Vol. 7, No. 4.

Royal Meteorological Society

WIND, WEATHER and WHITECAPS
THE PROBLEMS of SMALL CRAFT

J. E. Michie
K. T. McLeod
R. C. Graham

CANADIAN
BRANCH

25¢

Vol. 7 A Publication of the No. 4

Royal Meteorological Society, Canadian Branch

EXECUTIVE COMMITTEE 1956

Additional copies of this publication are available at a price of 25 cents each. All enquiries and correspondence concerning the Canadian Branch of the Royal Meteorological Society and its publications should be addressed to

The Secretary
Royal Meteorological Society, Canadian Branch
315 Bloor Street West,
Toronto 5, Ontario

WIND, WEATHER AND WHITECAPS - THE PROBLEMS OF SMALL CRAFT

by

J. E. MICHIE

National Yacht Club

K. T. McLEOD and R. C. GRAHAM

Meteorological Service of Canada

In presenting his introductory talk Mr. Michie outlined some of the problems of the operators of small craft. He described the situations which small craft face and indicated what measures the operators have been taking. In his description Mr. Michie dealt at some length with weather proverbs and indicated wherein he felt they had merit. As Mr. Michie spoke without a written text, his talk is not published; tests of the talks given by K. T. McLeod and R. C. Graham follow.

WIND, WEATHER AND WHITECAPS - THE PROBLEMS OF SMALL CRAFT

by

K. T. McLeod

There is likely to be fairly general agreement that waves, particularly when they are of any substantial size, can be a very considerable nuisance to small craft. When considering such wave conditions a number of questions may occur to us. One may well wonder why fairly substantial waves are present with very little in the way of wind. On other occasions, even with a fairly fresh wind blowing, there may be no waves of any appreciable size, and one wonders when, if ever, the waves will begin. And sometimes the surface of the water is so rough and confused it is difficult to tell whether there is any definite wave pattern or not, while on other occasions the wave pattern is very clear and regular.

In attempting to find reasons for these conditions let us consider the inter-action between the wind, which generates the waves, and the water as it responds to the frictional effects of the wind moving over it. Let us suppose that a calm situation exists with no waves present. An off-shore wind begins. For a time not much happens, for the friction of the wind on the smooth water surface is quite small. After a time, small waves appear, close together, and then the wind gets a better leverage on the water and the height and spacing of the waves increases fairly rapidly. In general the speed of the wind and the length of time the wind has been blowing determine the rate at which waves form and the height of the waves. One can put this another way and say that the size of the waves produced depends on the speed of the wind and the distance from the shore, or generating area. This distance is called the 'fetch'.

The speed at which waves move is usually much slower than the speed of the wind. It is only after a considerable period of time that the wind is able to force the waves to move along at a speed even approaching its own. It is perhaps interesting to note that the wave length or distance between the crests of two successive waves is fairly closely related to the speed at which the waves move. A simple rule is that the speed of the wave equals $\frac{4}{3}$ the square root of the wave length. For example, with wind speed in knots and the wave length in feet, when waves are moving at 12 knots, the wave length is 81 feet. The period of the waves or the time it takes successive waves to pass a buoy, or a fixed object is in turn related to the speed of movement of the waves in a way that can be simply expressed. The speed of waves in knots is approximately equal to three times the period in seconds, so that for a wave speed of 12 knots the period would be four seconds. The above rules apply for the deeper water and would not hold strictly true for waves in shallow water.

When the formation of waves is studied from the shore with an off-shore wind one sees that the height and length of the waves increases gradually with distance. However, at some distance out, the waves become of constant size and length. Careful observation shows that this point at which waves of constant size begins, moves steadily away the longer the wind continues to blow. As a result the stretch of water over which the waves increase in size becomes steadily longer, and in turn the size of the waves in the steady state increases gradually. The duration of the wind therefore determines the size of the waves in the steady state. There is, however, a maximum height of wave for any speed of wind, and also a maximum height for any value of a fetch. On open water with an unlimited fetch, waves seem to have a maximum size of about 50 feet. With light to moderate winds careful observation has led to the rule that the maximum height of waves is approximately equal to half the wind speed. A persistent wind of 20 mph, blowing over an unlimited fetch of deep water could, therefore, produce 10 foot waves.

Small craft are generally concerned with waves formed on lakes or coastal regions where the fetch is of the order of a few miles up to perhaps 50 miles. Here the maximum size of wave is determined more by the length of the fetch than the speed of the wind. Since the fetch usually varies in different directions the maximum size of wave for winds from different directions may be readily estimated. The rule relating size of wave to length of fetch is as follows. The height of wave is approximately equal to $\frac{3}{2}$ the square root of the fetch in miles. For a fetch of 16 miles the wave height would be $\frac{3}{2}\sqrt{16}$ or 6 feet.

These rules provide a reasonable guide to wave size, length, and growth. However, there are other factors which control the growth of waves such as air and water temperatures and these will be discussed in some detail later.

On the other side of the lake toward which the wind is blowing and the waves are moving, our chief concern is likely to be that we cannot estimate in any way, just when the waves will appear and a rough sea will be on us. During the war, this problem came in for a very considerable amount of study, particularly in 1942 during the planning of the Invasion of North Africa. At that time wave forecasting techniques were investigated and rules developed to forecast the time of arrival of waves, their height and period. From the studies made, a number of methods of wave forecasting were developed which seem to have proven quite useful. For one thing, the effects of wind on water are more straightforward, as one might expect, than conditions created by a similar wind over various types of land surfaces such as hills, trees and mountains. Over water the large scale features of the wind distribution are all that is in general required. Useful methods of predicting certain wave characteristics from the broad meteorological weather picture have therefore been developed, even though the theories so far presented do not actually explain what happens and are not at all satisfactory. Forecasts of the arrival time of dangerous waves can be very helpful. For example, on January 1st and 2nd of 1947 a nearly stationary storm centered about a thousand miles to the northeast of the Hawaiian Islands set up a wave pattern which travelled out from the storm area and moved along as a swell for a very considerable distance through the previously calm area outside. This swell, which is estimated to have reached a maximum wave height of 38 feet (from top of wave crest to bottom of trough) arrived at Hawaii in 28 hours with a wave height of about 22 feet. The waves were unexpected and resulting damage was estimated at between one and two million dollars. Twenty-nine hours later three of the larger waves, still 12½ feet high, completely inundated one of a group of islands of an atoll about 900 miles south of Hawaii. The arrival of such giant waves, created many miles away, is in many cases quite unexpected and methods for forecasting their arrival and intensity can obviously be most helpful to coastal areas.

To get a picture of the way waves move into calm water and to obtain an estimate of their arrival time let us take a Superman's look out over the water in the direction from which the waves will arrive. Stretching well ahead of the wave section, or train, of waves of constant size, are waves which decrease in size rather quickly and fade into the calm water ahead.

As the first or lead wave moves into the calm area it gives up part of its own energy to the calm water ahead to give it motion. It therefore passes ahead a portion of its energy and is weakened itself. But each successive wave behind passes ahead a portion of its own energy, such that there is a constant forward transfer of energy from wave to wave. As a result there are many very small waves far ahead of the main wave train, but just ahead of the waves in the steady state, the height of these waves increases surprisingly rapidly where the amounts of energy transferred are large. This situation often leads to trouble for small craft for the waves may be deceptively small for a considerable time with a fairly steady wind blowing and then surprisingly quickly the waves increase to their maximum size. One should anticipate then, that when there are small but gradually increasing waves and a steady wind, sooner or later the water surface can be expected to become quite rough rather suddenly and continue rough for a considerable time. This rather sudden arrival of the larger waves can be quite disconcerting and small craft owners should be on the alert for it. As a guide in estimating the arrival time of the major waves it may be helpful to know that the forward end of the train of waves in the steady state, and also the area where waves build up most rapidly is generally about midway between the first small waves that appear and the farther or windward shore, or generating area.

The wave structure as it extends out from the windward shore would appear something like Figure 1.

On the downwind side the pattern of approaching waves would appear something like Figure 2.

If the speed of the waves is known it would be assumed that the time of arrival of a train of waves could be readily estimated. However, the real forward movement of a wave train is actually about half the speed of the waves, such that a train of waves moving with individual speeds of 20 mph is moving forward as a unit at about 10 mph. This arises because at the leading edge of the wave train individual waves are constantly breaking down as they transfer their energy to the wave ahead. Keeping this rule in mind, and with some knowledge of the wave speed and position of the wave train, useful forecasts could be made of the arrival time of the major waves.

Some knowledge of the structure of an individual wave and the movement of the various parts of the wave can be useful. It has been found that much of the damage from a storm is caused by the wave action rather than the strong winds. If we could continually watch one drop or particle of water, in the same way as we would observe a small piece of floating wood, we would see that the surface water does not actually move forward with the speed of the waves, but rather has an almost circular local motion only. It is the shape or pattern of the waves only that moves forward, as a ripple along a rope. The individual particles of the water move in circles, such that a particle at the crest of a wave will move forward, slide down the back or rear side of the wave, move backward in the trough, and upward and forward again along the leading side of the next wave. In making its circle the particle or drop does not arrive back at quite the same place at the top of its circle, but just a bit downwind of its previous position. The path of the water particles is therefore along a cycloid in the direction of the wind as shown in Figure 3. The surface water consequently moves very slowly along as a wind generated current. The speed of this wind current is approximately 2% of the speed of the wind, such that with a 50 mph wind the surface water would be drifting downwind at about one mile per hour.

The rotation of the earth leads to a rather odd effect that might be mentioned in passing. Because of the rotation of the earth all moving objects are given an apparent deflection to the right in the northern hemisphere. For this reason water moving parallel to a coast line has a tendency to curve to the right and enter openings in the coast line. This effect is particularly noticeable along the Dutch and English coasts where there is a marked tendency for the water to hug the coast line and to move into fjords and rivers, producing a considerable rise in their level.

The forward motion of the water in the crests of the waves and the backward motion of the water in the troughs explains the sport of riding the surfboards, and the easy gliding motion of birds which move along by apparently riding the crests of the waves. Pilots of seaplanes taking off into the wind are well aware of the backward drag of wave crests on the hull of the craft, which is at times great enough to prevent heavily loaded aircraft from getting clear of the water.

Those concerned with the pounding of waves on a breakwater or the effect of waves on a sandy shoreline should realize that a cubic yard of water weighs about a ton. To illustrate, consider a wave with a height of 40 feet, from crest to trough. The water particles are moving in an orbit or circle 40 feet in diameter. They would make one complete circuit in about 9 seconds travelling at around 14 feet per second and moving at their fastest in the crest of the wave. The tons of water in the crests of such giant waves moving forward at the rate of around 14 feet per second creates a tremendous impact against ships, breakwaters, lighthouses, and such obstacles in their path.

Since the fetch on a lake usually determines the maximum height of waves, it is apparent that the strength and size of the breakwater you should build will vary in different directions and can be determined by considering the length of the fetch to the opposite shore in the different directions. It is generally known that water tends to pile up at the downwind end of a lake because of the wind current which drives the surface water in that direction. This effect may raise the water level at the downwind end of a lake by as much as several feet. When the waves, surface water and surf move towards a shore there is in turn an undercurrent or undertow in the outward direction. This concealed counter current can be extremely dangerous as swimmers have come to realize, at times too late, particularly along the shores of Lake Huron and Georgian Bay.

In the deeper water a diver will note that with increasing depth the up and down motion of the water is gradually damped out. The rate at which this motion of the water is damped with depth is as follows. For each 1/9 the length of the surface wave, below the surface of the water, the up and down motion of the particles is cut by half. A submerged submarine rides steadily at not too great a depth despite a heavy storm above.

The rather simple picture of wave formation and structure so far described does not always agree with the conditions that occur. Often one finds that there is no clear cut pattern of waves on a lake, but a rather confused type of surface. This is the result of the combined action of two or more sets of waves or wave trains which have been raised by different winds. A wave pattern may be present although there may be no local wind, having been raised by a wind at a distant generating source. Such a wave pattern not due to local winds is called a 'swell'. The wave pattern due to the local wind is called the 'sea'. A swell can arise either from a distance generating wind source or be due to the wave pattern that persists after a local wind dies away. If a swell exists and a wind is blowing in a different direction, then both a swell and a sea will be present. The swell will continue to persist in its original direction with a constant wave length and very slowly diminishing height of wave. The new set of wind waves or 'sea', will cut across this wave train and produce a criss-crossing type of pattern which is often very confused. This is especially likely in a large body of water where there may be swells from two or more directions as well as a 'sea' from the local wind. In each train of waves there are always a number of waves which are larger or more significant and when these are observed to cut across the significant waves of another train the water particles are subjected to the combined energies of both wave trains and at the points of intersection of the crests, waves are usually high. These larger waves due to combined crests can be most troublesome in rough weather for their erratic nature make them difficult to anticipate.

When the wind dies away the wave pattern persists as a swell and according to theory should continue almost indefinitely with the same wave length, period and height of wave. However, it has been observed, that because of the friction between the air and the waves, the height of the wave dies gradually away while the wave length and the period appear to increase slowly. It is also apparent that the longer waves, which travel more quickly, persist much longer than short waves which decay fairly quickly into a regular pattern of low undulations.

There seems to have been a tendency in recent years to leave the weather watching to the professional weathermen and to rely on them more and more as specialists who will provide all the weather information and warnings needed to make boating pleasant and safe. This type of reliance, plus a 'take-a-chance' attitude is neither logical nor safe. Watching the weather can be fascinating fun and at times a most useful hobby as well. By studying the sky you can soon learn that the winds, the clouds, and the color of the sky, combine in endless variety and in logical sequence. The fishermen and shepherds in olden days saw patterns in the changing weather and found signs for the future weather in the rainbow, the heaped up cumulus and halo cirrus clouds. You too can become familiar with the families of clouds, know the signs of summer showers, measure the distance of a thunderstorm and know its inner secrets. The great outdoors can be your hobbyshop. With your eyes and your memory you can match your wits with the weather, test the long standing sayings, use the best of them and add a few of your own to suit your local weather. Leisure time or time taken for this special purpose of making the study of weather a hobby can be of great help to small craft operators by enabling them to take advantage of the weather by showing them how to adapt to meet it, and by helping them to avoid the hazards that forever lie in wait for the unwarned and the unwary.

WEATHER ON THE WATER

by

R. C. Graham

The small boat sailor has two possible sources of weather predictions: the forecasts prepared by weather services; and his own predictions, based on his observations and his ability to interpret them. The former have the advantage of being based on observations made over a large area, interpreted by professional meteorologists. The latter have the advantage of using the sailor's current observations of the weather in his immediate area of interest and taking account of local factors affecting weather to an extent not possible in forecasts issued for areas of several hundred square miles and for periods of a day or so. To get the maximum advantage from both sources of information, the sailor may take the professionally issued forecasts and add to them deductions from his own observations and his own knowledge of local conditions, thereby refining them in time and space so they can be applied to his own immediate problems:- "What is the wind doing on the other side of the island?" or "Must I run for shelter now before a squall strikes, or can I safely stay out another hour?"

The small craft sailor may often be where he has available only his own judgment of the weather. This is just one facet of the self-reliance that is part of the challenge of small-boat sailing. Ability to predict the weather is one of the traditional attributes of the skilled sailor and adds to pleasure as well as safety.

Tonight in the rest of my talk I propose to discuss some ideas that may help in interpreting forecasts or making your own predictions of the weather.

One factor affecting the local wind is the relation between the temperature of the air and the temperature of the surface over which the wind is blowing. Aloft, the air is flowing freely while near the ground its movement is restricted by friction. If the air is much colder than the land or water, the effect is like water boiling on a hot stove; the air is completely and continuously mixed and the momentum of the air aloft is carried down to the surface. Under these conditions we usually have brisk gusty winds. If, on the other hand, the air is warm and the land or water cold, the light warm air aloft glides smoothly over the heavy cold air near the water, and the wind is much brisker aloft than on the surface. The sailboat with a high rig has an advantage under these conditions. In addition to the change in speed, the wind veers with height - an interesting by-product of this is that sailing craft should on the average do better on the port tack than the starboard tack, in view of the normal sag to leeward of the upper part of the sail.

I have found it useful to think of sailing weather in four general classes, which as a non-meteorologist I used to identify by easterly winds, southwesterly winds, northwesterly winds and "fluky" winds. Later I learned that these correspond respectively to the weather ahead of a depression, in the warm sector, behind the depression, and in the centre of a high pressure area.

In "eastwind" weather, there is generally not a great contrast between the air temperature and the temperature of the surface, and except in the lee of a shore, the breeze is fairly steady and reliable. It tends to stay up at night as well as by day. Indeed, along the north shore of a large body of water, as along the Toronto water front, the effect of the cooling of the land at night and heating in daytime tends to cause an increase of an east wind at night.

Typically the "eastwind" weather pattern has gradually increasing cloud and finally rain, but usually there is a day or two of fine sailing before the rain arrives. Sometimes it leads up to thunderstorms but generally, although the east wind may become very strong, it increases gradually and does not give rise to treacherous conditions.

In the "southwesterly" type of conditions, the air is usually much warmer than the water and the wind is markedly stronger aloft than at the surface. There may be only a 5 knot wind at the height of your sails and a 30 knot wind a few hundred feet aloft. The stronger winds may break through to the surface in places, giving a patchy pattern of light and strong winds. I have seen under those conditions winds stronger in Toronto Bay than over the open lake, because the passage of the air over the Island stirred it up enough to bring down the stronger wind from aloft. The cold air in the lower layers tends to become trapped when it comes up against a lee shore resulting in a condition of light wind and sloppy sea that is most frustrating under sail.

Southwesterly weather may be treacherous, not only because the wind may change rapidly in strength, but because it often precedes an approaching cold front which may bring thunderstorms and severe squalls. My advice is to keep a good watch on the sky to the west and when it becomes black, watch out for trouble. The common sequence is increasing southwest to south winds, perhaps dropping or shifting to the east just a few minutes before the squall, then a thunderstorm with vicious squalls from the west shifting to northwest and clearing, bringing us into the "northwesterly" class of weather.

In this, the air is generally colder than the surface and is well stirred. The wind is gusty, especially in the lee of land in the daytime. The wind drops at night, and rises in the daytime. The weather is usually fine, and the main precaution to be taken is against the gustiness of the wind in the daytime, and to avoid being mislead by the deceptive calmness in the morning which may give way to strong winds later on. Along a windward shore, of course, one must in small craft be aware that the calmness of the lake near shore will give way to quite a choppy condition a few miles out.

As a spell of "northwesterly" weather continues, the winds become lighter until, in the centre of the high pressure area, there is little pressure gradient to drive the air and one experiences light, variable winds. The tendency is for light on-shore winds by day and calm or light off-shore winds at night. Far from shore it may be completely calm. Skies are generally clear. This weather condition is probably one of the most pleasant for power boating, although frustrating if trying to get anywhere in a sailboat. It is in this condition that knowledge of local winds are of great advantage in a sailing race.

These classes are generalizations, and as with all generalizations there are often exceptions. Depending upon how pressure systems are oriented, the weather types described above may occur with winds of direction substantially different to the characteristic directions that I have described. The changes may be rapid or slow depending on the motion of the weather system. However, identification of the general types of weather situations is a valuable aid to the small boat sailor, in relating his activities to the weather.

Fig. 1. Gradual increase in size of waves out to the steady state, due to offshore wind.

Fig. 2. Long area of small waves, then rapid increase in size near steady state on downwind side.

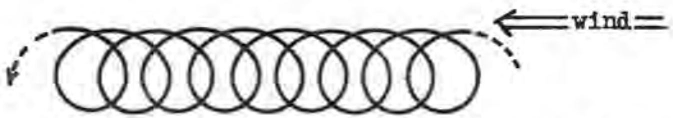

Fig. 3. Path of water particle at surface due to wave shape and differing movements of parts of the waves.