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NOAA Technical Memorandum NWS CR-46

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service

THE TEMPERATURE CYCLE OF LAKE MICHIGAN

2. Fall and Winter

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CENTRAL REGION
Kansas City, Mo.

SEPT. 1971

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

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9 Heavy Snow or Glazing.

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

11 Public Probability Forecasts.

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14 Forecasting Probability of Summertime Precipitation at Denver.

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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)

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2. (Fall and Winter)

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CENTRAL REGION

KANSAS CITY, MISSOURI
September 1971

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2. (Fall and Winter)

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

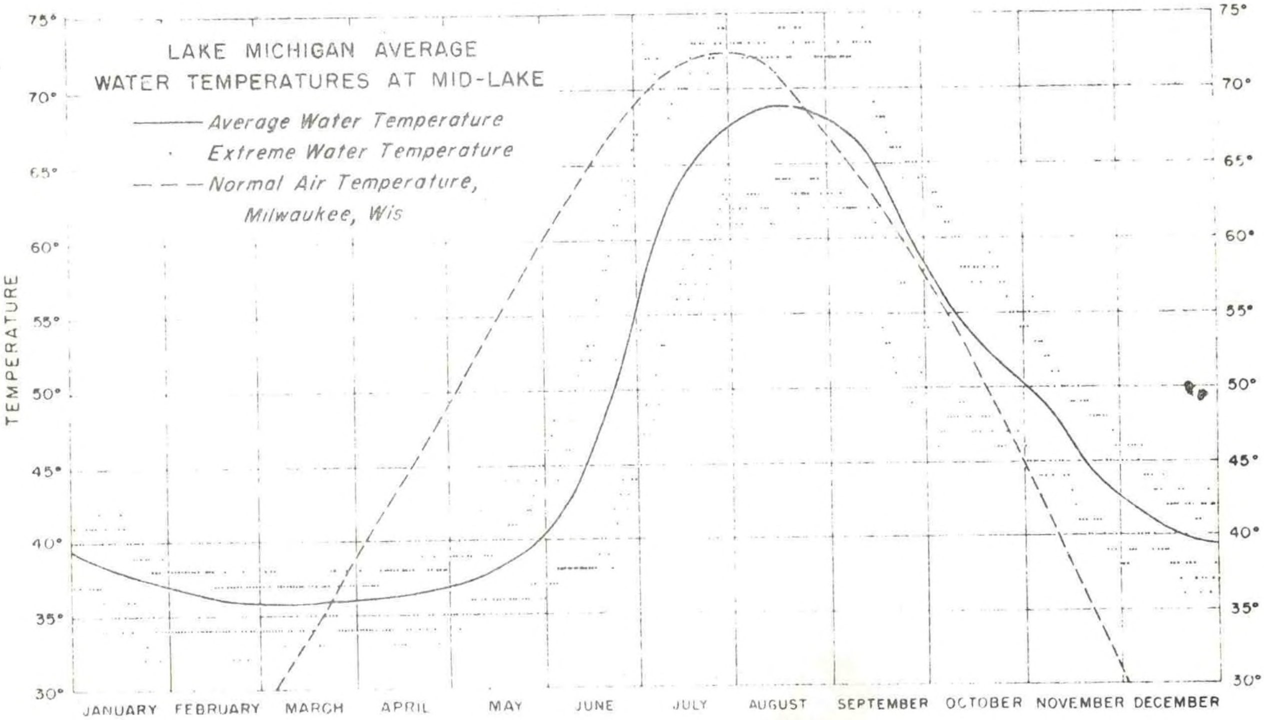


Fig. 1 – Lake Michigan average and extreme water temperatures at mid-lake, 1941-1954 (from Ahrens).

this figure for fall and winter is that the water temperature drops rapidly with the air temperature through the fall season, at the end of which it is near the temperature of maximum density (about 39°F), and it stays close to that temperature through the entire winter.

Another point is the large range of extreme temperatures in late September and early October. These are most likely brought about by variations in the amount of storminess, as the high winds with storms will mix the warm surface water with the colder deep water and drop the surface temperature a great deal in a short time (see Figures 3 and 4). Almost all of the temperature drop in the upper levels of the water occurs in the fall (see Figures 2, 7, and 10). On the average, the coldest water occurs in March. Because the surface water is rarely colder than the air during fall and winter, fog is uncommon, except for steam fogs. These occur when the water is very much warmer than the air; however, they are not much of a navigational problem, and they do not move inland.

When the water is warmer than the air, there is convection, turbulence, and thorough mixing of the air in the lowest levels. This means that the wind near the water is closer to that represented by the isobars on the sea-level chart than it is in summer, and, for a given isobar spacing, the waves produced will be higher than in summer situations. Appropriate correction factors for this are given in Tech. Memo. CR-21, "Wind Waves on the Great Lakes" (p. 3).

By far the most important and dramatic effect of the open water in winter is the addition of heat and moisture to the very cold air and the resultant instability producing snow. The larger the air-water temperature difference, the greater the tendency toward heavy snow. Thunderstorms with snow are not uncommon with the large temperature differences, and water spouts also occur.

A point for forecasters to keep in mind is that the largest air-water temperature differences will occur in the depths of winter rather than in the fall. The main reason for this is that the cold air from Canada moving out over the water drops as much as 120°F from summer temperatures to winter temperature, while the lake is cooling only about 30°F. Thus, the largest differences occur with the extremely cold arctic air, where surface temperatures in air just before passing out over the lake can be as cold as -60°F. At times of these very large temperature differences, the clouds over water, as seen from satellite photos, are markedly banded, with the bands parallel to the low-level wind flow. Radar (at Chicago) suggests these bands do not move much, so snowfall rate and deposition on land could be very variable in quite small distances. Of course, visibility would also be highly space variable.

The key to heavy snow forecasting is not only the large air-water temperature difference, however, but is tied prominently to <u>persistence</u> of flow with a <u>long fetch</u> over water and preferably some prominent terrain rise close to the shore. Under such favorable conditions with wind along the long axis of a narrow lake, snow of several feet in depth can occur in a day or so in a small area, whereas nearby areas may only have an inch or so, because of the much shorter fetch of the onshore flow.

A factor related to the air-water temperature difference, that is less obvious, is the vorticity tendency. This is discussed by Petterssen (1956). In his development equation, there is a term which says that the vorticity increases in a locality in which more heat is added than in its surroundings. The Great Lakes as a whole are such a heat source in the large scale, and as such show up as an area with a maximum of both cyclones and cyclogenesis in winter, and a minimum of anticyclones and anticyclogenesis, as reported by

Petterssen (1956) from 40 years of historical charts tabulated. This means that Lows moving over the Lakes tend to strengthen a bit when the air is colder than the water, but more so it means that the cold arctic highs tend to weaken and are deformed by or actually move around the Lakes. It takes a very strong High to move across the center of the Lakes in the depths of winter. The extent of this effect on portions of one Lake, say southern Lake Michigan, is unknown, but may be a factor in the details of lake snow deposition on land. Satellite pictures coupled with radar may eventually provide an answer.

The maximum and minimum temperature, as well as the diurnal temperature cycle, are obviously affected by lake temperatures for stations close to the shores and even well inland on the lee sides of a lake. However, these effects are so obvious as to need no special comment.

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 captions to the figures. 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.

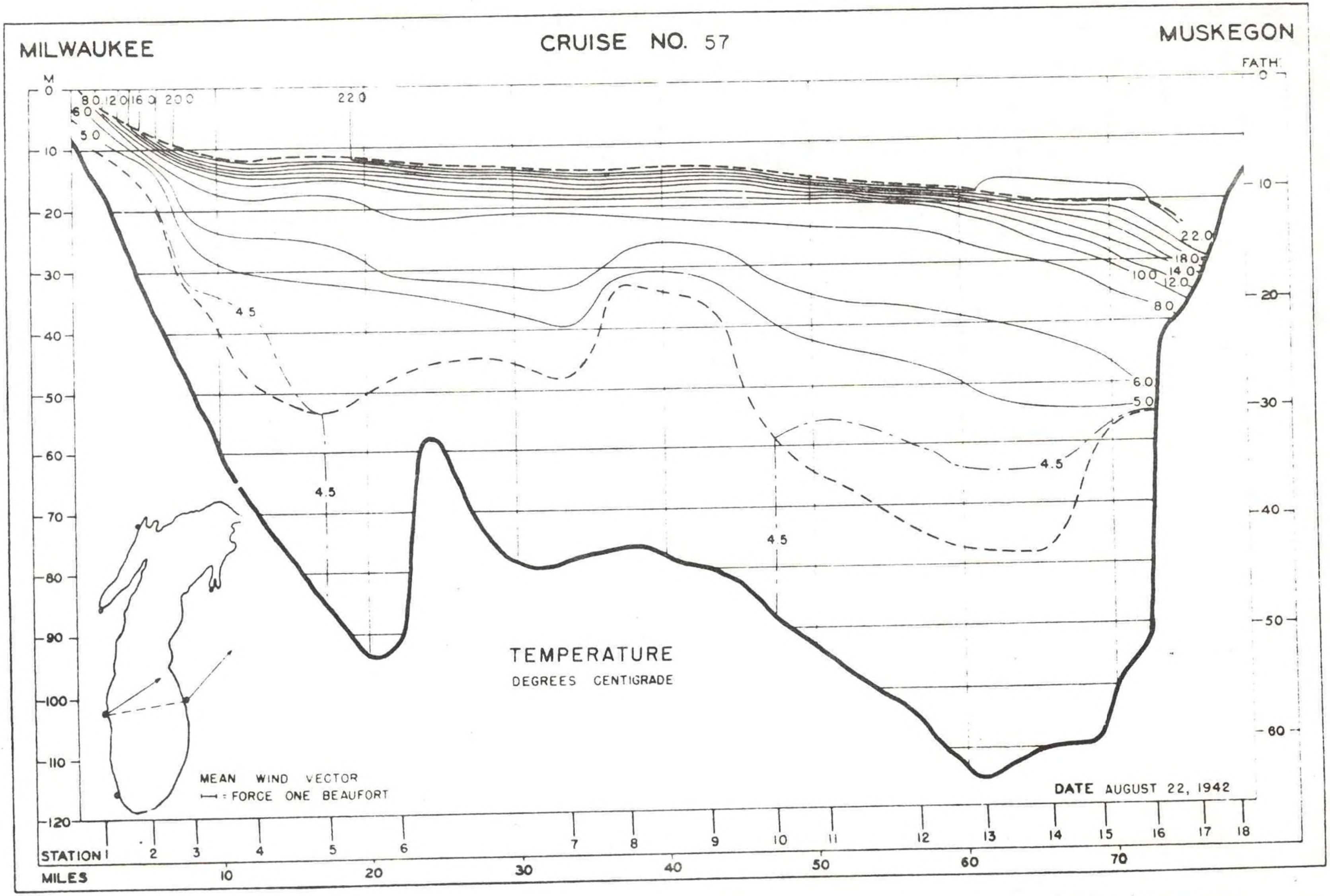


Figure 2 - The warmest condition of the season, with a strong thermocline. There is considerable upwelling effect on the west shore due to recent strong west winds, including the passage of a Low.

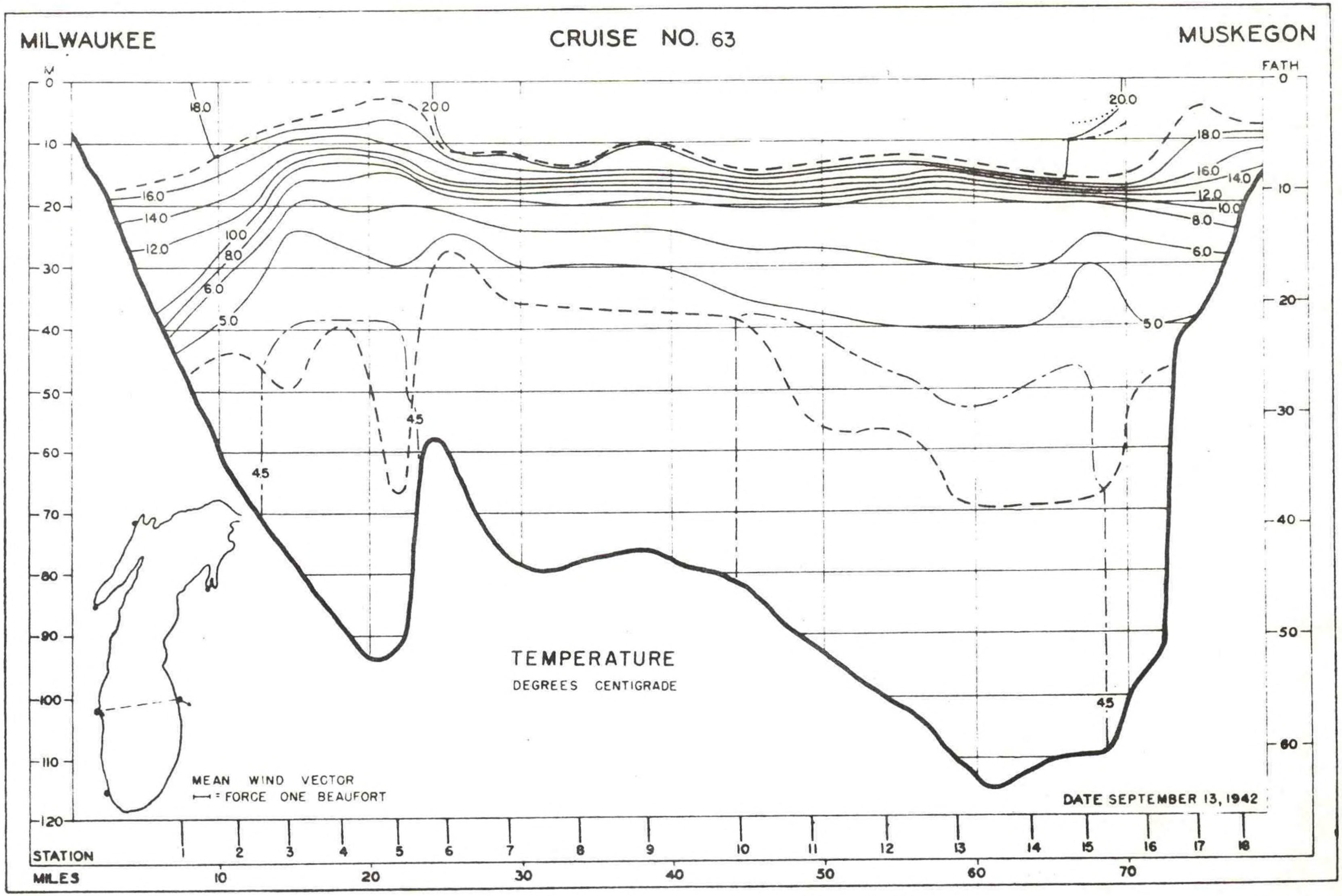


Figure 3 - Some cooling even in mid-lake but not much even yet.

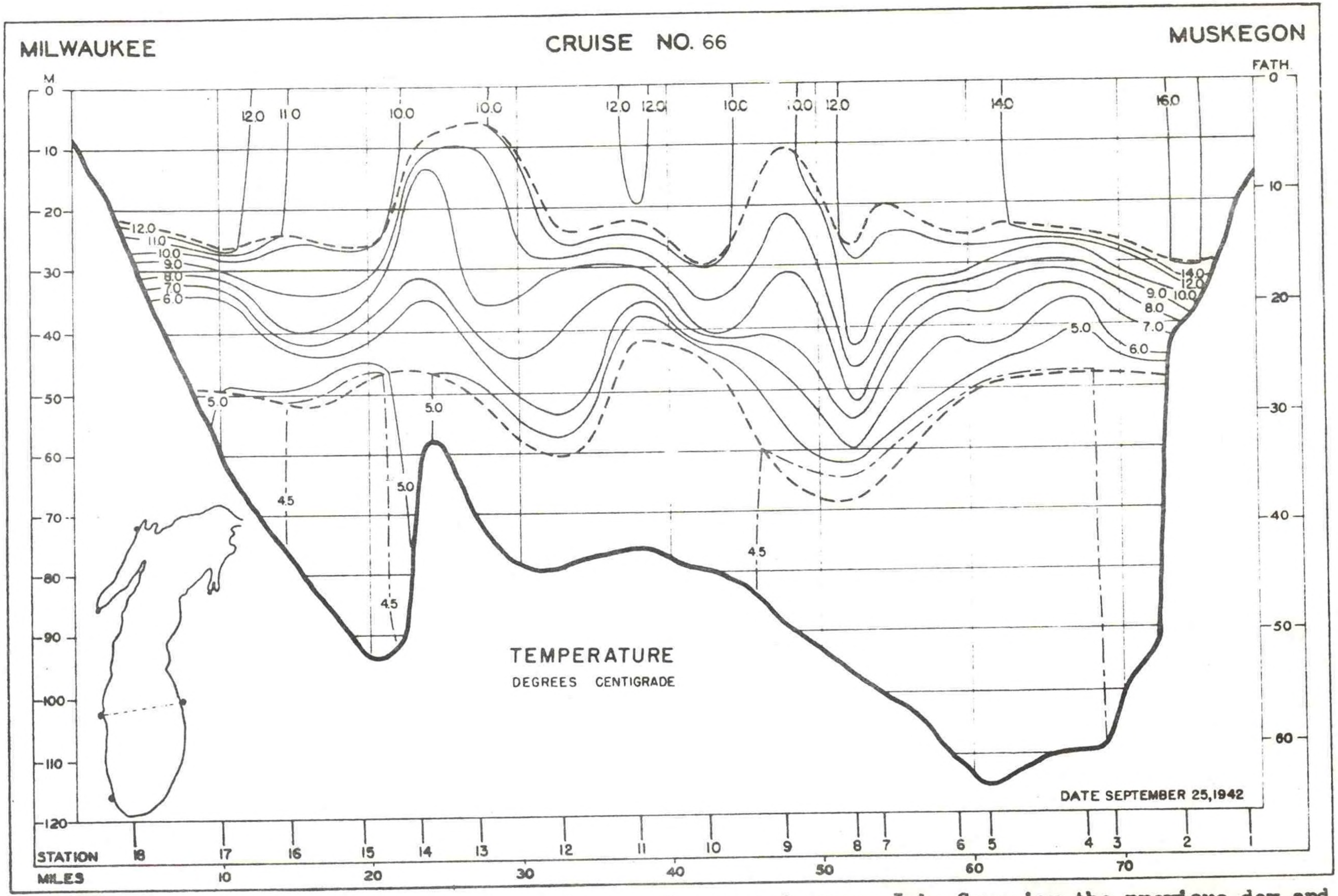


Figure 4 - The first really strong storm since spring passed across Lake Superior the previous day and the great mixing that resulted brought an end to the summer quasi-steady temperature condition. The conditions of the previous chart, excluding the upwelling effect, likely existed with little change 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.

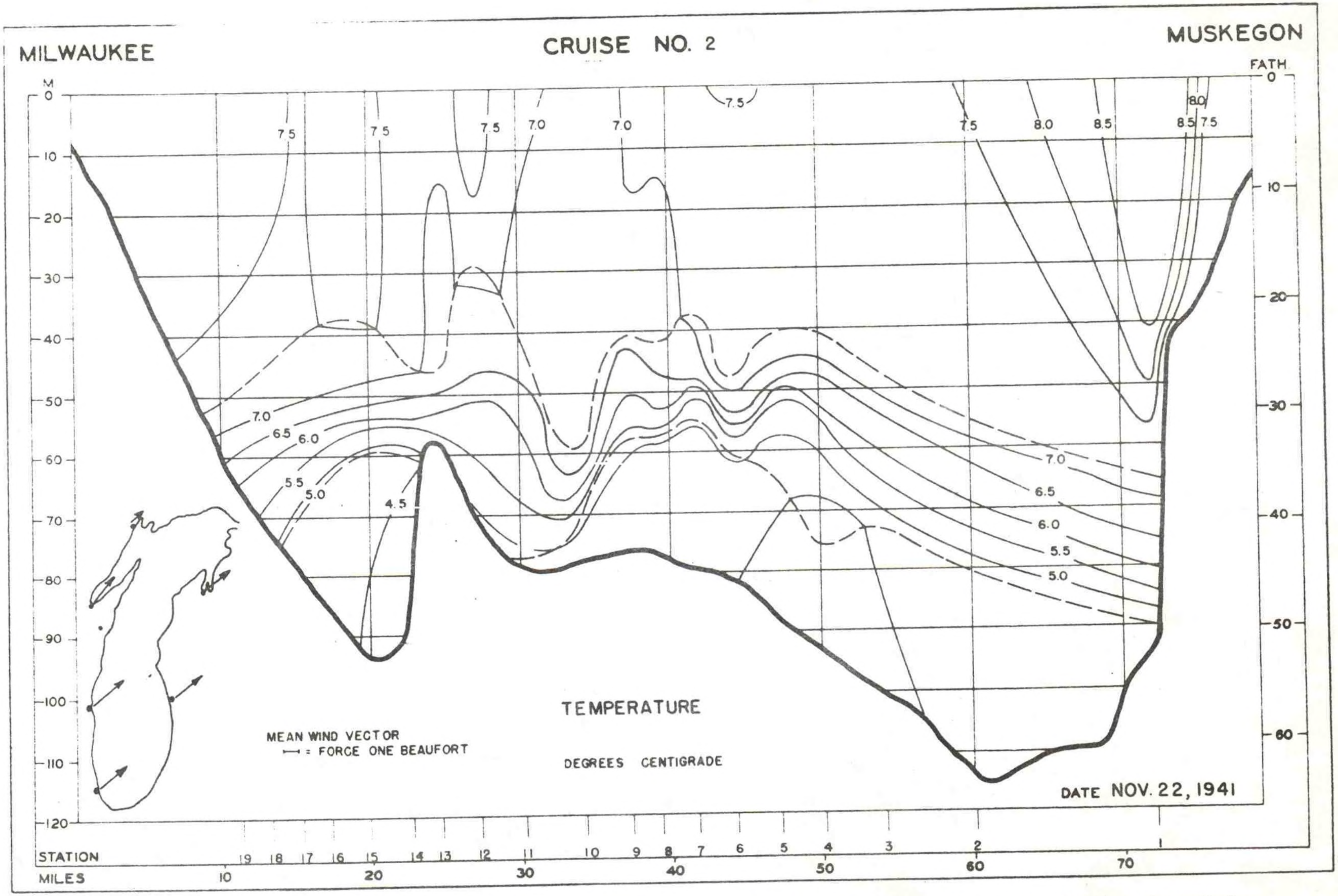


Figure 5 - The thermocline has lowered by cooling in the upper and middle layers, while the mixing, having now reached to the bottom, has warmed the deep water slightly. There is still a horizontal temperature gradient at the water surface, with the warmest water on the lee shore. Three full months of cooling has dropped the surface water temperature about 15°C (about 27°F), to a temperature of about 45°F. Lowering of the surface water temperature will proceed more slowly now that low stability in the upper half of the water will allow easy mixing to a large depth.

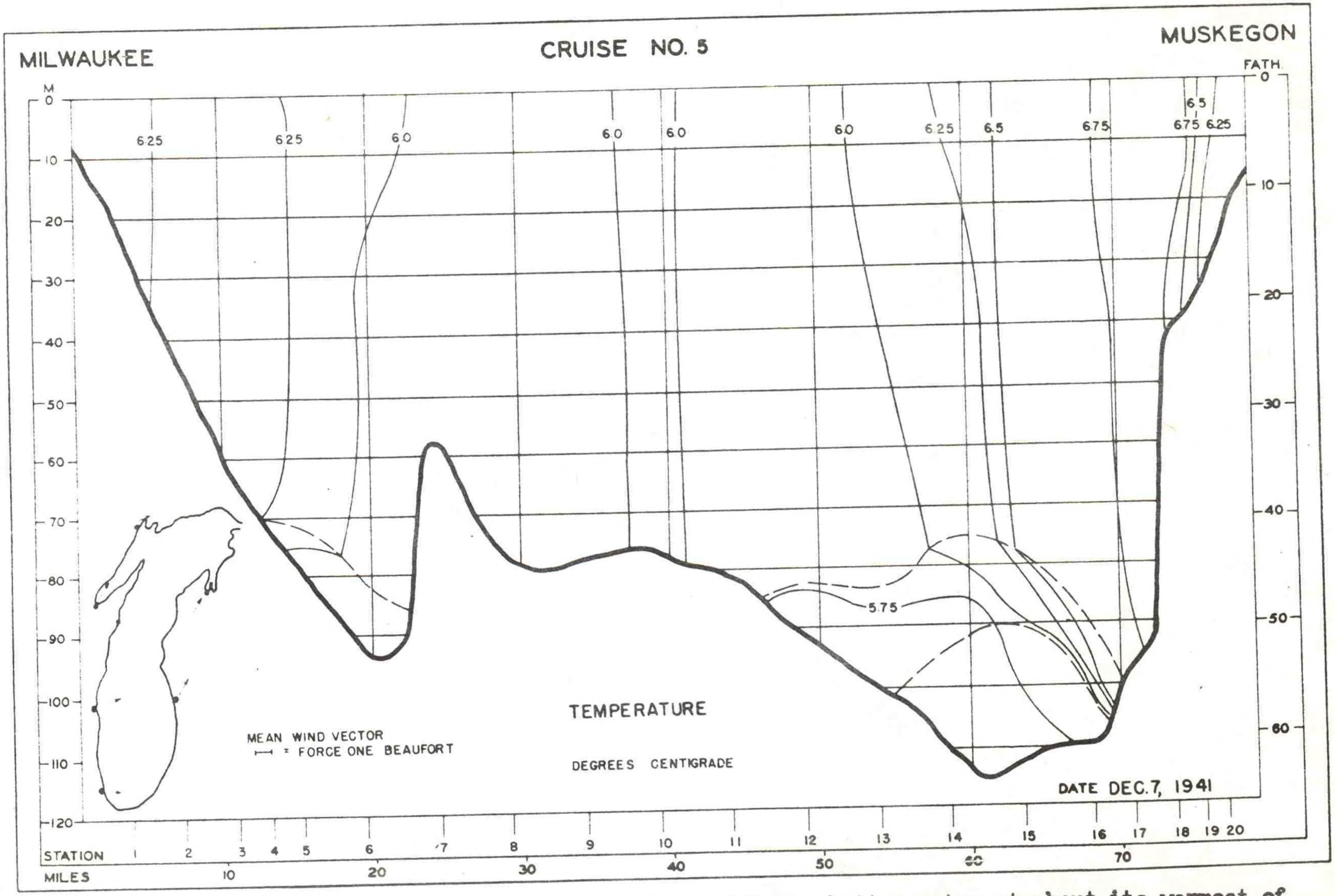
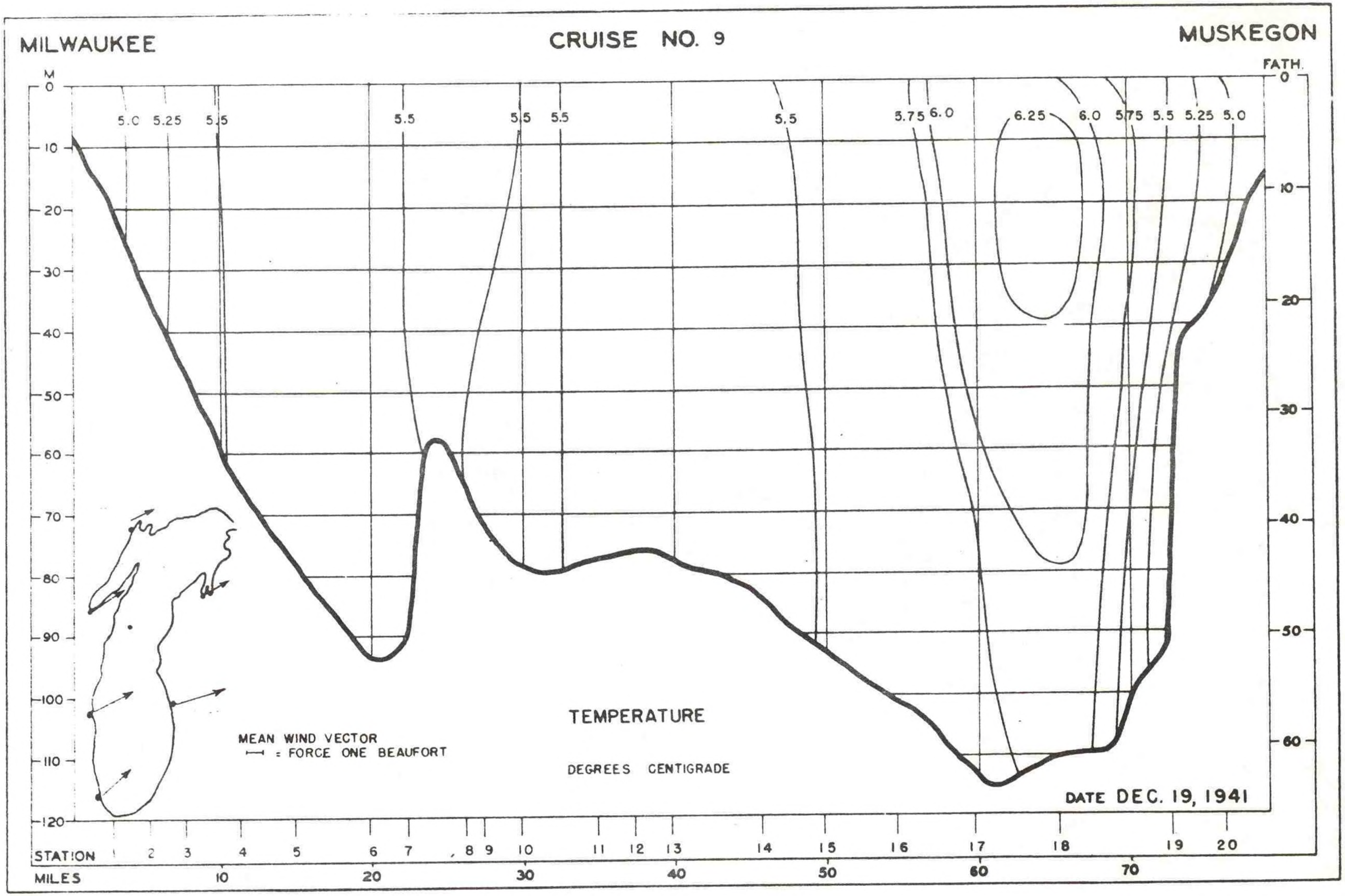


Figure 6 - The lake is almost vertically homogeneous, with the bottom water at about its warmest of the year. There is little horizontal temperature gradient at any level. For the next three and a half months there will be a slow drop in temperature at all levels, with only weak horizontal and vertical temperature gradients at all levels. The strongest gradient will be near the surface and near the shores, where mixing with the warmer deep water is restricted by the shallowness of the water, so the cooling is concentrated in a shallower layer. Strong storms have little effect on lake temperatures from early December through April and at times even into May.


MILWAUKEE
CRUISE NO. 9
MUSKEGON
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FATH.
5.0
5.25
5.5
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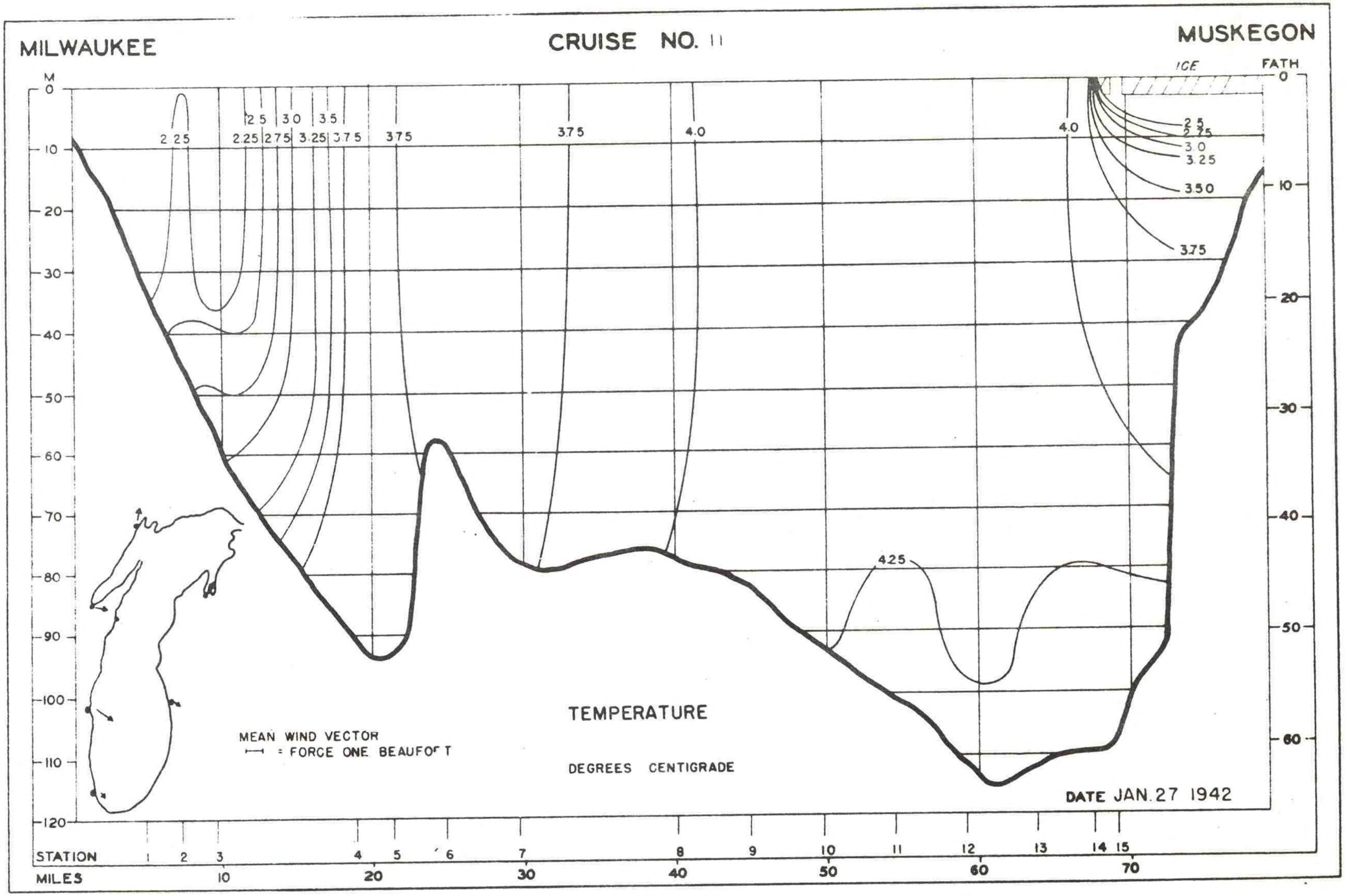
5.75
6.0
6.25
6.0
5.75
5.5
5.25
5.0
TEMPERATURE
DEGREES CENTIGRADE
MEAN WIND VECTOR
⊢⊣ = FORCE ONE BEAUFORT
DATE DEC. 19, 1941
0 10 20 30 40 50 60 70 80 90 100 110 120
0 10 20 30 40 50 60
STATION 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
MILES 10 20 30 40 50 60 70

Figure 7


MILWAUKEE
CRUISE NO. 11
MUSKEGON
ICE
FATH
M
2 25
2.5
3.0
3.5
2.25
2.75
3.25
3.75
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3.75
4.0
4.0
2.5
2.75
3.0
3.25
3.50
3.75
4.25
TEMPERATURE
DEGREES CENTIGRADE
MEAN WIND VECTOR
= FORCE ONE BEAUFORT
DATE JAN. 27 1942
STATION
MILES
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10
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70
80
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100
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120
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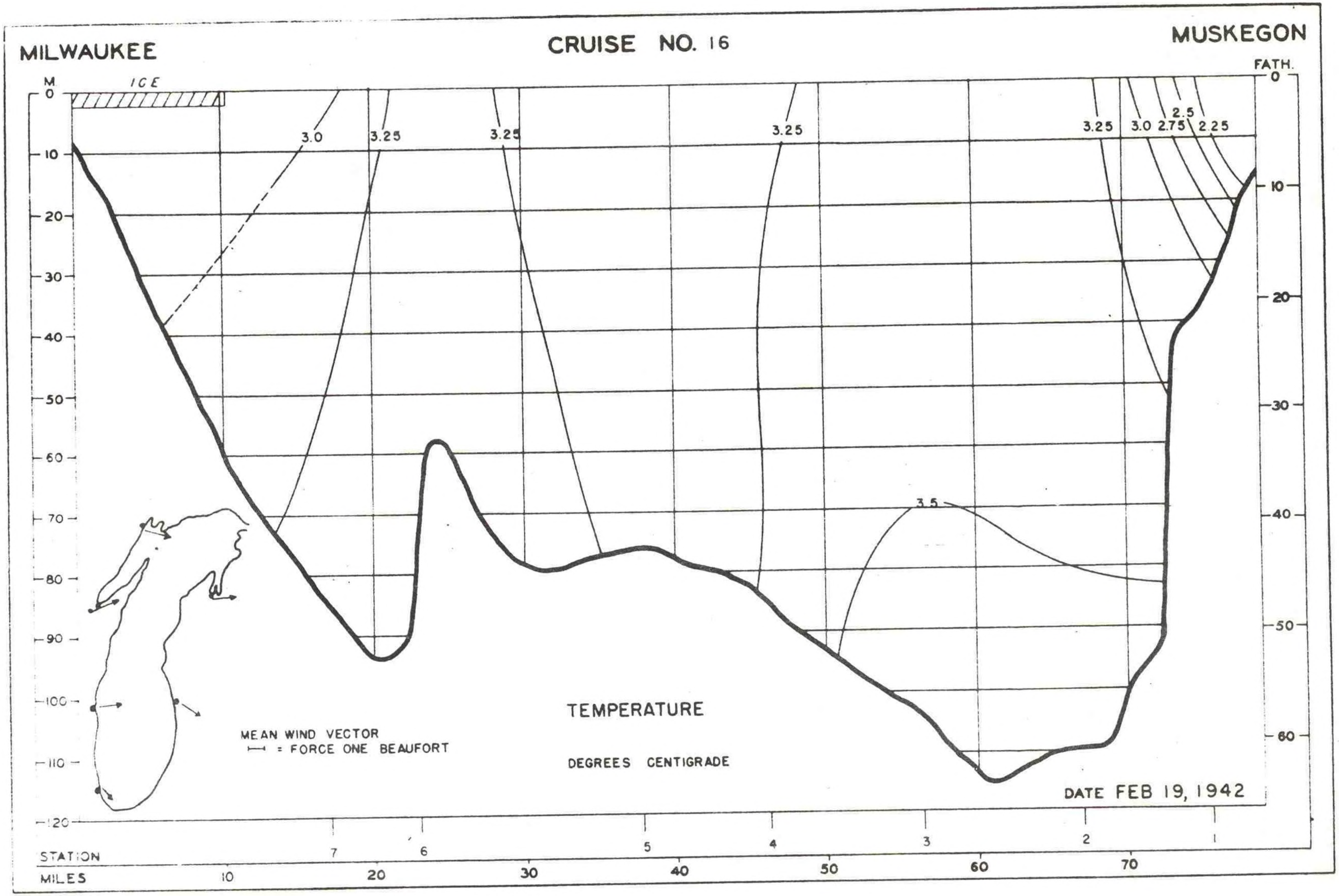
Figure 8


MILWAUKEE
CRUISE NO. 16
MUSKEGON
M
FATH.
ICE
3.0
3.25
3.25
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3.25
3.0
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2.5
2.25
3.5
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10
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70
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110
120
0
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20
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60
TEMPERATURE
DEGREES CENTIGRADE
MEAN WIND VECTOR
⊢ = FORCE ONE BEAUFORT
DATE FEB 19, 1942
STATION
7
6
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Figure 9

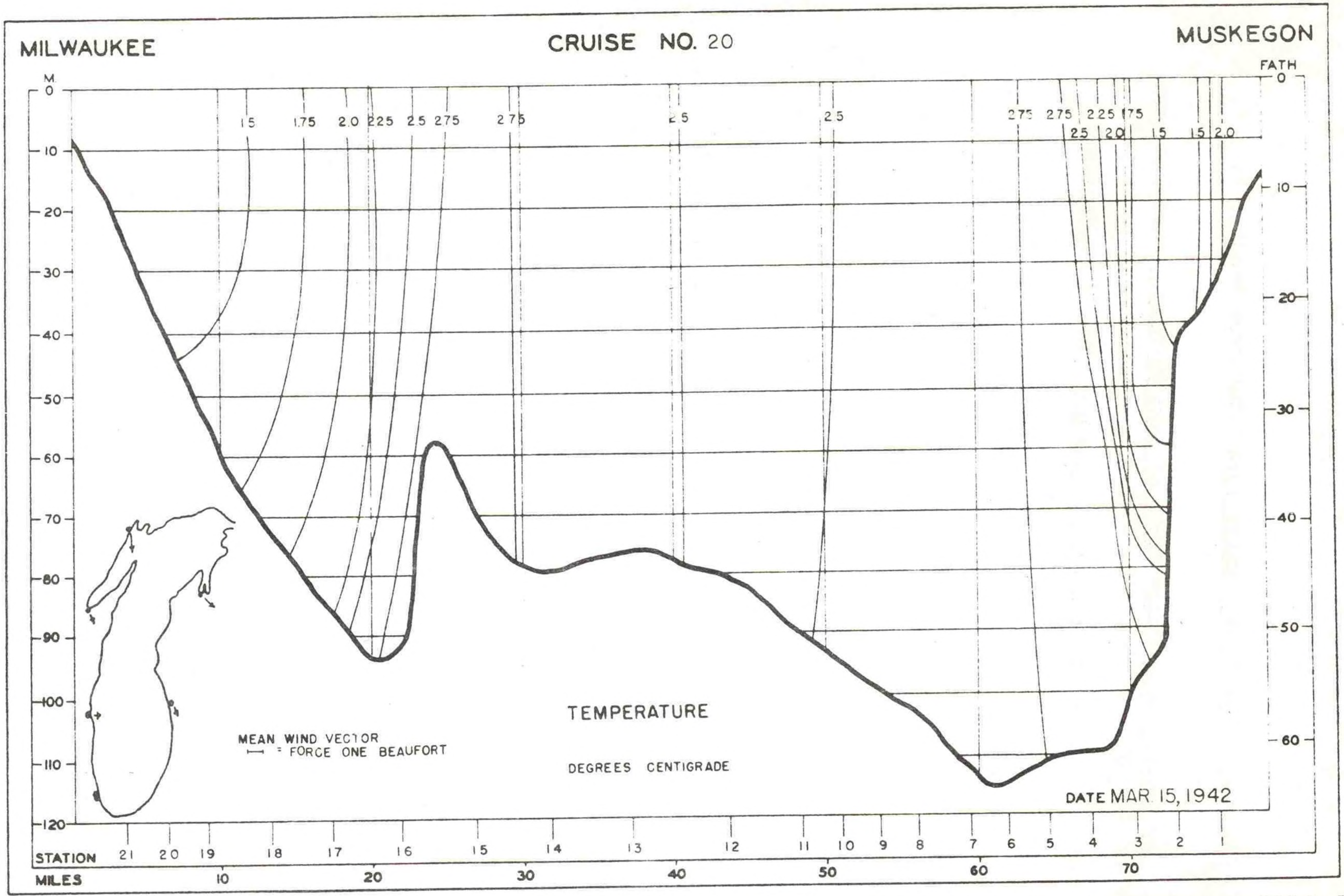

Figure10 - The lake is at its coldest. The water is isothermal top to bottom at a temperature a bit below that of maximum density (essentially 4°C). The warmest water is in the open lake well away from shore, but there is little horizontal temperature variation at any level. Upwelling, produced by strong offshore 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.

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29 An Aid for Tornado Warnings.

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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.

41 The Temperature Cycle of Lake Michigan 1. (Spring and Summer).

42 Dust Devil Meteorology.

43 Summer Shower Probability In Colorado As Related To Altitude.

44 An Investigation Of The Resultant Transport Wind Within The Urban Complex.

45 The Relationship of Some Cirrus Formations To Severe Local Storms.