NOAA Technical Memorandum NWS ER-74

The Climatology of Lake Erie's South Shoreline

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The Setting

The dominant factor in the climatology of Lake Erie is the lake's position in the east central portion of North America's interior plain. This location allows both warm humid air from the Gulf of Mexico and cold dry air from Canada to approach and pass by Erie with little hindrance. The location of the lake also exposes it to the influence of two major storm tracks--one from the northwest, and the other from the southwest. Storms approaching from the northwest generally precede the intrusion of Canadian air into the area. Storms coming from the southwest are usually associated with air from the Gulf moving north. These storms from the southwest generally provide the lake basin with its heaviest episodes of precipitation, especially when they pass just to its south.

The net result of the weather systems that affect Lake Erie as a consequence of its location is a basic climate similar to that of other continental locations in the mid latitudes--that is cold winters, warm to hot summers, and frequent temperature changes accompanied by storms in the spring and autumn. However, while the general pattern of weather in the lake basin is the same as in other North American locations at the same distance from the equator, the presence of such a large body of water does produce significant regional effects.

These regional effects are enhanced by the nature of the surrounding lands. Figure 1 shows the lake and its environs. On most sides the topography is relatively flat. As an extreme example, if one leaves the lake in the vicinity of Toledo and travels southwest, it is necessary to journey more than 50 miles to reach an elevation 100 feet higher than the mean lake level. However on its southeast side Lake Erie abuts the west slopes of the Appalachians and in those locations elevations change abruptly as one moves inland. Chardon, in northeast Ohio, is only 12 miles from the shoreline but nearly 700 feet above it. Even more dramatic changes in elevation occur at some places in Pennsylvania and New York State. These rapid increases in height play a major role in shaping the climate of the region from northeast Ohio to southwest New York, since they force air flowing across Lake Erie from the northwest to rise rapidly once it makes landfall. Where this enforced rising occurs, it has a major effect on the incidence of clouds and precipitation (especially snow) since when air is uplifted it tends to lose whatever moisture it is carrying. More will be said about the climate of Lake Erie's "snowbelt area" later.

Another significant factor in considering the climate of the lake and its basin is the depth of the lake water. This is important because the shallower a body of water is, the less time it takes to heat or cool, and the more sensitive it will be to the influence of the prevailing weather. Shallow water also enhances the rate and extent of wave formation. Since Erie's mean depth of 62 feet (with much lower values prevailing in broad expanses of its western portions), is by far the least of the Great Lakes, its water temperature shows a much greater response to changing air temperatures than larger, deeper bodies such as Superior. Changing water temperatures in Erie do much to render its climate unique among the Great Lakes.

The Climate of the Lake

Since the same air masses that control the meteorology of land locations in the north-central United States also dominate Lake Erie's weather, air temperatures over the lake follow the familar seasonal cycle. Mean readings are in the mid 20s in January, commence a rapid rise in March, reach the low 70s in July, and then fall rapidly again starting in September. This progression is quite similar to that which prevails at inland locations.

However, while <u>average</u> temperature conditions over the lake are similar to those over land, the thermal inertia of the large mass of water does serve as a buffer against extreme conditions. Cleveland, a typical lakeside community, experiences an average of only 8 days per year with temperatures of 90 or higher, and 7 days per year with readings at or below zero. In Chicago, a city at the same latitude as Cleveland but with relatively little lake influence, there are an average of 16 days per year with temperatures of 90 or more, and 13 days with the mercury falling to zero or less. Air temperatures over the lake also experience a smaller diurnal variation than over land. The fact that air over and nearby the lake is relatively resistant to temperature extremes has important implications for agriculture that will be discussed later.

Although Lake Erie's average air temperature climatology is not very different from that on the surrounding land, water temperature patterns in the lake are one of its truly unique features. These patterns are presented graphically in Figure 2. Since considerable time is needed to exchange heat between air and water, Erie warms in the spring and cools in the fall much more slowly than the air above and around it. However, the comparitive shallowness of the lake water means it is still much more responsive to the march of the seasons than is the case for any of the other Great Lakes.

Usually Erie is at its coldest in January and February when it is icebound or has temperatures just above freezing. Although warming begins over the drainage basin during March, the lake itself shows only a small temperature increase until April. Even after that, heating lags behind what is occurring in the air. The highest water temperatures occur in August while as far as the atmosphere is concerned July is the hottest month. When water temperatures reach their peak, they are generally in the low 70s, but in the relatively shallow western basin they normally climb to the mid 70s. In extremely hot years, the water in Lake Erie has been know to approach an average temperature of 80 degrees. The fact that the lake gets so warm in the summer is a major factor in rendering it a recreational mecca.

During the fall the water exhibits the same temperature lag compared to the air as during the spring. Significant cooling does not begin until October although above the lake and over the neighboring land the advent of cooler temperatures is in September.

The fact that at many times of the year there is a large temperature difference between the water and air plays a significant role on the occurrence of clouds, precipitation, and fog over the lake. Cloudiness is greatest in the late fall and early winter when the sky is at least half covered nearly 80 percent of the time. To a certain extent this peak in cloud cover is caused by an increase in storm systems that affect other areas besides the lake. However, a major factor why the skies over the lake become so cloudy in the fall is at that time of year the water is relatively warm compared to the air over the neighboring land. As a result air--especially when it is from the north--blowing over the lake undergoes warming. The warming of the air promotes the absorption of water vapor from the lake surface and also induces rising motion. Since cloud formation in turn is caused by the lifting of moisture laden air, the end result when Lake Erie is warmer than the land is a lot of cloudiness.

Cloudiness decreases markedly in the spring when both the number of storms decrease and the lake becomes cooler than the air crossing it. July on the average is the clearest month, with skies mostly free from clouds at least 50 percent of the time. Generally speaking, Lake Erie's propensity for cloudiness in the fall and winter outweigh the tendency for fair skies at other times of the year, and yearly average cloud cover is somewhat higher than for areas without a lake influence.

Precipitation patterns on Erie resemble those for cloudiness since both phenomena are caused by the same essential mechanisms. Although rain or snow occurs most frequently in winter, the greatest accumulations are actually received during the spring when heavy rainfall is most frequent. Since these spring rains also affect the land, there is not a radical difference between total yearly precipitation on the lake and on its environs. The average annual amount of rain and melted snow is about 31 inches at the western end of the lake. The extra precipitation caused by the lake increases the average annual total at its eastern end to about 35 inches.

Although Erie acts on average as a cloud and precipitation enhancer, with fog the situation is not so clear-cut. This is because fog most commonly occurrs when long clear nights encourage cooling of the air near the ground--an especially frequent situation in the fall. Since the lake water is comparatively warm in the fall, it often works to short circuit fog development. It is not uncommon for a very thick fog bank on land to stop quite abruptly at the shoreline. However the lake does serve to increase foginess in the spring when it is still cold enough to chill air moving in from the south. The end result of the lake water alternately serving as a source and sink of fog is that the number of days when fog is significant (i.e., enough to reduce visibility to 3 miles or less) is aproximately equivalent on both land and water.

Wind patterns on Lake Erie are dominated by weather systems too large and powerful to be influenced directly by such a comparitively small geographic feature. This means that the direction of prevailing winds over the water is about the same as on land. While winds are possible from all directions, they most commonly occur from the west or southwest, reflecting the typical pattern of mid-latitude weather. Figure 3 shows the distribution of wind direction and speed at various seasons. While the tendency for winds to be from the west or southwest is strong throughout the year, the figure shows there is a strong trend towards variability in the spring--a season of rapidly changing conditions--and also that summer sees more southerly winds than other seasons.

While wind directions over the water are similar to those at land locations, speeds are significantly higher across the liquid surface since it offers little obstruction to airflow. The overall mean wind speed over the lake is about 15 knots, compared to about 10 knots over the adjoining land. However great variations occur around this figure. Winds are 6 knots or less about 15 percent of the time, and are between 28 and 40 knots about 7 percent of the time. About 1 percent of all observations show speeds in excess of 40 knots, and most years see at least a few occasions where gusts peak over 50 knots. A few times a century winds of hurricane strength (70 knots or more) will occur. The strongest blows usually strike during the fall and winter, a result of the frequent and powerful cyclones that traverse the lake area during that time.

While most of the time Erie's winds are controlled by weather systems that are too large to experience direct lake effects, there are occassions when the lake itsself plays a major role in determining air movement. These occur when large scale weather patterns are relatively weak and a strong temperature difference exists between the land and the water. If the land is sufficiently warm it will heat the air over it enough to cause rising motion. The rising air will be replaced by relatively cool air coming from off the lake, resulting in an on-shore or "lake" breeze. If the lake is warmer than the land the situation may be reversed, causing an offshore or "land" breeze. In some circumstances there can even be a lake breeze during the day and a land breeze after cooling occurs at night. Lake and land breezes usually occur within only a few miles of the shore, but within that area they can be an important meteorological event.

As might be expected, wave climatology of the lake is closely coupled with wind climatology. Figure 4 gives an idea of open water wave height as a function of season. The figure is exaggerated to make the frequency of high waves easy to discern, but clearly shows a strong maximum in the winter and fall, when waves exceed 6 feet at least 50 percent of the time. This peak in wave activity of course reflects the stormy conditions that prevail during those seasons.

As with winds, waves on Lake Erie can show extreme variability, and in fact its shallow water makes the lake notorious for the speed at which it can rise. Sustained storm-force winds (i.e., 50 knots or more) with a sufficient fetch will produce wave heights approaching 20 feet within 6 hours. Even a local thunderstorm with winds of only 35 knots can generate 8 foot waves within a matter of minutes. The highest waves that ever develop on the lake are on the order of 22 feet. Such heights are possible only in very unusual situations when an extremely strong wind is blowing from either the southwest or northeast--the directions that allow maximum fetch. The fact that waves can develop so rapidly make Erie a very dangerous place to be when the wind rises. This is especially true because the recreational adavantages of the lake mean it is heavily frequented by small pleasure craft that may be easily overwhelmed by seas of even 3 to 5 feet--which can develop nearly instantly under the proper circumstances.

The fact that the water can be churned up so readily makes the occurrence of thunderstorms in the lake area of special interest. Figure 5 shows the percentage of time thunder occurs each month. The figure indicates an observer on the lake could expect thunder to be audible a little over 3 percent of the time in July, while in February he or she should hear no thunder at all. There is little evidence to suggest the distribution of thunderstorms on the lake is much different than it is on the land, although the temperature differences that sometimes prevail between the two regimes might lead one to suspect otherwise.

Several factors work together to cause this counter-intuitive phenomenon. During the spring when the temperature difference between the regimes is great, most thunderstorms are triggered by cold fronts approaching from the northwest. These fronts are too strong and fast to feel much affect from the water during the comparatively brief time they spend over it. As spring ends thunderstorm formation is more determined by relatively weak local factors that could be influenced by a land-water temperature gradient--but by the time these local factors become predominant usually the lake-land temperatures are approaching a rough equality.

However, if thunderstorm frequency is about the same on water and land, thunderstorm effects are not. On shore a storm powerful enough to cause significant damage is a fairly rare occurrence, but the tendency for winds and waves to increase rapidly on an open, shallow body of water can make a comparatively small storm into a killer for boaters. Winds equal to or greater than 35 knots--which would be nearly harmless on land--can produce extreme danger to the small craft that frequent the lake. While exact figures are not available, such hazards happen at each point on the lake at least several times a year.

Data on tornadoes over Lake Erie is scanty. Since thunderstorm development is little different than over land, and tornadoes are produced by thunderstorms, the lake probably has about the same tornado incidence as areas on the shore. One thing is certain: the presence of the lake water is no guarantee against twister formation. One of the most devastating tornadoes ever to strike Ohio formed over the lake on June 28, 1924, struck the town of Sandusky, moved back over the water, and then hit the city of Lorain. This storm killed 85 people, a record for Ohio that has never been seriously challenged.

Although Lake Erie may have relatively little effect on thunderstorm and tornado climatology, it does experience an interesting phenomena that is totally unknown inland--the waterspout, also known as the cold air funnel. Waterspouts in some respects resemble tornadoes, as can be seen in Figure 6. However, they are much less dangerous as they contain winds of only about 35 to 60 miles an hour (winds in a tornado may exceed 300 miles an hour). Waterspout formation is frequent in the early fall, when the first cold outbreaks of Canadian air move over the still quite warm lake. Although at rare intervals a waterspout may move onshore, the result is usually its rapid dissipitation and land damage from waterspouts is almost totally unknown. The only hazard they pose is to those small craft operators foolhardy enough to sail into them.

Waterspouts are more of a curiosity than anything else, but another phenomena peculiar to the lake itself--ice formation--has a major economic and climatological impact. Of all the Great Lakes, Erie experiences the greatest variation in ice development. This is because its comparative shallowness renders it vunerable to rapid cooling and freezing when the weather is cold, but its southerly location ensures it will experience some winters too mild to cause significant freezing at all.

The most typical pattern of ice development is for formation to commence west of Point Pelee in late December, spread east across the lake in January, and peak in February. Normally 90 to 100 percent of the lake will be frozen by late winter. Dissipation of ice also proceeds from west to east and generally starts in early March. Most of the water is normally clear by late April, although some ice commonly persists east of Port Colborne, Ontario into May. Under very cold conditions the lake may be mostly covered with ice as early as January 1, and in some cases a very extensive pack will persist into April. Figure 7 provides an illustration of ice development under unusually cold, normal, and unusually warm conditions.

Erie is the only one of the Great Lakes that mostly freezes over in the majority of winters. This freezing is a very significant event. It not only acts to preclude commerical traffic, but also serves to make the lake meteorologically indistinguishable from the snow cover that normally surrounds it during the cold season. This means that in many years mid and late winter may be sunnier and drier than earlier in the season when the open water acts as a cloud and precipitation enhancer. The fact that Erie freezes most winters also serves to slow its temperature increase in the spring, since heat energy from the sun and air that would otherwise go to warm the water is used in melting ice.

No discussion of Lake Erie's climatology would be complete without considering one more factor unique to bodies of water--the ability to rise and fall. The variation of the lake level is especially important in the more western reaches of its basin where the slope of the land away from the water is exceedingly gradual and even a small change in lake height can flood or leave dry significant areas. The level of the lake can be altered by two basic factors: changes in its volume, and the effects of wind.

Volume changes are controlled by the net balance of water entering and leaving, which in turn is determined by patterns of precipitation and evaporation over the entire basin. This basin is quite large since it includes all of the other Great Lakes except for Ontario, as well as their tributaries. The exceptional size of Erie's drainage area tends to act as a buffer against the influence of localized or short term weather events, so that only relatively long term patterns actually change the water content of the lake. An example of such a pattern is the yearly concentration of rainfall in the spring, which causes Erie's water levels to follow a cycle with its peak in the summer and a minimum in the winter. On the average, this yearly variation amounts to a little over a foot.

The lake can also experience cycles longer than the annual one, depending on whether precipitation over its basin averages above or below multi-year normals. These long-term trends can produce variations of more than 5 feet in the water level. While at the end of a several-year wet period levels can be so high as to cause serious shoreline flooding and erosion, long dry stretches can lower the depth enough to cause problems for commercial navigation. While there have been some assertions that Lake Erie's level follows a cycle of 5 or 12 years, evidence for such definite patterns is inconclusive.

While changes in lake level due to varying precipitation and evaporation take months or even years to manifest themselves, the second mechanism that can alter water elevations--the wind--acts in hours. Wind can change the height of the water simply by pushing it towards one end of the lake or another. The effect is strongest when the water is pushed along the long axis of the lake--that is from the southwest or northeast. This means wind generated changes in lake level are most noticeable in the vicinity of Toledo and Buffalo.

Such changes can be quite pronounced. At Toledo the water level has changed by nearly 4 feet in only about 18 hours (Figure 8). As one might expect, such variation is most significant when the lake is running either high or low due to earlier wet or dry conditions. For example, northeast winds caused major flooding around Toledo in the spring of 1986 when Erie was already at record heights from a succession of wet years. The extra impetus provided by the wind was enough to push water where it had never been before. Conversely, if the lake is already running low, a strong southwest wind can render large portions of its western basin too shallow for navigation. While water levels in northeastern Lake Erie undergo the same vagaries as in the southwest, the effect is relatively minor since depths are relatively great and the land slopes away from the water comparatively rapidly.

Once winds that are causing a change in lake elevation diminish an interesting effect called a <u>seiche</u> develops. This results from the fact that when the winds decrease, the water they piled up does not just settle back to normal, but rather sloshes back and forth from one end of the lake to the other. Although on a tremendously larger scale, the seiche is essentially the same thing that happens when water in a bathtub is agitated and continues to slosh around for a while. The period of a southwest to northeast Lake Erie seiche (the most pronounced kind) is about 15 hours. The water generally keeps sloshing back and forth for a couple of days until internal forces finally dampen its motion out. The existence of the seiche means that after a windy period a point on the lake will see a definite cycle of the water level reaching a maximum, receeding, and then reaching another maximum aproximately 15 hours after the first. Just as when water in a bathtub is disturbed, the greatest change in its level is at the ends, when a seiche occurs the greatest changes in water height are where the land bounds its track.

Climate of the Lands Adjoining the Lake

Not only does Lake Erie have unique climate of its own, it also provides one to the surrounding territories. Many aspects of the climate of the neighboring landscape are essentially identical to those to the lake and have already been alluded to. However some meteorological patterns that occur on the lands near the lake deserve special mention.

One of these is the famous "lake effect snow". As already mentioned, the lake water acts to enhance snow formation in the late fall and early winter when it is still relatively warm and cold winds blow across across it. Air that has absorbed warmth and moisture from the lake has an especially great propensity for snow formation when it is forced to rise rapidly by the topography it meets upon landfall. The southeast shore is well situated to feel the effects of of north to northwest winds with a long fetch over the water. It is also characterized by rapidly increasing elevations away from the shoreline. As a result, the region experiences frequent and heavy snowfalls during the cold season.

These snowfalls are sufficient to give the southeast shore radically different winter weather than locations only short distances away to the south or west. Figure 9 provides a good illustration of how dramatic the lake effect can be in Ohio. The maximum in Geauga County is associated with the crest of a ridge there. Even greater amounts can fall at high elevations in Pennsylvania and New York State. Figure 9 also shows that annual snowfall diminishes rapidly west of Cleveland. This is due both to the fact that the southwest shore rises only slowly from the lake and that cold air approaching the region rarely has much fetch over the water.

An equally important, but far more benign, characteristic of the the weather around Lake Erie is an extended growing season. Since the water serves as a heat reservoir in the fall, it helps to postpone the date of the first frost in adjacent areas. A good example of this can be found by comparing records from the Ohio communities of Sandusky and Norwalk. In Norwalk, about 15 miles south of the shore, the average date of the first freezing temperatures is October 10. In Sandusky, which is immediately adjacent to the water, freezing does not normally occur until October 30.

Although it may seem obvious the lake would serve to delay freezing in the fall, somewhat more surprising is that it acts to advance the date of the last spring freeze. In Norwalk the last freezing temperatures typically come on May 10, but in Sandusky they occur on April 17. The reason the lake works against late freezing in the spring is that while on the average it is colder than the land at that time of year, it does represent a source of relative warmth on chilly nights when frost might otherwise form.

Another agriculturally important feature of the lake during the spring is that until it warms up it exerts a chilling influence along its shore and tends to retard the growth of vegetation there. This effect is not very comfortable for the people who live near the water--who may experience temperatures in the 50s on a spring day while readings are in the 70s a few miles to the south. However, the fact that spring comes only slowly to the shore area helps to render vegetation there more resistant to late season cold spells than the more developed crops farther inland.

In a nutshell, Lake Erie both lengthens the growing season of its environs and renders crops there resistant to any late freezes. This makes the area near the shore favorable for a variety of agricultural activities. Orchards and vineyards abound, as do farms growing speciality crops such as tomatoes. Unfortunately, as can be seen by contrasting the frost dates for Sandusky and Norwalk, the agriculturally beneficial effects of the lake extend only a few miles inland.

While heavy snow and a long growing season are two of the outstanding features of the climate of the region around Lake Erie, perhaps the most important of all is that the area is a pleasant place to live. While winters may be cloudy and snowy, and spring is sometimes chilly, overall climatic conditions are as good or better than in many other locations. The moderating influence of the lake reduces the incidence of extremely cold temperatures in the winter. It also often brings long strings of pleasantly mild days in the summer when other regions are sweltering through heat waves. Precipitation in the Lake Erie area is sufficient to ensure a good water supply for agriculture and other activities, severe weather is relatively infrequent, and the presence of the lake itsself provides an almost limitless resource for recreation, commerce, and industry.

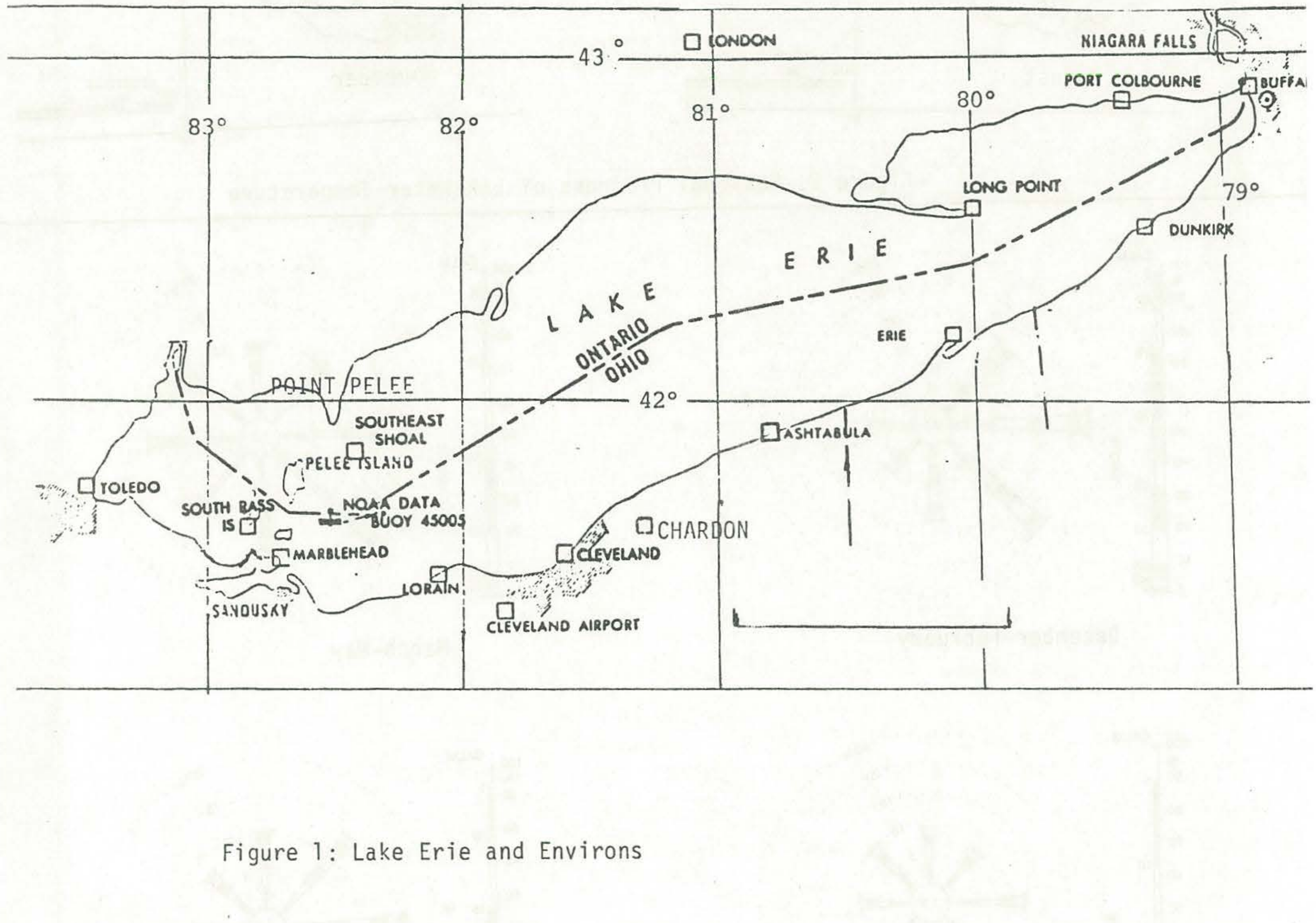


Figure 1: Lake Erie and Environs

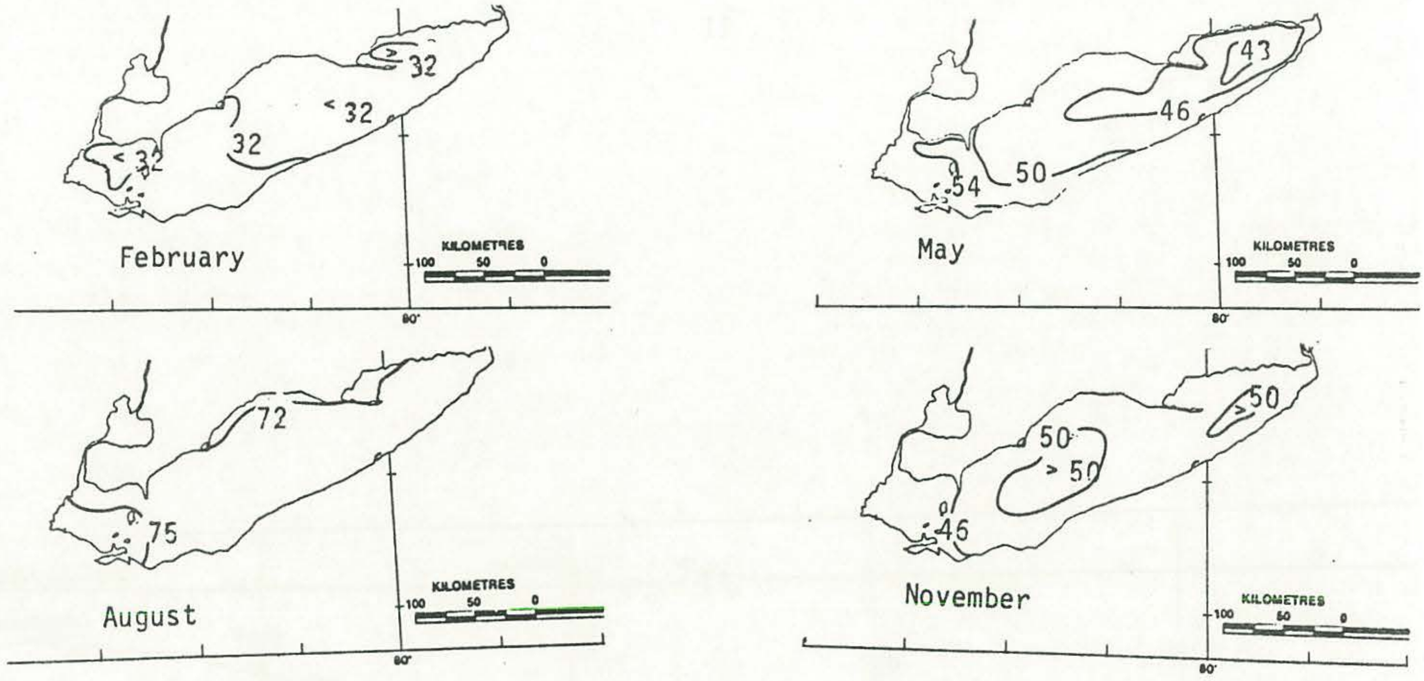


Figure 2. Seasonal Progress of Lakewater Temperature

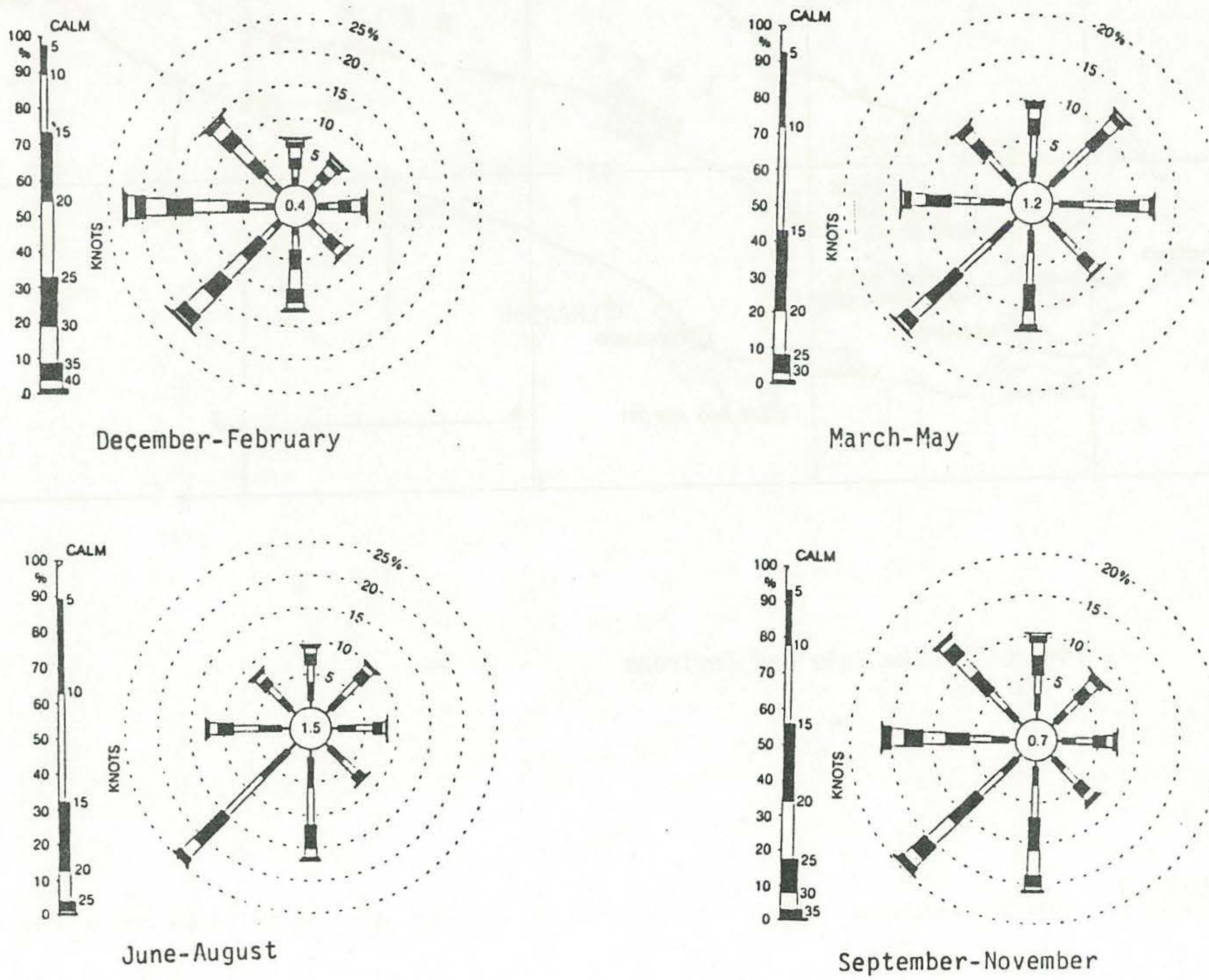


Figure 3. Seasonal Progress of Wind Speed and Direction

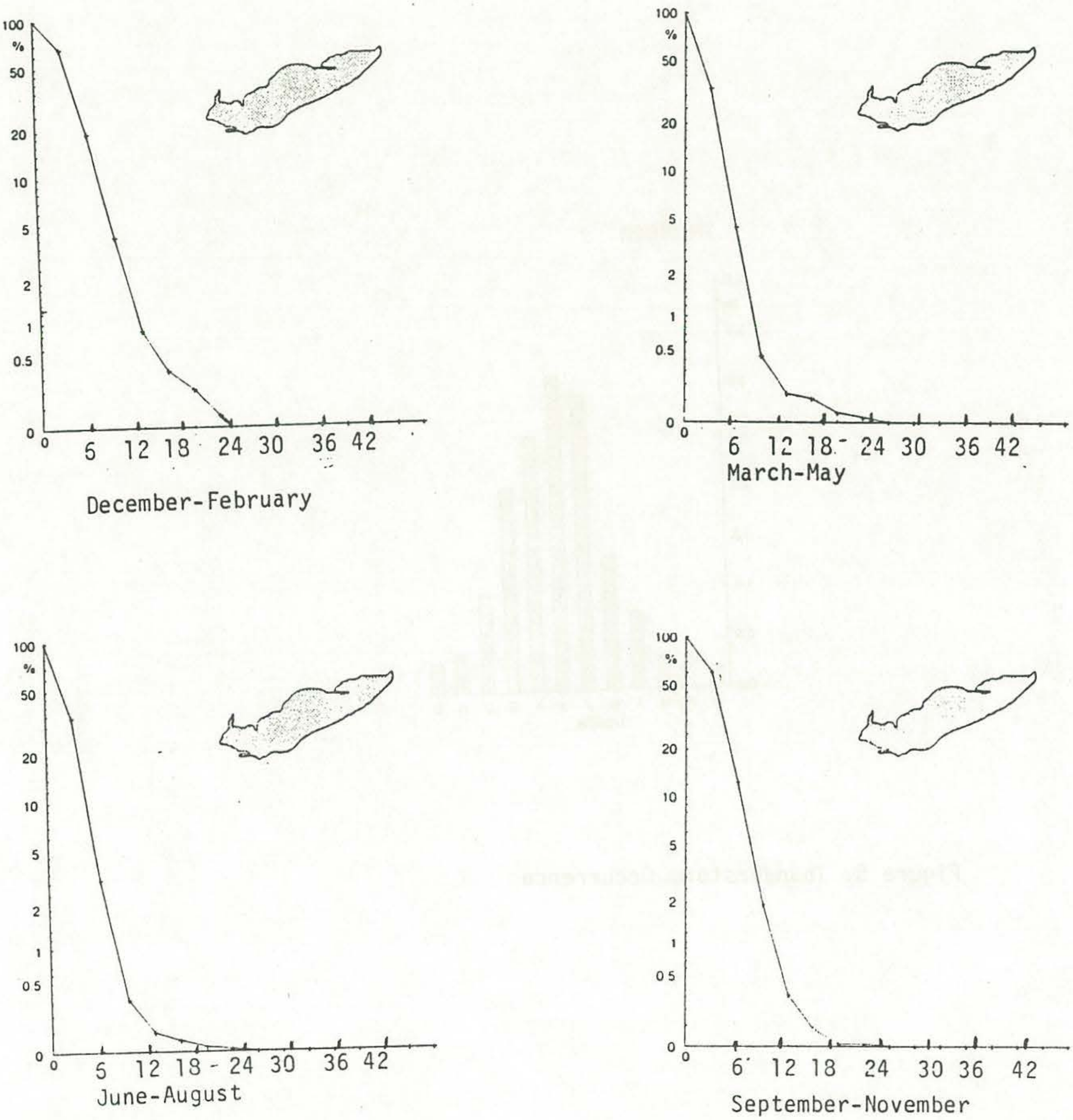


Figure 4. Seasonal Wave Distribution (heights in feet)

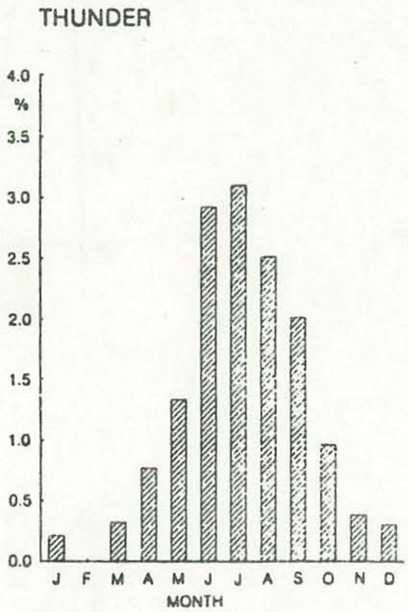
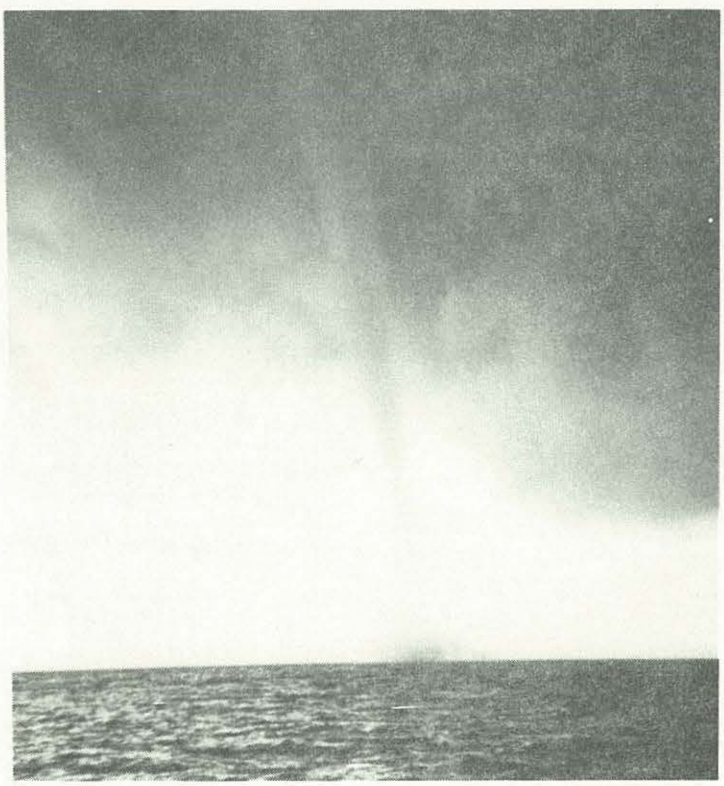


Figure 5. Thunderstorm Occurrence

No. 1

No. 2



No. 3

No. 4

Figure 6. Waterspout Formation over Lake Erie

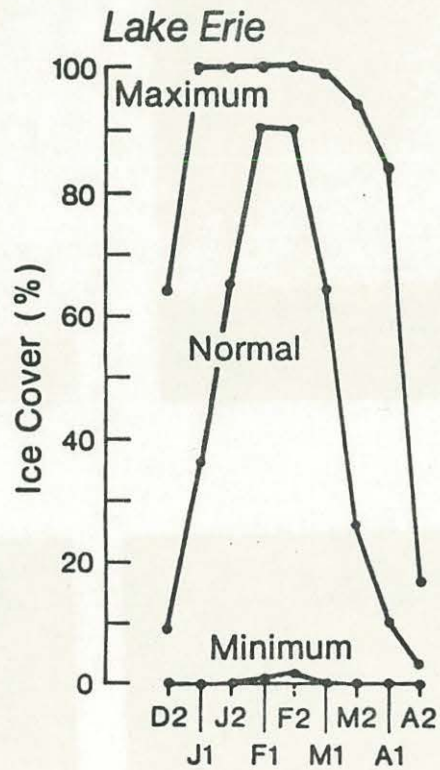


Figure 7. Freezing Patterns on the Lake

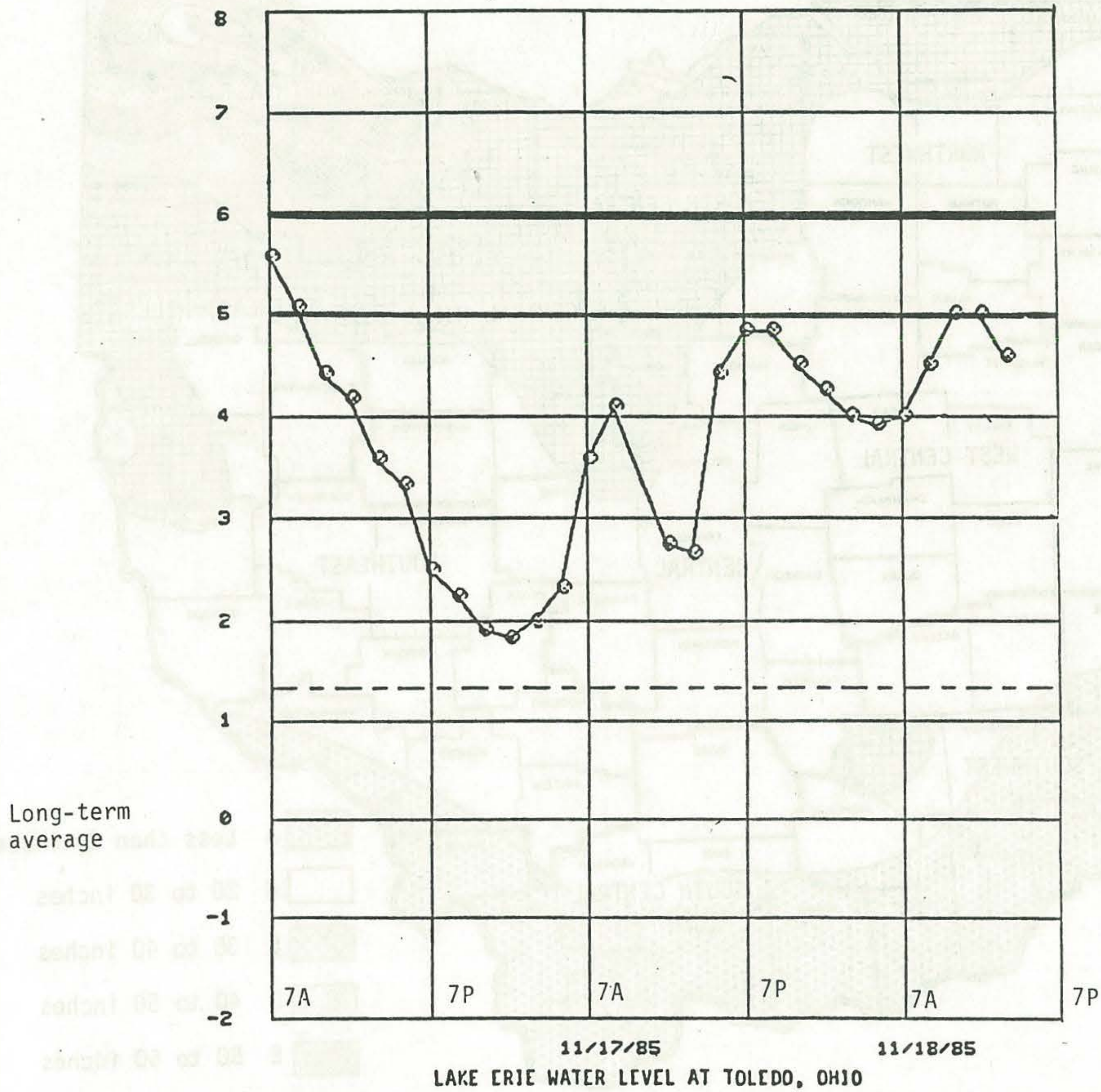
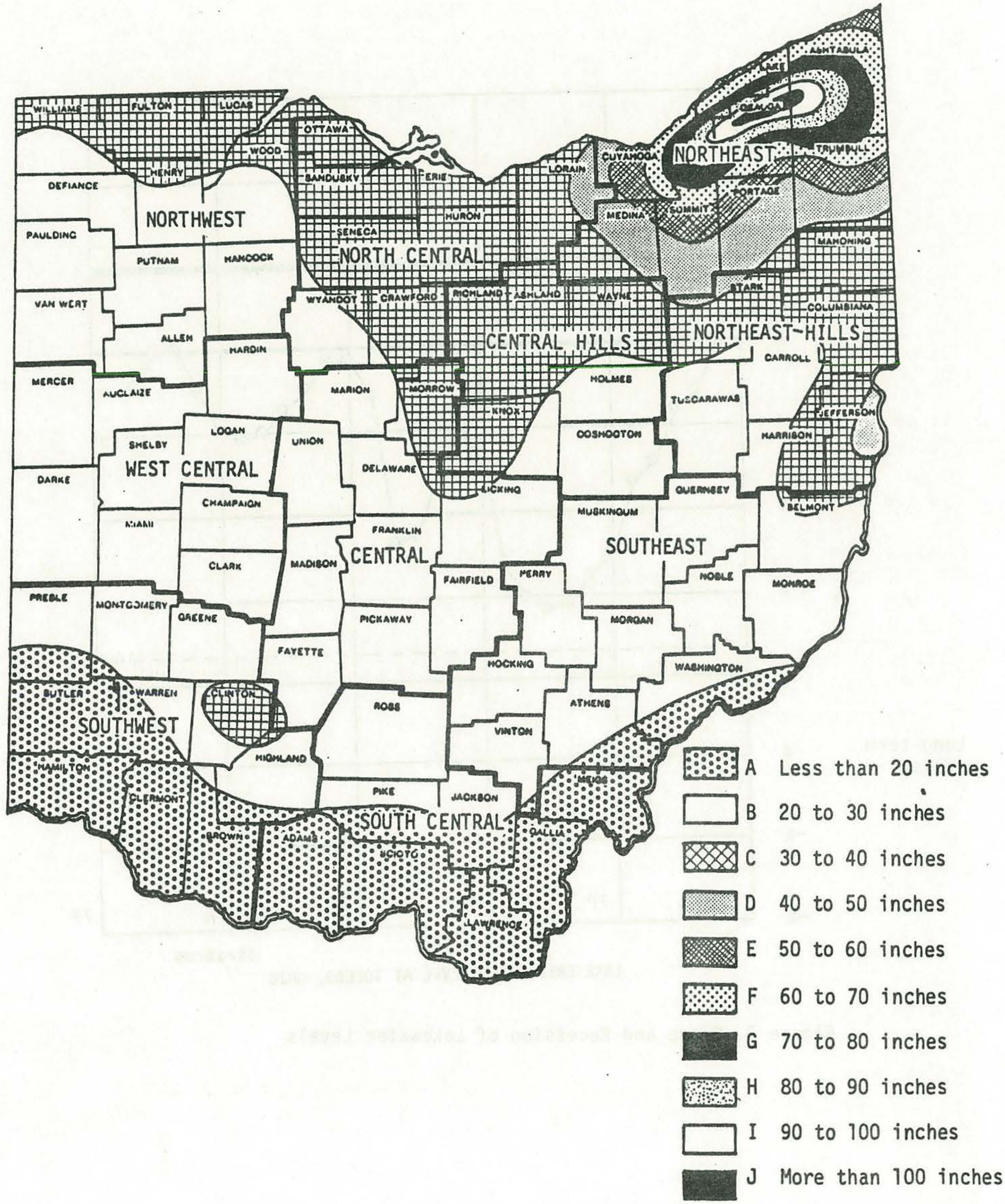


Figure 8. Surge and Recession of Lakewater Levels



Mean snowfall for winter season (inches).

Figure 9. Snowfall in Ohio. The Maximum in the Northeast is Caused by Lake Erie