

Advanced Weather for the Mariner

A Night-Watch Lecture

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.

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.

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.

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Now come down from the planetary scale to the scale you work in, and let's talk about pressure — the mariner's most useful instrument, and the most routinely misread.

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.

Now — 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. In the free atmosphere above the friction layer, wind blows along the isobars, not across them.

Down at the surface, friction slows the air, weakens the Coriolis 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. That's why the surface wind you feel is backed slightly from the gradient wind aloft, and why it's 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.

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Let's build a depression properly, because 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. Now the warm air is actively advancing on the eastern side of the system, riding up over the cold air ahead of it, and that's your warm front. On the western side, cold air is advancing, undercutting the warm air, shovelling it upward, and that's your cold front. The warm sector is the wedge of mild, moist air between them.

The two fronts behave completely differently, and this is worth knowing in your bones.

The warm front has a shallow slope — one in a hundred and fifty, sometimes one in three hundred. Warm air can't shove cold air out of the way, so it climbs gently over the top. That gentle, extended ascent gives you a long, orderly, thoroughly readable sequence, and the sequence is the same every time.

First, cirrus. High, wispy, mare's tails, six hundred miles or more ahead of the surface front, often a full day before anything happens. If those cirrus are thickening and lowering rather than drifting and dissipating, that's your first warning, and it arrives long before the barometer moves.

Then cirrostratus — that milky veil that puts a halo around sun or moon. The halo is a genuinely useful sign; it's ice crystals aloft, and it means the frontal cloud sheet is arriving.

Then altostratus, the sun becoming a watery blur, then vanishing. Then nimbostratus, and steady rain that goes on and on. Wind backing and freshening, barometer falling steadily, visibility going down, and often fog forming in the rain ahead of the front.

Then the surface warm front passes, and everything changes at once. Rain eases to drizzle or stops. Temperature jumps — noticeably, sometimes several degrees in minutes. The barometer stops falling and steadies. And the wind veers — clockwise in the Northern Hemisphere, southwest to west, say. You're now in the warm sector: mild, murky, often drizzly, poor visibility, perhaps sea fog if that warm moist air is riding over colder water.

Then the cold front, and the cold front is nothing like its sibling. Its slope is steep — one in fifty, sometimes one in thirty. Cold dense air acts like a plough, driving under the warm air and hurling it violently upward. Violent ascent means deep convection, so you get cumulonimbus rather than layer cloud: a narrow, savage band of squalls, heavy rain, thunder, hail, and a hard wind shift.

The passage is abrupt. Wind veers sharply — often forty-five to ninety degrees in a matter of minutes, west through northwest. The squall at the front can double the wind speed with no warning worth the name. Barometer stops falling and begins to rise, sometimes steeply. Temperature drops hard. Then, behind it, the sky opens into that scoured, brilliant, showery northwesterly airstream — bright between the showers, cold, gusty, with towering cumulus marching through and a nasty steep sea because the wind has shifted across the existing swell.

That wind shift across the swell is worth dwelling on. Before the cold front you had a southwesterly sea running. Afterward you have a strong northwesterly blowing across it. For some hours you're in a genuine cross sea, and that's the most dangerous water in the whole depression — not the strongest wind, but the most confused sea. More vessels are hurt in the hours after a cold front than during the front itself.

And then the last act: occlusion. The cold front travels faster than the warm front — steeper slope, denser air, more momentum — so it catches up. It lifts the entire warm sector clear of the surface and the system becomes occluded. The warm air is now aloft, cut off from its energy source, and the low begins to fill and die. On a chart you'll see the occluded front drawn with alternating triangles and semicircles on the same side. Practically, it gives you a muddled mixture — prolonged rain, cloud, a wind shift that's less clean, and a system that's weakening.

Life cycle: wave, deepening, mature, occluded, dying. Two to five days, usually. And they come in families, one after another down the polar front, each one riding the jet stream east. That's why one bad system so often means several.

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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 that

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 has areas of divergence aloft — where air is spreading apart — it evacuates air from the top of the column faster than the surface can supply it. Pressure at the surface falls. That's what deepens a depression. A surface low sitting 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. It develops great north-south waves — Rossby waves — and those waves determine everything on the timescale of a week. When the jet is running fairly straight west to east, zonal flow, systems race across quickly, one after another, and weather changes fast. When the jet buckles into deep meridional waves, north and south, systems slow down, dig in, and park. That's when you get a week of the same miserable thing, or a blocking high that won't shift.

For passage planning that distinction matters enormously. Zonal, expect a parade of fast-moving systems and pick your gap. Meridional, expect whatever you've got to persist, and understand that a bad setup will stay bad for days.

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Now: tropical systems, which are a wholly different animal, and the confusion between the two kinds of storm causes real harm.

A mid-latitude depression is powered by temperature contrast — it's a frontal system, it needs cold air meeting warm air, it's cold-cored, and it strengthens with height. A tropical cyclone has no fronts at all. It's warm-cored, powered by latent heat released as water vapour condenses, and it's strongest at the surface, weakening with height. Different engine, different structure, different behaviour, different tactics.

Genesis requires several things at once. Sea surface temperature of about twenty-six and a half Celsius, eighty degrees Fahrenheit, through a good depth — not just a warm skin. A pre-existing disturbance to organize around, often an easterly wave off Africa. Enough distance from the equator, five degrees or so, for the Coriolis deflection to get rotation started — which is why you never see a hurricane on the equator itself. Moist mid-levels, so entrainment of dry air doesn't choke the convection. And critically, low vertical wind shear, because shear tears the developing core apart before it can organize.

That last is the forecaster's great friend and why some seasons stay quiet despite warm water. Shear kills tropical systems. And note the difference from our thunderstorm conversation, where moderate shear helps organize a supercell. In the tropics, shear is purely destructive to the system as a whole.

The structure: the eye, calm and clear, subsiding air, often ten to forty miles across. Around it the eyewall, the ring of most violent wind and heaviest rain — the strongest winds on the planet's surface. Outside that, spiral rainbands feeding inward, with their own squalls and sometimes tornadoes. And out beyond, the storm's influence on the sea extending hundreds of miles further than its wind.

Now — the mariner's part, the dangerous semicircle, and this deserves real precision.

Take a Northern Hemisphere hurricane moving, say, northwest. Its winds circulate anticlockwise. On the right-hand side of the track, relative to the direction of motion, the rotational wind and the forward motion of the storm are in the same direction, so they add. On the left-hand side, they oppose, and partially cancel.

So if a storm has a hundred-knot circulation and is moving at twenty knots, the right side sees something like a hundred and twenty, and the left side something like eighty. Forty knots of difference — the difference between very bad and catastrophic.

But the arithmetic isn't the whole of it, and this is the part people miss. On the right side, the wind direction tends to veer as the storm passes, and it tends to drive a vessel into the storm's path — ahead of the advancing centre. On the left side, the wind backs, and it tends to blow you away from the track. So the right side is dangerous twice over: stronger wind, and a wind that pushes you where you least want to go. Hence: right side dangerous semicircle, left side navigable semicircle. In the Southern Hemisphere everything mirrors — circulation clockwise, and the left side is the dangerous one.

Practically, how do you know which side you're on? Watch the wind direction over a few hours. Northern Hemisphere: if the wind is veering steadily — say east, to southeast, to south — you're in the dangerous right semicircle. If the wind is backing — east, to northeast, to north — you're in the navigable left semicircle. And if the wind direction holds steady while the barometer keeps falling and the wind keeps strengthening, that is the worst news of all: you're on or very near the track, directly ahead of the centre, and the storm is coming straight down on you.

The classic avoidance tactics, Northern Hemisphere. In the dangerous semicircle, put the wind on your starboard bow and make as much way as you can — that carries you away from the centre and out of the path. In the navigable semicircle, put the wind on the starboard quarter and run, which carries you away behind the storm. And if you're directly in the path, get the wind on the starboard quarter and run to move into the navigable side.

Everything reverses in the Southern Hemisphere: port bow, port quarter.

And know the thirty-four knot rule that the professionals use: plot the storm's forecast track, draw the radius at which winds reach thirty-four knots, and add a generous allowance for forecast error that grows with time — because once you're inside thirty-four knots, your ability to manoeuvre out is already compromised. You don't avoid a hurricane at close quarters. You avoid it two days out, with sea room and a decision made early.

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Let's talk about things that happen at your scale — the local phenomena that no synoptic chart will ever show you.

Sea breeze and land breeze. 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 typically starts late morning, builds through afternoon, peaks mid-afternoon, dies at sunset. It can reach fifteen or twenty knots, and there's usually a sea-breeze front you can see as a line of cloud inland. On a sunny coast it dominates everything the gradient wind is trying to do.

At night the process reverses, weaker — land cools, air drains seaward, and you get a light land breeze, often strongest just before dawn. Weaker because night-time temperature differences are smaller.

Katabatic winds are the more 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 can 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 valley, the bora off the Dinaric Alps into the Adriatic. Anchorages below high ground with a valley leading down to them deserve real respect, especially on clear, cold, calm nights, because those are exactly the conditions in which cold air pools.

Fog, which is where a lot of mariners come unstuck. Two main kinds, and they behave differently.

Advection fog — warm moist air moving over colder water. The air is cooled from below to its dew point and fog forms. This is your sea fog, and it's 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 persist in twenty knots of breeze and lie over hundreds of miles of ocean for days. Classic locations: warm air over a cold current, the Grand Banks being the textbook case, where Gulf Stream air meets the Labrador Current.

Radiation fog — land cools at night by radiating heat to a clear sky, chills the air above it, and fog forms in the low ground. This is a land phenomenon, forms in calm conditions, and burns off with the morning sun. It drifts out over harbours and estuaries at dawn and clears by mid-morning. Much less dangerous, much less persistent.

The practical test: compare air temperature to sea temperature. When the dew point of the air is at or above the sea surface temperature, expect fog. Watch that gap closing and you have warning before you lose your visibility.

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Two more things and then let me bring this in to anchor.

First, the thing I'd most want you to take away about forecasts themselves. Every forecast you read comes from a numerical model — a fluid-dynamics simulation on a grid — and every model has three unavoidable weaknesses. It has finite resolution, so anything smaller than its grid cell is not simulated but parameterized, meaning approximated by rule of thumb. Convection, squalls, the sea breeze, the katabatic — all of it, essentially, guessed at. It has imperfect initial conditions, because the ocean is very thinly observed. And the atmosphere is chaotic, so small errors grow exponentially. Useful skill out to about five days for the broad pattern; the specifics degrade far sooner.

Which is why ensemble forecasting exists — run the model fifty times with slightly perturbed starting conditions and see how the members diverge. If they all agree, confidence is high. If they scatter wildly by day three, the atmosphere is in a state where small differences matter enormously, and no amount of staring at a single deterministic run will save you. The spread is the information. When you see forecast models disagreeing about a storm track, that disagreement is telling you

something real and you should 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 your sea state give you truth at your position, right now, and the model gives you pattern over the region, in the future. Neither replaces the other. The forecast tells you what ought to be happening; the instruments tell you what is. And 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, and it's a good one to sleep on. Take Buys Ballot — back to the wind, low on your left in the Northern Hemisphere. Now compare the bearing that gives you with where the forecast says the low is. If they agree, you understand your situation and you can trust the forecast's next move. If they disagree by a significant angle, something has gone wrong — the system is displaced, or deeper, or slower than forecast — and you should reason from your own observations from that moment on, and treat the forecast with real suspicion until the two come back into agreement.

That's the whole discipline in one sentence, really. Use the model for the shape of things. Use your senses for the truth of things. And when they part company, believe the sea.

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That's the tour: heat engine, rotation, circulation, pressure, wind, depressions, fronts, the jet, tropical systems, the semicircles, local effects, fog, and the honest limits of forecasting.

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

Georgia Hilton — US Navy Veteran, USCG Master & OICNW

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