

ADVANCED MARINE WEATHER

The Complete Night-Watch Lecture — from the Sun to the Passage Plan

One lecture, read straight through. It begins with the heat that drives everything, builds the whole machine a piece at a time, teaches you to read it off the sky, the sea and the chart, and finishes where a mariner actually stands — planning a passage and writing the weather report for the bridge, and sending its own observations back to the fleet. The narrative is meant to be read or heard; the boxed rules and tables are what you keep.

PART ONE

Where Weather Comes From

1 · The Atmosphere as a Heat Engine

Let's begin where any honest discussion of weather must begin: with the admission that the whole apparatus is a heat engine. That's all it is. The sun pours energy onto a rotating, tilted, unevenly painted ball — ocean here, desert there, ice at the ends — and the atmosphere and ocean spend their entire existence trying, and forever failing, to even that heat out.

Every wind you've ever leaned into, every front that's soaked you, every calm that's left you rolling your guts out in a windless swell — all of it is the atmosphere moving heat from where there's too much to where there's too little. Hold that idea like a compass rose in the back of your mind, because everything else hangs off it. Weather isn't a collection of phenomena. It's one process, heat transport, wearing a thousand costumes.

The equator takes sunlight nearly head-on all year. The poles get it at a slice, spread thin across the curve of the earth, and for half the year they get none at all. So there's a permanent surplus of heat in the tropics and a permanent deficit at the poles, and the temperature difference between them is the voltage that drives the entire circuit.

If the earth didn't rotate, that circuit would be simple — hot air rising at the equator, flowing aloft to the poles, sinking there, returning along the surface as one vast convection loop per hemisphere. One cell. A steady equator-to-pole surface wind. Beautifully simple, and completely wrong, because the earth does rotate. And rotation is the second great fact that shapes everything you see from the deck.

Three things complicate that simple picture, and those three complications are most of what there is to learn. The earth is tilted, about twenty-three and a half degrees, and the tilt stays put while the overhead sun swings north and south through the year — that is the seasons, and the seasons reshape the weather. The earth spins, a thousand miles an hour at the equator and not at all at the poles, and that spin bends every large flow of air. And water and land take up heat completely differently — the sea warms slowly and enormously and lets its heat go slowly; the land heats and cools in a day. Hold one more idea while you read the rest: the parcel. Picture a bubble of air that keeps to itself as it rises or sinks, expanding as the pressure falls and cooling as it expands. Ask what a parcel would do, and the answer usually falls out on its own.

- The tropics run a permanent heat **surplus**; the poles a permanent **deficit**.
- The temperature difference between them is the **voltage** that drives all weather.
- Gravity holds the air on and makes cold air sink and warm air rise — the vertical half of every system.

- A non-rotating earth would need one convection loop per hemisphere. Because it spins, that loop breaks apart.

KEY RULE

All weather is the transport of heat from surplus to deficit. Hold that idea like a compass rose; everything else hangs off it.

2 · The Coriolis Effect

Now, the Coriolis effect — the most misunderstood force in practical meteorology, and most explanations of it do more harm than good. It is not a force in the ordinary sense. Nothing pushes the air sideways.

What happens is this: you, your vessel, your chart, your whole sense of a fixed north, are standing on a spinning platform, and you insist on measuring motion relative to that platform. Air set in motion travels, as far as the universe is concerned, in a nearly straight line. But the earth turns underneath it while it travels. So from our rotating point of view, the air appears to curve — right in the Northern Hemisphere, left in the Southern.

The deflection is zero at the equator, strongest at the poles, and proportional to how fast the air is already moving. Slow air, weak deflection. Fast air, strong deflection. It acts always at right angles to the motion, so it can bend a wind but never speed it or slow it. Fix that firmly: Coriolis turns, it does not drive.

One more figure is worth carrying, because it explains a great deal. The deflection goes with the sine of the latitude: nothing at the equator, half its full strength by thirty degrees, about seven-tenths by forty-five, everything at the pole. That is why a tropical revolving storm cannot form within about five degrees of the equator — there is simply not enough turning underneath the air to get a circulation started — and it is why the same pressure pattern gives you far more wind in high latitudes than in low ones.

- Deflection: **right** in the Northern Hemisphere, **left** in the Southern.
- **Zero** at the equator, **strongest** at the poles — it follows the sine of the latitude.
- Proportional to the speed of the air; acts at right angles to the motion.
- It can only turn a wind, never speed it or slow it.

KEY RULE

Coriolis **turns**; it does not **drive**.

3 · The Three-Cell Circulation

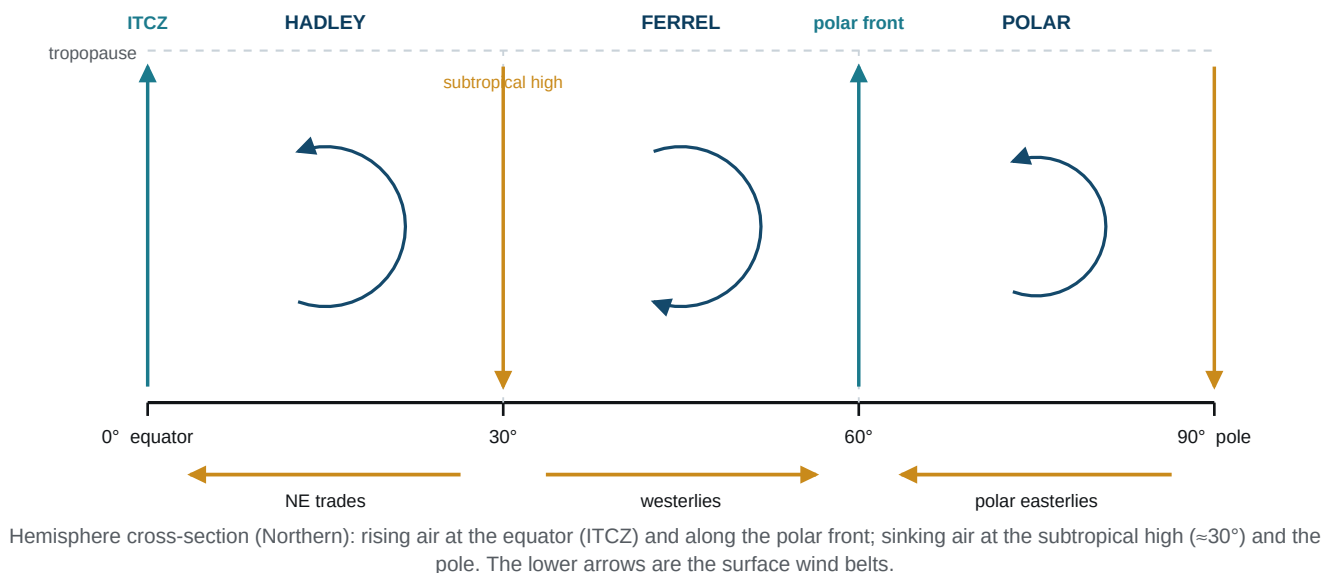
Put those two facts together — the heat surplus at the equator, and the turning — and the single simple convection cell breaks into the structure you actually navigate under.

The air rising at the equator flows poleward aloft, but as it goes, the deflection bends it further and further east, until by about thirty degrees of latitude it's running almost due east and has stopped making poleward progress altogether. It piles up there, cools, and sinks. That's the horse latitudes — the subtropical high-pressure belts. Descending air warms as it compresses, and warming air holds more moisture rather than less, so it dries as it comes down. That's why the great deserts of the world sit in a ring around thirty north and thirty south. And it's why the Bermuda-Azores High and the Pacific High sit parked over the subtropical oceans, dominating everything a mariner does in those waters.

From that sinking region the air splits at the surface. Some runs back toward the equator, deflecting right in the Northern Hemisphere to become the northeast trades, left in the Southern to become the southeast trades. Where they meet: the Intertropical Convergence Zone. The doldrums. Rising air, towering convection, squalls, and maddening calms.

The rest runs poleward from that high, deflecting right again into the prevailing westerlies of the mid-latitudes — the belt where you and I do most of our sailing and take most of our punishment. Further north it meets cold polar air spilling equatorward, and that collision zone is the polar front: the birthplace of every mid-latitude depression that ever ruined a passage plan.

So — three cells per hemisphere. Hadley, Ferrel, Polar. Not tidy, not fixed, migrating north and south with the season as the sun's overhead point wanders. But that's the skeleton. Everything else is muscle hung on it.



- **ITCZ / doldrums (0°):** rising air, towering convection, squalls and calms. Nursery of tropical storms.
- **Horse latitudes (~30°):** sinking, warming, drying air — the subtropical highs and the world's deserts.
- **Trades:** surface flow back toward the equator — NE in the north, SE in the south.
- **Westerlies (30–60°):** the mid-latitude belt where we take most of our weather.
- **Polar front (~60°):** cold meets warm — the nursery of depressions, with the jet overhead.

4 · The Jet Streams

Let's go up to the jet stream, because it governs the whole business and it's where the real forecasting skill lives. The jet is a narrow ribbon of very fast wind near the tropopause, thirty thousand feet or so, running west to east, sometimes a hundred and fifty knots or more. It exists because of the temperature contrast across the polar front; a strong contrast means a strong jet. It's the steering current: surface lows travel roughly along it, at roughly half its speed.

But it does more than steer. Where the jet diverges aloft — where air spreads apart — it evacuates the air column faster than the surface can supply it, surface pressure falls, and the depression deepens. A low under a divergent region of a strong jet will bomb out; the same low under a flat, unremarkable jet will amble along and fizzle.

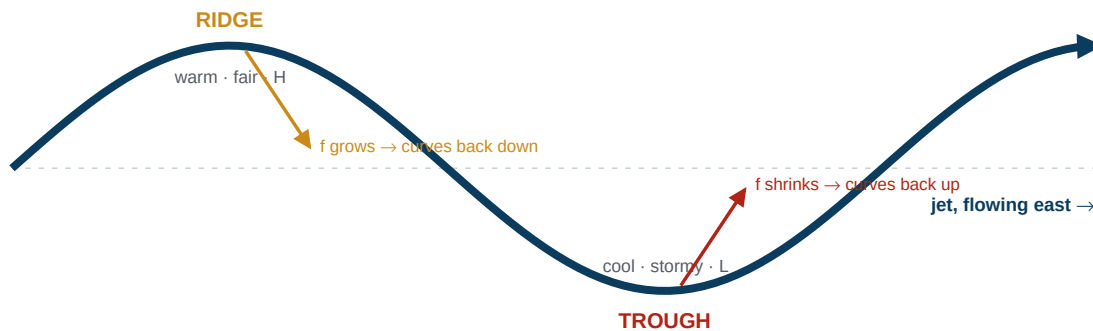
And the jet meanders, developing great north-south Rossby waves that set the pattern for a week at a time. Running straight west to east — zonal flow — systems race across quickly, one after another, weather changing fast. Buckled into deep meridional waves, systems slow down, dig in, and park; that's your week of the same miserable thing, or a blocking high that won't shift. Zonal, pick your gap. Meridional, expect whatever you've got to persist.

Why it meanders — Coriolis, the waves, and the jet as one mechanism

It is worth slowing down on why the jet meanders at all, because the answer ties the three ideas together — Coriolis, the Rossby waves, and the jet — into a single mechanism. The key is the one thing about Coriolis people file away and forget: it is not a fixed number. It grows with latitude, from nothing at the equator to its full strength at the pole — that is the sine-of-latitude rule from the second section, put to work. So a parcel of air in the westerlies carries two kinds of spin at once: the planetary spin it inherits just from sitting on a turning earth, which is Coriolis, and whatever spin of its own it has picked up from curving through the flow. Nature tends to keep the sum of those two constant, and that single accounting rule is the engine of the whole pattern.

Follow one parcel and watch it work. Nudge it poleward and its planetary spin increases, so to keep the sum constant its own spin must fall — it takes on clockwise, anticyclonic curvature, and that curvature bends its track back toward the equator. Let it overshoot to the south and the opposite happens: planetary spin drops, its own spin rises, it acquires cyclonic curvature and swings back poleward. The parcel can never settle; it oscillates north and south as it runs east, and that oscillation, drawn right around the hemisphere, is a Rossby wave. The poleward bulges are the ridges — warm, anticyclonic, fair — and the equatorward dips are the troughs — cool, cyclonic, the business end where depressions are bred. The jet is nothing more exotic than the fast core of wind threading along the crests and troughs of that wave, quickest where the temperature contrast packs the flow tightest.

POLEWARD — Coriolis (f) is STRONGER



EQUATORWARD — Coriolis (f) is WEAKER

The vorticity see-saw that makes the waves. Because Coriolis strengthens toward the pole, a parcel pushed north gains anticyclonic curvature and turns back south; pushed south it gains cyclonic curvature and turns back north. The result is a standing north–south wave train with the jet running through it — ridges warm and fair, troughs cold and stormy.

Two consequences fall out of this and both reach the bridge. First, there are only ever a handful of these long waves around the hemisphere at once — three to six — and the long ones move slowly, sometimes even backward against the flow, while shorter waves ride east through them. The practical effect is downstream development: a disturbance far upstream today becomes your weather in two days, arriving well before any single system has physically crossed the ocean to reach you — which is why a forecaster watches the wave pattern, not just the nearest low. Second, there is a trade between the jet's speed and how far it buckles. A strong, fast jet tends to run flat and zonal, straight west to east, and the weather races through in a fair-foul-fair parade. Let it weaken and it buckles into deep meridional loops that crawl, and if a ridge amplifies far enough it can pinch off into a blocking high — an Omega-shaped block, or a high sitting stubbornly over a low — that shoulders every system around it and holds the same weather in place for a week or two. When you see the upper pattern go loopy, stop expecting change and provision for persistence.

KEY RULE

The see-saw, in one breath: push air poleward and f grows, so its own spin must shrink — it curves back equatorward; push it equatorward and f shrinks, its spin grows — it curves back poleward. That restoring swing **is** the Rossby wave. Troughs (equatorward, cyclonic) breed lows; ridges (poleward, anticyclonic) bring fair. Strong jet → flat, zonal, fast weather; weak jet → deep loops, slow-moving, prone to blocking.

- The **polar-front jet** sits near 60° at about 30,000 ft — the one that steers mid-latitude depressions.
- The **subtropical jet** sits near 30° at about 40,000 ft, generally weaker.
- They are tubes, not lines: 200 kt in the core, 80 kt at the edges. They **follow the sun** and are strongest in winter.
- Find the jet and you have found the storm track. A trough upstream feeds a low; a ridge suppresses it.

KEY RULE

Zonal flow (straight, W–E): a fast parade of systems, weather changing quickly. Meridional flow (deep N–S waves): systems slow, dig in and park — plan for persistence.

5 · Air Masses

An air mass is nothing more than a very large body of air that has sat still long enough over one kind of surface to take on its character, and then carries that character with it when it moves. Give air a week over the ice and it comes away cold, dry and stable. Give it a week over a warm ocean and it comes away warm, humid and ready to convect. There are only two questions worth asking of any air mass — where was it born, high latitude or low, and what was underneath it, water or land — and those two questions give you the five labels you will ever need: continental or maritime, and arctic, polar or tropical.

But the label is not the point. The point is what the air mass is doing relative to the surface it is crossing now. Cold air moving over warmer water is heated from below, and heating from below makes air unstable — it lifts, it throws up cumulus and showers, it gives you gusty winds and, between the showers, very good visibility. That is the polar airstream behind a cold front, and it is why the sky breaks into towers once the front has gone through. Warm air moving over colder water is the exact opposite, and it is the dangerous one. It is cooled from below, it goes stable, and it condenses at the bottom: sea fog, low stratus, drizzle, and visibility that can shut from ten miles to two cables while the glass never moves and the wind stays soft. The quiet weather is the one that puts ships ashore.

Code	Source	Character	What it brings
cA / cP	Polar ice, high-latitude land	Cold, dry, stable	Clear and cold; unstable once over warm sea
mP	High-latitude ocean	Cool, damp, unstable	Showers, good visibility between, bumpy air
cT	Low-latitude land, desert	Hot, very dry	Haze, dust, the dry side of a dryline
mT	Low-latitude ocean	Warm, very humid	Fog and drizzle over cold water; storms over warm land

KEY RULE

Cold air over warm water — unstable: cumulus, showers, gusts, good visibility. Warm air over cold water — stable: fog, stratus, drizzle, visibility gone. The quiet one is the dangerous one.

6 · Cloud, and the Cost of Lifting Air

Cloud forms for exactly one reason, and it is worth saying plainly because half of meteorology hangs off it: 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 the pressure around it falls, so it expands, and expanding costs energy, so it cools, whether or not anything took heat out of it. Cool it far enough and the moisture condenses. The height where that happens is your cloud base.

Whether the parcel keeps climbing once it starts is the whole of stability, and it comes down to comparing three rates. The air around the parcel gets colder with height at its own rate — about two degrees Celsius per thousand feet in a standard atmosphere, and that is the one you measure. A dry parcel, lifted, cools faster than that, about three degrees per thousand, purely from expanding. And once it is condensing, the latent heat it releases slows its cooling to about a degree and a half. Now compare. If the parcel cools faster than its surroundings it soon becomes colder and heavier than the air around it, sinks back, and nothing happens — a stable atmosphere, flat layered cloud, haze, poor visibility. If it cools slower it stays warmer and lighter and keeps climbing on its own — unstable, and that is your cumulus, your squalls, your thunderheads. That one comparison is the difference between a grey stratus afternoon and a line of storms.

Étage	Base	Typical cloud	What it tells you
High	6,000 m +	Cirrus, cirrostratus	Ice crystals. Warm front on the way, or fair
Middle	2,000–6,000 m	Altostratus, altocumulus	Thickening ahead of a front; clearing behind
Low	0–2,000 m	Stratus, nimbostratus	Steady rain, poor visibility
Vertical	low base, huge top	Cumulus congestus, Cb	Instability — squalls, hail, wind shifts

KEY RULE

Environmental lapse $\sim 2^{\circ}\text{C} / 1,000 \text{ ft}$. Dry parcel $\sim 3^{\circ}\text{C}$. Saturated $\sim 1.5^{\circ}\text{C}$. Parcel cools faster than its surroundings → stable (layers, haze, fog). Parcel cools slower → unstable (cumulus, showers, storms).

PART TWO

Pressure, Wind, and the Depression

7 · Pressure and the Barometer

Now come down from the planetary scale to the scale you work in. The barometer measures the weight of the column of air above you. That's all. High pressure, more air stacked overhead, generally sinking, generally settled. Low pressure, less air, generally rising, generally unsettled. But here's what matters, and what the old hands drum into you: it isn't the height of the barometer that tells you the weather, it's the rate of change. A glass sitting at 1005 and steady is telling you something benign. A glass at 1015 falling three millibars in three hours is telling you something is coming, and coming hard.

Keep these thresholds. A fall of one to two millibars in three hours means a system approaching — worth attention. Three to four millibars in three hours means a vigorous system, gale force likely. Five or more in three hours means a storm, and you should already be taking action rather than thinking about it. And the reverse holds: a barometer that rises too fast is not good news either. A sharp rise behind a cold front brings its own squalls and a hard, gusty northwesterly.

There's an old rule worth carrying. Long foretold, long last; short notice, soon past. A slow, steady, grinding fall over a day and a half means a big system that will sit on you for days. A violent drop over three hours means

something fast and sharp that will be through and gone by morning.

KEY RULE

Read the **rate of change**, not the height of the glass.

Long foretold, long last; short notice, soon past.

3-hour fall	What it means	What you do
1–2 mb	System approaching	Take note; watch the trend
3–4 mb	Vigorous system — gale likely	Prepare the vessel; secure for weather
5 mb or more	Storm developing	Act now — don't deliberate
Sharp rise	Cold front through; gusty NW'ly	Expect squalls behind the front

8 · Wind, Highs and Lows, and Buys Ballot

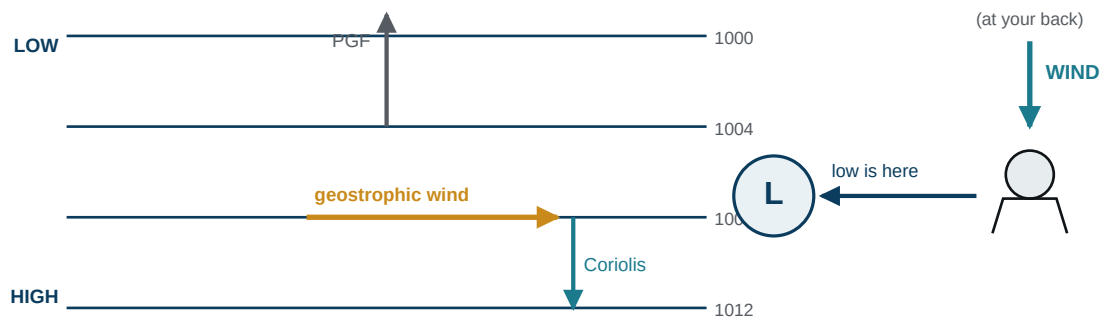
Why does wind blow at all? Pressure difference. Air moves from high toward low, and the steeper the pressure gradient, the harder it blows. On a synoptic chart, the isobars are contour lines of pressure, and their spacing is your wind speed: tight isobars, strong wind; slack isobars, light air. That's the single most valuable thing on a surface analysis, and you can read it at a glance from across the chart table.

But the wind does not blow straight from high to low, and here's where Coriolis returns. Air starts moving down the gradient, and the moment it moves, the deflection begins bending it right. It keeps bending until the pressure gradient force pulling it inward is balanced by the Coriolis deflection pushing it outward — and at that point, the air is running parallel to the isobars, not across them. That's geostrophic wind. Down at the surface, friction slows the air, weakens the deflection, and lets the wind fall back across the isobars toward the low — by about fifteen degrees over open water, more like thirty over land, and a touch weaker.

From this falls out the single most practical rule in all of marine weather. Buys Ballot's Law. In the Northern Hemisphere, stand with your back to the true wind, and the low pressure is on your left — roughly to your left and slightly behind. In the Southern Hemisphere, reverse it: back to the wind, low on your right.

Think about what that gives you. Standing on deck, with no chart, no forecast, no radio, you can locate the centre of the system that's working you. And by taking that bearing repeatedly over some hours and watching how it shifts, you can work out whether the thing is coming at you, passing ahead, or passing behind. That rule is three hundred years old and it still works in the middle of the ocean with the electronics dead.

Stand back from a single wind and look at the whole spiral, because it explains why lows are foul and highs are fair. Air cannot pile up at a point. When surface air spirals into a low it has nowhere to go but up, and rising air cools, reaches its dew point and gives cloud, rain and wind — that is a low, in one sentence. A high is the same argument run backwards: air sinks into it, warms and dries, and you get settled weather, light winds, and often haze and trapped fog because nothing is stirring. And there is a coupling you cannot see from the deck but must respect: a surface low only keeps deepening if the air rising out of it is carried away aloft faster than the surface can supply it. That removal happens in particular places under the jet, which is why a forecaster reads the upper chart before committing to a surface forecast — the surface chart shows the system, the upper chart shows whether it is being fed or starved.



Northern Hemisphere: back to the wind, low on the LEFT

Aloft: pressure-gradient force balanced by Coriolis; the wind ends up parallel to the isobars.

Find the low with no instruments: back to the wind, low on the left (N. Hem.).

KEY RULE

Isobar spacing is wind speed: tight isobars, strong wind; slack isobars, light air.

Buys Ballot (N. Hem.): back to the true wind, the low is on your **left** and slightly ahead. Southern Hemisphere: low on the **right**.

Surface wind over the sea $\approx$ 70–80% of geostrophic, backed 10–20°; over land $\approx$ 50%, backed 30°.

9 · Fronts, and the Life of a Depression

The mid-latitude low is the machine that generates most of your bad days. Start at the polar front — that boundary where cold polar air meets warm subtropical air. It isn't a smooth line; it's a shear zone, and shear zones are unstable. A small wave forms on it, a kink where warm air noses poleward and cold air noses equatorward. If conditions are right, that kink doesn't damp out. It amplifies.

Pressure falls at the kink. Air begins circulating around it — anticlockwise in the Northern Hemisphere. The warm air advances on the eastern side, riding up over the cold air ahead of it: your warm front. On the western side, cold air undercuts the warm air, shovelling it upward: your cold front. The warm sector is the wedge of mild, moist air between them.

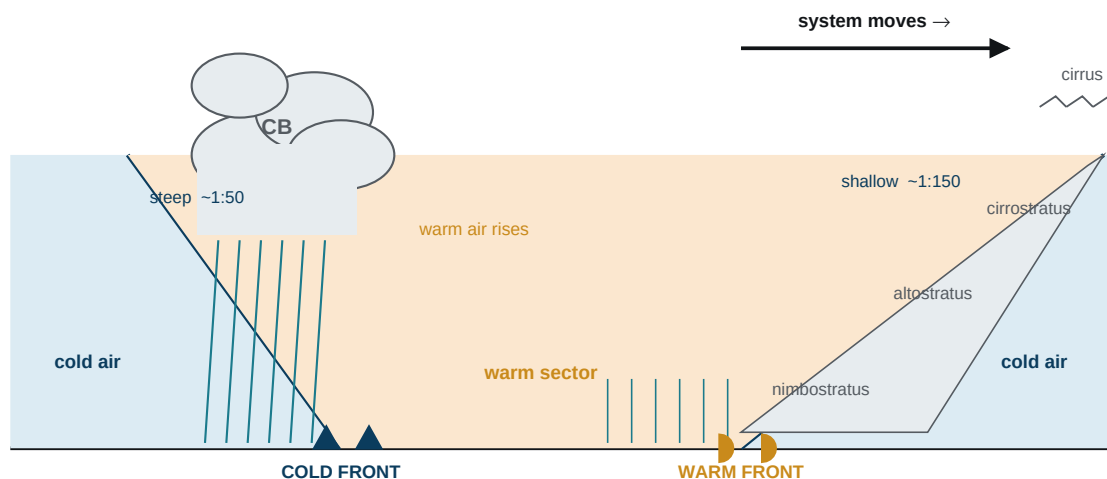
The warm front has a shallow slope — one in a hundred and fifty. Warm air can't shove cold air aside, so it climbs gently over the top, and that long ascent gives a slow, orderly, readable sequence, the same every time. First cirrus, mare's tails, six hundred miles ahead, often a full day early — thickening and lowering is your first warning. Then cirrostratus, the milky veil with a halo round sun or moon. Then altostratus, the sun a watery blur; then nimbostratus and steady rain, wind backing and freshening, glass falling, visibility down.

Then the surface warm front passes and everything changes at once. Rain eases, temperature jumps, the barometer steadies, and the wind veers — clockwise in the north. You're in the warm sector: mild, murky, poor visibility, perhaps sea fog over colder water.

The cold front is nothing like its sibling. Its slope is steep — one in fifty. Cold dense air acts like a plough, driving under the warm air and hurling it violently upward: deep convection, cumulonimbus, a narrow savage band of squalls, heavy rain, thunder, hail. The passage is abrupt — wind veers sharply, often forty-five to ninety degrees in minutes, the squall can double the wind speed with no warning, the glass turns and rises, temperature drops hard. Behind it the sky opens into a scoured, bright, showery northwesterly, cold and gusty, with a nasty steep sea because the wind has shifted across the old swell.

That cross sea is worth dwelling on. For some hours after the cold front you have a strong new northwesterly running across the old southwesterly swell — the most dangerous water in the whole depression. Not the strongest wind, the most confused sea. More vessels are hurt there than in the front itself.

The last act is occlusion. The faster cold front catches the warm front, lifts the entire warm sector clear of the surface, and the low, cut off from its warm air, fills and dies. Life cycle: wave, deepening, mature, occluded, dying — two to five days. And they come in families, one after another down the polar front, each riding the jet stream east. That's why one bad system so often means several.



Vertical section through a depression (system moving right). Shallow warm-front ramp with its long, orderly cloud sequence ahead; steep cold front driving deep convection behind.

	Warm front	Cold front
Slope	Shallow (~1:150)	Steep (~1:50)
Cloud	Layered: cirrus → cirrostratus → altostratus → nimbostratus	Convective: towering cumulonimbus
Precip	Long, steady rain well ahead	Narrow, violent squall band
Wind shift	Backs, then veers on passage	Veers sharply — 45–90° in minutes
Pressure	Falls steadily, then steadies	Stops falling, then rises
Temp	Rises into the warm sector	Drops hard behind

The whole life is four acts and it is always the same play. A stationary front along the polar boundary is stored energy, waiting for a kink. A wave forms on it and a low is born, with a warm front running east and a cold front trailing south-west and the warm sector between. The low deepens, the isobars tighten, both fronts sharpen — and because the cold front runs about twice as fast as the warm one, it catches it up. That overtaking is the occlusion: the warm sector is lifted clear of the surface, the low is cut off from its fuel, and it fills and dies. But do not relax at the sight of an occluded front — a depression is often deepest, and its winds strongest, at or just after occlusion. Read it as the top of the curve, not the far side of it. And they come in families down the same polar front, so a glass falling again after a clearance means look astern, not up.

ON DECK

The worst water in the whole system is the **cross sea** in the hours after the cold front — a hard new NW'ly running across the old SW'ly swell. More vessels are hurt there than in the front itself. It is confusion, not strength, that does the damage.

PART THREE

Reading the Sky and the Sea

10 · Reading the Sky

A cloud is a snapshot; the sequence is the forecast. Nobody was ever warned by a single photograph of the sky — what warns you is the trend, whether it is thickening or thinning, lowering or lifting, over an hour or two of watching. So ask three questions every watch, in this order. Which way is it going — not the wind on deck, but the high cloud, crossing the wind at your back? Is it thickening or thinning — lowering and hardening means weather coming, lifting and going crisp at the edges means it is leaving? And what does the glass say — because the sky proposes and the barometer confirms, and a falling glass under a clean sky means look harder, something is coming you have not yet seen.

The warm front gives you up to two days of it, in order, and the order is your clock. First the mare's tails, cirrus hooked high and thin, the earliest thing a front sends ahead. Then cirrostratus, the blue going milky with a halo round the sun or moon — the sky committing itself. Then altostratus, the sun a watery disc with no shadow on deck. Then nimbostratus, low and grey and raining steadily, the glass falling and the wind backing and freshening. Then the front passes into the warm sector: the rain eases, the temperature jumps, the glass levels, and the wind veers hard. The cold front behind it is a different animal and it gives you hours, then minutes — fair-weather cumulus hardening into towers, the anvil spreading downwind to point where the cell is going, and then the shelf cloud, a dark low wedge on the leading edge. The gust front runs ahead of the rain, sometimes by miles: the wind can veer ninety degrees and double while the sky above you is still dry. Act on the shelf cloud, not on the rain.

There is one trick worth more than any single cloud. Put your back squarely to the surface wind and watch the highest cloud. If it crosses from left to right, the weather is deteriorating — a warm front and its low are ahead of you. Right to left, it is improving — the system is clearing and the glass is building. Running with the wind, little will change. It is Buys Ballot again: with your back to the wind the low is on your left, the upper cloud is steered round that same low, and when the two cross at right angles you are looking straight at a front.

Back to the wind, watch the high cloud	What it means
High cloud crossing left → right	Deteriorating — warm front and low ahead. Rain within a day.
High cloud crossing right → left	Improving — system clearing, pressure building, wind settles NW.
High cloud running with the wind	Little change — no front crossing you. Check again in a few hours.

KEY RULE

Old sayings that hold: *red sky at night* — clear dry air to the west, where your weather comes from. *Mare's tails and mackerel scales* — cirrus and altocumulus together, the standard front signature. *Rain before wind* — the warm-front pattern, much more behind it; *wind before rain* — a squall line, violent and short.

11 · Reading the Sea

You are offshore, the glass has not moved and the sky is clean — but the sea is already carrying the news, in its period, its direction, and the way it stacks and crosses. Every surface is the sum of two things, and the first skill is telling them apart. Wind sea is the water answering the wind blowing on it now: short, steep, ragged, running with the wind and dying when the wind drops. Swell is the smooth, long-period leftover of wind that blew somewhere else, days ago and hundreds of miles away: long rounded crests with a slow heave, holding their own direction. Wind sea reports your local weather; swell reports distant weather — and the swell is the one worth reading.

Swell is a range-finder if you count the seconds. In deep water long waves travel faster than short ones, so a distant storm's longest waves outrun the pack and arrive first, long and clean and low — the bass note of weather still below the horizon. The speed in knots is roughly one and a half times the period in seconds, so a twenty-second swell is running at about thirty knots. But the direction of change is what matters most. Watch the period over a few hours: shortening, and the storm is closing on you — you are getting the slower waves now, so the source is nearer; lengthening, and it is moving away. And the swell points back to where the storm was when the waves left it, not where it is now — the most common misread at sea. A new swell train from a new bearing, long and shortening, is often the first word you get of a system nobody has told you about.

The danger sign is the cross sea. When two trains — or a swell and a wind sea — run at a large angle to each other you get a checkerboard of pyramids where crests intersect, and where two crests meet the height briefly far exceeds either train alone. It defeats the usual tactic of quartering the swell, because there are two swells, and capsizes in confused water happen where the trains cross. Ordered ranks of parallel crests are one organised swell and manageable; a grid of pyramids with no clear direction is two systems interfering — slow down, pick the dominant train, and give yourself sea room. The surface is also a live wind gauge: the first white horses appear around ten to twelve knots, and when the foam starts blowing in streaks along the wind you are into Force 7 and the sea has stopped being merely choppy and started being organised by strong wind.

Everything so far assumes deep water. Once the depth drops below about half the wavelength the waves feel the bottom, and the changes are navigation cues. Shoaling slows and steepens them, so a long swell that looked harmless offshore rears into a breaking wall over a bar — a line of breakers in open water is a shoal announcing itself before the sounder catches it. Refraction bends the waves to the bottom contours, wrapping them onto headlands, which is why headlands are rough and bays are calm. And the range-finding trick stops working inshore, because in shallow water all the wavelengths slow to the same speed and the period-sorting is gone.

You see	It means
Long smooth swell from a new bearing	A distant system, maybe unreported. Note bearing and period.
Period shortening over hours	The source is closing. Lengthening → moving away.
A grid of pyramidal, crossing crests	Cross sea — slow down, pick the dominant train, take sea room.
First scattered whitecaps	Local wind ~10–12 kt. Foam in streaks → Force 7 and building.
A line of breakers in open water	A shoal or bar showing before the sounder does.
Swell steepening against a current	Rogue conditions — steeper and worse than the wind implies.

KEY RULE

The sea usually tells you something before the sky does. Swell is the forerunner — it arrives ahead of the weather that made it. Count the seconds, watch the bearing, and you are forecasting from the deck with your eyes and a watch.

12 · Sea and Swell — the Wave You Meet Once

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 away and the sea cannot fully develop, which is why the forecast wind speed on its own tells you very little; a fifty-knot squall for twenty minutes builds far less sea than thirty knots steady for a day. And when waves outrun the wind that made them they become swell, sorted long and low and regular by the passage.

The number in the forecast is the trap. Significant wave height is the average of the highest third of the waves — a useful figure, and not the biggest wave out there. In a real sea one wave in ten beats the significant height, and over a long watch you will meet one at half again that height, and a rare one higher still. Rogues form where energy briefly concentrates — two crests coinciding, or swell running against a strong current, which shortens and steepens it savagely. An ebb tide on a bar against an incoming swell, or a storm swell meeting a major current head-on, is the textbook rogue-maker. Set your ship up for the wave you will meet once, not for the average one.

How a wave travels, and why a distant storm sends only its longest swell

It is worth understanding how a wave actually travels, because it explains the single most useful thing the sea ever tells you — that a swell from a far-off storm arrives long before the storm does, and arrives long. A wave carries energy, not water: each parcel of water merely circles in place, forward under the crest and back under the trough, while the shape and its energy move on through it. And here is the key fact — in deep water a wave's speed depends on its length: long waves travel faster than short ones. Speed in knots comes out close to one and a half times the period in seconds, so a fourteen-second swell rolls along at about twenty-one knots while a six-second wind-sea manages only nine.

A storm a thousand miles away throws up a jumble of every length at once. But because the long ones travel faster, they draw ahead of the pack and reach you first, while the short, steep stuff lags behind and — being short — bleeds its energy away and dies on the road. The ocean has worked as a sorting machine; we call it dispersion, and what finally lifts under you from a distant gale is smooth, low, very long-period swell: the forerunner. That is why a long, slow, clean swell out of an empty horizon is worth more than any single cloud — it is the leading edge of weather still below the curve of the earth. Time the period and watch its trend: lengthening means the source is far and holding off, shortening means it is bearing down. And take the bearing the swell rolls from, because it points back to where the storm stood when the waves left it, not to where it is now.

KEY RULE

Deep-water wave speed $\approx 1.5 \times$ period (seconds), in knots — long waves outrun short. So a distant storm's longest swell arrives first, low and clean: the forerunner. Period lengthening → source far or receding; shortening → closing. A wave moves energy, not water.

In a 5 m (17 ft significant) sea	Height
Most frequent wave	8.5 ft
Average wave	11 ft (3 m)
Significant wave (avg of highest third)	17 ft (5 m)
Average of the highest tenth	22 ft (7 m)
One wave in ~200 (about half an hour)	over 35 ft (11 m)

KEY RULE

A forecast of '5 metre seas' is not a forecast of 5 metre waves. One in ten will beat it; somewhere in a watch you meet one half again as high. Wind against tide or current shortens and steepens everything.

PART FOUR

Tropical Systems

13 · Tropical Revolving Storms

Tropical systems are a wholly different animal, and confusing the two kinds of storm causes real harm. A mid-latitude depression is powered by temperature contrast — a frontal system, cold-cored, strengthening with height. A tropical cyclone has no fronts at all: warm-cored, powered by the latent heat released as water vapour condenses, and strongest at the surface, weakening with height. Different engine, different structure, different tactics.

Genesis requires several things at once: sea surface temperature of about twenty-six and a half Celsius, eighty Fahrenheit, through a good depth; a pre-existing disturbance to organize around, often an easterly wave off Africa; enough distance from the equator, five degrees or so, for Coriolis to start the rotation — which is why you never see a hurricane on the equator; moist mid-levels; and critically, low vertical wind shear, because shear tears the developing core apart before it can organize. Note the difference from a supercell, where moderate shear helps — in the tropics, shear is purely destructive to the system as a whole.

The structure: the eye, calm and clear, ten to forty miles across; the eyewall around it, the ring of most violent wind and heaviest rain, the strongest winds on the planet's surface; spiral rainbands feeding inward, sometimes with tornadoes; and the storm's sea running hundreds of miles beyond its wind.

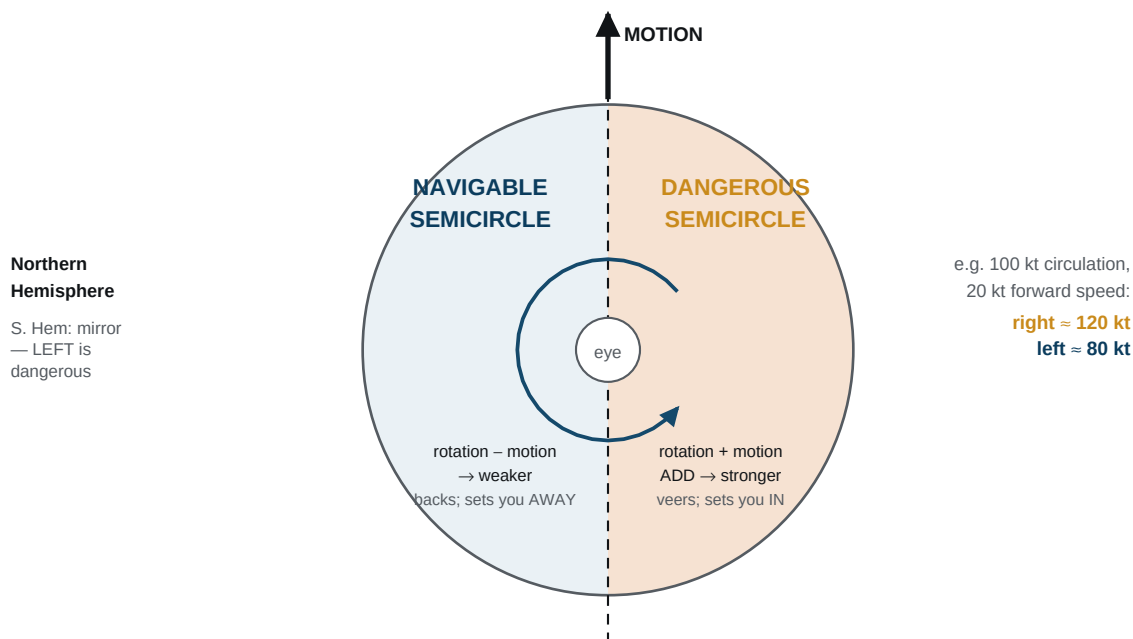
Now the mariner's part, the dangerous semicircle, and this deserves precision. Take a Northern Hemisphere hurricane moving northwest, winds circulating anticlockwise. On the right of the track, the rotational wind and the storm's forward motion run the same way and add; on the left they oppose and partially cancel. A hundred-knot circulation moving at twenty gives roughly a hundred and twenty on the right, eighty on the left — the difference between very bad and catastrophic.

But the arithmetic isn't the whole of it. On the right side the wind veers as the storm passes and tends to drive you into its path, ahead of the centre. On the left it backs and tends to set you away. So the right is dangerous twice over: stronger wind, and a wind that pushes you where you least want to go. Right side dangerous, left side navigable — and in the Southern Hemisphere everything mirrors, the left side dangerous.

How do you know which side you're on? Watch the wind over a few hours. Veering steadily — east, southeast, south — you're in the dangerous right semicircle. Backing — east, northeast, north — the navigable left. And if the direction holds steady while the glass falls and the wind builds, that is the worst news of all: you're on the track, dead ahead of the centre.

The tactics, Northern Hemisphere: in the dangerous semicircle, wind on the starboard bow and make what way you can, out of the path; in the navigable semicircle, wind on the starboard quarter and run; directly in the path, wind on the starboard quarter and run for the navigable side. Everything reverses in the south — port bow, port quarter. And know the thirty-four-knot rule: plot the radius at which winds reach thirty-four knots, add a growing margin for forecast error, and stay outside it. You don't dodge a hurricane at close quarters. You avoid it two days out, with sea room and the decision made early.

	Mid-latitude low	Tropical cyclone
Engine	Temperature contrast (fronts)	Latent heat of condensation
Core	Cold-cored, strengthens with height	Warm-cored, weakens with height
Fronts	Yes — warm, cold, occluded	None
Shear	Moderate shear helps organize	Shear is purely destructive



Northern Hemisphere storm. On the right of the track, rotation and forward motion add and the wind sets you into the path — the dangerous semicircle. On the left they oppose and set you away.

Wind over a few hours	Where you are (N. Hem.)	Action
Veers (E→SE→S)	Dangerous right semicircle	Wind on starboard bow , make way out
Backs (E→NE→N)	Navigable left semicircle	Wind on starboard quarter , run
Steady, glass falling	On the track, ahead of centre	Wind on starboard quarter, run for the navigable side

ON DECK

Southern Hemisphere: mirror everything — the **left** side is dangerous; use the **port** bow and quarter. You do not dodge a hurricane at close quarters. Avoid it **two days out**, with sea room and the decision made early. Stay outside the 34-knot wind field — it can reach 100–200 NM from the centre. The old 1-2-3 rule (+100 / 200 / 300 NM on the 34-kt radius at 24 / 48 / 72 h) was withdrawn by NHC in 2016 for over-warning, but it is still a fair back-of-the-envelope. The forecast cone describes the centre only — the dangerous winds routinely lie outside it, so plot the wind radii, not the cone.

Two old rules will place the storm for you before any bulletin does, and both belong in your head, not just in the book. The first finds the centre. Face squarely into the true wind and, in the Northern Hemisphere, the eye lies roughly 100 to 125 degrees off your right hand — a little abaft the starboard beam — when the storm is still two hundred miles or so away; it is Buys Ballot bent by the storm's own inflow, and it is close enough to act on. The second reads the glass. A tropical barometer is a quiet instrument, so do not wait for a dramatic fall: when the corrected pressure sits about three millibars below the monthly mean for your position — the Sailing Directions

carry that mean — treat a storm as possible and start plotting. The old watch rule was to hold your course until the glass falls five millibars, or three with a hard wind already up, and then to work away from the track without further argument.

KEY RULE

Locating the centre (N. Hem.): face the true wind — the eye bears about 100–125° off your RIGHT hand at ~200 NM (off the LEFT hand in the Southern Hemisphere). Detection: corrected glass ~3 mb below the monthly mean (Sailing Directions) → suspect a TRS; a 5 mb fall, or 3 mb with high wind already up, is act-now.

PART FIVE

Local Effects, Fog, Tides and the Ocean

14 · Local Effects

Now the things that happen at your scale — the local phenomena no synoptic chart will ever show you. Land heats faster than water by day and cools faster by night, because water has enormous thermal inertia and mixes its heat through depth. By day the land warms, air over it rises, pressure falls slightly, and cooler air flows in off the water — the sea breeze. It starts late morning, builds through the afternoon, peaks mid-afternoon, dies at sunset, can reach fifteen or twenty knots, and on a sunny coast it overrides a light gradient wind. At night the process reverses, weaker: a light land breeze draining seaward, strongest just before dawn.

Katabatic winds are the serious cousin. Cold dense air pools on high ground — a plateau, a glacier, a mountain — and when it spills down a valley or fjord, gravity accelerates it and the terrain funnels it. These arrive without warning, at gale force or worse, on a night that looks perfectly benign. The Mediterranean has a whole vocabulary for them: the mistral down the Rhône, the bora off the Dinaric Alps into the Adriatic. Anchorages below high ground with a valley leading down deserve real respect on clear, cold, calm nights — exactly the conditions in which cold air pools.

ON DECK

Give real respect to anchorages below high ground with a valley leading down — especially on clear, cold, calm nights, which are exactly when cold air pools and spills.

15 · Fog

Fog is where a lot of mariners come unstuck. Two main kinds, and they behave differently. Advection fog is warm moist air moving over colder water, cooled from below to its dew point — your sea fog, and the dangerous one, because wind does not disperse it. Wind actually helps it: it keeps the moist air coming and mixes the cooling upward. Advection fog can hold in twenty knots of breeze and lie over hundreds of miles of ocean for days. The textbook case is the Grand Banks, where warm Gulf Stream air meets the cold Labrador Current.

Radiation fog is a land phenomenon: the ground cools at night under a clear sky, chills the air above it, and fog forms in the low ground. It needs calm, and it burns off with the morning sun — it drifts over harbours and estuaries at dawn and clears by mid-morning. Much less dangerous, much less persistent. The practical test for both: compare air temperature to sea temperature. When the dew point reaches the sea surface temperature, expect fog. Watch that gap close and you have your warning before you lose the visibility.

Two more kinds are worth a line. Sea smoke, or frost smoke, is the opposite case — very cold air moving over much warmer water, so the water evaporates and instantly recondenses; it is usually shallow, and often clear above it from the bridge. And frontal fog forms where warm rain falls through cold air and saturates it, along a warm front's rain belt, and it clears when the front goes through. But the one to plan for is always advection — it forms over open water, it does not care what time of day it is, and it can sit for days. Remember too that fog is a Rule 19 problem before it is a weather problem: safe speed, sound signals, radar plot, extra lookout.

Type	How it forms	What clears it
Advection (sea fog)	Warm moist air over colder water	A change of airstream, or wind over ~15 kt. Not the sun.
Radiation (land fog)	Land cools at night, chills the air on it	The morning sun, within a few hours
Sea smoke	Very cold air over much warmer water	Usually shallow; clears as air modifies
Frontal fog	Warm rain saturates cold air below	Passage of the front

KEY RULE

Watch the air temperature and the dew point converge. When the spread closes to about 2°C and still shrinking, you are running out of margin — and warm moist air over cold water will not burn off. That is a forecast you can make an hour ahead with two thermometers.

16 · Tides

Tides are not weather, but they are the same physics — a fluid on a spinning body — and they are the one that puts you aground, so they belong in the same lecture. The puzzle everyone meets first is why there are two bulges, not one. The moon's gravity is stronger the closer you are to it: on the near side the water is pulled toward the moon harder than the solid earth is, so it bulges toward the moon; on the far side the solid earth is pulled harder than the water, so the earth is dragged out from under the water and it is left behind as a second bulge. The water to build them is drawn from the sides, which is why the low waters sit at right angles to the bulges and why most places see two highs and two lows in roughly a day.

The range breathes through the month with the sun. At new and full moon the sun and moon pull in line, the two effects add, and you get spring tides — the biggest range, highest highs and lowest lows, and nothing to do with the season; the word just means to spring up. At the quarters they pull at right angles and partly cancel, and the range is smallest — neaps. The sun's tidal pull is about forty-five per cent of the moon's, vast but far away. And the moon rises about fifty minutes later each day, so the tide runs about fifty minutes later too, roughly twelve hours and twenty-five minutes between highs.

Where the theory stops is where 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 coast than on the moon. Use the tables. And remember the weather rides on top: a deep low lifts sea level by roughly a centimetre per millibar, and a strong onshore gale piles more on — a storm surge arriving on a spring high is how ports flood, and a hard offshore blow can take half a metre off the predicted height when you least want it gone.

The gravity, drawn as vectors

Draw the force and the two bulges stop being a riddle. What raises a tide is not the moon's pull itself but the difference between its pull at a given spot and its pull at the centre of the earth — a vector subtraction. Gravity weakens with distance, so on the side facing the moon the local pull is a little stronger than the pull on the earth as

a whole, and the leftover vector points toward the moon; on the far side the local pull is a little weaker, and the leftover vector points away from it. Two residual forces, aimed in opposite directions, stretching the ocean into an egg — that is why there are two bulges and not one, and why they lie along the earth–moon line and sweep round as the earth turns beneath them.

You can tell the same story with inertia. The earth and moon both swing around their common centre of mass, and the water on the far side, wanting to carry straight on, is thrown outward just enough to raise the second bulge — the two pictures give the identical answer. Two numbers finish it. The sun works the same trick at about forty-six per cent of the moon's strength — enormous, but so distant that its gradient is gentle, so it modulates the tide rather than ruling it. And the clocks: the moon circles the earth once in about 27.3 days against the stars, but because the earth is meanwhile moving round the sun it takes 29.5 days from new moon to new moon; each day the moon returns to your meridian about fifty minutes later, so the whole tide walks roughly fifty minutes later each day, about twelve hours twenty-five minutes crest to crest.

KEY RULE

Springs at new and full moon — biggest range. Neaps at the quarters — smallest. The theory tells you a big tide is coming; only the tables give you the height of water on the bar. Wind and pressure can add or subtract half a metre the tables never saw.

17 · The Ocean as a Heat Engine

The atmosphere gets the credit for moving heat around the planet, but the ocean does more of it, and does it slower. Sunlight warms the top couple of hundred metres of the sea — an enormous mass, warmed and cooled only slowly — while on land the sun heats the top few inches and the ground swings hot and cold in a day. That single contrast is behind sea breezes, behind mild maritime climates and harsh continental ones, and behind the ocean's role as the planet's heat store. Below the sunlit layer the temperature drops away through the thermocline, and under that the deep ocean sits at about four degrees everywhere on earth, whatever the latitude above it.

For a passage the currents are the part you plan around, because two and a half knots is a third of a day over a North Atlantic crossing. Eastbound, the Gulf Stream and the North Atlantic Current carry you and the storm track runs more or less with them; westbound, all of it is in your face, which is why the two directions are never the same passage. Where the warm Stream meets the cold Labrador Current you get the cold wall — sea temperature falling ten or twelve degrees in thirty miles, and fog with it. And one current is a hazard in its own right: off south-east Africa the Agulhas runs south-west at up to five knots, and when a south-westerly gale raises a sea running north-east straight into it, the Sailing Directions warn of abnormal waves with a deep hole in front of the wall — the hole is what breaks the ship's back. If a cold front with strong south-westerlies is forecast there, keep well clear of the seaward edge of the shelf.

Current	Speed	What it means to you
Gulf Stream, off Florida	up to ~4.5 kt	Narrow and fast; a fair set for a northbound crossing
Gulf Stream, off Hatteras	~2.5 kt	Axis wanders tens of miles and throws eddies the other way
Labrador Current	0.5–1 kt, cold	Carries the ice; the cold wall and fog where it meets the Stream
Agulhas	up to 5 kt	Abnormal waves in a SW gale. This one has killed ships

The heat pump — the global conveyor

There is a slower, deeper circulation beneath the currents you plan around, and it is the closest thing the planet has to a heat pump. Warm surface water is carried poleward by the wind-driven currents — the Gulf Stream and its kin — shedding heat into the air the whole way, which is what keeps north-west Europe far milder than its latitude has any right to be. By the time that water reaches the far North Atlantic it is cold, and cold water is denser; it is saltier too, because sea ice forming up there freezes out fresh water and leaves the salt behind. Cold and salty is heavy, so the water sinks — a slow, vast waterfall in the open ocean — and turns back toward the equator along the bottom.

That sinking is the pump. Deep water spreads along the sea floor, creeps for centuries through the Pacific and Indian oceans, and eventually wells back to the surface far away, warms, and rejoins the surface flow — one great loop, the thermohaline conveyor, that takes on the order of a thousand years to turn once. It moves more heat than the atmosphere can, and it is why the deep sea everywhere on earth sits near four degrees: it is all the same cold water, sunk in a few small places and slowly returning. For the mariner the conveyor is mostly background — but its surface limbs are your currents, and its cold upwellings are the fog-and-fish coasts, Peru and California and north-west Africa, where deep water rises to meet the sun.

KEY RULE

The ocean's heat pump (thermohaline conveyor): warm water flows poleward and warms the air; it cools, sea-ice makes it saltier, and it sinks in the North Atlantic; it creeps back along the bottom and upwells elsewhere — one turn takes ~1,000 years. It stores and moves more heat than the air, and holds the deep ocean near 4°C worldwide.

PART SIX

Reading the Chart

18 · The Surface Analysis and the Station Model

A chart is not a picture of the weather. It is a set of measurements drawn to a convention, and the convention is learnable in an afternoon. The surface analysis is everything happening at sea level at one instant — valid for one hour, usually 0000, 0600, 1200 or 1800 UTC, every observation on it taken at that hour. That simultaneity is the whole point of the word synoptic: you are seeing a pattern, not a scrapbook of readings taken at different times. Isobars are lines of equal pressure, drawn every four millibars and reduced to sea level so a station on a hill can be compared with a ship. The H and L are the centres. Fronts carry their symbols on the side they are moving toward — blue triangles for cold, red semicircles for warm, the two alternating in purple for an occlusion. And before you read anything else, look at the spacing: isobars close together mean a steep gradient and strong wind, and that you can read across a room. The tightest gradient is often not at the centre but on the flank, frequently just behind the cold front.

Each little cluster on the chart is one ship or buoy report, and it packs six things around one circle in fixed positions, so once you learn the layout you never think about it again. Temperature upper left, dew point lower left, coded pressure upper right, its three-hour change lower right, the circle shaded for how much cloud, and the shaft pointing into the wind with barbs for its speed. The pressure is the one that catches everybody: three digits in tenths of a millibar with the leading nine or ten left off, so you put it back — 500 or more, prefix a nine; under 500, prefix a ten. So 004 is 1000.4 and 982 is 998.2. It works because sea-level pressure essentially never leaves the band 950 to 1050. The barbs are simple arithmetic — a half-barb five knots, a full barb ten, a pennant fifty — and in the Northern Hemisphere they sit on the side of the shaft toward lower pressure, which makes every plot a

free cross-check on Buys Ballot.

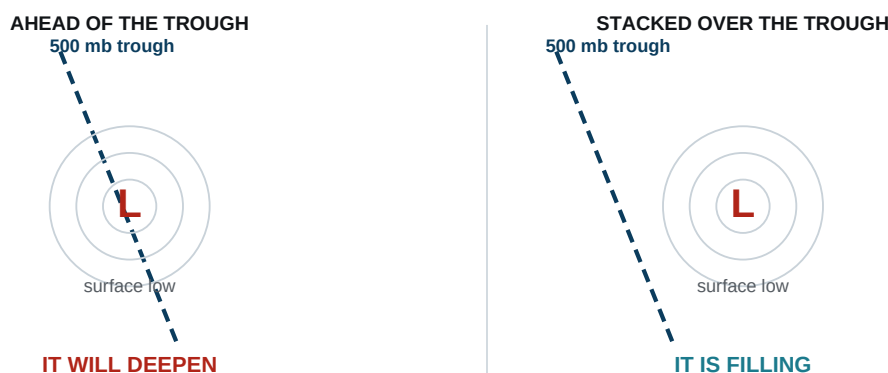
Position	What it is	In the example	What it tells you
Upper left	Air temperature	62 °F	The air mass you are in
Lower left	Dew point	60 °F	How much moisture is actually there
Upper right	Coded pressure	004 = 1000.4 mb	Prefix 9 if ≥500, 10 if under
Lower right	3-hour change	−0.6 mb, falling	The trend — worth more than the reading
The circle	Sky cover (oktas)	seven eighths	How much cloud
The shaft	Wind speed / dir	SW at 25 kt	Points into the wind; half 5, full 10, pennant 50

19 · Up the Stack — the Upper-Air Charts

The surface chart tells you what is happening; the charts above it tell you what happens next, because the weather you get at sea is decided several miles above your masthead. Above the surface, forecasters stop drawing maps at fixed heights and start drawing them at fixed pressures — and the trick that makes it all click is that you are not mapping pressure on those charts, you are mapping the height of a pressure surface. The 500 millibar surface sits near 18,000 feet, but it bulges up over warm air and sags over cold, so low heights mean cold air and high heights mean warm, and the height contours behave exactly like isobars: close together means strong wind, the wind runs along them, low heights on the left in the north. Everything you learned on the surface transfers straight up.

You climb the stack for different questions. 850 millibars, about 5,000 feet, is the first level clear of surface friction — the true air-mass temperature, and where you read advection off the angle between wind and isotherms: wind blowing from warm toward cold is warm advection, rising air, cloud and rain; from cold toward warm is cold advection, sinking and clearing. 700 millibars, about 10,000 feet, is where the cloud and the rain are actually made. 500 millibars is the steering chart, half the atmosphere's mass below it, and the one a forecaster reads first — troughs, ridges and the shortwaves that carry a great deal of weather. And 300 to 200 millibars is the jet, and the divergence aloft that deepens surface lows.

Two charts subtracted give a third thing neither one holds. The thickness between 1000 and 500 millibars is a direct measure of the mean temperature of the lower half of the atmosphere — low thickness a cold column, high thickness a warm one — and the 5,400 metre line is the classic rain-or-snow divider over the sea. But the single most useful thing you can do with two charts takes ten seconds: look at where the surface low sits relative to the 500 millibar trough.



The one comparison that tells you the next thirty-six hours. Low displaced downstream of the upper trough (leaning back, fed from aloft) will deepen; low stacked under the upper low (standing straight, no support) is filling.

Level	Height	What it is for
Surface	sea level	Fronts, isobars, actual wind — the weather you get
850 mb	~5,000 ft	The air mass clear of friction; temperature advection
700 mb	~10,000 ft	Moisture and vertical motion — where the rain is made
500 mb	~18,000 ft	The steering chart; half the atmosphere below it
300 / 250 / 200 mb	~30–39,000 ft	The jet, and the divergence that deepens surface lows

KEY RULE

Warm advection = rising air = cloud and rain. Cold advection = sinking = clearing. At sea with no chart: if the wind **veers with height** that is warm advection (N. Hem.) — upper cloud moving clockwise of the surface wind means warm air on the way. Reverse it south of the equator.

20 · Wind Speed Straight off the Isobars

The chart will hand you a usable wind speed with nothing but a pair of dividers, and it is the most practical skill in the whole business. The pressure gradient drives the air, Coriolis bends it until the two balance and the wind runs along the isobars, and the closer the isobars the stronger that geostrophic wind. Most charts print a geostrophic wind scale in the margin — a fan of latitude lines you lay your dividers against — and it gives the same answer as the table faster, though it assumes straight isobars and makes no allowance for curvature. Note how hard it depends on latitude: the same four-millibar spacing that gives you a moderate breeze at sixty degrees is a full gale in the tropics, because Coriolis is so much weaker down there.

Then bring it down to what you will feel. Over the open sea the surface wind is about seventy to eighty per cent of the geostrophic value and backed ten to twenty degrees across the isobars toward the low; over land, nearer half, backed thirty. And curvature matters — round a low the flow is turning so the real wind is a little weaker than geostrophic, round a high a little stronger, which is why a small tight low is not quite as vicious as its spacing suggests and the edge of a big high is windier than it looks.

Isobars 4 mb apart	30°N	40°N	50°N	60°N
60 NM	78 kt	61 kt	51 kt	45 kt
100 NM	47 kt	37 kt	31 kt	27 kt

Isobars 4 mb apart	30°N	40°N	50°N	60°N
150 NM	31 kt	24 kt	20 kt	18 kt
200 NM	23 kt	18 kt	15 kt	14 kt
300 NM	16 kt	12 kt	10 kt	9 kt

Geostrophic wind at ~600 m. Surface over the sea ≈ 70–80% of this, backed 10–20°.

Work one so it sticks. You are at forty degrees north; you lay the dividers across the tightest isobars near you and they measure a hundred and fifty nautical miles apart. Run down the 40° column to the 150-mile row: twenty-four knots geostrophic. Take three-quarters of it for the surface and back it about fifteen degrees toward the low — roughly eighteen knots, gusting higher — and you have read the wind off the paper before the anemometer ever confirms it. Notice the two levers in the table: tighten the spacing or drop the latitude and the wind climbs hard, which is why the same isobars mean a stiff breeze off Newfoundland and a screaming gale in the tropics.

KEY RULE

Reading wind off the isobars, four steps: (1) measure the isobar spacing at the worst point near you; (2) note your latitude; (3) read the geostrophic wind from the margin scale or the table above — tighter spacing and lower latitude both mean more wind; (4) take 70–80% for the surface over water (about 50% over land) and back it 10–20° toward the low. Curved round a low, shave a little off; round a high, add a little.

PART SEVEN

The Ship, the Seaway, and the Limits

21 · Wind on the Ship

This is where weather stops being a forecast and becomes a shiphandling problem, because a ship's side is a sail and it cannot be reefed. The one lesson is that wind pressure rises with the square of the wind speed — double the wind and you quadruple the load. The dynamic pressure is about 0.004 times the speed in knots squared, in pounds per square foot; multiply by the side area and by a drag coefficient of about one for a bluff ship's side, and you have the force. Mind the units: the 0.004 is for knots, and the 0.00256 you meet in engineering texts is the same thing for miles per hour — feed knots into that and you read a quarter low.

Work it once for a loaded box boat — a thousand feet long, seventy-five feet from the waterline to the top of the stack, call it 60,000 square feet of side — and the numbers stop being abstract. At Beaufort 6, a strong breeze and nothing dramatic, the wind on the beam is already one whole tug's worth of bollard pull, spent before you have moved the ship an inch. At Beaufort 8 it is two and a half tugs; at Beaufort 10, four and a half. That square law is the arithmetic behind every berthing wind limit you will ever be given, and it is why the limits tighten so fast as the wind builds. And it is worse in ballast, high and light, with more sail area and less grip on the water at the same time.

Beaufort	Wind	Force on 60,000 sq ft	In tugs (60 t each)
4	12 kt	16 t	under 1
6	25 kt	68 t	1.1
8	37 kt	149 t	2.5
10	50 kt	272 t	4.5

Beaufort	Wind	Force on 60,000 sq ft	In tugs (60 t each)
12	64 kt	446 t	7.4

KEY RULE

Dynamic pressure $q = 0.004 \times V^2$, V in knots (result in lb per sq ft). Force = side area $\times q \times$ drag (about 1.0 for a ship's side). Double the wind, four times the force — every time.

22 · How the Ship Answers Back

The sea does not slow you evenly and it does not roll you at random, and understanding how the ship answers back is what turns a weather forecast into a routing decision. Two different things get called slowing down. Involuntary speed loss is the sea taking speed off you — added resistance, the propeller racing — while the engine makes the same power and burns the same fuel, so your fuel per mile climbs. Voluntary reduction is you pulling the throttle back to stop the ship hurting herself, and because power falls with the cube of speed, that actually saves fuel per day; it costs you time, not bunkers. The shape of the speed-loss curve is the thing to feel: in a following sea a ship holds most of her speed well into a gale, but in a head sea she is down a quarter by five metres and a half by seven. That asymmetry is why eastbound and westbound crossings of the same ocean are not the same passage.

The number everything hangs on is the encounter period — not the period of the sea, which belongs to the sea, but the period at which it arrives at your ship, which depends on your speed and heading. The same ten-second swell can arrive every six seconds head-on at twenty knots or every thirty seconds running before it. That matters because the ship has a natural roll period of her own, set by her beam and her stability, and when the two get close the sea starts feeding the roll. And here is the trap that catches people: more stability is not more comfortable — a stiff ship has a short, snappy roll and throws cargo and people about. There are four ways a seaway hurts you, and the cure for all four is the same: change course, change speed, or both.

Danger	When	What to do
Synchronous roll	Encounter period $\approx$ the ship's roll period	Change course or speed to break the match
Parametric roll	Wavelength near ship length, head or following	Alter out of the head/following sea; change speed
Surf-riding / broaching	Following/quartering seas, high speed	Slow down; mainly a small- or fast-vessel problem
Successive high waves	Long groups, H_s large, in phase	Change course or speed to break the group

KEY RULE

Encounter period, not sea period, decides whether you roll comfortably or dangerously. When she starts rolling badly, change course or change speed — doing nothing is a decision, and it is the wrong one.

ON DECK

Caught out in a squall or thunderstorm. The warnings are a hard, low, sharp-edged leading cloud, a sudden gusty wind shift, a choppy sea building from several directions at once, and a quick drop in temperature. Meet it head-on: bring the bow into the wind and the principal sea at about 30–45° and hold a slow, steady steerage speed to ride it through. If the engine fails, stream a sea anchor off the bow to keep her head up and out of the trough. It passes quickly — do not try to run across the front of it.

23 · The Limits of Forecasting

Two more things, and then let me bring this in to anchor. Every forecast you read comes from a numerical model — a fluid-dynamics simulation on a grid — and every model has three unavoidable weaknesses. Finite resolution: anything smaller than a grid cell — convection, squalls, the sea breeze, the katabatic — is not simulated but parameterized, approximated by rule of thumb. Imperfect initial conditions, because the ocean is very thinly observed. And chaos: small errors grow exponentially, so useful skill runs to about five days for the broad pattern, and the specifics degrade far sooner.

Which is why ensemble forecasting exists — run the model many times with slightly perturbed starting conditions and watch the members diverge. If they agree, confidence is high. If they scatter by day three, the atmosphere is in a state where small differences matter enormously, and no amount of staring at a single run will save you. The spread is the information: when models disagree about a track, plan for the envelope, not the average.

And second, the reason you look out of the wheelhouse as well as at the screen. Your barometer, your eyes, your thermometer and the sea give you truth at your position, right now; the model gives you pattern over the region, in the future. The forecast tells you what ought to be happening; the instruments tell you what is. When the two disagree, the instruments win, every time, because the atmosphere is under no obligation whatsoever to match the model.

Here's the old cross-check to sleep on. Take Buys Ballot — back to the wind, low on your left in the north — and compare that bearing with where the forecast puts the low. If they agree, you understand your situation and can trust the next move. If they disagree by a significant angle, something is displaced or deeper or slower than forecast; reason from your own observations until the two come back together. Use the model for the shape of things. Use your senses for the truth of things. And when they part company, believe the sea.

- **Finite resolution:** squalls, the sea breeze, the katabatic — smaller than a grid cell, so approximated by rule of thumb.
- **Sparse data:** the ocean is thinly observed, so the starting point is imperfect.
- **Chaos:** small errors grow. Useful skill runs to about five days for the pattern; the specifics fade far sooner.
- **Ensembles:** run it many times — if they agree, confidence is high; if they scatter, **the spread is the information.**

KEY RULE

Use the model for the **shape** of things and your senses for the **truth** of things. When they disagree, **believe the sea** — the atmosphere is under no obligation to match the model.

PART EIGHT

Planning the Passage

24 · Who Owns the Plan, and the Four Stages

A passage plan is not paperwork. It is the document that says, before you leave, exactly where this ship may go and where she may not — written while you are rested, ashore, and not being shouted at. The legal responsibility sits with the master, always; in practice a navigating officer does the work, but the master approves it before the voyage and answers for it afterwards. SOLAS Chapter V Regulation 34 makes it law and pulls in the IMO guidelines that would otherwise be advice, and Regulation 34-1 is the one worth knowing by number: no owner, charterer or company shall prevent or restrict the master from any decision that in his professional judgement is necessary for safety of life at sea. It exists because ships have been lost with a charterer's voice in the master's ear.

The method itself is four stages, and every examiner will ask you to name them. Appraise — gather everything, and not just the charts: the state of the ship, the cargo and the crew as well. Plan — in detail, berth to berth, including the water where you will have a pilot, because the pilot is an adviser and the plan is still yours. Execute — with the tide, the traffic, the visibility and the weather you actually have, with extra hands where the plan says you need them. And monitor — continuously, by more than one means, against the plan rather than just against the chart. The part that gets forgotten is the loop back: a change made at sea is not a change until it has been re-appraised, re-planned, approved by the master, and marked on the chart.

KEY RULE

Appraise · Plan · Execute · Monitor. The plan runs berth to berth, including pilotage waters. Marked and recorded, approved by the master before sailing. SOLAS V/34-1: nobody can order the master to keep going.

25 · Appraisal, and What Goes on the Chart

Appraisal is the stage crews rush and examiners love, and its output is not a list — it is a clear picture of three things across the whole passage: where it is dangerous, where safe navigation is possible, and where environmental measures apply. If you cannot say those three things about every stretch, you have not finished appraising. The single most common bridge finding in a port-state inspection is the easiest to avoid: a track laid on an uncorrected chart is not a plan, it is a hypothesis. The correction state of the chart is the appraisal.

Then you plan, and good practice puts far more on the sheet than the bare true course. No-go areas, hatched, so a depth judgement becomes a yes-or-no the officer of the watch does not have to compute under pressure. The wheel-over point, not the waypoint, because a ship turns through an advance and a transfer and if you wait for the waypoint you are already past it. The abort point — the last position from which she can still turn round — decided before you get there, which is the whole point of it. A parallel index off a radar-conspicuous mark, the cheapest continuous cross-track check on the bridge. Clearing bearings for a single-glance answer to ‘am I still safe?’. The fixing method and interval, two independent methods rather than one method twice. And contingencies — where do I go if the engine stops here, if visibility closes here — written down once, calmly, so nobody has to think about it at once, badly.

Mark on the chart	Why it is there
No-go areas	Turns a depth judgement into a yes/no under no pressure
True course on every leg	Required; and it settles the compass-error argument in advance
Wheel-over point	A ship turns through advance and transfer, not at a point
Abort point	The last position from which you can still turn back
Parallel index / clearing bearings	Continuous monitoring with no plotting
Contingency anchorage / refuge	Somewhere for the abort decision to go

What appraisal actually pulls together

Appraisal has a reading list, and an examiner will want to hear you name it — but the point of the pile is not the paper. It is that, between these sources, you can say for every mile of the passage where it is dangerous, where it is safe, and what rules apply. Gather them before you draw a single line.

Charts / routeing	Ship / environment
Chart catalogue; corrected charts + Notices to Mariners	Draughts, UKC and stability data

Charts / routeing	Ship / environment
Ocean Passages of the World; routeing charts	Type and stowage of the cargo
Sailing Directions / Coast Pilots	Tidal atlases; tide / tidal-stream tables
List of Lights; List of Radio Signals	Navigational and weather warnings; forecasts
Mariner's Handbook; Guide to Port Entry	Company standing orders; master's instructions

26 · Under-Keel Clearance and Squat

This is the one part of the plan where being approximately right is the same as being aground, so it is worked out, never assumed. The water you actually have is the charted depth plus the height of tide at the moment you pass — which means an error in your ETA is an error in your depth — and against that you set your draught, your squat, an allowance for heel and wave response, and a margin you keep in hand. Know which datum the chart uses: US charts read from mean lower low water, British and most IHO charts from the lowest astronomical tide, which is lower and therefore safer. And a negative surge is real — a hard northerly in a shallow sea can take half a metre off the predicted height, so if the plan only works on the predicted tide, the plan does not work.

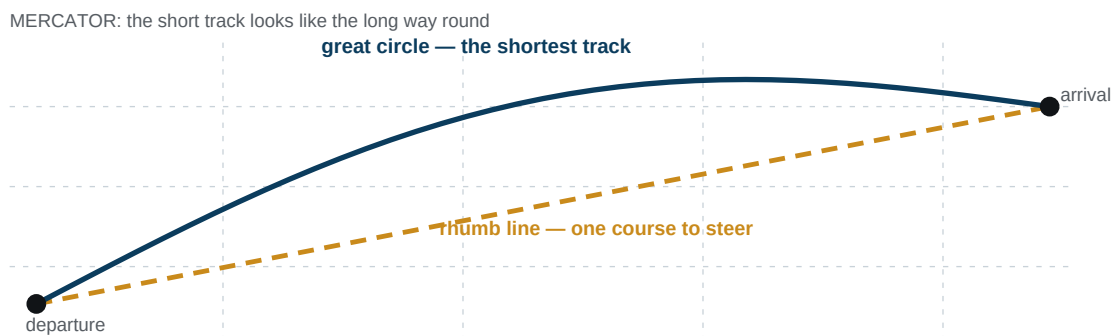
Squat is the trap in shallow water. A ship moving through it pulls herself bodily down and trims, because the water has less room to get past her, so it speeds up and its pressure drops and she settles into the hole she has made. It grows with the square of the speed and bites hardest in a narrow channel — and that gives you the one thing you need at three in the morning: halve the speed and you quarter the squat. When the clearance is marginal, slowing down buys more water than almost anything else you can do, and it is free.

KEY RULE

Water you have = charted depth + height of tide. An ETA error is a depth error. **Halve the speed and you quarter the squat.** Add up draught, squat, heel and margin before you sail, not in the channel.

27 · The Three Sailings

Before any weather comes into it there is a geometry problem: the earth is round and the chart is flat, so the shortest track and the easiest track are not the same line. A rhumb line crosses every meridian at the same angle — a straight line on a Mercator chart and a single course to steer from end to end, which is its whole virtue and not a small one. A great circle is the genuinely shortest track between two points on the sphere, a straight line on a gnomonic chart and a curve on a Mercator, so you sail it as a series of short rhumb legs between waypoints. On a North Atlantic crossing the great circle might buy you three per cent of the distance — and pay for it by climbing hundreds of miles north into the winter storm track. In July you take it and think nothing of it. In January you had better have a reason. And when the great circle's vertex is somewhere you will not go — into the ice, north of a company limit — the composite is the answer: a great circle up to a limiting latitude, a run along that parallel, and a great circle down to the destination.



The same two tracks on a Mercator. The great circle is shorter but bows poleward; the rhumb line is one steady course. Lay the great circle off on a gnomonic where it is straight, lift the waypoints, and transfer them to steer.

KEY RULE

Rhumb line: one course, no alterations — the easy track. Great circle: the shortest track, but it carries you toward the pole and into worse weather. Distance is not what you are optimising — time, fuel and damage are, and they do not agree with each other.

28 · Climatology, Routing, and the Isochrone Method

Before there is a forecast there is a climatology — what this ocean usually does, in this month — and that is the pilot chart, a century of logbooks boiled onto one square of ocean. A forecast tells you what will happen for four days; a pilot chart tells you what to expect for a month, and it is the right tool for the decision you make before you sail: which season, and which window inside it. No amount of clever routing recovers a passage planned into the wrong month. One caution repays itself — the wind rose on a pilot chart is not a wind barb: the length of each arrow tells you how often the wind blew from that direction, and the feathers give the average force. Read it as a barb and you get the answer exactly backwards.

Weather routing is the part of the plan that will not hold still — the plan you made on Monday against an ocean that has its own ideas by Thursday. Its aim is not to dodge every gale; it is to find the most efficient route through the weather there is, and the honest case for it is not that it makes every passage faster on average — it is that it takes the tail off, it removes the crossings that go badly wrong. Underneath the software is one idea simple enough to draw by hand, and drawing it once is what stops the software being magic. An isochrone is the line of everywhere the ship could reach in a given elapsed time: fan out candidate headings from your position, look up the speed the ship makes in the forecast sea for each angle, advance one time step, and join the outermost points. Do it again from every point on that curve with the next forecast, and again, until an isochrone touches the destination — then back-trace to recover the route. Where a gale bites, the isochrone develops a notch, and the best track runs round the outside of it. That is all a router does, in more places and faster.

KEY RULE

The pilot chart decides the month; the forecast decides the day; the router finds the cheapest path through a field that changes while you cross it. A routing service advises — it sees more weather than you and less of your ship than you. SOLAS V/34-1 is for the moment the two views disagree.

One practical thing the router needs from you before it can help — the terms of the voyage — and there are three ways they are usually written. Say which one you are on before you ask the question, because each turns the very same weather into a different answer.

Routing basis	What it means
Fixed speed	One speed set by the charter party; the router optimises the track only.
Flexible (variable) speed	A speed band the router may work within to dodge weather and save fuel.
Fixed ETA	Arrive at a set time; the router varies both speed and track to hold the ETA while easing the ship's motion.

PART NINE

The Synthesis — the Plan and the Report

29 · Building the Passage Plan

Now put it together, because everything to this point has been a piece of one argument. Take a single winter crossing, one 180-metre ship making fifteen knots in calm water, and lay it three ways against the same forecast — a deep 957 millibar low out in mid-ocean and a second developing off the coast. The great circle is the shortest line on the sheet, and it is the slowest passage of the three: it drives you north into the worst of the low, the head sea takes a third of your speed, and you arrive last, on the most fuel, having spent days in seas over six metres. The rhumb line is easier and quicker. And the weather-routed track is 370 miles longer than the great circle — and gets in nearly three days sooner, on ninety tonnes less fuel, having never seen a sea over five metres, because it spends its extra miles going round the storm instead of through it.

That is the whole of it in one comparison: the shortest track is not the best passage. The best passage is the one where nothing on board breaks and nobody has to stop. So the plan you sign is the routed track, drawn berth to berth with its true courses, its no-go areas, its wheel-over and abort points, its under-keel clearance worked for the shallow bits and its contingencies written down — and it carries, in the margin, the reason you went the long way. Do not oversell it: a three-day saving comes from one ship meeting one bad storm, and a typical routed saving is a few per cent, not a quarter. But the tail is where ships are lost, and taking the tail off is worth paying for on every crossing that turns out quiet.

Track	Distance	Passage	Fuel	Max Hs
Great circle	2,808 NM	13.1 days	419 t	9.0 m
Rhumb line	2,896 NM	11.7 days	376 t	7.5 m
Weather routed	3,178 NM	10.3 days	330 t	5.0 m

Same ship, same forecast, three tracks. The longest track is the fastest, cheapest and safest passage — because it goes round the storm, not through it.

30 · A Weather Report for the Bridge

The last thing a mariner does with all of this is the plainest, and it is where the lecture ends: you take real charts, a real position and a real morning, and you write one page the master can act on. Put yourself on the chart first — nothing else works until you have — and read outward from your own position about three hundred miles in every direction, because that is what reaches you inside a day. Read what is around you, then run the sequence: one chart is a photograph, three charts are a film, and the film is what you forecast from. Read the validity line before the picture, every time — a six-day forecast chart and today's analysis look almost identical at a glance, and using the wrong one is the most common chart-reading mistake there is. Get the numbers down on a data sheet for yourself; then write the report in English for the master, who wants to know what happens to his ship

and what to do about it.

The morning — a worked example

The ship is a merchant vessel at 36°30'N 073°30'W, about eighty miles east-south-east of Cape Henry, at 1500Z on a Thursday in mid-August. She is sitting on a weak stationary front, seventy miles east-south-east of a 1011 low on the Virginia coast, and the isobars around her are hundreds of miles apart — a slack gradient, which means light wind no matter what else is drawn on the sheet. Run the three forecast charts forward and the low fills from 1011 to 1013 over the next day while a 1020 high builds in behind it: there is no gale in this pattern, and that single conclusion, read off three charts in thirty seconds, is the most valuable thing you will tell the master today.

Observed / derived	How you got it
Position 36°30'N 073°30'W	80 NM ESE of Cape Henry
Pressure ~1012 mb, slow fall	Interpolated between isobars
Surface wind SSW–SW 8–12 kt	70–80% of a 13 kt geostrophic, backed ~15°
Air mass maritime tropical	Southerly flow off the Gulf Stream
Air 28°C, dew point 24°C → spread 4°C	Wet and dry bulb; RH ~79%
Convective cloud base ~1,600 ft	Spread × 400 ft
Sea temp 28°C ≈ air	No advection fog
24 h trend: low fills 1011→1013	The 00Z / 06Z / 12Z sequence

ON DECK

WEATHER REPORT — 36°30'N 073°30'W — 1500Z 13 AUG to 1500Z 14 AUG

We are on a weak stationary front, ~70 miles ESE of a 1011 low on the Virginia coast. The pattern is slack, so the wind stays light all period — SW 8 to 12 knots, occasionally 15; slight sea 2 to 3 feet with a low SE swell; visibility good but hazy in the humidity.

The one thing to watch is thunderstorms. This is maritime tropical air off the Gulf Stream, dew point 24°C, cloud base near 1,600 feet — the atmosphere is loaded, and a trough reaches the coast this evening. Expect storms to build inland after dark and drift over us roughly 0200 to 0800 local; in any one of them the wind will jump to 30 or 40 knots from a new direction with almost no warning, heavy rain, visibility to a cable.

The low itself is no threat — it fills 1011 to 1013 and a 1020 high builds in behind. There is no gale in this pattern. After the window the trough clears, the wind veers NW and freshens, the glass rises and visibility improves.

RECOMMENDATION: no routing change. Secure the decks for squalls before 2000 local rather than after; brief the watch on the overnight storm risk and keep the radar on for cells.

Notice what that report does, and what it refuses to do. It leads with the wind, because that is what the master asked even if he did not say so. It names the one real hazard — and it is not the low; the low is the biggest thing on the chart and the least dangerous thing in the forecast. It gives the storms a time window and a magnitude, because ‘chance of thunderstorms’ is not actionable and ‘0200 to 0800, thirty to forty knots, no warning’ is. It says what happens after the window, because the master is planning further ahead than you are. And it ends with one recommendation, not four options, and it does not hedge — because uncertainty spread evenly over a whole report to protect yourself is how a real warning gets lost.

31 · Reporting the Weather — the Voluntary Observing Ship

There is one last duty that closes the circle, and it is the one that makes every forecast on this ship possible — you send your own weather back. The ocean is thinly watched; the models we lean on are only as good as the observations fed into them, and out in the middle of an ocean the nearest observation is very often your own. That is the whole idea of the Voluntary Observing Ship scheme — some five thousand merchant ships across a couple of dozen nations, under the World Meteorological Organization, keeping a synoptic eye on the sea where no buoy or shore station reaches. When you file a report you are not doing paperwork; you are paying back the forecast you leaned on this morning.

The reporting hours are the main synoptic times — 0000, 0600, 1200 and 1800 UTC, four times a day; close in, within about two hundred miles of the U.S. or Canadian coast, the ask tightens to every three hours. What you send is the same handful of things the station model holds — pressure and its tendency, air and dew-point temperature, the wind, cloud, sea and swell, visibility and present weather — encoded into groups of five figures, the WMO ship weather code. It is fiddly the first few times and automatic after that, and the authority for every group is the National Weather Service Observing Handbook No. 1. Keep one distinction straight: the report you SEND is the ship observation code; MAFOR (the marine FOREcast code) is the forecast you RECEIVE — different animals that are easy to muddle by name.

How a group is built — the cloud-and-wind example

Take the group that trips everyone, the one carrying cloud cover and the wind together. Cloud goes in first, in eighths — a half-covered sky is four oktas, so the group opens with a 4. Then the wind, and here is the catch the maneuvering board exists to solve: you measured the APPARENT wind off a moving ship, and the code wants the TRUE wind. So you take the ship back out of it — course and speed worked against the apparent — to get, say, a true wind from 220° at 5 knots. Direction is encoded in tens of degrees (220 becomes 22) and speed in whole knots (05), so the finished group reads 42205. Solve the true-wind vector first and the rest is only bookkeeping — which is exactly why the true-wind board is on the exam.

Group	Carries	Worked example
1snTTT	Dry-bulb air temperature	sign sn (0 = +, 1 = -) then tenths °C; -1.1°C → 11011
2snTdTdTd	Dew-point temperature	same sign rule; -4.0°C → 21040
Nddff	Cloud (oktas) + TRUE wind	4 oktas, 220°T, 5 kt → 42205 — solve true wind first
99LaLaLa / QcLoLoLoLo	Ship's position	latitude to 0.1°, then quadrant (1 NE, 3 SE, 5 SW, 7 NW) + longitude to 0.1°

ON DECK

Two habits keep a VOS report honest: correct the barometer (height, temperature and index) before you encode it, and always convert the apparent wind to true — the wind you feel on a moving ship, sent raw, is worse than no report at all. Full code tables: NWS Observing Handbook No. 1, at vos.noaa.gov.

APPENDIX

The Beaufort Scale — Wind and Sea

One reference sheet worth keeping, because the Beaufort number is the common language between the forecast, the deck log and your own eyes. Learn to read the force off the surface of the sea and you can check any forecast against the water in front of you — which, when the model and the sea disagree, is the whole game.

F	Wind (kt)	Sea (open ocean)	What the surface looks like
0	0	—	Glassy calm
1	1–3	0.1 m	Ripples, no foam
2	4–6	0.2–0.3 m	Small wavelets, glassy crests, not breaking
3	7–10	0.6–1 m	Large wavelets, crests begin to break, a few whitecaps
4	11–16	1–1.5 m	Small waves, frequent whitecaps
5	17–21	2–2.5 m	Moderate waves, many whitecaps, some spray
6	22–27	3–4 m	Large waves, white foam crests everywhere, spray
7	28–33	4–5.5 m	Sea heaps up; foam blows in streaks (near gale)
8	34–40	5.5–7.5 m	Moderately high waves; well-marked foam streaks (gale)
9	41–47	7–10 m	High waves, dense foam, spray hurts visibility (strong gale)
10	48–55	9–12.5 m	Very high waves; the sea takes on a white look (storm)
11	56–63	11.5–16 m	Exceptionally high waves, sea all but covered in foam
12	64+	14 m +	Air filled with foam and spray; sea completely white (hurricane force)

Sea heights are for the open ocean with a well-developed sea; fetch- or duration-limited waters run lower for the same wind.

IN ONE BREATH

Say These Until They Are Automatic

Two dozen lines. If a student can recite these cold, they carry the whole lecture in their head.

- | | |
|---|--|
| 1. Weather is heat moving from surplus to deficit. | 14. Right semicircle dangerous, left navigable — Northern Hemisphere. |
| 2. Coriolis turns; it does not drive — and it follows the sine of the latitude. | 15. Stay outside the 34-knot field. Avoid the storm two days out. Plot the wind radii, not the cone. |
| 3. Cold air over warm water is unstable; warm air over cold water is fog. The quiet one is dangerous. | 16. Swell points to where the weather was, not where it is. Period shortening, it is closing. |
| 4. Parcel cools faster than its surroundings → stable; slower → unstable. | 17. A grid of pyramids is two seas crossing — slow down, take sea room. |
| 5. Isobar spacing is wind speed. Tight isobars, strong wind. | 18. Significant wave height is the average of the highest third; one in ten beats it. |
| 6. Read the rate of change, not the height of the glass. | 19. Dew point up to sea temperature — expect fog. |
| 7. Long foretold, long last; short notice, soon past. | 20. Double the wind, four times the force on the ship's side. |
| 8. Back to the wind, low on the left — Northern Hemisphere. | 21. Encounter period, not sea period, decides how you roll. Change course or speed. |
| 9. Surface wind ≈ 70–80% of geostrophic over the sea, backed 10–20°. | 22. Halve the speed and you quarter the squat. |
| 10. The cold front runs twice as fast as the warm front — that is the whole life of a depression. | 23. The shortest track is not the best passage. Go round the storm, not through it. |
| 11. The cross sea after the cold front does the damage. | 24. When the model and the sea disagree, believe the sea. |
| 12. Veering wind with height is warm advection — rising air, rain coming (N. Hem.). | 25. Face the wind — the eye bears about 112° off your right hand (N. Hem.). |
| 13. Low downstream of the upper trough deepens; stacked under it, fills. | 26. Send your weather back — true wind and a corrected glass, four times a day. |

The whole discipline in one habit

Use the model for the shape of things and your senses for the truth of them. Read the glass, the sky and the sea before you read the bulletin, and let the chart tell you what is coming while the deck tells you what is here. Plan the passage while you are rested, mark the reasons on it, and keep the ship where nothing breaks and nobody has to stop. And when the model and the sea disagree, believe the sea.

Georgia Hilton — US Navy Veteran, USCG Master & OICNW

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Sleep well. The watch is quiet and the glass is steady.