THE PREDICTION OF SURGES IN THE SOUTHERN BASIN OF LAKE MICHIGAN

Part III.[1] The Operational Basis for Prediction

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ABSTRACT

The development of operational surge prediction in southern Lake Michigan is reviewed through the 10-year span starting with the disastrous surge of June 26, 1954 which took several lives in the Chicago area. Particular emphasis is given to the application of the work of others, especially Platzman, to the surge-prediction problem. Considerable detail is given on the surge of August 3, 1960, for which a successful prediction was made. This example, with its messages to the public, could serve as a model for future surge predictions. Finally a set of steps is given by which a prediction is made, followed by comments on those items still needing research before we can evaluate all parameters for an operational surge prediction.

1. INTRODUCTION

The first operational Great Lakes surge (seiche)[3] forecast was made on July 6, 1954 by Gordon E. Dunn, then Meteorologist-in-Charge at the Chicago office of the U.S. Weather Bureau. Since the Chicago office's forecast and warning responsibility for the United States portion of the Great Lakes had begun many years prior to 1954, that office, and Dunn in particular, had experience in observing these surges.

Public attention was drawn to this type of phenomenon by the disastrous surge 10 days earlier (June 26), in which seven people were drowned while fishing from a breakwater at the entrance to Montrose Harbor (Chicago). The cause of these surges was not known at the time but in his report to the Chief of the Weather Bureau on the June surge Dunn said ". . . every seiche which has been brought to my attention during my 15 years in Chicago has occurred in connection with a squall line, a pressure jump, and in the early morning or forenoon."

In August 1954, in a letter to Maurice Ewing of Columbia University, Dunn gave the basis for his seiche forecast of July 6 by saying: "Noticing the extraordinary pressure jump and the similarity of the conditions with the June 26th squall-line, I issued a seiche warning and the Coast Guard cleared all beaches and piers in the Chicago area and there was no loss of life. Since I do not understand the physical processes involved, the excellent verification is considered entirely fortuitous." This letter was in response to a request for information about the June 26 surge. Ewing and collaborators were interested in this case and an exchange of letters occurred between them and Dunn in August 1954. Soon thereafter Ewing, Press, and Donn [2] published their theory; they said ". . . one can explain the Lake Michigan wave on the basis of resonant transfer of energy from the traveling pressure jump and its associated high winds in the air to a gravity wave traveling with equal velocity in the lake. Only for equal velocities can a large wave be generated." They then showed that the atmospheric and water waves were moving with equal speeds—about 65 m.p.h.—in the June 26 case. They also said that if their thesis was correct, several hours advance warning might be possible in the future.

Harris [3] published a more detailed study of the June 26, 1954 surge, and in his conclusions mentioned the following important point: "In determining which pressure jump lines will be accompanied by important water level disturbances in Chicago, it is likely that the orientation of the pressure jump will be equally or more important than the speed of the disturbance. This is because shoaling, reflection, and convergence due to the contours of the shore must all be considered to account for a disturbance of the observed magnitude."

As a result of the work of Ewing et al. and of Harris, the Meteorologist-in-charge at the Chicago office of the U.S. Weather Bureau in July 1955, J. R. Fulks, instructed his forecasters to be alert for possible seiche conditions at Chicago, adding, "I suggest we issue seiche warnings whenever an intense squall line, oriented approximately NE–SW, with surface winds 50 m.p.h. or greater in squalls, passes Chicago moving southeastward at a speed of 40 m.p.h. or greater, provided the squall

[1] Part I (by G. W. Platzman) and Part II (by S. M. Irish) appear elsewhere in this issue.
[2] Present location: U.S. Weather Bureau, Kansas City, Mo.
[3] In the *Glossary of Meteorology* of the American Meteorological Society one definition of seiche is given as: "In the Great Lakes area, any sudden rise in the water of a harbor or a lake, whether or not it is oscillatory. Although inaccurate in the strict sense, this usage is well established in the Great Lakes area."

line extends across or most of the way across Lake Michigan."

These instructions were sound, but knowledge at that date was not sufficient for preparing quantitative forecasts of the surge, particularly of its magnitude. The work of Platzman [6] on the surge of June 26, 1954 and of Jelesnianski [5] on that of July 6, 1954 later provided some quantitative information, particularly on time of arrival of the surge.

2. FORECASTING THE SURGE OF AUGUST 3, 1960

The August 3, 1960 surge, studied by Irish [4] and reported as Part II of this series, was the first prominent surge known to have occurred since 1954. Until this time no seiche forecast had been issued from Chicago since the one by Dunn in July 1954. Only several hours after the initiation of the squall line that eventually produced the surge, the Weather Bureau forecasters at Chicago realized the threat of the surge; by 0900 CDT, using mainly the papers of Platzman [6] and Harris [3], they were aware of the close analogy of the situation to that of the June 26, 1954 surge, and were quite confident a significant surge would occur.

About that time the squall-line thunderstorms were approaching the Chicago area and a public warning of locally damaging winds was currently in effect. In order to prevent confusion of warnings, the surge warning was not issued until the damaging wind storm had passed, because it was realized that this delay still permitted adequate time to take such precautions as could be taken for the surge. Instead, a warning was sent to the Weather Bureau station providing local service to the eastern shore of Lake Michigan, as the surge would hit there first before being reflected toward Chicago.

At 10:45 a.m. CDT the Chicago office of the Bureau issued the following warning for Chicago:

PROVISIONAL WARNING OF POSSIBLE SEICHE CONDITIONS CHICAGO LAKE SHORE. THE WEATHER CONDITIONS TODAY ARE THOSE UNDER WHICH SEICHES ARE KNOWN TO HAVE OCCURRED ALONG THE CHICAGO SHORE OF LAKE MICHIGAN IN THE PAST. ALL PERSONS ALONG THE LAKE SHORE ARE ADVISED TO TAKE PRECAUTIONS. THE MOST LIKELY TIME OF RISE AND FALL OF WATER LEVELS IF A SEICHE DOES OCCUR IS BETWEEN NOON AND ONE PM CENTRAL DAYLIGHT TIME TODAY WEDNESDAY AUGUST 3. WITH A SEICHE THE WATER LEVEL RISES AND FALLS BY SEVERAL FEET. IF THE FLUCTUATIONS OF WATER LEVEL DO OCCUR, THEY WILL LIKELY BE REPEATED AT INTERVALS DURING THE AFTERNOON BUT WITH LESSER AMOUNT OF RISE AND FALL.

The predicted time of the peak surge was 1225 CDT, based on Platzman's paper, and the small time range given in the warnings was considered adequate because of (1) the closeness of the situation to that of June 26, 1954, (2) the success of the timing in Platzman's study, and (3) the knowledge that the factors influencing the speed of the *water* wave were much more certain than the usual variables in meteorology. Too much leeway in the timing probably would have caused the police much difficulty in restraining the people from returning to their bathing and fishing before the surge hit. On the other hand, more uncertainty was intended in the forecast of *magnitude* of the surge, since this was dependent on many uncertain meteorological variables.

The public was kept informed by the Weather Bureau at Chicago through the following additional messages:

SPECIAL WEATHER BUREAU BULLETIN ISSUED 1245 PM CDT AUGUST 3, 1960 ON SEICHE ALONG CHICAGO SHORE. THE LAKE SHORE LEVEL ROSE ABOUT TWO AND ONE HALF FEET AT WILMETTE AT NOON AND ABOUT FOUR FEET AT MONTROSE HARBOR THREE FEET AT BELMONT HARBOR SHORTLY AFTER NOON. THIS SURGE SHOULD BE THE STRONGEST ONE BUT LESSER SURGES ARE LIKELY TO CONTINUE THROUGH THIS AFTERNOON. CONTINUED CAUTION ALONG THE LAKE SHORE FOR THE NEXT FEW HOURS IS ADVISED.

SPECIAL WEATHER RELEASE 145 PM CDST WEDNESDAY AUG. 3, 1960

SEICHES AT CHICAGO

THE SUDDEN RISE OF WATER THAT HAS COME TO BE CALLED A SEICHE TAKES PLACE WHEN A FLAT WAVE MOVES AGAINST THE SHORELINE AND PILES UP WATER BECAUSE OF ITS MOMENTUM. ITS FORCE AGAINST THE SHORELINE CARRIES THE WATER SOMETIMES TO A CONSIDERABLY HIGHER LEVEL THAN THE OPEN LAKE CREST OF THE FLAT WAVE. THE AMOUNT OF SHORE RISE AND THE EXACT TIME OF ITS OCCURRENCE VARIES WITH CONFIGURATION OF THE SHORELINE AND THE SLOPE OF THE LAKE BOTTOM OUT FROM THE SHORE.

SCIENTIFIC STUDIES CONFIRMED BY CRIB GAGE READINGS OFFSHORE AT CHICAGO SHOW THAT THE OPEN LAKE WAVE WHICH PRODUCES THE SEICHE IS LONG AND FLAT SEVERAL MILES ACROSS AND PERHAPS A FOOT HIGH AT THE CREST. SHORTER WAVES CONCEIVABLY HIGHER MAY AT TIMES BE OBSERVED ON THE OPEN LAKE BUT HAVE NO RELATION TO SUDDEN RISES OF WATER ALONG THE LAKE SHORE.

TO THE BEST OF OUR PRESENT KNOWLEDGE THE LONG FLAT WAVE IS CAUSED BY A LINE OF THUNDERSTORMS WHICH EXERTS A VERY SLIGHT AIR PRESSURE EFFECT ON THE WATER AND AN ADDITIONAL EFFECT OF WIND, THE TWO ACTING TOGETHER TO FORM AT FIRST A WAVE OF VERY SLIGHT AMPLITUDE WHICH THEN BECOMES AMPLIFIED ONLY IN THE VERY SPECIAL CASE WHEN THE SQUALL LINE IS MOVING AT OR NEAR THE NATURAL SPEED OF MOVEMENT OF THE WATER WAVE.

THE SEICHES WHICH HAVE BEEN OBSERVED AT CHICAGO ARE THE RESULT OF A WAVE WHICH FIRST HITS THE SOUTHEASTERN SHORE OF THE LAKE FROM WHERE IT IS REFLECTED BACK TO THE CHICAGO SHORE.

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SPECIAL BULLETIN ON SEICHE ALONG CHICAGO LAKE SHORE ISSUED BY U.S. WEATHER BUREAU 340 PM CDT AUGUST 3, 1960.

ALL CLEAR STATEMENT. SINCE THE FIRST RISE OF WATER AROUND THE NOON HOUR TODAY ALONG THE CHICAGO LAKE SHORE, THE FURTHER FLUCTUATIONS HAVE BEEN OF DECREASING STRENGTH AND ARE NOW BUT LITTLE GREATER THAN ARE COMMON ALONG THE BEACHES. THE WEATHER CONDITIONS WHICH PRODUCED THE SEICHE NO LONGER EXIST AND WHILE SOME CONTINUED RISE AND FALL OF WATER MAY BE EXPECTED UNTIL THIS EVENING, THESE FURTHER FLUCTUATIONS ARE NOT CONSIDERED DANGEROUS.

These releases along with others dealing with the wind storm provided the main material for the many excellent newspaper stories that appeared that evening. Nevertheless, a full-page press release was made the following morning briefly stating what was done, what a seiche was, how it was caused, and the scientific references which provided the basis for the prediction. In spite of the amount and promptness of information released, there were numerous requests, especially from the press services, for further information.

3. IMPROVEMENTS IN TECHNIQUE AFTER THE 1960 SURGE

The accuracy of the August 3, 1960 surge forecast, although perhaps not so fortuitous as that of Dunn in July 1954, nevertheless was still felt to be dependent upon the close similarity between the August 1960 and June 1954 cases. The full effects of the meteorological variables of speed and direction of the squall line and the strength of its pressure jump and squall winds were unknown when the forecast was made.

Discussions with Platzman after the 1960 surge brought answers to many questions. Work in progress in Platzman's group at the time of the 1960 surge yielded graphs relating surge *amplitude* to the direction and speed of the squall line (for a unit pressure jump), and a similar set relating the *time of arrival* of the strongest surge to the velocity of the squall line. He also prepared a graph for computing operationally the speed and direction of movement of the squall line from pressure-jump times at several stations. Most of this information is given in Part I [7] appearing elsewhere in this issue of the *Review*.

Use of these charts required the determination of an empirical shoaling factor to convert the offshore surge heights of the graphs to heights at the shore. This determination was made on the basis of the surge at Montrose Harbor in the June 1954 case, and gave a factor of 7.5. All this information was assembled in a check sheet for forecasters. The graphs for the "wind only" effect as given by Platzman [7] in Part I were not available when the check sheet was made. This effect is incorporated implicitly in the empirical shoaling factor and therefore corresponds to the 50- to 60-kt. gusts of the June 1954 case. This was the extent of the understanding in early May 1962.

4. THE SURGES OF MAY 1962

May 1962 was unusual in that two prominent but not damaging surges occurred within a few hours of each other, and another lesser surge occurred two days later. The first two occurred on May 10 at about 0730 and 1000 CDT on the Chicago shore. The second of these surges was the larger, but it did not attain the height of the 1960 surge. No warning was issued for either of these surges because the squall line did not extend as far across the Lake as in the 1954 and 1960 surges and the wind gusts were insignificant, so the surge amplitudes were expected to be minor. In retrospect, the magnitude of these surges (especially the second one) was large enough that warnings would have been desirable. The second surge was particularly interesting in that the fall of water was considerably greater than the rise, causing boats in at least one harbor area to rest on the bottom before the water level returned to normal.

The third surge occurred around noon on May 12, and a warning was issued. Operationally this surge appeared to have great threat. While the pressure-jump line had a speed of only about 40 kt., it was moving toward the southeast, the pressure jump in the Chicago area exceeded that of the June 1954 surge, and the wind gusts were strong, reaching 64 kt. at O'Hare Airport in Chicago. The warning mentioned that the surge might be as high as the severe 1954 surge, but the surge height turned out to be more like the weaker surge of two days earlier. Again the *drop* in water level well exceeded the rise. The forecaster was aware that only a small pressure jump had occurred at Milwaukee and thus that the squall line probably was shorter than in the 1954 and 1960 surges; but Chicago did not as yet have its WSR–57 radar to use in determining line length and other radars were either out of operation or did not reach far enough to permit line-length determination. Because of the uncertainties in length of the squall line and in the effect of line length, the forecaster had to provide for the greatest threat compatible with the information available.

From the surges so far reported here, especially these last three, we additionally know, or at least have great suspicion, that the length of the squall line is a major factor in the magnitude of the surge on the Chicago shore but that line length does not affect the timing of the surge. This last is believed because the timing was good on the May 12 surge. If the squall line reaches north of Milwaukee so that it will pass over the whole Southern Basin of the Lake, the empirical shoaling factor of 7.5 given earlier is appropriate. For squall lines shorter than this, the shoaling factor probably is smaller, but a quantitative relation is not yet known. With the WSR–57 radar now well established at Chicago, the development of an empirical correlation of length of the line with magnitude of the surge is possible.

An indication that the pressure effect on the water wave may be more important than the wind effect can be found in these May surges, because in the surges of May

10 the wind gusts were insignificant and the surge was rather high, whereas on May 12 the gusts were quite high but the surge was not. A reason why the pressure effect may be more important, in spite of Platzman's [7] results showing them to be about the same, is that his assumption for the profile of the pressure is likely to be considerably better than his assumption for the wind profile.

From these May surges, it also appears that when the squall line is shorter than the width of the Southern Basin of the Lake, the negative surge, or drop in water levels, is greater in absolute value than the positive surge. There is a clear need to rerun Platzman's calculations using varying lengths of squall lines to determine the dependence of surge conditions upon this parameter. The curvature of the line could also be of significance (Platzman [6] used a straight line whereas most squall lines are curved). Irish [4] attributed some of the errors in the computation of the August 1960 surge to the curvature of the real squall line.

5. OTHER SURGES

Several known surges have occurred on Lake Michigan at Chicago since May 1962; namely, August 21, 1962; July 19 and August 13, 1963; May 16 and July 7, 1964. None of these was significant in the Chicago area although a warning was issued for the southeastern shore of Lake Michigan in the May 16, 1964 case. Probably other small surges also occurred. It is likely that any squall line passing over at least a portion of the Southern Basin of Lake Michigan and moving toward some point in the southeastern quadrant will produce some surge, and that there have been many occurrences not significant enough to report. As interest and awareness have risen, there have been more reports of lesser surges such as those listed above. There were very few reports of lesser surges prior to 1962.

This type of surge is not unique to Lake Michigan; for example, Donn [1] reported a 1952 surge in Lakes Huron and Erie. In this case the surge moved rapidly over the deep water of Lake Huron and slowly over the much shallower water of Lake Erie, and thus resonant coupling of atmospheric and water disturbances was possible in both Lakes. Donn gave 30 m.p.h. as the resonant speed for Lake Erie in the Cleveland area. Surges of the type considered here should occur anywhere in the world where pressure-jump lines cross lakes or bays with speeds near that of gravity waves in the water. However, the significance of surge occurrences, and the frequency of *reported* occurrences, especially reports via press, radio, and TV, depend greatly on land use and population.

6. SUMMARY AND CONCLUDING REMARKS

The impression of Dunn, given earlier, that surges occur in Chicago with squall lines, pressure jumps, and in the early morning or forenoon has generally been borne out by events since that 1954 statement.

Just why surges usually occur before or shortly after noon has not been studied. It is probably because the strong northwesterly flow aloft needed to produce a fast-moving squall line also favors the production of strong nocturnal thunderstorm and squall-line activity in the northern Great Plains—an area with a nocturnal maximum of such activity. The squall-line speed needed to produce significant surges is such that the lines would generally arrive over southern Lake Michigan before noon from their northern Great Plains nocturnal source region. There is no known contradiction of this hypothesis in the surge cases discussed here, as all squall lines involved formed in or on the edge of the northern Great Plains after midnight and before 0600 CST, and all moved for great distances before decaying. In the June 26, 1954, surge, the squall line was identifiable all the way to the east coast and even then did not lose identity.

Ewing, Press, and Donn [2] as well as Harris [3] have discussed the physical explanation of this surge in terms of resonant coupling of the atmospheric and water disturbances associated with squall-line pressure jumps. Platzman [7] in Part I has given quantitative information from which detailed and accurate forecasts of the occurrence and extent of these surges are possible for the Southern Basin of Lake Michigan. However, the additional parameter, not treated by Platzman, of the length of the pressure-jump line (and possibly the curvature of the line) would probably contribute materially to the quality of the forecast. Timing of the strongest surge is probably adequately defined by Platzman, but the magnitude of the peak surge is not reasonably certain unless the pressure-jump line, or squall line, extends across the entire width of the Southern Basin of Lake Michigan.

The highest surge on the Chicago shore occurs with squall lines moving toward the southeast at about 55 kt. and occurs in the Montrose Harbor area. The surge travels with the squall line as it crosses the Lake and thus, for the usual west to east motion, occurs on the eastern shore *with* the squall line, but must be reflected to reach the western shore. This means that the west-shore surge can and usually will occur at a time of meteorological quiet and thereby can catch people unaware unless they are alerted to the danger. The magnitude of the surge is believed to be linearly related to the pressure-jump magnitude and may be in nearly linear relation with the percentage of the lower Basin covered by the squall line, although this last point has not been tested theoretically yet.

If a fast-moving squall line is expected to move across Lake Michigan, a surge forecast can be made with considerable confidence in the following steps. (Incidentally, the velocity of the squall line appears to be essentially that of the 700-mb. flow, which provides a fast and early first approximation to whether a surge threat will exist.)

1. Obtain the speed of the squall line, and the direction *toward* which it is moving. The line is assumed to move perpendicular to itself. Radar should be excellent for this purpose.

2. Obtain the magnitude of the pressure jump on the upstream (usually western) side of the Lake. This has been taken as the average of the jumps at Milwaukee, O'Hare Airport, Midway Airport, and the Weather Bureau Forecast Center in Chicago.

3. Determine the time of the pressure jump at O'Hare Airport.

4. Using the graphs given by Platzman [7] as figure 5 in Part I and the information in 1 and 3 above, compute the time of arrival of the surge at the desired point. The surge on the eastern shore will occur approximately with the passage of the squall line. Note that the time of arrival of both the incident *and* reflected surge is nearly independent of the squall line speed. This is probably because the water wave, once formed, moves at a speed independent of the atmospheric wave.

5. For squall lines reaching across the full Southern Basin of the Lake, multiply Platzman's offshore amplitudes given in his figure 4 ("pressure only") by the number of hundredths of inches of the average pressure jump and then by 7.5 to obtain the height of the maximum surge in feet at the shore.

As an example, take a squall line moving toward 135° at 50 kt. with an average pressure jump of 0.09 in. From figure 5 in [7] we see that the reflected surge at Montrose Harbor should arrive about 135 min. after the pressure jump at O'Hare Airport. The magnitude of the maximum surge occurring at that time at Montrose Harbor would be $0.080\times9\times7.5=5.4$ ft., where 0.080 ft. is the offshore height of the wave from figure 4 for a pressure jump of 0.01 in., and 9 is the number of hundredths of inches of the pressure jump. Similar computations can be made for the other seven stations. Note that the "wind only" graphs have not been used. Whether the wind and pressure effects are really additive, and if so what the respective shoaling factors are, is still for the future to determine.

Although this has not yet been tried, it may be appropriate to make some adjustment for wind by lowering the estimated surge heights slightly when the wind gusts are unusually low ($\leq$40 kt.), and raising them when the gusts are unusually high ($\geq$70 kt.). Otherwise ranges of plus and minus about half an hour in arrival time and 1 ft. in amplitude from the values computed above are probably sufficient to use in the warning, provided the squall line extends across the full Southern Basin of the Lake. If the line does not extend fully across the Basin, the computed arrival time is still probably adequate, but the amplitude is likely to be less than that computed, by an amount which at present is probably best taken as the percentage of the Southern Basin *not* covered by the line. The range of expected surge should perhaps be larger in such cases.

The warning for Chicago normally should be withheld until the squall-line weather has passed Chicago, to avoid confusion in warnings, and it should be sent first to stations on the southern and eastern shores where the surge will occur with the squall-line passage.

The surge does not occur with the rapidity or power of a breaking water wave created by the wind. Instead, the rise of water is gradual over several minutes, although some wave action similar to that of waves created by the wind may occur as the peak is approached. The threat to life is thus mainly to non-swimmers—such as fishermen on a pier or breakwater, or children wading or playing at the water's edge—in general to persons who may be unaware of the gradually rising water until too late to retreat to safety.

With these aids I am confident that this type of surge is one of the fairly rare events that can be forecast with high certainty and accuracy.

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