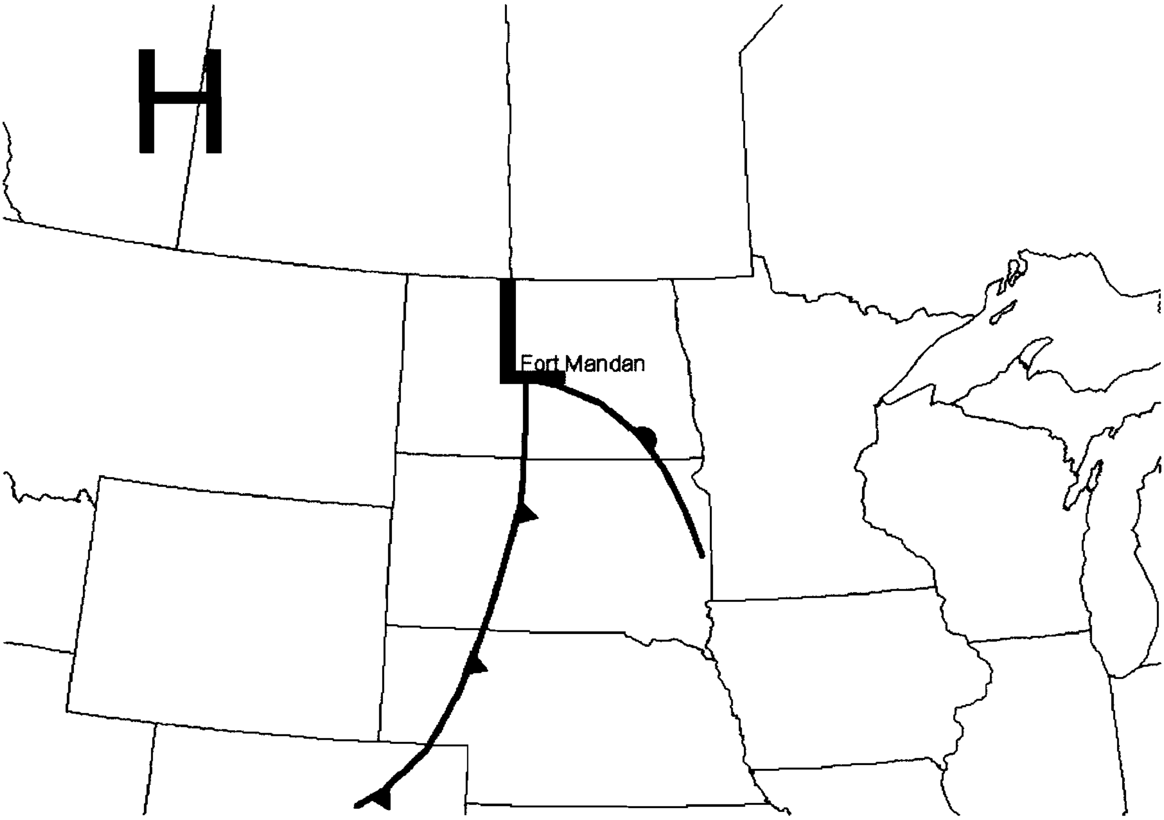


Figure 3-16: Hypothetical Weather Map 15 December 1804. The solid line with triangles is a cold front and the solid line with semicircles is a warm front. The center of the winter storm moved across Fort Mandan. Snow ended that night, as a massive Arctic high pressure moved in.

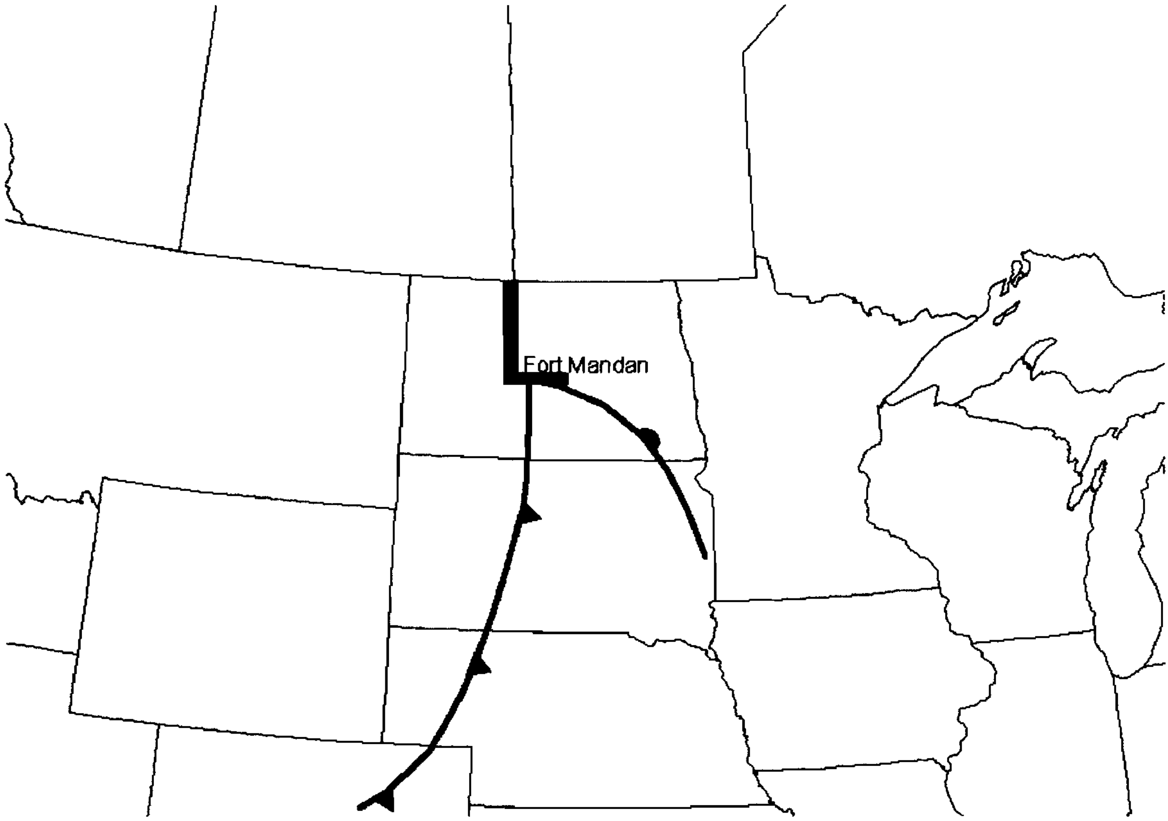
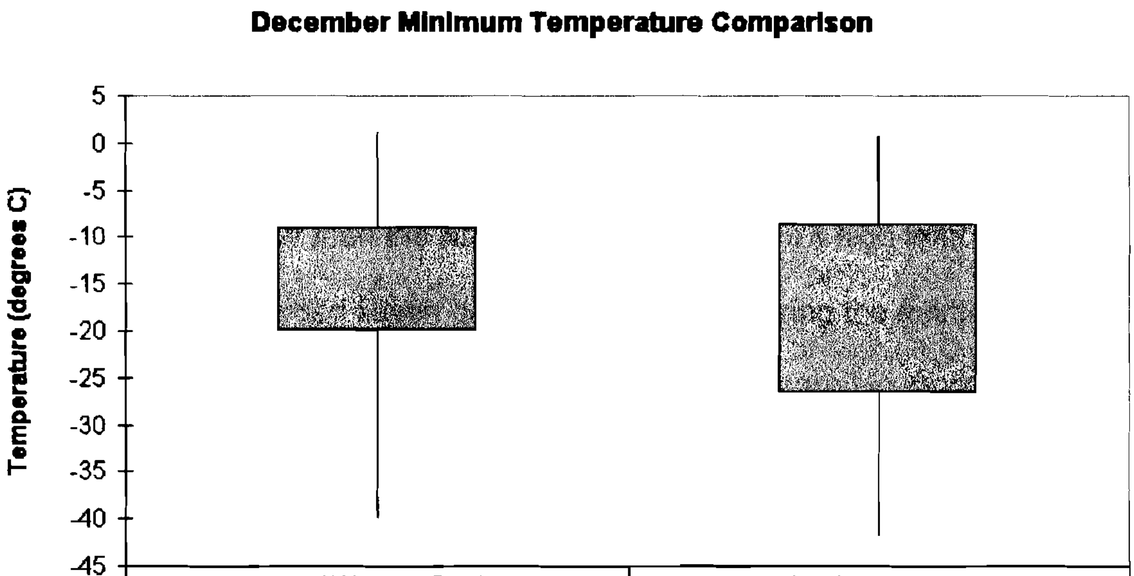


Figure 3-17: Hypothetical Weather Map 24 December 1804. The solid line with triangles is a cold front and the solid line with semicircles is a warm front. The center of the storm system moved across Fort Mandan. Snow ended the next day.



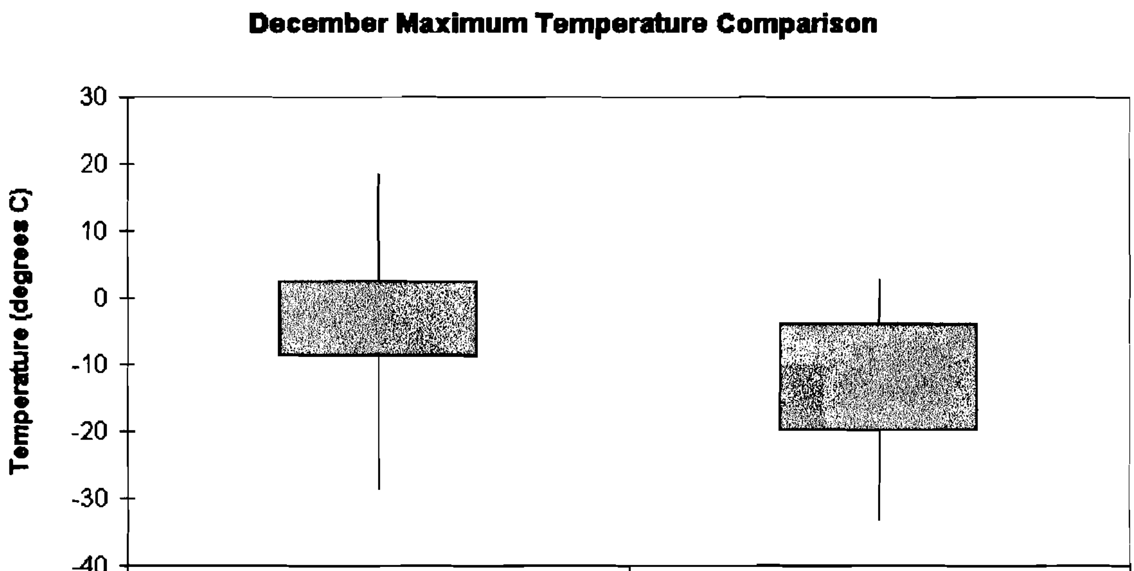
	National Weather Service	Lewis and Clark
75th	-8.9	-8.6
Max	1.1	0.6
Min	-40	-41.7
25th	-20	-26.65

Figure 3-18: Comparison of the National Weather Service's minimum temperatures to Lewis and Clark's minimum temperatures.

colder end of the scale when compared to today's readings (Fig. 3-19). Their data included one day when the low temperature was around 2°F colder than the National Weather Service's low temperatures and another day when the high temperature was around 4°F colder than the National Weather Service's high temperatures. Lewis and Clark recorded seven days of precipitation during the month of December. This value is slightly above average as compared to modern values (Fig. 3-20).

Storm Track Discussion 27 October 1804 – 31 December 1804

As mentioned earlier, 1804 is thought to be a moderate El Niño year (Quinn et. al, 1987). The storm track during the days Lewis and Clark spent at Fort Mandan in 1804 was possibly from northwest to southeast across the northern Plains states (Fig. 3-21). During a modern El Niño event the storm track is usually located farther northeastward in Canada (Ahrens, 2000), which is depicted in Fig. 3-22. The two storm tracks are similar in that they run parallel to each other. The difference is that the 1804 track is farther south. This does not mean that this storm track does not support the El Niño of 1804 hypothesis. Instead, it strengthens the hypothesis because the storm track could have easily been shifted southwestward by the expanse of polar climates during the Little Ice Age. So instead of Fort Mandan receiving little to no snowfall and warmer temperatures, the affects of the Little Ice Age allowed Fort Mandan to receive a few decent snowstorms and an outbreak of Arctic air even during an El Niño event. Given the El Niño event of 1804 was coming to an end by late in 1804, another possible explanation for the hypothetical



	National Weather Service	Lewis and Clark
75th	2.5	-3.9
Max	18.3	2.8
Min	-28.9	-33.3
25th	-8.9	-20

Figure 3-19: Comparison of the National Weather Service's maximum temperatures to Lewis and Clark's maximum temperatures.

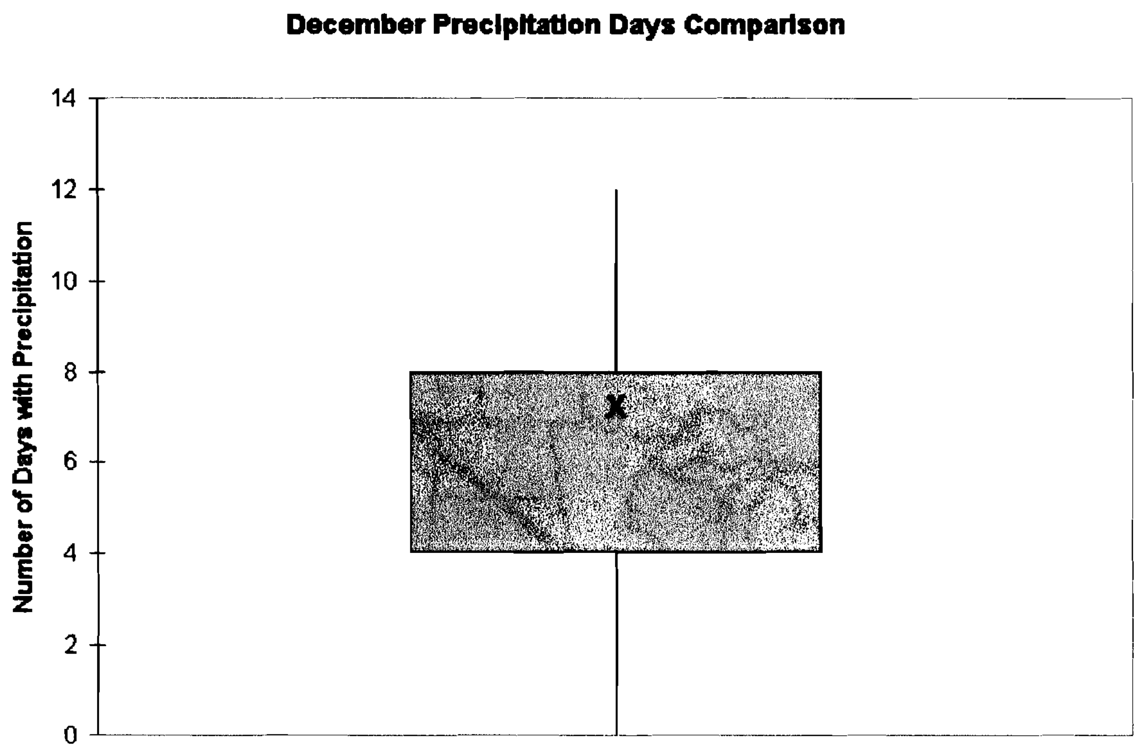


Figure 3-20: Comparison of the National Weather Service's number of days with precipitation to Lewis and Clark's number of days with precipitation. The box plot in the figure depicts the National Weather Service's range of days with precipitation. The "X" in the figure depicts the number of days Lewis and Clark experienced precipitation.

Figure 3-21: Possible average position of the polar jet stream from late-October through December 1804.

Figure 3-22: Average position of the polar jet stream during a typical modern El Niño event.

storm track (Fig. 3-21) is simply the atmosphere returning to normal as the El Niño event ends. This would also allow the polar jet stream to shift farther southwestward.

January 1805

The first strong storm system of the new year moved in by the 3rd of January (Fig. 3-23). In the journals it is mentioned that "the snow is 9 Inches Deep" (Lewis, 1959: 182) on this day. The 9 inch snow total is probably new snow on top of old snow. Nonetheless, several inches of new snow probably fell from this storm system from the 3rd on into the 4th of January. Another cold front moved through the area on the 4th of January (Fig. 3-24). This cold front brought a refreshing shot of Arctic air with it and lowered temperatures to around –20°F at sunrise and around –10°F to –15°F at 4 p.m. (Lewis, 1959). On the 6th of January, the expedition reported "at 12 oClock to day two Luminous Spots appeared on either side of the Sun extreemely bright" (Lewis, 1959: 182). These two bright spots were presumably sundogs. They formed as a result of sunlight refracting through ice crystals (Ahrens, 2000) and indicated that there was likely some cirrostratus clouds overhead during this particular day. Cirrostratus clouds are a type of high cloud that occurs 6,000 m (20,000 FT) above the ground (Ahrens, 2000). The next frontal system moved into the area by 9 January (Fig. 3-25). Given that the air before the cold front passed was in the range of –10°F to –20°F (Lewis, 1959), the frontal system was starved for moisture. Thus, only an increase in cloud cover was noted by the expedition as the front passed. This front brought the second massive outbreak of Arctic air to the

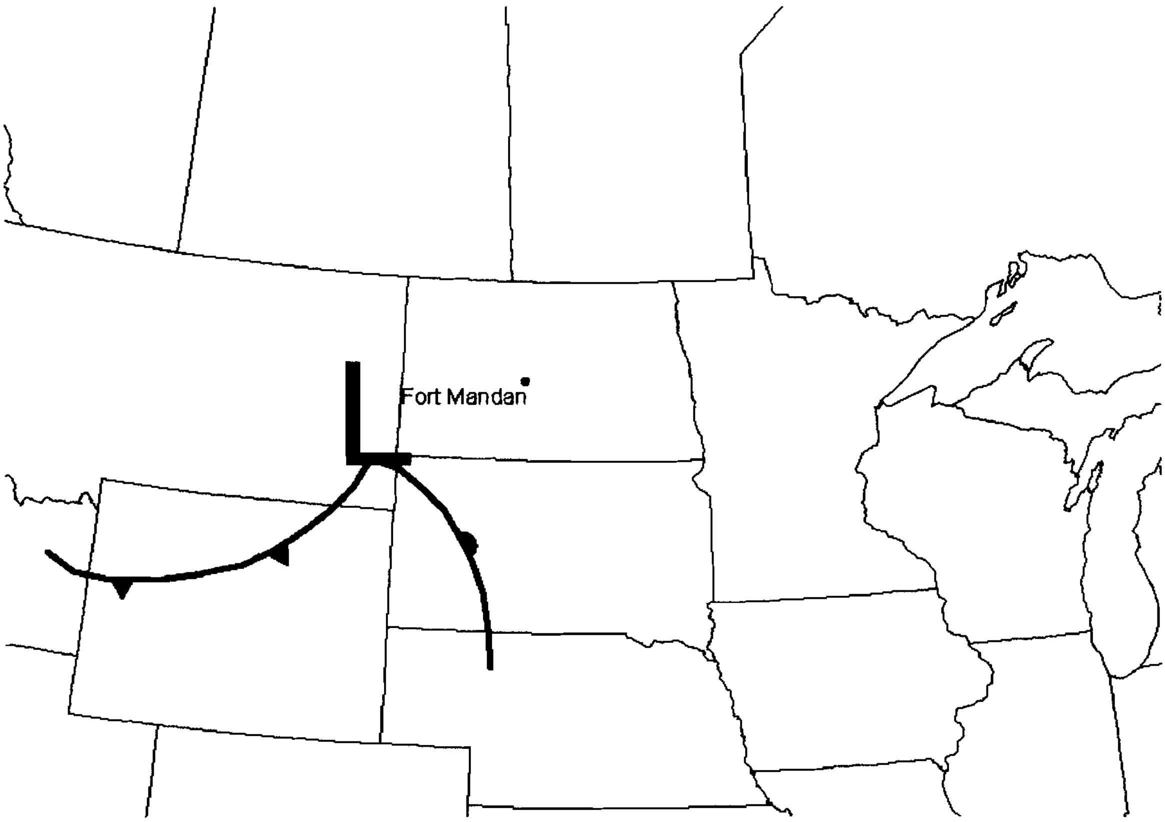


Figure 3-23: Hypothetical Weather Map 3 January 1805. The solid line with triangles is a cold front and the solid line with semicircles is a warm front. The center of the winter storm developed to the southwest of Fort Mandan and moved toward the expedition. Snow commenced during the afternoon.

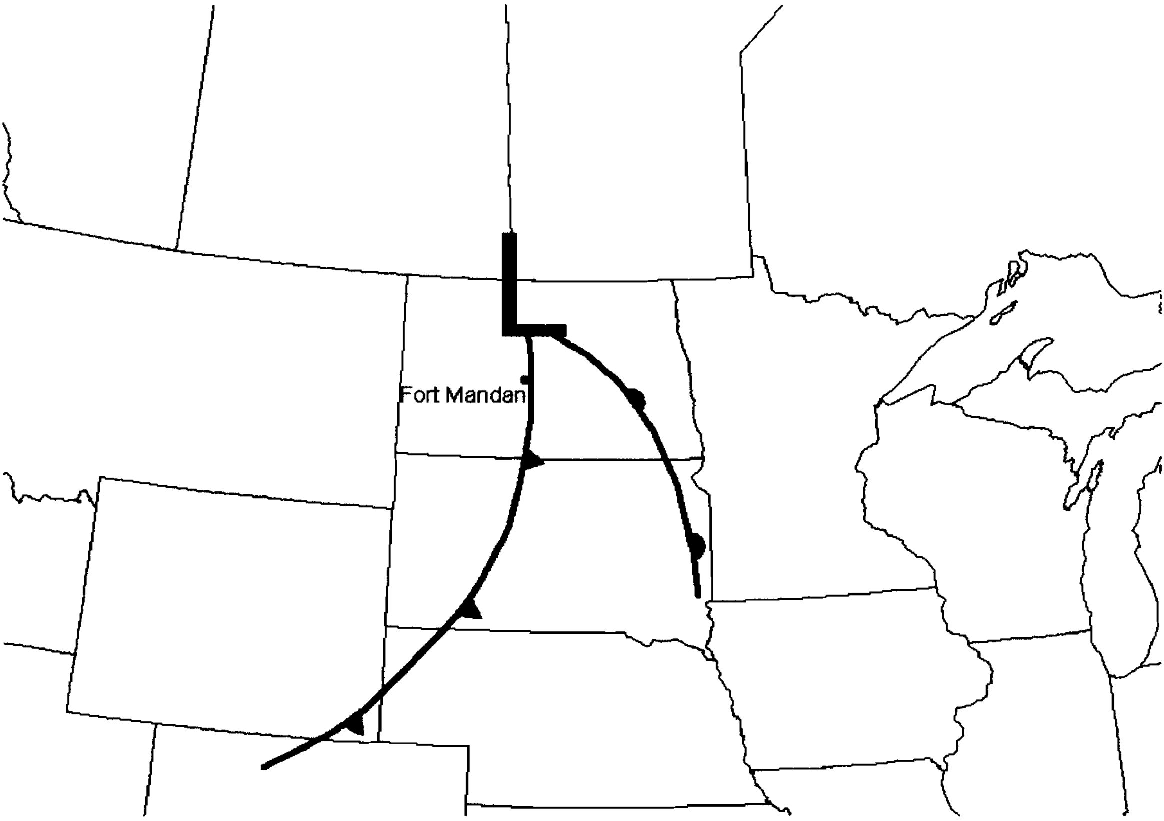


Figure 3-24: Hypothetical Weather Map 4 January 1805. The solid line with triangles is a cold front and the solid line with semicircles is a warm front. The center of the winter storm moved on to the northeast away from Fort Mandan by the afternoon with snow ending.

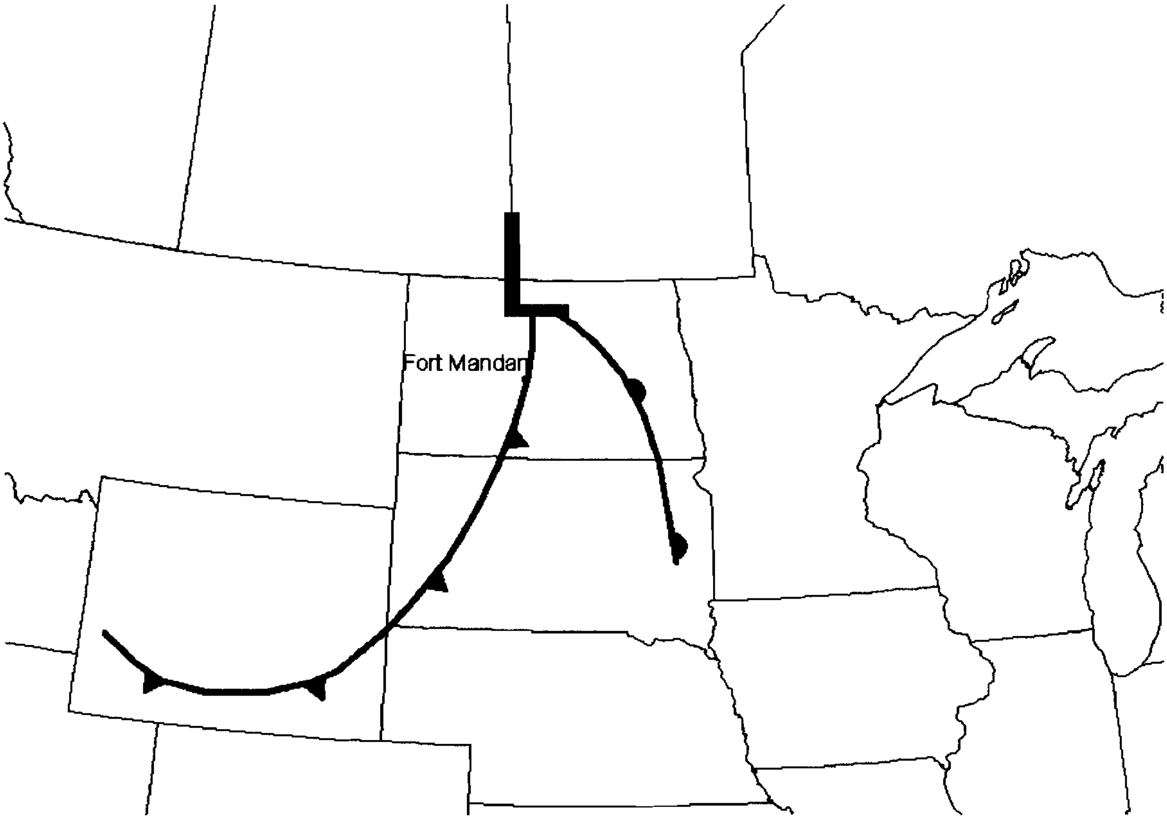


Figure 3-25: Hypothetical Weather Map 9 January 1805. The solid line with triangles is a cold front and the solid line with semicircles is a warm front. Another massive Arctic air mass moved in behind the cold front. No precipitation was reported by the expedition.

expedition. The temperature by sunrise on the 10th stood at –40°F and the temperature at sunrise on the 11th stood at –38°F (Lewis, 1959).

A reinforcing shot of Arctic air moved across on the 12th with northwesterly winds continuing and sunrise temperatures dropping from –20°F to –34°F. The expedition also observed a distinct halo at 9:30 p.m. on the 12th. A halo is a ring or series of rings that form around the Sun or the Moon, as sunlight or moonlight refracts through ice crystals (Ahrens, 2000). Again, this suggests that there were cirrostratus clouds covering the Moon during that time, and that was what caused the halo. Another winter storm moved in by the 23rd of January (Fig. 3-26) and brought another round of moderate to heavy snow to the area. The expedition reported that the snow was 4 inches deep and still falling by sunrise on the 23rd (Lewis, 1959). The high pressure system developed in the area on the 25th with a sunrise temperature of –26°F reported.

Another interesting note made by Lewis and Clark on the 25th was the following "it frequently happens that the [sun] rises fair and in about 15 to 20 minutes it becomes suddenly turbid, as if the [sun] had some chemical effect on the atmosphere." (Lewis, 1959: 182). In other words, just after sunrise, the wind speed increases. This is a normal condition, as long as there are no storm systems around the area at the time. After sunrise, the temperature begins to increase. However, the temperature increase in one area may be much slower than in another area. This was likely the case during the coldest part of the winter that Lewis and Clark experienced at Fort Mandan, where the temperature increase at Fort Mandan was very modest compared to a temperature increase farther south in South Dakota.

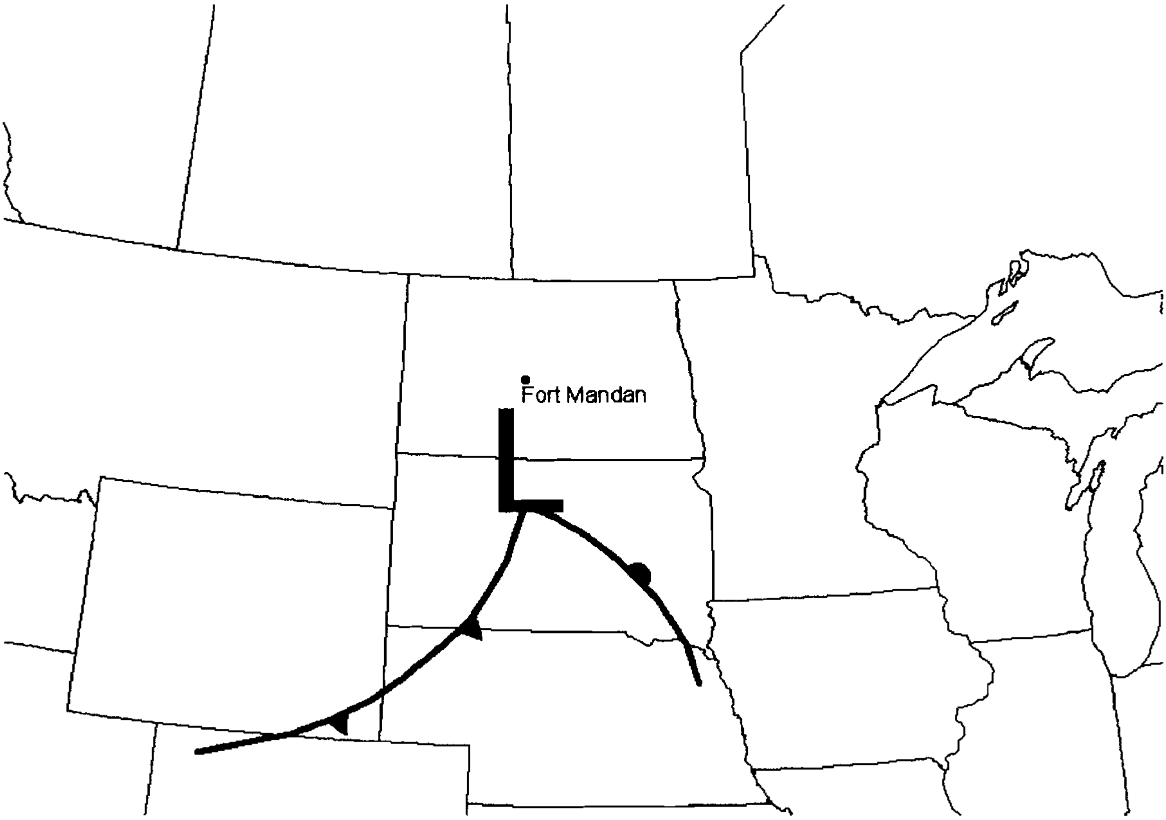


Figure 3-26: Hypothetical Weather Map 23 January 1805. The solid line with triangles is a cold front and the solid line with semicircles is a warm front. The center of the winter storm moved to the south of Fort Mandan and brought snow to expedition. The snow ended by the afternoon.

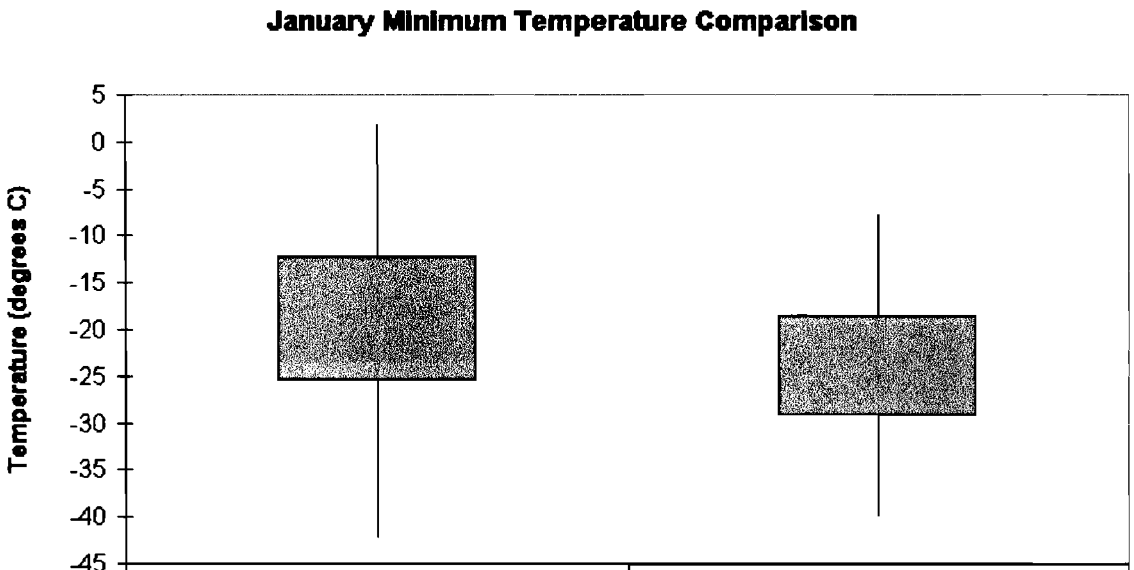
This would setup a strong temperature contrast. Per the Ideal Gas Law (Equation 1-1), the strong temperature contrast gives a strong pressure contrast and an increase in the wind speed.

Lewis and Clark's temperature readings were in the lower range of those commonly observed today (Figs. 3-27 and 3-28). In fact, Lewis and Clark's lowest maximum temperature in January 1804 is lower than any of the National Weather Service's modern readings. Lewis and Clark experienced nine days with precipitation in January 1805. This value is in the upper end of the more common values observed nowadays (Fig. 3-29).

February 1805

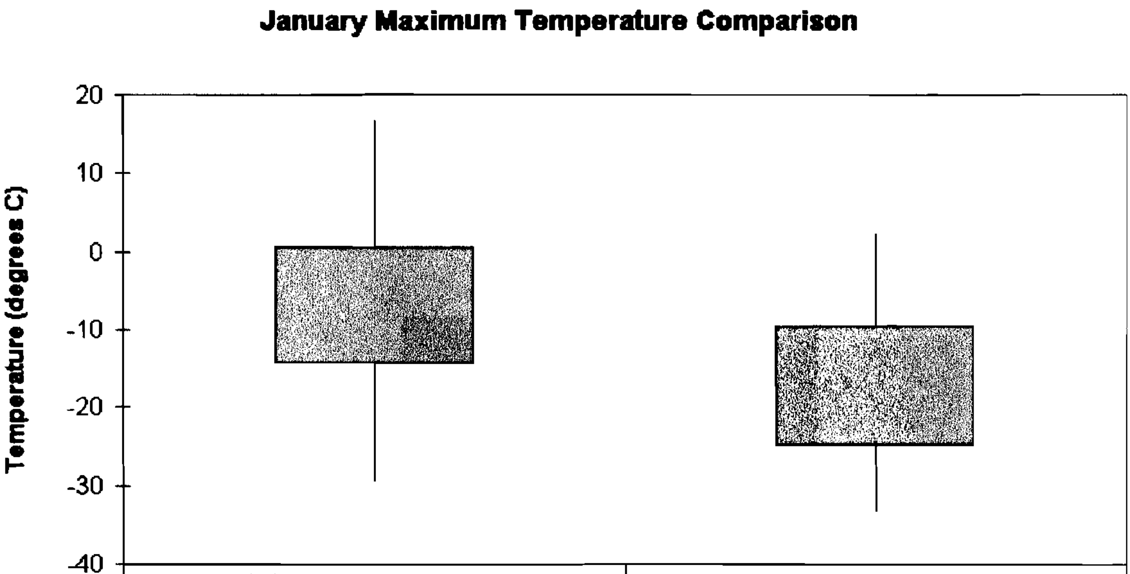
The first frontal system of the month moved into the area late on the 9th (Fig. 3-30). Some snow fell on of the 10th, but the main story with this front was the cold air. Sunrise temperatures of –18°F were observed on the 10th and the 11th (Lewis, 1959). A snowfall amount from this system was not reported. The next snow producing mid-latitude cyclone moved into the area on the 13th (Fig. 3-31). It appears that moisture arrived just in time with this storm system with just cloudy skies noted as the low pressure system tracked to the south and some snowfall noted before sunrise on the 14th. The expedition reported a total of 3 inches of snow (Lewis, 1959).

A strong warm front approached the area by late in the day on the 22nd (Fig. 3-32), and brought the first liquid precipitation of the year, in the form of a mix of rain and snow, to the area. No rain or snow amounts were reported by the expedition.



	National Weather Service	Lewis and Clark
75th	-12.2	-18.5
Max	1.7	-7.8
Min	-42.2	-40.0
25th	-25.6	-29.3

Figure 3-27: Comparison of the National Weather Service's minimum temperatures to Lewis and Clark's minimum temperatures.



	National Weather Service	Lewis and Clark
75th	0.6	-9.6
Max	16.7	2.2
Min	-29.4	-33.3
25th	-14.4	-25.0

Figure 3-28: Comparison of the National Weather Service's maximum temperatures to Lewis and Clark's maximum temperatures.

January Precipitation Days Comparison

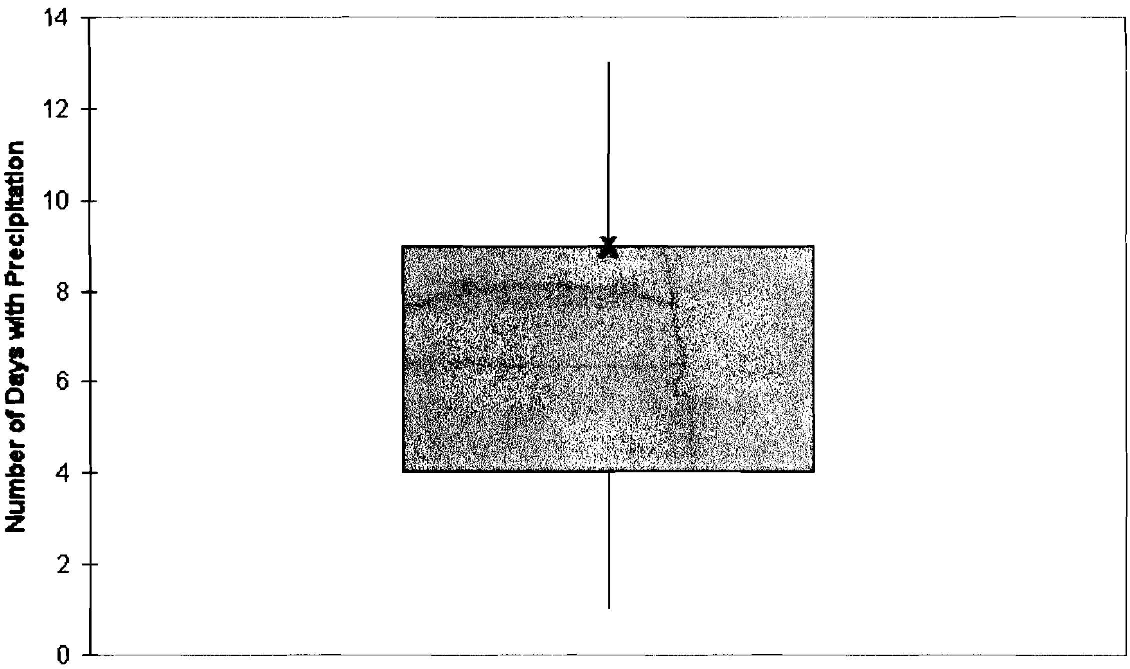


Figure 3-29: Comparison of the National Weather Service's number of days with precipitation to Lewis and Clark's number of days with precipitation. The box plot in the figure depicts the National Weather Service's range of days with precipitation. The "X" in the figure depicts the number of days Lewis and Clark experienced precipitation.

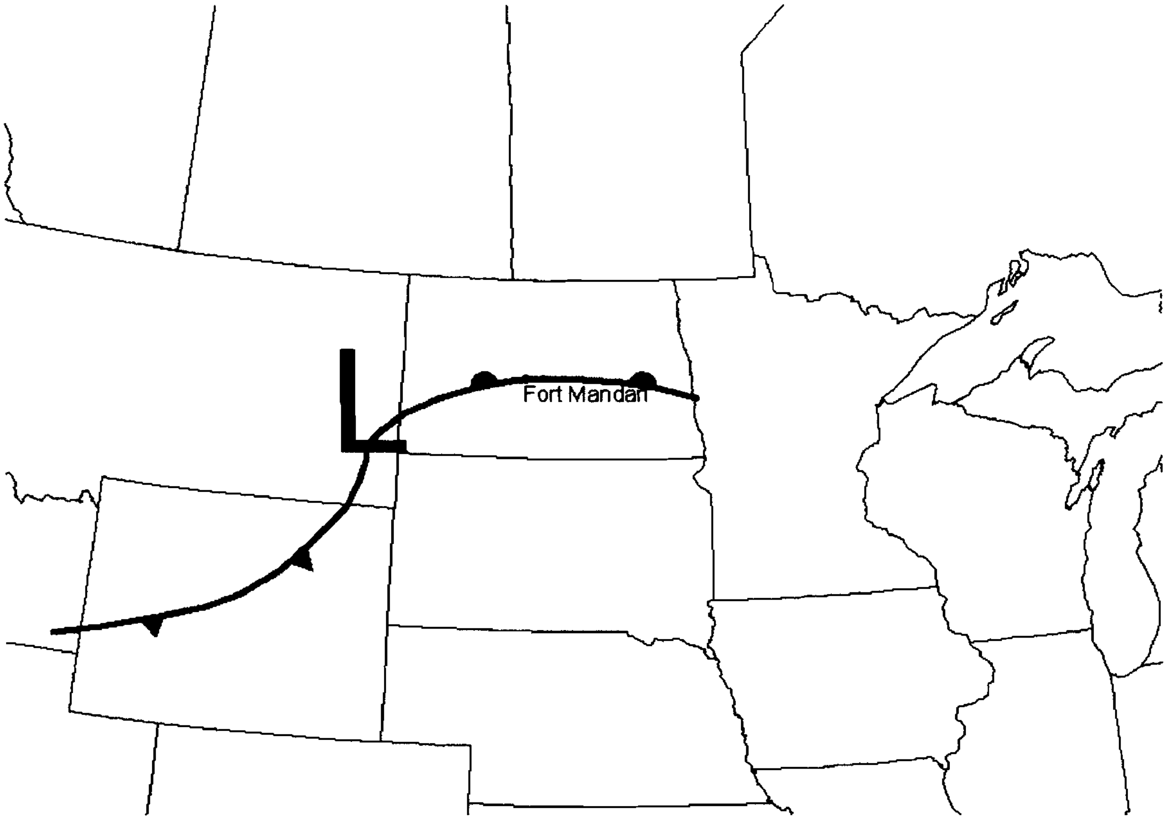


Figure 3-30: Hypothetical Weather Map 9 February 1805. The solid line with triangles is a cold front and the solid line with semicircles is a warm front. The center of the frontal system moved in from the west. Some snow was reported as the cold front came through.

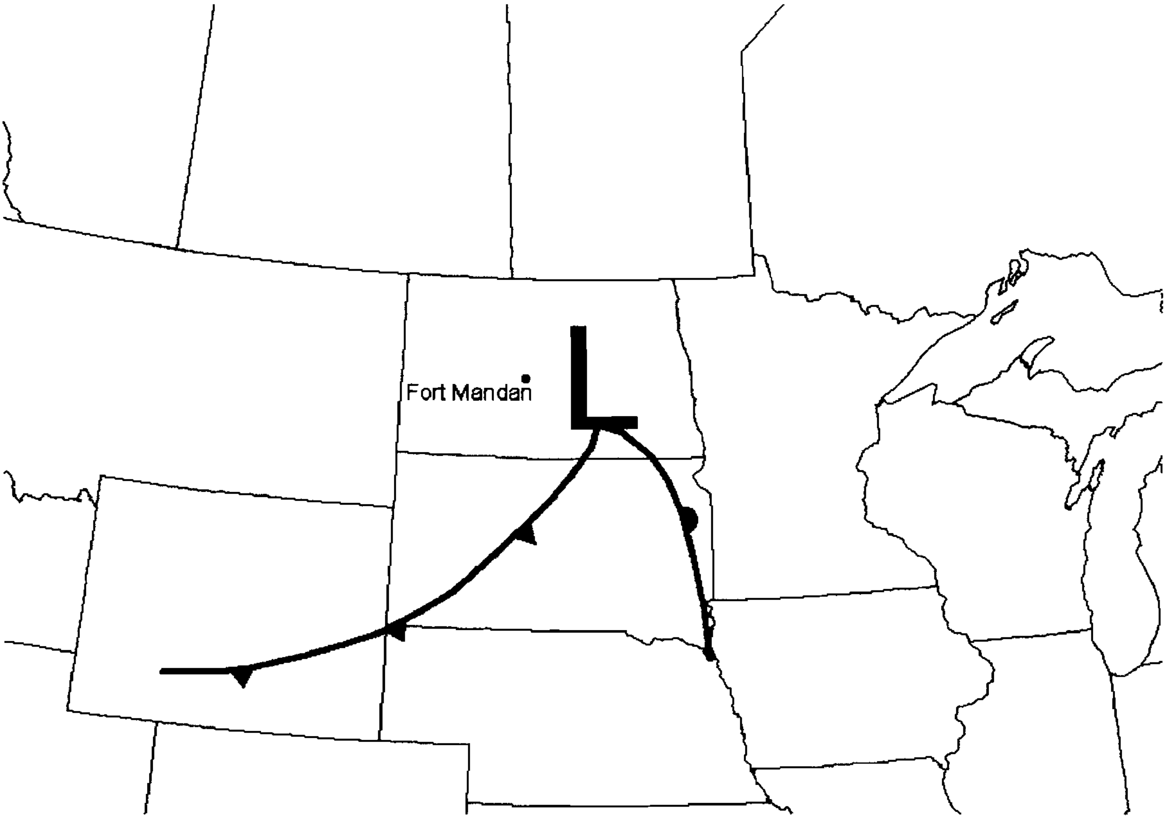


Figure 3-31: Hypothetical Weather Map 13 February 1805. The solid line with triangles is a cold front and the solid line with semicircles is a warm front. Moisture returned as the low pressure system began to move away from Fort Mandan. Snow occurred for a brief time before sunrise on the 14th.

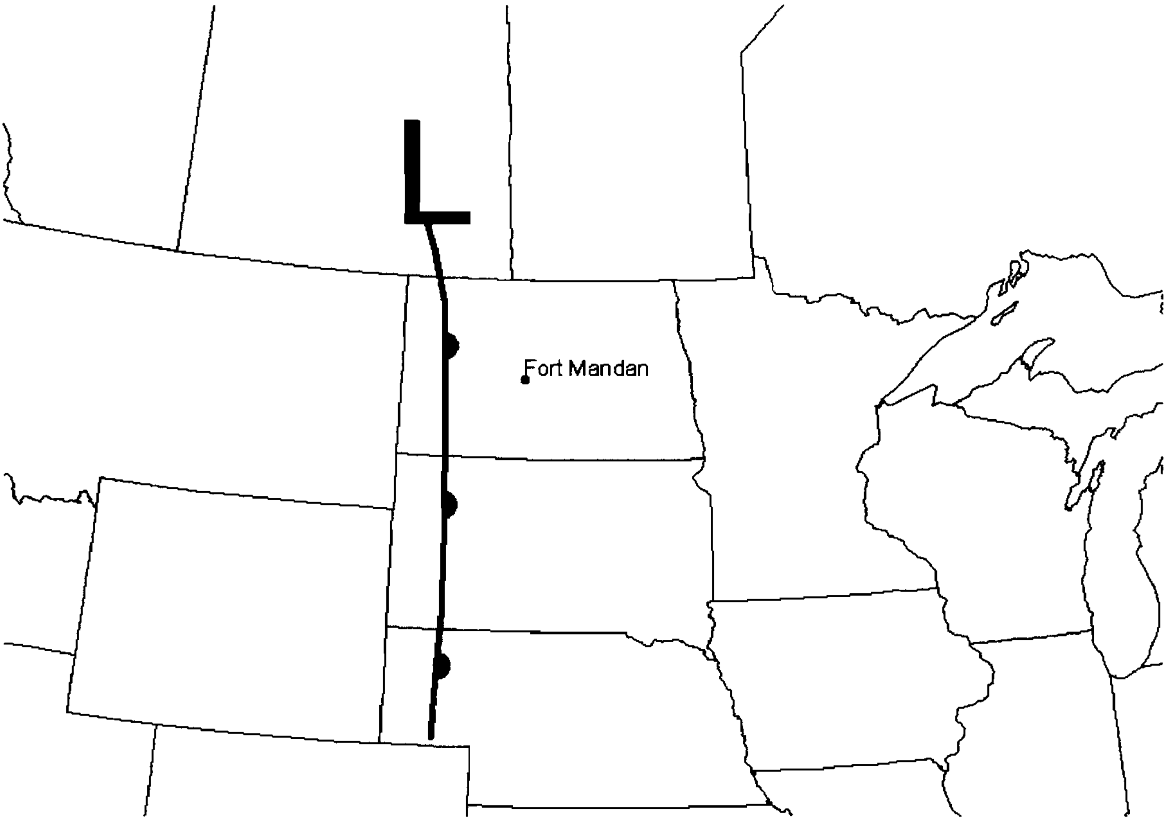


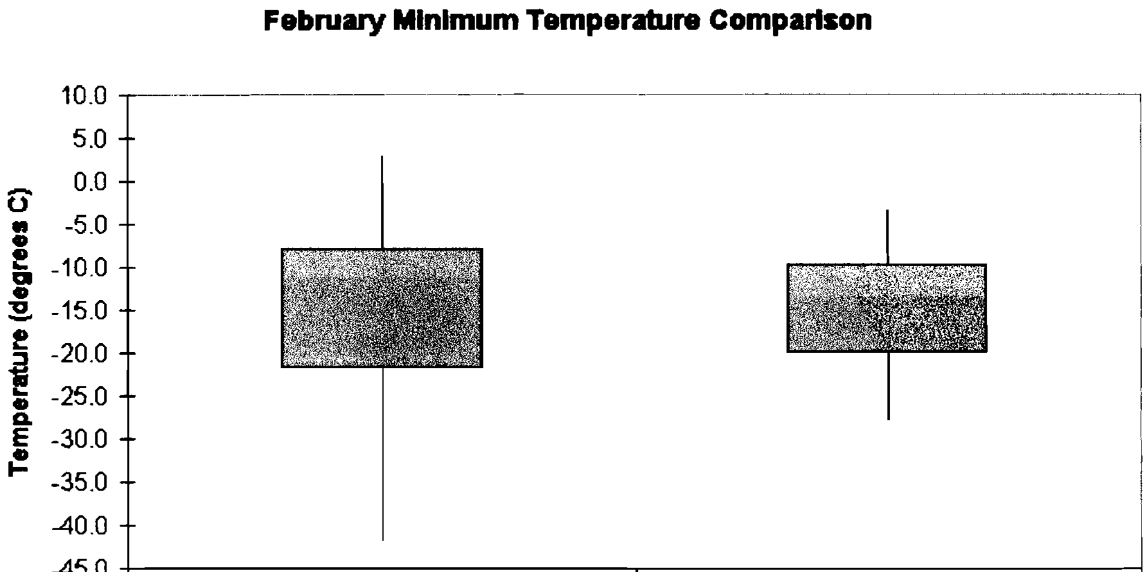
Figure 3-32: Hypothetical Weather Map 22 February 1805. The solid line with semicircles is a warm front. As the warm front moved across Fort Mandan, rain and snow was reported by the expedition.

For the rest of the month of February temperatures rose into the middle to upper 30s each afternoon with no further precipitation reported (Lewis, 1959).

Lewis and Clark's temperature records for the month of February do match well with the National Weather Service's temperatures from today (Figs. 3-33 and 3-34). Lewis and Clark's maximum temperature range is smaller but within bounds of modern data (Fig. 3-34). For the first time during their stay at Fort Mandan, the number days with precipitation Lewis and Clark experienced were lower than most of the National Weather Service's data (Fig. 3-35).

March 1805

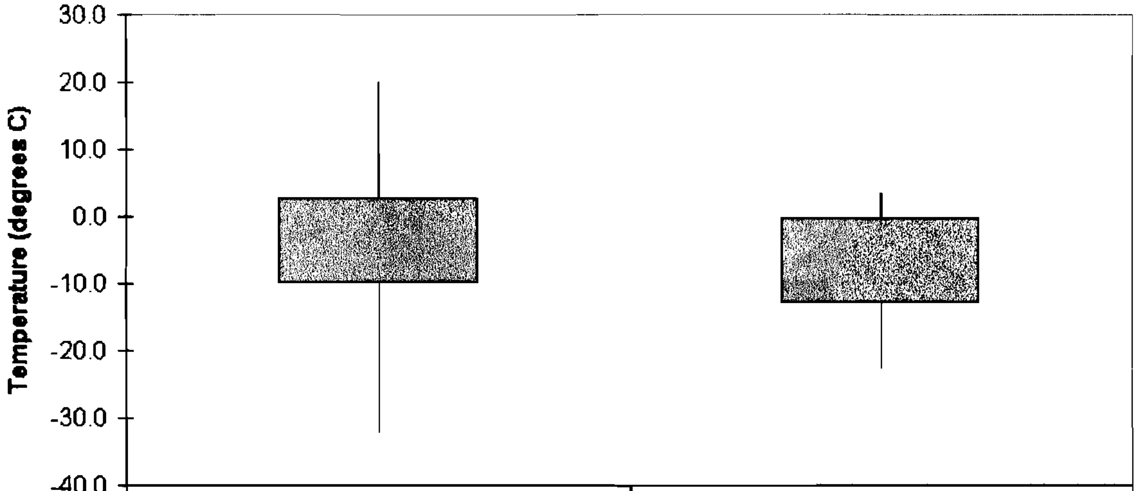
Cool easterly winds affected the expedition on the 7th of March and brought colder temperatures into the area. The cold front, however, moved in from a different direction. This type of cold front is called a backdoor cold front. Instead of the front arriving from the west, northwest, or north, it comes in from the northeast or east (Ahrens, 2000). The frontal map during this day is depicted in Fig. 3-36. By the 9th, another system developed to the southwest of Fort Mandan and moved eastward. This system seems to have been moisture starved, so just a shift in the wind direction was reported with no change of air mass or significant precipitation. The next storm system to affect the expedition developed to the southwest of Fort Mandan on the 11th and moved northeastward. The path taken by the storm allowed for the dry slot (Fig. 3-37), or a wedge of dry air in a winter storm (WeatherData, Inc., 1984/1999), to move over Fort Mandan and allow for some fair skies (Fig. 3-38). Then as the storm system began to move out on the 12th, some light snow moved



	National Weather Service	Lewis and Clark
75th	-7.8	-9.7
Max	2.8	-3.3
Min	-41.7	-27.8
25th	-21.7	-20.0

Figure 3-33: Comparison of the National Weather Service's minimum temperatures to Lewis and Clark's minimum temperatures.

February Maximum Temperature Comparison



	National Weather Service	Lewis and Clark
75th	2.8	-0.1
Max	20.0	3.3
Min	-32.2	-22.8
25th	-10.0	-13.1

Figure 3-34: Comparison of the National Weather Service's maximum temperatures to Lewis and Clark's maximum temperatures.

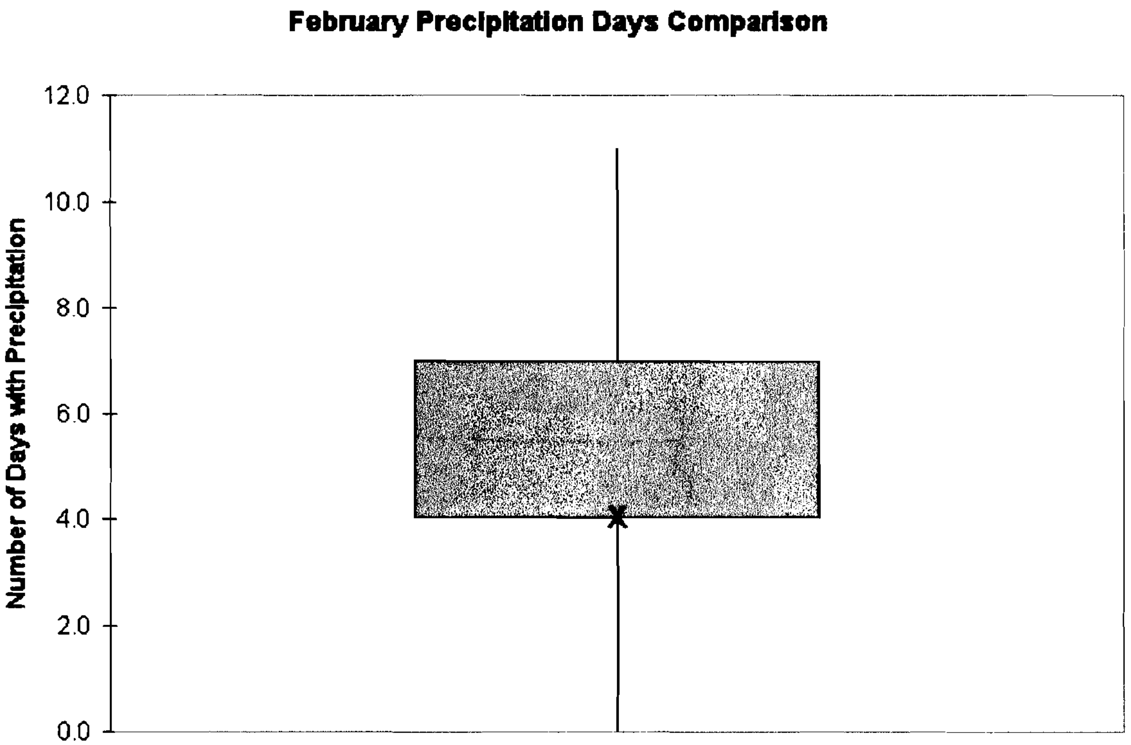


Figure 3-35: Comparison of the National Weather Service's number of days with precipitation to Lewis and Clark's number of days with precipitation. The box plot in the figure depicts the National Weather Service's range of days with precipitation. The "X" in the figure depicts the number of days Lewis and Clark experienced precipitation.

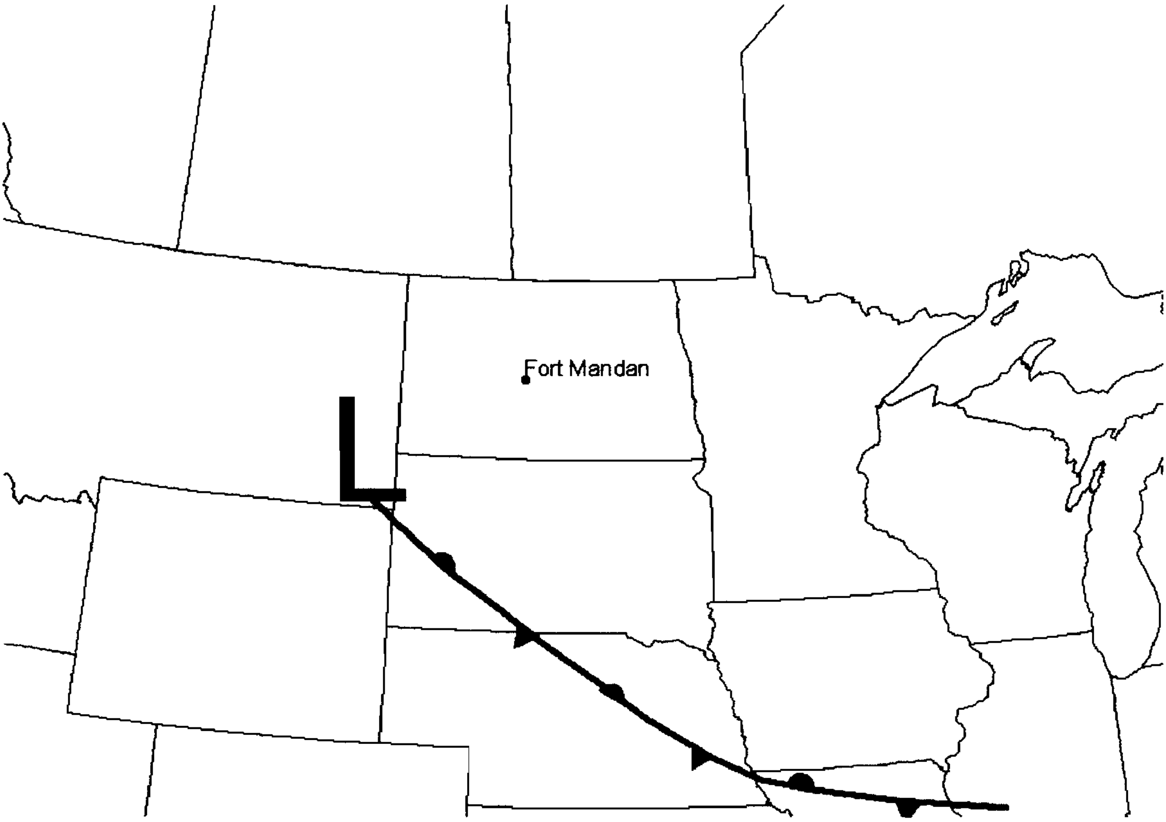


Figure 3-36: Hypothetical Weather Map 7 March 1805. The solid line with alternating triangles and semicircles is a stationary front. A low pressure system developed in southeastern Montana, and moved on to the south of Fort Mandan, but no precipitation was reported.

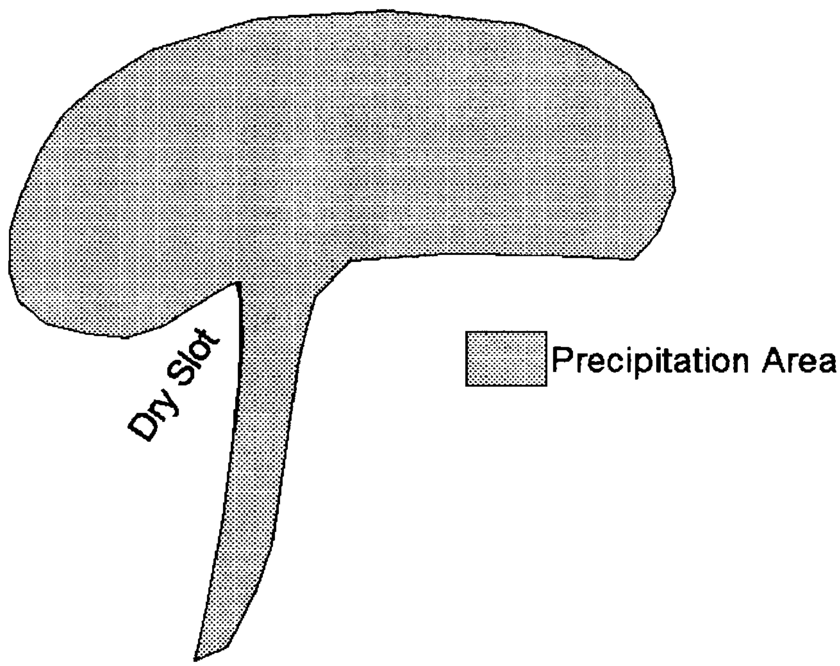


Figure 3-37: Generalized map view of the structure of a typical winter storm.

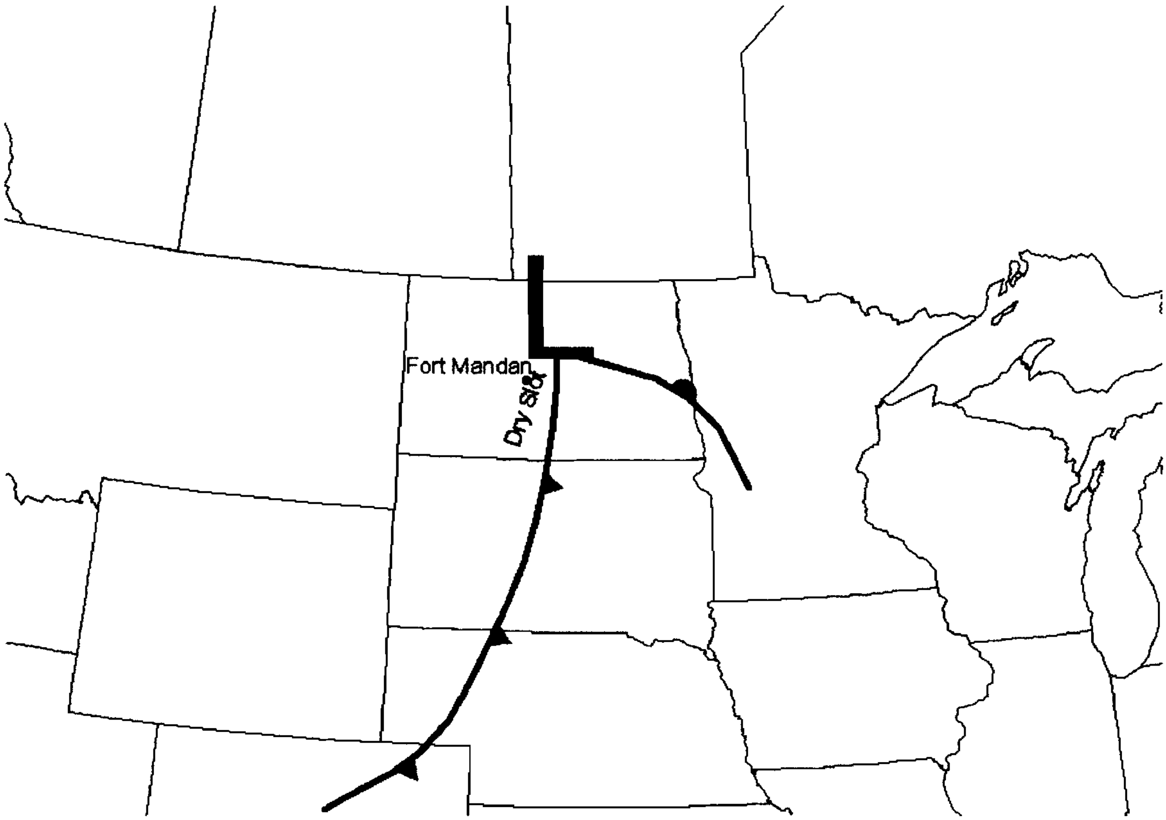


Figure 3-38: Hypothetical Weather Map 11 March 1805. The solid line with triangles is a cold front and the solid line with semicircles is a warm front. The dry slot was over Fort Mandan with fair skies being observed. Precipitation probably occurred to the east, north, and west of Fort Mandan.

across the area (Fig. 3-39). A warming trend then occurred through the 17th of March with a 4 p.m. temperature on the 17th of 30°F (Lewis, 1959). The next cold front moved through before sunrise on the 18th and shifted the winds around to the north (Fig. 3-40). An area of snow moved across late on the 18th or early on the 19th, but according to the journals it was not enough to cover the ground (Lewis, 1959). Temperatures remained cold on the 21st, as a warm front approached from the south. By the afternoon, a mixture of snow and sleet was reported with the winds shifting to the south, as the warm front moved across Fort Mandan (Fig. 3-41). The precipitation eventually became all snow and then ended by the morning of the 22nd, as the warm front moved north of the area (Fig. 3-42).

By the 23rd, the low pressure system that had probably been organizing to the west of Fort Mandan moved eastward. A cold front accompanied by rain had moved across the area by 4 p.m. on the 23rd (Fig. 3-43). Snow moved into the area prior to sunrise on the 24th and continued into the afternoon hours (Fig. 3-44). According to the journals, little snow accumulation occurred (Lewis, 1959). Warmer temperatures moved back into the area by 27th with 4 p.m. temperatures around 60°F (Lewis, 1959).

Lewis and Clark's minimum and maximum temperatures were within the range of modern National Weather Service data for March (Figs. 3-45 and 3-46). Lewis and Clark recorded 7 days of precipitation during the month of March. That value is higher than the majority of the National Weather Service's data (Fig. 3-47).

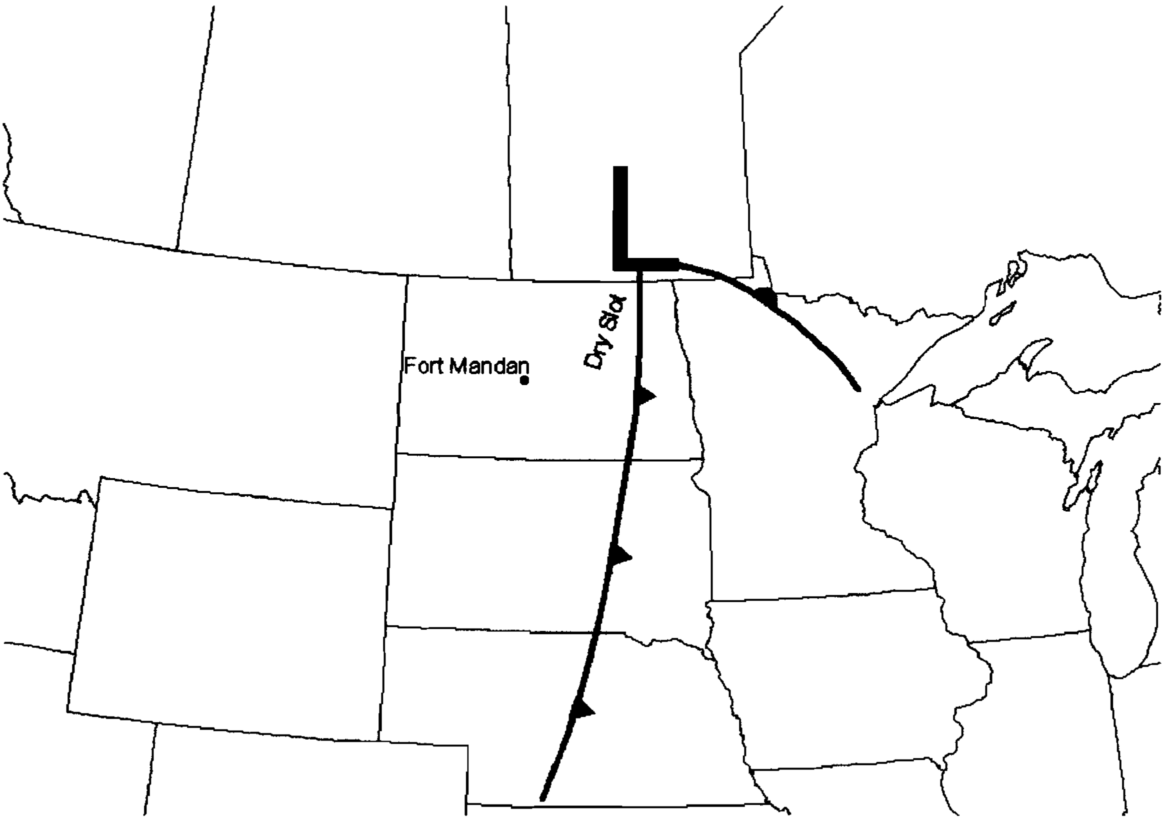


Figure 3-39: Hypothetical Weather Map 12 March 1805. The solid line with triangles is a cold front and the solid line with semicircles is a warm front. The dry slot was now east of Fort Mandan and the expedition did report light snow prior to sunrise.

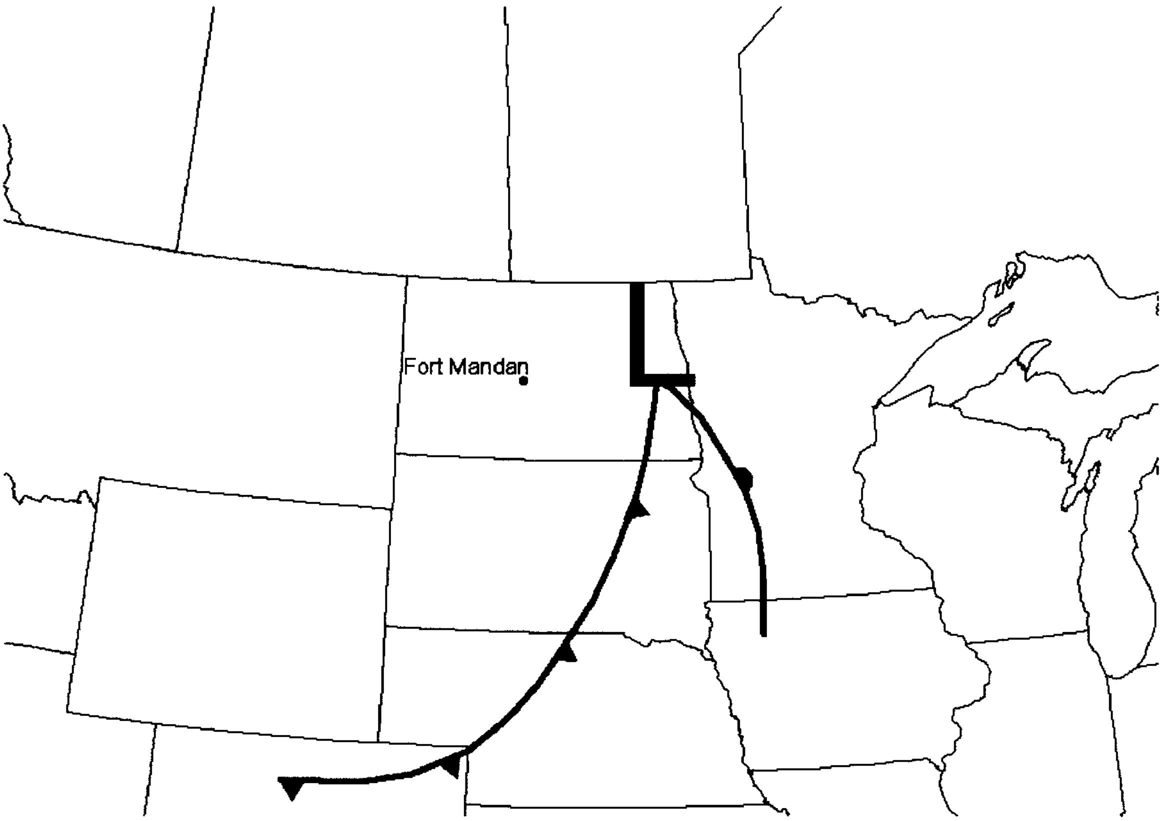


Figure 3-40: Hypothetical Weather Map 18 March 1805. The solid line with triangles is a cold front and the solid line with semicircles is a warm front. Light snow fell at Fort Mandan into the early morning of the 19th, as the low pressure center slowly moved eastward.

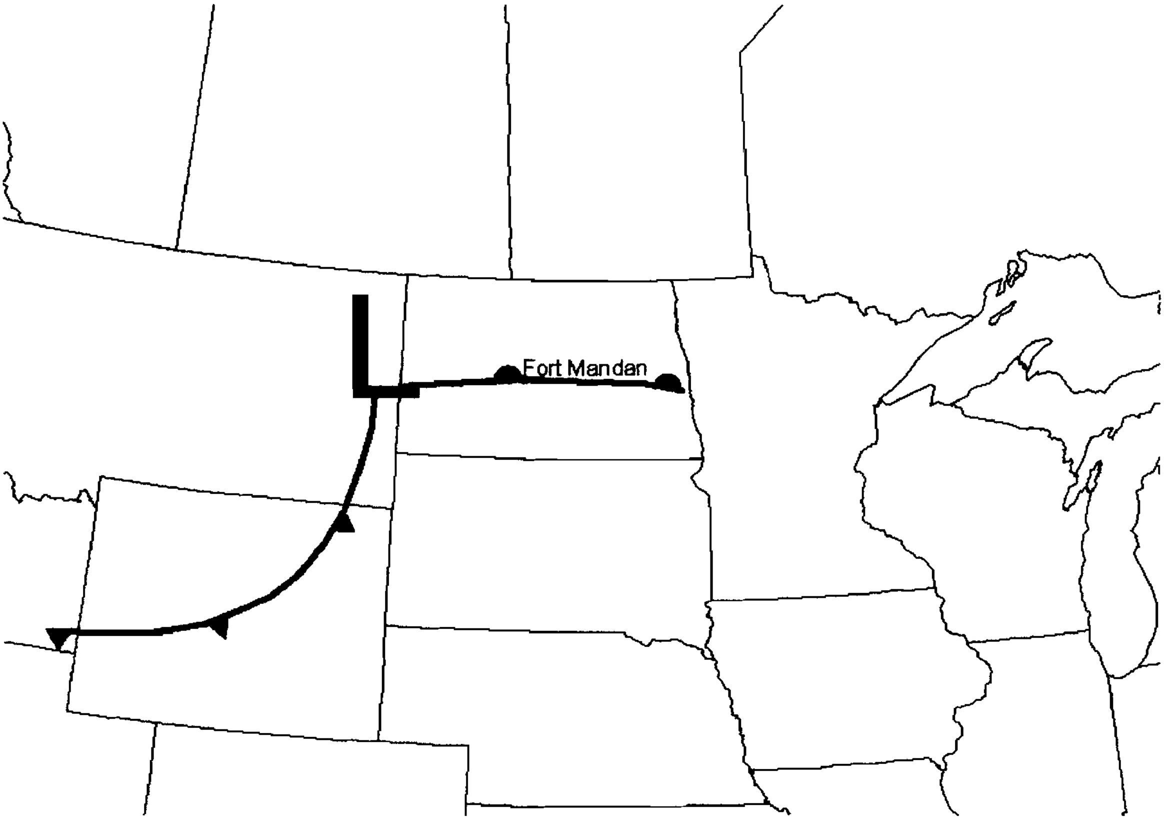


Figure 3-41: Hypothetical Weather Map 21 March 1805. The solid line with triangles is a cold front and the solid line with semicircles is a warm front. Light snow fell at Fort Mandan into the early morning of the 19th, as the low pressure center remained nearly stationary.

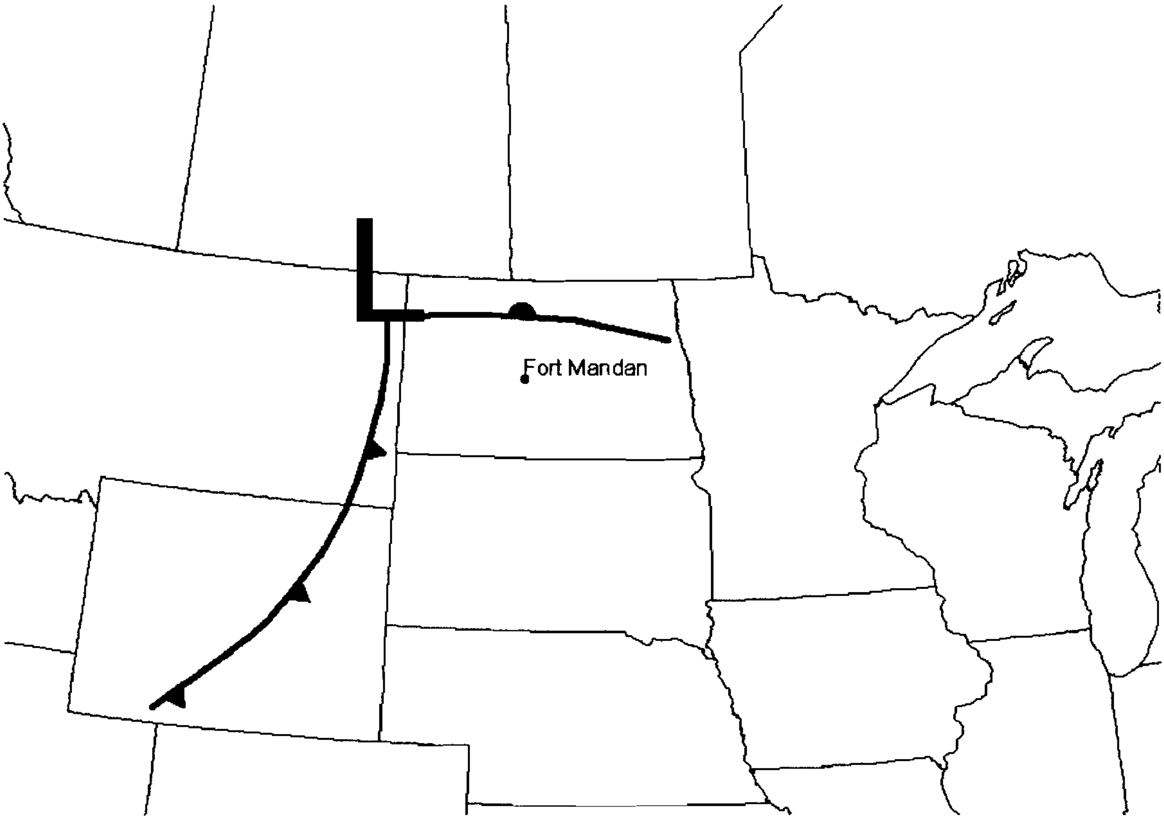


Figure 3-42: Hypothetical Weather Map 22 March 1805. The solid line with triangles is a cold front and the solid line with semicircles is a warm front. Snow ended prior to sunrise, as the warm front moved north of Fort Mandan.

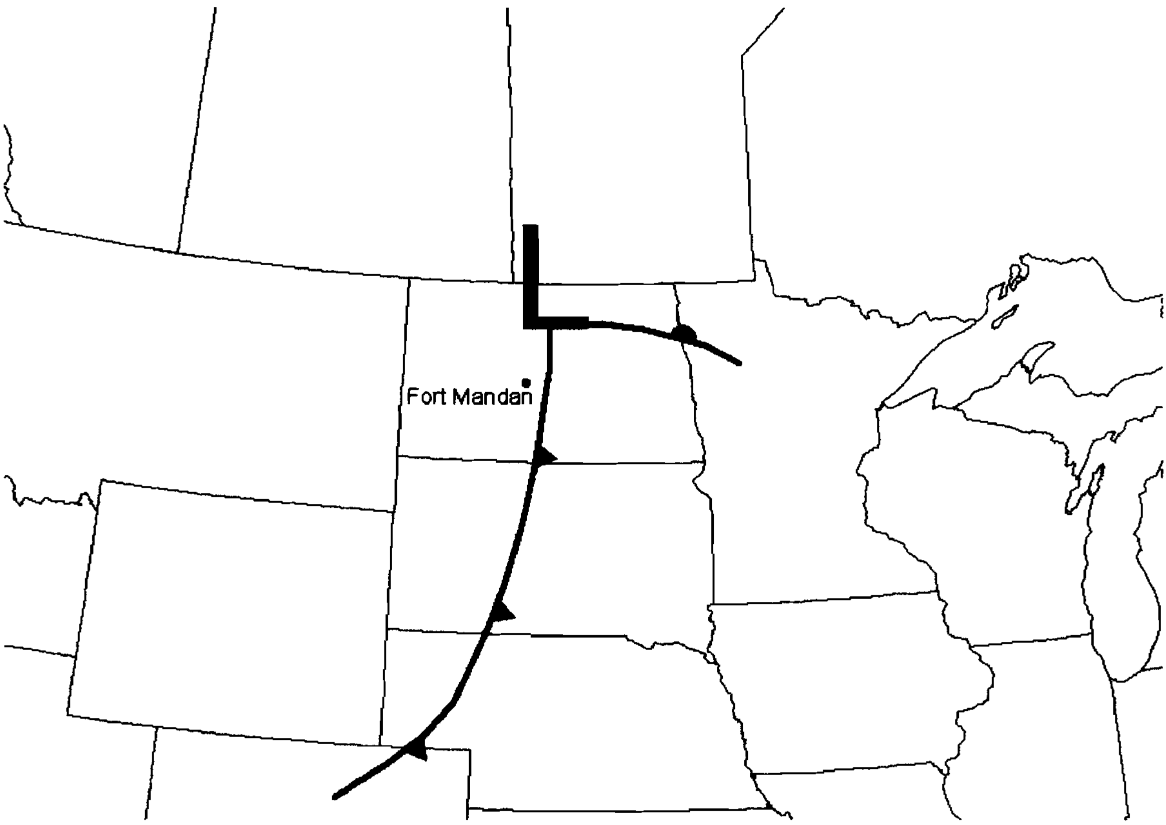


Figure 3-43: Hypothetical Weather Map 23 March 1805. The solid line with triangles is a cold front and the solid line with semicircles is a warm front. Rain was reported by the expedition, as the cold front moved across Fort Mandan.

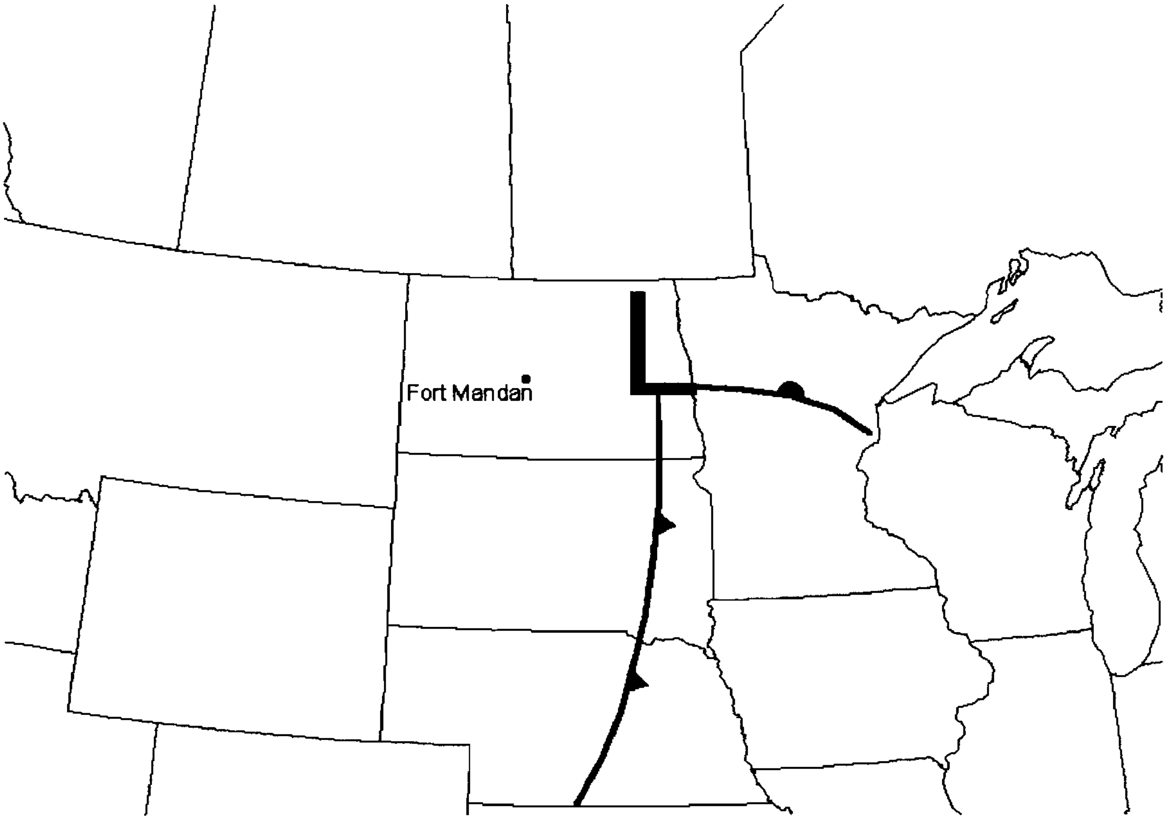
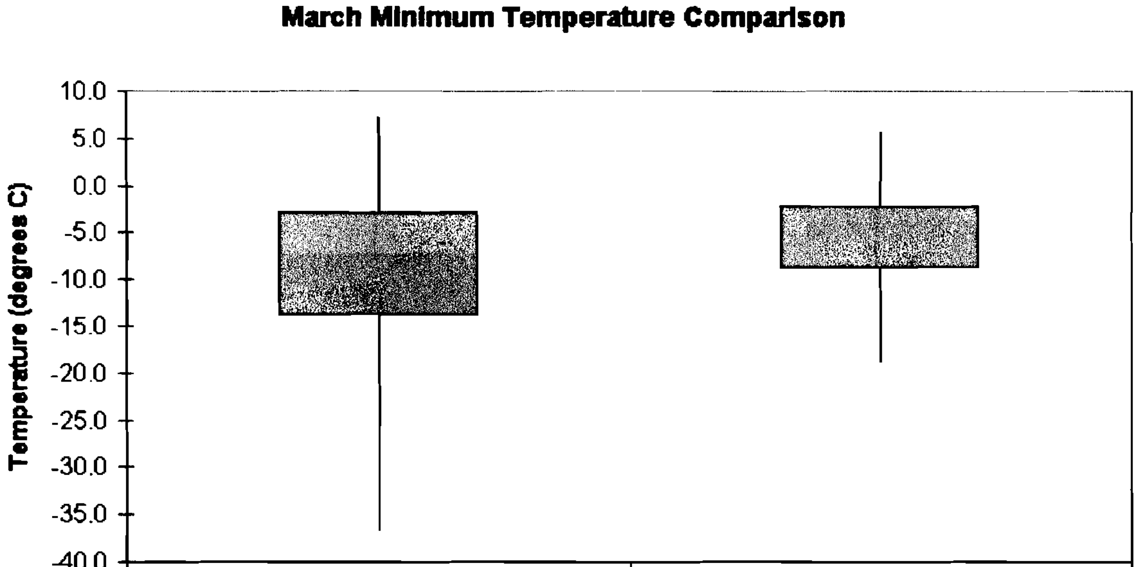
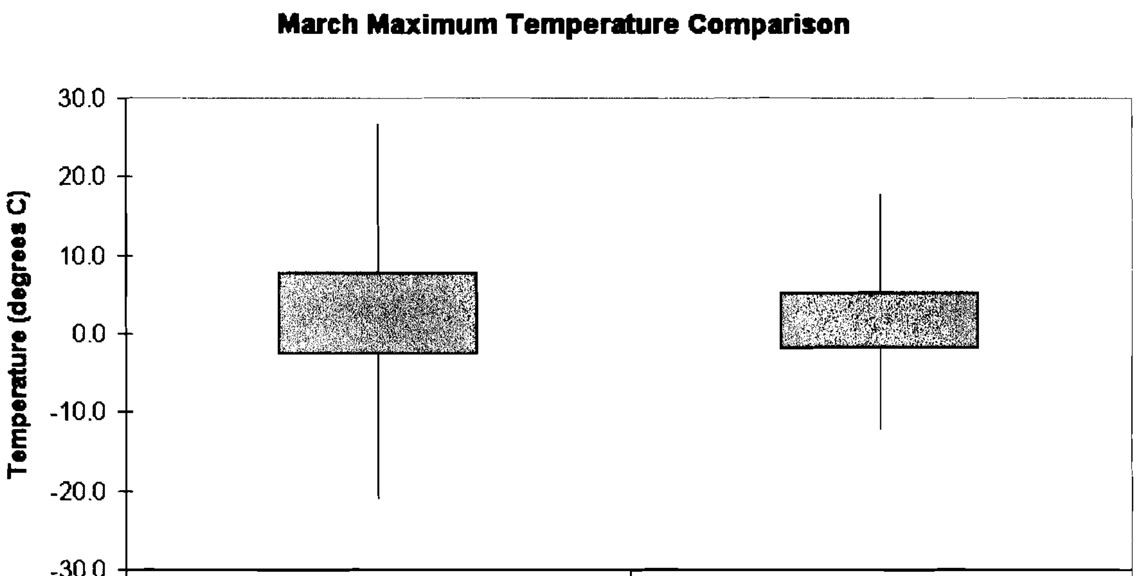


Figure 3-44: Hypothetical Weather Map 24 March 1805. The solid line with triangles is a cold front and the solid line with semicircles is a warm front. Snow was reported by the expedition as the low pressure system moved eastward during the day. Snow ended in the afternoon.



	National Weather Service	Lewis and Clark
75th	-2.8	-2.2
Max	7.2	5.6
Min	-36.7	-18.9
25th	-13.9	-8.9

Figure 3-45: Comparison of the National Weather Service's minimum temperatures to Lewis and Clark's minimum temperatures.



	National Weather Service	Lewis and Clark
75th	7.8	5.3
Max	26.7	17.8
Min	-21.1	-12.2
25th	-2.8	-1.9

Figure 3-46: Comparison of the National Weather Service's maximum temperatures to Lewis and Clark's maximum temperatures.

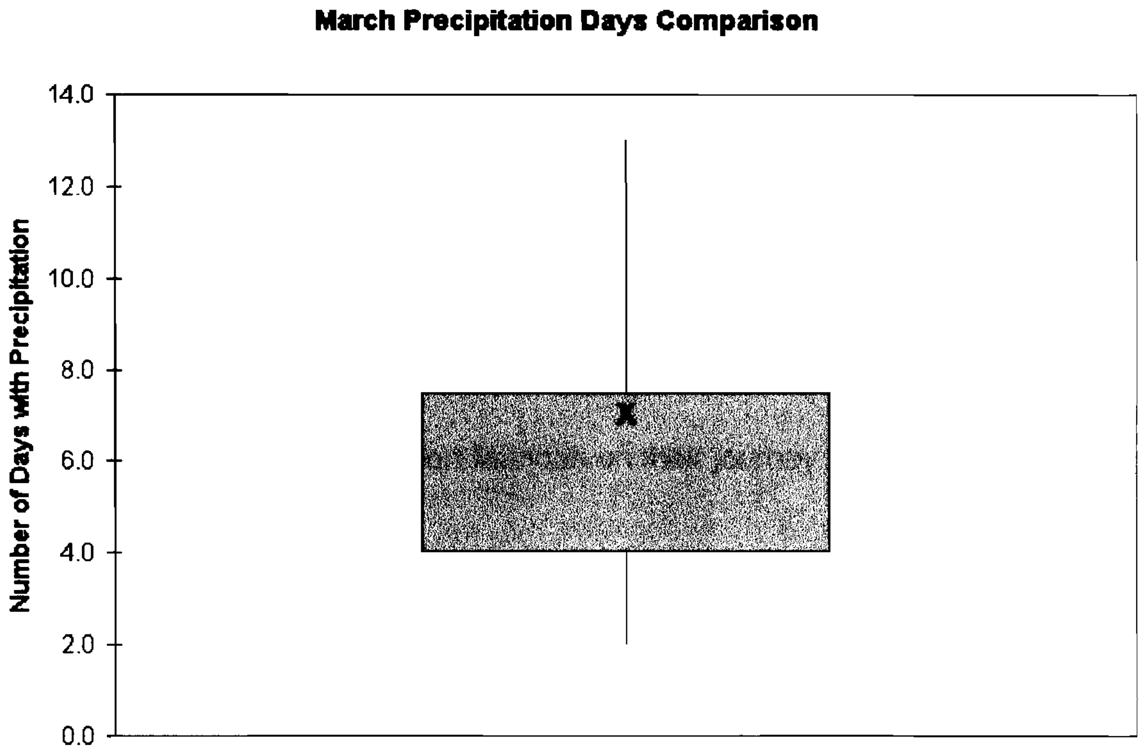


Figure 3-47: Comparison of the National Weather Service's number of days with precipitation to Lewis and Clark's number of days with precipitation. The box plot in the figure depicts the National Weather Service's range of days with precipitation. The "X" in the figure depicts the number of days Lewis and Clark experienced precipitation.

1 April 1805 – 7 April 1805

The first storm system of the month entered on the 1st and brought with it the first round of the thunderstorms experienced by the expedition in the year 1805 (Fig. 3-48). No severe hail or severe wind was reported by the expedition. After a brief cool spell on the 2nd, temperatures warmed through the 7 April. A 4 p.m. temperature of 64°F occurred on the 7th (Lewis, 1959). At 5 p.m. on 7 April 1805, Lewis and Clark set out from Fort Mandan on their journey to the Pacific Northwest (Lewis, 1959).

During the short period of time Lewis and Clark spent at Fort Mandan in April, their temperature maximums and minimums were very similar to the National Weather Service's (Figs. 3-49 and 3-50). The number of days with precipitation, however, was higher than the majority of the National Weather Service's modern data (Fig. 3-51).

Weather From Fort Mandan, North Dakota to Fort Clatsop, Oregon

As Lewis and Clark traveled farther to the west into Montana, they encountered more windy days, and the High Plains are known for their windy days. Temperatures continued to warm as Lewis and Clark traveled westward. Afternoon temperatures were in the upper 70s to the low 80s from the 13-16 April 1805. They also recorded some snowfall on the 20th of April (Lewis, 1959).

Quite a few rain events occurred in May of 1805. On 30 May 1805, the expedition noted "...more rain has now fallen than we have experienced since the 15th of September last." (Lewis, 1959: 191). This seems normal as compared to

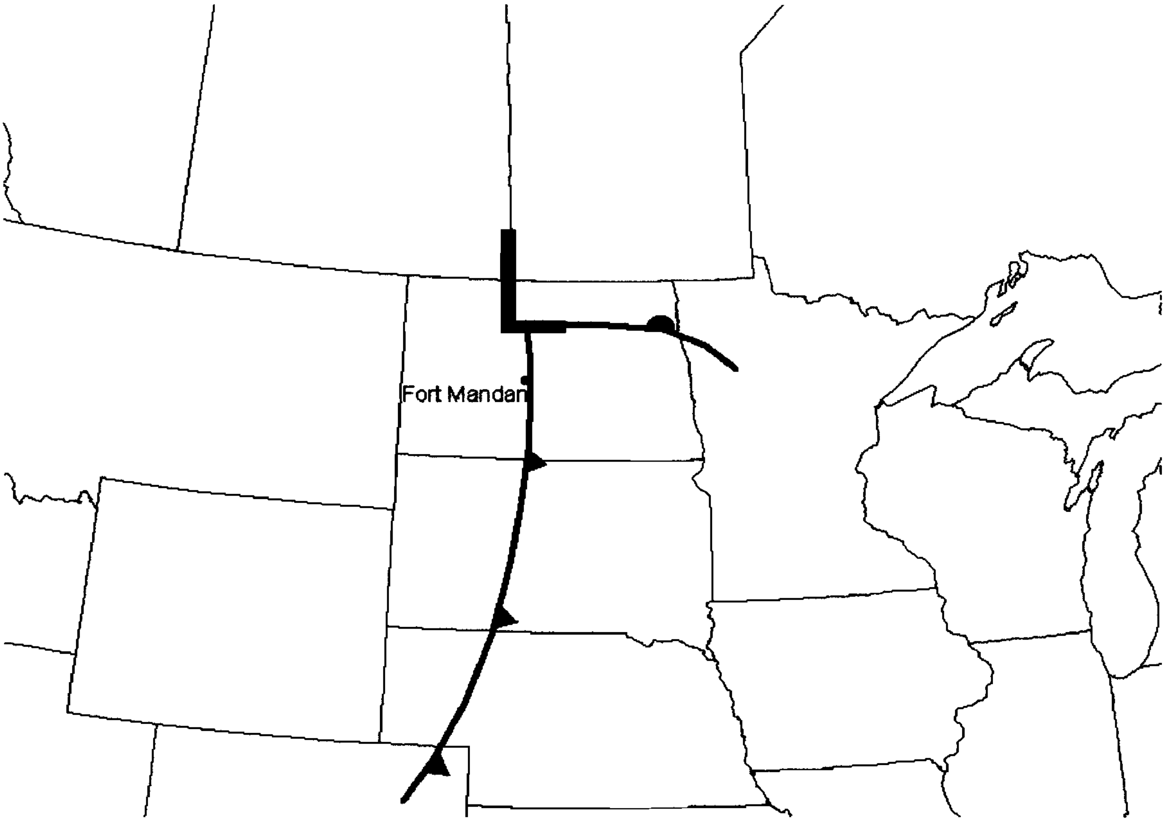
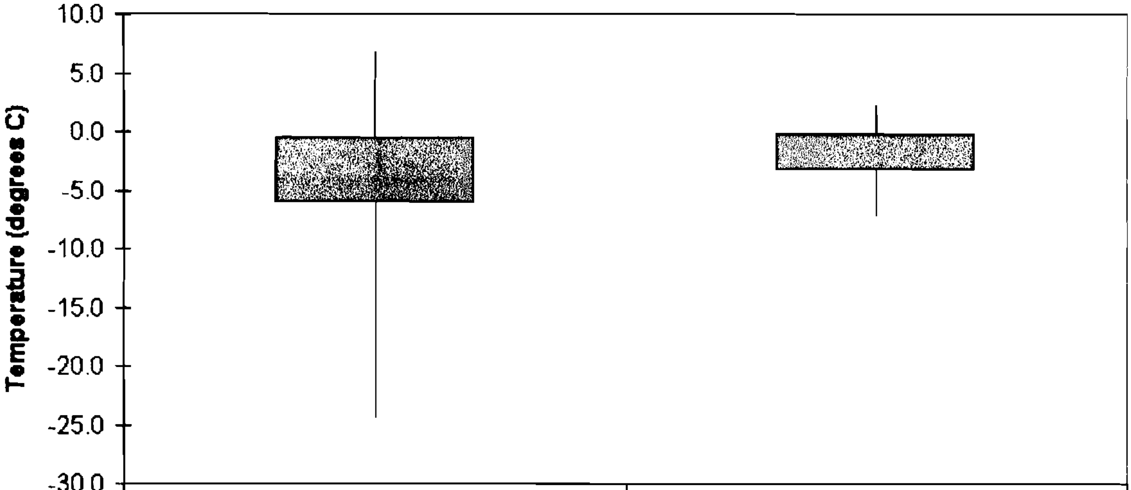


Figure 3-48: Hypothetical Weather Map 1 April 1805. The solid line with triangles is a cold front and the solid line with semicircles is a warm front. Thunderstorms with hail were reported as the cold front moved across Fort Mandan. There was no indication of any severe hail.

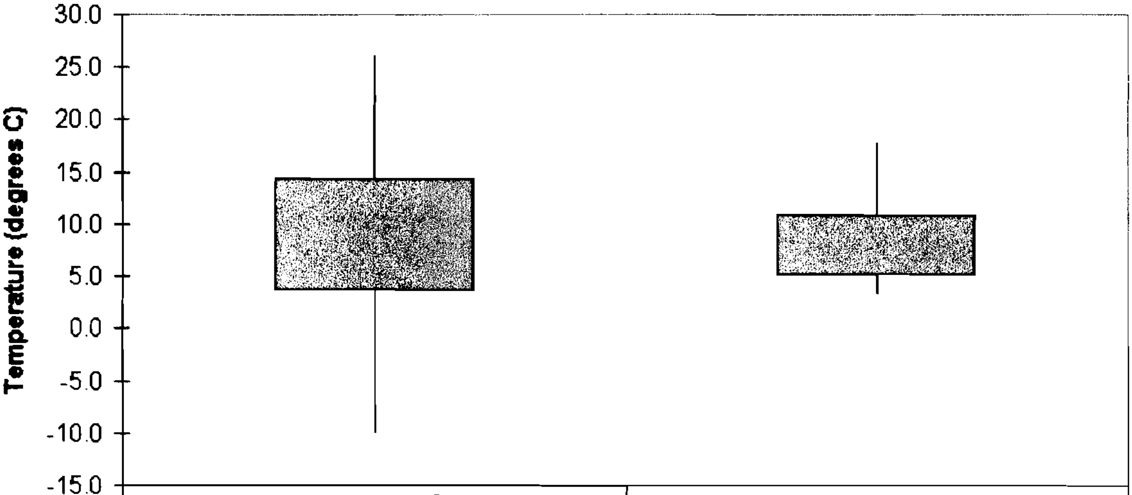
April Minimum Temperature Comparison



	National Weather Service	Lewis and Clark
75th	-0.6	-0.3
Max	6.7	2.2
Min	-24.4	-7.2
25th	-6.1	-3.3

Figure 3-49: Comparison of the National Weather Service's minimum temperatures to Lewis and Clark's minimum temperatures.

April Maximum Temperature Comparison



	National Weather Service	Lewis and Clark
75th	14.4	10.8
Max	26.1	17.8
Min	-10.0	3.3
25th	3.6	5.0

Figure 3-50: Comparison of the National Weather Service's maximum temperatures to Lewis and Clark's maximum temperatures.

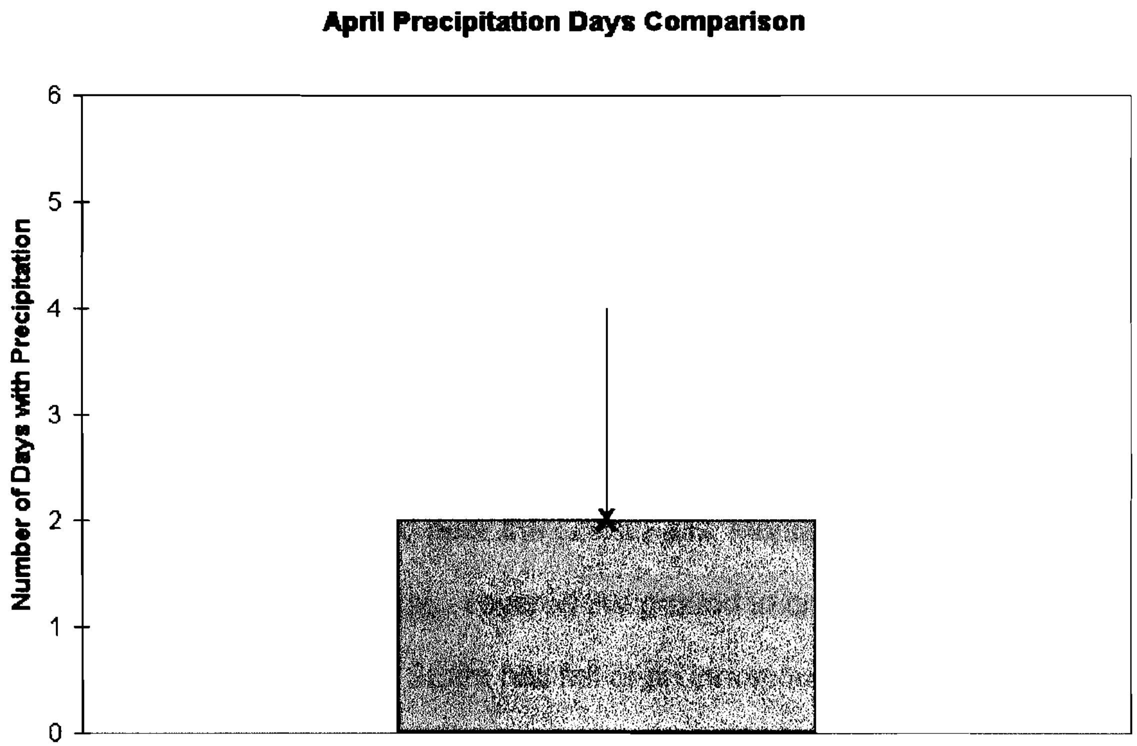


Figure 3-51: Comparison of the National Weather Service's number of days with precipitation to Lewis and Clark's number of days with precipitation. The box plot in the figure depicts the National Weather Service's range of days with precipitation. The "X" in the figure depicts the number of days Lewis and Clark experienced precipitation.

today, since the polar jet stream is usually found across the northern United States by this time of year. It has been mentioned before that the polar jet stream is the track the mid-latitude cyclones take. Thus, where the polar jet stream moves, the rain also moves and therefore Lewis and Clark experienced more rain.

A couple of interesting things occurred in June of 1805. One was that the expedition did not encounter one temperature below freezing for the first time of the year. On the 27th of June, Lewis and Clark likely encountered their first severe thunderstorm as they traveled near the Great Falls, Montana area. They mentioned hail "...the size of pigions eggs...covered the ground to one inch and a half. for about 20 minutes during this Storm hail fell of an innomous size driven with violence almost incredible" (Lewis, 1959: 193). Lewis measured one these hail stones and found it had a circumference of 7 inches (Lewis, 1959) or 2.2 inches (5.6 cm) in diameter. A hailstone that is 0.75 inches (1.9 cm) in diameter is considered severe (Ahrens, 2000). The value of 2.2 inches (5.6 cm) is far greater than 0.75 inches (1.9 cm). Therefore, the thunderstorm they encountered was severe. In fact, this value is between golf-ball size hail and tennis-ball size hail. Clark mentioned "I am Convinced if one of those had Struck a man on naiked head would certainly fractured his Skull" (Lewis, 1959: 193).

Lewis and Clark encountered another thunderstorm with hail on the 6th of July. On this day "hail covered the ground and was near the size of Musquet balls." (Lewis, 1959: 194). Given that musket balls are about 0.65 inches (1.7 cm) in diameter, the thunderstorm Lewis and Clark encountered was not severe. Higher afternoon temperatures occurred from July into August with 4 p.m. temperatures rising into the 90s. The diurnal temperature range increased in middle August, but this was also a time when Lewis and Clark were moving through the mountains. Thus, what appears to be a 59°F rise in temperature on the 21st of August 1805 (Lewis, 1959) is probably misleading because of the travel through the mountains.

As Lewis and Clark continued into the Pacific Northwest by late-October, rainfall began to increase. In November, there were many rainy days described and two days which were described as foggy.

Weather At Fort Clatsop, Oregon

7 December 1805 – 31 December 1805

A mid-latitude cyclone moved across the area from the 6th through the 7th of December (Fig. 3-52). The next relatively strong storm system moved to the south of Fort Clatsop in the middle of the month and allowed the rainfall to mix with snow and sleet (Fig. 3-53).

Lewis and Clark experienced a number of days with precipitation during this period. The Pacific Northwest is known for its numerous days with precipitation, but this period was even higher than usual (Fig. 3-54).

January 1806

Considerable precipitation occurred in January 1806. The expedition also makes some very valid remarks. One of which was "the changes of the weather are exceedingly sudden" (Lewis, 1959: 202). This is common in the Pacific Northwest,

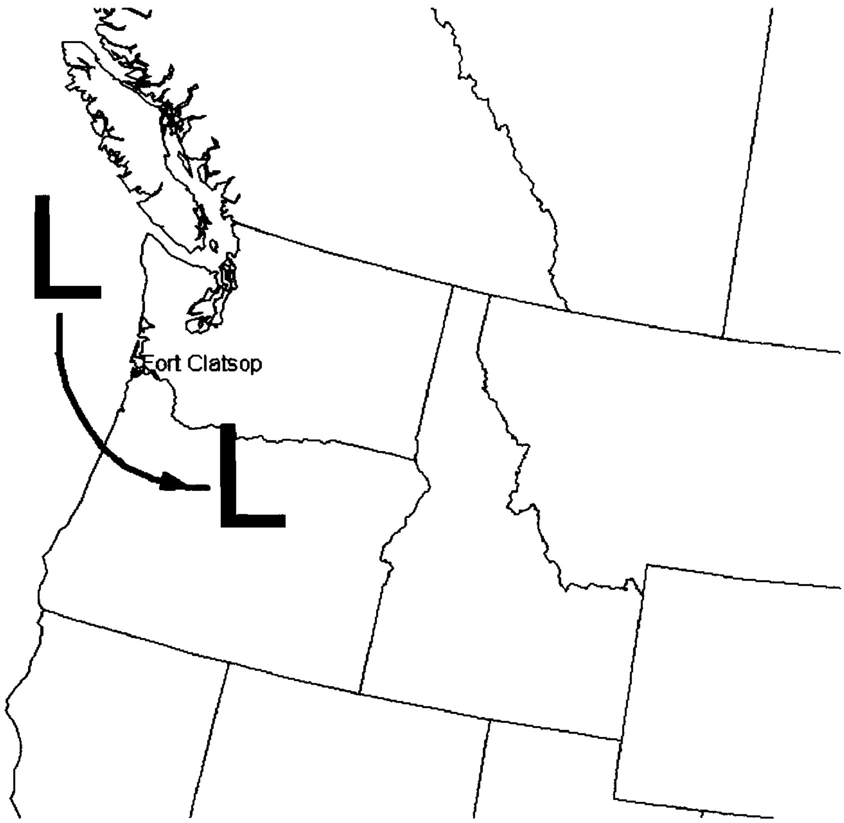


Figure 3-52: Hypothetical Storm System Movement from 6-7 December 1805. The low pressure system passed to the south of Fort Clatsop, but temperatures remained warm enough for all precipitation to be rain.

Figure 3-53: Hypothetical Storm System Movement from 17-18 December 1805. The low pressure system passed to the south of Fort Clatsop. The expedition reported rain and sleet while the storm system on the 17th and rain, sleet, and snow mix on the 18th.

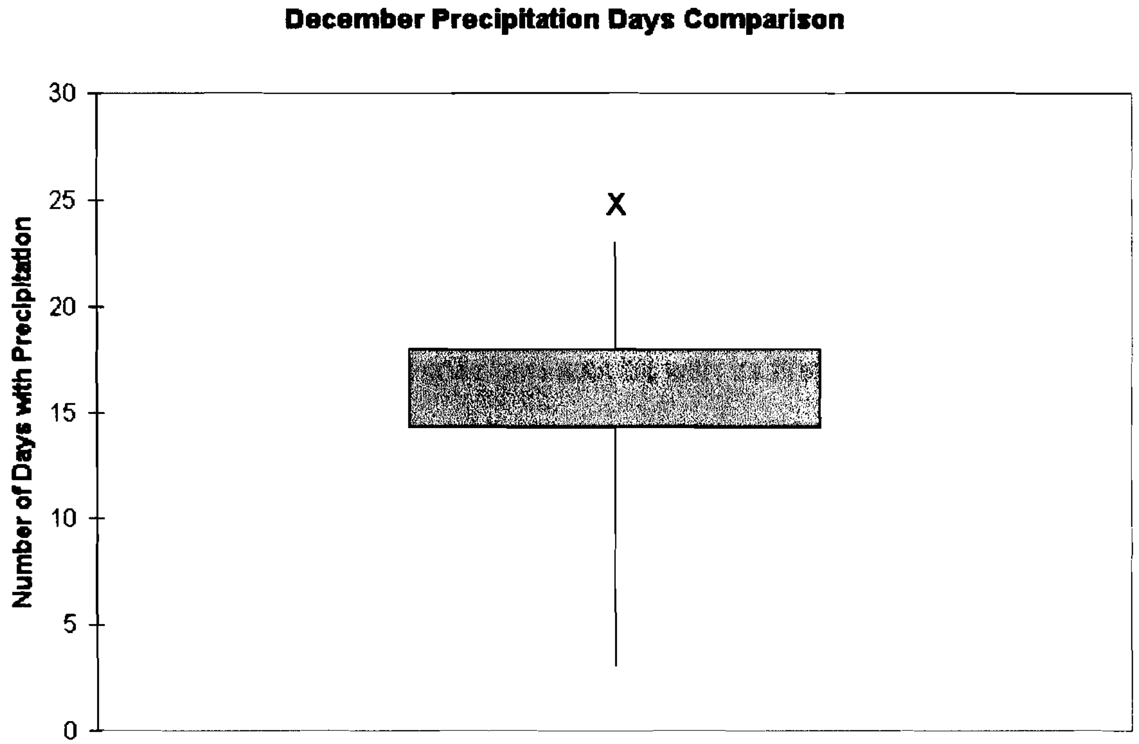


Figure 3-54: Comparison of the National Weather Service's number of days with precipitation to Lewis and Clark's number of days with precipitation. The box plot in the figure depicts the National Weather Service's range of days with precipitation. The "X" in the figure depicts the number of days Lewis and Clark experienced precipitation.

especially during this time of year. Even without a thermometer, Clark mentioned "I am confident that the climate here is much warmer than in the same parallel of Latitude on the Atlantic Ocean" (Lewis, 1959: 203). Clark's statement is correct because the air masses that move into the Pacific Northwest originate over the water and not over the land, and these air masses do not have extreme temperature ranges (Ahrens, 2000). The expedition was hit with its first significant snowfall from the 24th through the 27th of January 1806, as a storm system slowly moved across the area (Fig. 3-55). The expedition reported 6 inches of snowfall (Lewis, 1959).

The number of days Lewis and Clark experienced precipitation continued to be above the usual amount experienced in this area. Fig. 3-56 shows that the majority of the National Weather Service's days with precipitation fall under Lewis and Clark's value.

February 1806

Calm weather prevailed through the 7th of February 1806, then rainy conditions set back in. The next storm system arrived from 9 to 10 February (Fig. 3-57). The expedition reported a dusting of snowfall (Lewis, 1959). The overall pattern began to change by middle February with the storm system on the 16th and 17th of February (Fig. 3-58) moving farther northward. Sleet and snow covered the ground by the morning of the 17th (Lewis, 1959).

The amount of precipitation Lewis and Clark experienced in February 1806 was once again more than the usual amount. Fig. 3-59 shows the majority of the National Weather Service's values fall under Lewis and Clark's value.

Figure 3-55: Hypothetical Storm System Movement from 24-27 January 1806. The low pressure system passed to the south of Fort Clatsop. A mixture of rain, sleet, and snow was reported at Fort Clatsop from the 24th through the 25th. Sleet and snow was reported at Fort Clatsop for the first part of the day on the 26th with all snow reported through the afternoon of the 26th on into the 27th. Six inches of snow was on the ground by the 27th.

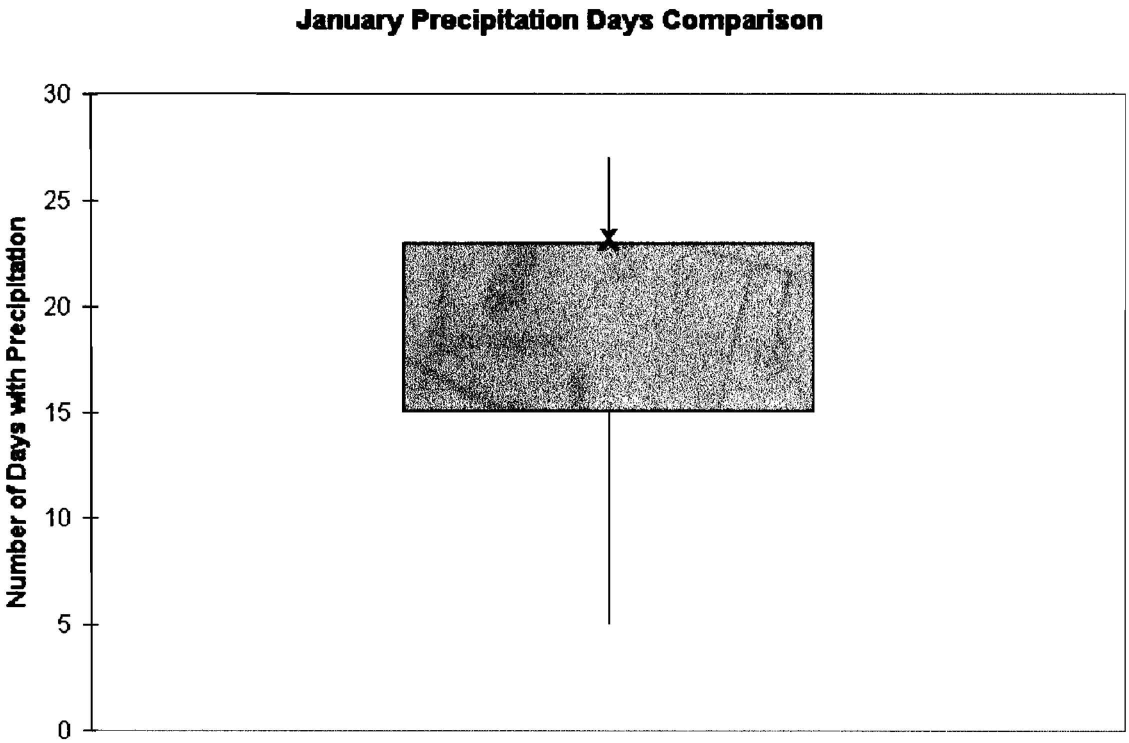


Figure 3-56: Comparison of the National Weather Service's number of days with precipitation to Lewis and Clark's number of days with precipitation. The box plot in the figure depicts the National Weather Service's range of days with precipitation. The "X" in the figure depicts the number of days Lewis and Clark experienced precipitation.

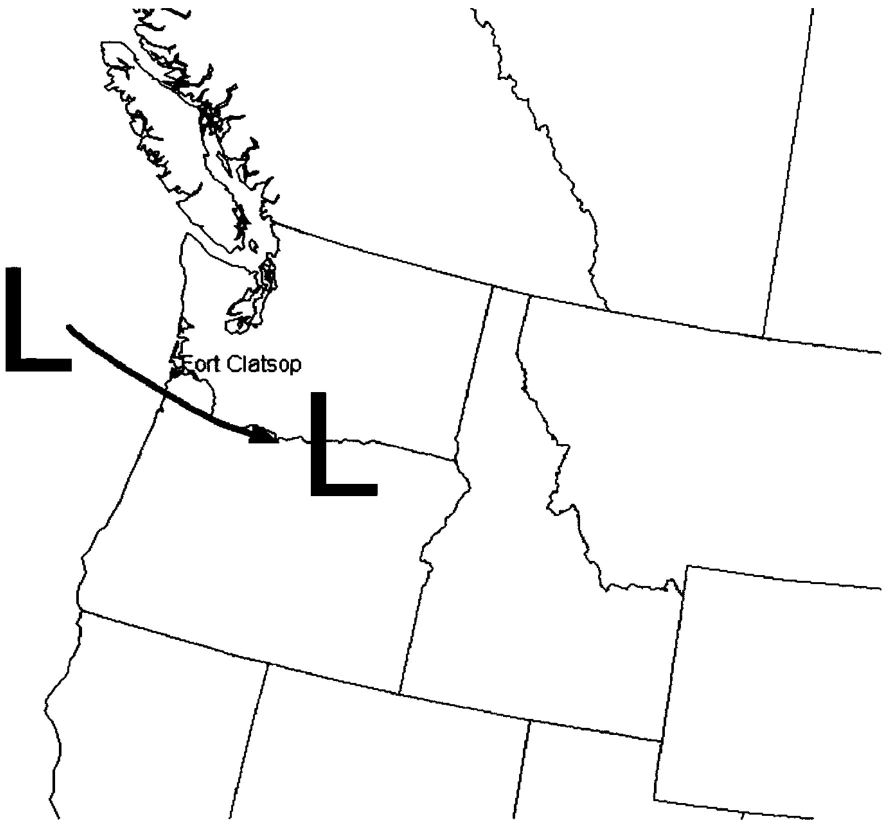


Figure 3-57: Hypothetical Storm System Movement from 9-10 February 1806. The low pressure system passed just to the south of Fort Clatsop. A mixture of rain and sleet was reported at Fort Clatsop on the 9th. Rain, sleet and snow was reported at Fort Clatsop for the first part of the day on the 10th. Lewis and Clark saw a dusting of snowfall from this storm system.

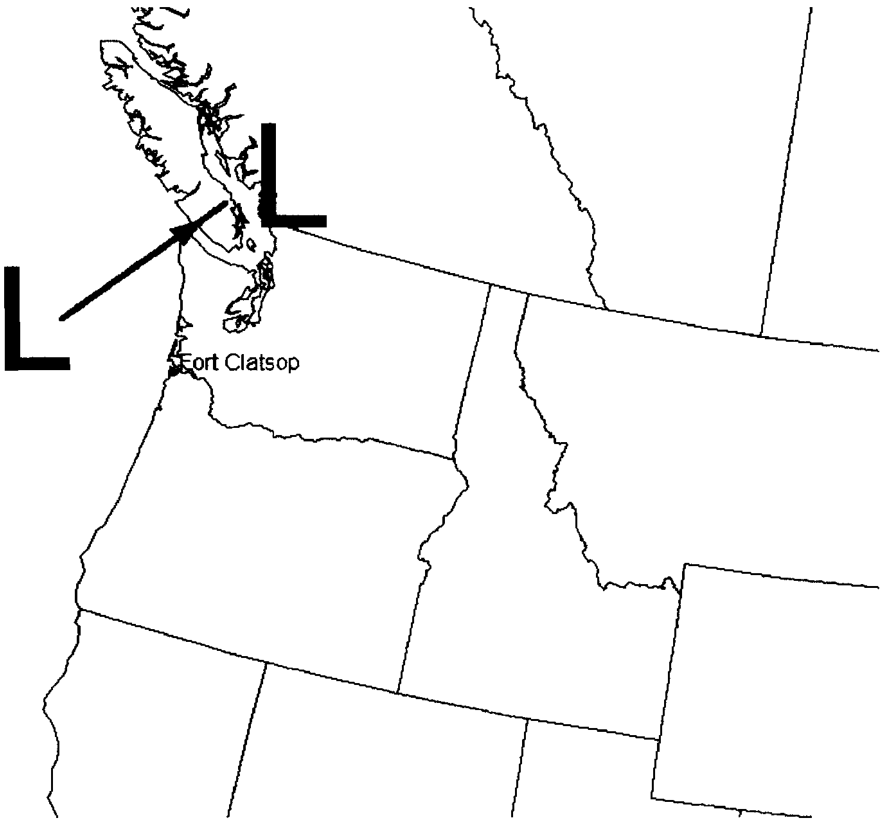


Figure 3-58: Hypothetical Storm System Movement from 16-17 February 1806. The low pressure system passed to the north of Fort Clatsop. A mixture of rain and snow was observed on the 16th and rain, sleet, and snow was observed on the 17th. By the morning of the 17th, sleet and snow covered the ground.

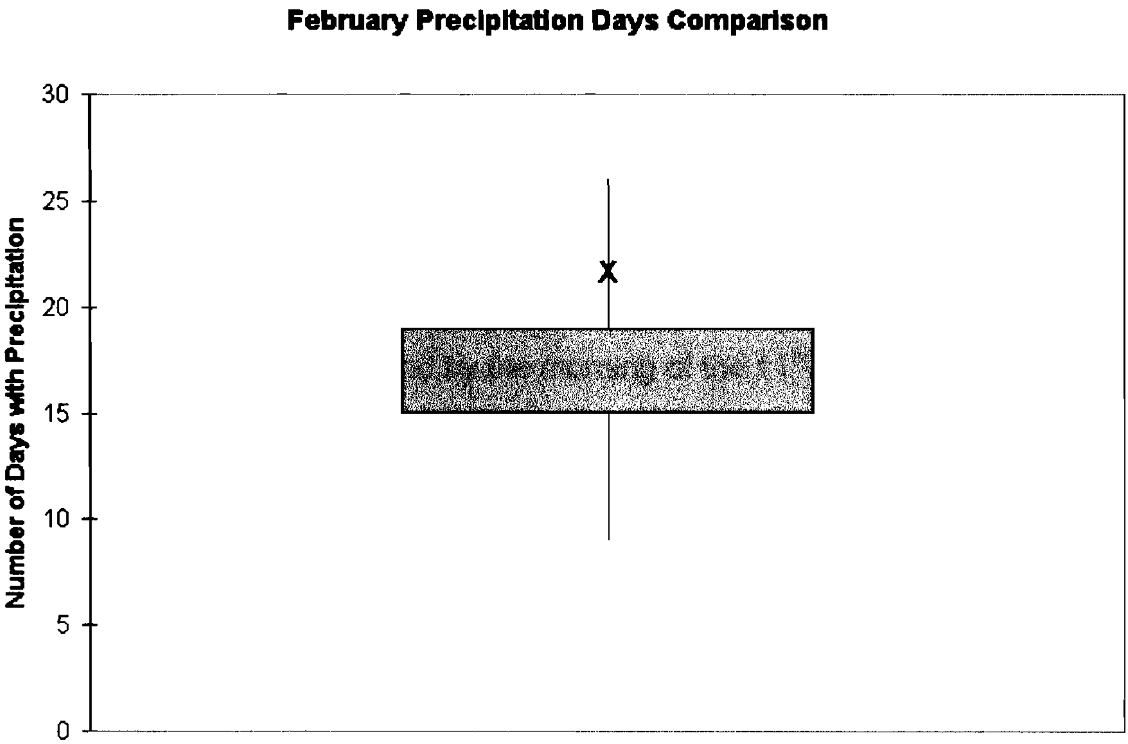


Figure 3-59: Comparison of the National Weather Service's number of days with precipitation to Lewis and Clark's number of days with precipitation. The box plot in the figure depicts the National Weather Service's range of days with precipitation. The "X" in the figure depicts the number of days Lewis and Clark experienced precipitation.

1 March 1806 – 23 March 1806

Rainy conditions continued on through March. Snow and sleet accumulated to around 1 inch (Lewis, 1959), as a storm system moved near the expedition on the 8th and 9th of March (Fig. 3-60). Another low pressure system approached on the 10th of March and lasted into the 12th (Fig. 3-61). According to the expedition, 1 inch of new snow was on the ground by the morning of the 11th (Lewis, 1959).

Days with precipitation continued to be high during the time Lewis and Clark spent at Fort Clatsop during March 1806. Lewis and Clark experienced 20 days with precipitation. This value is at the top of the National Weather Service's range of values (Fig. 3-62).

Return Trip Weather

As Lewis and Clark departed the Pacific Northwest, the weather continued to be very rainy. The rainy weather decreased after the 14th of April 1806 (Lewis, 1959). The expedition encountered more heavy rain and thunderstorms by late-May, but nothing severe was reported. The scattered rain and thunderstorm events continued through June as well, but again neither Lewis nor Clark reported anything severe.

Lewis and Clark split up in July 1806 and took different paths. They would later join back up on the 12th of August. During this time, both Lewis and Clark encountered several rain events. An interesting day occurred on 6 August 1806 in eastern Montana. On this day both Lewis and Clark experienced heavy thunderstorms. Lewis reported a thunderstorm with hail (Lewis, 1959), but gave no

Figure 3-60: Hypothetical Storm System Movement from 8-9 March 1806. The low pressure system passed by Fort Clatsop to the west. However, the storm system did bring a mixture of rain, sleet, and snow to Fort Clatsop on the 8th and 9th. The snow and sleet was one inch deep by the morning of the 9th.

Figure 3-61: Hypothetical Storm System Movement from 11-12 March 1806. The low pressure system passed to the south of Fort Clatsop. A mixture of rain, sleet, and snow was reported as the storm system passed by. One inch of snow was on the ground by the 11th. Precipitation came to a quick end by the 12th, as the storm system moved away.

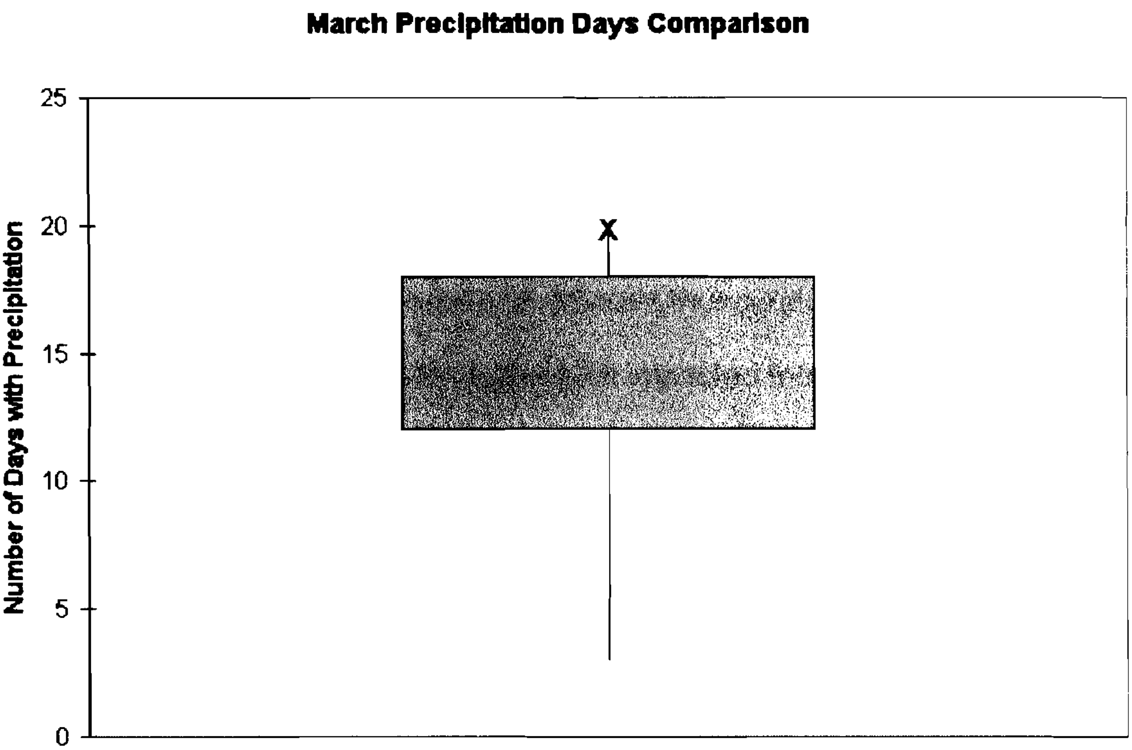


Figure 3-62: Comparison of the National Weather Service's number of days with precipitation to Lewis and Clark's number of days with precipitation. The box plot in the figure depicts the National Weather Service's range of days with precipitation. The "X" in the figure depicts the number of days Lewis and Clark experienced precipitation.

indication of the hail size. Clark did not experience hail, but he did experience heavy rain and high wind (Lewis, 1959). While there is no indication of severe weather, it is possible that a squall line impacted the expedition on that day. A squall line is a line of strong to severe thunderstorms (Ahrens, 2000). Another possibility is that Lewis and Clark happened to experience two different thunderstorms on the same day.

Another thunderstorm with high winds impacted the expedition in Missouri on the 31st of August, but Lewis or Clark gave no indication of severity. A few rain events occurred as the expedition neared St. Louis, Missouri in September. One violent thunderstorm was encountered at 6 p.m. on the 4th of September. Clark mentions that the storm lasted until about 10 p.m. with the wind remaining hard until about 3 a.m. in the next morning (Lewis, 1959). There is no direct indication that this was a severe thunderstorm, but without a doubt the mid-latitude cyclone that moved through was strong given the high winds continuing well past the departure of the thunderstorm.

Chapter 4

Discussion

Fort Mandan, North Dakota

The weather and air masses that Lewis and Clark encountered seem similar to today's in most cases. The majority of Lewis and Clark's temperature and precipitation data seem to fall within the range of the modern National Weather Service's temperature and precipitation data. Some of the differences noted were the maximum temperatures and the number of precipitation days Lewis and Clark observed during the months of December 1804 and January 1805. During a modern El Niño in Bismarck, North Dakota, temperatures would usually be above average (Climate Prediction Center, 2001). Lewis and Clark's temperatures were not on the warmer end of the range of temperature readings today but rather they were on the colder end. Also during a modern El Niño in Bismarck, North Dakota, it would usually be a little drier than average (Climate Prediction Center, 2001), and Lewis and Clark experienced somewhat wetter conditions.

There are two possible explanations for these differences. One is a combination of the supposed El Niño of 1804 and the Little Ice Age. Given the expansion of polar climates during the Little Ice Age, the polar jet stream could have been pushed farther southwestward to the position shown in Fig. 3-21. This would then account for the differences Lewis and Clark observed. The other possible explanation is that given the supposed El Niño of 1804 was ending at that time, the atmosphere could have been returning to normal and this too could have allowed the polar jet stream to shift farther southwestward to the position shown in Fig. 3-21. This would also account for the differences Lewis and Clark observed.

The number of precipitation days Lewis and Clark recorded fell in February 1805, but they increased in March and April 1805 and this is another one of the differences noted in their data. There is insufficient evidence to say what actually accounted for the higher number of days with precipitation in March and April. Perhaps it was due to a climate cycle and Lewis and Clark just happened to explore the area during a rainy period. Perhaps this climate cycle was due to the atmosphere returning to normal after an El Niño event.

Fort Clatsop, Oregon

The Pacific Northwest is known for its wet weather, especially during the time Lewis and Clark were there. The storm tracks Lewis and Clark encountered do appear to be similar to those of modern day. However, the time Lewis and Clark spent in the Pacific Northwest also appears to be one of the wettest times known historically. During their stay in the Pacific Northwest, the majority of Lewis and Clark's days with precipitation were well above the majority of the National Weather Service's days with precipitation. In March 1806, Lewis and Clark's number of days with precipitation was on the top of the National Weather Service's range of days with precipitation. Some of this data could be a bit misleading, since Lewis and Clark gave no indication of how heavy the precipitation was each day. Therefore, they may have counted a day with drizzle falling, and the National Weather Service may not have counted that particular day due to the amounts being on the order of a trace or less.

If the counts are accurate, then the question becomes what could have accounted for the increase in precipitation Lewis and Clark observed. The answer may lie in the Little Ice Age. Perhaps the amount of coldness brought on by the greater amount of polar climates during the Little Ice Age produced a stronger temperature contrast and intensified the polar jet steam which intensified the individual storm systems. A more reasonable explanation for the amount of precipitation, however, is a phenomenon known as La Niña. La Niña is defined as cooler than normal ocean water off the coast of Peru (Ahrens, 2000). It has been found that the year after an El Niño event ends, a La Niña event usually develops. During a modern La Niña event, the Pacific Northwest usually has a higher amount of rainfall than normal (Ahrens, 2000). Thus, a shift to a La Niña event in the winter of 1805-1806 seems to be a strong candidate to account for the amount of precipitation Lewis and Clark experienced at Fort Clatsop.

Introspection

The Lewis and Clark data could be supported with further research in a few areas. One of these areas would be in the realm of tree ring analysis. Using this data in conjunction with Lewis and Clark's data may help support the conclusions presented. Another area to look at would be analysis of sunspots. Studies show that the sunspot cycle may have an impact on climate patterns. Thorough analysis here may give support for the Little Ice Age in addition to support for Lewis and

Clark's findings. Finally, climate also comes in cyclic episodes, and some of the differences encountered with the Lewis and Clark's data may be able to be explained better by taking into account cyclic climate episodes.

Chapter 5

Conclusions

The following are reasonable conclusions based on the study of the weather Lewis and Clark experienced while on their journey from St. Louis, Missouri northward and westward to the coast of the Pacific Northwest:

1. The maximum temperatures during December 1804 and January 1805 at Fort Mandan appear to be somewhat colder than modern data.
2. The number of days with precipitation during December 1804 and January 1805 at Fort Mandan appears to indicate somewhat wetter conditions than modern observations.
3. The number of days with precipitation during March 1805 and April 1805 at Fort Mandan appears to indicate somewhat wetter conditions than modern observations.
4. The time Lewis and Clark spent at Fort Clatsop appears to be one the wettest times known historically.

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