Can the other vessel see you on radar?

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It is important that skippers of radar-equipped vessels know the capability of their own radar to detect other vessels in order to avoid collisions. However, it is critical for skippers of all vessels to know if radar on another vessel can detect their own vessel. This is especially important as weather deteriorates and visibility decreases. The range at which a vessel can be detected by radar depends on many variables such as the radar power, antenna, the vessel's radar cross section (how strongly it reflects radar), and the environmental conditions (weather, waves, rain, fog) etc. This article explains how the more common environmental conditions affect detection range and provides guidelines on the range at which radar can detect a pleasure vessel in various weather conditions. The intended reader is the skipper of a 20 to 50 foot pleasure vessel who desires to know when another vessel, especially a large ship, can detect his vessel.

Nominal Detection Range in Ideal Conditions

Marine radar ranges from small recreational systems transmitting between 2 kW and 4 kW, to professional systems transmitting between 12 kW and 50 kW. Radar cross section (RCS), expressed in square meters (m^2), measures how strongly a target reflects radar pulses. Radar detects larger RCS targets with less power, at longer range, and in more severe weather conditions. Targets addressed in this article range from one square meter radar cross section (1 m^2) for a person or small inflatable to about 10 m^2 for a large recreational vessel, with 5 m^2 being representative of pleasure boats. The table summarizes maximum detection ranges in clear weather for typical marine radars and targets. While detection may occur at greater ranges than shown in certain circumstances, most of the time environmental conditions and weather limit detection to shorter ranges.

The table indicates that low-power radar on a pleasure vessel will usually not detect another pleasure craft at much more than one mile whereas a commercial ship will not detect it at more than four to five miles, in good weather. Large trans-oceanic ships with powerful scanners might double this. If these detection ranges seem short, remember that recreational vessels are small, both physically and as reflectors of radar pulses. For example, the radar cross section of a Navy cruiser, which is not an especially large ship, is about 160,000 m^2. It is huge compared with the typical 5-m^2 pleasure boat. Other things being equal, radar that detects a cruiser at ten miles will not detect a pleasure sailboat at more than one mile.

The table also illuminates the difference between the typical 48-mile recreational radar (4 kW) and the typical 16 or 24-mile radar (2 kW). The greater maximum range is useful only for detecting high cliffs when far out at sea or storm clouds at altitude as anything on the surface beyond 16 miles would be well below the radar horizon and undetectable. The main difference is that greater power usually comes with a better antenna and more sensitive electronics, resulting in a three-fold improvement in detection range (everything else being the same).

Nominal Maximum Radar Detection Range in Ideal Conditions
(nautical miles)

Target	**Radar System**			
	2 kW Low-power Recreational	**4 kW High-power Recreational**	**12 kW Low-power Professional**	**50 kW High-power Professional**
Dinghy	0.7	2.1	3.0	6.9
Small pleasure boat	1.1	3.3	4.5	10.3
Large pleasure boat	1.3	3.9	5.5	12.4

Maximum Pleasure Vessel Detection Range

- **Low-power recreational radar probably will not detect an average pleasure vessel at much more than a mile**
- **Professional radar will probably not detect you beyond 4.5 miles, or 10 miles if it is high-power**

Flat Seas Decrease Detection Range

Detecting a vessel in perfectly calm water is more difficult than detecting it in moderately rough seas. Although this is counter-intuitive, detection in a seaway is complicated because every pulse transmitted by the scanner goes to the target over two paths. One path is direct from the antenna to the target; the other path includes reflection from the water. The two pulses combine at the target with the result that power delivered to the target may be quite different from what would be the case in the absence of reflection from the water. One effect of this "multipath" pulse cancellation is to reduce maximum detection range for targets on the surface of the water. Since most of the radar-reflecting elements of a small boat are in the hull, close to the water, maximum detection range for a pleasure vessel in smooth water is much shorter than given in the table; roughly a third. Multipath pulse cancellation decreases as the seas build and the ranges shown in the table become more accurate as seas reach about seven feet. The thing to remember is that flat-sea maximum detection ranges are much shorter than shown in the table.

Flat Seas

- **Maximum detection range is less than shown for "ideal conditions" when the waves are smaller than about seven feet**
- **Maximum detection range is about one-third the values shown for "ideal conditions" when the water is perfectly smooth**

Fog Attenuates Radar Pulses and Reduces Detection Range

Fog attenuates the radar signal and reduces detection range. How much the fog reduces detection range depends on the visibility distance, scanner power, and the extent of fog between scanner and target. Here we assume that fog extends over the entire distance between scanner and target vessel.

When the maximum detection range in clear weather is short to begin with, for example, the target vessel is small, or the radar on the other vessel is a low-power recreational system, percentage reduction in detection range does not mean much in absolute terms. For example, fog with six-meter visibility reduces detection range of two miles in clear weather to 1.5 miles, an absolute reduction of half a mile. On the other hand, when the maximum detection range in clear weather is long, for example, the target vessel's RCS is large or the radar on the other vessel is a high-power professional system, percentage reduction in detection range is far more significant. Fog with six-meter visibility reduces ten-mile detection range in clear weather to less than four miles, a six-mile reduction.

Fog Attenuation

- **Fog with visibility at least 60 meters does not have serious effect**
- **Fog does not have much effect if detection range is short to begin with, as when the radar is low-power or the target is small**
- **Thick fog with 6 meter visibility may reduce long detection ranges by 60 %, i.e. 10 miles in clear weather to less than 4 miles**

Sea Clutter Limits Detection at Short Range

Waves produce target-masking clutter. Since waves cover a large area of the sea, they produce numerous blips covering a large area of the display. These mask returns from useful targets like your vessel by filling up, or "cluttering", the display with blips due to waves. While the radar operator can adjust controls to minimize the visual cluttering effect, reliable target detection is possible only if the target produces a stronger return than the nearby waves. The operator simply decreases the gain until the clutter disappears, leaving blips representing desired targets. Of course, this works only if the target is stronger than the clutter. That is, the target must stand out against the background clutter. Scanner power is irrelevant, since increasing power simply increases both clutter return and target return the same amount.

Waves reflect radar pulses when the wave face is perpendicular to the radar beam. The distance from the scanner at which the waves are perpendicular to the radar beam is proportional to wave height and to the height of the scanner. The strength of the reflection, i.e. the effective radar cross section of the sea surface, depends on the wave height and distance from the scanner. It peaks at a certain "sea-clutter limit" distance, which depends on the antenna height and sea state. The radar return from more distant waves becomes insignificantly small. At shorter distance, the radar return from waves remains roughly constant. Usually the wave clutter appears in the direction from which the waves approach, generally to windward. Five-foot waves produce a sea clutter limit of about a half mile around a scanner ten feet above the waterline. Doubling the wave height or doubling the antenna height each doubles the clutter limit. The same five foot waves that produce a half mile clutter limit around a pleasure powerboat might produce a two-mile clutter limit around a small ship with scanner 30 feet above the water, and out to six miles for a very large ship. Skippers of radar-equipped pleasure boats used to seeing a small area of sea-clutter on their radar display must understand that a large ship experiences a much larger clutter limit because of the scanner height.

Summarizing the effect of sea clutter on detection range is difficult because of the dependence on antenna height and wave height. Generally, the larger radar systems are generally on larger ships and are higher, so the clutter ring is larger. Consequently, you will disappear into the clutter at greater range from a large ship than from a recreational vessel. You should remember that detection of your vessel outside the sea-clutter limit ring is determined by signal power (i.e. RCS, transmitter power, distance, and attenuation from fog and rain). Sea clutter limits detection inside the clutter ring.

Waves Can Shadow a Vessel at All Ranges

Since most of the reflecting material in a pleasure boat is in the hull, waves larger than a vessel's freeboard can shadow the vessel whenever it is in the trough between waves. The vessel can be detected only when it is on the crest of a wave; it will be masked and undetectable when in a trough. The resulting intermittent detection makes it difficult for a human radar operator to see the vessel's radar blip and virtually impossible for automated systems like ARPA to detect and track.

Waves

- **Waves surrounding the target vessel establish a sea-clutter limit**
  - **Outside this limit, wave clutter does not limit detection**
  - **Inside this limit detection is possible only if the target stands out against the sea clutter**
  - **Five foot waves produce a clutter limit of about half a mile around a recreational radar (low scanner) to about two miles around a professional radar (high scanner)**
- **Waves to 1 foot: wave clutter effect is negligible**
- **Waves of 5 feet: a typical (5 m^2) recreational vessel won't be detected at less than one mile**
- **Waves of 8 feet: a large (10 m^2) recreational vessel won't be detected at less than one mile**
- **Waves 10 feet and up: you probably won't be detected inside the sea clutter ring**
- **Detection outside the sea-clutter limit ring is problematic in waves as large as your vessel's freeboard**

Rain Attenuates Radar Pulses and Reduces Detection Range

Rain and other precipitation such as snow and sleet reduce detection range in two ways. First, rain attenuates the radar pulses just as fog does. The difference being that the amount of rain is described as rainfall rate in millimeters per hour (mm/h), rather than as visibility range. Second, rain produces clutter like waves, discussed in the next section

Rain Attenuation.

- **Rain up to Moderate (4 mm/h) does not cause serious attenuation**
- **Rain does not have much effect if detection range is short to begin with, as when the radar is low-power or the target is small**
- **Excessive rain (40 mm/h) can reduce long detection ranges by 60 %, i.e. 10 miles in clear weather to less than 4 miles**

Rain Clutter Limits Detection at Long Range

Rain also produces clutter return similar to wave clutter, although the details are different. When rain surrounds the target, clutter is invariably the dominant factor rather than attenuation. Since the clutter return is proportional to the amount of rain (and the rainfall rate) in the volume of space covered by the beam, and the beam fans out with range, there is always a rain-clutter-limited-detection-range that depends only on the rainfall rate and target RCS. Beyond this limit, you will not be detected. Closer than this limit you may be detected if range and attenuation don't prohibit it. The key concept is that detection is possible only at ranges shorter than the rain-clutter limited detection range, which depends only on the rate of rainfall.

Consider a large recreational vessel target and a small professional 12-kW radar. In clear weather, the target may be detected at 5.5 miles. If rain surrounds the target, detection range is clutter-limited to slightly less than 3.5 miles by drizzle and to slightly more than 1 mile by light rain. Moderate or heavier rain limits detection to less than 0.5 miles.

Rain surrounding the vessel severely restricts detection. Even light rain will limit detection in most cases to little more than a mile. A high-power professional radar will do better because the beamwidth is narrow and it is less affected by rain clutter. You should remember that detection of your vessel inside the rain-clutter limit ring is determined by signal power (i.e. RCS, transmitter power, distance, and attenuation from fog and rain). Rain clutter limits detection outside the clutter ring.

Rain Clutter Surrounding the Target Vessel.

- **Rain surrounding a vessel establishes a rain-clutter ring that depends only on rainfall rate and target radar cross section. Detection is not possible outside the rain-clutter limit ring. Inside the ring detection depends on attenuation due to fog or rain and on scanner power**
- **Drizzle (0.25 mm/h) limits detection of large pleasure craft to around three and a half miles. This is not a limiting factor for recreational radar because a low-power radar couldn't detect a recreational vessel at three and a half miles in clear weather, but it is a limiting factor for professional systems**
- **Light rain (1 mm/h) limits detection of large pleasure craft to around 1 mile**
- **Moderate rain(4 mm/h) limits detection of large pleasure craft to around half a mile**
- **Heavier rain surrounding your vessel probably precludes detection**

Summary

Pleasure vessels are not strong radar targets, multipath pulse cancellation limits detection range in calm sea conditions, shadowing limits detection when the waves are larger than the freeboard, and the radar horizon is limited because the target is on the surface. Fog and rain attenuate the signal and reduce the probability that a pleasure vessel is detected. Clutter from waves and rain may make detection impossible regardless of the scanner power.

As skipper of a pleasure vessel in good weather and calm seas, you may think in terms of being detected by low-power recreational radar at half a mile or so and by professional radar on a large ship at four miles or so. Detection range improves about three to one as the seas build to seven feet or if a good radar reflector is mounted on the vessel. Other than that, darkness, light drizzle, moderate fog, and waves to three feet have little effect on detection range.

Detection in bad weather is problematic. Thick fog and drizzle extending over large areas may attenuate the radar signal greatly and reduce detection range severely. If the rain surrounds your vessel, clutter restricts detection to ranges shorter than the rain clutter limit range, which is about one mile in light rain, half a mile in moderate rain, and even shorter in heavier rain. This is independent of the radar. Detection range may be better if your vessel is large or if you have a good radar reflector, but the skipper of a recreational vessel should not count on being detected at more than half a mile in moderate rain.

Waves generate a clutter limit. Outside the clutter limit, wave clutter has little effect on detection. Inside, detection is possible only if the target is larger than the wave clutter. Three-foot waves are not much of a problem. Five-foot waves require a moderately large radar reflector; eight-foot waves require about 10 m^2; ten-foot waves probably preclude detection entirely. The sea clutter limit is proportional to antenna height and sea state; the larger ships, i.e. higher antennas, experience the larger clutter rings, up to several miles. Detection range may be better if your vessel is large or if you have a good radar reflector, but the skipper of a recreational vessel should not count on being detected at less than a mile in eight-foot waves.

It does not take much in the way of rain or waves to limit detection of a pleasure boat to a mile or less. A vessel approaching at 20 knots would have no more than three minutes to detect you, identify you, track you and determine risk of collision, and decide on a course of action. A large vessel would not be able to maneuver to avoid you under these time constraints. Your best option is to proceed with extreme caution in bad weather.

Radar Reflectors Improve Detection

A radar reflector is a small device that is a very strong reflector of radar waves. (A one-foot diameter radar reflector is often as strong a radar target as an entire sailboat.) One benefit from a radar reflector is that it overcomes the pulse cancellation effect of smooth seas, as long as you mount it high enough, because the radar target is no longer close to the surface. As a rule of thumb, mounting a radar reflector of the same RCS as the vessel hull 16 feet (5 meters) above the water overcomes the flat-sea pulse cancellation effect. With a good radar reflector, correctly mounted, the detection range table is applicable even in calm seas. A second benefit is that radar reflectors mitigate wave shadowing and improve detection reliability when the waves are about the same height as the target vessel's freeboard. A radar reflector mounted 16 feet above the waterline would be above the waves and would not be shadowed except in extreme conditions. A third benefit is extension of the radar horizon because the reflector is some distance above the waterline.

Unfortunately, nothing is free, and one must understand the second effect of pulse cancellation by smooth water. While the radar reflector generally increases the maximum range at which radar first detects you in smooth water, it also makes you invisible to radar in rather broad rings, or blind zones, around the radar scanner. However, since the blind zones are at ranges greater than the maximum detection range without a radar reflector, there is still a net improvement from mounting a radar reflector.

On balance, a radar reflector is a relatively inexpensive device that improves detection in many situations. In my opinion, every pleasure vessel should have one.

Radar Reflector

- **Improves detection in all conditions if it has larger RCS than the vessel it is mounted on**
- **Increases maximum detection range in calm seas, even if it's RCS is no larger than the vessel's**
- **Overcomes intermittent detection caused by waves shadowing the hull**
- **Extends the radar horizon**
- **Is invisible to radar in broad rings around the scanner in calm seas, depending on the heights of the scanner and radar reflector**