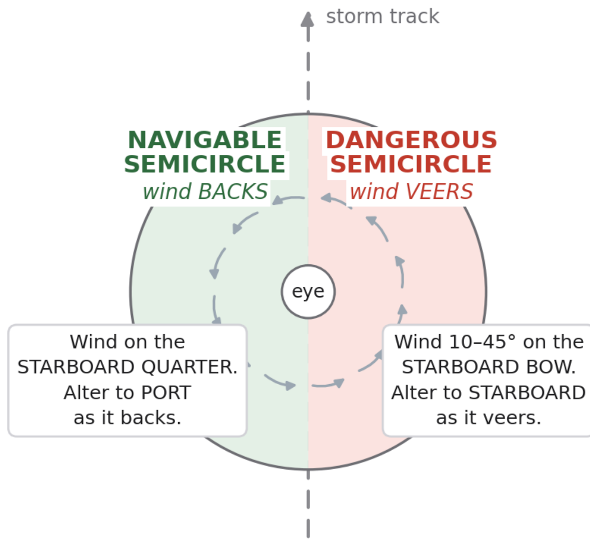
STUDY AID

Weather for the Mariner

Why the wind does what it does, what the sky is telling you, and how much of it your ship can take

Capt. Georgia Hilton



Northern hemisphere. Either way: run — maximum safe speed.

This is a primer, not a textbook. It is meant to give you the shape of the thing — enough to look at the sky, look at the barometer, and know what is coming and what to do about it. Everything in here is worked from first principles so you can check it yourself. Chart analysis and frontal systems have their own companion guide, *Synoptic Meteorology*.

Four questions. If you can answer all four, you are weather wise.

1. A tropical cyclone is forming near you. What do you do?
2. What tells you a thunderstorm is going to be a bad one?
3. What causes wind shifts?
4. You see long, large swells. What are they telling you?

SECTION 1

Where weather comes from

All of it — every front, every gale, every calm — starts with one fact: the sun does not heat the earth evenly.

Weather is made of heat. The equator receives the sun's energy nearly head-on; the poles receive it at a glancing angle, spread thin over more surface. That difference has to even out, and the only way the atmosphere can move heat is to move air. Moving air is wind. Wind makes seas. That is the whole machine.

None of it would happen without gravity. Gravity is the only thing holding the atmosphere on — without it the air would simply spin off into space. Gravity is also what makes cold air sink and forces warm air up out of its way, which is the vertical half of every weather system in this guide.

Three things complicate the picture, and those three complications are most of what you need to learn.

The earth is tilted. The axis leans about 23.4° and that lean stays put — what changes through the year is where the sun is overhead. That is the sun's *declination*, and it swings from 23.4°N at the June solstice to 23.4°S in December, passing through zero at the equinoxes around 21 March and 23 September. Declination gives us the seasons, and the seasons reshape the weather.

The earth spins. At the equator the surface is moving about 1,000 mph; at the poles it is not moving at all. Every hour the earth turns 15°. That spin bends every large-scale flow of air — the Coriolis effect — and it is why weather systems rotate instead of simply running downhill from high pressure to low.

Water and land behave differently. Sunlight penetrates clear water to a couple of hundred metres and warms an enormous mass slowly. On land it heats the top few inches, fast. So the land warms quickly and cools quickly; the sea does neither. That mismatch drives sea and land breezes on a daily cycle, and on a global scale it makes the ocean the planet's heat reservoir and its conveyor belt.

Numbers worth carrying

Circumference: **24,901 statute miles** round the equator (21,639 NM) — 24,860 statute miles round the poles.

1 NM = 1.15 statute miles. Rotation: 360° in 24 hours, so **15° per hour**.

Axial tilt **23.44°**, fixed. Solar declination varies ±23.44° over the year.

1°C = 1.8°F. To convert: °F = (°C × 1.8) + 32. The deep ocean sits at about 4°C, which is 39°F.

Standard sea-level pressure **1013 mb**. Isobars are drawn every **4 mb**.

Parcels — the unit meteorology actually works in

Almost everything that follows is easier if you think in **parcels**. A parcel is a notional bubble of air of no particular size that keeps its identity and its characteristics as it rises or sinks — the same way a balloon does. It does not exchange much heat with the air around it; it just expands as the pressure falls and contracts as the pressure rises. Ask what a parcel would do, and the answer usually falls out.

SECTION 2

The Coriolis effect

Nothing is pushing the air sideways. The air travels straight; the earth turns underneath it.

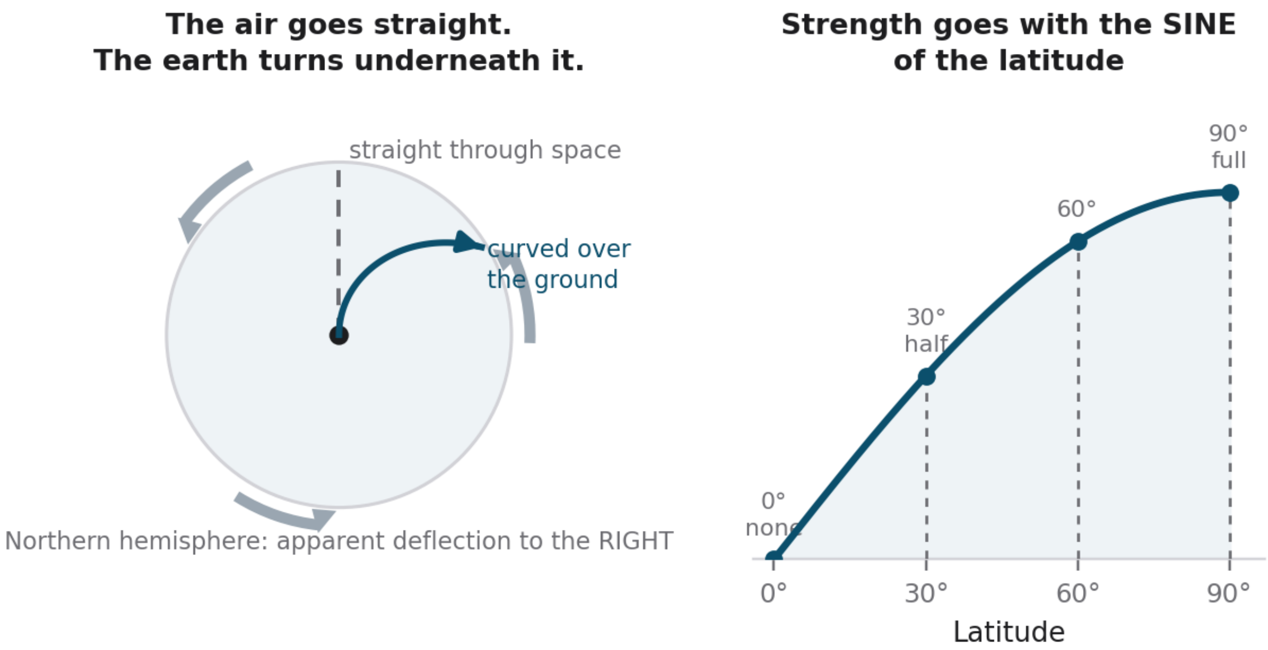


Figure 1 — The deflection is apparent, not applied. But you still have to navigate around its consequences.

From where we stand, on the turning surface, a straight path looks curved. That apparent curve is Coriolis, and it is why meteorologists call it a fictitious force. Fictitious or not, it is the reason weather systems spin, the reason the trade winds come from the north-east rather than the north, and the reason wind blows along the isobars instead of straight down the pressure gradient.

> **The one rule**
>
> Moving air is deflected to the **RIGHT** in the northern hemisphere, to the **LEFT** in the southern.
>
> The deflection is **zero at the equator** and **strongest at the poles** — it goes with the **sine of the latitude**. At 30° it is half its polar value; at 45°, about seven-tenths.
>
> At the equator there is no rotation of the surface underneath a horizontally moving object, so there is nothing to deflect it. This is also why tropical revolving storms cannot form within about 5° of the equator — there is not enough spin to get them turning.

SECTION 3

Three cells, not one

If the earth did not spin, each hemisphere would have one enormous convection loop. Because it does spin, that loop breaks into three.

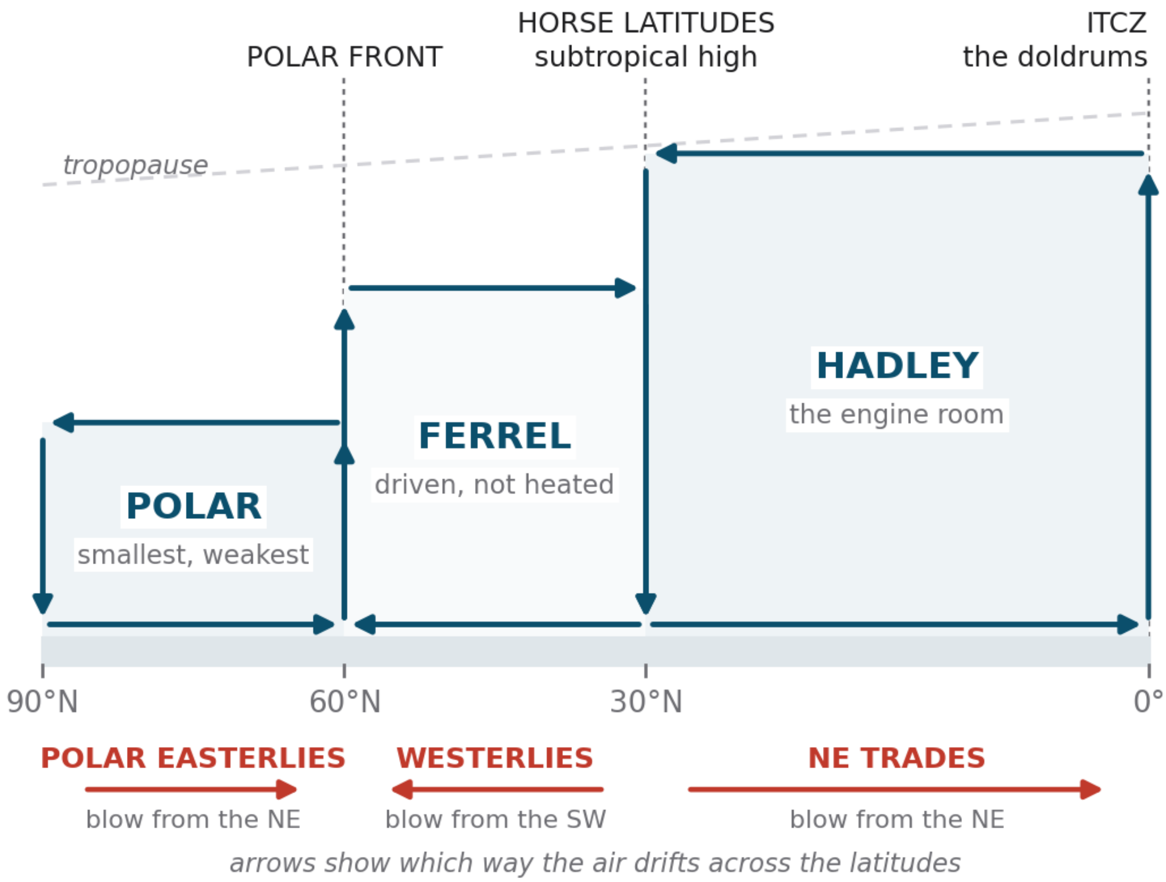


Figure 2 — The three-cell circulation, northern hemisphere. The southern hemisphere is the mirror image, with the deflection to the left.

The Hadley cell is the engine room. Air over the equator is heated, rises to the tropopause, runs poleward at altitude, cools, and sinks around 30° latitude. At the surface it flows back toward the equator — and Coriolis bends that return flow to the right, which is why it arrives as a wind from the north-east. Those are the trades.

The Ferrel cell in the mid-latitudes is not heated from below; it is dragged around by the two cells either side of it. Surface air moves poleward and is bent right, giving the prevailing westerlies of 35–60°. Ferrel's cell was the first explanation that accounted for those westerlies without appealing to a simple equator-to-pole temperature difference — they come from friction and rotation, not from heating.

The polar cell is the smallest and weakest. Cold, dense air sinks over the pole, spreads out at the surface, is bent right, and arrives at 60° as the polar easterlies.

The boundaries matter more than the cells

- **The ITCZ** — where the two Hadley cells meet at the equator. Light and variable winds, towering convection, torrential rain. The doldrums. It is also the nursery for tropical revolving storms.
- **The horse latitudes** near 30° — where the Hadley air sinks. Sinking air warms and dries, so this is where the world's deserts and the subtropical highs sit. Light winds, clear skies.
- **The polar front** near 60° — where polar easterlies meet mid-latitude westerlies. Cold air against warm air along a continuous boundary. This is the birthplace of the depressions that give the mid-latitudes their weather, and the polar jet runs directly overhead.

Two heights, two charts

Surface charts are drawn at **1000 mb** (about 300–360 ft). Upper-air charts are drawn at **500 mb** (about 18,000 ft), which is where the jet stream activity that steers the surface systems shows up.

Air converging and sinking aloft piles up and makes a surface high; air rising out of a surface low has to diverge aloft to make room for it. That coupling is why forecasters look at both sheets. It is worked through properly in the companion guide, *Synoptic Meteorology*.

SECTION 4

The jet streams

Ribbons of wind five to seven miles up, running west to east at up to 200 mph. They are the steering wheel for everything below them.

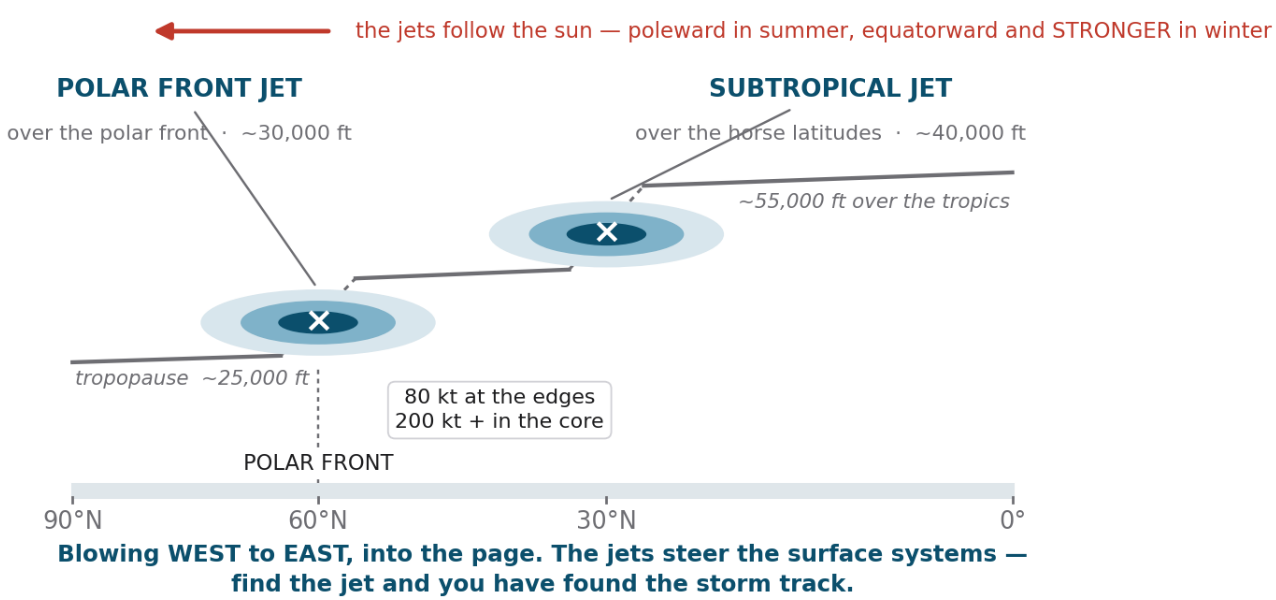


Figure 3 — The two jets sit in the breaks in the tropopause, where the temperature contrast between the cells is sharpest.

The sun does not heat the earth evenly, so warm and cold air masses sit against one another in bands. Where the contrast is sharpest the pressure gradient aloft is steepest, and Coriolis turns that gradient into a fast river of air running **west to east**. At 30,000–40,000 ft there is essentially no friction, so nothing slows it down.

- The **polar front jet** sits over the polar front near 60°, at about 30,000 ft. This is the one that matters to a mariner in the mid-latitudes: it steers the depressions.
- The **subtropical jet** sits over the horse latitudes near 30°, at about 40,000 ft, and is generally the weaker of the two.
- They are **three-dimensional** — not lines but tubes, with a fast core and slower edges. **200 kt and more in the core, 80 kt at the edges.**

- They **follow the sun**: poleward in summer, back toward the equator in winter. And they are **strongest in winter**, when the equator-to-pole temperature contrast is greatest — which is exactly why the winter storm track is so much more active.

> **Why you care**
>
> **Find the jet and you have found the storm track.** Surface depressions form under it, run along it, and deepen where it accelerates.
>
> A deep **trough** in the jet upstream of you means a surface low is being fed and will deepen. A **ridge** means the surface system will be suppressed and the weather will settle.
>
> When the jet buckles into large slow meanders, weather systems stop moving on and sit over the same patch of ocean for days.

SECTION 5

Highs, lows and Buys Ballot

Air moves from high pressure toward low pressure. If that were all, the wind would blow straight down the gradient. Coriolis makes it spiral instead.

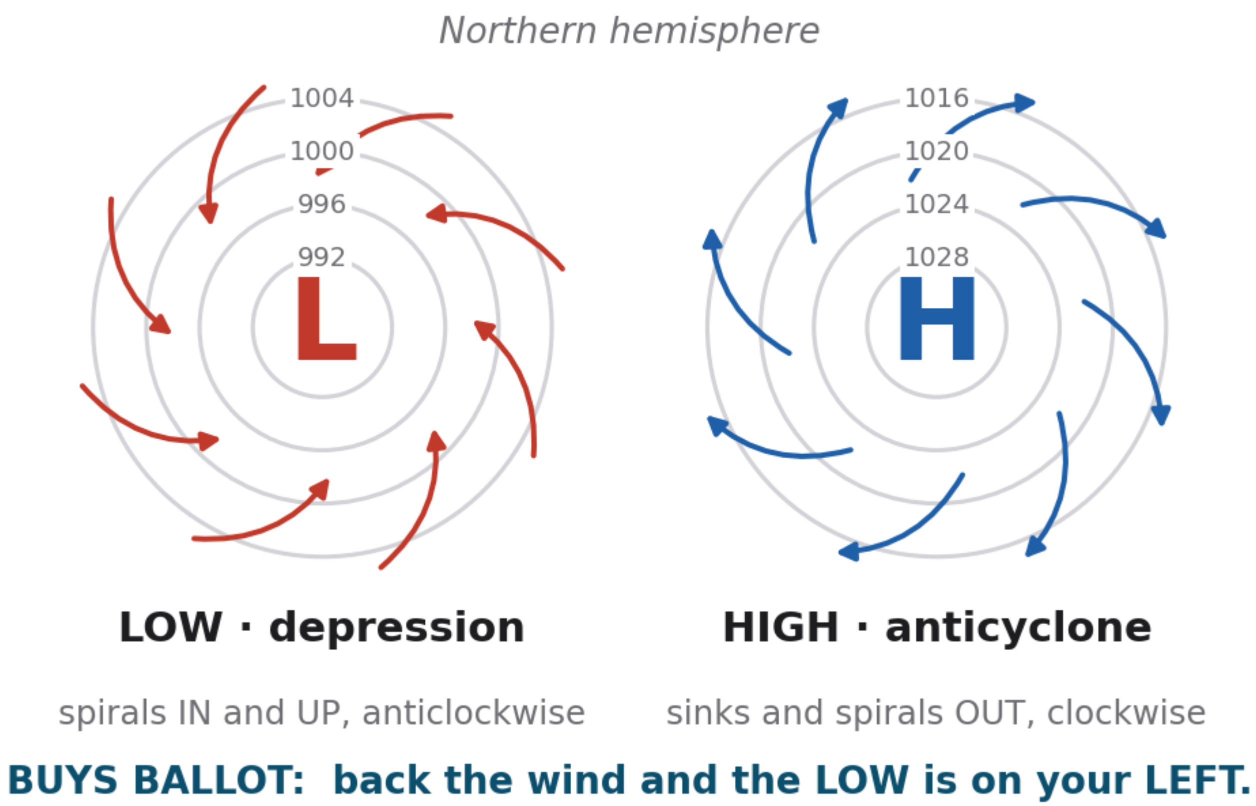


Figure 4 — Surface flow around a low and a high, northern hemisphere. The wind crosses the isobars — inward around the low, outward around the high — because friction has broken the balance.

Around a **low** in the northern hemisphere, air spirals in anticlockwise and rises. Rising air cools, cannot hold its moisture, and gives you cloud, rain and wind. Around a **high**, air sinks and spirals out clockwise. Sinking air warms and dries: settled weather, light winds, and often poor visibility because nothing is stirring.

Air cannot pile up. Whatever converges at the surface of a low has to go somewhere, and the only place left is up. That is why lows are wet and windy, and it is the same reason a front — where dense cold air shoves in under warm air and lifts it — produces cloud along its whole length.

Buys Ballot's Law — the one rule that needs no instrument

Northern hemisphere: stand with the wind at your back. The low pressure is on your **LEFT**, and slightly **ahead** — friction turns the surface wind inward across the isobars, so the centre lies forward of your left beam.

Southern hemisphere: wind at your back, low pressure on your **RIGHT**.

Some texts phrase it facing into the wind, which flips the answer. Pick one wording and stay with it. The point is the same: the wind itself tells you where the centre is, without a chart and without a forecast.

SECTION 6

Cloud, and what it costs to lift air

Cloud forms for exactly one reason: air was cooled until it could no longer hold the water it was carrying.

Lift a parcel — over a front, over a mountain, over a hot patch of ground — and it expands as the pressure round it falls. Expanding costs it energy, so it cools, whether or not anything took heat out of it. Cool it far enough and the moisture condenses. That is your cloud base.

Three rates matter, and the difference between them is the whole of stability.

- **Environmental lapse rate** — how fast the air *around* the parcel gets colder with height. Standard atmosphere: **2°C per 1,000 ft** (6.5°C/km, or about 3.5°F per 1,000 ft). This is the one you measure.
- **Dry adiabatic lapse rate** — how fast an unsaturated parcel cools as it rises, from expansion alone: **3°C per 1,000 ft** (9.8°C/km).
- **Saturated adiabatic lapse rate** — once it is condensing, the latent heat released slows the cooling to roughly **1.5°C per 1,000 ft**. This is why a cloud, once it gets going, keeps going.

Now compare. If the parcel cools *faster* than the air around it, it quickly becomes colder and denser than its surroundings, sinks back, and nothing happens — a **stable** atmosphere, flat layered cloud, haze, poor visibility. If it cools *slower* than the air around it, it stays warmer and lighter than its surroundings and keeps climbing on its own — **unstable**, vertical development, showers, squalls, cumulonimbus. That single comparison is the difference between a grey stratus day and a thunderstorm.

Étage	Base height	Typical cloud	What it tells you
High	6,000 m and up	Cirrus, cirrostratus, cirrocumulus	Ice crystals. Warm front on the way, or fair weather
Middle	2,000–6,000 m	Altostratus, altocumulus	Thickening ahead of a front; clearing behind one
Low	Surface to 2,000 m	Stratus, stratocumulus, nimbostratus	Steady rain, poor visibility
Vertical	Low base, huge top	Cumulus congestus, cumulonimbus	Instability. Squalls, hail, lightning, wind shifts

Two corrections worth making

Cloud does not stop at 20,000 ft. The tropopause — where the temperature stops falling and begins to rise again, which is what caps convection — sits near **36,000 ft in the mid-latitudes**, higher over the tropics and lower over the poles. Cirrus routinely forms above 20,000 ft, and a well-fed cumulonimbus will punch to 40,000 ft or more and spread its anvil along the tropopause. The anvil is the cloud telling you it has hit the ceiling.

Watch the units on the lapse rate. The standard figure is **2°C per 1,000 ft** — not 2°F, and not per 100 m. In °F it is about 3.5° per 1,000 ft; per 100 m it is only 1.2°F. The ‘2’ belongs to Celsius and to thousands of feet, and it is easy to carry it onto the wrong pair.

SECTION 7

Fog

The weather that kills the most ships is not the loudest. It is the quietest.

Fog is cloud with its base on the surface, and it forms for the same reason all cloud does — air cooled to its dew point. What matters at sea is *which* mechanism did the cooling, because that tells you how long it will last and what will clear it.

Type	How it forms	Where and when	What clears it
Advection fog (sea fog)	Warm moist air moves over colder water and is chilled from below	The big one at sea. Warm sector of a depression; any warm airstream over a cold current. Persists day and night	A change of airstream, or wind over about 15 kt to mix it out. Sunshine will **not** shift it
Radiation fog	Land cools overnight and chills the air resting on it	Rivers, estuaries and harbours on calm clear nights. Drifts seaward at dawn	The sun, within a few hours of sunrise
Sea smoke (frost smoke)	Very cold air moves over much warmer water; the water evaporates and immediately recondenses	High latitudes, and off a cold continent in winter	Usually shallow — often clear above it from the bridge
Frontal fog	Warm rain falls through cold air and saturates it	Along a warm front, in the rain belt	Passage of the front

The seamanship of it

Advection fog is the one to plan for. It forms over open water, it does not care what time of day it is, and it can persist for days. If you are carrying a warm humid airstream over a cold current — a warm sector crossing a cold shelf, or the classic Grand Banks setup — expect it.

A closing spread is your warning. Watch air temperature and dew point converge. When they meet you are in it, and that is a forecast you can make an hour ahead with a wet and dry bulb.

Fog is a COLREGS problem before it is a weather problem. Safe speed, sound signals, radar plot, extra lookout — and remember that Rule 19 changes what you are permitted to do.

SECTION 8

Fronts, in brief

The full treatment is in the companion guide. This is what a mariner needs in the head, without a chart in front of them.

A **front** is the sloping boundary between two air masses. What matters on watch is that a front changes your wind, and it changes it in a predictable direction.

Veer and back — commit these to memory

VEER = clockwise. NE → E → SE. **BACK = anticlockwise.** NE → N → NW.

Warm front: wind **backs** as it approaches, then **veers** on passage. Cloud lowers in sequence — cirrus, cirrostratus, altostratus, nimbostratus — over 12 to 24 hours. Slow, wet, and it gives you plenty of notice.

Cold front: wind **veers sharply**, all at once, sometimes through 90° in minutes. Cumulonimbus, squalls, heavy rain, possibly hail. Short, hard, then it clears behind.

Both fronts travel the same way, with the depression, generally eastward. The cold front simply runs about twice as fast — which is why it catches the warm front up and the system occludes.

A hard veer with a rising barometer and a temperature drop means the cold front has gone through. Expect the wind to settle in the new direction, the sea to stay confused for some hours, and visibility to improve. That sudden shift is the single most common reason a following sea unexpectedly ends up on your beam.

SECTION 9

Wind on the ship

This is the section that turns weather from a forecast into a shiphandling problem. A ship's side is a sail, and it does not have the option of being reefed.

Wind pressure rises with the **square** of the wind speed. That is the whole lesson. Double the wind and you quadruple the load.

The formulae

$q = 0.004 \times V^2$ where **q** is dynamic pressure in pounds per square foot and **V** is wind speed in **knots**

$F = A \times q \times C_d$ where **A** is the sail area (windage) in square feet and C_d is the drag coefficient

Units matter more than anything else here. The 0.004 coefficient is for wind in **knots**. The 0.00256 figure you will meet in engineering texts is the same quantity for wind in **miles per hour** — feed knots into it and you will read about a quarter low. The exact knots coefficient is 0.00339; the 0.004 rule of thumb runs about 18% high, which is the direction you want to be wrong in.

C_d for a ship's side is about 1.0. A ship broadside on is a bluff body, not an aerofoil — the air does not flow round it, it piles into it. Use 1.0. Boxy deck cargo pushes it a little above; a clean hull sits a little below.

Worked example: a loaded box boat

Take a 1,000 ft container ship, loaded, standing about 75 ft from the waterline to the top of the stack. Call the average side area **800 × 75 = 60,000 square feet** of windage. Wind on the beam, C_d = 1.0. A modern ship-assist tug delivers roughly 60 tonnes of bollard pull.

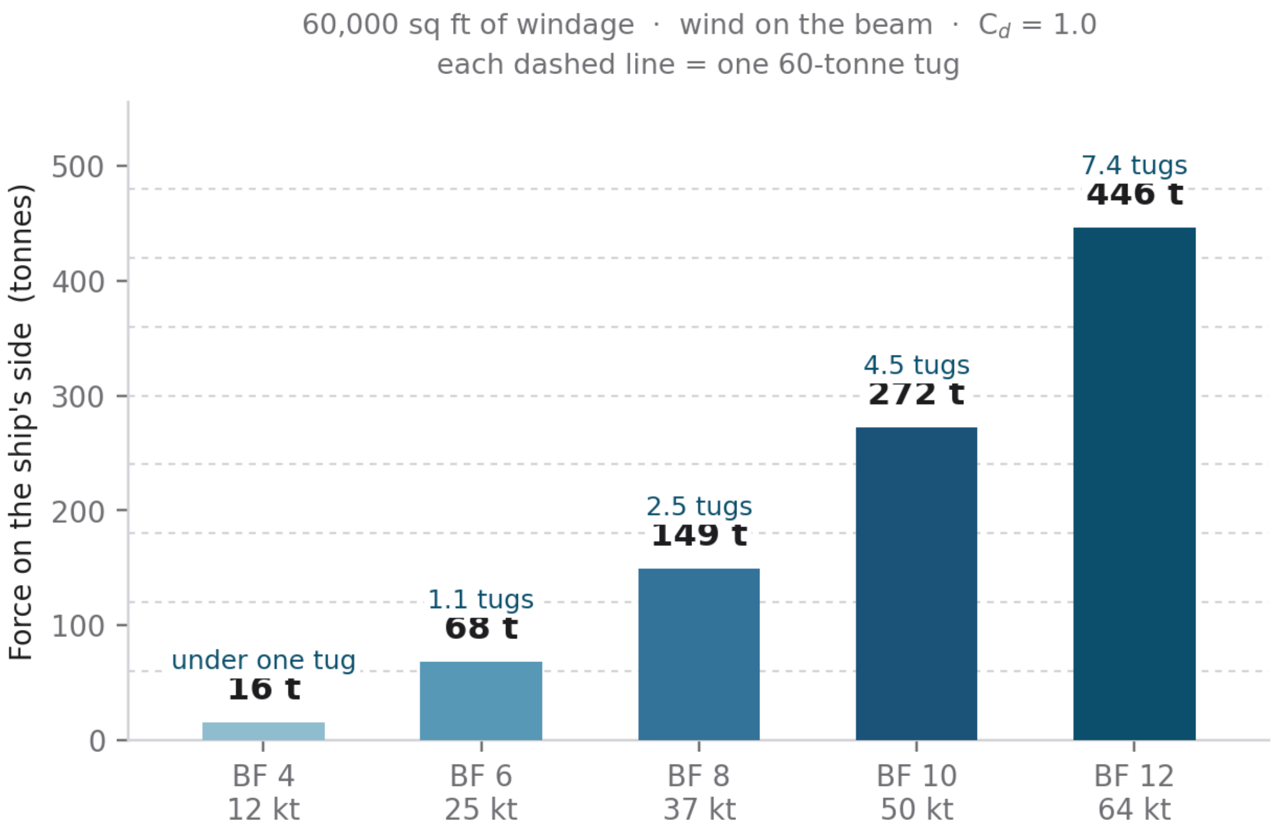


Figure 5 — Beam wind load on 60,000 sq ft of windage, expressed in tugs. Beaufort 6 needs one tug just to hold station. Beaufort 10 needs four and a half.

Beaufort	Wind	q (psf)	Force (lb)	Force (t)	Tugs
4	12 kt	0.58	34,560	16	under 1
6	25 kt	2.50	150,000	68	1.1
8	37 kt	5.48	328,560	149	2.5
10	50 kt	10.00	600,000	272	4.5
12	64 kt	16.38	983,040	446	7.4

What that actually means on the bridge

Beaufort 6 — a strong breeze, nothing dramatic — is already one whole tug pushing on your side. Everything the tugs are doing for you at that point is being spent on the wind, not on the manoeuvre.

At **Beaufort 8** you need two and a half tugs before you have moved the ship an inch. At **Beaufort 10**, four and a half.

This is the arithmetic behind every berthing wind limit you will ever be given. It is also why the limits tighten so fast as the wind builds — the square law is unforgiving.

And it is worse in ballast. Light, with high freeboard, you have more sail area and less grip on the water at the same time.

A second example, smaller ship

A 500 ft ship standing 40 ft high has about **20,000 sq ft** of windage.

- At 10 kt: q = 0.004 × 100 = 0.4 psf. F = 20,000 × 0.4 = **8,000 lb**.
- At 20 kt: q = 0.004 × 400 = 1.6 psf. F = 20,000 × 1.6 = **32,000 lb**.

Twice the wind, four times the force. Every time.

SECTION 10

Sea and swell

Waves are built by three things and three things only: how hard the wind blows, how long it blows for, and how far it blows across.

Strength, duration, fetch. Take any one of them away and the sea cannot fully develop. A 50-knot squall lasting twenty minutes builds far less sea than 30 knots blowing steadily for a day, which is why the forecast wind speed on its own tells you very little.

When waves outrun the wind that made them — or the wind stops and they keep going — they are no longer sea, they are **swell**. Swell sorts itself by wavelength as it travels, so what reaches you from a distant storm is long, low, and very regular.

Question 4, answered

Long, large swells mean a big storm, a long way off, and you are getting its first message.

The energy spreads out from the generating area like ripples from a stone — the longest waves travel fastest and arrive first, often a day or more ahead of anything else. A rising, lengthening swell from a direction that does not match your local wind is one of the oldest and most reliable warnings there is. In the tropics, take it seriously.

Why 'significant wave height' is not the wave you should worry about

Wave heights in a given sea are not all the same and they are not randomly scattered either — they follow a predictable distribution. **Significant wave height** is defined as the average of the highest third. It is a useful number, and it is not the biggest wave out there.

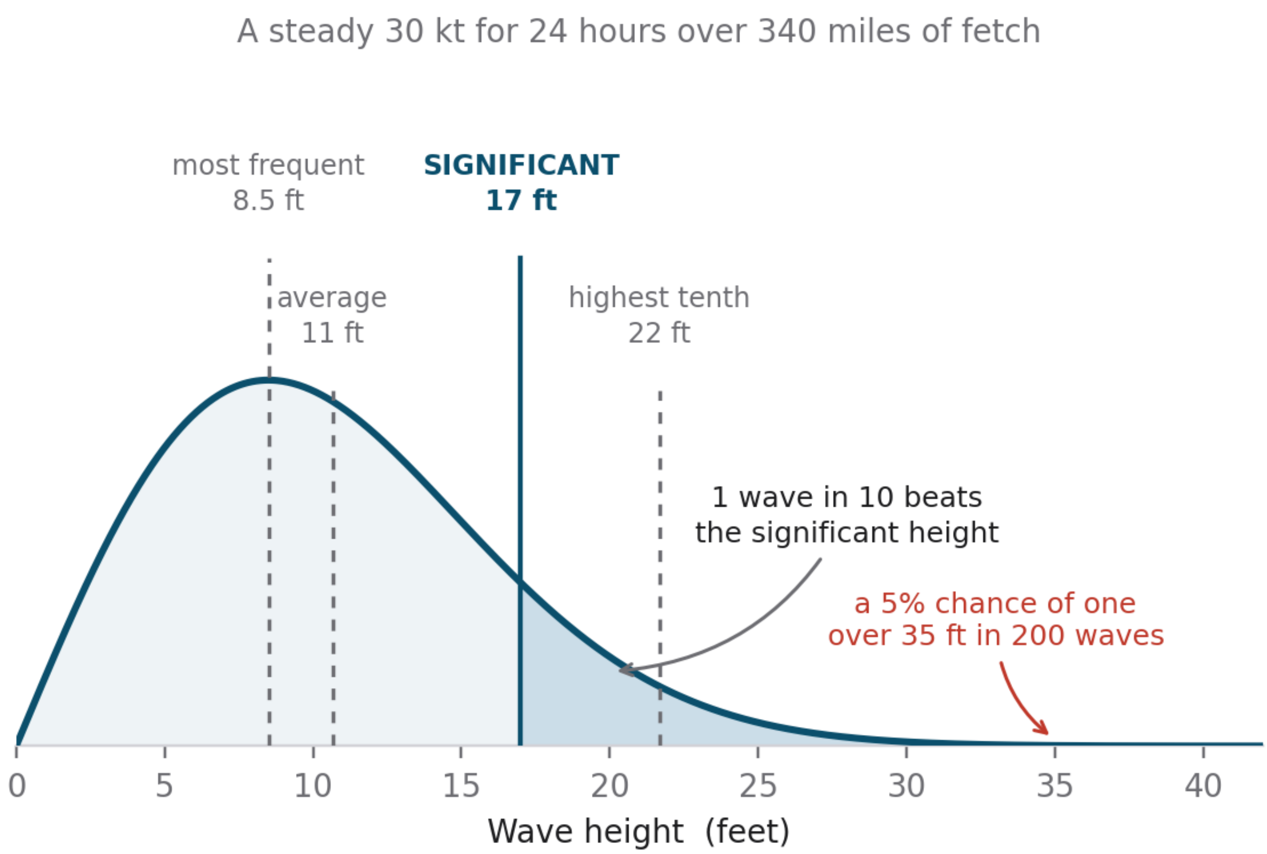


Figure 6 — The distribution of wave heights in a fully developed sea. A steady 30 kt for 24 hours over 340 miles of fetch.

In that sea	Height
10% of all waves are smaller than	3.9 ft
The most frequent wave height is	8.5 ft
The average wave height is	11 ft (3 m)
The **significant** wave height is	**17 ft (5 m)**
10% of all waves are bigger than	18 ft (5 m)
The average of the highest 10% is	22 ft (7 m)
A 5% chance of meeting one wave over 35 ft in any 200 that pass — about half an hour	35 ft (11 m)
A 5% chance of meeting one wave over 40 ft in any 2,600 that pass — about five hours	40 ft (12 m)

The point of that table

A forecast of ‘5 metre seas’ is not a forecast of 5 metre waves. It is a forecast that **one wave in ten will be bigger than that**, and that somewhere in a watch you will meet one at half again the height.

Set your ship up for the wave you will meet once, not for the average one.

Wind against tide or current shortens and steepens everything. The same wind speed over a foul current makes a far more dangerous sea than the numbers suggest.

SECTION 11

Tides

Not weather — but the same physics of a fluid on a spinning body, and the one that puts you aground.

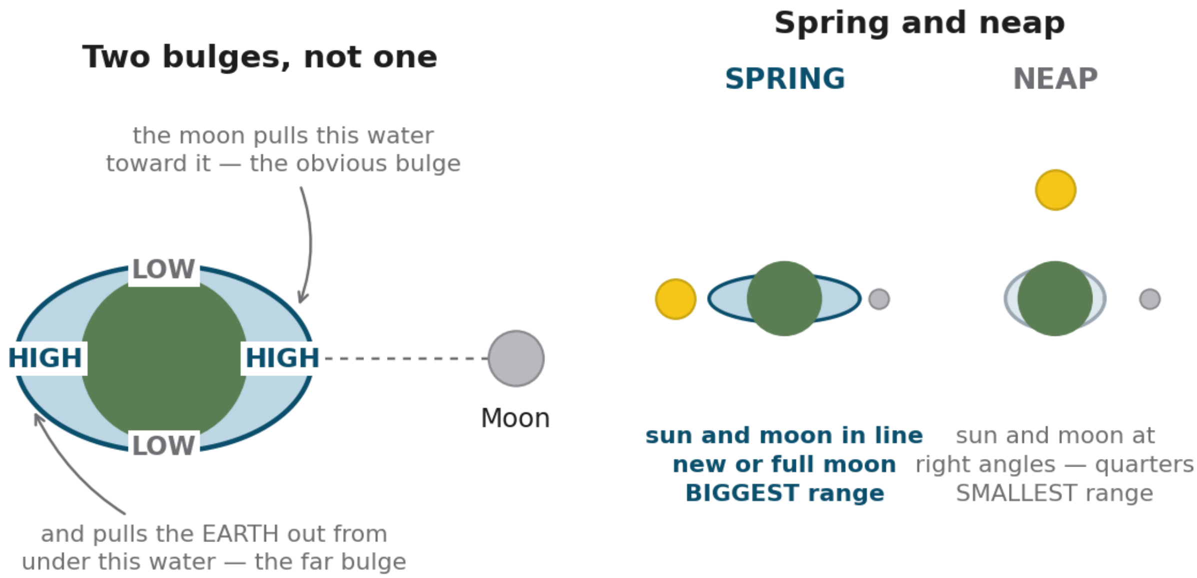


Figure 7 — Why there are two bulges rather than one, and why the range changes through the month.

Why two bulges? The moon's gravity is stronger the closer you are to it. On the near side of the earth the water is pulled toward the moon more strongly than the solid earth is, so it bulges toward the moon. On the far side the solid earth is pulled toward the moon more strongly than the water is, so the earth is dragged out from under the water and it is left behind as a second bulge. Put the other way: rotation and inertia want the far-side water to carry on in a straight line, and the moon's weakened pull out there is not enough to hold it in.

The water has to come from somewhere. It is taken from the sides — which is why the low waters sit at right angles to the bulges, and why most places get two highs and two lows in roughly a day.

- **Spring tides** — sun and moon in line, at **new and full moon**. The two pulls add, and you get the **biggest range**: highest highs and lowest lows. Nothing to do with the season; the word means to spring up.
- **Neap tides** — sun and moon at right angles, at the **quarters**. The pulls partly cancel and the range is at its **smallest**.
- The sun's tidal effect is about **45%** of the moon's — it is vastly more massive but much further away, and tidal force falls off with the cube of distance.
- The moon rises about **50 minutes later** each day, so the tides run about 50 minutes later too — roughly 12 hours 25 minutes between consecutive highs.

Where the theory stops and the tide tables start

Everything above describes an ocean with no continents in it. In the real world the tidal wave has to travel through basins and round headlands, and the local range and timing depend far more on the shape of the coastline than on the moon.

Use the tables and the tidal atlas. The theory tells you why a big spring tide is coming; it does not tell you the height of water on the bar.

Wind and pressure matter too. A deep low raises sea level by roughly **1 cm per millibar** below 1013, and a strong onshore wind piles more on top. A storm surge arriving on a spring high is how ports flood.

SECTION 12

Tropical revolving storms

An intense rotating depression over tropical ocean. Warm humid air, near-circular isobars, no fronts, a very steep gradient, and enormous intensity.

They form near the ITCZ, where the atmosphere is already unstable and the sea is warm enough to keep feeding them — convection runs from the surface all the way to the tropopause. Unlike a mid-latitude depression there are no fronts, because there is no cold air in it to make one.

Recognising one before it is on top of you

- **Watch the barometer, corrected.** Correct it for latitude, height and temperature, then compare against the seasonal mean for that area in the Sailing Directions. A corrected reading **3 mb below the mean** is your first warning.
- **A swift fall is the real signal.** Hold your course unless the barometer falls **5 mb**, or **3 mb accompanied by high winds** — then act.
- Long swell from an unexpected direction, and a hard, oily-looking sky.

Finding the centre

Face the wind. In the northern hemisphere the eye bears to your **right** — roughly **110°** when the storm is still several hundred miles off, and the angle **closes toward 90°** as you near the centre, because the wind blows more nearly along the isobars the closer in you get. Take several bearings over a few hours: how they change tells you whether the storm is heading for you or past you.

As a working assumption, a tropical storm does not move toward the equator. Below about 20° of latitude it is steered by the trades and tracks **west or west-north-west**. Somewhere around 25–30° it commonly **recurves** and runs off to the north-east, and the recurve is the part the forecast gets wrong most often.

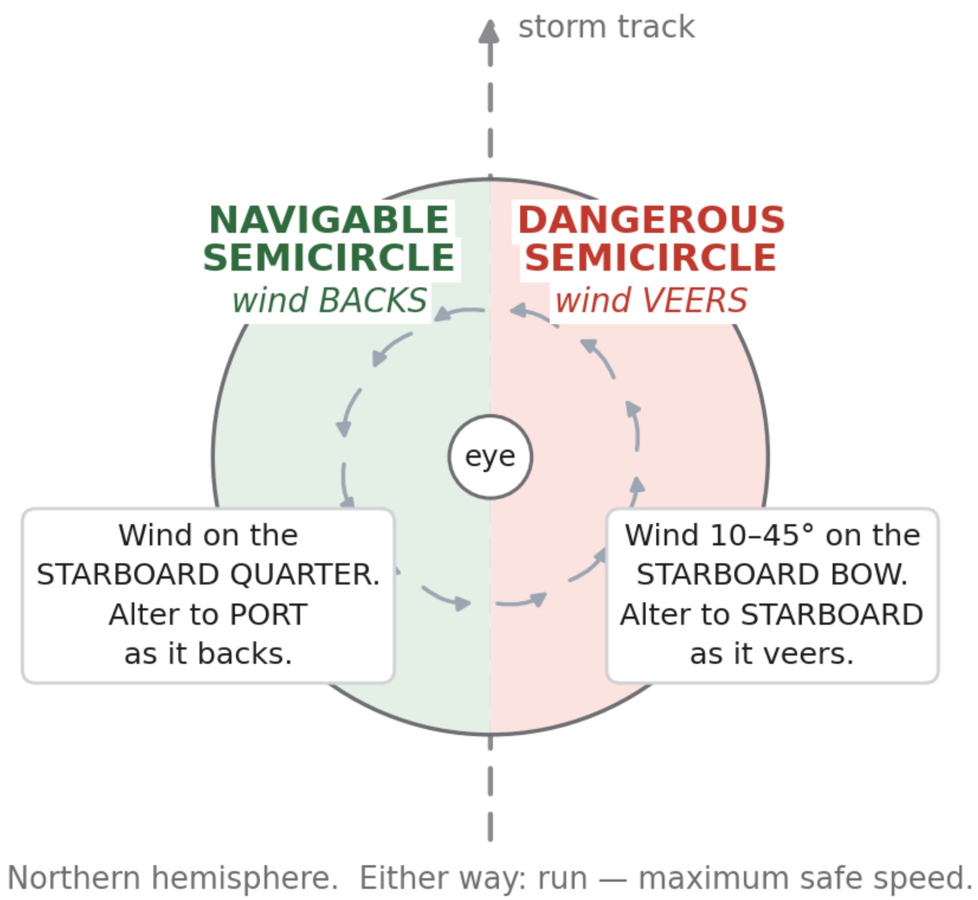


Figure 8 — The two semicircles, northern hemisphere. The wind shift tells you which one you are in, and the wind shift tells you which way to turn.

Northern hemisphere — which side am I on, and what do I do?

Wind VEERING (clockwise) → DANGEROUS semicircle. This is the right-hand side looking along the track, where the storm's own forward speed adds to its rotational wind and where you are being drawn into the path. Put the wind **10–45° on the starboard bow**, make maximum safe speed, and **alter to starboard** as the wind continues to veer.

Wind BACKING → NAVIGABLE semicircle. Bring the wind **on the starboard quarter**, make maximum safe speed, and **alter to port** as the wind backs. You are running away from the track.

Wind STEADY in direction, rising in force, barometer falling → you are IN THE PATH. This is the worst of the three, not a comfortable middle. Bring the wind **well on the starboard quarter** — about 160° — run at your best speed, and work yourself into the navigable semicircle. Do not wait to see which way it shifts.

In the **southern hemisphere** everything mirrors: the dangerous semicircle is on the left of the track, the wind backs in it, and you keep the wind on the **port** bow or quarter accordingly.

How far off is far enough

- Stay outside the **34-knot wind field** entirely. That is the number the advisories are built around — and in a mature hurricane that field can reach **100 to 200 NM** from the centre, so a few tens of miles off is not clearance, it is the storm.
- **Work to more than 200 NM from the centre.**
- **The 1-2-3 rule** for forecast error: add **100 NM** to the forecast 34-kt radius at 24 hours, **200 NM** at 48 hours, and **300 NM** at 72 hours. Track forecasts are good, but they are not that good, and the error is always in the direction you did not plan for.
- Steer for the area with the lowest wind and the shallowest sea, and keep going. Speed is what buys you sea room.

SECTION 13

Thunderstorms and heavy weather

The signs are all visual and they are all free. Look at the sky.

Question 2, answered: what makes it a bad one

- **Dark, threatening cloud — and the sharper, darker and lower the leading edge, the more severe the storm.** That hard leading edge is the gust front, and it is the thing that will knock you down.
- Wind or sea building steadily, or wind rising *against* a strong current — short, steep, dangerous sea.
- Sudden gustiness with heavy rain.
- The sea turning choppy with waves running in several directions at once.
- A noticeable drop in air temperature — that is the storm's downdraft arriving ahead of the storm itself.
- A falling barometer means foul weather coming; a rising one means it is clearing.

Handling it

Take the sea **on the bow, about 15–45° off**. Dead ahead means slamming; beam on means rolling, and beam on in a big sea is how ships get into real trouble.

Slow down. Maintain steerage and no more. Most heavy-weather damage is speed damage.

If the engine stops, stream a **sea anchor on a line from the bow** to keep her head up into it. A vessel lying beam-to and rolling is a vessel you are about to lose.

Question 3, answered: what causes wind shifts

- **Frontal passage** — the big one. Ahead of a cold front the wind is typically south to south-west; behind it, west to north-west. That shift can arrive in minutes.
- **Thunderstorms, supercells and squall lines** — violent, local, and largely unforecast at the scale that matters to you.
- **Waterspouts** — a rapid increase in wind with a complete change of direction.
- **Sea and land breezes** — predictable, daily, and reversing.
- **Simply moving round a pressure system** — the wind follows the isobars, so if you change your position relative to the centre, your wind changes with it.

Sea breeze and land breeze

The same physics as everything else, on a daily cycle, in sight of the coast. By day the land heats faster than the sea; the air over it rises, pressure falls, and air flows in off the water — the sea breeze, which builds through the afternoon. Around sunset the two even out and it goes calm. Overnight the land cools faster than the sea, the gradient reverses, and the land breeze flows offshore. Plan coastal passages around it, because it is one of the few wind shifts you can set your watch by.

SECTION 14

The ocean as a heat engine

The atmosphere gets the credit for moving heat around the planet. The ocean does more of it, and does it slower.

The sea absorbs sunlight down to roughly 200 metres, and it takes an enormous amount of energy to warm that much water — which is why the ocean changes temperature so slowly and stores so much heat. On land the sun's energy penetrates only a few inches, so the ground heats and cools fast. That contrast is the whole reason for sea breezes, for maritime climates being mild, and for continental ones being extreme.

- **Epipelagic zone**, 0–200 m — the sunlit surface layer. This is where the heat is stored and where the weather touches the sea.
- **Mesopelagic zone**, 200–1,000 m — holds the **thermocline**, where temperature drops away sharply with depth.
- Below that, the deep ocean sits at about **4°C (39°F)** everywhere on earth, whatever the latitude above it.

The **thermohaline circulation** — the conveyor belt — is driven by density, and density depends on temperature and salt together. In the North Atlantic surface water is chilled and, as sea ice forms, the salt it rejects is left behind in the water below. Cold and salty together makes it dense enough to sink. It spreads through the deep ocean and upwells slowly, mostly in the Pacific, on a round trip that takes something like a **thousand years**. That circulation is how heat gets moved from the tropics to the poles by water instead of air, and it sets the background climate that all the weather sits on top of.

SECTION 15

Reporting, sources and further reading

The forecast you rely on is built from observations, and a good share of them come from ships like yours.

The **Voluntary Observing Ship** programme, run under the World Meteorological Organization as part of the Global Observing System, gathers weather and oceanographic observations from merchant vessels underway — several thousand ships across more than twenty nations. Over the open ocean there is often nothing else.

- Standard reporting schedule: **four times daily at 0000, 0600, 1200 and 1800 UTC**.
- On the Great Lakes and within 200 miles of the US or Canadian coast (including Alaska, Hawaii and the Gulf states): **every three hours** — 0000, 0300, 0600, 0900, 1200, 1500, 1800, 2100 UTC.
- **MAFOR** forecasts are coded: a date-time group, the area name, then one or more five-figure groups.

Where to go next

NOAA JetStream — noaa.gov/jetstream. A free online school of weather, and the source of several diagrams in the companion guide. The best plain-language reference there is.

National Weather Service Observing Handbook No. 1 — vos.noaa.gov. The VOS observer's manual, free.

Bowditch, *The American Practical Navigator* — the meteorology and oceanography chapters. Free, and it is what the exam is written from.

SOLAS Chapter V (Safety of Navigation) and **IMO Resolution A.893(21)** (Guidelines for Voyage Planning) — the regulatory side.

Modern forecast services give ten-day wind direction and velocity; apps such as Windy run to fifteen. **Treat anything past about five days as a trend, not a forecast.**

SECTION 16

The Beaufort scale

Beaufort was designed to be read off the sea surface, not off an instrument. It still works, and on a bad day it may be all you have.

Force	Knots	Description	The sea	Wave ht
0	under 1	Calm	Mirror	—
1	1–3	Light air	Ripples, no foam	0.25 ft
2	4–6	Light breeze	Small wavelets, glassy crests	0.5–1 ft
3	7–10	Gentle breeze	Large wavelets, scattered whitecaps	2 ft
4	11–16	Moderate breeze	Small waves, frequent whitecaps	3.5 ft
5	17–21	Fresh breeze	Moderate waves, many whitecaps	6 ft
6	22–27	Strong breeze	Large waves, foam crests, spray	9.5 ft
7	28–33	Near gale	Sea heaps up, foam blows in streaks	13.5 ft
8	34–40	Gale	Moderately high waves, well-marked streaks	18 ft
9	41–47	Strong gale	High waves, dense foam, spray hurts visibility	23 ft
10	48–55	Storm	Very high waves, surface white, heavy tumbling	29 ft
11	56–63	Violent storm	Exceptionally high waves, sea covered in foam	37 ft
12	64+	Hurricane	Air filled with foam and spray, sea entirely white	45 ft +

Wave heights are for the open sea, fully developed. Enclosed water and short fetch give less; wind against tide gives worse.

TEAR THIS OUT

The Quick Card

VEER AND BACK

VEER = clockwise. NE → E → SE. **BACK = anticlockwise.** NE → N → NW.

Warm front: **backs** ahead, **veers** on passage. Cold front: **veers sharply**, all at once. Both travel the same way; the cold one is twice as fast.

BUYS BALLOT — NORTHERN HEMISPHERE

Wind at your back → **LOW on your LEFT**, slightly ahead. (Southern hemisphere: LOW on your right.)

TROPICAL REVOLVING STORM — NORTHERN HEMISPHERE

Barometer **3 mb** below the seasonal mean: warning. **5 mb fall**, or **3 mb with high wind**: act.

Face the wind — eye bears about **110° to starboard** well off, closing toward **90°** near the centre.

Wind VEERS → DANGEROUS. Wind 10–45° on the **starboard bow**, alter to **starboard**.

Wind BACKS → NAVIGABLE. Wind on the **starboard quarter**, alter to **port**.

Wind STEADY, rising, glass falling → YOU ARE IN THE PATH. Wind **well on the starboard quarter** (~160°) and run.

Stay outside the 34-kt field. **1-2-3 rule:** +100 / +200 / +300 NM at 24 / 48 / 72 hours.

WIND LOAD ON THE SIDE

$$q = 0.004\ V^2 \qquad F = A \times q \times C_d$$

V in knots. q in lb per square FOOT. A in square feet. C_d = 1.0 for a ship's side.

Double the wind → four times the force. A 60,000 sq ft box boat: **BF 6 = one tug. BF 8 = two and a half. BF 10 = four and a half.**

SEA AND SWELL

Waves need **strength, duration and fetch**. Remove any one and the sea cannot build.

Significant wave height = the average of the highest third. One wave in ten beats it; one in a hundred is half again as big.

Long swell, wrong direction = big storm, far away, telling you first. Wind against tide makes everything worse.

LAPSE RATES — STABILITY IN ONE LINE

Environmental **2°C** / 1,000 ft. Dry adiabatic **3°C**. Saturated adiabatic **1.5°C**.

Parcel cools **faster** than its surroundings → stable: layer cloud, haze, fog. Parcel cools **slower** → unstable: cumulus, showers, squalls, CB.

FOG · CHART SENSE · HEAVY WEATHER

Warm air over cold water = sea fog. Day and night; needs a new airstream or 15 kt+ to shift it. Watch the temperature/dew-point spread close.

Isobars every **4 mb**, sea level **1013 mb**. Tight isobars = strong wind. **Low:** in, up, anticlockwise. **High:** down, out, clockwise.

Sea **15–45° on the bow**, never beam on. **Slow down** to steerage way. Engine stopped → **sea anchor from the bow**.

Sharpest, darkest, lowest leading edge = worst storm.

Weather for the Mariner · Capt. Georgia Hilton · captaingeorgia.com · free to use for study