NOAA TM NWS CR-41

NOAA Technical Memorandum NWS CR-41

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
National Weather Service

THE TEMPERATURE CYCLE OF LAKE MICHIGAN

1. Spring and Summer

Lawrence A. Hughes

CENTRAL REGION
Kansas City, Mo.

APRIL 1971

The Central Region [illegible] k dissemination of material not appro[illegible] blication. Material is primarily of re[illegible] le. References to this series should [illegible] ..s unpublished reports.

1 Precipitation Probability Forecast Verification Summary Nov. 1965 - Mar. 1966.

2 A Study of Summer Showers Over the Colorado Mountains.

3 Areal Shower Distribution - Mountain Versus Valley Coverage.

4 Heavy Rains in Colorado June 16 and 17, 1965.

5 The Plum Fire.

6 Precipitation Probability Forecast Verification Summary Nov. 1965 - July 1966.

7 Effect of Diurnal Weather Variations on Soybean Harvest Efficiency.

8 Climatic Frequency of Precipitation at Central Region Stations.

9 Heavy Snow or Glazing.

10 Detection of a Weak Front by WSR-57 Radar.

11 Public Probability Forecasts.

12 Heavy Snow Forecasting in the Central United States (An Interim Report).

13 Diurnal Surface Geostrophic Wind Variations Over The Great Plains.

14 Forecasting Probability of Summertime Precipitation at Denver.

15 Improving Precipitation Probability Forecasts Using the Central Region Verification Printout.

16 Small-Scale Circulations Associated With Radiational Cooling.

17 Probability Verification Results (6-Month and 18-Month).

18 On The Use and Misuse Of The Brier Verification Score.

19 Probability Verification Results (24 Months).

20 Radar Depiction of the Topeka Tornado.

21 Wind Waves On The Great Lakes.

22 Seasonal Aspects of Probability Forecasts: 1. Summer.

23 Seasonal Aspects of Probability Forecasts: 2. Fall.

*24 The Importance of Areal Coverage In Precipitation Probability Forecasting.

25 Meteorological Conditions As Related To Air Pollution, Chicago, Illinois, April 12-13, 1963.

26 Seasonal Aspects of Probability Forecasts: 3. Winter.

27 Seasonal Aspects of Probability Forecasts: 4. Spring.

28 Minimum Temperature Forecasting During Possible Frost Periods At Agricultural Weather Stations In Western Michigan.

(Continued on back inside cover)

*Prior to T.M. 37 this series was labeled as the ESSA Technical Memoranda.

U.S. DEPARTMENT OF COMMERCE
U.S. NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE

NOAA Technical Memorandum NWS CR-41

THE TEMPERATURE CYCLE OF LAKE MICHIGAN
1. (Spring and Summer)

Lawrence A. Hughes

CENTRAL REGION

KANSAS CITY, MISSOURI
April 1971

THE TEMPERATURE CYCLE OF LAKE MICHIGAN
1. (Spring and Summer)

Lawrence A. Hughes
Central Region Headquarters
Kansas City, Missouri

Knowledge of the temperature cycle of the water of the Great Lakes is essential to forecasting for the lake surface or over-lake conditions, or forecasting conditions over land adjacent to the Lakes. By adjacent to the lake it is not meant only areas within a few miles of shore. For example, the cloud activity in Indiana resulting from strong north winds over the relatively warm Lake Michigan water in winter can be enhanced by direct result of lake effects almost as far south as the Ohio River. However, it is true that the strongest effects are close to the shore in most cases. While the data given are only for lower Lake Michigan, they should be applicable to the other three deep Lakes and perhaps to the deep portions of Lake Erie.

Figure 1 shows the average condition of lake surface water temperature and air temperature through the year over Lake Michigan. The main point in

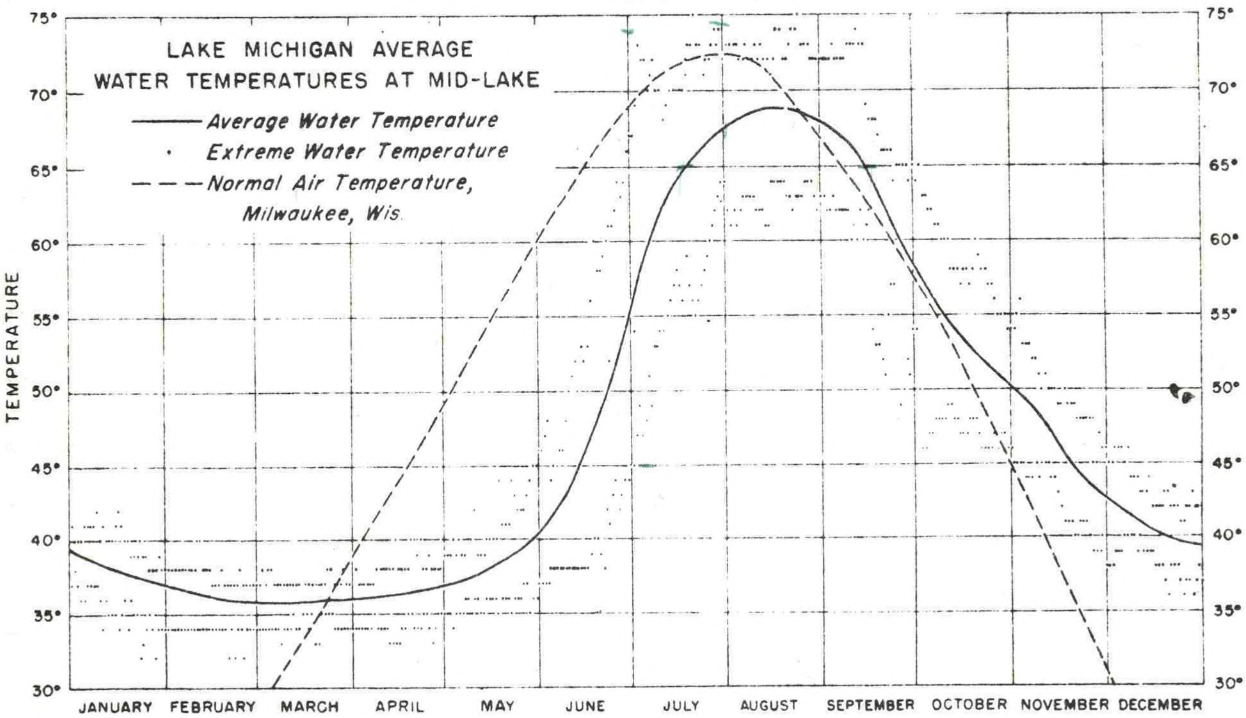

Fig. 1 - Lake Michigan average and extreme water temperatures at mid-lake, 1941-1954 (from Ahrens).

this figure is the extreme water-air temperature difference in the months of May and June (water colder). This occurs because of the great lag in water heating caused by low stability in the water which allows the heat received to be mixed to great depth until, with a series of warm days with light winds, the surface water stabilizes, is no longer mixed to great depth, and a thermocline forms.

Another point is that the range of extreme water temperatures shown, which is only 5°F during most of the year, ranges up to 20°F around July 1. This means that in late spring and early summer there can be large differences from one year to the next. These differences are most likely brought about by the amount of storminess, as the high winds with storms cause mixing to greater depths and thus distribute the heat more and give low water temperature, while light winds allow the surface water to warm without distributing the heat in depth and give warm waters. Note also that the warmest surface water temperature tends to occur around mid-August--a bit after the warmest mean air temperature, and that the water and air temperatures are very close from late August into late October.

The following lake-produced effects are influenced by the water temperature mainly through the air-water temperature difference:

1. SUPPRESSION OF SHOWER ACTIVITY

Showers are suppressed by the relatively cold water, if ground heating is a significant factor in shower development. However, if large scale dynamics, e.g., an upper-level trough and PVA, is the causative factor, the effect of the water can be small.

2. CREATION OF FOG

The Great Lakes and their adjacent shores are high fog frequency areas. The fog is created when warm moist air passes over cold water, and the air temperature lowers to the dewpoint (probably with some addition of water as well as cooling). It is thus most frequent in May and June when the water is the coldest with respect to air temperature, but April and July also are quite significant fog months, and possibly August, especially in the more northern waters. An example of an unexpected and probably lake-caused fog occurred when late afternoon thundershowers cooled and moistened the air too late for daytime heating to reheat it much. This air, with a dewpoint above the lake temperature, then passed slowly across the lake and gave a surprise fog on the far shore. Such a fog coming onshore at night or early morning can pass fairly far inland before being destroyed by mixing or heating.

3. LAKE BREEZE STRENGTH OR PENETRATION

The lake breeze is so dependent on the air-water temperature difference, that lake cooling brought on by the water stirring of late spring storms can have a pronounced effect. The lake breeze is a local circulation, extending only a few miles either side of the shoreline, but since the near-shore water temperatures rise faster in spring than mid-lake temperatures, they can drop more when a storm mixes the water quite a bit. A persistent offshore wind will also drop the near-shore temperature, but this is only a shifting of the warmer water across the lake to the far shore from whence it will eventually return. However, for at least a short period after the offshore stronger winds subside, an enhanced lake breeze is possible.

4. HEIGHT OF WAVES

When the air temperature, before passing over the water, is much higher than the water temperature, great stability is created in the air just above the water. This causes the frictional effect of the earth's surface on the moving air to be concentrated in a much shallower layer than is usual over land, which, in turn, causes the surface wind over water to be much lighter than the wind over land, even with the lesser friction of water compared to land. This effect tends to maximize in May and June. However, this point should be considered even in summer, if moderate offshore winds cause considerable upwelling of cold deep water along the upwind shore, and on any hot day.

5. MISCELLANEOUS

The maximum and minimum temperatures, as well as the diurnal temperature cycle, are obviously affected by lake temperatures at stations close to the lake on all shores and well inland on the lee shores, but the effects are so obvious as to need no special comment. The effects of water temperature on the comfort of recreational boating and on swimming also are obvious. However, the upwelling condition perhaps is not obvious to the less experienced lake boater or swimmer, so this point makes good material for talks.

With these effects in mind, let us look at the cycle of temperature as seen in cross-sections of lower Lake Michigan at intervals of about a month (less at critical times). These figures are a selection taken from Church (1942). While the data apply to only one year, they have generality for other times, when the comment given is applied. We have provided the caption to each figure and it explains the key points in the figure. The y axis of the figures is the water depth in meters, while the x axis contains both the distance from the west shore and the location of the temperature soundings used to make the cross-section. The small map in the lower left of the figure gives the mean wind condition observed in the four to seven days preceding the crossing, and thus some indication of the wind condition that produced the water temperature effects noted. The wind speed is proportional to the length of the shaft, the temperatures are in Celsius, and the date of the chart is in the lower right.

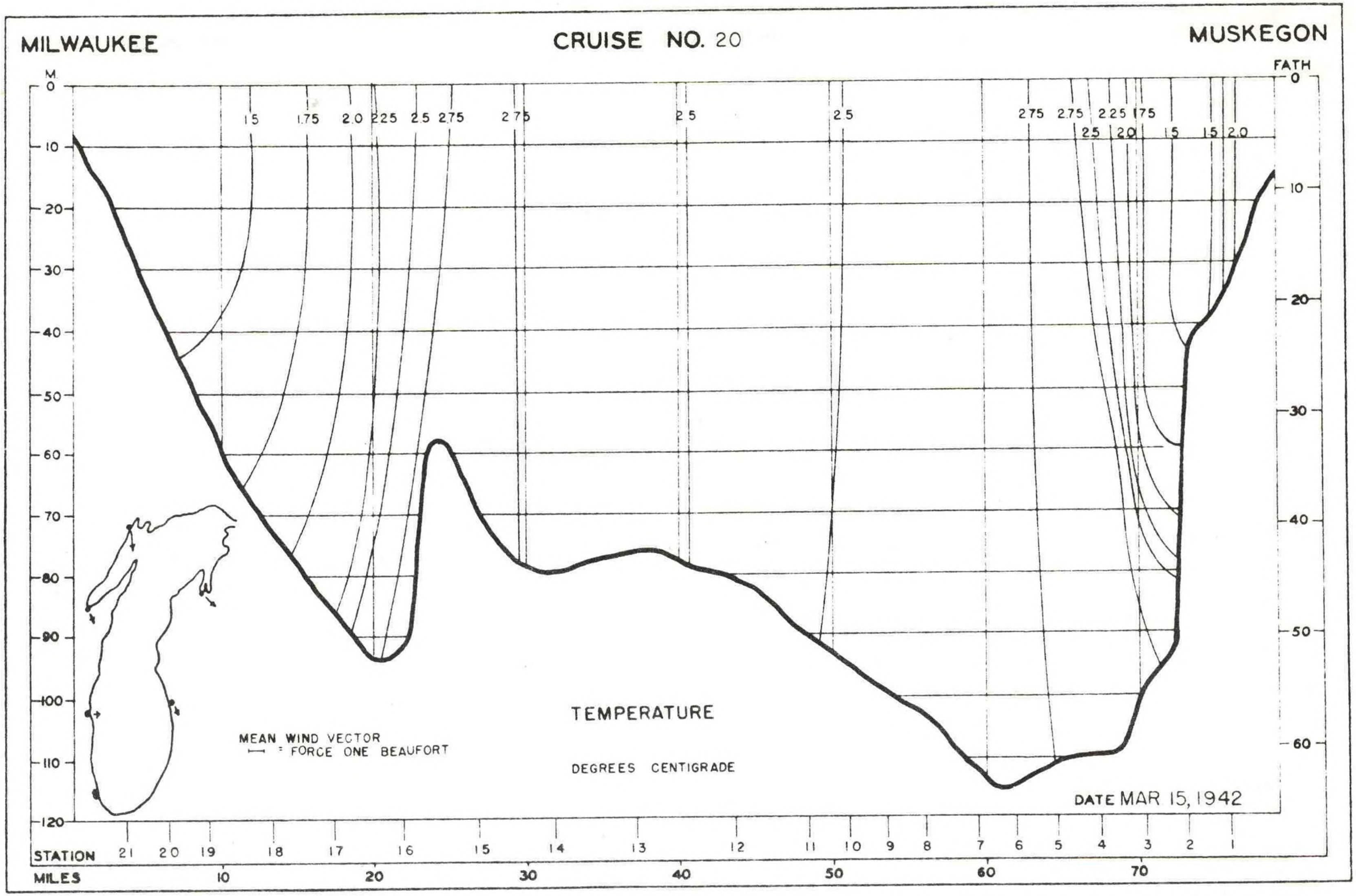

Figure 2 - The lake is at its coldest. The water is isothermal top to bottom at a temperature a bit below that of maximum density (essentially 4°C). The warmest water is in the open lake well away from shore, but there is little horizontal temperature variation at any level. Upwelling, produced by strong off-shore winds, can bring up warmer water from the depths and thus help to melt ice, even if the air temperature is subfreezing. Of course, if the lake were frozen over (a rare event), the surface temperature would be a bit colder.

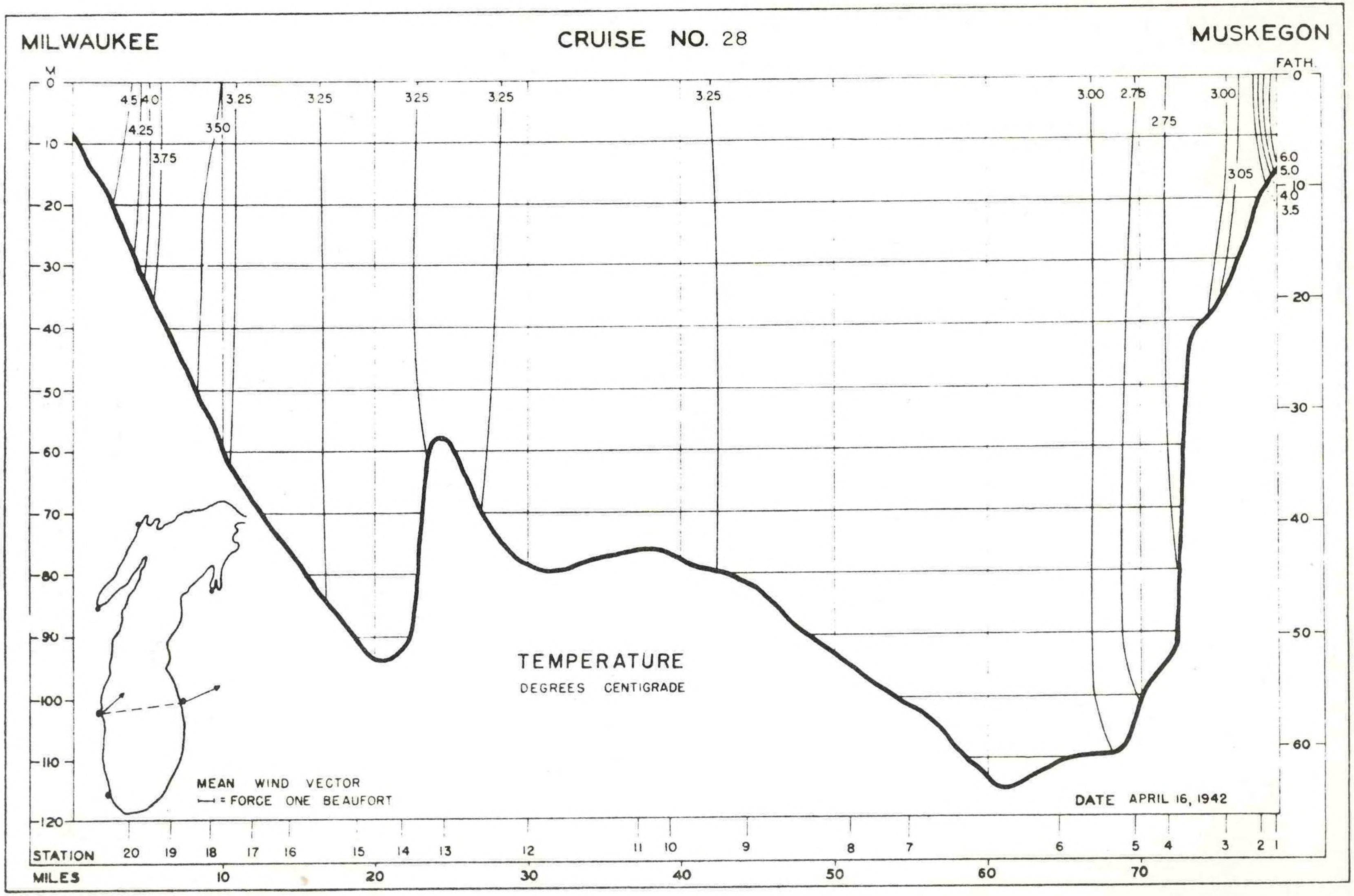

Figure 3 - One month later shows little change. The water is still isothermal, because the heat added to the upper waters made the water more dense, and thus unstable, so mixing occurred and the heat distributed in depth. However, now the warmest water is near the shores, and a little warming has occurred even in mid-lake. Upwelling will no longer bring up warmer water.

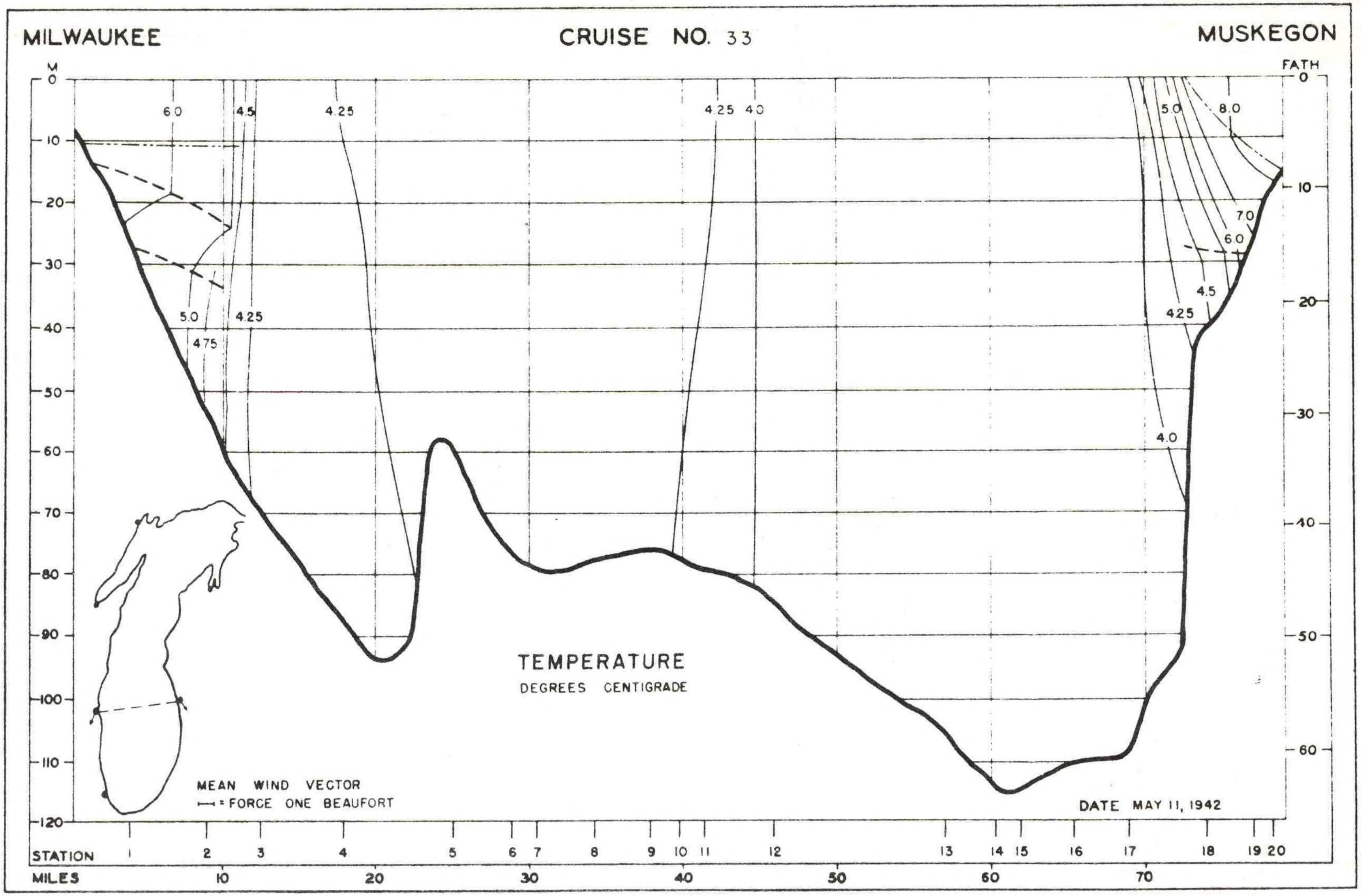

Figure 4 - Almost another month and still little warming. This is because the bulk of the water is still essentially at the temperature of neutral stability (4°C), equivalent to the adiabatic lapse rate in air. However, some tendency toward stability is occurring with the start of a thermocline (between dashed lines) close to the shores.

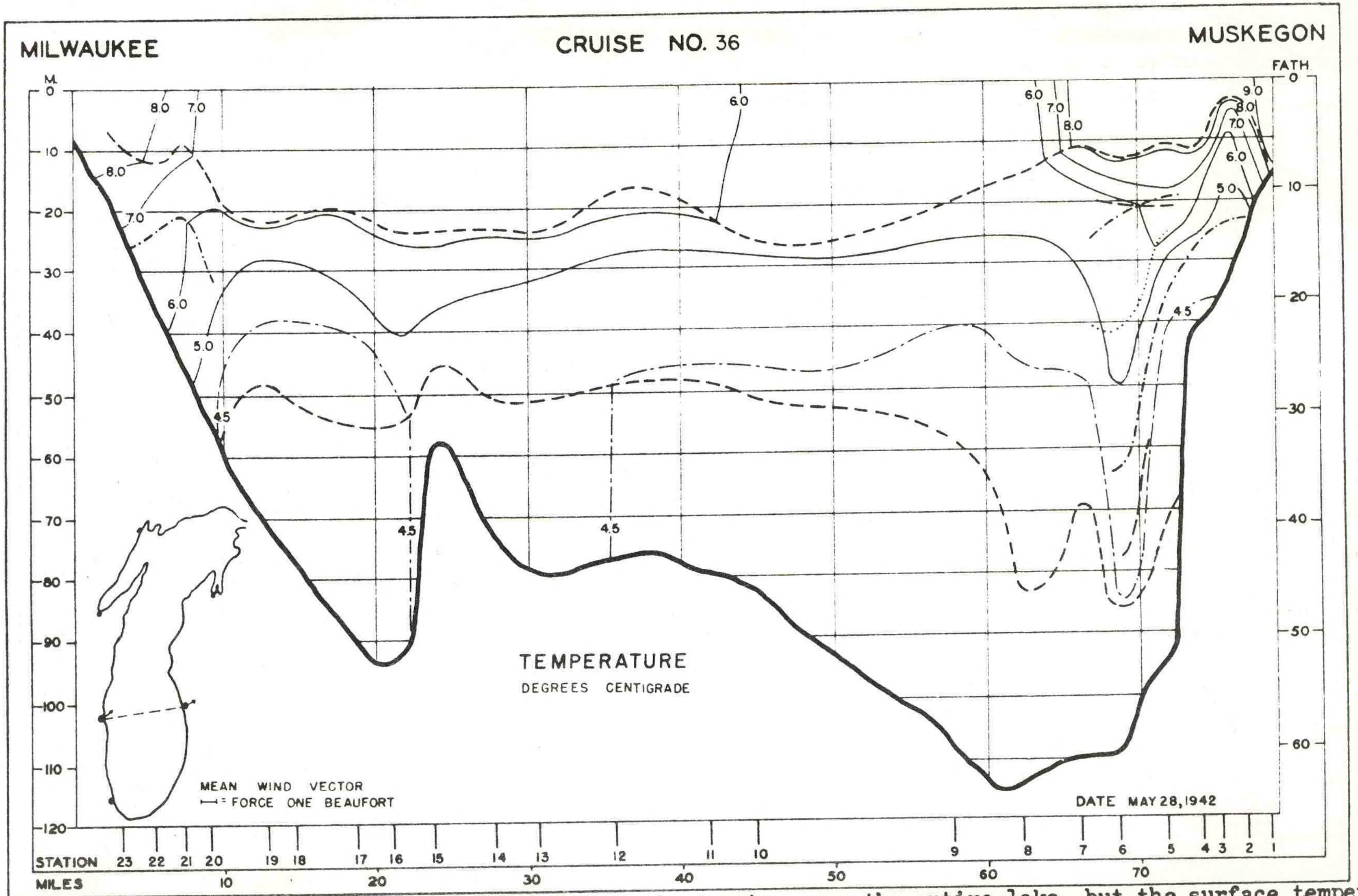

Figure 5 - By the end of May, a thermocline is usually forming over the entire lake, but the surface temperature in mid-lake is still only 3-4°C warmer than it was at its coldest time 2-1/2 months earlier. At this time, wind conditions are critical for the continued formation of the thermocline and additional heating of the surface water. If it is windy, mixing to great depth is still easily accomplished, and the heat received can be lost from the surface to the deep water. But if light winds persist for a period, the surface water will warm quickly, as density is now decreasing, creating stability. In 1942, it was windy in mid-May, but w[illegible] not much wind after that, although the fact that the top of the thermocline is 20 meters down (it had b[illegible] shallower earlier) indicates some wind mixing.

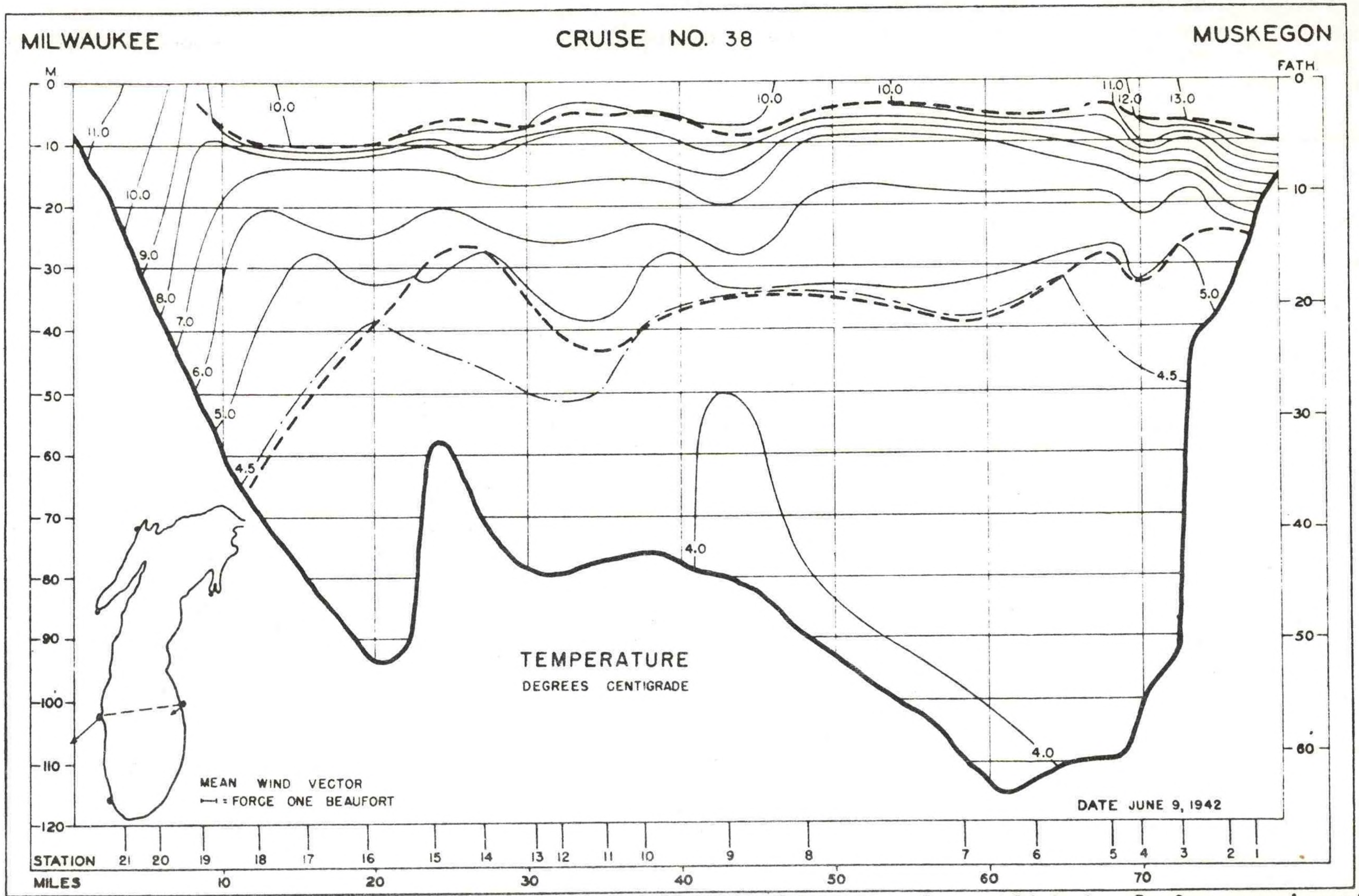

Figure 6 - The winds in early June were light, and a thermocline is well established. Surface warming of the water is occurring rapidly, but only a shallow nearly homogeneous surface layer exists. The deep water is now isolated from the surface and will remain that way at a temperature of 4-5°C through the summer. Occasionally, some deep water will reach the surface when strong upwelling occurs, as we will see later. Notice that the thermocline is temporarily destroyed near the west shore because of the stronger winds there. If it had been really windy in the past week, the surface water could easily have been 4-5°C colder at this time (see next figure).

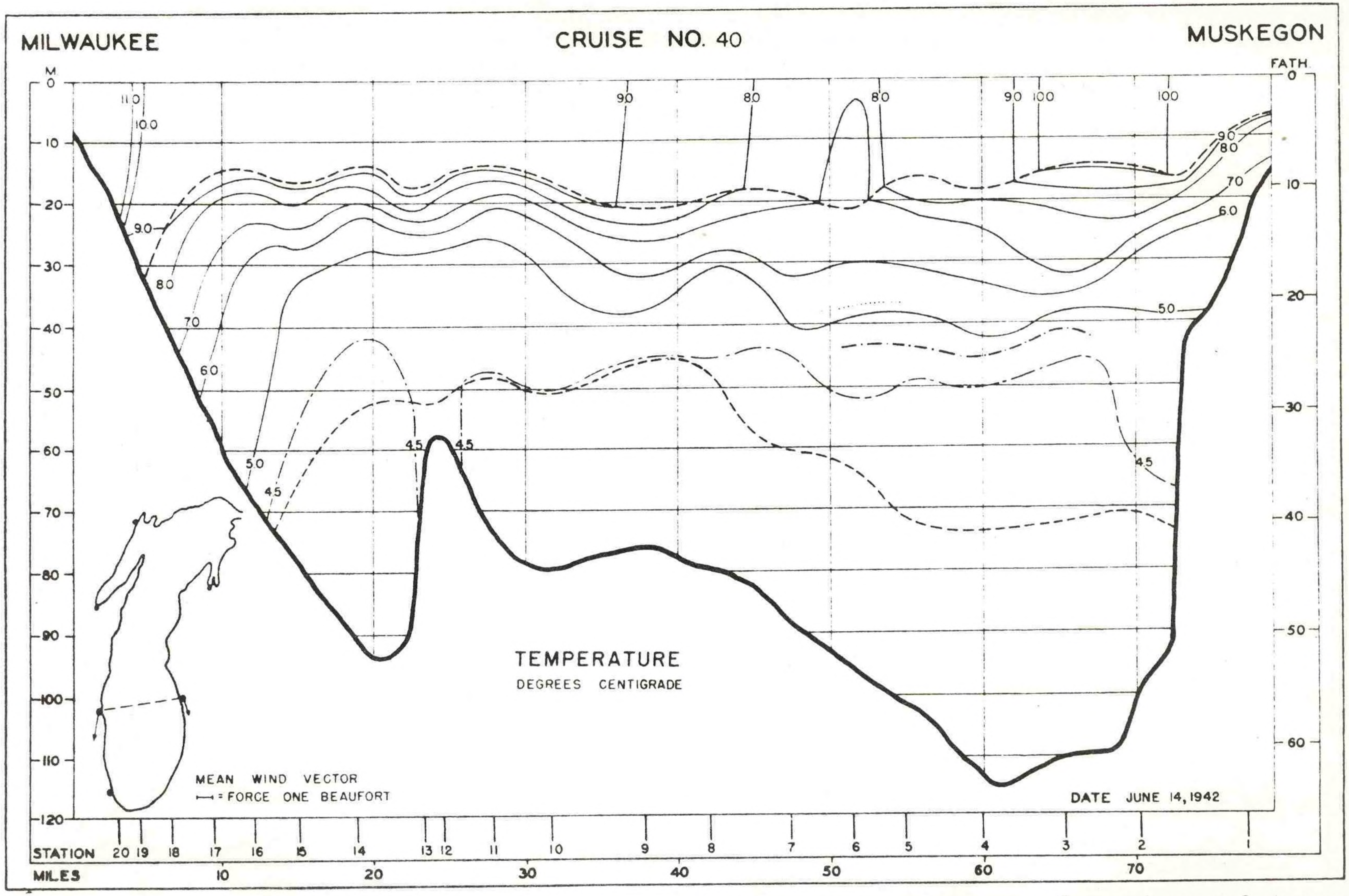

Figure 7 - About a week after the previous figure, but the water temperature has lowered several degrees because of the moderate storm that went by a couple of days ago. The mixing has pushed the top of the thermocline to over double its depth in the previous figure. A crossing a day later in the northern portion of the lake (from Manistique to Frankfort) showed surface temperatures about the same or a trifle warmer than in southern portion, so there is no lag with latitude here.

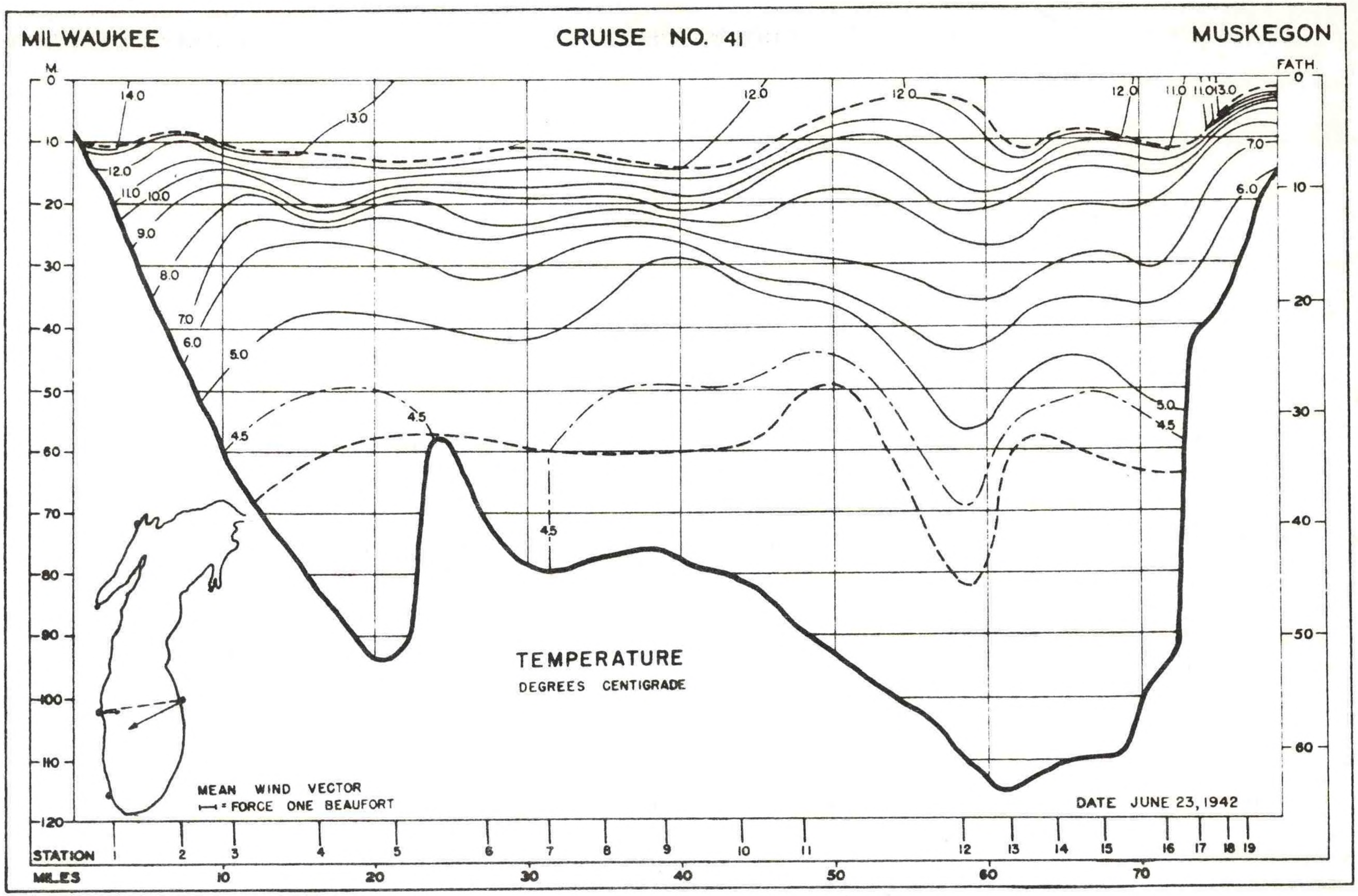

Figure 8 - Almost two weeks of quite light winds has allowed the surface water to warm a lot and the surface mixed layer to get shallower simply by adding isotherms on top of the old ones. The strong east winds at Muskegon converging with those at Milwaukee, as shown, are hard to see in a review of the daily surface maps. However, it has brought about upwelling at Muskegon but the upwelling has not quite reached the surface.

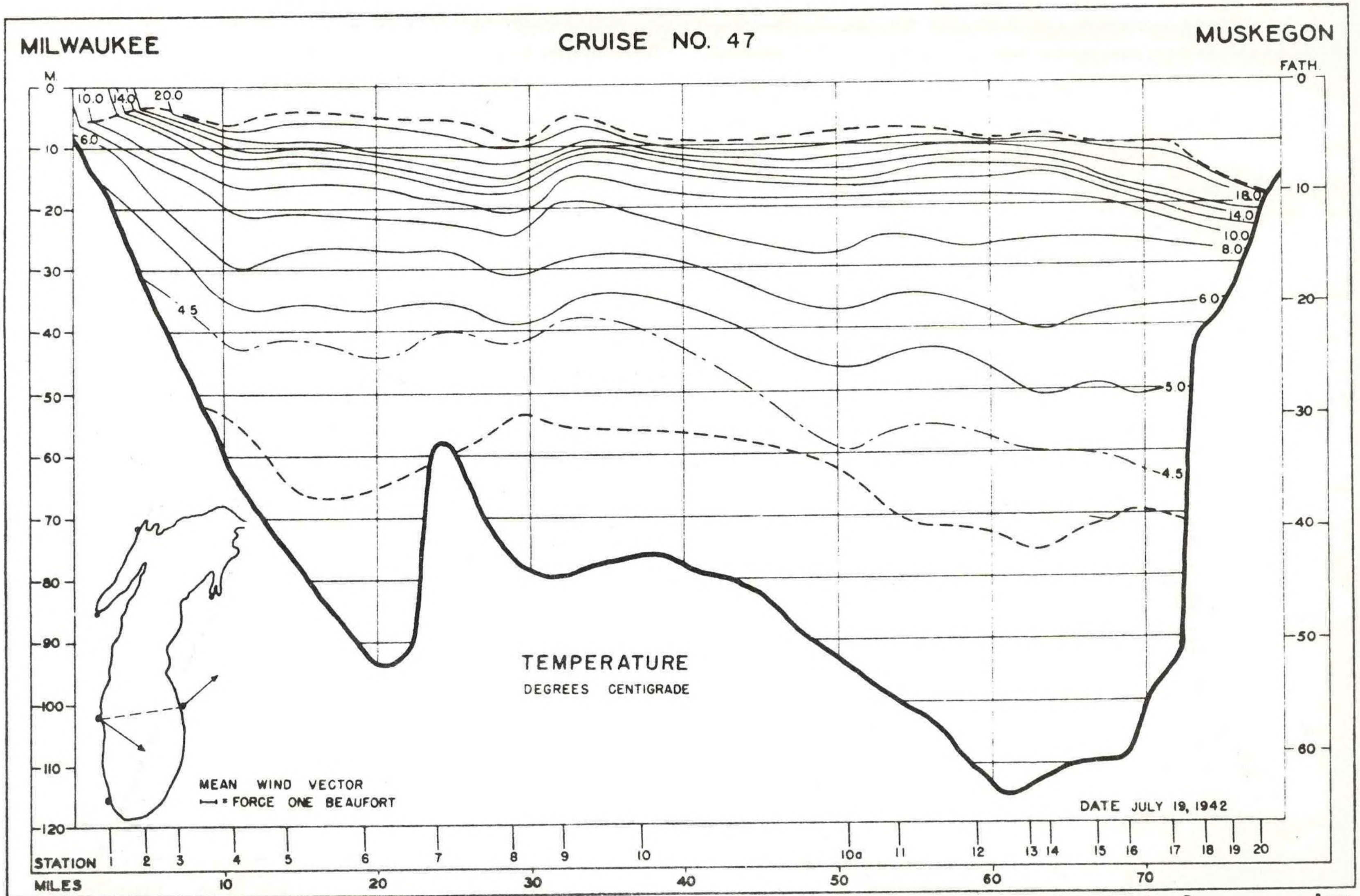

Figure 9 - Winds have been seasonable for the past four weeks, and continued heating took place, warming the surface to near maximum conditions. A Low of moderate intensity (for summer) was centered over Lake Superior on this date, giving a fairly strong west wind and the strong upwelling, which took place in spite of the strong thermocline. Note that surface temperatures on the west coast are well over 10°C colder than on the east coast--no swimming that day for Milwaukians. A sounding farther north (E-W into Frankfort) a day earlier gave surface temperatures 2-4°C colder, showing some latitudinal variation, but two weeks later this was essentially gone.

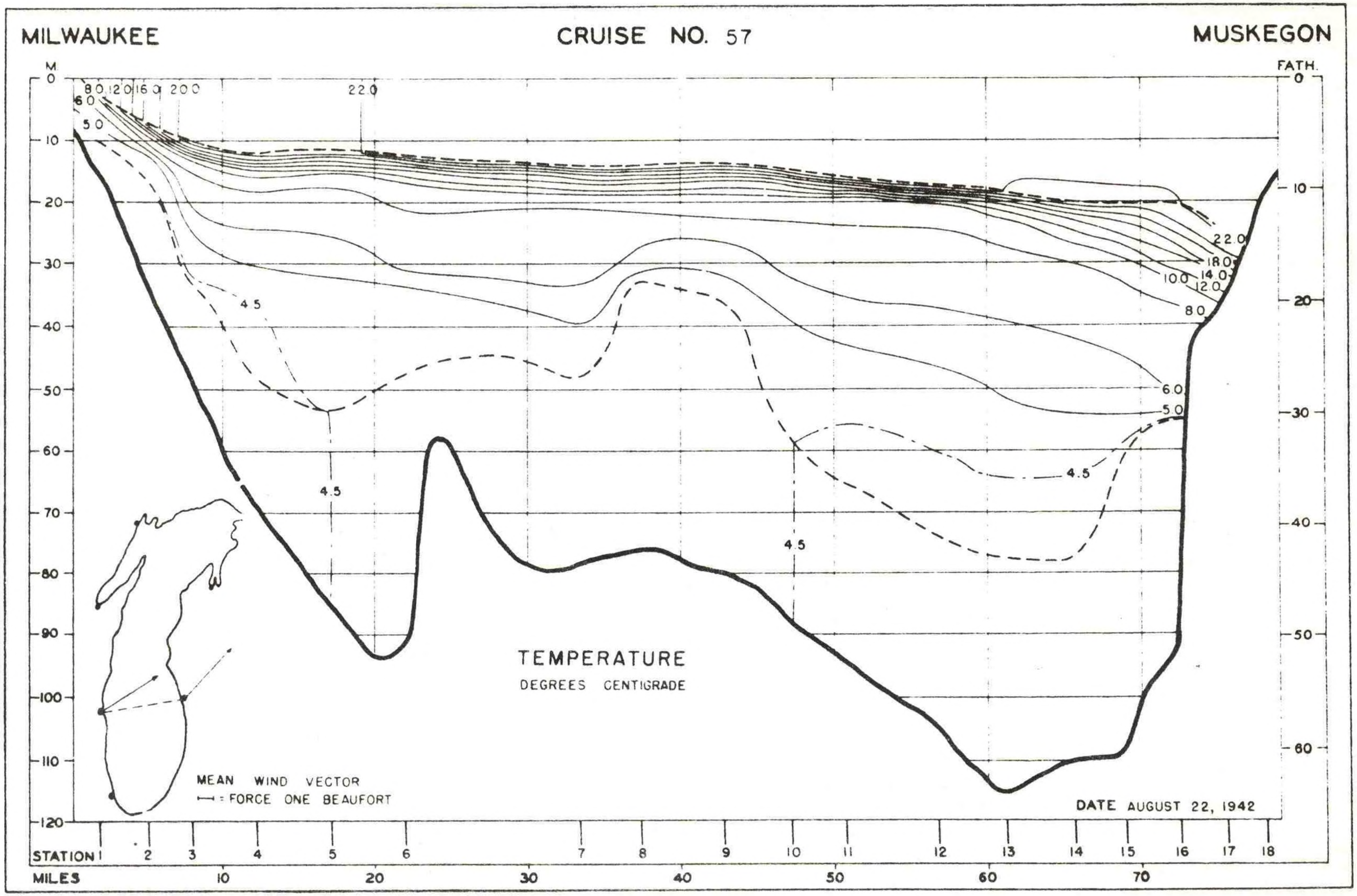

Figure 10 - The warmest condition of the season, although another Low over eastern Lake Superior has given strong west winds and very strong upwelling. Perhaps the reason the upwelling is so strong is that the winds have been westerly and not light for several days, and the process was probably already started when the Low came along.

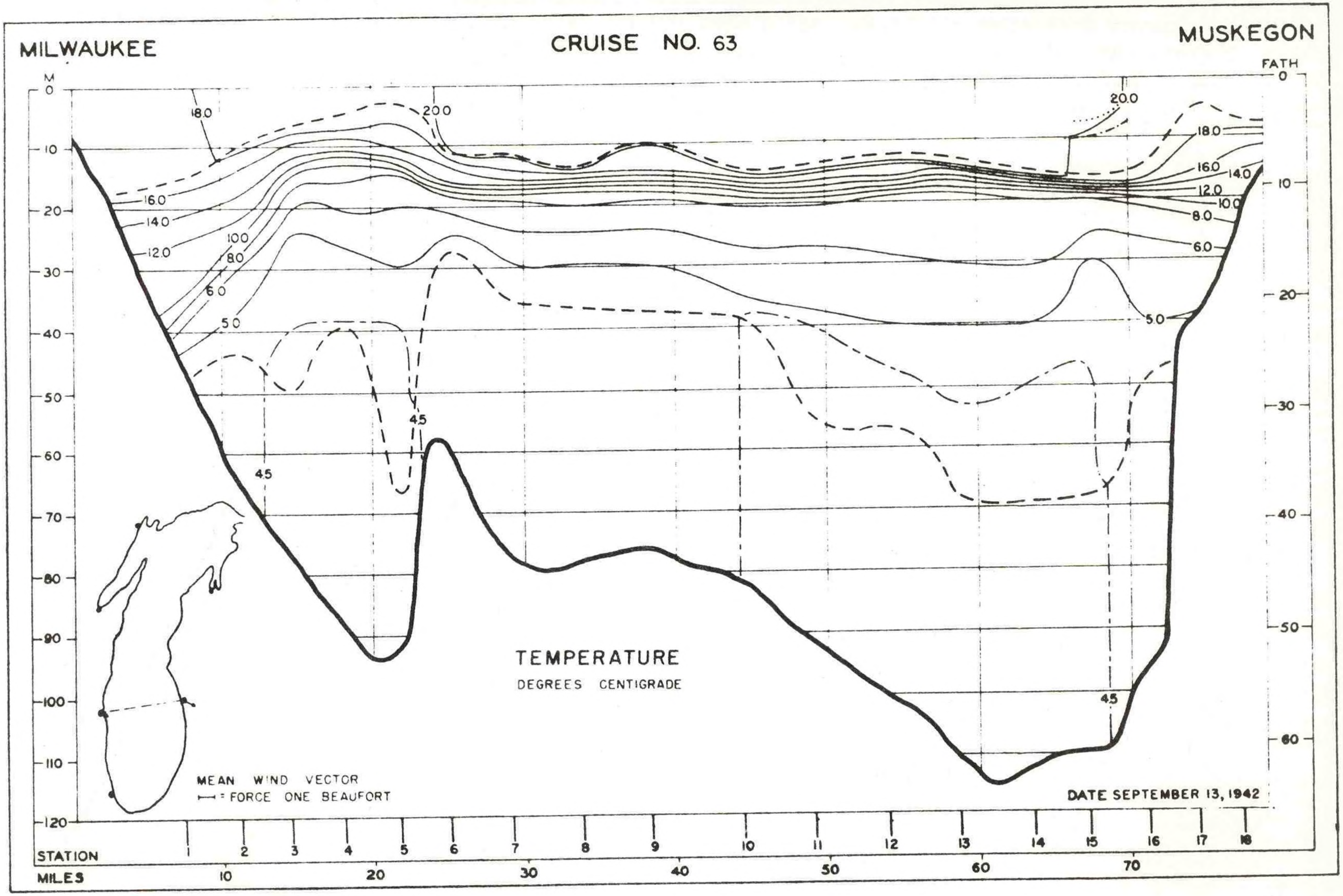

Figure 11 - Some cooling even in mid-lake but not much even yet.

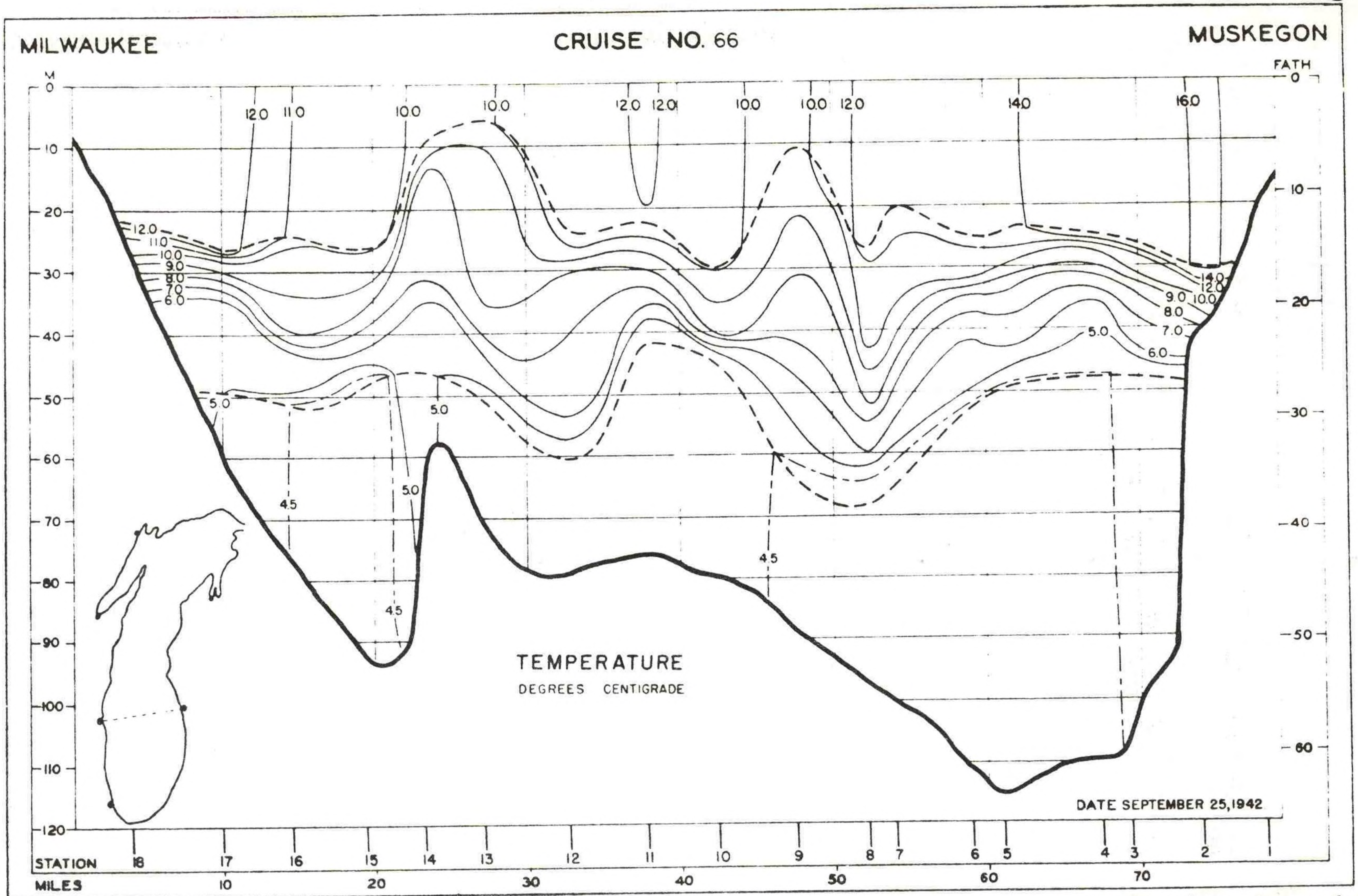

Figure 12 - The first really strong storm since spring passed across Lake Superior the previous day and the great mixing that resulted brought an end to the summer quasi-steady temperature condition. The last previous chart shown in the Church work was September 13, 1942, when a very strong thermocline and surface water temperature of 20°C still existed. It is likely that there was little change in these until the strong storm churned up the thermocline and mixed water to considerable depth on the 24th. The summer condition is usually ended by one strong storm rather than a series of lesser storms over a longer period.

REFERENCES

Ahrens, R. J., "Lake Michigan Water Temperatures", Mariners Weather Log, V. 3, No. 3, May 1959.

Church, P. E., The Annual Temperature Cycle of Lake Michigan, Miscellaneous Reports No. 4 and 18, Univ. of Chicago, 1942.

29 An Aid For Tornado Warnings.

30 An Aid in Forecasting Significant Lake Snows.

31 A Forecast Aid for Boulder Winds.

32 An Objective Method For Estimating The Probability of Severe Thunderstorms.

33 Kentucky Air-Soil Temperature Climatology.

34 Effective Use of Non-Structural Methods in Water Management.

35 A Note On the Categorical Verification of Probability Forecasts.

36 A Comparison of Observed and Calculated Urban Mixing Depths.

37 Forecasting Maximum and Minimum Surface Temperatures at Topeka, Kansas, Using Guidance from the PE Numerical Prediction Model (FOUS).

38 Snow Forecasting for Southeastern Wisconsin.

39 A Synoptic Climatology of Blizzards On The North-Central Plains of the United States.

40 Forecasting the Spring 1969 Midwest Snowmelt Floods.