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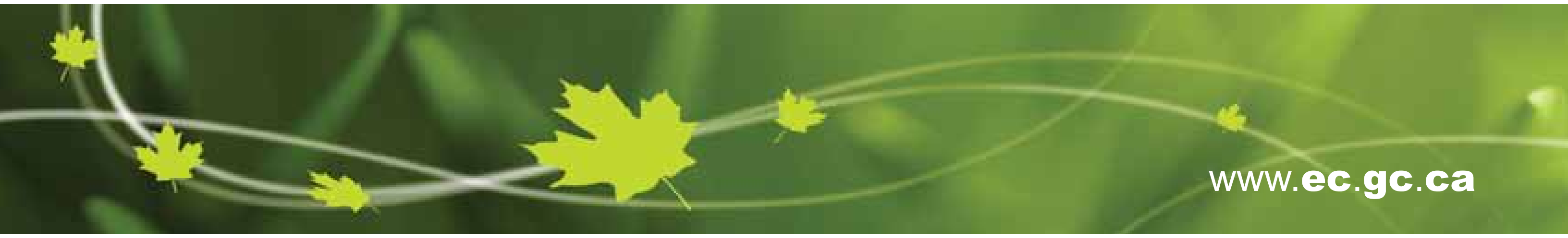

National Marine Weather Guide

Canada

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Foreword

The *National Marine Weather Guide* is intended to provide mariners of all levels of ability with practical information and advice on safe navigation on the wide range of weather conditions they may encounter while travelling in Canadian waters.

While it is not necessary to have prior knowledge of marine weather or local weather effects to use the Guide, readers are strongly encouraged to familiarize themselves with the contents of this chapter, which serves as a primer for the rest of the publication.

The Introduction explains the basics of how to read a weather map and interpret forecasts, provides an overview of the effects of physical geography on local weather conditions, and discusses the role of mariners in the forecast process. A section on marine meteorology explains basic meteorological concepts.

The Guide itself is divided into two sections: *Meteorology 101* and *Regional Weather*. The first section includes this chapter and five others focused on wind, sea state, fog, ice, and other hazardous weather. The second section offers detailed information on local weather conditions in the Atlantic, Pacific, Ontario, St. Lawrence/Quebec, Prairie, and Arctic regions.

The Guide is organized so that readers can pick and choose the topics of interest to them and integrate the information they need to adapt forecasts to their specific location. It can be easily printed—either in its entirety or in sections—and used as a reference on the water whenever the elements present a challenge.

A list of the main subjects in the Guide is provided in the table of contents, and a glossary of meteorological and oceanographic terms can be found in the appendices. Throughout the publication, readers will find a large number of web links to useful products, services, and sites available from Environment Canada (EC), Transport Canada (TC), and the Canadian Coast Guard (CCG). Before setting out, mariners are encouraged to obtain as much information as possible about the area in which they will be navigating.

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CHAPTER 1: MARINE METEOROLOGY PRIMER

1. Convention for Units of Measurement

Although it is standard practice for Canadian publications to use the International System of Units (SI)—more commonly known as the "metric system"—mariners traditionally use a mix of nautical and imperial units of measurement. To avoid redundancy, the following convention has been adopted for this Guide (a conversion table is provided in Appendix A):

- **Distance:** Nautical miles (NM) or miles (mi) for long distances; metres (m) for short distances (e.g., between waves)
- **Speed:** Nautical miles per hour or knots (kt)
- **Height and Width:** Kilometres (km) if at least 1 km (e.g., clouds, mountains, storms); metres (m) if 1 m or more but feet (ft.) if less than 1 m (e.g., waves)
- **Quantity or Thickness:** Centimetres (cm) or millimetres (mm) (e.g., rain, ice)
- **Rate of Accumulation:** Centimetres per hour (cm/h) or millimetres per hour (e.g., rainfall, vessel icing)
- **Atmospheric Pressure:** Millibars (mb)

2. Weather Maps

The weather map is to a meteorologist as the compass is to a mariner: a vital tool of the trade. Mariners, however, can also benefit greatly by understanding the basic elements of a weather map, which provides valuable information on the location, strength, and other characteristics of weather systems. The following is common weather-map terminology:

- **High-Pressure Centre:** An area where pressure decreases in all directions outward from the centre. Central pressure values are expressed in mb. High-pressure centres (also referred to as "highs") are often associated with fair weather.
- **Ridge:** An elongated region of higher pressure in which the pressure decreases in directions perpendicular to the ridge. Ridges, like highs, are also often associated with fair weather.
- **Low-Pressure Centre:** An area where pressure increases in all directions outward from the centre. Central pressure values are given in mb. Low-pressure centres (also known as "lows") are often associated with poor weather.
- **Trough:** An elongated region of lower pressure in which the pressure increases in directions perpendicular to the trough. Like lows, troughs are often associated with poor weather.
- **Isobars:** Lines joining areas of equal pressure, usually drawn at intervals of 4 mb. The closer they are together, the stronger the wind. Isobars can be thought of in the same way as contour lines on a relief map, with highs like hills and lows like bunkers. As their names suggest, troughs and ridges are also similar to their terrain-based namesakes.
- **Cold Front:** The leading edge of an advancing cold-air mass, which usually moves southeastward.
- **Warm Front:** The leading edge of an advancing warm-air mass (or the trailing edge of a retreating cold-air mass), which usually moves northeastward.
- **Wind-Speed Flags:** The shaft of the arrow indicates the direction the wind is blowing. The wind speed, given in kt, is represented by the number of barbs and/or flags on the shaft.
- **Stationary Front:** A front that has no discernible motion. Alternate cold- and warm-front symbols on opposite sides of the front indicate a lack of motion.
- **Occluded Front:** A front (warm or cold) that has occluded or pulled-away from its associated low-pressure centre. Alternate cold and warm front symbols on the same side of the front are used to designate the occlusion.
- **TROWAL (trough of warm air aloft):** A specific type of occlusion in which the warm sector has been completely displaced above the earth's surface. The "hooks" on the TROWAL point towards the warm air.
- **Upper Cold-Front:** A cold front in the upper atmosphere that does not reach the surface. Quite often, this carries the weather of a surface cold-front but not the wind shifts or pressure changes. It usually precedes a surface cold-front.
- **Upper Warm-Front:** A warm front in the upper atmosphere, not reaching the surface. Quite often, this carries the weather of a surface warm-front but not the wind shifts or pressure changes.

- **Frontogenesis:** The formation—or "genesis" stage—of a front.
- **Frontolysis:** The dying stage of a front.
- **Squall Line:** A continuous line of significant convective weather (usually thunderstorms) apart from a cold front.

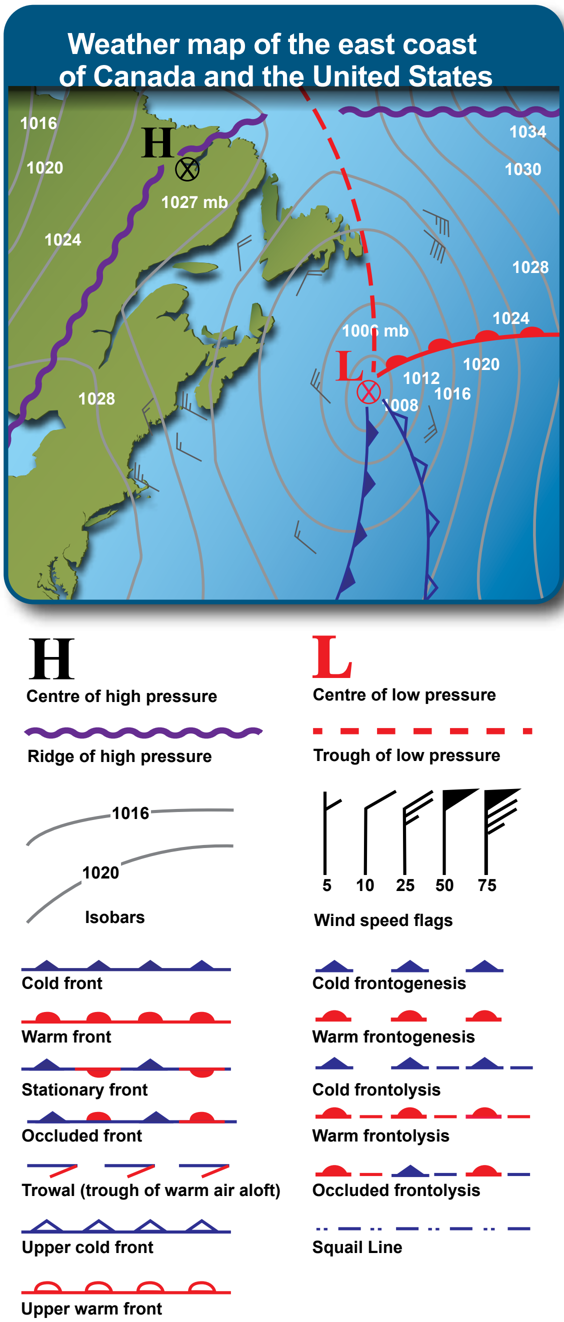


Figure 1a-1 – Weather map of the east coast of Canada and the United States. A high-pressure system onshore is indicated by a blue "H", with a wavy blue line indicating the ridge of high pressure. A low-pressure system offshore is indicated by a red "L", with a dotted red line showing the trough of low pressure and a red line with semicircles along the top indicating the warm front. A blue line with solid spiky waves indicates a cold front, while a blue line with spikes outlined in blue indicates an upper cold-front. Black circles with white numbers are isobars indicating pressure. Black lines with one to four diagonal lines coming out of the top on the right indicate different wind speeds, with more diagonal lines representing greater speeds.

Blue "H"	Centre of high pressure
Black curving lines with numbers	Isobars
Wavy horizontal blue line	Ridge of high pressure
Red "L"	Centre of low pressure
Red horizontal dashed line	Trough of low pressure
Vertical lines with barbs and/or flags coming out the top on the right. Each barb represents a speed of 10 knots, with half a barb representing 5 knots, and each flag represents a speed of 50 knots. Adding up the barbs and flags represents the wind speed.	Wind Speed Flags
Blue horizontal line with solid spiky waves	Cold front
Red horizontal line with round bumps	Warm front
Horizontal line alternating between blue line with a spiky wave on top and red line with a round bump on the bottom	Stationary front
Horizontal line alternating between blue line with a spiky wave on top and red line with a round bump on top	Occluded front
Repeating blue horizontal lines with a diagonal red line connected to the right	Trowal (tough of warm air aloft)
Blue horizontal line with spiky bumps outlined in blue.	Upper cold front
Red horizontal line with hollow red bumps	Upper warm front
Repeating blue spikes	Cold frontogenesis
Repeating red semi-circles	Warm frontogenesis
Alternating blue spike and short horizontal blue line	Cold frontolysis
Alternating red semi-circles and short red horizontal lines	Warm frontolysis
Alternating red semicircle followed by short red line and blue spike followed by short blue line	Occluded frontolysis
Two dots followed by a short black horizontal line, repeated	Squall line

Figure 1a-2 - Weather map symbols and what they represent.

3. Forecasting

3.1 Marine Weather Services

EC's regional weather offices produce a variety of forecasts and bulletins aimed at alerting and informing mariners of current and anticipated weather conditions in marine environments from coast to coast—24 hours a day, 365 days a year.

The data used to create these products come from many sources, including staffed and automated weather observing stations, offshore weather buoys, remote-sensing technologies such as satellites and radar, Automated Volunteer Observing Ships, and a network of volunteer weather observers.

In recent years, the way in which weather information has been disseminated has changed drastically, with traditional vehicles—such as EC's Weatheradio, the CCG's Marine Radio, AM/FM radio broadcasts, and alpha-numeric broadcasts—being bolstered by a growing number of new media.

Television programs and even entire networks are now devoted to the weather—and the Internet has made worldwide weather information available, at the click of a mouse, to anyone with a portable computer, notebook, or smart phone. As these and other new technologies become available, so too does the possibility of implementing more proactive methods of dissemination—such as enabling users to subscribe to instant cell-phone messaging for weather warnings and other products.

3.1.1 Forecasts and Bulletins

EC issues a variety of marine-related forecasts and bulletins including the following:

Regular marine forecasts are issued two to four times daily, depending on the region and program, and provide detailed weather information for the next 48 hours—including wind speed and direction, weather conditions and precipitation, visibility, freezing spray, and air temperature.

Extended marine forecasts provide a more general outlook of marine wind conditions, including speed and direction for the three days after the period covered by the regular marine forecast. They are issued twice daily.

Technical marine synopses are issued with and cover the same time period as regular marine forecasts. They provide a brief, generic description of major weather systems affecting the forecast area, as well as their latitude, longitude, and movement. In some locations, the potential for a storm surge is included when coastal water levels at least 2 ft. above normal are expected.

A ***marine weather statement*** is a non-scheduled bulletin issued at the forecaster's discretion to describe potentially high-impact marine weather conditions that are expected to occur beyond the period covered by the regular marine forecast.

Wave-height forecasts are prepared twice daily for most marine areas, and provide information on significant wave-heights for ocean waters at least 50 m deep. Great Lakes forecasts are issued for lake centres and where buoys are located. They are typically valid for 24 to 30 hours.

Ice forecasts are issued daily during the ice season and valid for 24-48 hours. They describe the coordinates of the ice edge, the total concentration of ice, the predominant stage of ice development, and the concentration of the oldest ice type.

Iceberg bulletins describe the furthest extent of icebergs in Canada's East Coast waters and, where applicable, the western limit in the Gulf of St. Lawrence. Their limit is given in latitude and longitude coordinates. General information on the number of known icebergs within each marine area is also provided.

MAFOR (Marine FORecasts) is a North American code used to compress meteorological and marine information for convenience during radio broadcasting. EC issues MAFOR-coded forecasts for the Great Lakes and the St. Lawrence and Saguenay Rivers that contain information on wind speed and direction, weather, visibility, and sea state.

NAVTEX (Navigational Telex) is an international, automated direct-printing service for the delivery of navigational and meteorological warnings and forecasts—and urgent marine safety information—to ships at sea. EC issues NAVTEX compatible forecast bulletins for select marine areas in the Pacific, Arctic, Great Lakes, St. Lawrence River, Gulf of St. Lawrence, and Atlantic Region.

Marine warnings and watches are issued when forecast conditions warrant, and are broadcast immediately by all participating radio stations. They include synoptic (larger-scale) warnings, which are included in the marine forecast bulletin; localized (smaller-scale) warnings and watches, which are issued in a special bulletin; and ice warnings, which are also issued in a special bulletin.

- **Synoptic warnings** are issued when potentially hazardous winds or freezing spray are expected to affect a significant part of a marine district or multiple marine districts. They cover the following conditions:
  - ***Strong winds*** (20-33 kt) (during recreational boating season only)
  - ***Gale-force winds*** (34-47 kt)
  - ***Storm-force winds*** (48-63 kt)
  - ***Hurricane-force winds*** (64 kt or higher)
  - ***Freezing Spray*** (moderate or higher)
- ***Localized warnings and watches*** are issued for potentially hazardous marine weather events affecting a localized area of the marine district. Both are issued for tornadoes,

squalls, and special weather-related phenomena, with warnings also issued for high water levels in coastal areas and watches for waterspouts.

- ***Ice warnings*** are issued when ice is expected to pose a potential hazard to vessels (e.g., due to strong ice pressure, rapid closing of coastal leads, or other unusual or significant ice events).

A ***hurricane or tropical storm statement*** is issued when a hurricane or tropical storm is expected to cause winds of gale force or higher in any marine area within 72 hours (and more frequently if the storm is forecast within 48 hours). Statements contain information on the location and movement of the storm and reported and forecast wind speeds.

More information can be found on EC's website under Marine Weather Forecasts and Marine Forecasts and Warnings for Canada.

3.1.2 Additional Resources

The CCG publishes monthly *Notices to Mariners* that include important information and amendments to marine charts and publications. These notices are free and can be obtained at Fisheries and Oceans Canada website.

The Canadian Hydrographic Service is the top source for information on nautical charts and tide and current tables. It publishes a number of guidebooks for boaters, including *Sailing Directions, Canadian Aids to Navigation System, Radio Aids to Marine Navigation*, *List of Lights*, and *Buoys and Fog Signals*.

3.2 Forecast Tailoring

The notion of an "accurate forecast" is intimately related to the needs of the particular user. To maximize the value of EC's forecasts, mariners must take into consideration constraints related to scale, timing, and format, and adapt the forecast to their own circumstances. This is known as "forecast tailoring" and is essential to ensure that boaters have a complete and accurate picture of the weather conditions they might encounter on any given day.

3.2.1 Scale

Meteorologists typically prepare what is known as a "synoptic" forecast, which covers designated marine areas up to a million square kilometres in size. Mariners, however, operate in much smaller areas and may experience significant weather differences over a distance of just a few kilometres.

Meteorologists refer to these local weather effects—which include such things as thunderstorms, sea breezes, and valley winds—as "mesoscale" effects. Other weather phenomena—such as steam devils and wind fluctuations across the bow of a boat—occur at an even smaller scale. Although these "microscale" effects can have major consequences, they are almost impossible to forecast.

Although efforts are made to include mesoscale effects in marine forecasts, mariners must adjust the synoptic-scale forecast to the mesoscale and even microscale by incorporating their own knowledge and experience of local weather conditions.

3.2.2 Timing

Meteorologists usually treat an entire marine forecast area as if it were a single point. For example, a forecast might refer to weather changes that will take place in the "afternoon"—an average time for the entire area. Knowing this, mariners can adjust the forecast to suit their location in the area. They should also be listening to forecasts for adjacent marine areas, as the weather may carry over from one area to another.

3.2.3 Format

To provide the most useful service to mariners, meteorologists must keep their weather forecasts brief. Providing detailed information on each and every change expected to occur would make forecasts too long and tedious—in particular, since many are still broadcast on the radio.

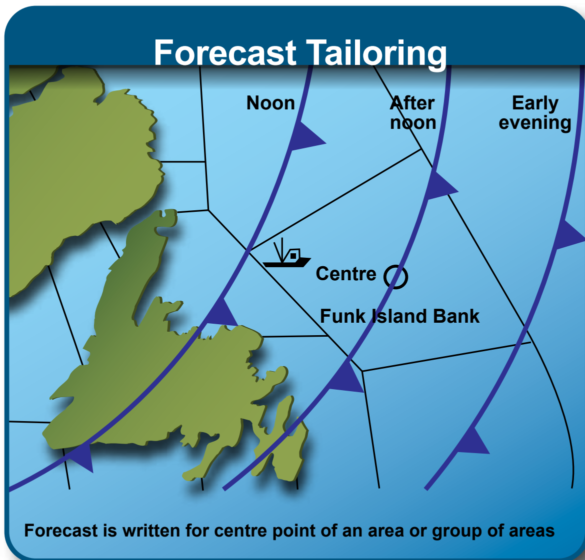


Figure 1b – In this example, a cold front in the Newfoundland marine area of Funk Island Bank is moving at such a speed that it enters the western tip of the area at noon and does not reach the easternmost edge until early evening. It is well known that significant wind changes take place along a cold front, so a mariner operating in the extreme western part of Funk Island Bank should expect the wind change to occur a bit sooner than forecast.

As such, meteorologists use "significant thresholds" or general descriptions of the average weather conditions expected. For example, wind direction is described in terms of only eight compass points, so boaters will hear of winds that are northerly or northeasterly but never north-northeasterly.

If, as another example, a low-pressure centre passing just north of a location was expected to cause winds to shift from easterly gales to southeasterly gales, to light southerlies, to strong southwesterlies—all within the next three hours—the forecast would simply talk about easterly gales veering to strong southwesterlies. A non-threatening wind event expected to last under three hours would likely not be mentioned at all.

Providing brief, generalized forecasts makes it easier for listeners to pick and choose the information they need to make sound decisions related to their navigational safety. It is important, however, for boaters to be aware of and account for more specific changes occurring at the local scale.

3.2.4 Marine Forecast Checklist

Boaters can use the following checklist to tailor forecasts to their situation:

✓ ***What is the present weather?***

- Listen to reports from along the planned route and keep a "weather-eye" open.

✓ ***What is the forecast trend: worse, the same, or better?***

- Consider how long you will be at sea.

✓ ***What marine warnings are in effect or forecast?***

- Interpret weather warnings as they apply to you:
  - Are forecast conditions beyond your capability or the limits of your vessel?
  - Will local effects create conditions beyond your capability or the limits of your vessel, even if no warnings are in effect?

✓ ***What is the weather summary?***

- Consider the location and forecast movement of fronts and pressure systems described in the synopsis.

✓ ***What forecast areas are important to you (e.g., where are you)?***

- Be sure you are listening to the right forecast.
- Listen to the forecast for adjacent areas.
- If you are near one end of a forecast area, you may need to adjust the time at which the weather will affect you, depending on where it's coming from.

✓ ***Where are you going?***

- Monitor reports and forecasts for all areas through which you are going to travel.

✓ ***Where is the weather coming from?***

- Listen to reports from areas where the significant weather is now.

✓ ***Are you offshore or near shore?***

- If you are offshore, the forecast may require only a few minor adjustments.
- If you are near shore, you may need to make your own, more significant adjustments to the forecast based on the features of the land.

3.3 Other Considerations

3.3.1 Topography and Bathymetry

Topography (the physical shape of the land) and bathymetry (the physical shape of the sea bed) can have a profound influence on both the general climate and the local weather along Canada's coastlines. The combination of rugged landscape and generally cold seas can produce some of the harshest marine weather conditions imaginable.

Winds are significantly affected by terrain. Mountainous areas in some parts of Canada produce katabatic winds and lee-wave effects that can cause gale- or even hurricane-force winds. Fjordic inlets and narrow bays can affect wind speed and direction through processes known as funneling and channeling.

Bold capes and prominent headlands are subject to cornering effects and wave refraction. The shape and depth of the sea bed, together with the shape of the adjacent coastline, can give rise to unusual tides, strong currents, shoaling, and treacherous tidal rips—all of which are made worse by opposing winds and seas.

The many freshwater rivers flowing into the ocean can create unpredictable wave and current effects. Freshwater discharges, along with the varying depth of ocean water throughout a region, affect water temperatures and sea ice cover.

More detailed information on the effects of topography on marine weather conditions is included in the individual chapters of this guide on Wind, Sea State, and Ice.

3.3.2 Wind

Wind is a unique and complex element that is extremely sensitive to the effects of terrain and can vary dramatically with even the tiniest changes in elevation. Unlike other elements, it is measured at different heights, over different surfaces (e.g., land and water), and using different instruments that may employ different averaging periods. As a result, wind observations may not give mariners a complete picture of the strength and potential of the wind.

How is sustained wind speed determined from observations?

Unlike temperature, there is no such thing as a "steady" wind. Because wind speed varies continuously, the "sustained wind" reported in forecasts is estimated by averaging wind observations over time.

Electronic anemometers typically measure wind speed once per second. For land-based weather stations, the sustained wind is a 2-minute average; for marine buoys, a 10-minute average. As a result, sustained wind-speed reports from a buoy will be lower than those from a nearby land-based weather station.

Anemometers located in the same area may also produce very different results because of variations in their respective averaging periods.

How are wind gusts determined?

A gust is a sudden, brief increase in the speed of the wind. Gusts are defined as the highest 5-second average of 1-second wind-speed observations.

Unlike regular forecasts, marine forecasts report only sustained winds—not gusts. There are ways, however, for mariners to estimate the potential speed of wind gusts by using information on the sustained wind speed.

The ratio of the gust to the sustained wind is known as the "gust factor". For example, if a weather station or buoy reports the wind as southeast at 20 kt gusting to 30 kt (SE20G30), the gust factor is 30/20 or 1.5. The gust factor varies with the season and is dependent on many other variables, including the stability of the air and the strength and direction of the wind.

Research has shown that over most bodies of water in summer, a sustained wind of 20-30 kt will usually have a gust factor of about 1.25. This means that mariners can safely add about 25 percent to the forecast of the sustained wind to get an idea of the gusts to be expected on the water.

When gusts are high, mariners can be certain that they will have to deal with even higher bursts of peak or instantaneous winds on the water. This is particularly critical to sailboats, because the force on the sail is a function of the square of the wind speed. As such, a doubling of wind speed actually quadruples the force on the sail.

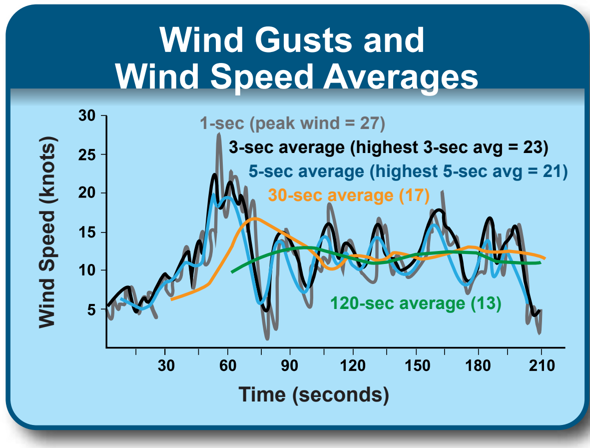


Figure 1c-1 – The dramatic smoothing that occurs when observations taken every second are averaged over periods of 3, 5, 30 and 120 seconds. In this example, the highest 2-minute average (13) is 50 percent of the instantaneous 1-second peak wind (27).

Figure 1c-2 – The force on a sail is a function of the square of the wind speed, making sudden bursts of wind on the water particularly dangerous for sailboats and sailboards.

How are buoy observations different?

Buoys may report significantly lower winds than nearby land-based weather stations or those experienced by mariners operating in the area. The main reason for this is that wind speeds are slower at the surface because of the effects of friction, but they increase rapidly as elevation increases.

Anemometers are typically mounted at 5 m above water level, while land-based anemometers are usually placed 10 m above ground. As such, buoys may potentially record much lower wind speeds than land instruments or those mounted on the mast of a nearby vessel.

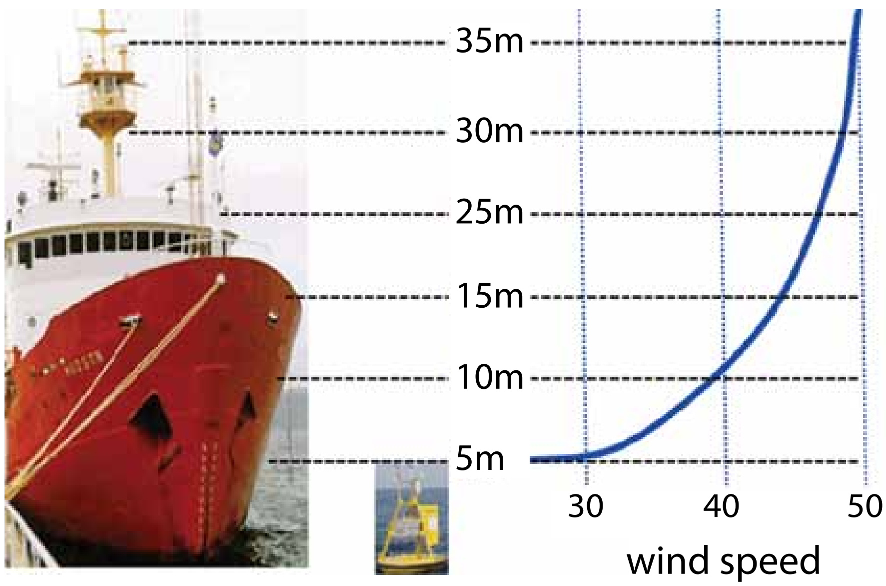


Figure 1c-3 – A buoy measuring the wind speed at 5 m above sea level may report speeds of 30 kt, while an anemometer mounted 35 m above sea level on a nearby vessel may report speeds of 50 kt—a difference of more than 60 percent.

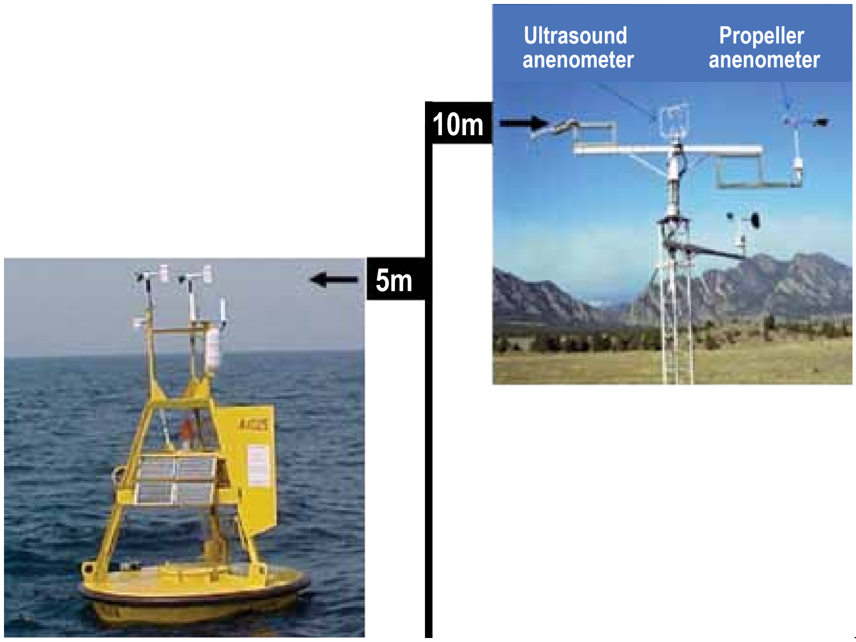


Figure 1c-4 – Differences in the height at which the instruments used to measure wind speed are placed affect the sustained winds reported in a particular area.

Buoys may also report lower wind speeds because they ride huge swells and waves during stormy weather. When a buoy "bottoms-out" in the trough between wave crests, the anemometer is somewhat protected by the waves and will record lower wind values than it would at the wave-crest. Because the weaker winds experienced in the trough are averaged with the stronger winds at the crest, the overall wind-speed values are lower.

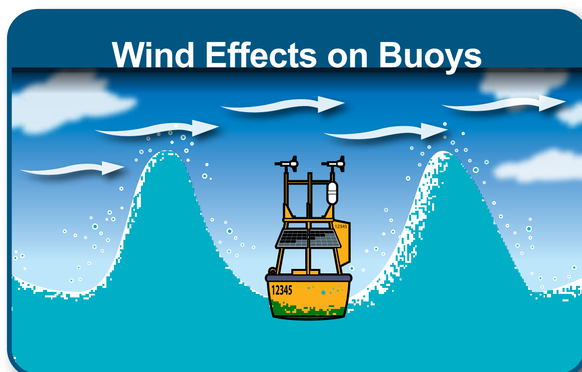


Figure 1c-5 – A buoy sheltered from the wind between two waves. Waves do not have to be as high as the buoy to affect wind measurement: even those half its height or less could result in lower wind speeds because of the frictional effects of wind off the surface.

Mariners' Tips

Wind directions given in the marine forecast are "true" (that is, referenced to the actual North Pole) as opposed to "magnetic" (that is, referenced to a compass heading). For example, in eastern Canada, a forecast westerly would be a true westerly or a magnetic southwesterly.

3.3.3 Waves

The sea state is mostly chaotic: a wild combination of swell from distant storms and wind-driven waves of various sizes. Like wind, waves are continuously changing, so some averaging must be done in order to measure them.

Sea state is typically described using the term "significant wave height" or "sig-wave", a value estimated by averaging the height of the highest one-third of the waves in the area. It is essential, in interpreting wave and sea-state forecasts, that mariners realize that the "peak" wave height expected to occur over a forecast period is twice the height of the sig-wave. Therefore, a forecast calling for "seas to build to 3-4 m" implies peak wave heights of 6-8 m.

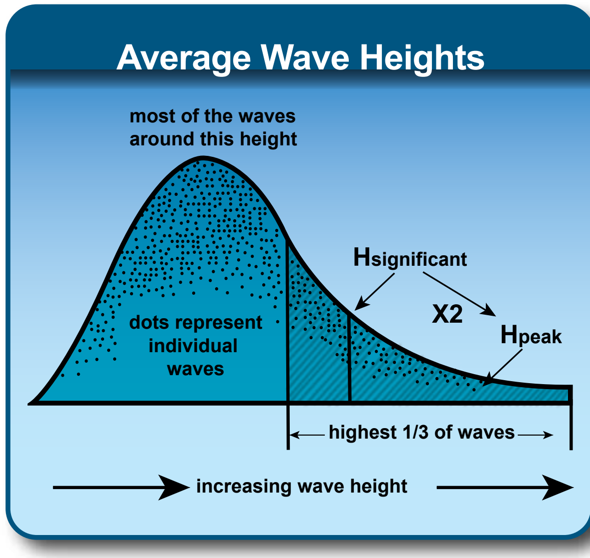


Figure 1d – The significant wave height (Hsignificant) of a large group of waves can be expressed as a mathematical distribution similar to a Bell Curve. Most of the wave heights in this group are clustered around the top of the curve. To the right, in darker grey, is the sub-group composing the highest one-third. Near the middle is the average of the highest one-third, or the Hsignificant. The largest wave (Hpeak) is represented by the furthest right dot.

According to models of wave distribution, about one wave in 10 will be the same height as the sig-wave, and about one in 1000 will be twice that height. For example, if the sig-wave is 5 m, one in 10 waves will be approximately 5m and one in 1000 will be approximately 10 m.

The time between peak waves can be estimated using the wave period, which is the time is takes for a wave to travel one wave length (that is, the distance between the crests of two waves). If the wave period is 6 seconds, it means that 10 waves will pass in one minute and 600 will pass in one hour. If peak waves occur every 1000 waves, a mariner might expect a peak wave roughly once every two hours.

4. Marine Safety

All small vessels are required to have and maintain safety equipment as specified in the *Small Vessel Regulations (2010 Edition)*. The regulations cover requirements for life jackets and personal flotation devices (PFDs), communications equipment and signaling devices, fire and detection equipment, and emergency first aid kits. Also included are requirements related to construction standards, equipment maintenance, and the safe operation of pleasure craft.

The *Vessel Certificates Regulations* may have additional equipment requirements, depending on the size of the vessel and its area of operation. The Marine Safety Directorate issues *Ship Safety Bulletins* to owners and operators of commercial vessels as updates become available.

Complete information about safety equipment can also be found in the *Safe Boating Guide* and the *Small Commercial Vessel Safety Guide*.

Life Jackets and PFDs

The *Small Vessel Regulations (2010 Edition)* and the *Ship Safety Bulletin: Wearing and Using Flotation Devices in Small Non-Pleasure Craft and Small Commercial Fishing Vessels 06/2012* require that all vessels carry an approved flotation device for each person on board and that it be properly sized for the person who will wear it.

Communication Equipment and Signaling Devices

Regardless of its size or where it operates, all vessels must carry some means of communication, such as a cellular or satellite phone or portable VHF radio if a regular radio is not fixed or mounted in the boat.

Marine Emergency First Aid Kits

First aid and survival kits must be in a waterproof case, with the inspection checklist inside the case, and equipped with a breakable seal. The contents of the survival kit are dependent on the type of the boating activities and the risks associated.

Onboard Marine Radar

Marine *radar* is an essential piece of equipment for any large boat. In crowded sea lanes, especially at night or in fog-bound situations, radar is an important tool for tracking the position of vessels and buoys and the proximity of land. It can also alert boaters to the approach of adverse weather. User manuals should be read thoroughly to understand equipment limitations and the possible effects of weather and topography on the quality of the signal.

5. Marine Meteorology

Marine meteorology is the study of weather that affects large bodies of water—including lakes, rivers, and oceans. While the science behind the forecasts may be daunting to some, having a basic understanding of marine meteorology is extremely useful when it comes to recognizing when and where hazardous weather might occur. This section is intended to give mariners an overview of the major forces that drive the weather, so they can better interpret forecasts and make informed decisions to ensure their safety on the water.

5.1 The Sun

The weather we experience draws its energy from one basic source: the sun. The sun heats the surface of the earth, which, in turn, heats the atmosphere from below.

This heating is uneven because different surfaces on the land and water absorb and reflect the sun's rays in different ways. For example, snow and ice reflect most of the sun's energy back into space, while oceans and forests absorb it. The lay of the land also has an effect on the angle at which the sun strikes the earth's surface: in the Northern Hemisphere, southern slopes receive more direct rays, while northern ones may be entirely in shade. The potential hours of sunshine in a deep valley may be greatly reduced by surrounding hills.

The amount of direct sunshine an area receives also varies by time of day, season, and latitude. Over the course of a day, the sun's rays strike the earth at different angles, with the intensity of direct sunshine greatest at "high noon" when they are vertical. In the morning and evening, when the sun is lower on the horizon, less heat is generated because the rays of the low-angled sun are spread out over a greater area.

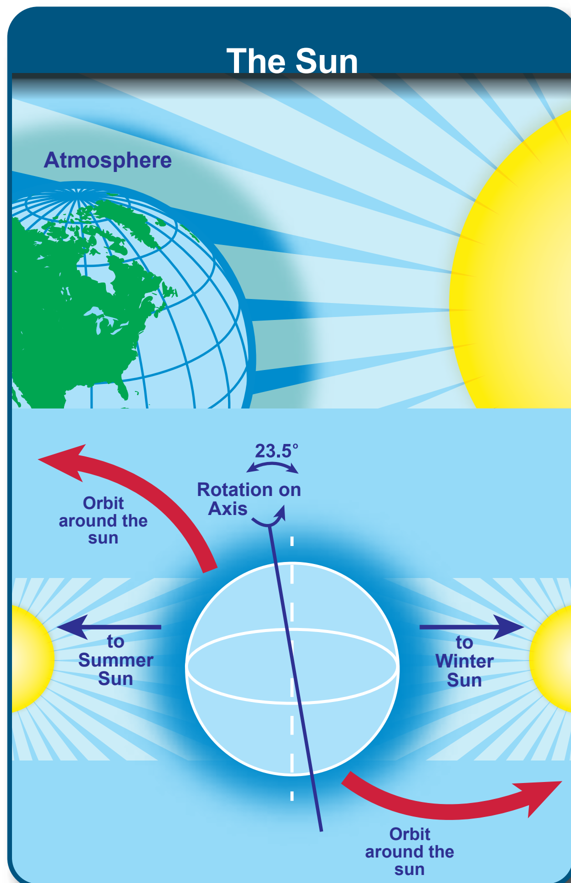


Figure 1e – Top image: The sun's rays strike the region near the equator directly but on an angle as they move toward the poles. Bottom image: In the summer, the Northern Hemisphere is tilted towards the sun; however, in the winter, it is tilted away.

Although the sun is closest to the earth in winter, other factors counteract its heating potential. In winter and at high latitudes, even the noon sun is at a low angle, while in summer and at low latitudes, it is almost directly overhead. As well, the earth's tilted axis means that it leans toward the summer sun and away from the winter sun.

The clearer the atmosphere, the more direct sunshine reaches the earth's surface. Dust, clouds, moisture, and certain gases all reflect, scatter, and absorb the sun's rays. The further they travel through the atmosphere, therefore, the more their heat is "filtered" out before it reaches the surface. This is evident at middle and high latitudes, where the sun's rays pass through the atmosphere at a lower angle—and therefore have to travel further—than they do in tropical latitudes. This effect also varies with the seasons, being greatest in winter when the sun's rays are lowest on the horizon and at a shallow angle to the higher latitudes.

Variations in the duration of sunlight due to latitude and season also have an effect, as the longer the period of sunlight, the greater the heating. At the equator, day and night are always equal in length—yet, in the Polar Regions, daylight lasts up to 24 hours in summer and zero in winter. At the summer solstice, when the sun is at its northernmost point, the North Pole region receives more hours of direct sunshine per day than anywhere else on earth, but most is reflected back into space by the ice- and snow-covered surfaces.

5.2 Air Masses

Even though air is made up of invisible gases, it still has weight. Colder air is denser or heavier than warmer air, so it exerts more pressure on the surface of the earth.

Air pressure is simply a measure of the weight of a column of air over a given area and is directly related to air temperature. The "hot" and "cold" spots around the world—caused by uneven heating from the sun—generally correspond to areas of low- and high-pressure.

An air mass is a large body of air that has a uniform temperature and moisture content. Air masses move around the earth trying to even out differences in temperature, usually from areas of higher pressure to areas of lower pressure. It is this motion that causes wind, which is covered in greater detail in Chapter 2, *Wind*.

From vicious hurricanes and pea-soup fogs to gentle sea breezes, all forms of weather are ultimately linked to differences in air pressure. For example, low-pressure centres travel thousands of miles to try and balance the difference in temperature between the North Pole and the equator, shunting warm air northward and allowing cold air to flood south.

Another important characteristic of air is that its temperature and moisture quickly conform to those of the surfaces over which it travels. When the earth's surface is heated by the sun, the air in immediate contact with the surface is also heated. If the earth's surface loses heat, the air also cools.

5.2.1 Lows and Troughs

When the lower layer of air near the surface of the earth is warmed, it becomes lighter and more buoyant than the air around it. As it begins to rise, and the pressure caused by its weight decreases, it creates an area of low pressure known as a "low".

This rising action causes a deficit of air near the surface, and the surrounding air rushes in to fill the void. If the air warms (and therefore rises) quickly, so too will the air that takes its place, creating wind. If the central pressure drops, the pressure pattern strengthens and the system intensifies. If, on the other hand, it starts to rise and the pressure pattern weakens, the low is said to be "filling".

Lows vary in intensity but are usually systems that create cloudy skies, precipitation, and wind. Generally speaking, the deeper the low, the worse the weather associated with it. A trough is an elongated region of lower pressure that also usually brings unsettled weather and strong, sharp wind shifts. Troughs on a weather map are like valleys on a contoured relief map, while lows are like dugouts or bunkers.

5.2.2 Highs and Ridges

As low-level air is cooled by various mechanisms, it becomes denser and heavier than the air around it. This causes it to sink and become denser, its added weight on the surface creating an area of high pressure known as a "high".

As the heavy air builds up at the surface, it spreads outward and moves away from the area. High-pressure centres typically begin as a "stagnant" air mass that remains over a region for an extended period of time. These systems tend to be weak and slow moving, with light winds near the centre and the weather usually quiet, dry, and settled. The generally cloudless skies associated with highs, however, do make fog or frost more likely (see Chapter 4, *Fog*).

Highs build if the pressure within them rises and weaken if it falls. A ridge is an elongated region of higher pressure that is also generally associated with fair weather and usually has light winds along its axis. Pressure ridges on a weather map are like ridges on a contoured relief map, while highs are like hills.

5.3 Fronts

Sometimes, when air masses crowd each other, the boundary between them closes up—and what started as a gradual temperature difference spread out over a very large distance becomes compacted into a narrow band only hundreds or even tens of kilometres in width.

This elastic, ever-changing barrier—which separates heavy, colder air on one side and lighter, warmer air on the other—is called a "front". A cold front occurs when the air on the cold side is advancing and the warm air is retreating; a warm front, when the opposite is occurring. When neither air mass is strong enough to replace the other, this boundary is referred to as a "stationary front" because it tends to stay in the same area for a long time.

At the edge of all fronts, the constant clash between cold and warm air creates unique weather conditions. The difference in conditions between one side of the front and the other may be gradual or abrupt, depending on the contrast in temperature and moisture.

A wide variety of weather can be found along a stationary front, but clouds and precipitation are common and can persist for long periods of time.

5.3.1 Cold Fronts

A cold front is like an advancing wedge of cold air, with the thin edge of the wedge arriving first. A cold front's slope is usually steep, causing sudden and sometimes severe weather. Since a cold front slopes away from the direction it is travelling, there is little notice before it arrives.

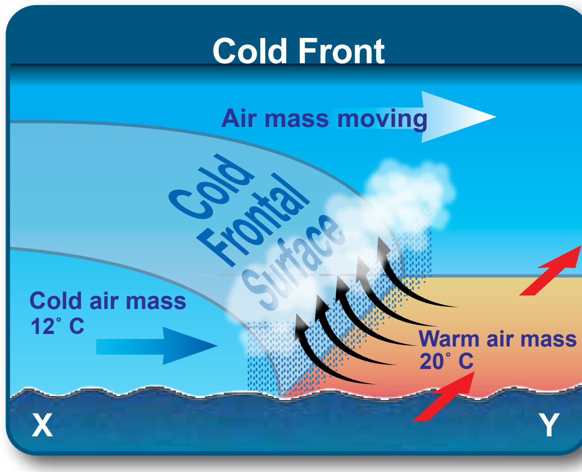


Figure 1f – Cross-section of a cold front. A cold air mass moves into a warm air mass, pushing the warm air upwards. The boundary between the cold air and the warm air is called the cold frontal surface. As the warm air rises along the front of this surface, it forms clouds and rain. In this example, the warm air ahead of the warm front is moving in a different direction, so there will be a significant shift in the wind.

TYPICAL SEQUENCE OF WEATHER WITH A COLD FRONT			
	Front Approaching	As It Passes	Behind Cold Air
Wind	backs and increases close to front	sudden veer and often includes gusts or squalls	can back slightly, then steady its direction
Cloud	stratus and stratocumulus thickening to nimbostratus	towering cumulus and/or cumulonimbus	often total clearance; cumulus develops
Rain	heavy rain near front	heavy rain, perhaps hail and thunder	usually fine for an hour or two, then showers
Visibility	moderate or poor, perhaps fog	poor in rain	very good
Pressure	falls near front	rises suddenly	rise gradually levels off
Dewpoint	little change	falls suddenly	little change

5.3.2 Warm Fronts

Warm fronts slope in the direction they are moving, with the highest part arriving first and the lowest (nearest the ground) arriving last. As the warm airovertakes the colder air, it begins a long, steady climb up and over it.

The wispy cirrus clouds (or "mares' tails") at the top of the slope are the first sign that a warm front is approaching, and provide advance warning that the base of the front is on its way but still a good way off. The slope of a warm front is usually much shallower than that of a cold front, extending as much as several hundred kilometres and bringing continuous precipitation for up to 24 hours.

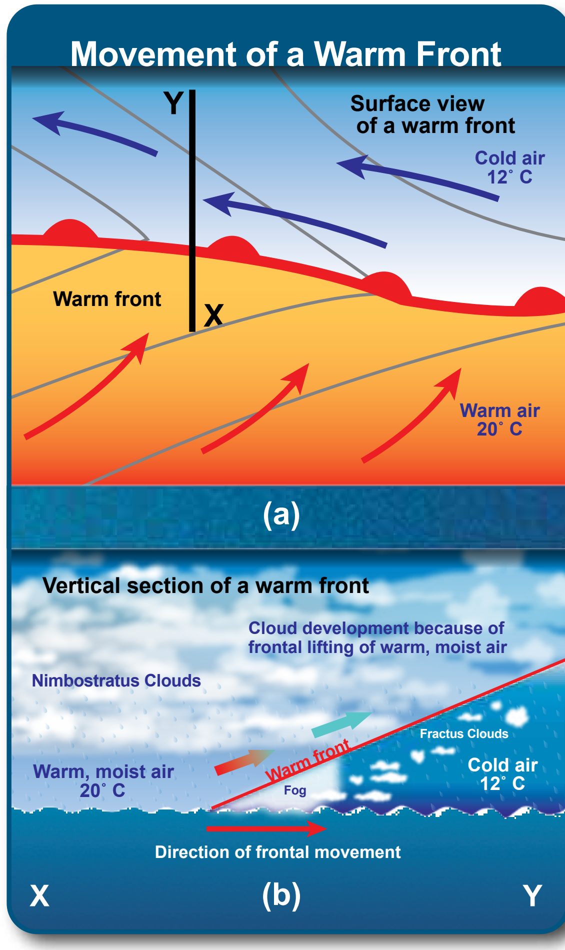


Figure 1g – Two different views of a warm front, both moving from x to y. A long, large cloud is present along the length of the front, and rain is falling along much of the back end.

TYPICAL SEQUENCE OF WEATHER WITH A WARM FRONT			
	Front Approaching	As It Passes	Behind Cold Air
Wind	increases and often backs	veers	direction steady
Cloud	sequence of: cirrus, cirrostratus, altostratus, nimbostratus, stratus	nimbostratus	stratus, stratocumulus
Rain	becomes heavier and more continuous	stops or turns to drizzle	occasional drizzle or light rain
Visibility	deteriorates slowly as rain gets heavier	deteriorates	moderate or poor, fog likely
Pressure	falls at increasing rate	stops falling	falls if low centre deepening, otherwise steady
Dewpoint	little change	rises	little change

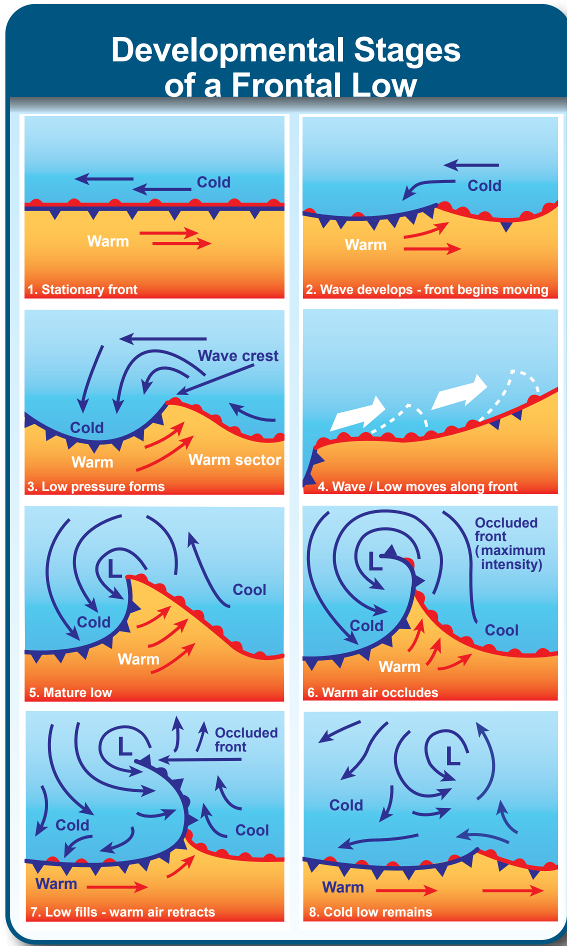


Figure 1h – The different stages of development of a frontal low.

Mariners' Tips

"Smelling" a change in the weather is a valid part of observing it. The high pressure that usually accompanies fair weather tends to keep scents and odours dormant. When it is replaced by a low-pressure system, these scents are gently released, telling our noses that a storm is coming.

5.3.4 TROWALs and Upper Cold Fronts

A TROWAL (trough of warm air aloft) is a frontal structure that forms during the occlusion process of a frontal low. The warm air lifts out of the low and away from the surface. When this happens and the warm air is forced aloft, it results in a "trough" in the warm air overhead.

In recent years, satellite imagery and upper atmosphere studies have shown that upper cold fronts were often identified as TROWALs in the past. The distinction between the two is significant, however, as TROWALs indicate a system that is beginning to die, while upper cold fronts have quite different implications.

An upper cold front, pushed by higher winds aloft, moves well ahead of the surface cold front, carrying most of the significant weather with it. Meanwhile, the surface cold front, still lying in a trough of low pressure, has the usual wind shifts and pressure changes expected by the mariner.

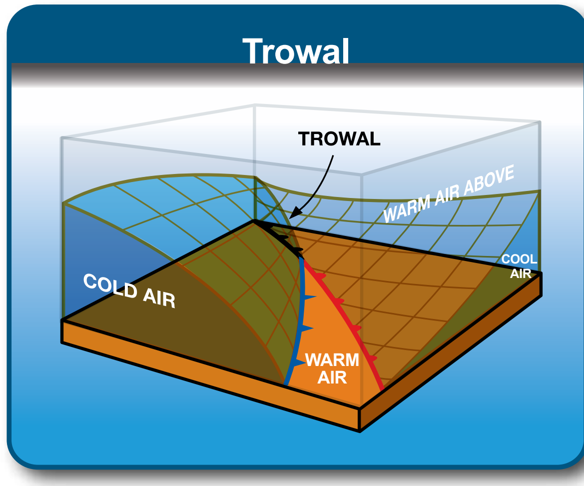


Figure 1i – With warm air aloft, a convex wedge of cold air is separated from a concave wedge of cool air by a trough of warm air at the surface. The convex wedge of air is being led by a cold front, while the trough of warm air is being led by a warm front. Where the two fronts (and the two old air masses) meet, is a TROWAL.

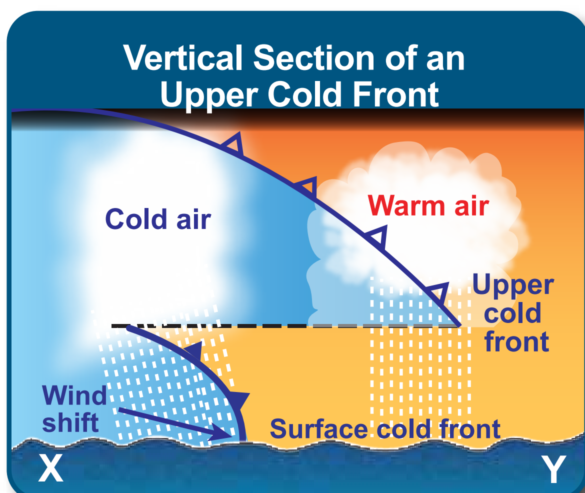


Figure 1i-2 – A wedge of cold air (moving from x to y) curves up and back from the surface, creating the surface cold front. It then extends out horizontally, past the surface cold front, curving up and back again to create the upper cold front. As the upper cold front meets warm air, it creates clouds and rain well ahead of the surface cold front.

5.3.5 The Conveyor-Belt Model

The "conveyor-belt" model, while oversimplified, is another way of looking at mid-latitude lows. It is based on the concept that air flows through lows on three main airstreams or "conveyor belts": a warm conveyor belt, a cold conveyor belt, and a dry airstream. The model was developed by studying slow-moving frontal lows that had undergone little development; it should be noted that airflows in rapidly deepening lows are much more complex.

Warm Conveyor Belt

The warm conveyor belt consists of air that originates in the south and moves northward. It rises and becomes saturated with moisture near or north of the warm front, then continues rising until it joins the upper-level westerlies (the upper prevailing winds) northeast of the low-pressure centre.

Cold Conveyor Belt

North of the warm front, the air flow relative to the low's motion is from the east. Much of the air on the cold side of the warm front flows towards the region north of the low. This stream of air, called the cold conveyor belt, originates from the descending air in an earlier high-pressure system to the north.

Air in the cold conveyor belt flows westward beneath the warm conveyor belt, drawing moisture from the precipitation falling out of the warm air. The cold air then ascends as it turns around the low centre until it also joins the westerlies at upper levels.

Dry Air Stream

The dry air stream originates at upper levels (10 km) to the west of the low centre. Some of this air moves eastward and subsides, reaching the surface behind the cold front.

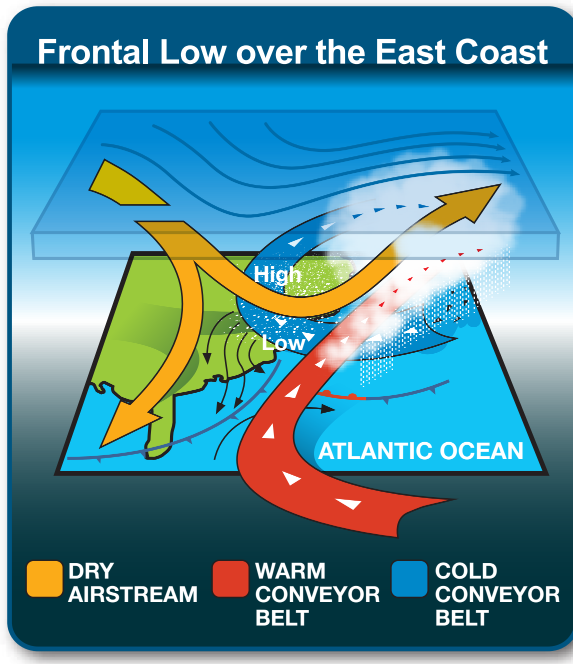
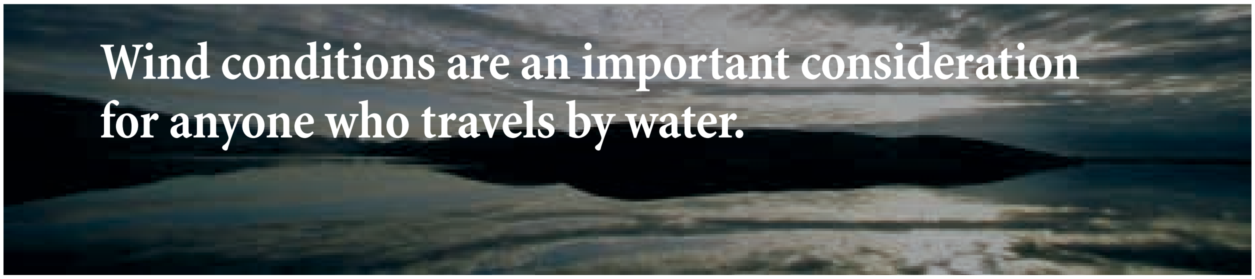


Figure 1j – A frontal low over the eastern coast of the United States. A warm conveyor belt of air from the south rises up to 10 km and into a large cloud above a low. A cold easterly conveyor belt of wind turns clockwise, curving upward to join the cloud. A dry airstream flows from the northwest, descends, and splits to the south and the east, the eastern stream also rising up to join the cloud. At 10 km, winds are blowing to the east; near the surface, winds are turning clockwise around the low on the coast, where there is snow. Further north, there is a high over the land, and there is rain on the eastern side of the cloud, over the Atlantic Ocean.

CHAPTER 2: WIND



1. Introduction

Wind conditions are an important consideration for anyone who travels by water. Vessels of all types and sizes – from canoes and sailboats to fishing boats and cruise ships – are affected by the wind to different degrees.

Strong, gusty winds can force boats off course or into hazards, such as rocks, shoals, or the shoreline. They can also cause high, choppy waves that can make boats difficult to handle or, in extreme cases, swamp or capsize them. Strong winds and rough water from winds accounted for over 40 percent of recreational boating deaths by drowning and hypothermia in Canada between 1991 and 2008.[1]

Weather maps can be used to help determine the prevailing wind direction on a large scale. On a local scale, however, differences in the stability of the atmosphere and the physical qualities of the earth's surface have a major impact on the speed and direction of the wind.

A clear understanding of these effects can help a mariner better prepare for the day's winds by taking into consideration both the prevailing wind direction and the local conditions. This chapter explains how different wind conditions form, the hazards associated with them, and tips for mariners on how to deal with them as safely as possible. For information on how to interpret wind information on a weather map, please see Chapter 1.

2. How Wind is Formed

Air near the earth's surface is heated or cooled by the land and water below it. Where the surface is warmer, it heats the overlying air, causing it to rise. Warm air rises because it is less dense – and therefore lighter – than cold air. The rising air creates a lack of air pressure in the area, called a "low". Where the surface is cooler, it cools the overlying air, causing it to sink. This creates an excess of air pressure, called a "high".

This differential heating of the earth's surface and the resulting system of high and low pressures can form on a global scale as well as a local one.

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[1] Transport Canada and the Canadian Red Cross Society. *Boating Immersion and Trauma Deaths in Canada: 18 Years of Research (1991-2006)*, 2010.

Wind is the term for moving air. It is created when air in a higher pressure area flows into an area of lower pressure to take the place of the air that is rising away. This restores balance to the system. An easy way to understand this is to imagine the atmosphere as a bucket of water: if a scoop of water is taken away (creating a low), the surrounding water (a high) rushes in to replace it.

The more difference there is in pressure between two areas, the more forcefully the air will flow between them – and the stronger the wind will blow.

If the earth did not turn, this pressure gradient force would cause air to flow directly from a high-pressure area to a low-pressure area. Since the earth does turn, another force – called the Coriolis force – causes the air to turn as well.

In the northern hemisphere, the wind around a high turns clockwise and the wind around a low turns counter-clockwise. The opposite is true in the southern hemisphere. When the effects of the pressure gradient force and the Coriolis force combine, the result is called the "geostrophic" wind.

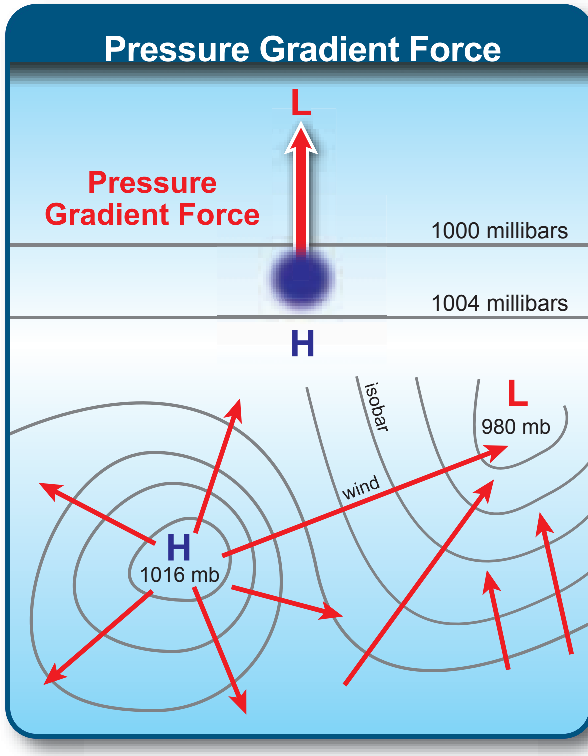


Figure 2a – Under the effect of the pressure gradient force alone, wind would flow from an area of high pressure directly to an area of low pressure.

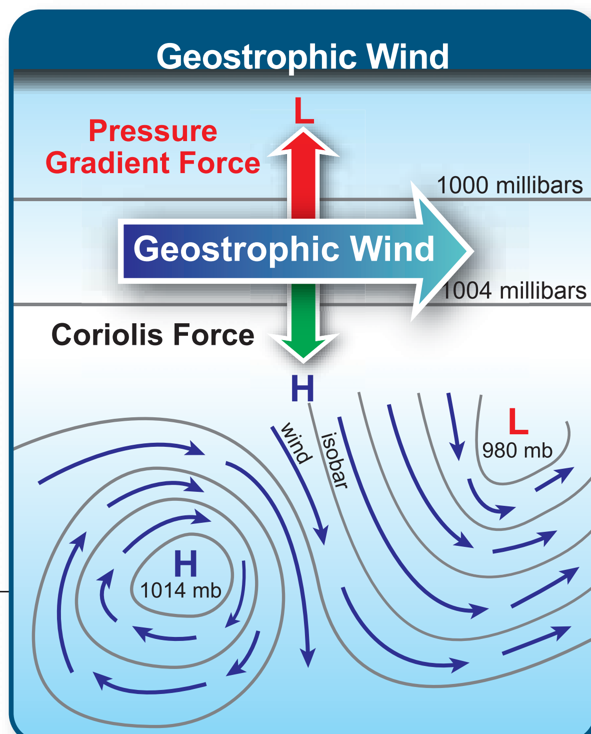


Figure 2b – The geostrophic wind is the combined effect of the pressure gradient force and the Coriolis Force, which causes air flowing around areas of high and low pressure to turn in opposite directions.

When the wind flowing around highs and lows comes in contact with the surface of the earth, friction causes it to slow down and shift slightly counter-clockwise. This allows the wind to blow slightly from areas of high pressure to areas of low pressure. It is important to remember that different surfaces have different levels of friction. Wind over water experiences less drag than it does over land, so it maintains more speed and shifts only 15 to 20 degrees. Wind over land, on the other hand, can change direction by as much as 30 to 40 degrees.

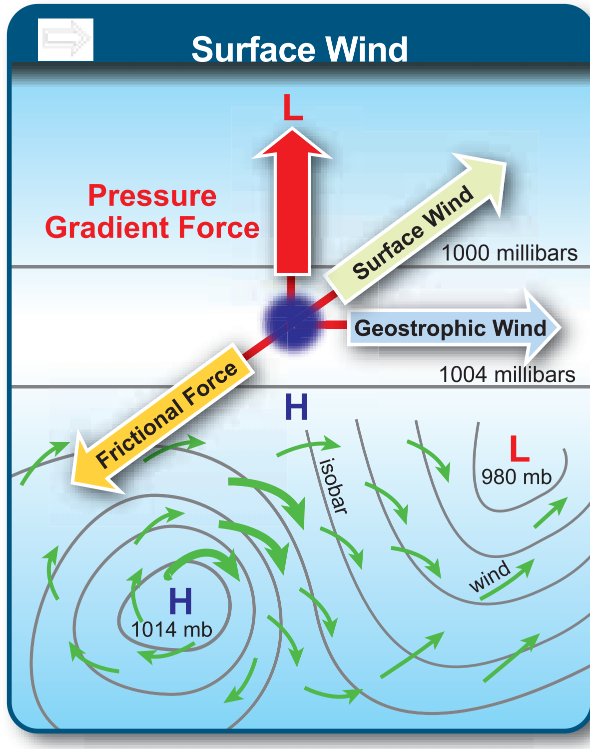


Figure 2c – The speed and direction of the surface wind depends on how the geostrophic wind is affected by friction from the earth's surface.

3. Effects of Atmospheric Stability on Wind

As explained in Chapter 1, atmospheric stability is a measure of whether the atmospheric conditions in an area make it harder or easier for air to rise and fall. A stable atmosphere makes this upward and downward motion more difficult, while an unstable atmosphere encourages it. Atmospheric stability can be the same over a large area or isolated to a small, protected area. This is an important factor to take into account when determining wind speeds.

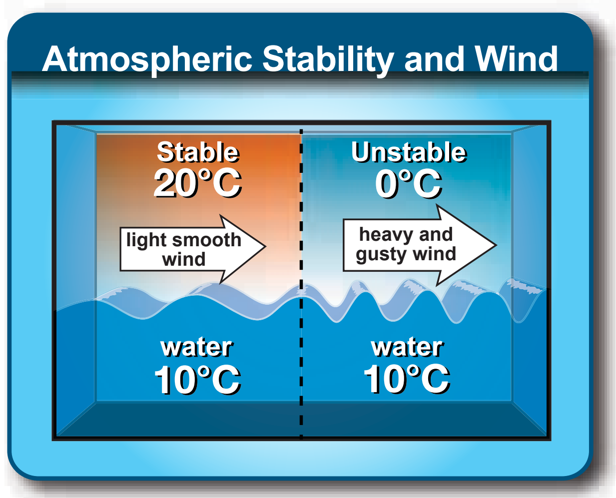


Figure 2d-1 – Whether the atmosphere makes it harder (stable) or easier (unstable) for air to rise and fall also has a significant effect on wind.

3.1 Stable Atmosphere

When a parcel of air cools faster than the surrounding atmosphere, it is not able to rise because it is heavier than the air around it. The atmosphere is "stable" because it is experiencing little or no vertical movement.

How does a stable atmosphere affect wind?

Stable conditions mean winds are generally lighter and less gusty. A stable atmosphere over water can create cool, calm conditions throughout the day, even if it is windy over the land nearby.

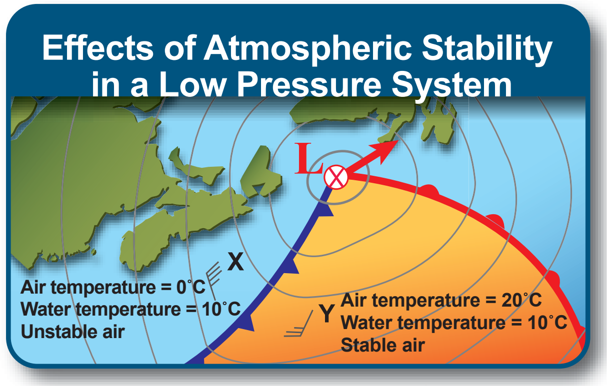


Figure 2d-2 – Although the whole area on this map is under a low-pressure system, the air over X is much cooler than the water below it and the air over Y is much warmer. This creates unstable atmospheric conditions and stronger winds (illustrated by the line of pointed wind barbs) over X and a stable atmosphere and more predictable winds (illustrated by the line of rounded wind barbs) over Y.

Mariners' Tips

The presence of small, puffy clouds on a fair day is a good sign that the atmosphere is stable. The clouds cannot rise because they are blocked by a layer of warm air.

For the same reason, if smoke rising from a chimney or industrial smoke stack on a calm day has a sharp cut-off point where it spreads out horizontally instead of rising further, the atmosphere is stable.

If the atmosphere is stable and there are no other factors at play, winds should be about the same as or lower than they would appear on a weather map (see Chapter 1, section on How to Read a Weather Map).

3.2 Unstable Atmosphere

When a parcel of air cools more slowly than the surrounding atmosphere, it will continue to rise because it is lighter than the air around it. The atmosphere is "unstable" because it is experiencing vertical movement.

How does an unstable atmosphere affect wind?

When the atmosphere is unstable, warmer air at the surface rises and draws down some of the cold, windy air from higher in the atmosphere. This causes gusty

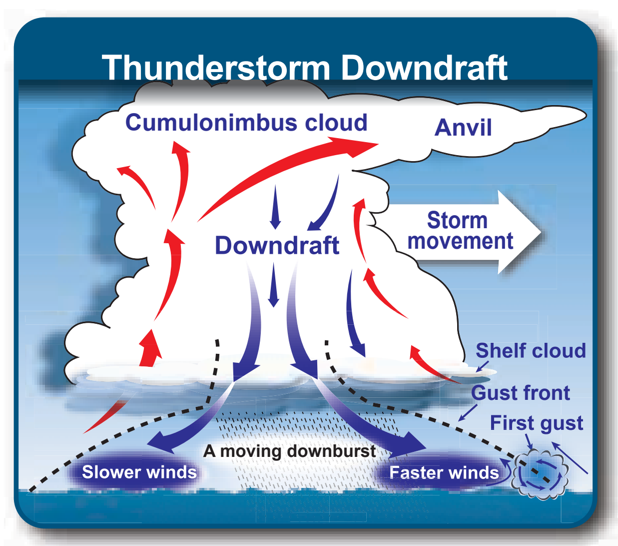


Figure 2e-1 – Thunderstorm downdrafts create stronger winds well ahead of a storm front and slower ones in its wake.

winds that can vary suddenly in speed and direction. If the air rises rapidly, large towering clouds, showers, or even thunderstorms may develop.

When rain or hail from a thunderstorm cloud falls through dry air and evaporates, it cools the surrounding air. The cool air drops quickly to the surface of the earth and spreads out, an effect known as a "thunderstorm downdraft" or "gust front". This can cause sudden shifts in wind speed and direction, a drop in temperature, and heavy precipitation—sometimes several kilometres ahead of an advancing storm.

Mariners' Tips

A sky heaped with towering dark clouds is a sign that the air is rising rapidly and the atmosphere is unstable. It can also mean that a powerful thunderstorm is approaching.

A gust front is often marked by the appearance of a low, horizontal, wedge-shaped cloud, called a "shelf cloud", on the front of an approaching thundercloud.

Figure 2e-2 – A shelf cloud is an indication that a gust front is approaching.

4. Nearshore Effects on Wind

Near the coastline and on lakes, winds are greatly affected by local factors. These include differences in the way the sun heats the land and water and in the physical features of the land itself. When winds interact with these factors, they can change drastically from what mariners might expect based on weather maps alone.

4.1 Solar Heating

Not all parts of the earth's surface heat up and cool down at the same rate. Heat from the sun is absorbed and released faster by some surfaces than others. For example, land warms more quickly than water, but water holds its heat longer.

Solar heating also depends on the location of the site, its exposure to the sun, the season, and the time of day. In mountains and valleys, for example, some areas are cooler because they are in the shade for much of the day.

This differential heating creates a small-scale system of highs and lows that alters the direction of the prevailing wind.

4.1.1 Sea Breeze

A sea breeze is a cool wind that blows onshore: that is, from the sea or any other large body of water toward the land. It usually starts in the morning and can intensify over the course of the day. Sea breezes are typically felt up to eight kilometres offshore but can reach as far as 30 kilometres. They are stronger off east- or south-facing shorelines, which receive more direct sunlight.

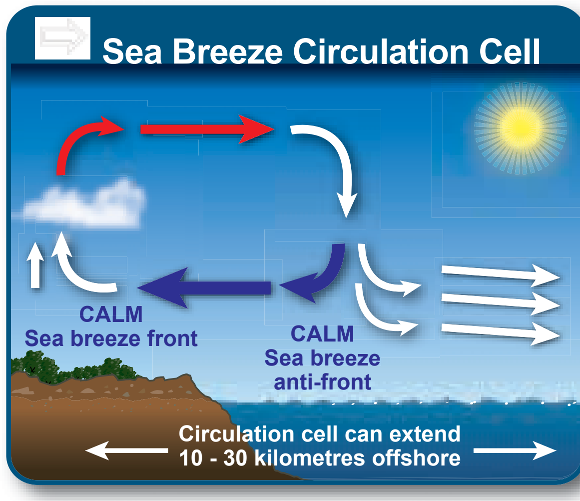


Figure 2f-1 – A sea breeze circulation cell forms when warm air over the land rises and flows out over the water. As the air cools, it sinks and flows back onshore to take the place of the rising air.

How is a sea breeze formed?

Sea breezes form when the prevailing winds are relatively light (usually around 15 knots) and the cloud cover is less than 50 percent. They typically start in the morning as the heat from the sun causes the land to warm up at a faster rate than the water. This creates a "low" over the land and a "high" over the water, which causes cool air from the sea to flow inland to replace the warm air that is rising and flowing out to sea. This circulation pattern strengthens over the course of the day as the temperature difference between the land and water increases. As the day progresses, wind speed increases and wind direction shifts clockwise 50 to 60 degrees.

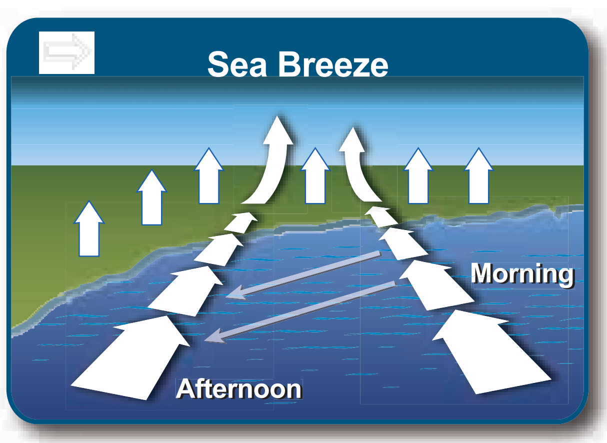


Figure 2f-2 – As the day progresses, the sea breeze shifts direction clockwise.

Winds are usually light beyond the outer edge of the sea breeze, where the warm air flowing out to sea cools and falls to the surface of the water. This area of calm – called the sea breeze anti-front – moves further offshore as the circulation strengthens. Sea breezes typically die out or weaken substantially an hour before sunset.

How are sea breezes affected by irregular coastlines?

Sea breezes that blow near an irregular coastline with a number of bays and islands behave differently than they do elsewhere and can pose a challenge to mariners.

In the morning, air flows from the water toward the land wherever the two touch. This can create strange breezes around islands and cause the winds in a bay to blow in several different directions.

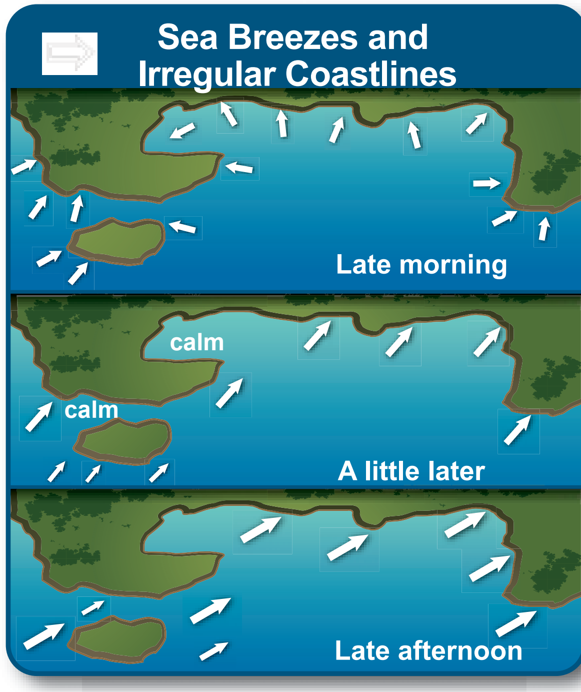


Figure 2f-3 – Sea breezes blow in different directions along an irregular coastline depending on the time of day.

As the day progresses, sea breezes start to blow as if the coastline is straight: that is, more directly inland. This creates calm conditions in areas hidden behind an island or protected by a spit of land. In the late afternoon, when the wind has sped up and shifted direction, areas that were calm will experience the same conditions as their neighbours.

What hazards are associated with sea breezes?

Sea breezes can create winds of 10 to 15 knots near shore. Wind speeds can be even higher if the prevailing winds are blowing the same direction or the physical features of the shoreline have a funnelling effect (see Section 4.2.2). If a sea breeze blows a fog bank toward shore, navigation can be hazardous.

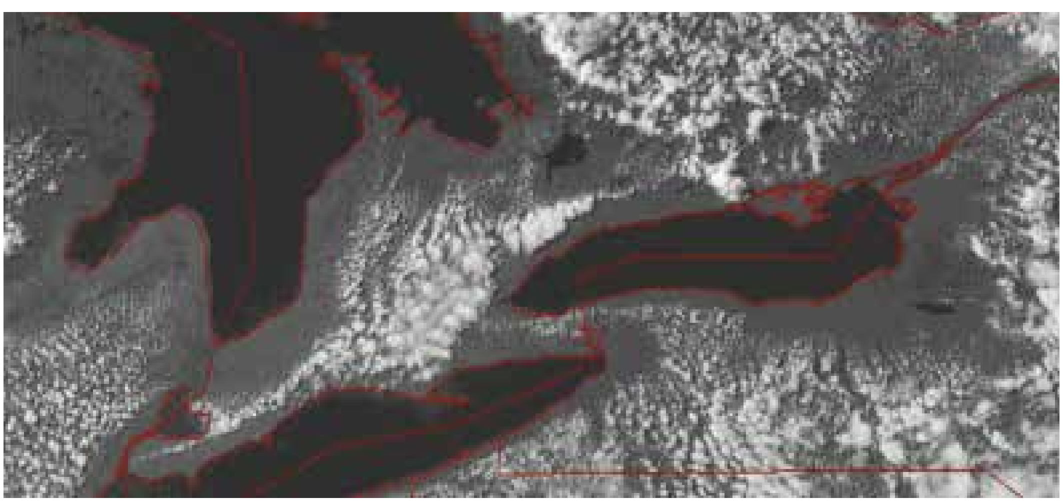


Figure 2f-4 – Cloud formation over the Great Lakes during a well-established sea breeze.

Mariners' Tips

Sea breezes can often be detected as a line of clouds over the coastline or a line of low clouds, just offshore, that dissolves quickly. Other signs include sudden calm winds or irregular bursts of wind, a sudden drop in temperature, and a sky that clears faster than usual.

4.1.2 Land Breeze

A land breeze is the reverse of a sea breeze, in that it blows offshore—from the land towards the sea or any other large body of water. Land breezes are generally weaker and less frequent than sea breezes but can still cause gusty wind conditions for boaters.

How is a land breeze formed?

Land breezes form at night or during the day in colder seasons when the temperature of the air at the surface of the land drops lower than the temperature of the air at the surface of the water. They can also form when the shore has been in shadow most of the day and is colder than the water.

These temperature differences occur because land not only warms up faster than water but also cools down faster. Water, on the other hand, holds its heat longer.

The cooler air over the land creates a high-pressure area, while the warmer air over the water creates an area of low pressure. If the prevailing winds are not strong enough to oppose it, a circulation pattern will be set in motion in which the cool air from the land blows offshore to take the place of the warmer air rising over the water. Land breezes die out once the sun returns and the land warms up again.

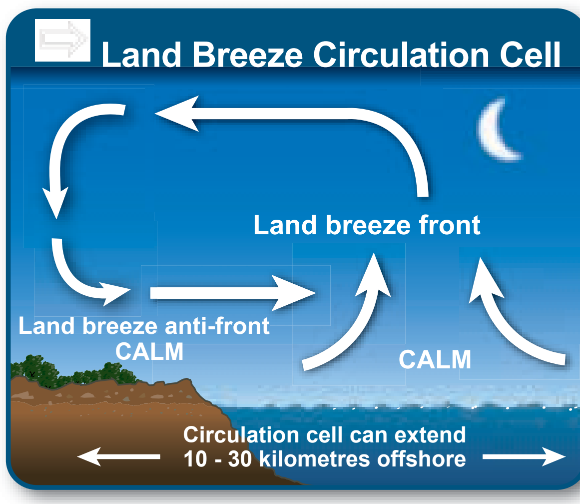


Figure 2g-1 – A land breeze circulation cell is formed when warm air over the water rises and flows over the land. As the air cools, it sinks and flows out toward the sea to replace the rising air.

How do similar conditions occur at ice edges?

Sea ice and open water can create circulation patterns similar to a land breeze. In this case, the colder air over the sea ice rushes out toward the open water to take the place of the warmer air rising from the ocean. This creates strong, gusty winds over the open water.

What hazards are associated with land breezes?

Although land breezes are usually weaker than sea breezes, they are still very gusty – particularly when they are in full force. They can be even stronger if the prevailing winds are blowing in the same direction or the physical features of the shoreline have a funnelling effect (see Section 4.2.2). If there is enough moisture in the air and the atmosphere is unstable, land breezes can also cause showers or thunderstorms over the water.

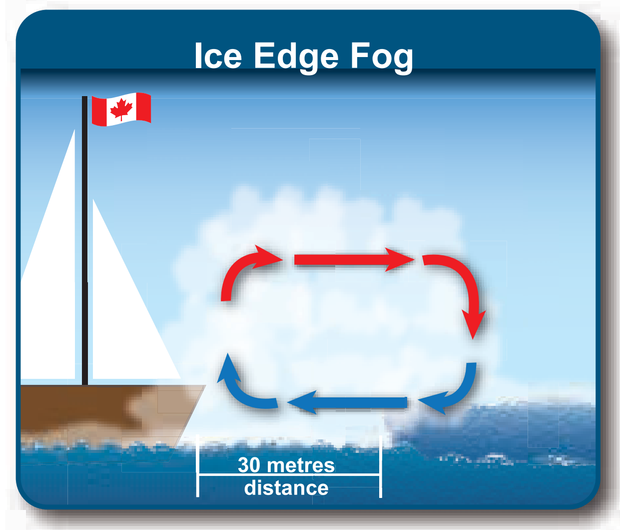


Figure 2g-2 – In calm prevailing wind conditions, wind similar to a sea breeze can form near ice edges. Warm air over the open water rises and flows over the cool ice, where it eventually sinks and flows back toward the water to replace the rising air.

4.2 Topography

Topography refers to the physical features of the earth's surface. Deep valleys, tall peaks, and narrow channels are just some examples of the different types of topography that can alter the speed and direction of the wind. Added effects are caused by friction from trees, snow and ice, and other land cover, as well as from water.

4.2.1 Wind Blowing Between the Shore and the Water

Wind Blowing Offshore

Water creates less friction than land, so wind blowing offshore picks up speed and veers clockwise slightly. Wind speed stops increasing within about 16 kilometres of the shore but can become quite high if the atmosphere is unstable.

What hazards does this pose?

Since wind gathers speed as it blows offshore, boaters should consider how much stronger it might be the further out they are.

At the same time, boaters sticking close to shore, where the offshore winds are usually lighter, should think about how the topography of the shoreline might affect wind speed and direction.

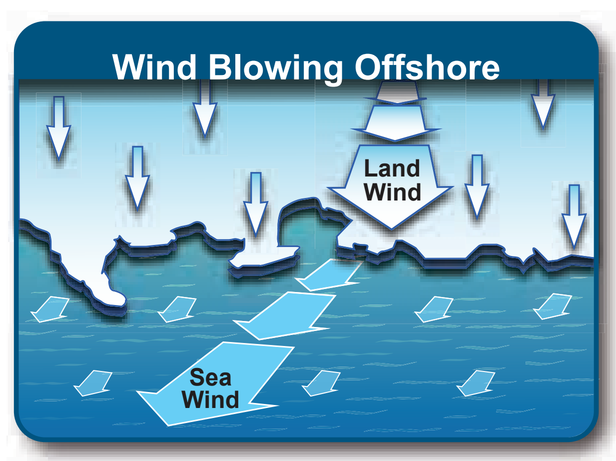


Figure 2h – Wind blowing offshore speeds up and shifts direction clockwise.

Wind Blowing Onshore

Wind blowing onshore slows down and veers or "backs" counter-clockwise slightly, due to the added frictional drag caused by the land.

What hazards does this pose?

Because wind loses speed over land, the wind speed reported by a land-based station –even one very close to shore—could be much lower than the wind speed occurring further offshore.

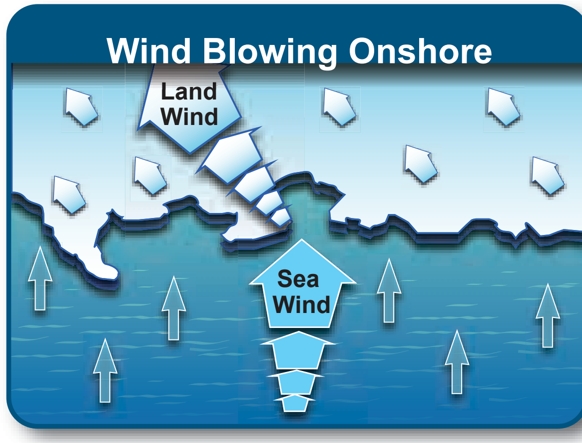


Figure 2i – Wind blowing onshore slows down and shifts direction counter-clockwise.

Lee Effect

Lee effects are winds experienced on the downwind (lee) side of an obstacle. Near the shoreline, they often occur when winds blowing either toward the land or toward the water interact with the face of a cliff or other steep embankment.

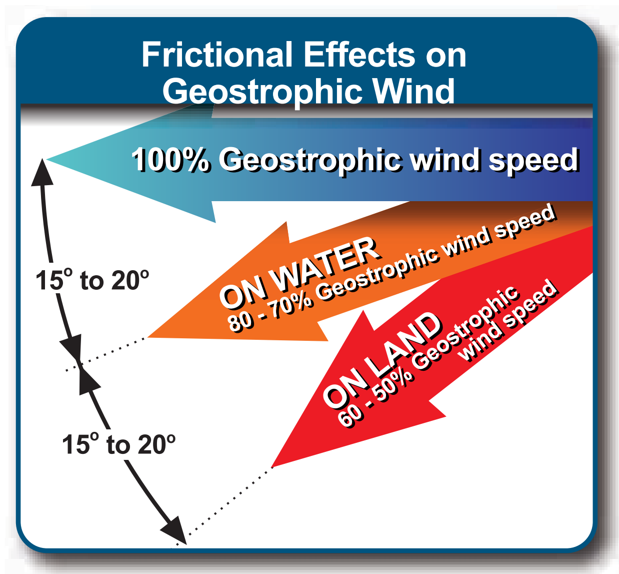


Figure 2j – The speed and direction of the geostrophic wind is influenced by whether it blows over water or land. Over water, its speed decreases by 20-30 percent and it shifts direction counter-clockwise by 15 to 20 degrees. Over land, its speed decreases by 40-50 percent and it shifts direction counter-clockwise by 30 to 40 degrees.

What causes lee effects?

When wind blowing onshore is blocked by a cliff face or other steep obstacle, some of it is deflected downward and reverses direction while the rest is forced up and over the cliff. This makes the wind turbulent and unpredictable near the shoreline.

When wind blowing offshore passes over a cliff edge, it flows down toward the surface of the water. Where it touches the water, it splits in two directions, creating an area of calm. Part of the wind flows back toward shore, where it interacts with the cliff face and creates turbulent conditions near shore. The rest flows out to sea, creating alternating zones of gusty and light winds as it touches down and bounces away from the surface in a wavelike motion.

What hazards do lee effects pose?

Wind blowing onshore becomes turbulent and gusty when it collides with a cliff near the shoreline. This can make activities near shore difficult and dangerous.

Wind blowing offshore also becomes turbulent and gusty as it passes over the edge of a cliff. With small cliffs, this may result in an area of calm near the shore. With larger ones, strong gusty winds can persist even near the shoreline.

Offshore wind also creates alternating zones of strong and light winds further out to sea – within a distance of about seven to ten times the height of the cliff. While the strong winds usually stay in the same place, the light ones sometimes change speed or reverse direction – in particular, when they are downwind of higher cliffs.

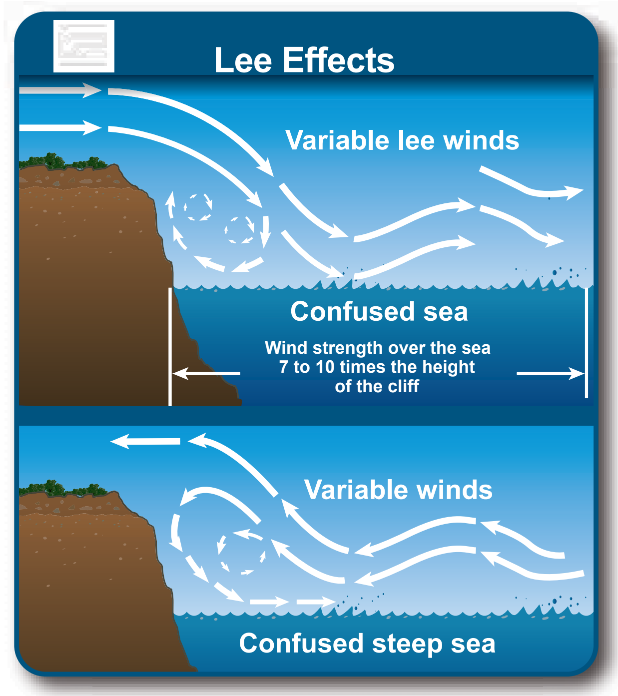


Figure 2k – When wind is blowing offshore over a cliff, a pattern of alternating strong and calm winds can be put in motion over the water. When wind is blowing from the water directly toward a steep cliff, strong gusty winds can occur near the shoreline.

Mariners' Tips

Offshore wind blowing over the edge of a cliff causes a variety of calm and turbulent conditions between the shoreline and the open water further out to sea. Boaters should be aware that conditions could vary drastically as they move through this zone.

4.2.2 Wind Blowing Along the Shoreline

Coastal Convergence

Coastal convergence causes a band of stronger wind to occur within a couple of kilometres of the shoreline. It happens when the shoreline is to the right of the direction the prevailing winds are blowing.

What causes coastal convergence?

Coastal convergence is caused by differences in the frictional properties of water and land. When the shoreline is to the right of the prevailing wind direction, this difference causes the wind over the land to shift drastically toward the water. Where it collides with the wind over the water, the two pile up. Coastal convergence can be enhanced by an inversion.

What are the hazards of coastal convergence?

Coastal convergence can cause winds around 25 percent stronger than those blowing over the nearby land or further out to sea. This could cause problems for some smaller boats.

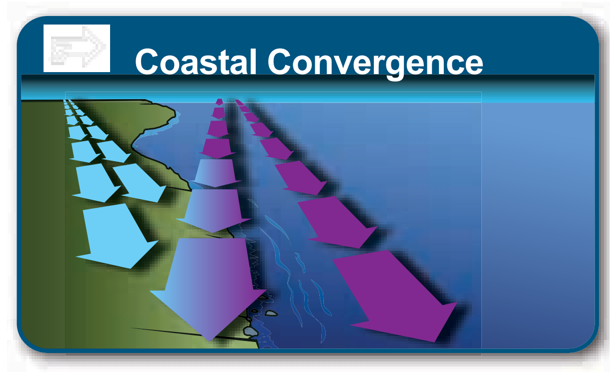


Figure 2l – When the shoreline is to the right of the prevailing wind direction, the wind over the land and the wind over the water will collide, creating a band of stronger winds just offshore.

Mariners' Tips

In a situation where coastal convergence is well established, there are more clouds along the coastline. This happens because the piling up of the air forces some upward, where the moisture in the air is able to form clouds. These areas of enhanced cloud can produce precipitation and, under certain circumstances, cause heavy downpours and reduced visibility.

Coastal Divergence

Coastal divergence causes a band of weaker wind to form within a couple of kilometres of the shoreline. It happens when the shoreline is to the left of the direction the prevailing winds are blowing.

What causes coastal divergence?

Coastal divergence is caused by differences in the frictional properties of water and land. When the shoreline is to the left of the prevailing wind direction, this difference causes the wind blowing over the two surfaces to separate at the coast.

Figure 2m – When the shoreline is to the left of the prevailing wind direction, the wind over the land and the wind over the water separate, creating a band of weaker winds just offshore.

What are the hazards of coastal divergence?

When coastal divergence is occurring, winds can be up to 25 percent lighter within a couple of kilometres of the shore. This can give boaters a false sense of the prevailing wind direction and wind speed further out to sea.

Channelling

Channelling occurs when the prevailing wind is forced to change direction because it comes into contact with a physical feature of the land—be it coastline, a mountain range, or the walls of a river valley. Channelling does not affect wind speed.

What causes channelling?

When the wind encounters an obstacle, it shifts direction so it can continue flowing without being blocked or impeded. As it blows along the coastline, for example, the wind is constantly being redirected to follow the outline of the land.

What are the hazards of channelling?

Channelling can make the wind direction on the water very different from the prevailing wind or even the forecasted wind direction.

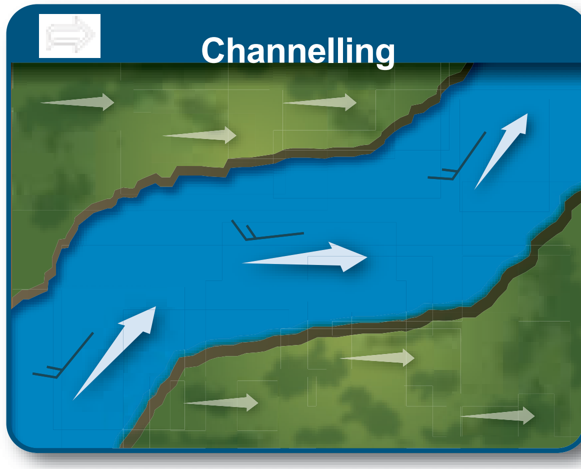


Figure 2n – When wind encounters a physical obstacle, its direction is altered but not its speed.

Funnelling

Funnelling occurs when the wind flows through a narrow opening between two adjacent pieces of land, such as a narrow channel between two islands or a narrow river valley. This causes the speed of the wind to increase but does not affect its direction.

Figure 2o – When wind flows through a narrow opening in the land, its speed is altered but not its direction.

What causes funnelling?

In the same way water flowing out of a hose increases in pressure when part of the nozzle is blocked, wind picks up speed when it passes through a narrow opening in the land. Wind flowing along a shoreline, for example, often speeds up as it blows between two islands, between an island and the coastline, or into a narrow inlet or bay.

What are the hazards of funnelling?

Even when the prevailing wind is light, boaters should be prepared for higher wind speeds in areas prone to funnelling. In particular, caution should be exercised near narrow openings, where winds can be very gusty and their speeds up to twice as high.

4.2.3 Downslope Wind

Downslope winds are warm, dry, and gusty winds that flow down the lee (downwind) side of a mountain range. They are known locally by many other names, including Chinook winds, foehn winds, les suetes, and wreckhouse winds.

How are downslope winds formed?

Downslope winds form when a deep layer of air near the earth's surface is forced up and over a mountain. As the air flows down the lee side of the mountain, it picks up speed and becomes warm and dry.

If the atmosphere is very stable, a condition called "atmospheric inversion" can occur, in which the air temperature increases the higher it is from the ground. When an inversion occurs, downslope winds flow even faster because their warm air is trapped and cannot dissipate into the atmosphere. Inversions also make it possible for downslope winds to form on hills and mountains that would otherwise be too small to produce them. This condition usually lasts only an hour or two but can sometimes persist for days.

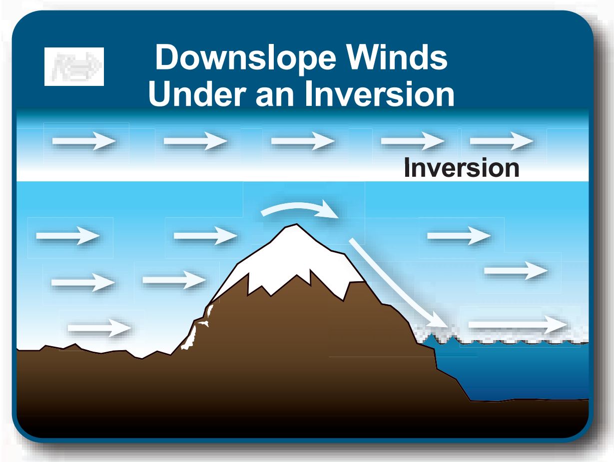


Figure 2p – When an atmospheric inversion occurs, it can amplify the speed of downslope winds.

What hazards are associated with downslope winds?

Downslope winds can reach surface speeds of 40 to 50 knots if they are combined with an inversion. Boaters should be cautious when navigating on the leeward side of mountains or other slopes.

Mariners' Tips

An unusual, lens-shaped cloud above a mountain is a sign that downslope winds are forming. Downslope winds also often clear away cloud cover as they flow down a mountainside.

Figure 2p-2 – The appearance of "lenticular" or lens-shaped clouds over a mountain is a sign of downslope wind conditions. Photo: Brewster Travel Canada

4.3 Combined Effects

Wind on oceans, lakes, and rivers is usually a combination of many different factors happening at once. They include conditions in the atmosphere and conditions at the earth's surface. While topographic features, temperature, and friction each have their own unique effects, they never act alone. The potential combined effects of these factors are endless, but some common ones are explained further in this section.

4.3.1 Combined Effects of Topography

Gap Wind

Winds that have been affected by both channelling and funnelling are called gap winds. This means that they have not only been forced to change direction by a physical feature of the land but also to increase in speed by being squeezed through a narrow gap.

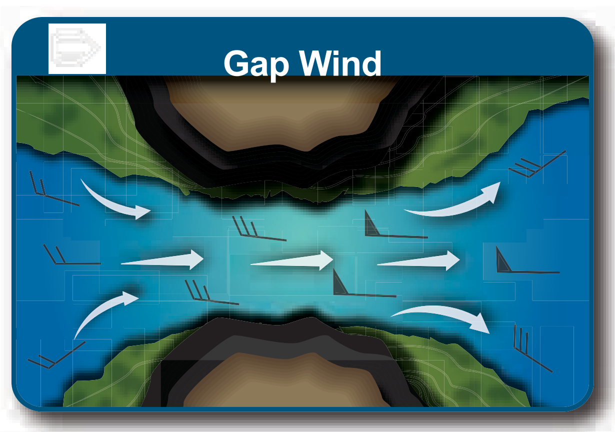


Figure 2q – Winds affected by both channelling and funnelling change direction and speed.

Gap wind is often used to describe wind that occurs where the coastline narrows and changes direction at the same time. It is also used more generally to describe any wind affected by a narrow gap. Outflow winds and fiord winds are types of gap winds, in that they are created by the same processes but under different conditions.

Outflow Wind

Outflow winds are strong winds created when air is forced to flow between two mountains or a break in a mountain range. The uneven shape of the mountains also causes the wind to change directions as it passes through. In some parts of the country, these winds are better known as Arctic outflow winds.

Fiord Wind

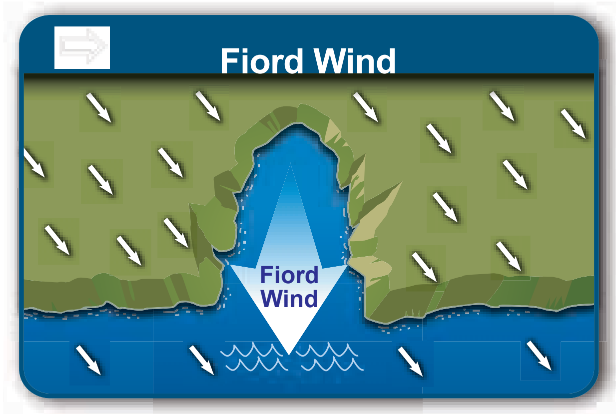


Figure 2r – Wind blowing at a slight angle to a fiord can increase the speed of the prevailing wind by as much as double.

Fiord winds are winds funneled through the steep walls of a fiord. Depending on the direction of the prevailing wind, winds inside the fiord and at its downwind opening can be either stronger or much weaker.

If the prevailing wind is blowing the same direction as the fiord, wind speed will increase slightly due to the effect of funnelling. If it is blowing at a slight angle to the fiord, the combination of funnelling and channelling could cause the wind speed to almost double. If the prevailing wind direction is perpendicular to the orientation of the fiord, the wind speed within it will be much weaker.

What are the hazards of gap winds?

Gap winds can create strong, gusty wind conditions between narrow coastlines, mountains, and fiords. Mariners should be very careful when navigating in gaps or crossing in front of them, as winds in these areas can be much stronger and the direction they are blowing can be unexpected. Near the exit to the gap, the wind speed can be 30 knots or more than that of the prevailing wind.

Mariners' Tip

When winds are blowing at a right angle to a narrow gap in the terrain, mariners may find shelter within the gap, where the winds will be significantly lighter.

Barrier Wind

Barrier winds are strong and sometimes gusty and turbulent winds that occur along a steep shoreline when the winds are blowing from the water. They are a kind of "lee effect" caused by a combination of coastal convergence and funnelling.

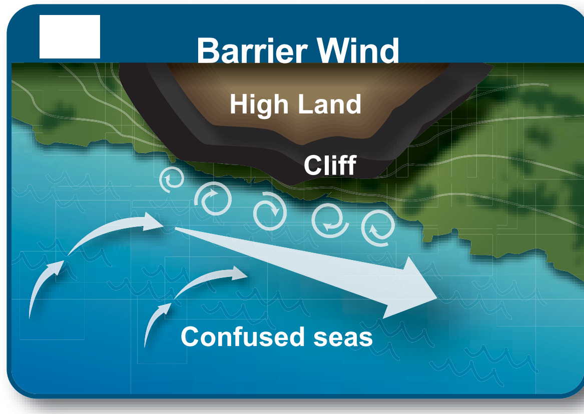


Figure 2s – Onshore winds blowing toward a steep coastline can create hazardous wind conditions near shore.

How are barrier winds formed?

When winds blowing from the water toward the coastline strike a cliff or steep embankment, they change direction. If they strike at an angle, they shift to follow the shoreline and their speed can as much as double. If, however, they blow directly at the shore, some will be deflected back and some will shift and run along the shoreline. This causes gusty and turbulent conditions near the coast.

What are the hazards of barrier winds?

Barrier winds can create strong, turbulent wind conditions along the coast. This can make boating in the area near the shoreline unsafe.

Corner Effects

Corner effects are the effects of funnelling combined with either coastal convergence or coastal divergence. In certain conditions, they can cause strong winds and turbulent, gusty conditions around steep islands and peninsulas.

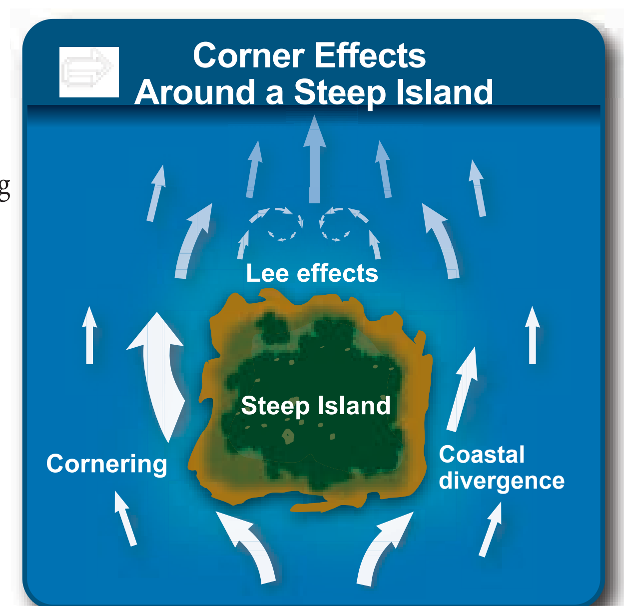


Figure 2t – When wind flows around a steep island, if the shoreline is to the right of the prevailing wind direction, it will experience stronger winds than the opposite shore. Gusty and turbulent conditions will occur on the downwind side of the island.

How are corner effects formed?

When wind is blocked by a steep island or peninsula, it is forced to travel over and around it. In the case of an island, wind is forced around both sides. In the case of a peninsula, the wind shifts direction to flow around the corner.

When the shore of an island is to the right of the prevailing wind direction, coastal convergence and funnelling will combine to increase wind speed. When the shore is to the left, funnelling will still occur, but it will be weakened by the effect of coastal divergence. Some wind also flows up and over the island, creating gusty and turbulent winds on its downwind or lee side.

When the shore of a peninsula is to the left of the prevailing wind direction, coastal divergence and funnelling combine to create weaker winds near the shore. When the shore is to the right, coastal convergence and funnelling create stronger winds.

What are the hazards of corner effects?

Mariners navigating around a steep island with the prevailing wind at their back will have to deal with much stronger winds on its left shore and more gusty and turbulent winds directly in front of it. In the case of a peninsula, boaters will encounter stronger winds when the shoreline is to the right of the prevailing wind direction.

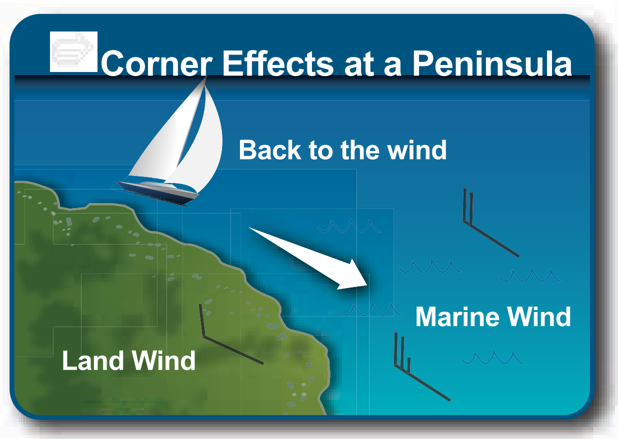


Figure 2u – When the shore of a peninsula is to the right of the prevailing wind direction, stronger wind conditions will occur.

Mariners' Tips

When approaching a steep island with the wind at their back, mariners should navigate around the right-hand side of the island, as the winds will be lighter than on the left. Boaters should be mindful of stronger wind conditions when navigating around a peninsula that lies to the right of the prevailing wind direction.

4.3.2 Combined Effects of Heating and Topography

Differences in the way the land and water heat up and cool down influence the speed and direction of the wind, as shown in Section 4.1 of this chapter. "Differential heating" also occurs because of the physical features of the land. Where steep, sloping terrain is involved, heating and topography often combine to influence wind conditions.

Katabatic Wind

Katabatic wind is a strong, gusty wind that blows down the sides of a mountain, cliff, fiord, valley, or other steep slope from about midnight until early morning. It is known locally by other names, such as mountain wind, drainage wind, glacier wind, and blow-me-down.

How is a katabatic wind formed?

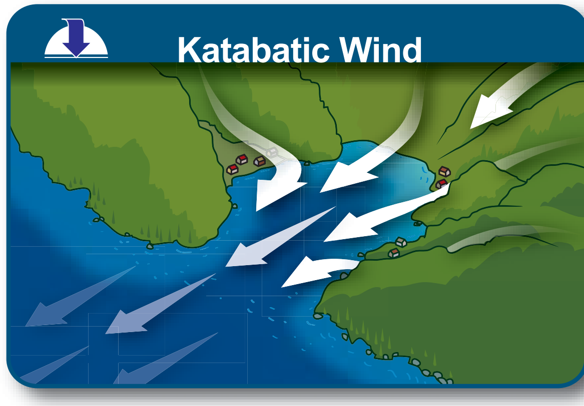


Figure 2v – Cool air flowing down the sides of a steep slope creates gusty, unpredictable offshore winds over the water.

On a clear evening, heat from the surface of the earth radiates out into space, causing air temperatures near the surface to cool down. In areas sheltered by steep terrain, the air near the base of the slope stays warm longer than the air above it. This causes the cooler, heavier air near the top of the slope to flow downward—creating a strong wind. The speed of katabatic wind increases until just after dawn, when it starts to die out. Where slopes are topped with icy glaciers, katabatic wind is a more or less permanent condition.

What hazards are associated with katabatic winds?

Katabatic winds can create unexpectedly windy conditions overnight. If they combine with a land breeze, they can reach even higher speeds. Depending on their strength, katabatic winds can be felt as far as three kilometres off shore.

Mariners' Tips

Mariners should be careful when anchoring for the night in a harbour with high terrain nearby. A cove next to a steep coastline that seemed calm and sheltered the evening before may suddenly experience strong, gusty winds the next morning.

Anabatic Wind

An anabatic wind is a mild wind that blows up the sides of a mountain, cliff, or other steep slope during the day. It is also known as a valley wind.

How is an anabatic wind formed?

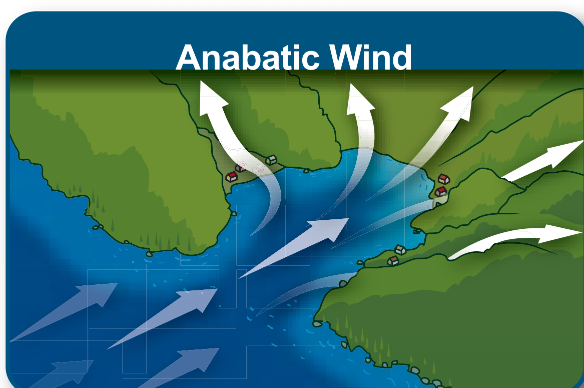


Figure 2w – Warm air flowing up the sides of a slope creates weak onshore winds over the water.

During the day, when the sun shines on a mountain, valley, cliff, or other steep terrain, it warms the sides of their slopes faster than it does the sheltered area at their base. This causes the warmer air on the slopes to rise and blow gently upward. Valleys with gentle slopes and slopes that face south have the strongest anabatic winds.

What hazards are associated with anabatic winds?

Although anabatic winds are usually light, they can speed up and cause gusty conditions in harbours if they mix with a sea breeze.katabatic winds can be felt as far as three kilometres off shore.

Mariners' Tips

Puffy clouds above the sides of the valley are a sign of anabatic wind.

Cross Valley Flow

A cross valley flow is a wind that circulates up one side of a valley and down the other. It happens during the day when downslope and anabatic winds occur at the same time in an enclosed, steep-walled lake valley or in a coastal inlet surrounded by steep topography.

How is cross valley flow formed?

A cross valley flow forms when the slope on one side of a valley is facing direct sunlight while the slope on the other side is in shadow for an extended period of time. This causes an anabatic wind to form on the warm slope and allows a weak downslope wind to persist or form on the slope that is in shadow. This effect is enhanced or reduced by the prevailing wind direction and speed.

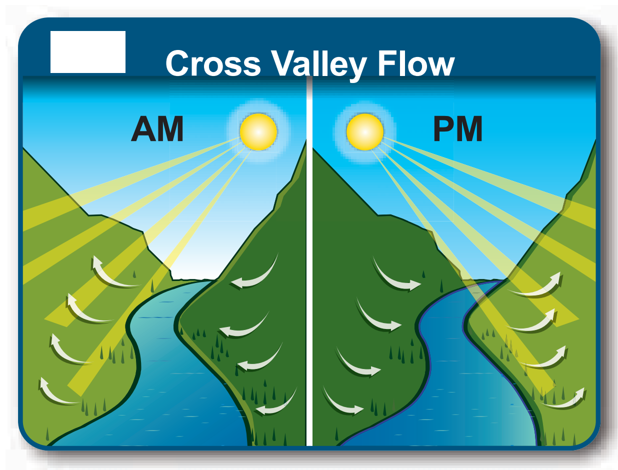


Figure 2x – When wind flows up the sunny side of a valley and down the opposite, shady side, it sets in motion a circulation pattern that can be enhanced or diminished by the prevailing wind.

This sets in motion a unique circulation pattern. The warmer air from the anabatic wind flows upward and crosses over the valley to the top of the shadowed slope. There, the air cools and starts flowing downward—forming or strengthening a down slope wind. At the base of the slope, the cool air rushes across the water to the opposite side to take the place of the warm air rising with the anabatic wind.

Over the course of the day, as the sun moves across the sky and the sun and shade shift from one slope to the other, a cross valley flow can reverse direction.

What hazards are associated with a cross valley flow?

Cross valley flows create unexpectedly different wind directions on either side of a basin of water. Boaters may also be surprised by the presence of anabatic winds that are much stronger than usual and downslope winds happening during the day.

CHAPTER 3: SEA STATE

1. Introduction

Sea state refers to the overall condition of the surface of a large area of open ocean or sea resulting from the combined effects of wind-generated waves, swells, and surface currents. It is described in terms of how rough the waters are based on wave height.

Taking sea state into consideration is of primary importance to mariners, as high waves and confused seas can easily swamp a vessel or cause it to capsize. Each year, rough seas cause many tragic losses on Canadian waters, with large waves identified as the highest risk factor in recreational boating deaths by drowning and immersion hypothermia between 1991 and 2008.[1]

Code	Wave Height (meters)	Characteristics
0	0	Calm (glassy)
1	0 to 0.1	Calm (rippled)
2	0.1 to 0.5	Smooth (wavelets)
3	0.5 to 1.25	Slight
4	1.25 to 2.5	Moderate
5	2.5 to 4	Rough
6	4 to 6	Very rough
7	6 to 9	High
8	9 to 14	Very high
9	Over 14	Phenomenal

Figure 3a – The World Meteorological Organization's codes for sea state include wave heights and descriptive characteristics.

Since wind is the main factor affecting sea state—the general rule of thumb being "the stronger the wind, the rougher the seas"—the information contained in the previous chapter on Wind is key to understanding the concepts covered in this section. Other factors also affect sea state, however, including some that are locally driven and influence smaller areas.

This chapter will help boaters understand how and why rough seas commonly occur, so they can anticipate and avoid hazardous conditions, where possible. It will also teach them how to use current wind speeds and wind forecasts to predict the wave conditions they are likely to encounter on the open sea, while taking into consideration other factors at play.

[1] Transport Canada and the Canadian Red Cross Society. Boating Immersion and Trauma Deaths in Canada: 18 Years of Research (1991-2006), 2010

2. The Anatomy of a Wave

2.1 How Waves Form

Wind-waves (or “sea”, as they are also known) are created by the force of the wind on the water. They are generated fairly quickly (often within an hour or so) in the immediate area where the wind is blowing, and they usually subside shortly after it dies down.

The size of the waves that develop is determined mostly by a combination of wind speed and duration and fetch length; however, the height and motion of the existing swell also has an influence.

2.1.1 Wind

Generally speaking, the stronger the wind and the longer it persists in the same direction without changing speed, the larger the waves.

While it is no longer used for modern forecasting, the Beaufort Wind Scale—developed in the 19th century by the British Navy—is a simple tool for estimating wind speed based on sea state and vice versa.

2.1.2 Fetch

Fetch is the horizontal distance over which wave-generating winds blow from a single, constant direction. A fetch of at least 320 kilometres or 200 miles is usually required for waves to develop to their maximum potential height on the open sea.

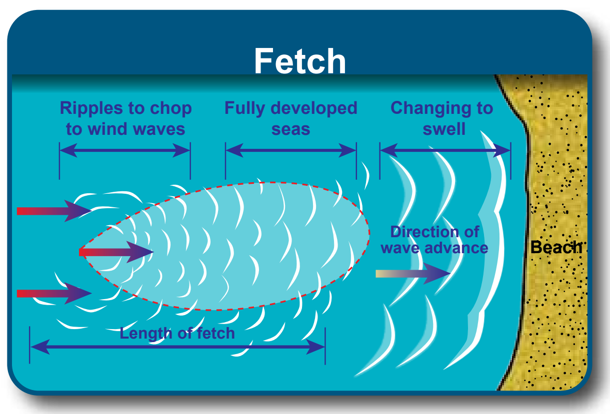


Figure 3b-1 – As the length of fetch increases, so too does the height of the waves.

Mariners’ Tips

The length of time the wind blows consistently from a single direction can give boaters an idea of the size of the waves that will develop.

2.1.3 Swells

Swells are the remains of wind waves that have moved away from the area where they were generated. Because they are long waves that contain a lot of energy, swells can travel vast distances and take days to subside. The period between swells usually ranges from 5 to 30 seconds.

Depending on the direction they travel and how they interact with wind-generated waves, swells can amplify existing surface conditions or cause heavy, confused seas.

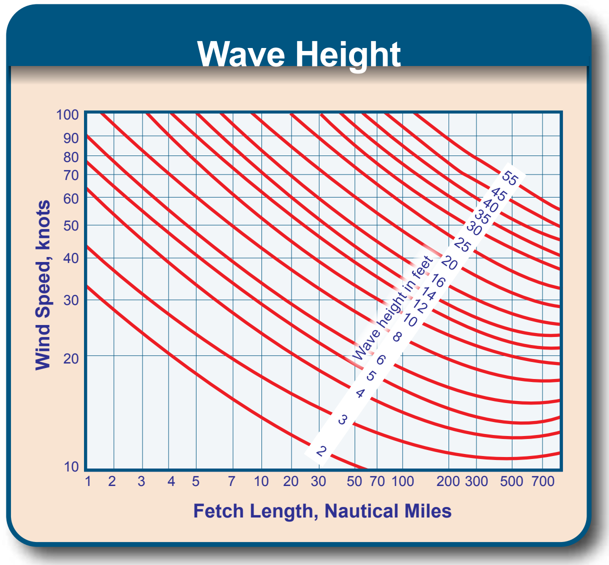


Figure 3b-2 – Wind speed and fetch length can be used to calculate wave height.

Mariners' Tips
An approaching storm usually causes swells to increase within 24 hours of its arrival. If swells increase when the winds are light, it is a strong indication that a storm is near.

2.2. Wave Characteristics

Waves are described by four main characteristics: height, length, period, and frequency.

Wave height is the vertical distance between the crest and trough of a wave—or its highest and lowest points. The term **significant wave heigh**t or "sig-wave" is used to describe deep-water waves, and is estimated by averaging the height of the highest one-third of the waves in the area.

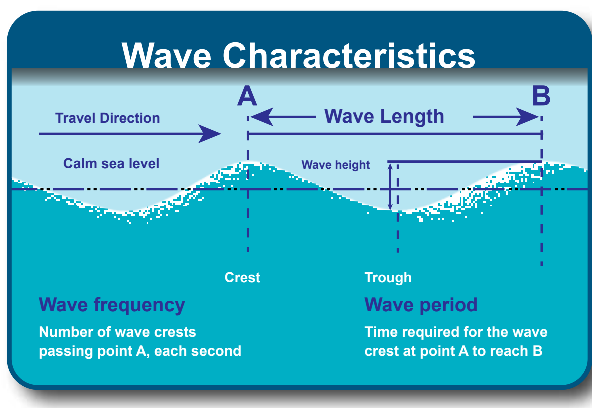


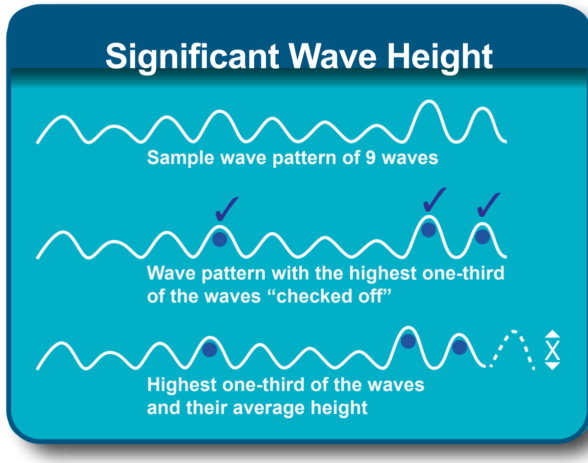
Figure 3c-1 – The four characteristics by which waves are typically described are height, length, period, and frequency.

When Environment Canada forecasts 2-metre seas, for example, it is forecasting the sig-wave height. Sig-waves can be used to estimate average wave height and the highest waves likely to occur over a period of up to 24 hours.

Wave length is the horizontal distance between consecutive crests (or troughs) of waves in the direction they are moving.

Wave period is the time interval between the passage of successive crests (or troughs) of waves at a fixed position.

Wave frequency is the number of wave crests that pass a fixed point each second.



Average wave height	.625 X Sig Wave
Highest wave likely over a 10-minute period	1.6 X Sig Wave
Highest wave likely over a 3-hour period	2.0 X Sig Wave
Highest wave likely over a 12-hour period	2.25 X Sig Wave
Highest wave likely over a 24-hour period	2.35 X Sig Wave

Figure 3c-2 – The relationship between the sig-wave and other wave heights. While the average wave height is only a fraction that of the sig-wave, extreme waves can be over twice as high.

2.3 Understanding Wave Forecasts

2.3.1 Data Collection

Environment Canada collects wave data from approximately 50 buoys, just under half of which are seasonal and active only during ice-free conditions.

Strategically located in open water, the buoys collect wave-height and wave-period data for 30 to 35 minutes per hour. The data are transmitted hourly by cellphone or satellite signal to Environment Canada forecasters, who combine them with other meteorological information to assess current and future sea-state conditions. For more information on marine weather data visit this link.

Figure 3d – Environment Canada buoys collect and transmit data on wave heights and wave periods to forecasters on an hourly basis.

2.3.2 Forecasting

Wave forecasts, like wind forecasts, reflect only open-water conditions. Near the shoreline and around islands, waves can be difficult to predict and may be stronger or weaker than expected because of the shape, orientation, or steepness of the nearby land and underlying sea floor.

Currents and tidal flow can also have a significant impact on the size and steepness of waves, especially around headlands, where dangerous seas can occur even in moderate winds. As waves encounter shallower water, they also tend to slow down and build in height—and may even change direction to run more parallel to the shoreline.

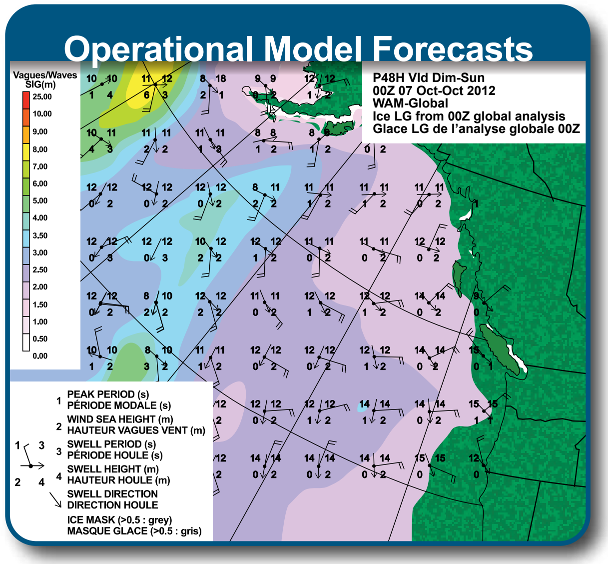


Figure 3e – Operational model forecasts provide local information on peak periods, wind sea height, ice wash, and the height, period, and direction of swells.

The effects of the interactions between winds, tides, currents, and other local conditions are not included in marine forecasts. Boaters are strongly advised to learn about these effects (covered in the next section of this chapter) so they can more accurately assess the sea states they might encounter after leaving port.

As explained in Section 2.2, Environment Canada's forecasts are based on significant wave height. To estimate the maximum wave height for the next three hours, multiply the sig-wave by two; to determine the average wave height, multiply it by two-thirds. In other words, with a forecast of 2-metre seas, mariners should expect waves that average 1.3 metres in height and the possibility of a wave as high as 4 metres.

3. Other Influences on Waves

3.1 Water-Related Effects

3.1.1 Currents

A current is the steady flow of surface water in a certain direction. Lake, river, and ocean currents occur at many different scales, but most flow in the same direction all the time. Currents are affected by wind, gravity, atmospheric pressure, underwater topography, the temperature and salinity of the water, and the rotation of the earth.

The Labrador Current—a cold-water current in the North Atlantic Ocean—and the Alaskan Current—a warm-water current off the coast of British Columbia and the Alaska Panhandle—are large-scale, permanent currents that are well known to mariners. Much smaller-scale currents, however, can also interact with other conditions to cause dangerous waves, both at sea and on inland waters such as the Great Lakes.

How do currents affect waves?

The strength and direction of the current and the strength and direction of the wind have a combined effect on sea state. When wind-driven waves flow against an opposing current, their wave length decreases and their height increases dramatically. This rapid steepening can cause them to break, creating choppy and hazardous seas.

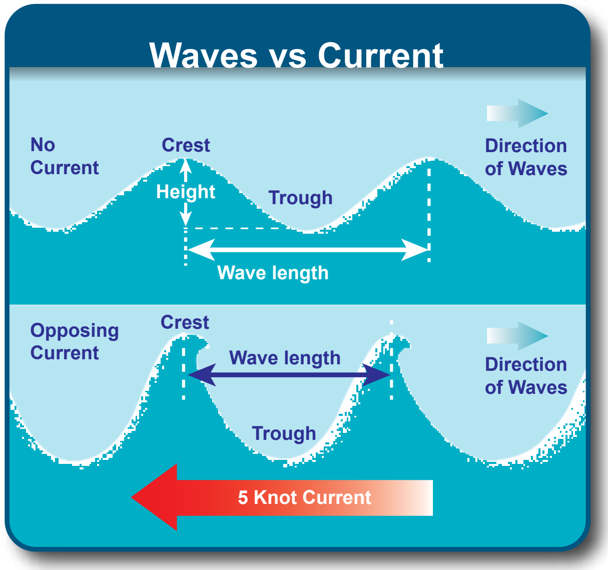


Figure 3f-1 – A three-metre high wave almost doubles in height when flowing against an opposing current of five knots, causing it to steepen to the breaking point.

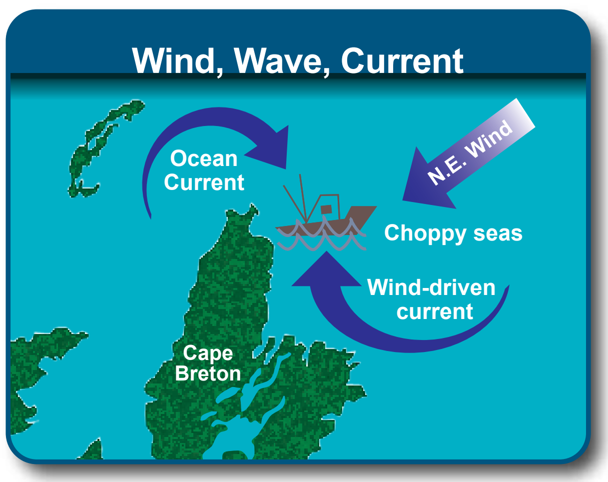


Figure 3f-2 – Wind-driven currents often override regular currents and tides. For example, after persistent easterly or north-easterly winds, a north-going current with a rate of one knot may flow from the vicinity of St. Ann's Bay to near Cape North. There, it meets the current flowing southeast from the Gulf of St. Lawrence. The direction of the currents, combined with the direction of the winds, can cause very choppy seas.

On the East Coast, wave-current interactions are common in the Northumberland Strait, off the southern tip of Nova Scotia, and along the northern edge of the Gulf Stream. On the West Coast, mariners often encounter them at Cape Mudge, Nawhitti Bar, and Scott Channel in British Columbia.

Longshore Currents

When waves approach the shoreline at an angle, the drag effect of the ocean or lake floor amplifies their angle of approach such that it runs almost parallel to the shore. This creates a "longshore current" that flows in the same direction as the coastline.

If the beach floor is irregular, waves may concentrate in some areas more than others. Longshore currents are weaker where there are large breakers and stronger where the waves are smaller. The water that has accumulated in the surf zone eventually flows back out to sea, often in strong, narrow currents known as "rip currents".

Rip Currents

When two tidal streams converge or a strong current flows out to sea over a shallow, irregular stretch of lake or ocean floor, a boiling action occurs at the surface. This area of churning, choppy water is called a "rip current" (also a "rip tide" or "tidal rip").

Rips, as they are commonly known, often form in low areas such as trenches between sandbars, under piers, or along jetties. These areas offer an easier route for the water carried in with the surf to retreat back out to sea. Because the strong surface flow of a rip current tends to dampen incoming waves, what may appear to be a particularly calm area of water may, instead, be very dangerous.

Rip currents range from a few metres to several hundred metres in width

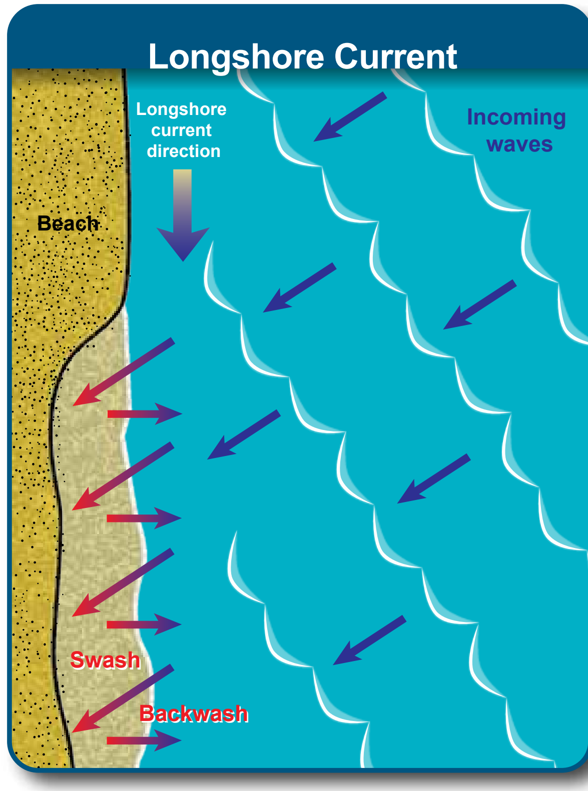


Figure 3f-3 – When waves approach the shoreline at an angle, they cause a "longshore current" that flows in the same direction as the shoreline.

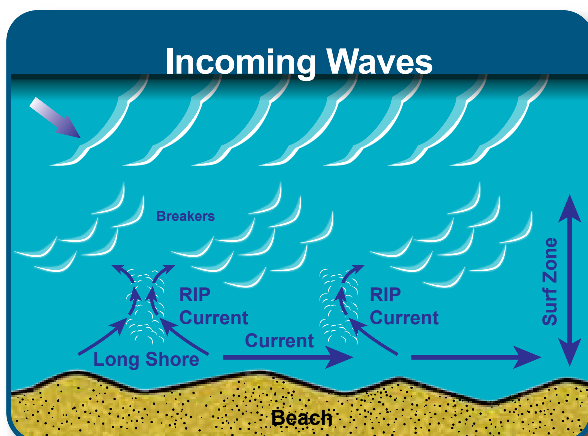


Figure 3f-4 – Water that has accumulated in the surf zone as a result of incoming waves and the longshore current eventually flows back out to sea, often in strong, narrow currents known as "rip currents".

and, while they usually extend just beyond the line of breaking waves, some can be felt hundreds of metres off shore. They can reach speeds of up to three knots and break violently when there are opposing winds.

Rips are particularly common in Atlantic Canada, especially on the north shore of Prince Edward Island and off the southwestern tip of Nova Scotia. On the West Coast, they frequently occur at the entrance to narrows and passes, such as Active Pass, Porlier Pass, and Johnstone Strait. Local Sailing Directions contain information on the location of well-known rips.

What hazards do rip currents pose?

Every year, drowning deaths occur at popular swimming locations that are prone to rip currents. Since boaters often drop anchor or moor near beaches to take a leisurely swim, it is important for them to understand where these powerful currents might form. Although some beaches post warnings when rip currents are in effect, most do not—especially in remote areas.

A swimmer being carried out toward the open water by a rip current should not struggle against it but rather swim across it, parallel to the beach. Once out of the rip, the waves will tend to carry the swimmer toward shore.

Mariners' Tips

Signs of a rip current include a channel of churning, choppy water; an area of water that is noticeably different in colour; a line of foam or debris moving steadily seaward; and a break in the pattern of the incoming waves.

3.1.2 Tides

Tides are the periodic rise and fall of sea level as a result of the gravitational influences of the moon and sun. The pull of the moon is about twice as strong as that of the sun, so the tidal cycle is generally in tune with the moon's orbit or a typical day. The sun's effect is usually evident only as an increase or decrease in the lunar tides.

As the Earth rotates, the moon's pull causes shifting "bulges" in the oceans on opposite sides of the planet.

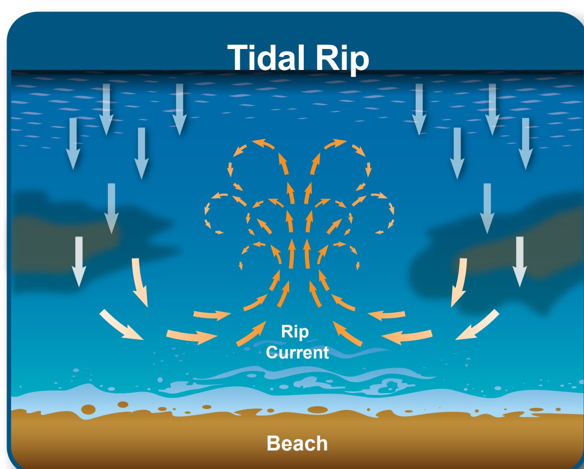


Figure 3f-5 – Rip currents range from a few metres to several hundred metres in width and usually extend just beyond the line of breaking waves—although some can reach much further.

The result is that most locations experience two high tides and two low tides (known as "semi-diurnal" tides) every 24 hours and 50 minutes. Diurnal tides (one high tide and one low tide) are also quite common. High tide and low tide are also referred to as high water and low water.

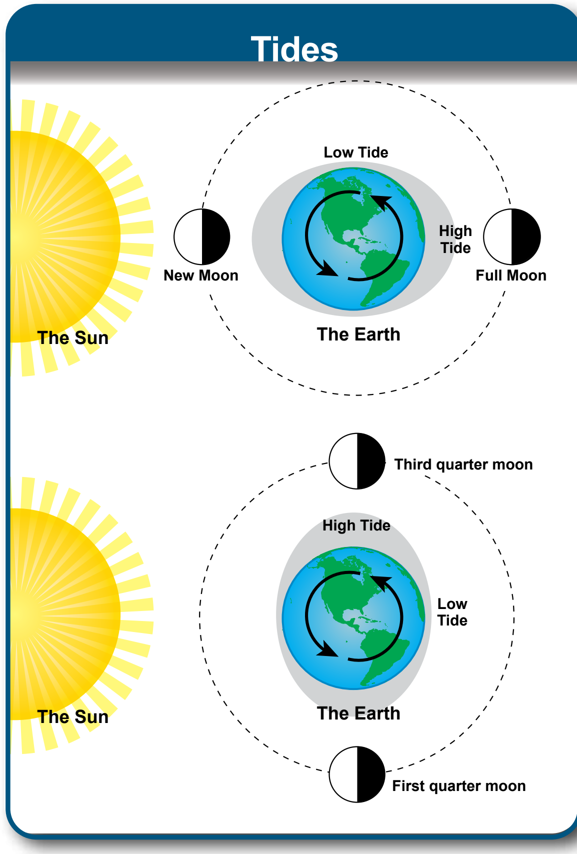


Figure 3g-1 – High and low tides occur because the moon's pull causes shifting "bulges" in the oceans on opposite sides of the planet.

Tidal Tidbit

Over time, the Earth's rotation has been slowing and the moon's orbit moving further away. A few thousand years ago, the tides were over 100 metres high in some locations; centuries from now, they will be even lower than they are today, even if water levels remain the same.

The incoming tide is called the "flood"; the retreating tide, the "ebb". When the moon and sun are in line with the Earth, their gravitational attraction combines to produce a "spring tide". These larger-than-average tides (also known as "large tides") usually occur one to three days after a new or full moon. When the sun and moon are at right angles to the Earth—that is, the moon is in its first or last quarter—smaller-than-average (or "neap") tides occur.

At the entrance to an estuary or river—where the water tends to be shallower—the low tide moves more slowly than the high tide. As such, the time between low and high water is shorter and the time between high and low water, longer.

How does wind affect the tide?

The stronger the wind, the greater its effect on both the height of the tide and the strength and speed of its flow. As winds and tides change, they can cause dramatic changes in sea state. When the two collide with swells—especially in shallow water—surface conditions can deteriorate rapidly.

When the wind has been blowing in the same direction as the tide for some time, it increases the height of the tide by building up the volume of water flowing in that direction. The opposite is true when the wind is blowing against the tide.

When the wind and the tide are moving in the same direction, boaters can expect a smoother ride, because the distance between the waves will be longer. When they are opposed, however, the distance will be shorter and the waves steeper. Depending on the strength of the wind, this could result in breaking waves and highly agitated seas.

When the tidal stream—that is, the mass of water flowing under the influence of the tide—comes into contact with shallower water or land, it flows more strongly in the middle than it does near its edges. The tidal stream flows faster when the wind is blowing with it, yet it slows only slightly when it is faced with even a strong wind.

The combined effects of wind and tide are even greater in areas where the tidal stream is concentrated by a narrowing of the land or shallow waters. This should be a serious consideration to boaters navigating in channels and tidal harbours or around headlands.

Mariners' Tips
Mariners should plan their routes to take advantage of the ebb and flow of the tide and consider information from weather forecasts, personal observations, and local sources (e.g., Sailing Directions, see the Local Weather section of this guide) in order to avoid potentially hazardous sea states.

Tides and Lagoons

Shallow coastal lagoons are uniquely affected by the tides because they are separated from the open ocean by shoals, reefs, or other features that restrict the flow of water between them. As a result, water levels in lagoons change more slowly than water levels in the ocean as the tide ebbs and flows.

Timing is critical when entering or exiting the channel to a lagoon, as boaters must ensure that water levels are high enough and the tidal current slow enough for safe passage. For example, the entrance channels to Sechelt Inlet and Seymour Inlet—two of the largest lagoons on the coast of British Columbia—are also the two fastest saltwater rapids in North America, so an error in timing could have serious consequences.

Figure 3g-2 – Timing is critical when entering or exiting the channel to a shallow coastal lagoon, as boaters must ensure that water levels are high enough and the tidal current slow enough for safe passage.

Boaters should never enter a lagoon when the tide is still rising, because the flow into the lagoon may be too strong and the water level inside it too low. It takes some time after high water has been reached outside the lagoon for the water level inside the lagoon to match. This point—known as "high water, slack current" because the height of the water inside the lagoon has reached its maximum and the entrance current its minimum for that tidal cycle—is the best time to enter or leave.

For some time after the tide outside the lagoon has reached low water, the water level inside the lagoon will be higher because it takes longer to drain. If the entrance channel to the lagoon is deep enough to accommodate a vessel (boaters should consult charts and inspect channel conditions before proceeding), passage into or out of the lagoon may be possible during low tide. Since entrance channels are shallowest at "low water, slack current", when the levels inside and outside the lagoon are the same, it is best to enter or exit just before this point in the cycle. Any earlier, and boaters attempting to enter could face a strong outflow of water from inside the lagoon.

Fisheries and Oceans Canada provides tidal calculations, water-level charts, and other related information. Additional tidal information is also available.

3.1.3 Seiches

Gravity works continuously to restore the surface of a body of water to an even horizontal level. In a fully or partially enclosed basin, however, wind, atmospheric pressure, seismic activity, and other factors cause the water to slosh back and forth. These long, rhythmic waves are known as "seiches".

Seiches cause water levels to rise and fall at a given frequency, determined by the size, depth, and contours of the basin and the temperature of the water. Small seiches can occur over a period of minutes and change water levels by as little as a few centimetres. Extreme seiches, on the other hand, can take hours and cause water levels to rise and fall several metres.

Seiches move as if hinged at the centre, like a teeter totter. The simplest ones have a single central node and one antinode at each opposing end, while others have multiple nodes and antinodes. In general, the fewer

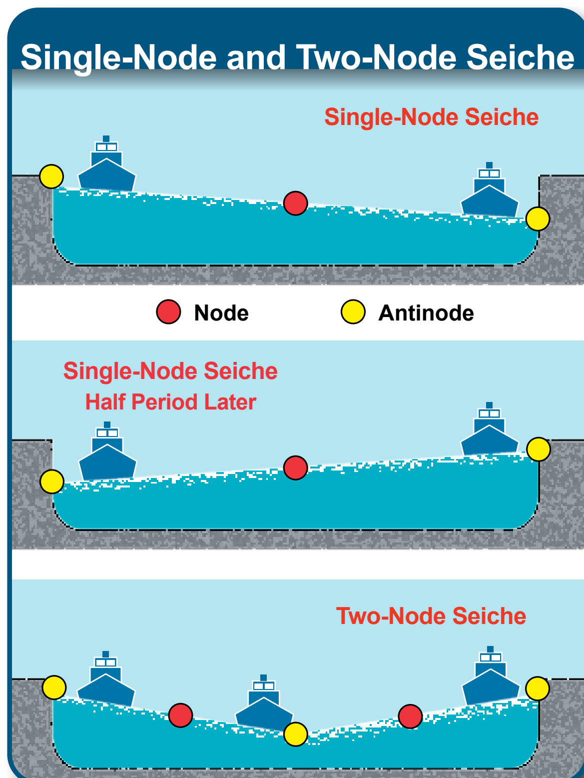


Figure 3h – With a single-node seiche, one antinode will be at its peak while the other is at its trough. After half an oscillation, these positions will be reversed. With a two-node seiche, the shoreline antinodes are in synch, rising and falling together, while the mid-lake antinode is in opposition, cresting when the shoreline antinodes are in trough and vice versa.

the nodes and the shallower the basin, the more pronounced the difference in water levels between the crest and trough.

What hazards do seiches pose?

Seiches are difficult to see with the naked eye because they have such long wave lengths. Wind-driven seiches—which are common in long, shallow lakes—can cause rapid and unexpected changes in water levels. At their peak, strong seiches may reach boats and other items thought to be safe on shore. When they recede, they may leave boats hanging from their docks by their mooring lines.

3.2 Topographic effects

3.2.1 Water Depth

Whether an area of water is considered shallow or not is determined not only by its depth but also by the length of the waves that are present. When the water depth is equal to or less than half the wave length, the water is shallow enough for the waves to feel the bottom of the sea bed.

Long waves feel bottom sooner than short ones, so water that is deep with respect to wind waves may be shallow with respect to longer swells. When waves come into contact with the sea bed, their height and direction are affected by two phenomena known as “shoaling” and “refraction”.

Shoaling

When deep-water waves approach a shallow area or “shoal” and start to feel bottom, they slow down—causing their crests to move closer together and the waves to become higher and steeper. When they are about the same height as the water is deep, they curl forward and break or tumble into surf.

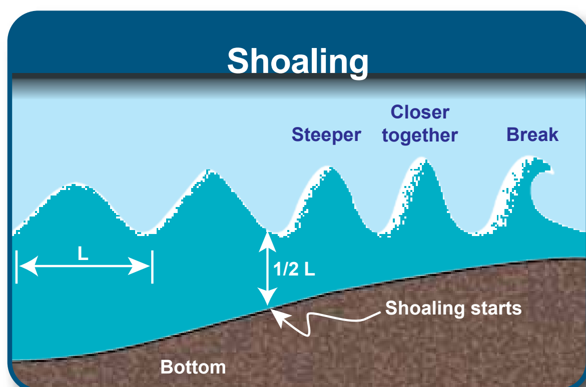


Figure 3i-1 – Shoaling occurs as waves approach a shallow area — usually at the point when the height of the waves is roughly equal to the depth of the water.

What hazards does shoaling pose?

Shoaling causes a dramatic increase in wave frequency, making conditions difficult for small watercraft. Breaking waves can also overturn small boats or drive them into jagged rocks or shoreline structures. Local sailing directions describe the shape of the sea bed and any unusual shoaling effects in the area.

Refraction

When the depth of water beneath a wave varies along its crest, it causes the wave to bend—a process known as "refraction". For example, when a line or "train" of waves approaches the shore at an angle, the end that is over the shallower water slows down and builds in height, while the part that is over the deeper water continues flowing as usual. As a result, the waves near the shore turn the direction the shoreline runs.

What hazards does refraction pose?

The old saying "points draw waves" comes from the fact that refraction often occurs at points, headlands, or capes, where waves bend inward and converge or pile up. This causes steep, confused seas in the vicinity of the shoreline.

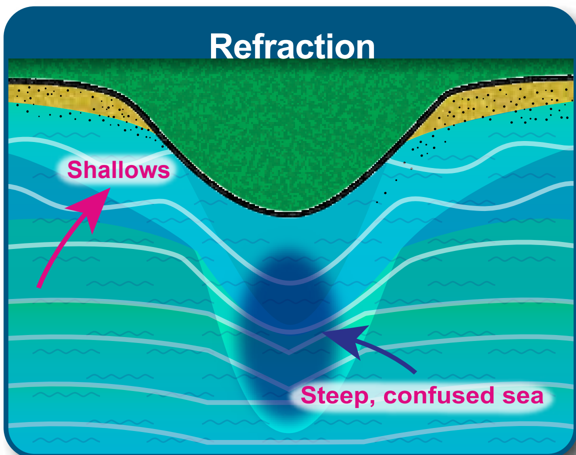


Figure 3i-2 – Rough seas are common near points of land, where refraction causes waves to bend inward and pile up.

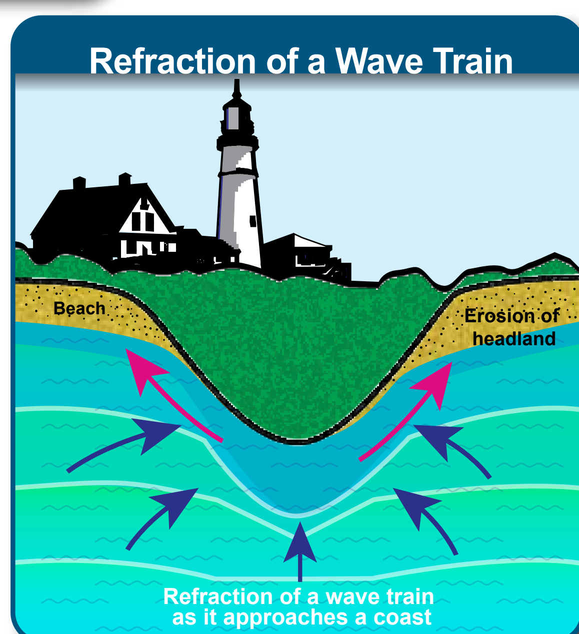


Figure 3i-3 – When a train of waves approaches the shore at an angle, the difference in the depth of water beneath it causes the waves to turn and run in the direction of the shoreline.

3.2.2 Physical Barriers

Reflection

When waves strike a vertical barrier, such as a cliff or wharf, they are reflected back in the direction from which they came. As they flow out to sea and meet the incoming waves, crests cross and wave heights build quickly. This produces choppy, confused seas as far out as a few nautical miles offshore.

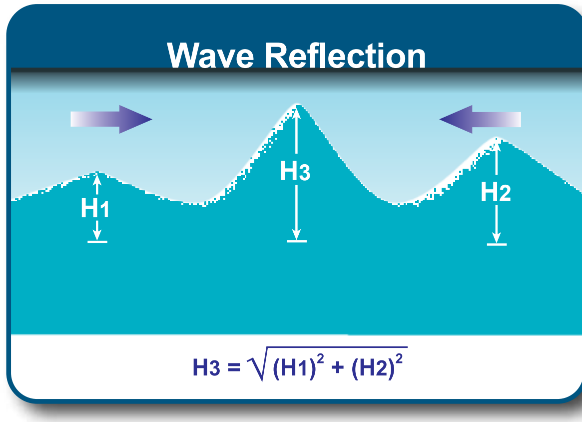


Figure 3j-1 – Using this formula (where H represents wave height), it is possible to determine how high waves will build as a result of reflection.

$$H3 = \sqrt{(H1)^2 + (H2)^2}$$

What hazards does reflection pose?

The rough, high seas caused by reflection not only create an uncomfortable ride for everyone on board but also can make it difficult for mariners to handle their crafts safely. This is particularly dangerous near shore, where waves could drive boats into hazards such as rocky shoals or piers.

Sheltering

Coastal land can also provide shelter to mariners when waters are rough or winds strong. Anchoring near shore minimizes the strength of wind blowing off the land by creating a "wind shadow". A harbour with a narrow or shallow mouth provides safer shelter during a storm because it prevents swell from entering the area and making the sea state even rougher.

Figure 3j-2 – Shallow waters at the entrance to a harbour can help shelter it from rough winds and waves, creating a safer haven for mariners.

Mariners' Tips

Although seeking shelter near shore may provide some shelter from winds blowing offshore, mariners must pay careful attention to forecasts and anticipate changes in wind direction caused by small-scale, localized events, such as outflows as thunderstorms.

3.3 Atmospheric Effects

3.3.1 Inverted Barometer Effect

Unusually high or low atmospheric pressure can cause temporary changes in sea level, which responds inversely—or in the opposite way—to atmospheric pressure. An area of low pressure, as is often found at the centre of an intense storm, causes the water level below to rise or bulge slightly. By the same token, an area of high pressure causes a slight depression in the water level. This phenomenon is known as the "inverted barometer effect".

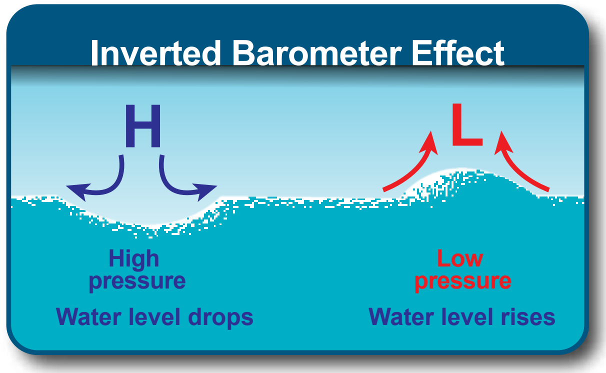


Figure 3k – Figure 3k During periods of high pressure, the water level tends to be lower than normal. During periods of low pressure, it tends to be higher than normal.

What hazards does the inverted barometer effect pose?

When an area of low pressure moves toward shore, the combination of high winds and high water can cause coastal flooding. High water can also pick up loose debris, such as logs and other material, that could pose a floating hazard to watercraft. In the opposite situation, boats could come dangerously close to touching bottom in shallow areas when water levels are further depressed by a high-pressure system.

Mariners' Tips

Increasing swell ahead of advancing storm clouds usually warns of an approaching low-pressure system with a large area of strong winds.

4. Special Types of Waves

4.1 Breaking Waves

When the crest of a wave becomes unstable, it collapses. The point at which this occurs depends on a number of factors, including the strength and direction of the wind and tide.

Breaking waves in open seas behave differently than those near shore or in shallow water. In open water, there are many different sets of waves—so their crests meet, peak, and break in irregular patterns and patches. Waves that move into shallow water, however, contact the sea bottom at the same time—so they slow down, build in height, and become unstable as a whole. This causes them to break in long, more continuous crests.

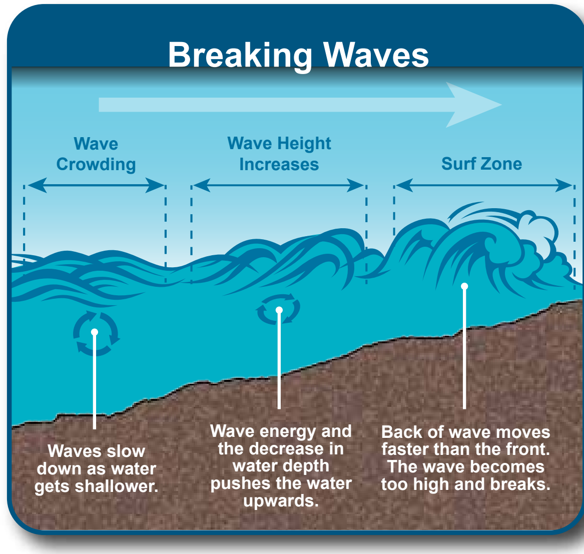


Figure 3l – When waves move into shallow water, they slow down, build in height, and become unstable, causing them to break in the surf zone.

What hazards do breaking waves pose?

Breaking waves or “breakers” cause very rough seas, and are a major hazard to boats of all sizes, depending on their height and frequency. Breakers that cause spray are of particular concern when temperatures are below freezing, as they can coat decks and rigging with a slippery layer of ice.

4.2 Crossing Waves

Crossing waves or “crossing seas” occur when one train of waves moves at an angle to another—as often happens when new waves are generated over swell from an earlier storm or when storms crossing an area are accompanied by abrupt wind shifts. This creates steep seas with short, sharp wave crests.

Figure 3m – Crossing waves or seas occur when two or more trains of waves move at an angle to one another.

When intense cold fronts move through the northern part of the Gulf of

St. Lawrence, heralded by strong southerly winds, the shifting winds that follow often cause crossing waves and confused and treacherous seas.

What hazards do crossing waves pose?

Depending on the height and period of the waves, the effects of crossing waves range from uncomfortable to hazardous for smaller vessels. They can be especially dangerous when combined with an underlying tidal current.

4.3 Tsunamis

The most destructive and dangerous of all waves, tsunamis are initiated by anything that causes a sudden, massive displacement of water—including underwater (submarine) earthquakes, bottom slides, volcanic eruptions, and landslides.

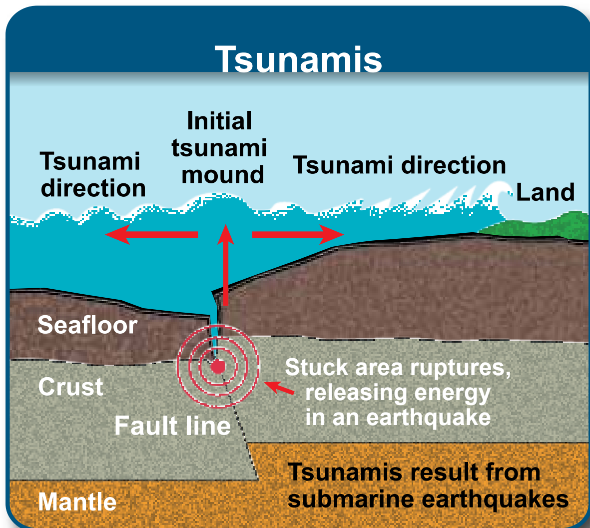


Figure 3n – Tsunamis move outward in both directions from the point at which they originate as the result of a submarine earthquake.

Tsunamis in the deep ocean have wave lengths of some 200 kilometres, making them difficult for ships to detect. Their impact, however, can be felt at great distances—often, across entire oceans. Tsunamis travel at ocean depths at speeds of about 400 knots or 740 kilometres per hour (the speed of a jet plane) and have periods ranging from 15 to 60 minutes. Even large ocean swells are a fraction of the size, travelling at 30 to 60 knots and having periods of 5 to 30 seconds.

When a tsunami crest reaches shallower, coastal waters, shoaling causes it to slow down and build in stature. Tsunamis can reach heights of 30 metres or more and often strike as a series of several enormous waves, each occurring as much as an hour apart.

Coastal Disasters in Canada

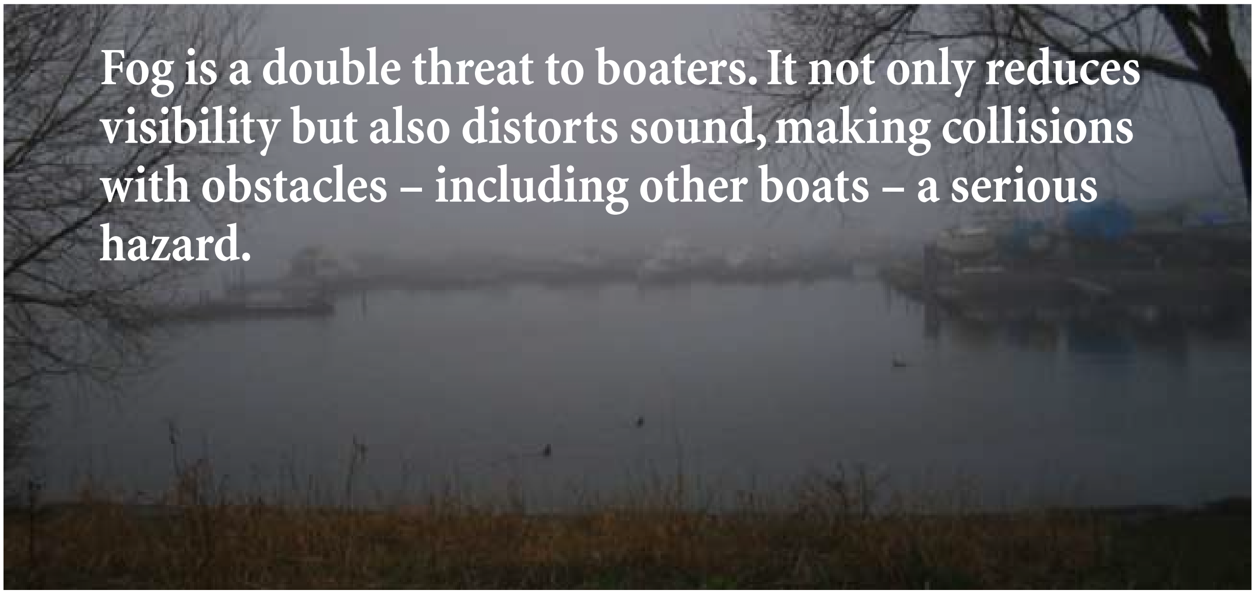
On November 18, 1929, an earthquake measuring 7.2 on the Richter Scale shook the floor of the Atlantic Ocean floor about 250 kilometres south of Newfoundland's Burin Peninsula. The tremors caused some Islanders to speculate that a mining explosion had occurred, but none were prepared for what would follow. The wrenching of the sea floor spawned an enormous tsunami that raced landward at nearly 140 kilometres per hour. A series of massive waves crashed into the Peninsula that evening, sweeping entire homes from their foundations and killing nearly 30 people. The shock of the quake broke undersea cables and knocked out the vital telegraph system, leaving victims isolated and the rest of the world unaware of the disaster for three days.

Over a century later, on March 27, 1964, a magnitude 9.2 earthquake—the second-largest reported at the time—triggered a tsunami that killed 130 people in areas along the Pacific Northwest, Japan, Hawaii, and Australia. In Canada, gigantic waves struck coastal areas of the Queen Charlotte Islands and Vancouver Island. The community of Port Alberni was the hardest hit, suffering about $5 million in damage (nearly $30 million in modern terms); fortunately, no Canadians lost their lives in the disaster.

Environment Canada, in cooperation with other federal and provincial partners, provides tsunami alerts for both the East and West coasts on Weatheradio. The Natural Resources Canada *Atlas of Canada* has more information on tsunami formation and risk in Canada.

For information on tsunami and earthquake preparations on the West Coast, consult the *Earthquake and Tsunami Smart Manual* prepared by Natural Resources Canada, Fisheries and Oceans Canada, and Emergency Management BC.

CHAPTER 4: FOG



Fog is a double threat to boaters. It not only reduces visibility but also distorts sound, making collisions with obstacles – including other boats – a serious hazard.

1. Introduction

Fog is a low-lying cloud that forms at or near the surface of the Earth. It is made up of tiny water droplets or ice crystals suspended in the air and usually gets its moisture from a nearby body of water or the wet ground.

Fog is distinguished from mist or haze only by its density. In marine forecasts, the term “fog” is used when visibility is less than one nautical mile – or approximately two kilometres. If visibility is greater than that, but is still reduced, it is considered mist or haze.

It is important to note that foggy conditions are reported on land only if visibility is less than half a nautical mile (about one kilometre). So boaters may encounter fog near coastal areas even if it is not mentioned in land-based forecasts – or particularly heavy fog, if it is.

Fog Caused Worst Maritime Disaster in Canadian History

The worst maritime accident in Canadian history took place in dense fog in the early hours of the morning on May 29, 1914, when the Norwegian coal ship Storstadt collided with the Canadian Pacific ocean liner Empress of Ireland. More than 1,000 people died after the Liverpool-bound liner was struck in the side and sank less than 15 minutes later in the frigid waters of the St. Lawrence River near Rimouski, Quebec. The Captain of the Empress told an inquest that he had brought his ship to a halt and was waiting for the weather to clear when, to his horror, a ship emerged from the fog, bearing directly upon him from less than a ship’s length away.

Fog poses a double threat to watercraft. By reducing visibility to as little as zero, it can cause boaters to lose their direction and wander off course into hazardous waters or commercial shipping lanes. The possibility of colliding with another boat is a real and serious danger in such conditions. Fog also distorts sound, which travels faster through moist air than it does through dry air, making it easy to become disoriented and underestimate speed and distance.

Mariners should treat fog with caution and be aware that visibility can change suddenly when approaching a fog bank. "If you can't see, don't go" is the best advice of all; however, even experienced boaters may be caught unaware by a sudden change in the weather.

To help mariners identify and avoid potentially hazardous situations, this chapter explains the various conditions that cause fog to form and dissipate. It also provides tips on how to navigate as safely as possible in fog, should the need arise. The International Maritime Organization's *Convention on the International Regulations for Preventing Collisions at Sea* also contains valuable information on this subject.[1]

2. Navigating in Fog

"Lights on, sound your horn, slow down, and post a lookout."

Boaters must be on full alert when navigating in fog. At the same time, they should be prepared to have their senses play tricks on them, as both sight and sound are affected by the presence of fog. It is very common, when staring out into shifting clouds, to see vague shapes—known as "fog gremlins"—that appear to be ships, islands, or lighthouses.

Although it is safest to stay on shore when fog is present or expected, mariners who are already on the water and find themselves in foggy conditions should follow these safety tips:

- Return to port, if possible.
- Slow down.
- Put on your fog lights and use radar reflectors if there is any possibility of shipping traffic.
- Use a horn or whistle to signal your presence.
- Don't distract yourself with music and conversation; stay alert for clues of land, buoys, or other boats.
- Make sure that all aboard are wearing a personal flotation device (PFD).
- Transmit your location and check for other traffic on your VHF radio.
- If you are lost, use the Canadian Coast Guard's online direction-finding service.
- Use a global positioning system (GPS), if you have one, and other means (e.g., compass, charts) to keep track of your speed, time, direction, and location.

[1] International Maritime Organization website at http://www.imo.org/ourwork/safety/navigation/pages/preventing-collisions.aspx.

3. How Fog Forms

The dew point is the temperature at which the air reaches its saturation point with respect to water vapour. This can happen when moisture is added to the air or the air temperature drops.

Water vapour is added to the air in many different ways. Heat from the sun causes it to evaporate from bodies of water and wet land. It falls from above in the form of precipitation. It is given off by plants. It can be drawn up into cool or dry air that passes over warmer water. And it can be injected into the atmosphere through human activities, such as manufacturing and transportation.

When the air temperature approaches the dew point, some of the moisture in the air condenses into liquid form and attaches itself to particles in the air, such as dust, smoke, ice, or salt. This causes fog, mist, dew, or clouds to form.

Generally speaking, fog forms when the air temperature is less than 2.5 degrees Celsius warmer than the dew point. However, even when the air temperature and dew point are the same—that is, the relative humidity is 100 percent—fog will not necessarily occur. At the same time, it can form at much lower levels of humidity under certain circumstances. For example, near the coastline and in rough seas, salt spray from breaking waves can cause fog to form even in relatively dry air.

The thickness of fog—that is, how high its top extends above ground level or water level—is largely determined by the height at which the layer of cooler air near the Earth's surface is capped by a warmer or drier air mass. This varies depending on the pressure of the air above it. For example, a fog bank may be "squashed" when the pressure above it is high but expand upwards if it starts to drop.

4. How Fog Dissipates

Any significant change in the conditions that caused fog to form will cause it to thin out or dissipate. As a general rule, fog tends to burn off in prolonged sunlight, thin out in stronger or more turbulent winds, or wash out in precipitation.

5. Fog and Precipitation

Fog commonly produces precipitation in the form of drizzle or very light snow. Drizzle often occurs when humidity reaches 100 percent and the tiny water droplets in the fog start to combine into larger droplets. Freezing drizzle occurs when the air temperature drops below zero degrees Celsius.

Precipitation can also induce fog. When warm rain falls through cooler air, some of the water in the rain evaporates and condenses in the cool air, forming fog. This kind of fog can be quite dense and generally persists until the rain moves out of the area.

When rain falls into pre-existing fog, it often improves visibility by washing out the high concentration of tiny droplets that make it hard to see. It is rare for visibility to be less than a kilometre when moderate rain and fog occur together. While heavy rain has the same effect, it can cause visibility problems because of its own intensity. On the other hand, visibility is often poor when drizzle and fog happen at the same time, likely because drizzle droplets are smaller and greater in number than raindrops.

6. Types of Fog

There are many different types of fog found in the marine environment. Fog that forms over land is only found relatively close to shore when there is an offshore wind blowing. Fog that forms over water, however, can be a hazard just about anywhere boats are found.

Being aware of the conditions under which different types of fog form helps mariners make informed decisions about whether or not it is safe to travel.

6.1 Fog that Forms Over Land

6.1.1 Radiation Fog

Radiation fog is a shallow fog (usually 1 to 10 metres deep) that forms over land but can drift over the water if light offshore winds develop at night. It usually extends no further than one kilometre from the shoreline. It is most common in late fall and early winter, when the nights are longer and the ground is moist.

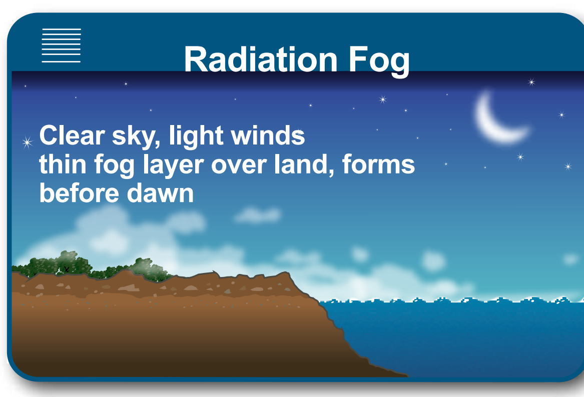


Figure 4b-1 – Radiation fog forms overnight when the ground is moist and the weather is relatively calm and clear.

How does radiation fog form and dissipate?

Radiation fog occurs over land—most commonly inland—on clear, moist nights when the wind speed is less than about five knots. It forms after sunset as the wet ground begins to cool, producing condensation in the nearby air.

The earlier radiation fog forms, the longer it lasts into the day; however, it usually burns off not long after sunrise as heat from the sun or an increase in wind speed causes the air to dry. On calm winter days, radiation fog can sometimes persist all day—especially in areas surrounded by high ground.

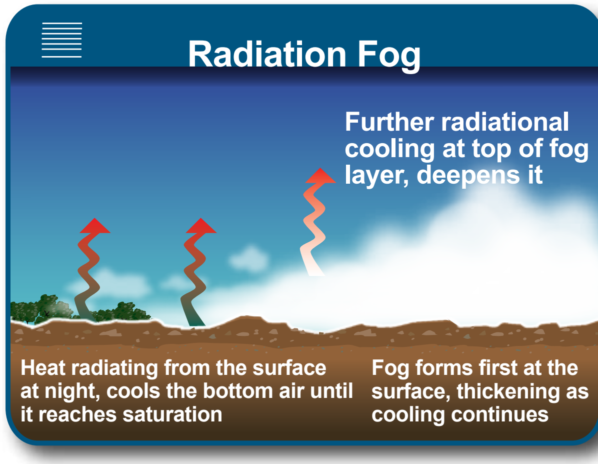


Figure 4b-2 – Thermal radiation plays a key role in the formation of radiation fog.

When radiation fog over water starts to lift, it often forms a layer of low stratus clouds that may quickly clear. If higher-level cloud cover moves in, it may take longer for the fog to dissipate; however, radiation fog is usually only a concern for morning boaters in harbours and at the mouths of rivers.

Mariners' Tips

Since radiation fog is generally quite shallow, climbing a mast may provide a clearer view of the surrounding area.

6.2 Fog that Forms Over Water

6.2.1 Advection Fog

Advection fog usually forms out at sea, although it can also occur over areas of ice and snowpack. It is generally thicker over water than it is over adjacent land masses and often covers a large area.

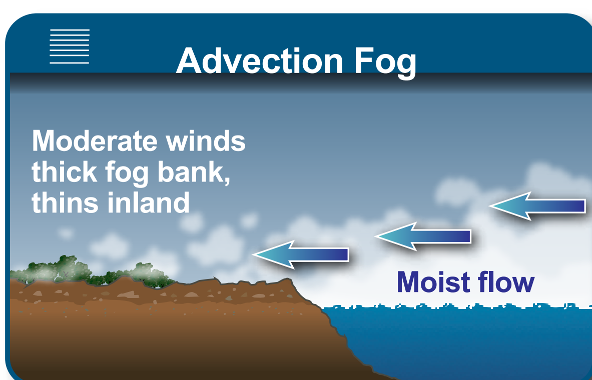


Figure 4c-1 – Advection fog typically forms at sea on breezy days.

How does advection fog form and dissipate?

Advection fog forms when warm, humid air moves over a cold surface, such as a large body of water. As the air cools, some of the moisture it contains condenses to form fog. Advection fog is generally associated with moderate winds (approximately 8 to 17 knots); lighter winds produce less dense fog and stronger ones create low stratus clouds.

Advection fog usually occurs at sea when relatively warmer air passes over cooler waters, but it can also form when a warm front moves over a significant snowpack. It often occurs on the east coast of Canada where the cold, south-flowing Labrador Current meets the warm, moist air of the Gulf Stream.

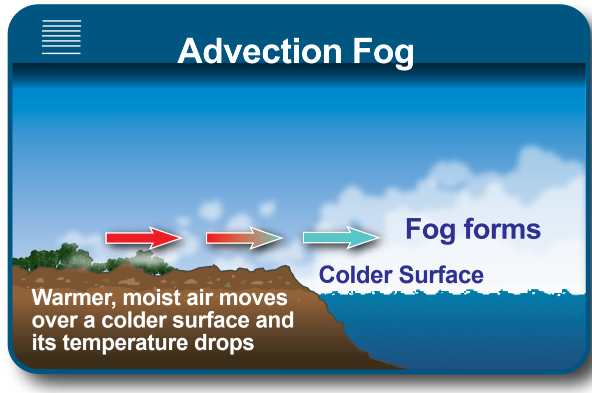


Figure 4c-2 – As warm, humid air passes over a colder surface, its temperature decreases, causing some of the moisture it contains to condense into fog.

Advection fog is particularly common in areas where currents force deeper, colder water to the surface: a phenomenon known as "upwelling". Upwelling is common at the mouth of the Saguenay River and along the entire west coast of North America. It can also be highly localized, so it is important for mariners to know about the physical properties of the areas in which they travel.

Sea-surface temperature charts or the presence of cold water currents show where advection fog is most likely to occur.

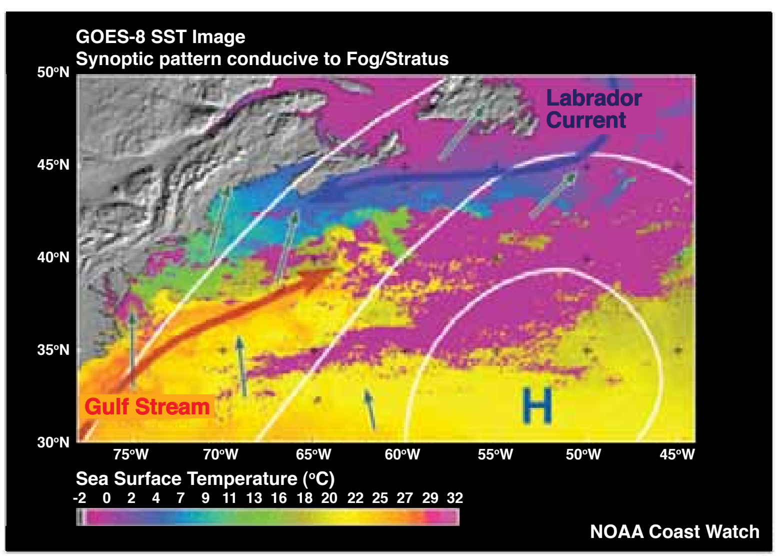


Figure 4c-3 – The movement of warm, moist air from the Gulf Stream over the much colder waters of the Labrador Current creates ideal conditions for the formation of advection fog.

Advection fog tends to be persistent and often lasts throughout the day over the water, although it may burn off closer to shore. It usually dissipates if the fog moves over a warmer current of water or after the passage of a cold front. Daytime heating and an increase in wind speed (18 knots or more) can also help dry up the air mass.

6.2.2 Steam Fog

Steam fog—named for the fact that it looks like steam rising from the water—is also known as sea smoke, Arctic sea smoke, or evaporation fog. It occurs during the cooler months of the year, when the air is much colder than the water below it.

Steam fog can be several metres thick. When it is heavy and the temperatures are below freezing, it is common for it to cause icing on boat surfaces, especially cables and runners.

Figure 4d – Formed through evaporation, steam fog is more common during the colder months, when the air is much colder than the water below it.

How does steam fog form and dissipate?

Steam fog forms as a result of evaporation when cold, dry air passes over warmer water. When the cold air makes contact with the warmer water, the lower layer of air near the surface of the water warms. Some of the water evaporates into this layer of warmer air, which then rises and mixes with the colder air above. This mixing cools the air enough that some of the newly added water vapour begins condensing into tiny droplets.

Steam fog forms more easily when there is a greater temperature difference between the air and the water. As such, it is most common in the early morning and in the fall. It is also more likely to occur when there is high humidity and the winds are relatively light. In the winter, steam fog often appears over open waters near the coastline and openings in the Arctic sea ice.

Steam fog usually dissipates once the wind exceeds five knots or the temperature difference between the air and water narrows to less than 15 degrees Celsius as a result of solar heating or wind blowing in from a warmer area.

6.2.3 Ice-Edge Fog

Ice-edge fog is a band of fog that forms near the edge of sea ice.

Figure 4e-1 – Ice-edge fog is particularly hazardous to boaters because it can hide the presence of sea ice and icebergs.

How does ice-edge fog form and dissipate?

Depending on the direction the wind is blowing, either advection fog or steam fog will form on a small scale within about 30 metres of an ice edge.

Advection fog occurs when the moist, warmer air over the ocean's surface encounters the much colder air near and over the ice. This causes some of the moisture in the air to condense, forming a localized patch of fog. Conversely, when the cool air over the ice blows over the open water, the temperature of the air over the water drops to the dew point, forming localized patches of steam fog.

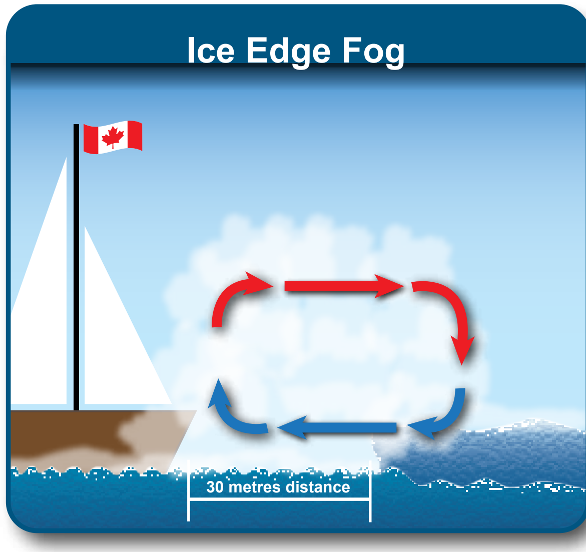


Figure 4e-2 – Ice-edge fog form two ways: when the cooler air that was over the ice blows over the warmer ocean; and when the warmer air from over the ocean blows over the colder ice.

In order for ice-edge fog to occur, the dew point of the air over the water must be higher than the temperature of the air near the surface of the ice. Favourable conditions for the formation of this type of fog are extremely light wind (or no wind) and a strong difference in temperature between the air over the ice and the ocean.

Ice-edge fog dissipates if the wind speed increases to even a few knots or if the water temperature drops to near the ice temperature.

Mariners' Tips

A telltale sign of sea ice in an area of open water is the presence of a thick band of fog, which often forms near the edge of the ice.

6.3 Fog that Forms Over Land or Water

6.3.1 Stratus Build-Down Fog

Stratus build-down fog is actually the base of a very low stratus cloud. It is not as common as advection or radiation fog.

Figure 4f-1 – When the base of a stratus cloud reaches the surface, it is called stratus build-down fog.

How does stratus build-down fog form and dissipate?

The process that causes stratus build-down fog to form usually begins at night, when there are clear conditions above a low stratus cloud. As its heat radiates out into space, the top of the cloud begins to cool and some of its moisture condenses into tiny water droplets. These additional droplets cause the base of the cloud to extend downward, until it reaches the surface.

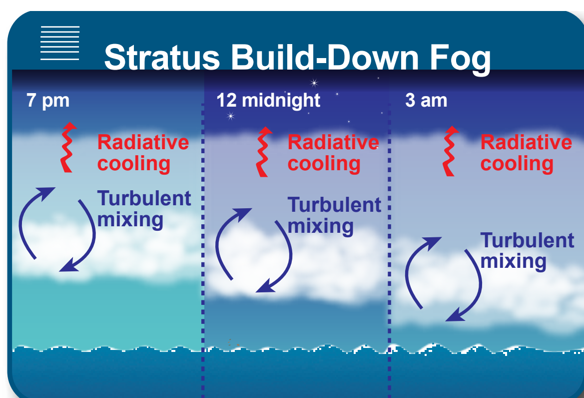


Figure 4f-2 – Radiative cooling plays a key role in the formation of stratus build-down fog.

Stratus build-down fog is most likely to form when the air near the surface of the Earth is cold and the atmosphere in very stable. Ideal conditions are when the marine inversion boundary layer is less than 400 metres high.

Stratus build-down fog dissipates when a cold front passes through and destabilizes the atmosphere or when solar heating or warm winds cause an increase in the air temperature near the surface.

6.3.2 Precipitation Fog

As its name suggests, this type of fog is formed by precipitation. It is also known as frontal fog because it often occurs ahead of warm fronts and behind cold fronts. If the rain moves away, so does the fog.

How does precipitation fog form and dissipate?

As precipitation falls from a cloud into the drier air below, some of its droplets evaporate into water vapour, increasing the moisture in the air. When the air reaches its saturation point, some of this vapour condenses into fog.

Precipitation fog is more likely to develop in drizzle than heavy rain, because the smaller droplets evaporate more easily and are also less likely to wash out the fog, once it has formed. The lighter the winds and the longer the duration of the precipitation, the more likely it is for the fog to occur.

When this type of fog is associated with a warm front, it is created mainly by the precipitation falling ahead of the front. This is known as "pre-frontal fog". Because the rain originates higher in the atmosphere, where the air is warmer, it evaporates more quickly than usual as it falls through the much cooler air below.

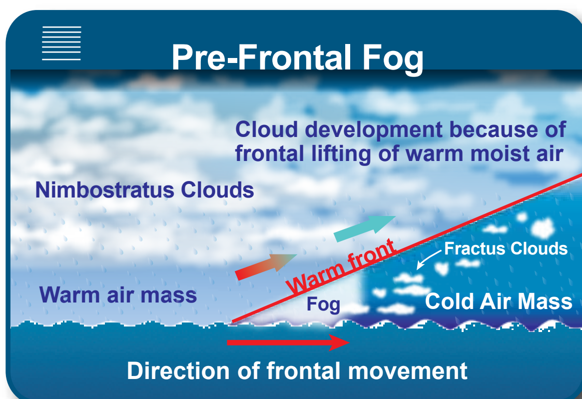


Figure 4g – When precipitation fog occurs ahead of a warm front, it is known as "pre-frontal fog".

Precipitation fog can also form behind a cold front. As the precipitation falls into the cold, stable air, it gradually increases the humidity until the air is saturated. Fog forms when the moisture in the air condenses. This "post-frontal fog" is similar to radiation fog because it also occurs when the sky is clear, the wind is light, and the surface is moist.

Precipitation fog dissipates when wind speeds increase, after the warm or cold front has passed by, and when the air in the lower layer of the atmosphere warms up.

Mariners' Tips

When a warm front is approaching and stratus fractus clouds (small, ragged fragments of cloud) develop in the precipitation, it is a good sign that pre-frontal fog is going to form.

6.3.3 Ice Fog

Also known as "frozen fog", ice fog is made up of tiny ice crystals. It occurs only in the cold winter months and most often in northern regions, as very low temperatures are required for it to form. In the Arctic, it is not uncommon for ice fog to reduce visibility to almost zero.

The tiny crystals in ice fog can create slippery conditions when they settle on the decks of ships and other surfaces. Ice fog can also cause sparkling pillars of light to appear in the air directly over a source of light. This unusual phenomenon is caused by the light being reflected and refracted by the ice crystals in the fog.

How does ice fog form and dissipate?

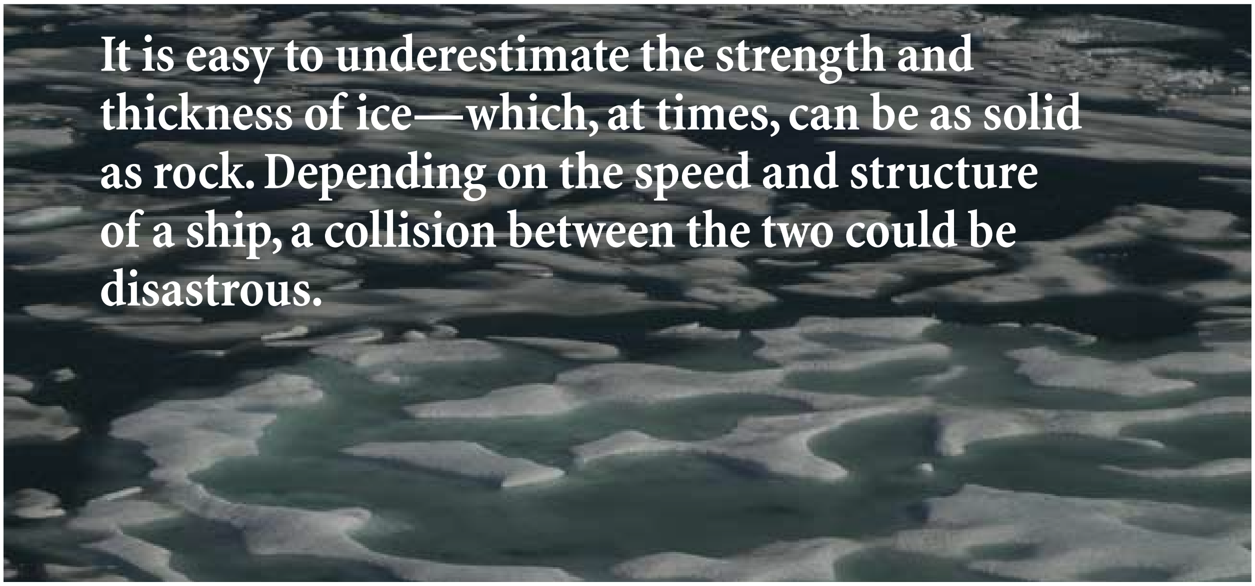
Ice fog occurs when extremely cold temperatures freeze tiny water droplets into ice crystals in midair.

Although different threshold temperatures apply at different locations, ice fog is very rare at temperatures warmer than -10° Celsius and is quite common when the air temperature is below -30°C. It can only form when there is a source of moisture nearby and the winds are light.

In the Arctic, sources of water vapour include cracks and other openings in the sea ice. Moisture also comes from internal combustion engines used for transportation, heating, and power generation.

Ice fog can be extremely dense and can persist night and day until the temperature warms up sufficiently. Ice fog also dissipates when surface winds increase to more than five knots or the lower atmosphere becomes unstable.

CHAPTER 5: ICE



1. Introduction

Countless tales of mariners whose ships have been trapped, lost, crippled, or sunk while navigating in winter or in the frigid passages of the North are a stark reminder of the challenges and hazards of operating a vessel in ice-covered waters.

It is easy to underestimate the strength and thickness of ice—which, at times, can be as solid as rock. Depending on the speed and structure of a ship, a collision between the two could be disastrous. Adding to the danger is the fact that localized fog often forms in the area where the ice edge and open water meet.

Changes in the consistency of the water due to the formation of ice crystals can also increase fuel consumption, and could lead to a vessel becoming stranded in extremely cold conditions.

While ice floes can provide shelter from rough seas and reduce vessel icing caused by freezing spray, mariners operating in or near ice-covered waters must factor extra precautions into their planning. They must also have the knowledge, equipment, and crew needed to navigate safely in such conditions.

This chapter provides basic information on the properties of different types of ice, how the local environment and weather influence ice conditions, and how to read and interpret ice and iceberg charts. Additional information is available in Chapter 4 of the Canadian Coast Guard publication *Ice Navigation in Canadian Waters*. Current and expected ice conditions can be found here.

2. Types of Ice

Three types of ice affect marine navigation: freshwater ice (found in lakes and rivers), sea ice (found in oceans), and icebergs (found in oceans, but created from freshwater glaciers).

Not all are the same. The strength and thickness of ice and the way it forms, moves, melts, and breaks up depends on a variety of different factors. Ice formation, for example, is affected primarily by the salinity (or salt content) of the water.

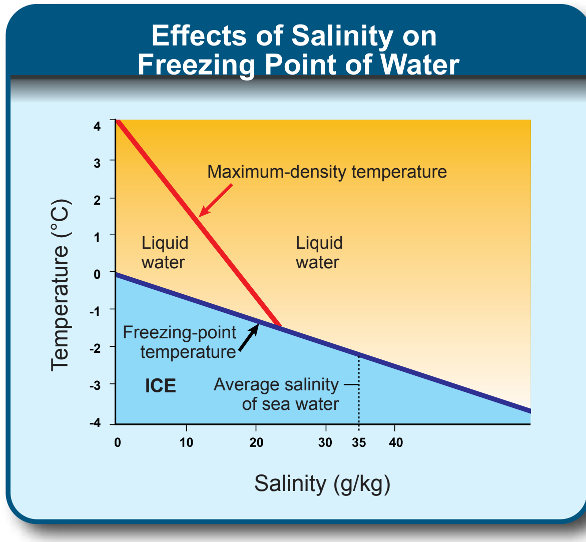


Figure 5a – Salinity affects the maximum-density temperature and, therefore, the freezing point of water. As a result, the higher the salt content, the colder it must be for ice to form.

2.1 Freshwater Ice

Fresh water—that is, water that has a salinity of less than 1 gram per kilogram—starts to freeze at approximately 0°C. Freshwater ice forms on inland lakes and rivers at times of the year when the temperature is below freezing for an extended period of time.

2.1.1 Formation

As fresh water cools, it becomes increasingly dense until it reaches what is known as "maximum-density temperature", which is approximately 4°C. As it drops below this temperature, the opposite occurs, and its density decreases—causing the cooler water to float to the surface. Once it reaches the freezing point, it forms a layer of ice. Ice forms in a different way on lakes than it does on rivers, where it is affected by fast-moving currents and other physical features, such as bends and narrows.

2.1.1.1 Lake Ice

The depth of the water and the strength of the currents in a lake determine where ice will form and how thick it will be.

When the temperature of the air drops below the temperature of the lake, the layer of water at the surface begins losing its heat to the atmosphere. As it cools and becomes more dense, this water sinks and is replaced by warmer water from below.

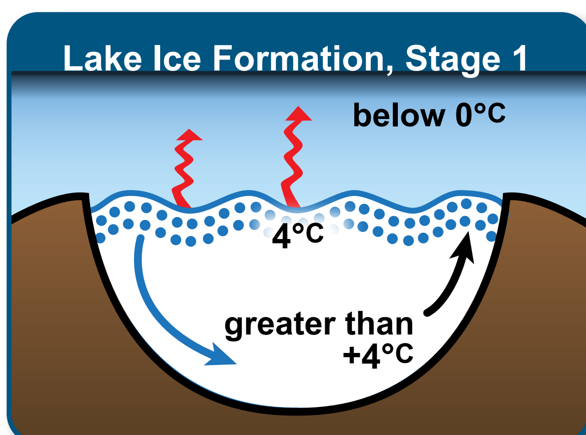


Figure 5b-1 – As water at the surface of the lake begins to lose its heat to the cooler air, it sinks and is replaced by warmer, less dense water from below.

This "mixing" continues until all of the water in the lake has reached maximum-density temperature, at which point it stops. As the top layer of water continues to cool, it drops below maximum-density temperature, becoming less dense—and, therefore, lighter—than the water below it. As a result, it remains at the surface.

The cooling process in this top layer of water is accelerated because mixing has ceased. It happens even faster if there is a brisk wind, which cools the surface the same way it does exposed skin. Once the water at the surface reaches the freezing point, ice crystals (or "frazil" ice) begin to form and thicken. These soupy conditions can make it difficult for small boats to navigate and can cause watercraft of all sizes to burn more fuel than usual.

As the crystals freeze together, they create a layer of ice on the surface of the lake, which thickens slowly as the water beneath it cools to freezing through conduction, or contact with the ice. By acting as an insulator, the surface ice allows water near the bottom of larger lakes to remain well above freezing throughout the winter.

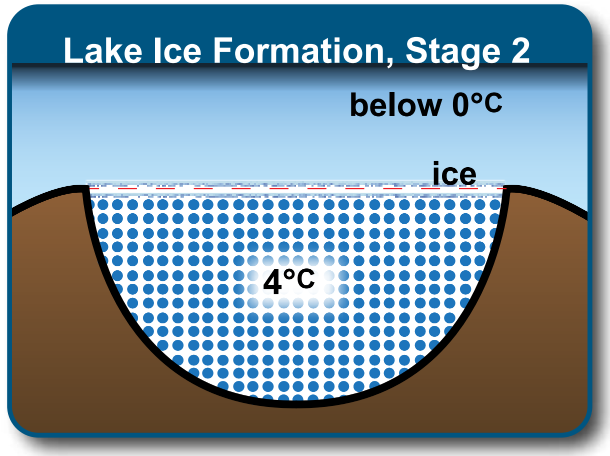


Figure 5b-2 – Once the entire lake has reached a maximum-density temperature of approximately 4°C, ice begins to form on the surface as the top layer cools to freezing.ice to form.

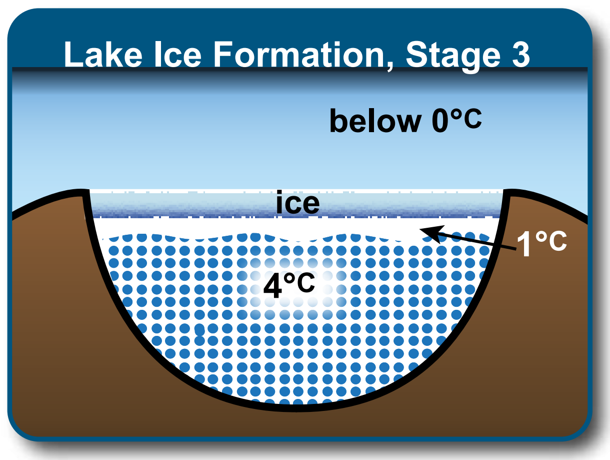


Figure 5b-3 – Once a uniform sheet of ice has become thick enough, the speed of growth begins to slow. The ice cools the adjacent water, allowing it to slowly thicken, but also insulates the water deeper in the lake, allowing it to remain above 0°C throughout the winter.

2.1.1.2 River Ice

Bends and narrows, the depth of the water, and the strength of the currents in rivers determine where ice will form and how thick it will be.

Ice forms first where the currents are weakest and the water is shallowest—often, near the banks of the river. As the air temperature drops further, clumps of frazil ice begin to form. These eventually float to the surface, where they freeze together to create "ice pans".

These ice pans, which are rough-edged from colliding with one another as they move with the current, can impede boats and cause damage to hulls and engines. They become an even more severe hazard when they freeze together to create larger "ice rafts". Ice pans and rafts often get caught and freeze together at bends, narrows, and bridges, causing ice to accumulate upstream of these areas as well.

The ice cover on a river grows thicker in two ways. One is through the same conduction process that occurs on lakes; the other is when the weight of the snow on the surface of the ice is heavy enough to push it down into the water, causing the water below to rise up onto the surface and freeze.

Although ice cover on a river can be significant, there are parts that may never fully freeze due to rapid currents and fluctuations in water level. As a result, sections of ice that appear to be as thick as others may, in fact, be much thinner.

2.1.2 Decay

Ice decays—in other words, it melts and breaks up—at different times and at different rates depending on a variety of local factors and the characteristics of the ice itself. In the same way that ice forms differently on lakes and rivers, it also decays differently.

2.1.2.1 Lake Ice

Lake ice decays mainly through two methods: melting caused by the sun's radiation and pools of meltwater on the surface of the ice; and heat conduction from the surrounding land and warmer water flowing under the ice from streams or runoff.

As air temperatures increase and meltwater ponds form on the ice's surface, the ice begins to lose strength.

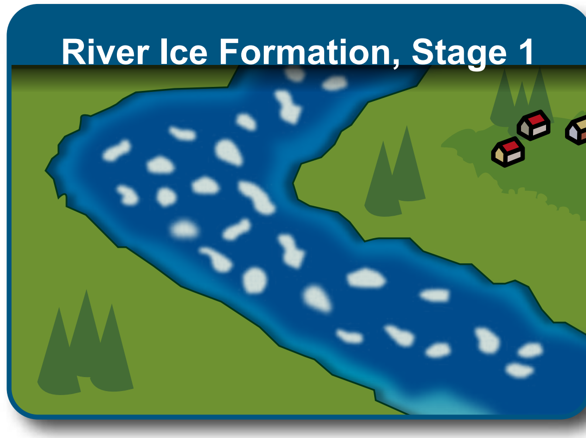


Figure 5c-1 – On rivers, ice forms first in calm or shallow areas. The water becomes thick and soupy with ice crystals.

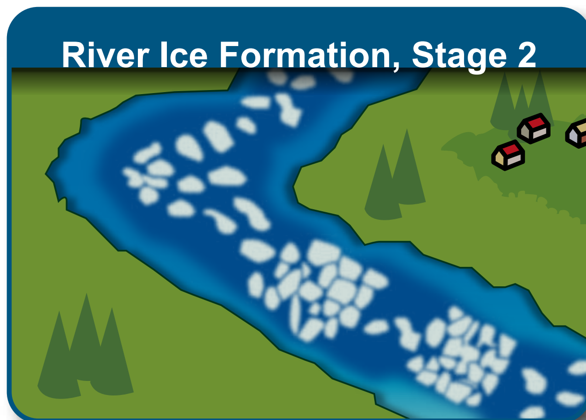


Figure 5c-2 – The ice crystals stick together and float to the surface, creating ice pans and, eventually, larger ice rafts. As the air temperature drops, the ice fuses together.and, eventually, larger ice rafts. As the air temperature drops, the ice fuses together.

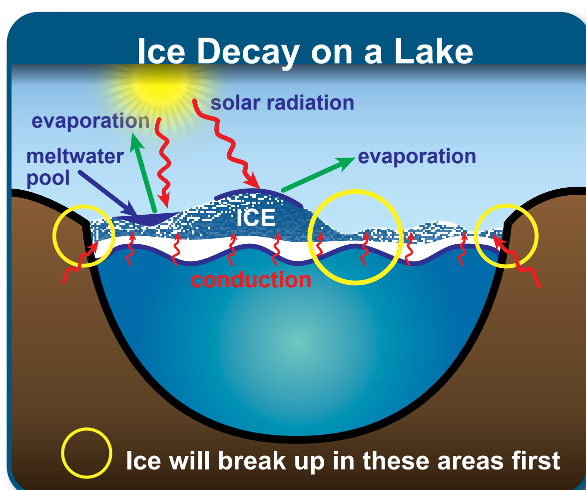


Figure 5d – On lakes, ice decays first in areas where it is thinnest or in contact with land.

Eventually, the thinnest parts and those in contact with the land reach 0°C and begin to melt. As portions of the lake become ice-free, and the water is heated directly by the sun, this process speeds up.

2.1.2.2 River Ice

Ice cover on rivers also decays by melting in place, as it does on a lake. As it breaks up, the pieces are then carried downstream on the current. River ice can also break up as a result of an increase in water levels resulting from rainfall, snow melt, or ice jams.

Rising water levels cause cracks to occur in the ice cover, where the thinnest areas have usually already been weakened by melting. The current breaks the fractured ice into sheets and carries it downstream. If the ice catches on islands or in narrow parts of the river, it can create a jam—blocking the flow of the water and causing water levels to rise even higher. Ice jams are extremely dangerous because they can cause flash floods and may suddenly break, sending massive waves of ice and water rushing downstream.

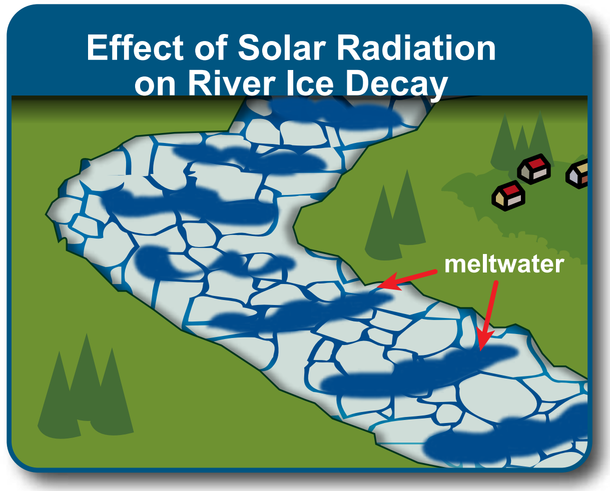


Figure 5e-1 – Heat from the sun creates meltwater ponds on the surface of the ice.

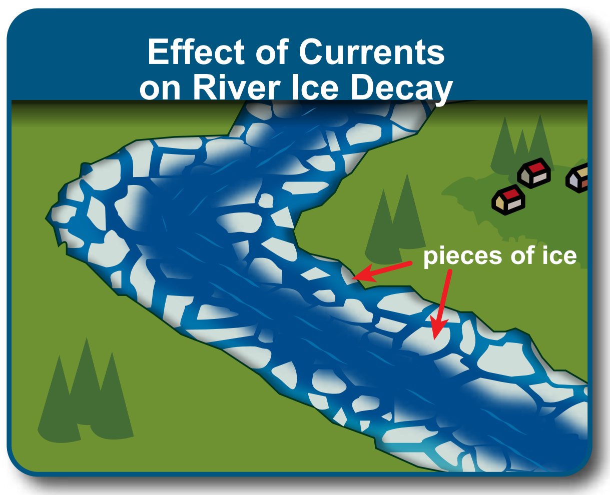


Figure 5e-2 – Ice weakened by melting is broken up by currents in the river.

2.2 Sea Ice

Sea water—which has a salinity of approximately 34 grams per kilogram—freezes at about -1.8°C (nearly two degrees lower than fresh water) because of its higher salt content. In Canada, sea ice is found in the waters of the Arctic, Hudson Bay, the Atlantic Coast, and the Gulf of St. Lawrence in consolidated sheets, moving packs, or separate floes.

2.2.1 Formation

Sea water not only has a lower freezing point but also reaches its maximum density at a lower temperature than fresh water. In fact, it reaches its freezing point before it starts to become less dense. If salinity levels at the surface are sufficiently high, and if similar salinity levels extend deep enough, the cooler water at the surface will sink and be replaced by warmer water from below. It is this property that makes it possible for open water to persist in parts of eastern Canada throughout the cold season.

Sea ice forms differently in the open water than it does near shore (where it is also known as "land-fast" sea ice).

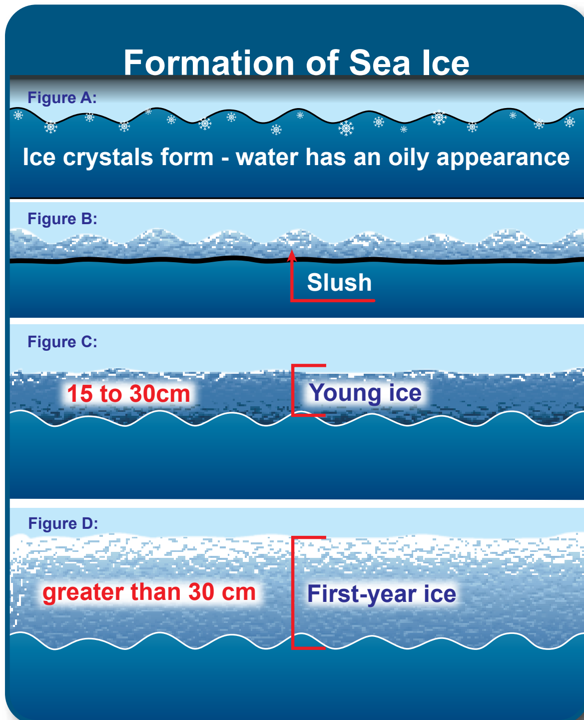


Figure 5f – A) Ice crystals form as the top layer of water cools below -1.8°C; B) As more surface water cools to freezing, a thick slush forms; C) An ice sheet forms, thickening through conduction with the water below until it is 10-30 cm thick, when it becomes known as Young Ice; D) Thickening continues through the same process until the ice exceeds 30 cm, at which point it is considered First-Year Ice.

2.2.1.1 Open-Water Sea Ice

Sea ice forms in a similar way to river ice, except it freezes at a lower temperature.

When the air temperature drops below the temperature of the sea water, the surface of the water begins to cool—a process enhanced by the presence of brisk winds, which create a wind-chill effect. As the water cools and becomes denser, it sinks and is replaced by warmer water from below.

When the water at the surface has reached -1.8°C, ice crystals begin to form, giving the water an oily appearance. This process continues until the surface is thick and slushy—a stage at which navigation is particularly difficult for smaller boats, and fuel consumption increases.

Eventually, the "New Ice" at the surface consolidates into a sheet and gradually thickens into "Young Ice", which has two categories of thickness: Grey Ice (10-15 cm) and Grey-White Ice (15-30 cm). Young Ice is less elastic than New Ice and often cracks in swells. It thickens as the warmer water below it loses its heat through the surface ice to the colder air above—cooling to the point where it freezes to the underside of the sheet. The greater the temperature difference between the air and water, the faster the ice thickens.

Once ice reaches 30 cm in thickness, it is known as "First-Year Ice" and classified as thin (30-70 cm), medium (70-120 cm) or thick (over 120cm). On October 1 of each year, all remaining First-Year Ice celebrates "ice birthday" and is henceforth known as "Second-Year Ice" or "Old Ice" (see the Local Effects chapter on the Arctic for more information). This date was chosen because it is the point in the season when the oceans in the northern hemisphere start losing more energy than they receive, and ice formation becomes more widespread than ice melt.

2.2.1.2 Land-Fast Sea Ice

Land-fast or near-shore sea ice forms in two ways: *in situ*, and through the accretion of floe ice.

In Situ

Ice grows easily in a sheltered bay or fiord, as water near the shore is much shallower than water out at sea, so it takes less time for its surface layer to cool to freezing. As with open-water sea ice, once the water has cooled to this point, ice crystals begin to form and thicken, eventually creating a sheet of land-fast ice—so called because it is attached to the shore.

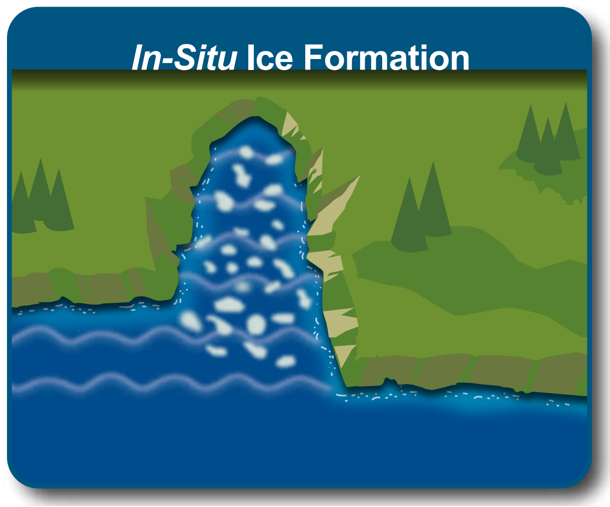


Figure 5g-1 – In-situ ice formation occurs in sheltered bays and fiords, where fragile, newly formed ice is protected from rough sea state.

Accretion of Floe Ice

Ice floes are sometimes pushed by winds or currents toward land or land-fast ice, where they freeze in place: a process known as "accretion". This ice may be a different thickness than the ice that is already there. Where rivers flow into the ocean, the sea water often freezes up first because ice pans that have already formed in the fresh water help lower the water temperature to freezing and salinity levels are lower due to the mixing of fresh and salt water.

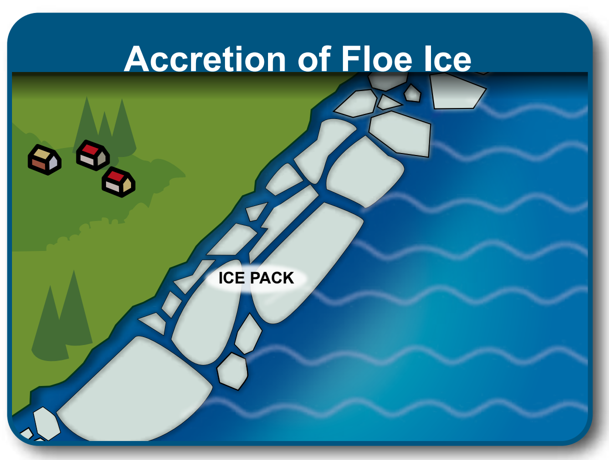


Figure 5g-2 – Ice can attach to the land if it is pushed against the shore and freezes in place.

2.2.2 Decay

Solar radiation and heat conduction from land and water cause sea ice to decay; however, the higher salt content of sea ice also causes some unique effects.

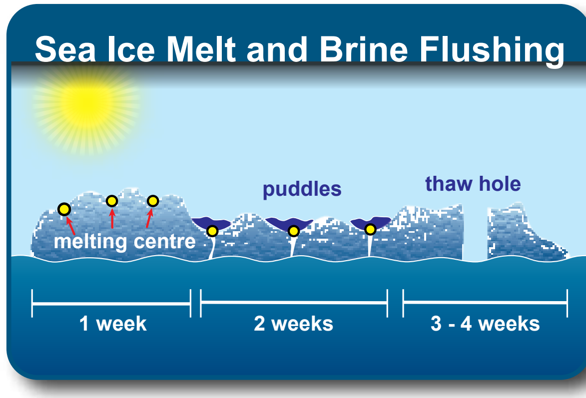


Figure 5h – Differences in the reflectivity of the sea ice and the pockets of brine and impurities inside it cause the latter to warm up faster, speeding the melting process in the surrounding ice. The melt holes travel through the floe, and the brine and impurities are eventually flushed out in the meltwater.

Pockets of brine (very salty water) and impurities such as dirt and dust that are trapped inside the sea ice have what is known as a lower "albedo" than ice, meaning they are less reflective and absorb more energy from the sun. As a result, they warm up faster, forming puddles in the ice that cause the surrounding ice to melt more quickly. This creates thaw or melt holes that travel all the way down through the ice floe, where the brine and impurities are flushed out in the meltwater. As these holes weaken the ice, it breaks into smaller pieces and eventually melts completely. The time it takes for this process depends on air temperature, but tends to be three to four weeks.

In some coastal areas, the upwelling of warm water from deep below the surface of the ocean can cause sea ice to melt through conduction, even in the middle of winter. In other conditions, melting can occur on top of the ice floe, while it continues to thicken from below. The ongoing process of flushing and growth helps to create Multi-Year Ice (covered in more detail in the Local Effects chapter on the Arctic), which is much stronger than younger ice because its salt content decreases as it ages.

Generally speaking, sea ice melts first

- where rivers drain into the ocean, because their warmer water speeds melting,
- along the edge of floes, where the ice is thinner and breaks off and melts faster,
- near open-water polynyas, because the sun-warmed water and the winds and currents that created the polynya helps melt the surrounding ice, and
- in areas where strong currents or large tidal variations wear the ice away from underneath.

2.2.3 Movement

Sea ice moves two ways, depending on the winds, tides, and currents affecting it: in an outward or divergent direction, or in an inward, convergent one. The direction in which the ice moves affects its distribution, thickness, and other physical characteristics.

2.2.3.1 Divergent Ice Floes

When ice floes diverge or disperse, they spread out to cover a larger area. As a result, they often create leads and cracks in the ice. While some openings may enable vessels to navigate through ice floes, mariners must be very careful not to become trapped if they suddenly freeze up or the ice shifts and the opening closes.

Polynyas are non-linear openings in the ice that regularly occur in areas where strong, warm currents and prevailing wind directions cause any ice that forms to quickly move away. More prevalent in the Arctic, they are critical to marine life in the winter.

A crack is a fracture in fast ice, consolidated ice, or a single ice floe. Cracks occur when an ice sheet breaks and reforms, and vary in width from a few centimetres to a metre. When ice is only a few inches thick, stress cracks are common—most of them associated with thermal stress caused by the temperature difference between the colder air above the ice and the warmer water below it. Larger cracks can also be caused by water level changes, heavy snow loads, or strong winds.

Leads are linear cracks in the ice that are wide enough to be navigable. When they form between the shore and an ice floe, they are called coastal or shore leads; between land-fast ice and an ice floe, "flaw" leads. Covered with thick, slushy waters as a new ice sheet begins to form, they can freeze suddenly and close up quickly if conditions switch from divergent to convergent.

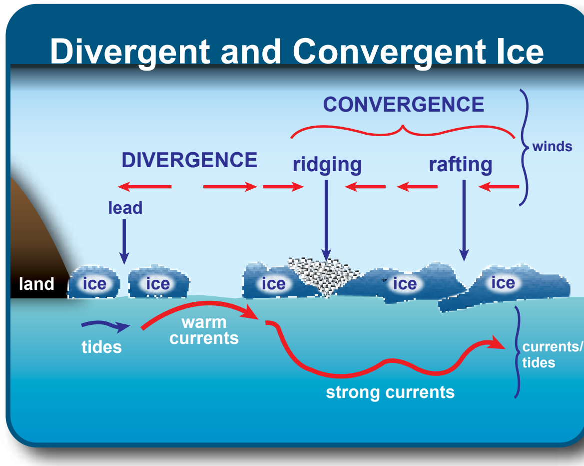


Figure 5i – Visual indications of divergent and convergent ice conditions.

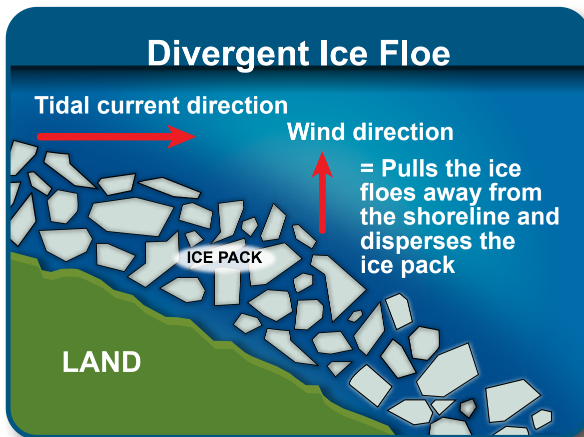


Figure 5j-1 – In a divergent ice floe, the ice pack disperses or spreads out over a larger area.

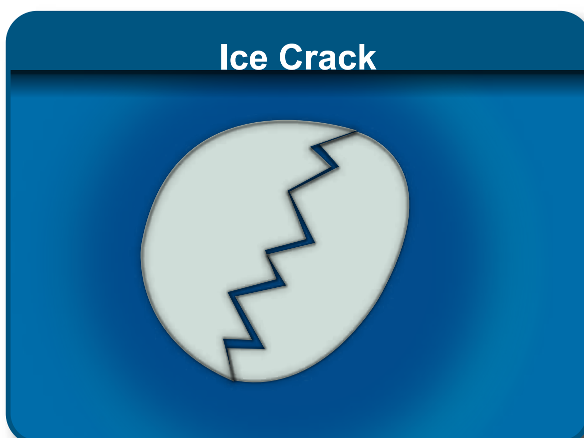


Figure 5j-2 – Ice cracks occur as a result of significant differences in temperatures above and below the ice, water-level changes, heavy snow loads, and strong winds.

2.2.3.2 Convergent Ice Floes

When ice floes converge, they are driven together into a smaller area, where they collide and often pile up. Floes pushed against the shoreline or land-fast ice by onshore tides and currents may be under particularly high pressure.

Ice floe convergence is associated with three unique phenomena—rafting, ridging, and hummocks—all of which result in stronger, thicker areas of ice. Convergent ice floes can be very hazardous to mariners, because vessels may become trapped between floes as they are forced together.

When younger, thinner ice floes collide under convergent conditions, the pressure often forces one to slide onto the other—a process known as "rafting". When these layers freeze together, they create stronger, thicker ice.

When older, thicker ice floes collide, their weight and density makes it more likely for the ice on their front edges to break into fragments along their seams, rather than pile up. This process is called "ridging" because these smaller pieces of ice are pushed together and freeze solid, creating a ridge of thicker ice between the two floes.

Small hills of broken ice—known as "hummocks"—that are caused by ridging can indicate the age of an ice floe. More weathered hummocks are associated with older, thicker floes (e.g., Multi-Year Ice), while fresher hummocks are characteristic

Figure 5j-3 – A lead in the ice may allow passage by vessels; however, mariners must be careful not to become trapped if it suddenly freezes closed or the ice shifts.

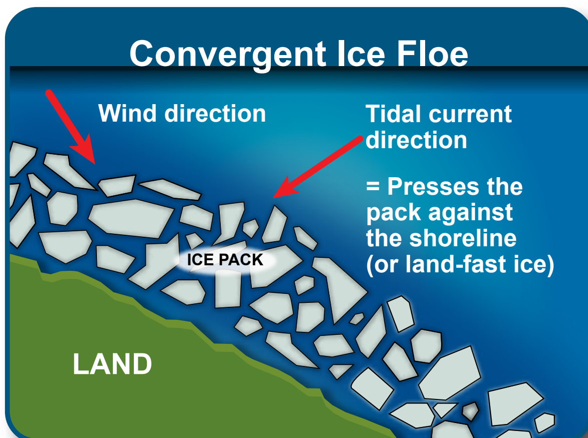


Figure 5k-1 – In a convergent ice floe, the ice pack is pushed together or up against the shoreline or land-fast ice.

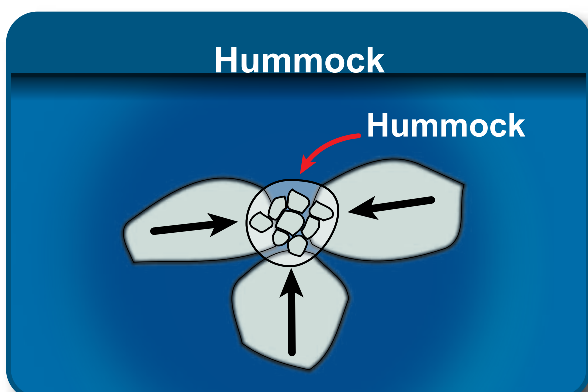


Figure 5k-2 – Hummocks are very strong because they are made up of pieces of ice that have piled up and frozen together as a result of convergence and because they contain less salt than normal sea ice.

of younger, thinner ones (e.g., First-Year Ice). Hummocks are much stronger than pressure ridges, as they are made of older sea ice that has lost much of its brine through the ongoing process of flushing and growth. As a result, they melt at the same temperature as freshwater ice (0°C), while sea ice floes melt at lower temperatures.

2.3 Icebergs

Icebergs are massive chunks of freshwater ice that have broken off a glacier or an ice shelf that extends over the ocean. Icebergs have a height-to-draft ratio of roughly 1:7, meaning that for every metre visible above the waterline, there are seven below it.

The result of centuries of snowfall, roughly 90 percent of the icebergs encountered in Canadian waters are from glaciers in western Greenland; however, some also come from Ellesmere Island. In Canada, they are found in the eastern Arctic and off the East Coast.

Figure 5l – The average direction of iceberg movement on the East Coast of Canada based on prevailing winds and currents.

Icebergs are a serious collision hazard for mariners because they are as hard as rock, are difficult to see in high waves, and most of their mass is hidden below water level. They can also shear off, break apart, or roll unexpectedly, creating large waves that could affect vessels in their vicinity.

2.3.1 Formation

Icebergs form as a result of waves and tidal action, which create stress fractures in the part of the glacier or ice shelf that extends over the ocean. Eventually, the weakened ice breaks along its fractures and is released into the ocean: a process known as "calving".

2.3.2 Decay

Wind-driven waves, collisions with sea ice and land, and frequent freeze-thaw cycles (both daily and seasonal) create crevasses in icebergs, enabling water to seep in and warm them to melting temperature. Before they dissolve completely, icebergs often break apart violently, creating large waves in the surrounding waters. Smaller pieces of iceberg are known as "bergy bits" or "growlers". Icebergs typically last three to six years, although those trapped in certain winds and currents can survive much longer.

2.3.3. Movement

Icebergs move with the wind and currents. In Canada, most icebergs drift from Greenland to Baffin Bay, through the Hudson Strait, and south to Newfoundland and Labrador, where they eventually melt.

3. Properties of Ice

3.1 Strength

The strength of ice is determined mainly by the temperature of the ice and the number of brine pockets it contains. Ice is much stronger at colder temperatures. As it approaches the freezing point, it loses up to 90 percent of its strength.

The strength of sea ice is lessened by the presence of brine pockets, which makes it less dense—and therefore weaker—than freshwater ice. As it gets warmer, these pockets expand, reducing the strength of the ice even further.

3.2 Thickness

The thickness of ice is affected by the same factors that affect its growth and decay. On lakes and rivers, for example, these factors include fluctuations in water levels, currents, ambient air temperature, prevailing wind direction and speed, and snow cover.

As melting occurs on the surface of the ice as a result of warmer air temperatures, the meltwater evaporates, leaving an ever-thinner layer of ice. Changes in water levels also speed the process by which ice decays. When the water level rises, it exerts an upward force on the ice above, causing it to crack and break, and flooding the surface with water. When the water level drops, it removes support from the layer of surface ice, causing it to eventually collapse under its own weight.

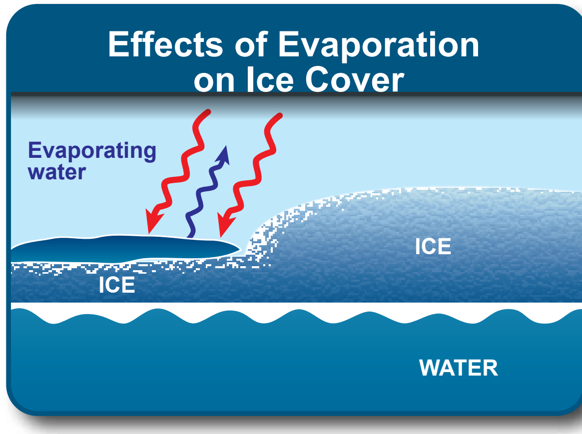


Figure 5m-1 – The evaporation of meltwater from the surface of the ice reduces its thickness.

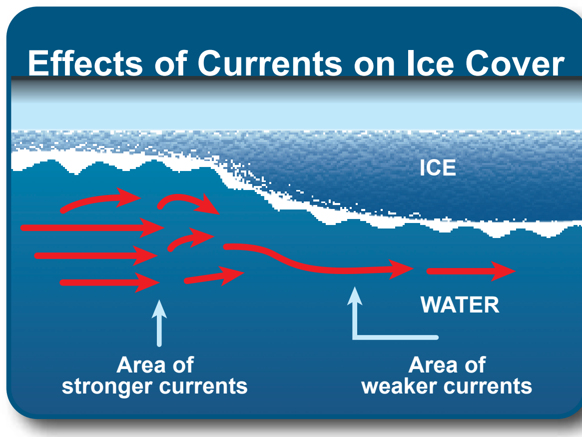


Figure 5m-2 – The stronger the current, the more it erodes the ice from below.

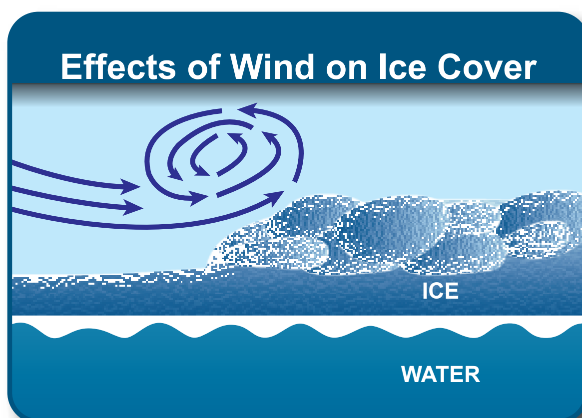


Figure 5m-3 - Figure 5m-3 The strength of the wind and the length of time it is blowing from one direction can cause ice to pile up, creating a thicker area than usual. Ice in the direction the wind is blowing from may be thinner as a result.

Currents within a river can break up ice cover and wear away ice thickness from below. If air temperatures increase to above freezing, the first effect of melting is a reduction in ice strength, the second a decrease in thickness.

If winds blow from the same direction for a long time, ice in the area where it piles up will be much thicker, while ice in the direction it came from, much thinner. This happens even faster when the winds are strong.

If there is a blanket of snow cover on the surface of ice when it is forming, it will slow its growth by insulating the water below the ice from the colder temperatures above it. This results in thinner ice than expected.

It is possible to estimate the thickness of ice from its appearance, using the following table:

Trait	Thin Ice	Thick Ice
Colour	Dark	White
Fractures	Appear like jagged tears	Occur in straight lines
Rafting/Ridging	Rafting	Ridges
Ioe Structure	Not readily distinct floes; jagged edges	Distinct floes; rounded edges

4. Ice Forecasting

A variety of forecast products are produced on a daily and weekly basis to provide mariners with the information they need to navigate as safely as possible in ice-covered waters. In order to understand ice charts properly, mariners must be familiar with the “egg code”: the coded symbol developed by the World Meteorological Organization to describe the qualities of both freshwater and sea ice.

4.1 Egg Codes

Egg codes are oval symbols that are divided into four sections, each of which provides different information on the ice present in a given area. From top to bottom, these sections indicate the following:

- **Total Concentration of Ice**: Given in tenths of total coverage.
- **Concentrations of Predominant Ice Types**: The concentration of the thickest types of ice in the area (up to three types). Also given in tenths of coverage.
- **Stage of Development**: The stage of development or thickness of each of the predominant ice types identified.
- **Floe Size**: The floe size of each of the predominant ice types identified.

For more details on the coding used to identify the stage of development and floe size of ice, or other information on egg codes, visit the Canadian Ice Service website.

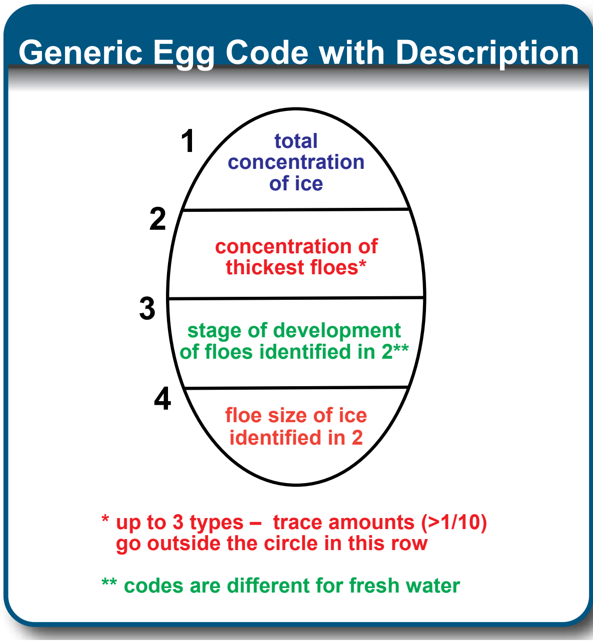


Figure 5n-1 – A generic egg code indicating the type of information provided in each section.

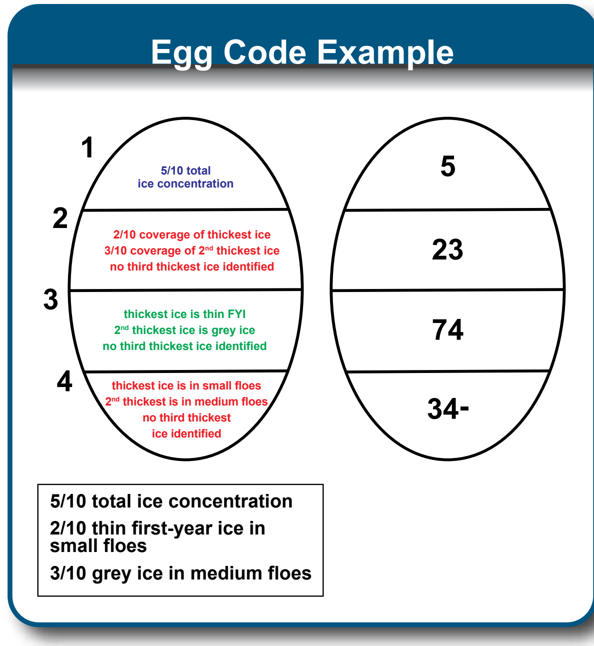


Figure 5n-2 – Example of an egg code as it would appear on an ice chart (right). The written description on the left explains the meaning of the numbers on the right.

4.2 Ice and Iceberg Charts

Ice and iceberg charts are used for both tactical (day-to-day) and strategic (longer-term) planning and operational purposes. Different types of charts provide different information, as indicated in the list below.

Daily ice charts provide daily estimates of ice conditions in areas of marine activity.

Regional ice charts provide weekly estimates of ice conditions and make up the official climate records.

Departure-from-normal-concentration charts indicate the difference in ice concentration between the current regional ice chart and the 30-year median.

Image analysis charts interpret ice conditions from satellite imagery.

Aircraft ice charts provide information on ice conditions observed from an aircraft survey.

Iceberg charts provide daily estimates of iceberg conditions.

CHAPTER 6: OTHER HAZARDOUS WEATHER

Figure 6a – In cold, wet conditions, a thick layer of ice can build up on the surface of a vessel's decks and rigging, causing a variety of operational problems. Photos : Canadian Coast Guard.

1. Introduction

Mariners caught on the open water when a severe storm hits face a host of hazardous weather conditions that can make navigation extremely dangerous. High winds can blow vessels off course and cause rough, choppy seas, while heavy rain can reduce visibility and create slippery conditions on deck. Lightning is a significant threat not only because water conducts electricity but also because mariners and their vessels are often the tallest objects on the open water.

While thunderstorms and tropical storms are serious forces to be reckoned with, hazardous weather doesn't just happen during the warmer months. Cold-weather phenomena, such as snowsqualls, freezing rain, freezing spray, and cold outbursts, also pose major hazards to boaters by affecting visibility or coating vessels with a solid layer of ice.

Spotting the signs of hazardous weather before it occurs—and taking steps to avoid it—is the safest tack for mariners to take in such situations. Because minutes matter, this chapter not only describes how, when, and why these conditions form but also provides boaters with a quick-reference guide on how to read the stormy sky.

2. Hazardous Cold-Weather Phenomena

2.1 Vessel Icing

Vessel icing is the process by which all or part of the external surface of a boat becomes coated with ice. It is a common occurrence in the Arctic and on the East Coast during winter.

What causes vessel icing?

Vessel icing can be caused by freezing rain, freezing spray, Arctic sea smoke, or any combination of the three (for more information on sea smoke, see Chapter 4, Fog). In order for these airborne water droplets to freeze on contact, both the air temperature and the surface of the vessel must be below freezing. As more layers build up, the ice becomes thicker and heavier. Warnings are issued when icing is moderate (building up at a rate of at least 0.7 cm/h) or higher.

What hazards does vessel icing pose?

Even mild vessel icing can have serious consequences. Stairs, decks, and railings coated in a slippery layer of ice can be treacherous for crew members working above deck. Rigging and other exposed equipment that has become encased in ice can be difficult to free, especially if it is hard to reach.

Icing not only increases the weight and draft of a vessel but also the drag placed on it by the wind and water, which reduces speed and increases fuel consumption. If ice builds up unevenly, it can alter a boat's centre of gravity, causing it to list and possibly capsize. A large accumulation of ice can even cause a vessel to sink.

Mariners' Tips

Even vessels equipped with a de-icing device may experience ice build-up on high, exposed areas. As such, it is always wise to avoid conditions that cause severe icing.

2.1.1 Freezing Spray

When a boat travels in rough, windy weather, the impact of the bow striking the waves causes water to spray high into the air. When the temperature is above freezing, spray can reduce visibility and make decks wet and slippery. When it is below freezing, it can cause vessel icing. Sixty percent of freezing spray is accompanied by falling snow or freezing rain, as they create an easier surface for the water to freeze to.

Figure 6b – The spray encountered by a ship travelling in rough, windy weather can cause significant vessel icing if the air temperature is below freezing. Photo : Canadian Coast Guard.

What causes freezing spray?

Freezing spray occurs when the wind is strong, the air temperature is below freezing (-2°C for sea water and 0°C for freshwater), and the sea-surface temperature is usually between -1.7°C and 5°C. The wind sets in motion the high waves that cause the spray and also give it enough force to reach the deck of a vessel.

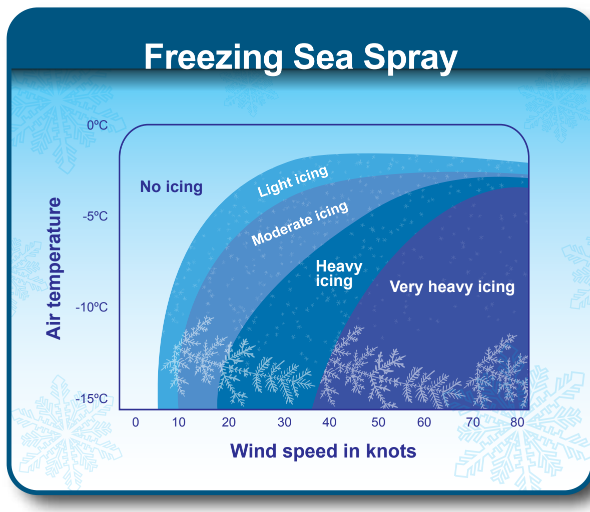


Figure 6c – The severity of vessel icing from freezing spray can be estimated based on air temperature and wind speed.

For most Canadian waters, freezing spray rarely occurs when the sea surface is warmer than 5°C. One known exception is along the West Coast, where freezing spray can occur near coastal inlets during strong Arctic outflow events, even though the sea surface is usually above 5°C. Freezing spray formation is dampened when the water itself becomes cold enough to freeze. When air temperatures are very low, droplets of spray freeze in mid-air, rather than on contact with a surface.

What hazards does freezing spray pose?

Freezing spray is the most dangerous type of vessel icing, as it can build up rapidly to thicknesses of 25 cm or more. Small fishing vessels are most at risk because they are relatively low to the water and their hulls tend to create a lot of spray. Freezing spray can also create serious problems for boats with extensive rigging.

Mariners' Tips

Slowing down, running downwind, and travelling close to an ice edge all help to reduce the amount of freezing spray a vessel will encounter; however, the best tactic in severe conditions is to seek shelter. If it is safe to do so, clear decks of any gear and rigging that might accumulate ice, and remove any build-up from the rigging and superstructure using a blunt (preferably wooden) object.

2.1.2 Freezing Rain

Freezing rain is made up of droplets of water that fall to the Earth when surface temperatures are below freezing, forming a thin glaze of ice on objects they come into contact with along the way.

How does freezing rain occur?

Freezing rain occurs when a layer of warm air rides up over a layer of cold Arctic air at the surface of the Earth. As the rain falling from the warm air passes through the lower layer, it becomes super cooled and freezes on impact with any solid object below 0°C—from trees and power lines to the boat decks and rigging.

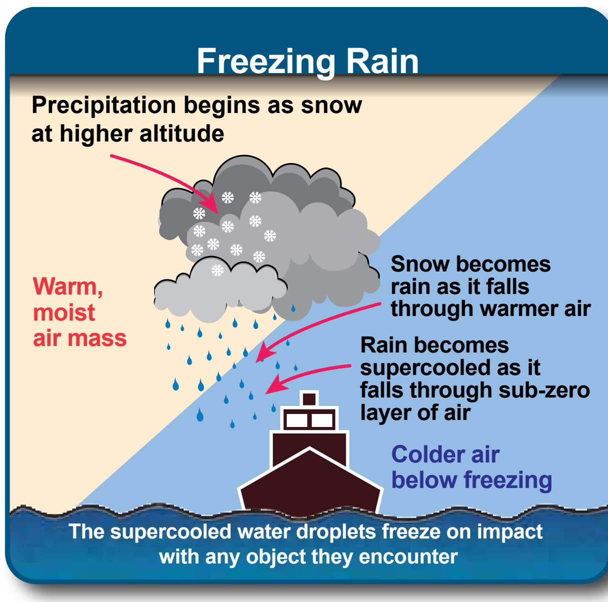


Figure 6d – The process by which freezing rain is formed.

What hazards does freezing rain pose?

While freezing rain generally forms a much thinner layer of ice than freezing spray, it can create hazardous footing for crew members who are working above deck. If the two happen at the same time, vessel icing can be unexpectedly severe.

2.2 Cold Outbreaks

One of the most challenging weather conditions mariners face during the fall and winter months is the "cold outbreak", the bitter blast of Arctic air that blows in behind a fierce storm. The powerful winds associated with cold outbreaks often cause heavy snowsqualls over water, as well as freezing spray and extreme wind-chill values.

What causes cold outbreaks?

The cold, storm-force winds characteristic of a cold outbreak often arise from an unstable, high-pressure atmospheric system. Outbreaks develop in different ways across Canada: on the West Coast, an Arctic high over the northern Rocky Mountains is often the culprit; in other parts of the country, a combination of complex weather patterns can come into play.

What hazards do cold outbreaks pose?

Crew members working above deck should take precautions to protect exposed skin from the effects of the extreme wind chill experienced during a cold outbreak. Frigid winds can also cause the sea state to rise quickly—with waves up to 10 m common—and magnify the likelihood and intensity of freezing spray. In some parts of the country, such as Squamish, British Columbia, a funneling effect can cause wind speeds in valleys to reach up to 60 kt. Strong winds and atmospheric instability also combine to increase the intensity of snowsqualls (see Section 2.3).

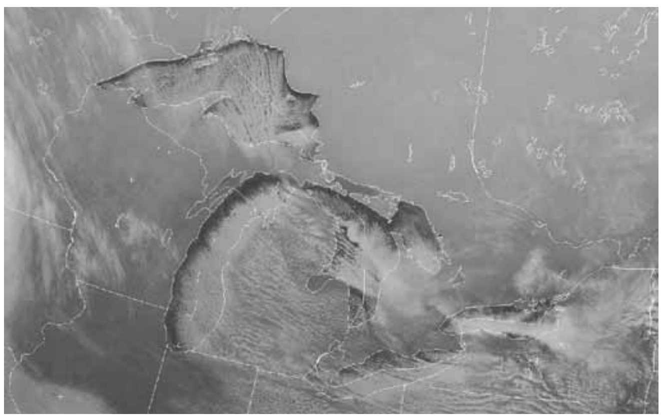


Figure 6f-1 – Lake-effect snow from a cold outbreak, January 22, 2013.

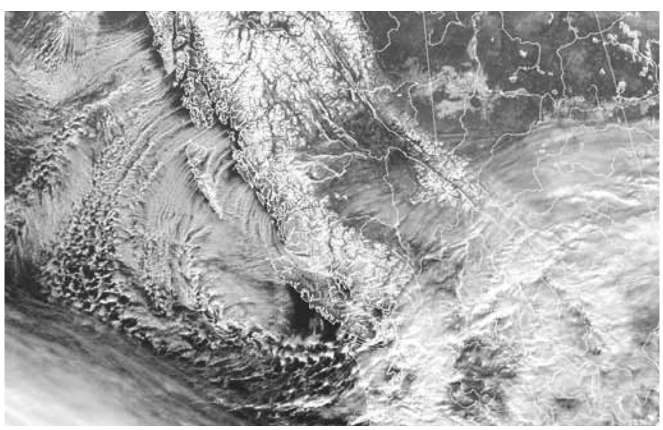


Figure 6f-2 – An Arctic outflow event on January 17, 2012, showing snowsqualls and streamers forming off the mainland inlets from the BC Central Coast to the Alaska panhandle. Easterly outflow winds near inlets were 40-50 kt, air temperature was approximately-15°C and the sea-surface temperature around 6°C. Freezing spray was reported at the Green Island lighthouse.

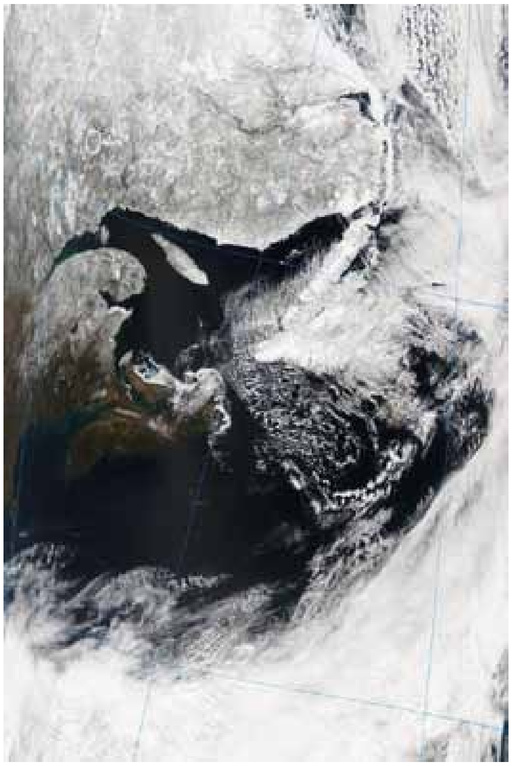


Figure 6f-3 – A typical west-to-northwest cold outflow, resulting in streamers over the Gulf of St. Lawrence, the Newfoundland shelf, and the Labrador sea.

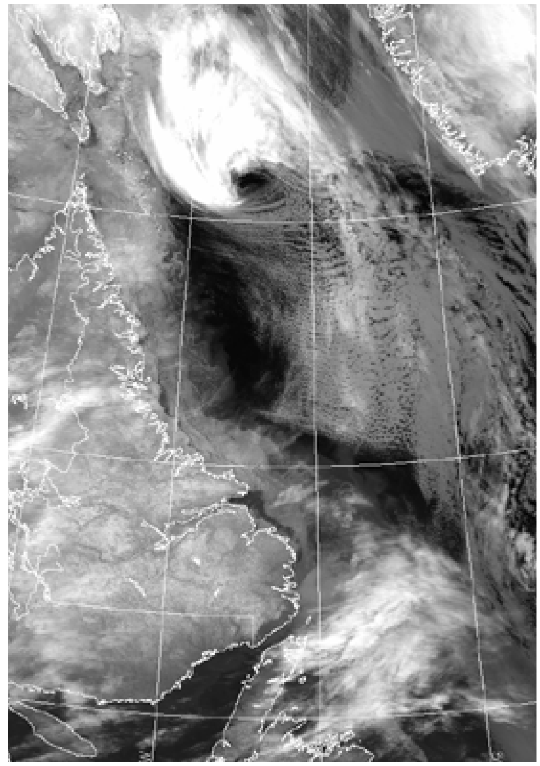


Figure 6f-4 – A low-pressure system that occurred on March 22, 2010, approximately 120 NM southeast of Iqaluit. The system generated a strong westerly flow and snowsqualls off the east coast of Labrador and over the Labrador sea.

Mariners' Tips

It is commonly known that it takes less wind to build the sea state in fall and winter than it does in summer. This is partly because cold air is denser and heavier than warm air, so it transfers more momentum or energy to the water as it blows over its surface. This enables the sea state to grow faster and higher than it would in warmer conditions.

2.3 Snowsqualls

Snowsqualls are sudden, moderately heavy snow flurries accompanied by strong, gusty surface winds. Although they are most often noticed over land, snowsqualls also form over large bodies of open water during the late fall and winter.

How do snowsqualls occur over water?

When cold Arctic air passes over a large, relatively warmer body of water, it becomes unstable, and large cumulus clouds begin to form. These clouds tend to line up with the wind in long, parallel bands, known as "streamers", which remain stationary and shift slowly. As they cool, these moisture-laden clouds release large quantities of snow in the form of flurries and snowsqualls.

Snowsqualls are highly localized: while areas beneath them may be buffeted by heavy snow and gusty winds, those just a few kilometres away may be experiencing fair weather. They are most intense when the winds are moderate, the fetch is long, and there is a significant difference between the air and water temperatures.

What hazards do snowsqualls pose?

Snowsqualls are characterized by erratic, gusty winds and sharp, localized reductions in visibility, sometimes referred to as "whiteouts".

Figure 6g – A narrow line of cumulus clouds and showers forms in the wind blowing off the Great Lakes. These intense disturbances often begin over water and extend a great distance.

3. Severe Storms

3.1 Tropical Cyclones

A tropical cyclone is the generic term given to members of a family of storms that frequent the middle latitudes from July to October. Many tropical cyclones experienced in Eastern Canada and central Ontario are spawned off the west coast of Africa and make their way across the Atlantic before turning northward. One or two tropical storms, on average, affect Atlantic Canada's land areas each year.

The different stages of a tropical cyclone are listed below in order of increasing severity:

- **Tropical disturbance:** A moving area of thunderstorms in the tropics that maintains its identity for 24 hours or more.
- **Tropical depression:** A tropical cyclone with maximum sustained winds of less than 34 kt.
- **Tropical storm:** A tropical cyclone with sustained winds of 34 kt or greater—not to be confused with a regular "storm", which is defined as having winds in excess of 47 kt. Tropical storms are identified by name, and detailed, routine bulletins are issued

on their track and development. A threat to life and property, they are commonly accompanied by rainfalls of 100-200 mm.

- **Hurricane:** A tropical cyclone with sustained winds of 64 kt or more, identified by the same name it had when it was a tropical storm. See Section 3.1.1.

How do tropical cyclones form and dissipate?

Tropical cyclones get their energy from the release of latent heat through condensation—the process by which invisible water vapour condenses into water droplets. As a result, they typically develop over very warm, tropical waters. Water temperatures of over 26oC are needed to spawn a hurricane, which can take up to a week to develop.

Tropical cyclones need warm water for fuel in order to survive. As they progress north in a clockwise curve that drives them into the eastern United States and Canada, they receive less and less energy from the sea. By the time they reach Eastern Canada, the end usually comes swiftly: colder air penetrates the swirling vortex, cooling the warm core of the storm and preventing further intensification.

Over land, tropical cyclones break up even faster. Cut off from their source of energy and slowed by frictional drag, their circulation rapidly weakens and becomes disorganized.

While large hurricanes may travel for days over cold North Atlantic waters, they eventually dissipate or are absorbed by pre-existing weather disturbances. As in the case of "Superstorm" Sandy in 2012, however, some receive a new surge of energy as they move up the East Coast and become extratropical cyclones (see Section 3.2).

What threats do tropical cyclones pose?

At their worst, tropical cyclones are the most dangerous forms of weather a mariner will ever face, bringing gale-force winds, heavy rainfall, and violent seas capable of swamping or capsizing even the largest vessels. To help mariners avoid such situations, the Canadian Hurricane Center issues bulletins up to five days in advance of impending storms.

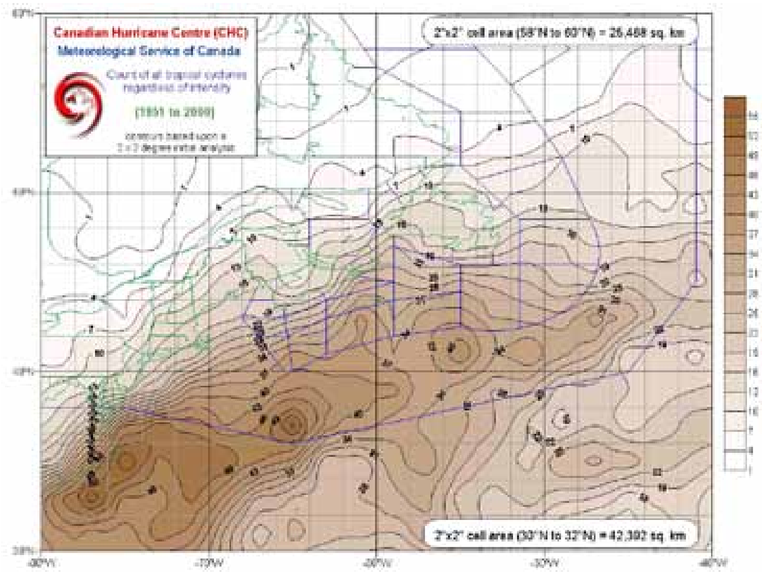


Figure 6h-1 – The primary region in which tropical storms and hurricanes are found over Eastern Canada and nearby offshore regions, indicating the sum total for both types of tropical cyclones over a 50-year period.

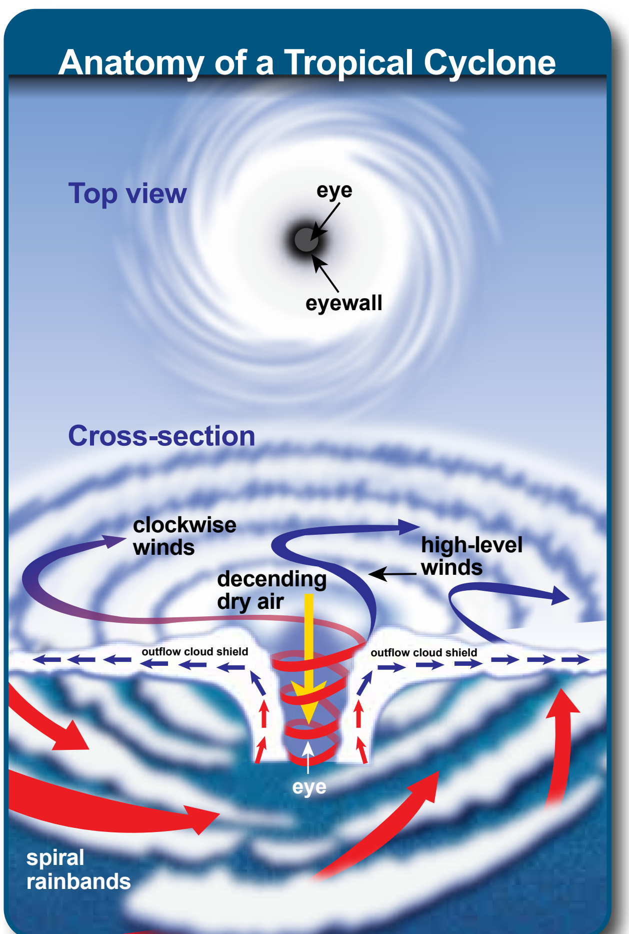


Figure 6h-2 – By the time a tropical cyclone reaches tropical storm or hurricane status, the thunderstorms that were involved in the initial stages of development are present in greater number and intensity. Winds at the surface feed into the interior of the storm and are sent rocketing skyward through the thunderstorms at the "eyewall"—where winds of 100 kt or more rotate counter-clockwise around the centre or the "eye" of the storm. At higher altitudes, the winds reverse direction and flow away from the eye, which averages 50-100 km in diameter. In the eye itself, a downward airflow produces clear skies, while a flat pressure gradient brings calm winds.

3.1.1 Hurricanes

Hurricanes—meaning “evil winds”, from the Carib Indian word huracan—are arguably the most powerful storms in the world. These atmospheric heat-engines transform the calm, stored energy of warm, moist tropical oceans into vicious winds, raging seas, torrential rains, and widespread flooding.

The Saffir Simpson Scale classifies hurricanes into five categories based on their sustained wind speed:

- Category 1: 64-82 kt
- Category 2: 83-95 kt
- Category 3: 96-112 kt
- Category 4: 113-136 kt
- Category 5: 137 kt or higher

Although hurricanes of Category 3 or higher have never been documented over land in Canada, measured wave heights in Canadian waters often exceed those produced in the tropics for Category 3 or greater hurricanes.

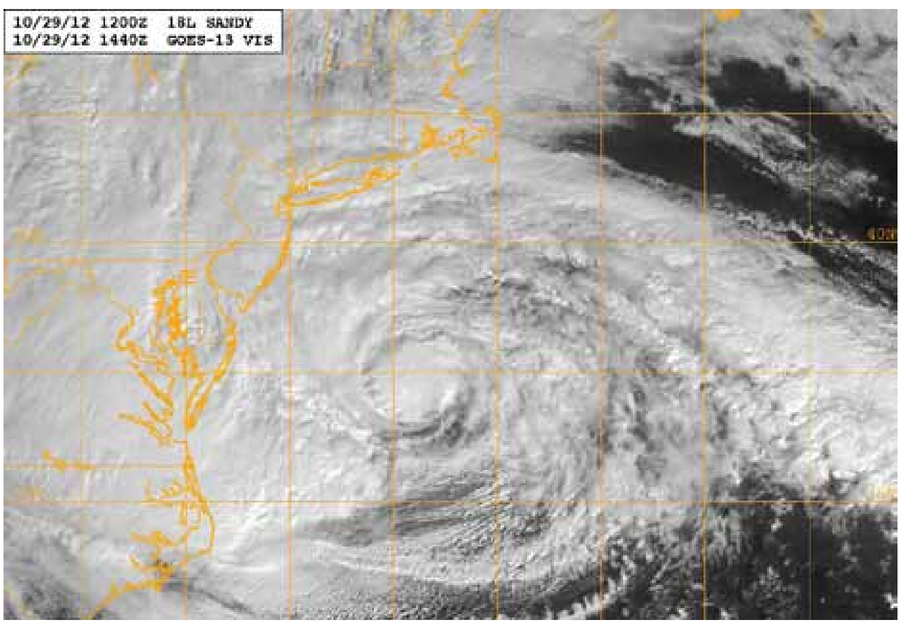


Figure 6i-1 – A satellite image of Hurricane Sandy in 2012.

The Power of a Hurricane

The heat energy a hurricane releases in one day through the process of condensation is equal to the energy released by the fusion of 400 twenty-megaton hydrogen bombs. If it were converted to electricity, this single day’s output would meet all of Atlantic Canada’s electrical needs for decades.

What hazards do hurricanes pose?

Hurricanes can pack wind speeds of well over 100 kt, cause torrential downpours of 100-200 mm of rain in a matter of hours, and create confused and mountainous seas of eight metres or more. Where they near land, the combined effect of the steep waves and storm surge (the high water level caused by strong winds and a low-pressure system) can swamp coastal areas and batter boats that are docked.

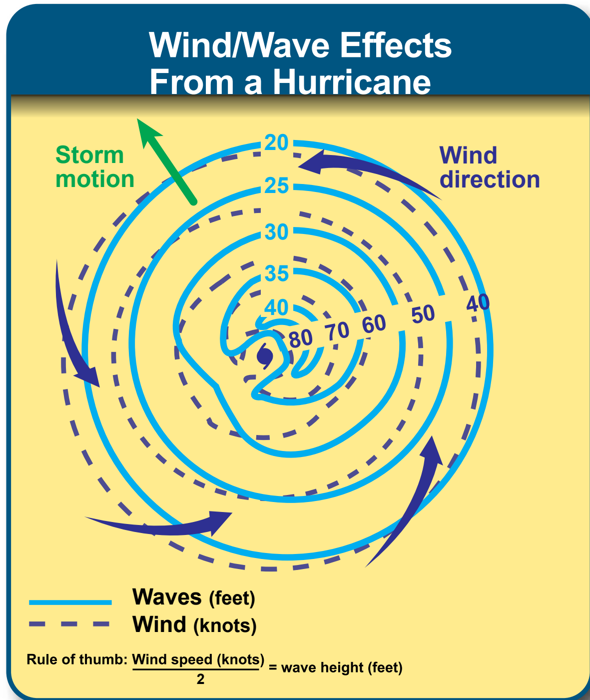


Figure 6i-2 – An easy way to estimate wave heights (in feet) for a slow-moving hurricane is to divide the wind speed (in knots) by two. For example, a wind speed of 80 kt would result in 40-ft seas.

The category alone does not indicate how much rain a hurricane will bring or how much damage it will cause. Other factors, such as recent weather conditions and local geography, also play a part. For example, coastal locations and areas surrounded by open terrain would be more exposed to wind damage, while those that received heavy rain in the days prior to the storm would be more vulnerable to flooding.

Mariners' Tips

Winds and waves are both higher in the semicircular zone to the right of a hurricane's track. Mariners should avoid this unnavigable area of the storm at all costs.

3.1.2 Pacific Cyclones

In Canada, most tropical cyclones affect the East Coast of the country; however, the West Coast is not entirely immune to these powerful storms. Pacific cyclones sometimes occur in the eastern Pacific Ocean, usually the remnants of typhoons that originated from further northwest.

In October 1962, the remnants of Typhoon Frieda slammed the southwestern edge of BC with near-hurricane force winds, toppling a number of large trees and damaging buildings in Vancouver. More recently, the remnants of a Pacific cyclone pounded the southern coast of the province and Vancouver Island with torrential rain and strong, gusty winds in November 2006.

How do Pacific cyclones form?

Pacific cyclones form in the same way as tropical cyclones, except over the Pacific Ocean during years when sea-surface temperatures are abnormally warm—such as during El-Nino events. They are rare in Canada because cooler sea-surface temperatures off the West Coast usually cause them to die out well before they reach land.

What hazards do Pacific cyclones pose?

Like tropical cyclones, Pacific cyclones produce strong winds, heavy rains, and rough seas that pose a serious hazard to vessels caught out on the open water.

3.2 Extratropical Cyclones

Extratropical cyclones—or frontal lows, as they are also known—get their energy from the contrast in temperature between warm and cold air. They typically occur in eastern Canada when tropical cyclones moving northward transform into a new, equally dangerous entity: the inner region of their hurricane-force winds diminishing to storm force or lower but expanding drastically.

This transformation can be rapid and unexpected, with extratropical cyclones developing into powerful, rejuvenated storms with wild wind, rain, and sea conditions. In 1954, Hurricane Hazel transformed from a tropical storm to an extratropical storm as it moved over land. Although no longer a hurricane, it left a wake of destruction, and dozens of lives were lost as a result of the extreme flooding it caused.

3.3 Thunderstorms

A thunderstorm is, by definition, a cloud that produces lightning. Canada experiences thousands of thunderstorms each year, hundreds of which become severe. Isolated thunderstorms, frontal thunderstorms (or cold fronts), supercells, and squall lines are different types of thunderstorms. Each is described in more detail later in this section.

How do thunderstorms form?

Many isolated midsummer storms grow simply from a cumulus tower into a thunderhead, which causes a heavy downpour and then slowly dissipates. Others undergo an evolution whereby new storms continuously form behind older ones as they progress, usually from west to east.

The anvil—a long cloud plume that extends out ahead of the storm—is the first indicator that a thunderstorm is approaching. It changes a bright blue sky to leaden grey, although this is often hidden from view by lower clouds or haze. The anvil may be accompanied by light rain or distant thunder. With more intense storms and squall lines, it thickens well ahead (sometimes several hours) of the approaching storm.

Before the heavy rain and lightning occur, a very low, dark cloud line—sometimes with a smooth, banded, light-coloured forward edge—will appear ahead of the storm, bringing strong winds. This is known as the "gust front". The more ragged and low the cloud line is, the stronger the winds are likely to be.

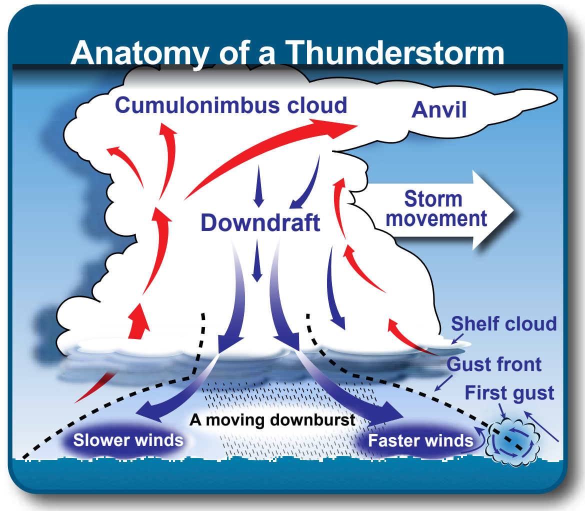


Figure 6j-1 – Weather conditions vary in front of, in the middle of, and behind a thunderstorm. Faster winds are common in advance of the storm, while rain and lightning are heaviest beneath its core.

As it passes, the gust front often brings a sudden increase in wind speed and abrupt change in wind direction, followed shortly by a deluge that gradually decreases to lighter rain and softer thunder. The gust front sometimes moves out, away from the storm, where it slows down and weakens. In this case, the cloud bank may be thin or absent and the winds lighter. With many gust fronts, the cloud bank grows into new storms separate from the original one.

The core—the dark area below the storm and behind the gust front—is where the heaviest rain, hail, and, often, lightning occur. It appears as a smooth, slate-grey or white wall, usually accompanied by lightning. If the storm is approaching from the northwest, west, or southwest, boaters should steer away from it to avoid the strongest winds, which usually occur just ahead of and on the southeast side of the core.

Thunderstorms arrive and peak suddenly, then decrease slowly. This progression is typical of all squall lines, most cold fronts, and a few isolated storms.

What hazards do thunderstorms pose?

Thunderstorms are a peril to boaters, as they can bring unpredictable and rapidly changing weather conditions—including fierce winds, blinding rain, damaging hail, intense lightning, and rough waters. All thunderstorms should be taken seriously and avoided, if possible, as they can test the limits of even the most seasoned mariner.

Mariners' Tips

Knowing what to look for and when to expect it can buy mariners valuable time to make it to safety before a severe thunderstorm strikes. When a storm is near, it is important to determine the direction it is moving and decide what is likely to occur next.

3.3.1 Severe Weather Cloud Types

Figure 6k-1 – Many storms arrive abruptly, characterized by low, racing clouds and a cold, gusty wind. 1) This gust front has surged a few minutes ahead of the heavy rain at the right. A fast-moving mass of low cloud with ragged fingers below it marks the leading edge of the wind. 2) A typical gust front on a hazy, humid day appears very quickly as a low, dark cloud line. When a line of very low, ragged clouds approaches, winds will suddenly increase. 3) Low clouds represent rising air, which often means a cool wind is pushing forward. 4) The leading edge of the wind will look like a low cloud bank or shelf with a turbulent sky beyond it. 5) A low cloud strip is moving out of the rain; the tuft above is where the rising air is condensing as it enters the storm at the right. Low cloud scraps indicate what surface winds are doing: if they are rising into a dark base, they are building cloud; if they are moving forward, they are being pushed by a strong wind.

Figure 6k-3 – 1) Warm air rises sharply at the lower right, fans out to form an anvil in successive pulses, then descends with the rain curtain. The storm survives by replacing older parts with new, maturing updrafts. Separate updraft towers, usually along an axis, grow to maturity in a long-lasting storm. 2) The diagram shows the structure of these stages. As the tower attains maximum height, it releases a heavy downpour. While it weakens and drifts downwind (to the right), another takes its place. In this way, a storm can constantly regenerate for many hours. 3) From the outside looking north, the newest parts are often at the west or south side, with the anvil and rain spreading northeast from there. 4) The anvil above some storms spreads out in all directions away from a powerful central updraft.

Figure 6k-3 – 1) From underneath, a storm has a grey anvil above, lowering to a dark rain core (distant here) with a bank of low clouds leading away from it to the south or west. This bank is an axis of growing towers that will either move up and merge with the storm's core or develop into new showers. A wind shift and cooling often accompany this line. 2) A mixed, "messy" sky has clouds at all levels, with scattered showers but less focus—and, therefore, less risk. 3) Storms that are more organized have a solid rain curtain with a bank of dark clouds around it, where new development is underway. 4) The relationship between rising air (dark, flat base) and descending air (with heavy rain) is pronounced. This contrast can lead to severe weather and high winds. 5) A turbulent sky is usually harmless. The mottled appearance comes from small downdrafts above a cool flow, a likely sign the storm is weakening.

3.3.2 Stormy Sky Quick Reference

Recognizing the signs of an approaching thunderstorm and heading for shore well before it arrives is essential to avoiding a potentially perilous situation on the water.

A lot can happen in a matter of minutes. When warning signs become apparent—a darkening sky, the sound of thunder, or increasing cool wind—don't delay. Particular attention should be paid to squall lines, which affect a large area and almost always herald the arrival of a powerful, long-lasting storm (see Section 3.3.5).

If you see…	This means	What to expect…	You should…
a sunny day give way to a high altostratus overcast (anvil), then showers and/or soft thunder	it will probably only be a weak thunderstorm	conditions will slowly worsen but may not be serious	listen and watch for an approaching dark area and frequent bolts or booms of thunder
thick anvil invades the entire horizon (may be obscured), booms of thunder are heard in the distance	a strong storm or a squall line with a gust front is moving up	expect a storm shortly with sharp changes in conditions	take immediate precautions for wind, lightning, and heavy rain
you see a line of low, dark, ragged clouds approaching quickly	the gust front will arrive in a few minutes	expect a sudden wind increase as the gust front passes, lasting 1-3 minutes. If dark behind line, heavy rain squall will follow	take immediate precautions, and turn your boat to face the oncoming squall
a cool wind has set in and the clouds above are churning and turbulent, but no rain or thunder is present	the gust front has just passed and the storm's core is either weak or passing you by	winds will abate and rain may arrive a little later	maintain a watchful eye – waters will become choppy if the wind persists
sky goes very dark and calm, with thunder heard to your NW/N	there may be new storms developing overhead or nearby	brief heavy showers, then breezy, cooler, and brightening	look to N for a gust front, and to W-NW for signs of lightning or heavy rain
you hear a steady, soft, rushing sound	could be heavy rain hitting the water or a strong wind nearby	if the sound becomes louder, expect a heavy downpour and/or a brief wind squall	if there's no thunder, event will be brief but prepare for sudden wind change
you see a thunder-head or hear thunder to your S or E or N only	storm is passing by or moving away	no change where you are, but watch for wind shifts	carry on, but watch for any new development to the west
stormy weather has ended and the sky becomes clear	storm/squall line is moving away	if it was the front, the winds will have shifted and stay that direction; otherwise, it will remain fair for several hours but clouds may increase again later	keep an eye on the sky until the cold front has passed for sure. Watch for gusty winds along or behind the cold front

Figure 6l – This table shows different thunderstorm situations and the conditions they are likely to bring. In all cases, it is assumed that the storm is in the quadrant from which the weather is moving (usually approaching from the west). Mariners should constantly check the movement of the storm and the position of its core to ensure that they are not in its path.

Mariners' Tips
In stormy weather, it is best to stay away from the windward shore of any islands, as it is safer to drift into the open water than be pushed onto rocks. Passing on the lee side buys time and decreases the risk of personal injury and boat damage.

3.3.3 Isolated Thunderstorms

An isolated thunderstorm is a single cumulonimbus cloud that produces lightning. These storms often form on warm, moist days from late spring to mid-summer—arriving slowly, peaking, and usually ending within an hour or two.

How do isolated thunderstorms form?

Isolated thunderstorms almost always form over land—sometimes along sea-breeze fronts or over higher terrain—and weaken if they move over water. This is especially true early in the spring, when water temperatures are still cold. Later, as they warm, this weakening effect decreases.

Since thunderstorms approach from the west in most parts of Canada, the eastern shores of lakes and the western shores of the open ocean are generally unaffected by them. In British Columbia and other mountainous areas of Canada, storms often move in the same direction as the valleys below them.

What hazards do isolated thunderstorms pose?

Isolated thunderstorms may be preceded by a weak gust front that causes a shift in wind direction and a cool breeze. The main part of the storm will remain near shore, bringing a brief period of heavy rain and lightning. An ominous-looking sky may persist for a while, bringing light, scattered showers, before it suddenly brightens.

Mariners' Tips
Boaters can monitor thunderstorm activity by listening to the crackle of static—caused by lightning discharges—on the AM band of their radio.

3.3.4 Frontal Thunderstorms

In the spring and fall, most thunderstorms accompany cold fronts and are either embedded in layers of rain cloud or form part of a squall line. This makes them more difficult to detect. Although they are usually stronger during the day, these frontal thunderstorms, as they are known, can also happen at night.

In the summer, thunderstorms also accompany cold fronts and are more active from late afternoon to late evening. When warm fronts are involved, these storms are usually more active late at night.

In spring and fall, frontal storms tend to arrive more from the northwest than the west, even though the clouds themselves move in from the southwest.

How do frontal thunderstorms form?

As a cold front nears, lines or groups of frontal thunderstorms form along and ahead of it. These storms often need the added heat of the afternoon sun to build up, so are most intense and widespread later in the day. If the front passes at night or early in the morning, it may bring only a band of clouds and a few showers.

What hazards do frontal thunderstorms pose?

While there is more advanced warning of frontal thunderstorms because changes in the sky begin well ahead of their arrival, they are still a formidable hazard to boaters. For one thing, they affect a vast area, so are difficult to avoid; for another, they can survive over large bodies of water, where their effect is exacerbated by hazy skies, fast-moving clouds, and increasing winds. The clouds ahead of a frontal storm can build quickly into new storms, causing unexpected gusts of wind and lightning. This may also lead boaters to overestimate their safety margin.

Figure 6m – After sending out a burst of cool air, a distant storm approaches quickly with a line of dark clouds.

3.3.5 Squall Lines

A squall line is a long-lasting line of thunderstorms and strong winds that forms alongside or ahead of a cold front. As it approaches, it usually appears as a dark band of thunderstorm clouds stretched out across the western horizon. The term "line squall" is sometimes used to describe its leading-edge winds.

How do squall lines form?

As thunderstorms develop along a fast-moving front, large volumes of cold air from high above descend in downdrafts, forming a wedge of cold air ahead of the system. This cold wedge lifts the warm, moist, and unstable air closer to the surface, causing a line of thunderstorms to form inside the air mass several kilometres in advance of the front. Although only one squall line typically passes a given location, a second one may follow one to three hours later before the main cold front passes.

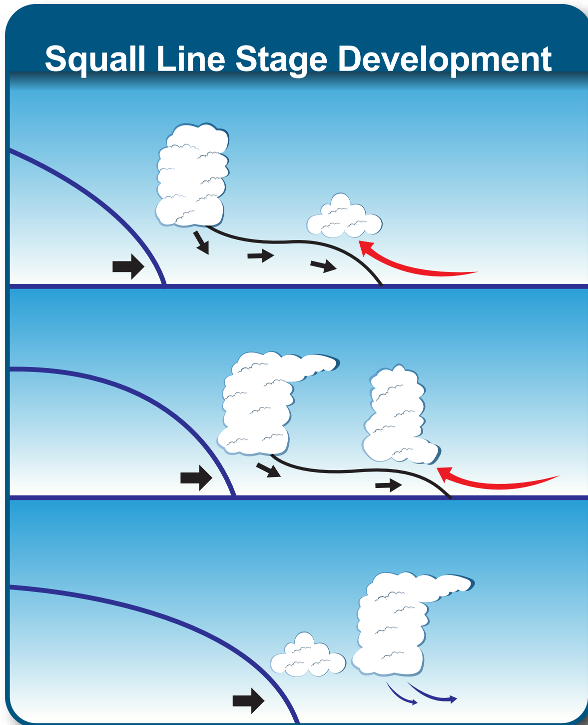


Figure 6n – As a squall line approaches, a wedge of cold air, formed by downdrafts from aloft, lifts the warm, moist air in front of the system, forming a line of thunderstorms.

What hazards do squall lines pose?

Squall lines are large, fast-moving, and persistent systems that leave boaters little room for escape out on the water. Strong winds may remain intense at a particular location for up to half an hour and, combined with sharp shifts in wind direction, cause sudden, extreme wave conditions. Since new storms often form up to three kilometres ahead of the main squall line, boaters may get caught in unexpected downpours and lightning.

3.3.6 Supercell Thunderstorms

A supercell thunderstorm is an extremely intense storm characterized by a large rotating cloud base with a persistent updraft. In Canada, supercells are most often seen in the southern Prairies, southern Ontario, and northwest Ontario between the Manitoba border and Thunder Bay.

How do supercell thunderstorms form?

Supercells display many of the same traits as other thunderstorms as they approach: an anvil thickens well ahead of the storm, light rain and distant thunder gradually increase. A shelf cloud may be present, signaling a gust front with strong outflow winds.

As the supercell approaches, the rain will intensify significantly, and may be followed by golf ball- or even baseball-sized hail. Unlike other storms, supercells usually save the worst for last. The rain and hail will suddenly stop, and an eerie calm will descend—the intense updraft visible nearby against the dark, rain-free, and often rotating cloud base. It is at this point that mariners should be on the lookout for a tornado.

In the case of the supercell that spawned an F3 tornado and a waterspout near Goderich, Ontario, on August 21, 2011, the worst part of the supercell hit first. To make matters worse, the tornado was hidden behind a shroud of rain and hail so was not visible until it slammed into the shore of Lake Ontario.

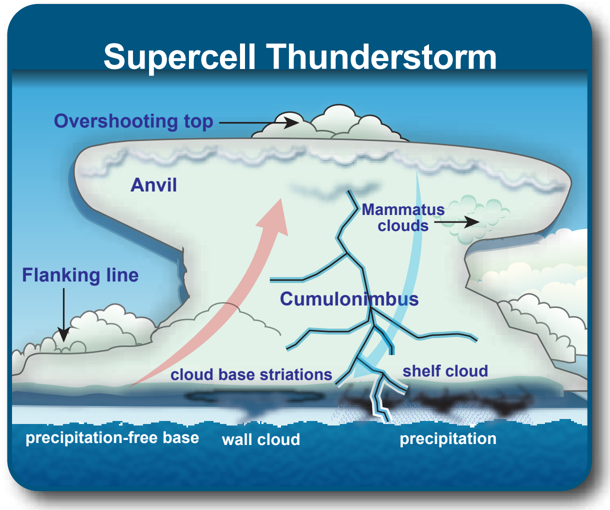


Figure 6o – The components of a supercell thunderstorm.

What hazards do supercell thunderstorms pose?

Supercells are large storms, so they are very difficult to avoid out on the water. They are capable of producing virtually every type of severe weather, including driving rain, large hail, damaging winds, intense lightning, waterspouts, and even tornadoes. The long, flowing anvil that appears ahead of a supercell is a surge sign to seek shelter immediately, especially if watches or warnings are already in effect.

3.4 Lightning

Lightning is a massive electrostatic discharge that occurs within a cloud (intra-cloud), from one cloud to another, or between a cloud and either the Earth's surface or an object on it.

What causes lightning?

The electrically charged regions of the atmosphere temporarily equalize themselves by emitting a flash of lightning—commonly referred to as a "strike" if it hits an object on the surface. Most lightning usually occurs in the heavy rain core of a thunderstorm; however, in severe storms or newly formed cumulonimbus clouds (without much rain present) bolts may come out of the clouds up to 30 km away.

Lightning is always accompanied by the sound of thunder, which may be heard from as much as 50 km away. On bright or hazy days, it is difficult to see beyond a short distance. As with all storms, there is often more happening than meets the eye. As one storm weakens, towers of developing cumulus clouds (recognizable by their dark, flat bases) can quickly mature into new storms, with lighting strikes nearby.

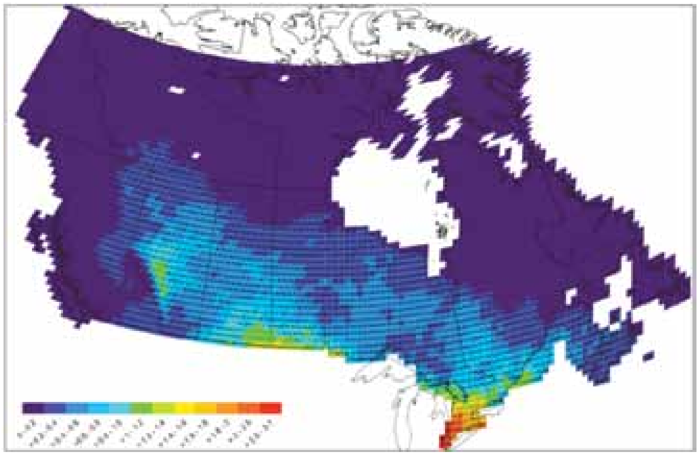


Figure 6p – Lightning flash density (flashes/km2/year) on a 50-km grid for a one-year period from 1999 to 2008.

What hazards does lightning pose?

Lightning produces voltages so high that even materials that are not normally considered "conductive"—including the human body—become able to conduct electricity. Anyone and anything on the water during an electrical storm is a possible target for a strike.

Even if a person is not struck directly, water is an extremely efficient conductor and can transport a paralyzing shock from a single lightning strike more than a kilometre away. Lightning can also puncture the hull of a boat or start a fire. Any vessel that is not properly equipped to handle a lightning strike should get off the water at the first sign of a thunderstorm.

Mariners' Tips

The vast majority of lightning injuries and deaths on boats occur on small vessels with no cabin or inadequate grounding. If possible, boats should be professionally grounded and have a 45-degree cone of protection.

3.4.1 Lightning Safety

Paying close attention to the latest weather information is critical to avoiding the possibility of being struck by lightning. If thunderstorms are forecast, mariners should not leave port. Those who are already out on the water and cannot get back to land should drop anchor and get as low as possible. Large boats with cabins, especially those equipped with lightning protection systems, and metal vessels are relatively safe. Those on board should stay inside the cabin, away from metal surfaces and any objects or parts of the boat that could conduct electricity. Stay off the radio unless it is an emergency.

When someone is struck by lightning, the strike may shock his or her heart into stopping. Even if a heartbeat cannot be detected, don't give up: victims of lightning strikes can often be revived by using cardio-pulmonary resuscitation.

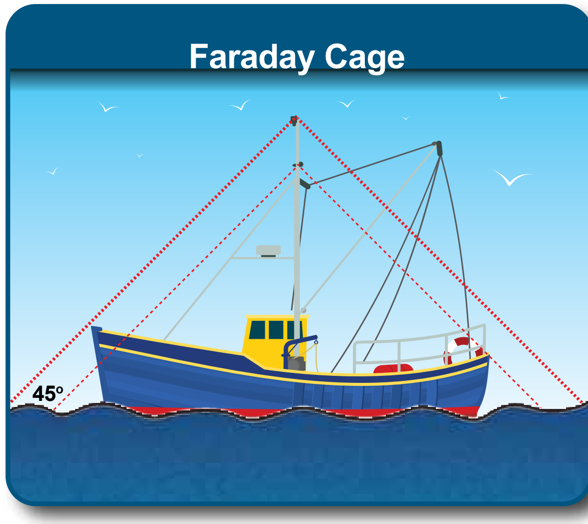


Figure 6q – A 45-degree cone of protection, known as a Faraday Cage, is recommended as a means of protecting vessels and their crew from the effects of a lightning strike.

Transport Canada recommends that all vessels be equipped with a cone of protection—known as a "Faraday Cage"—that extends 45 degrees in all directions from the tip of a metal protrusion above the boat. For example, if the aluminum mast of a sailing vessel is properly bonded to a major metal mass and has a direct, low-resistance conductive path to ground, the entire boat should be within this protected zone. Vessels with a wooden or composite mast should have a professional marine electrician install a metal spike at the top of the mast and run a heavy conductor as directly as possible to ground, usually through the engine and propeller shaft.

Environment Canada publishes information on lightning and lightning safety.

Mariners' Tips

Mariners caught on the water during a lightning storm can help to protect themselves by making their vessel a conductor and grounding it. Simply clip one end of a piece of conductive material (e.g., a chain or jumper cable) to the mast or shroud and let the other end drag in the water. Stay below, if possible, and avoid contact with tillers, masts, lifelines, and other parts of the boat that may conduct electricity.

3.5 Waterspouts

A waterspout is a violently rotating column of air and water that forms over the surface of a body of water. Although weaker than those that form over land, they are technically a type of tornado. Waterspouts are sometimes seen in families of two or more—the world record being 12 that formed in a row over Lake Huron in the 1980s. Waterspouts can move at speeds of up to 14 kt, span 15-50 m in diameter, and last up to 20 minutes.

Waterspouts are most frequently reported over the Great Lakes; however, they also occur over other major bodies of water, including the Winnipeg Lakes, Hudson and James bays, Great Bear and Great Slave lakes, and off both the East and West coasts.

Figure 6r – A family of waterspouts over Lake Huron near Kincardine, Ontario.
Photo: Kincardine Independent, © Environment Canada, 1999.

How do waterspouts form?

Waterspouts form during unstable conditions when cool air moves over relatively warmer water. They occur any time of day or night throughout the year, but in Canada they are most frequently sighted during August and September.

The earliest stage of a waterspout consists of a rotating column of spray near the surface of the water. As it strengthens, a funnel will begin to extend downward from the cumulus-type cloud directly above it. The waterspout reaches its greatest strength when the funnel touches the water surface, at which point associated wind speeds can exceed 50 kt.

What hazards do waterspouts pose?

Waterspouts can be strong enough to capsize small vessels and knock people overboard. Mariners who are on the water when a waterspout is nearby should move away at a right angle to its path. Those on shore should stay away from tall objects, as waterspouts have been known to topple large trees along the water's edge and cause damage to docks.

GLOSSARY

Advection Fog: Fog that forms when warm air flowing over a cold surface cools from below until saturation is reached.

Air Mass: A body of air covering a relatively wide area and exhibiting horizontally uniform properties.

Altocumulus Cloud: A medium-altitude (2400-6100 m) cloud characterized by globular masses or rolls in layers or patches, the individual elements of which are larger and darker than those of cirrocumulus and smaller than those of stratocumulus clouds.

Altostratus Cloud: A medium-altitude (2400-6100 m) cloud characterized by a generally uniform gray sheet or layer, lighter in color than nimbostratus and darker than cirrostratus clouds.

Anabatic Wind: Wind created by air flowing uphill.

Arctic Sea Smoke: Steam fog; often applied specifically to steam fog that rises from a small area of open water within sea ice.

Backing: A counterclockwise shift in wind direction (e.g., south winds shifting to the east).

Backwash: The motion of receding waves.

Bathymetry: The science of measuring the depth of water bodies (e.g., oceans, lakes, seas).

Beaufort Scale: A system invented in the early 19th century by Admiral Sir Francis Beaufort of the British Navy to estimate and report wind speeds based on conditions at sea. The scale has since been modernized for use on land.

Breaker: A heavy sea wave that breaks into white foam on a shore or shoal.

Buys-Ballots Law: The law stating that when a person is standing back to the wind, the area of low pressure will be to his or her left.

Circulation Cell: Large areas of air movement created by the rotation of the earth and the transfer of heat from the equator toward the poles.

Cirrocumulus Cloud: A high-altitude (6000-12 000 m) cloud characterized by thin, white patches, each of which is composed of very small granules or ripples.

Cirrostratus Cloud: A high-altitude (6000-12 000 m) cloud that appears as a whitish and usually somewhat fibrous veil across the sky—sometimes so thin, it is hardly visible. Cirrostratus clouds are composed of ice crystals and often produce halos.

Cirrus Cloud: A high-altitude (6000-12,000 m) cloud composed of ice crystals that appears as delicate, white filaments or as white (or mainly white) patches or narrow bands—and is often semi-transparent. Although thunderstorm anvils are a form of cirrus cloud, most cirrus clouds are not associated with thunderstorms.

Cliff Effect: A sudden shift in wind direction that occurs when wind encounters a steep barrier, such as a cliff.

Cold Front: The zone between two air masses in which the cooler, denser mass is advancing and replacing the warmer.

Cold Low: A low-pressure system that is cold at its core and has little change in temperature gradient along its horizontal plane.

Convection: The vertical transport of heat and moisture within the atmosphere.

Convergence Effect (Coastal Convergence): The process by which a band of stronger wind occurs near the shoreline when it is to the right of the prevailing wind direction due to frictional differences between water and land.

Coriolis Force (Coriolis Effect): The fictitious force (caused by the rotation of the earth) that accounts for the apparent deflection of a body in motion to the right in the Northern Hemisphere and to the left in the Southern Hemisphere.

Corner Effect: A small-scale but often quite severe convergence effect that occurs around steep islands and headlands.

Crossing Sea: A sea with a choppy surface, caused by the intersection of waves.

Cumulonimbus Cloud: A lower- to middle-layer cloud characterized by strong vertical development in the form of mountains or huge towers topped, at least partially, by a smooth, flat, and often fibrous anvil. Also known informally as a “thunderhead”.

Cumulus Cloud: A detached cloud, formed in the lower layer of the atmosphere, that is generally dense with sharp outlines and shows vertical development in the form of domes, mounds, or towers. Cloud tops are normally rounded, while bases are more horizontal.

Dew Point: A measure of atmospheric moisture indicating the temperature to which air must be cooled in order to reach saturation, assuming that both air pressure and moisture content are constant.

Ebb Tide: The period between high tide and the next low tide, during which the sea is receding.

Eddy: A swirling current of air or water flowing contrary to the main current.

Ekman Transport: The flow of surface currents at a 45-degree angle to the wind due to the balance between the Coriolis Force and the drags generated by the wind and water.

Fetch: An area in which ocean waves are generated by the wind; also refers to the length of the fetch area, measured in the direction of the wind.

Fathom: A unit of water depth equal to six feet or about 1.83 m.

Flood Tide: An incoming tide.

Fog: Water droplets suspended in the air at the earth's surface.

Front: A boundary or transition zone between two air masses of different density and, usually, different temperature.

Funnelling: The process whereby wind is forced to flow through a narrow opening between adjacent land areas, resulting in an increase in its speed.

Funnel Cloud: A condensation funnel extending from the base of a towering cumulus or cumulonimbus cloud that is associated with a rotating column of air that is not in contact with the ground.

Gale-Force Winds: Sustained winds at speeds of 34 to 47 kt.

Geostrophic Wind: Wind that would result from an exact balance between the Coriolis Force and the pressure gradient force.

Gust: A rapid fluctuation of wind speed, with variations of 10 kt or more between peaks and lulls.

Gyre: A vortex or spiral.

High (Anticyclone): A region of high pressure.

High Cloud: Cloud in the layer of the atmosphere above 6000 m.

High Water Slack: The period at high tide when the water is neither rising nor falling.

Hurricane: A tropical cyclone in the Atlantic Ocean, Caribbean Sea, Gulf of Mexico, or Eastern Pacific Ocean in which the maximum one-minute sustained surface wind is 64 kt or higher.

Hurricane-Force Wind: A sustained wind of 64 kt or higher.

Ice: Water in a frozen state.

Ice Fog (Ice-Crystal Fog, Frozen Fog, Frost Fog, Frost Flakes, Air Hoar, Rime Fog, Pogonip): Fog composed of suspended ice particles—some 20 to 100 microns in diameter but most (especially if the fog is dense) about 12 to 20 micron in diameter—formed by the direct freezing of supercooled water droplets with little growth directly from vapor.

Iceberg: A piece of a glacier that has broken off and is floating in the sea.

Inversion: An increase in temperature with height.

Isobar: The line on a weather map connecting points of equal pressure.

Katabatic Wind: Wind generated by air flowing downhill.

Knot: A unit of speed used in navigation that is equal to one nautical mile per hour.

Lake Breeze/Land Breeze: A thermally produced wind that blows during the day from the surface of a large lake toward shore, caused by the difference in the heating rates of the water and land.

Lapse Rate: The rate of change of an atmospheric variable, usually temperature, with height. A steepening lapse rate implies a rapid decrease in temperature with height and is a sign of destabilization.

Lee Effect (Lee Wave): A warm, dry wind that flows down the lee side of a mountain range.

Lee Trough (Lee Low): A trough or low caused by the stretching of a column of air as it descends the leeward side of highly elevated terrain, such as the Rocky Mountains.

Leeward: The direction downwind from a point of reference. The opposite of “windward”.

Light Winds: Sustained winds at speeds of less than 15 kt.

Low (Cyclone): A region of low pressure, the low centre of which is usually accompanied by precipitation, extensive cloudiness, and moderate winds.

Low Cloud: Cloud in the lower levels of the atmosphere, typically from near-surface level to 2000 m.

Low Water Slack: The period at low tide when the water level is neither rising nor falling. Magnetic Wind Direction: The direction from which the wind is blowing with respect to magnetic north.

Marine Inversion: Inversion that occurs when cold marine air underlies warmer air.

Mesoscale System: A weather system, such as a squall line or mesoscale convective systems, that is 80 km to several hundred kilometres in horizontal extent.

Microclimate: Climate conditions at the microscale level (typically, less than 2 km).

Microscale System: A weather system, such as a wind circulation or cloud pattern, that is less than 2 km in horizontal extent.

Middle Cloud: Cloud in the “alto” level of the atmosphere, from 2000 to 6000 m.

Millibar: A unit of atmospheric pressure equal to 1/1000 bar or 1000 dynes per square cm.

Mist: A visible aggregate of minute water particles suspended in the atmosphere that reduces visibility to less than 11 km, but not less than 2 km—at which point, it is considered “fog”.

Moderate Winds: Sustained winds at speeds of 15 to 19 kt.

Mountain Wave: An undulating flow of wind on the leeward side of a mountain ridge.

Nautical Mile: A unit of distance used in marine navigation and forecasts, equal to 1.15 miles or 1852 m. It is also the length of one minute of latitude.

Neap Tide: The lowest level of high tide, when the difference between the high and low tide is least.

Nimbostratus Cloud: A class of low-altitude (usually less than 2400 m) cloud characterized by a formless layer that is almost uniformly dark gray and brings light to moderate precipitation.

Pack Ice: An expanse of floating ice composed of large pieces that have been driven together into a nearly continuous mass, as occurs in polar seas.

Polar Low: A short-lived, mesoscale, low-pressure system (depression) found over the ocean areas on the poleward side of the main polar front, in both the Northern and Southern hemispheres.

Pressure: The exertion of force on a surface by a fluid (e.g., the atmosphere) in contact with it.

Pressure Gradient: The change in pressure measured across a given distance.

Pressure Gradient Force: The force that results when there is a difference in pressure across a surface.

Prevailing Wind: The wind coming from the most usual direction at a particular time or place.

Quasi-Stationary Front: A stationary front that is moving at a speed of 5 kt or less.

Radiation Fog: Fog that forms when outgoing, long-wave radiation cools the near-surface air below its dew point.

Reflection (of Waves): The process by which waves striking a vertical barrier, such as a cliff or wharf, are reflected back in the direction from which they came.

Refraction (of Waves): The process by which differences in the depth of water beneath a wave's crest cause it to bend and change direction.

Ridge: An elongated area of relatively high atmospheric pressure. The opposite of "trough".

Riptide: A stretch of turbulent water in a river or sea caused by one current flowing into or across another.

Salinity: The ratio of salt to water; saltiness.

Sea Breeze: Wind that blows during the day from a cool ocean surface onto adjoining warm land, caused by the difference in heating rates between the two.

Sea Fog: Advection fog caused by the transport of moist air over a cold body of water.

Sea State: The overall state of agitation of a large expanse of ocean or sea due to the combined effects of wind-generated waves, swell waves, and surface currents.

Seas: The combination of wind waves and swell, in which the two components are not distinguished from one another (i.e., Seas2 = S2+W2 where S is the swell height and W is the wind-wave height). Considered the same as Significant Wave Height.

Seiche: A standing-wave oscillation of water in large lakes usually created by strong winds, a large pressure gradient, or both.

Set: The direction towards which a current is headed (e.g., a current moving from west to east is "set to east").

Set-Up: The process whereby strong winds blowing the length of a lake cause the water level at the downwind end to increase and at the upwind end to decrease.

Shoaling: The process by which surface waves entering shallower water increase in height.

Significant Wave Height: The mean or average height of the highest one third of all waves in a particular area.

Slack Water: The state of the tide when it is turning, especially at low tide.

Snow Streamer: Narrow, intense bands of snowfall that occur on leeward shores during cooler atmospheric conditions, when cold winds move across long expanses of warmer water, picking up energy and water vapor.

Snow Squall: A sudden, moderately heavy snowfall with blowing snow and strong, gusty surface winds.

Spring Tide: A higher-than-normal tide that occurs around the time of the new moon and full moon.

Squall: A strong, sudden-onset wind in which the wind speed increases by at least 16 kt and is sustained at 22 kt or more for at least a minute. It is often used by mariners as a general term for a severe local storm.

Squall Line: A line of active thunderstorms, either continuous or with breaks between them, including adjacent areas of precipitation.

Stability: The degree to which a layer of air is resistant to vertical motion.

Stable Atmosphere: An atmospheric state in which vertical movement is inhibited by a layer of warm air capping a layer of cold air below it.

Starboard: The side of the ship that is on the right, when facing forward.

Stationary Front: A transition zone between two nearly stationary air masses of different density, neither of which is strong enough to replace the other.

Steam Fog: Fog formed when water vapor is added to air that is much colder than the source of the vapor (e.g., when very cold air drifts across relatively warm water).

Storm-Force Winds: Sustained winds at speeds of 48 to 63 kt.

Storm Surge: An abnormal rise in sea level accompanying a hurricane or other intense storm, usually estimated by subtracting the normal or astronomic tide from the observed storm tide.

Stratus Cloud: A low-level cloud that is generally gray in colour, has a fairly uniform base, and occasionally appears in the form of ragged patches. Fog is usually a form of surface-based stratus.

Strong Winds: Sustained winds at speeds of 20 to 33 kt.

Swell: Wind-generated waves that have travelled out of the area in which they originated. They characteristically exhibit smoother, more uniform crests and a longer period than wind waves.

Synoptic Scale: The spatial scale of the migratory high- and low- pressure systems of the lower troposphere, where the horizontal distance between systems is 1000 to 2500 km.

Thermal Trough/Low: An area of low pressure that is shallow in vertical extent and produced primarily by warm surface temperatures.

Thunderstorm: A local storm produced by a cumulonimbus cloud and accompanied by thunder and lightning.

Tidal Bore: A phenomenon that occurs where the ocean feeds into a river or bay, in which the leading edge of the incoming tide forms waves of water that travel inland against the current.

Tidal Range: The vertical difference between the high tide and the succeeding low tide.

Tidal Rip: A stretch of turbulent water in a river or the sea caused by one current flowing into or across another.

Topography: The shape of the land.

Tornado: A violently rotating column of air that usually forms a pendant to a cumulonimbus cloud, the bottom end of which reaches the ground.

Towering Cumulus: A large cumulus cloud with significant vertical development and, usually, a cauliflower-like appearance. It lacks the characteristic anvil of a cumulonimbus cloud.

Tropical Cyclone: A warm-core, low-pressure system that develops over tropical and, sometimes, subtropical waters and has an organized circulation. Depending on sustained surface winds, it is classified as a tropical disturbance, a tropical depression, a tropical storm, or a hurricane or typhoon.

Tropical Depression: A tropical cyclone in which the maximum one-minute sustained surface wind is 33 kt or less.

Tropical Disturbance: An area of organized convection that originates in the tropics or subtropics and maintains its identity for 24 hours or more. Often the first stage in the development of more intense tropical cyclones, it may or may not be associated with increased wind speeds.

Tropical Storm: A tropical cyclone in which the maximum one-minute sustained surface wind ranges from 34 to 63 kt.

Trough: An elongated area of relatively low atmospheric pressure, not usually associated with a closed circulation. The opposite of "ridge".

Trowal (Trough of Warm Air Aloft): A "tongue" of relatively warm and moist air aloft that wraps around to the north and west of a mature cyclone, often during winter.

True Wind Direction: The direction the wind is blowing with respect to true north.

Tsunami: A series of long-period waves (on the order of tens of minutes) that are usually generated by an impulsive disturbance that displaces massive amounts of water, such as an earthquake occurring on or near the sea floor.

Upwelling: In ocean dynamics, the upward motion of sub-surface water toward the surface of the ocean.

Unstable Atmosphere: An atmospheric state in which vertical movement is encouraged by the presence of a layer of cold air over a layer of warmer air.

Valley Wind: Wind that ascends a mountain valley during the day as a result of daytime heating.

Veering: A clockwise shift in wind direction (e.g., south winds shifting to the west).

Warm Front: The transition zone between a mass of warm air and the colder air it is replacing.

Water Vapour: Water in a vaporous form in the atmosphere.

Waterspout: A small, relatively weak rotating column of air that occurs over water, beneath a cumulonimbus or towering cumulus cloud.

Wave Length: The distance between the crest of one wave and the next, adjacent to it.

Wave Period: The time, in seconds, between consecutive wave crests passing a fixed point.

Wave Steepness: The ratio of wave height to wave length. Steepness is an indicator of a wave's stability; when it exceeds a 1/7 ratio, it typically begins to break.

Wave Height: The distance from the trough to the crest of a wave.

Whirlwind: A small, rotating column of air that may be visible as a dust devil.

Wind: The horizontal motion of the air past a given point. Winds originate from differences in air pressures.

Wind Shadow: An area having relatively little wind due to the effect of a barrier, such as a steep cliff or heavily treed shoreline.

Wind Shift: A change in wind direction of 45 degrees or more that takes place within a 15-minute period.

Wind Waves: Local, short-period waves generated by the action of the wind on the surface of the water.

Windward: The direction upwind from a point of reference. The opposite of “leeward”.