10

READING THE SEA AND SKY

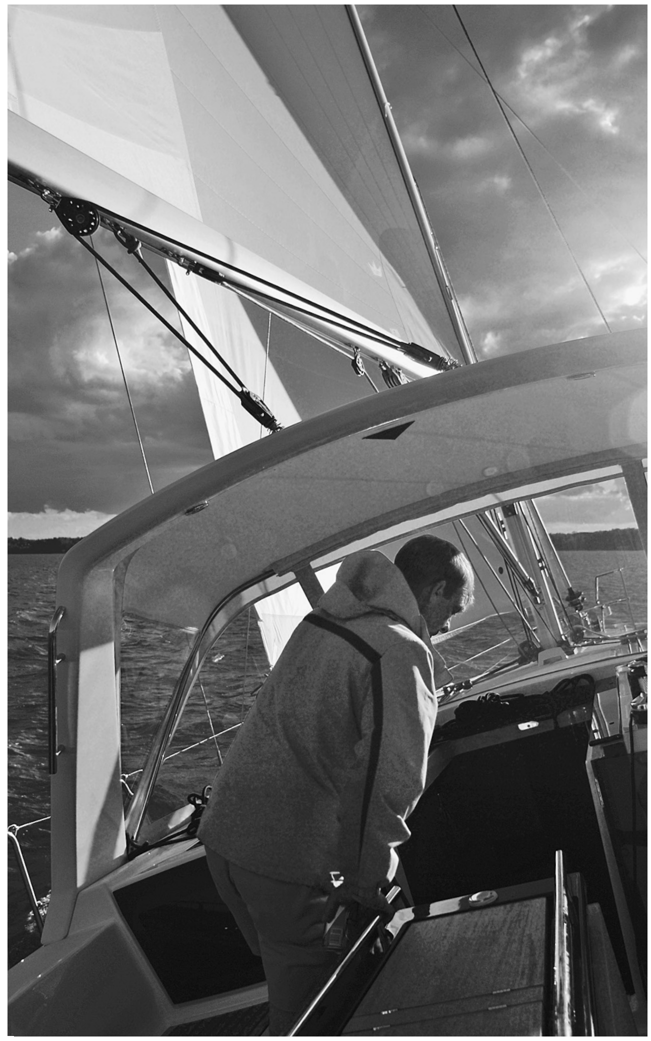
Benjamin Franklin, a constitutional framer and endearing Francophile, understood good wine and bad weather. He researched the Gulf Stream and coined the phrase "the weather wise and the otherwise." More than two centuries later, mariners can still be grouped accordingly, and the former are still safer and continue to get more enjoyment out of their time on the water.

Knowing what lies ahead is perhaps even more important than knowing what's causing the good or bad weather of the moment. This is especially true for sailors. It's hard to outrun bad weather at the speed of a slow jogger; the better bet is not to be in the neighborhood.

The more volatile the climate and the higher the latitude or the closer you are to hurricane season, the more advantageous a heads-up weather-driven game plan becomes. The good news for contemporary sailors is that more weather information than ever before is within easy reach of those poking along coastlines or sailing thousands of miles from home. There's only one catch: if you're after more than a look at how the barometer is trending, where the clouds are coming from, and which way the wind is blowing, you're going to have to make some decisions about hardware and software and ask yourself how much of an investment weather wisdom is worth to you.

There are three schools of thought when it comes to weather awareness. The first is exemplified by a dwindling group of stoics who prepare for weather contingencies, pick the right season for a passage, and endure what comes their way. Communication equipment takes a backseat to storm sails, vessel stability, and structural integrity for this group. Their gamble is one of higher stakes and greater challenges, as it was centuries ago, and the wise among them improve their odds with the sort of seamanship skills that were common in bygone centuries.

The second school of thought among passagemakers is a do-it-yourself approach that combines a "Weather 101" level of knowledge with a familiarity with what it takes to receive VHF, cellular, SSB, and satellite voice and data broadcasts. This approach assumes that the onboard decision maker can read a surface weather analysis chart, evaluate 24-, 48-, and 96-hour forecasts, and make sense of the contours of a 500-millibar chart—topics we'll discuss later in this chapter.



Knowing whether the clouds rolling by are the harbinger of an approaching cold front or the welcome departure of a low-pressure system is part of a sailor's weather awareness. A lot can be ascertained from trends in wind direction, barometric pressure, and cloud cover.

The third option is to relegate some or all of the weather strategizing to an expert who is not onboard. With an abdication of weather planning comes complete reliance on a communication link that could fail when you need it most, but those who can afford to have a full-time meteorologist on call can also afford redundant communications capability. The value of access to such unquestioned expertise is understood by commercial maritime ventures that enlist such services.

Climates vary with latitude, but equally as important are the influences of air masses and currents such as the Gulf Stream or Kuroshio Current that shunt warm or cold water into a region. This uptick in ocean-to-air heat transfer can result in fog and turbocharge a developing low. Assuming that regions of equal latitude will have similar climates can be a big mistake.

Many weather-wise passagemakers see the ideal approach as an amalgam of all three philosophies.

DEVELOPING WEATHER AWARENESS

Most sailors don't need to be told why weather is so important. Although you may not have experienced every meteorological danger, you've likely heard and read about them. Here's the short list of what mariners should understand:

- Gales
- Secondary lows
- Squeeze zones
- Gusts
- Squalls and thunderstorms
- Lightning
- Tropical storms and hurricanes
- Waterspouts
- Fog
- Waves

The Inuit people of the Arctic never studied thermodynamics or took a course in atmospheric science. Their weather awareness is intuitive and passed down, learned from direct observation and cataloged as folk wisdom. Living in their laboratory 24/7, they have survived by heeding the lessons learned. A more scientific approach to meteorology and oceanography can work for mariners, but it works best when linked to the sea sense accumulated from experience.

All it takes to get started is an understanding of a few general concepts regarding highs, lows, and frontal boundaries. Once you've mastered a few basic principles, you'll be ready to leverage forecast data. We'll cover the basics in this chapter; a text such as Jack Williams's informative and well-illustrated *Ultimate Guide to America's Weather* is a great source of more detailed explanations.

You can develop your weather awareness anytime—on the deck of your boat or while commuting to work. Start by paying attention to morning and evening map discussions on the Weather Channel broadcasts and website. Correlate what's in the forecast for your area with the clouds you see, the direction they're moving, and local changes in temperature and humidity. Phase two is to track barometric changes. Note several readings each day; when a deep low approaches or is replaced by a high-pressure system, try to note hourly readings.

The next step in this home-brew Weather 101 course is to look at weather maps on the Ocean Prediction Center website. The OPC, a division of the National Weather Service (an agency of the National Oceanic and Atmospheric Administration, or NOAA—see more on government forecast resources later in this chapter), generates analyses and 24-, 48-, and 96-hour forecasts for surface maps; equivalent analyses and forecasts for 500-millibar maps; and wind-wave chart analyses and forecasts, all of which are also broadcast via single-sideband radio (SSB) weather fax. We'll discuss these weather products later in the chapter; you can look at them compared with what's going on outside your office window and with the Weather Channel's latest update. Such comparisons of weather analysis maps and forecasts with direct observations help instill the seaman's habit of feeling the weather continuously, knowing when the atmosphere is unstable, and noticing when the tempo of a cold front has reached its crescendo and when the first hint of a wind shift to the north (in the Northern Hemisphere) is about to occur.

The third phase of home study is to check your weather-guessing accuracy and that of the pros at NOAA and the talking heads on the Weather Channel against recorded observations. The National Data Buoy system provides just such observations, and by scrolling through the 24-hour profiles on each buoy's web page (accessed from the National Data Buoy Center website), you can test and refine your Monday-morning quarterbacking. Keep in mind that wave reports are based on significant wave height, which is the average of the highest one-third of waves recorded over an hourly period. Statistics show that in open ocean areas, during a 24-hour period, there's at least one wave that's twice as high as the significant wave height.

Buoy data comprise a powerful tool that can confirm the passage of a cold front or the location of a low. Equally useful on a local scale is Doppler radar imagery, which highlights the rain in clouds and defines the intensity of thunderstorm cells. It also depicts the direction and speed of movement of these systems. These images can be found on the National Weather Service (NWS) website, the Weather Channel's home page, or Weather Underground's informative home page.

Of course, this home weather study can and should continue on the boat. Indeed, one of the best ways to cultivate weather awareness is by comparing the information from a VHF weather broadcast with direct observation of what's happening in the atmosphere around you. This look-listen-learn approach field-tests a forecast even as it gives you a preview of the weather changes waiting in the wings. Ongoing practice will give you more and more confidence when it comes to discerning the likelihood of thunderstorm development on a hot, humid summer afternoon or how a veering breeze (shifting clockwise) can announce the approach of a fast-moving cold front in the Northern Hemisphere. Comparing VHF weather broadcasts with careful 360-degree scans of the horizon gives a mariner a feel for the climate and the day-to-day weather changes each season holds.

VHF weather broadcasts are familiar to us all, but many of us underutilize them. They can be a great instrument for honing your weather knowledge. Try linking the cloud cover you see around you with the local VHF forecast. Listen for buoy reports, note wind directions, and see how your barometer compares with the atmospheric pressure reported from a nearby weather buoy.

REALLY UNDERSTANDING THE CAUSES OF WEATHER

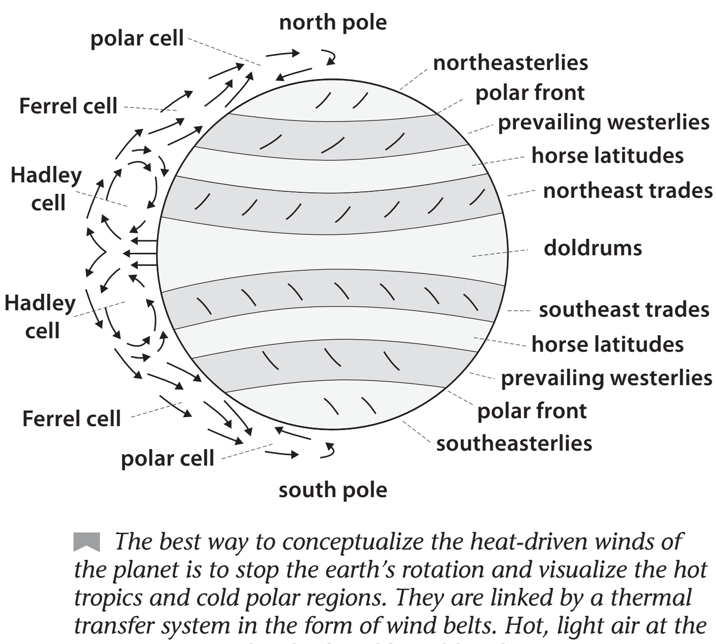
A weather-wise sailor views local conditions both close up and in the big picture—a full three-dimensional perspective. Although the wind on the surface rules a sailor's life, it's often what's happening midway up the atmosphere that drives these surface conditions. Newspaper weather maps, in contrast, are two-dimensional, but adding an understanding of the vertical dynamics pays off. The place to start is with an understanding of global circulation, fronts, pressure gradients, etc.

Surface Weather Systems

The atmsphere is a veil surrounding the planet, so thin that if the globe were reduced to the size of a softball, the atmosphere would have the thickness of an onion skin. Most weather takes place in the bottommost layer of the atmosphere, a roiling mix of gases—most notably nitrogen, oxygen, and carbon dioxide—called the troposphere, which varies from about 10 miles thick at the equator to about 5 miles thick at the poles. Above the troposphere, extending to an altitude of about 30 miles, is the stratosphere, which contains the ozone layer that prevents the most harmful of the sun's radiation from reaching the earth's surface.

Global Circulation Patterns

Just under half of the sun's incoming short-wave energy is reflected back to space or absorbed by the atmosphere. The rest passes through the thin atmospheric envelope and heats the land and oceans (the latter more slowly), which then re-radiate longer-wave, infrared energy back into the lower atmosphere. The equatorial regions soak up more energy from the sun than they re-radiate back to the atmosphere and would thus become hotter and hotter if this excess heat were not transported toward both poles via the atmosphere and ocean currents. Polar regions, meanwhile, absorb less heat than they lose by re-radiation and would thus become ever colder but for the heat received from lower latitudes. In effect, the oceans and atmosphere are sun-driven heat machines perpetually engaged in redistributing heat energy, and the result is weather, which is greatly influenced by seasonal changes in the sun's declination. Evidence continues to accumulate that global warming from human causes is leading to long-term changes in weather patterns. As warming proceeds, the earth's weather is becoming more volatile.



The best way to conceptualize the heat-driven winds of the planet is to stop the earth's rotation and visualize the hot tropics and cold polar regions. They are linked by a thermal transfer system in the form of wind belts. Hot, light air at the equator rises and is displaced by colder, denser air arriving from the poles. Add the earth's rotation and its attendant Coriolis effect, and the big belts become a series of smaller loops encircling set regions of the planet. The picture is further modified by seasonal changes and by the five ocean gyres that harness the major currents of the world.

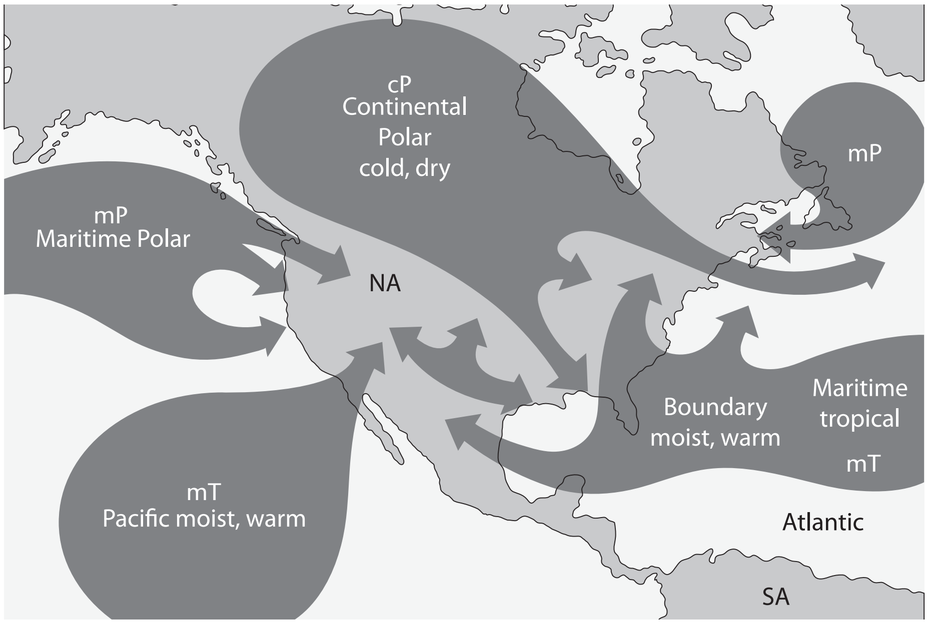
At the center of the weather-making machinery is the simple fact that hot, less dense air rises while cooler, denser air sinks. This simple dance plays out on a global scale, with warm air rising at the equator and forming a persistent band of low pressure around the equator known as the Intertropical Convergence Zone (ITCZ), or in popular parlance the doldrums. The width of this band is about 15 degrees of latitude, varying seasonally. The risen air moves toward higher latitudes aloft, some of it becoming cool and dense enough to subside at about 30 degrees north and south, forming bands of persistent high pressure there. These bands are the subtropical highs, or more popularly the horse latitudes. Since air flows from regions of high pressure to regions of low pressure, a portion of this sinking air flows back toward the equator along the earth's surface, and this return surface flow constitutes the northeasterly trade winds of the Northern Hemisphere and the southeasterly trades of the Southern Hemisphere.

The rest of the air that subsides at 30 degrees north and south flows poleward at the planet's surface: the prevailing westerlies of the northern and southern temperate zones.

While some air sinks at 30 degrees north and south, the rest remains aloft and continues to flow poleward before descending over the arctic and antarctic regions. The result is the prevailing easterly surface winds of the polar regions—northeasterlies in the Northern Hemisphere, southeasterlies in the Southern Hemisphere—and these meet the midlatitude prevailing westerlies at the so-called polar fronts—from 40 degrees (winter) to 60 degrees (summer) north and south—where the warmer air of the temperate-zone westerlies is forced aloft. As always when warm, moisture-laden air ascends, the results are instability and storms along the dynamic polar fronts.

Taken together, these circulations comprise three belts in each hemisphere, referred to as the Hadley (tropical), Ferrel (middle latitude), and polar circulation loops or cells. The Hadley and polar loops act as thermally driven conveyor belts, while the ball-bearing-like Ferrel loop separates the two and is significantly affected by the behavior of the jet stream. Within the Ferrel cell, the dry continental and moist maritime air masses march generally west to east, interacting along their boundaries as they go. Annual changes in the sun's declination drive the seasons and the locations of the cell boundaries.

Thus, air is set in motion within the great planetary circulation loops by the heat differential from the equator to the poles, and the spinning earth deflects the moving air (and ocean currents) to the right in the Northern Hemisphere and to the left in the



Wind belts and upper-level dynamics corral air masses and keep them in place long enough to acquire specific heat and moisture characteristics. Along the frontal boundary between two significantly different air masses—such as when warm, moist air from the Gulf of Mexico meets cold, dry air from Canada, shown along the Gulf coast here—the stage is set for extreme cyclogenesis and the birth of a classic extratropical low.

Key: mP = maritime polar; mT = maritime tropical (moist, tropical); cP = continental polar (cold, dry)

Southern Hemisphere, a phenomenon known as the Coriolis effect. These cells are a simplification of the complex thermodynamics in play. Storms help with thermal transfer between cells, as exemplified by hurricanes, which can extract heat from tropical Atlantic waters and take it all the way to England across two cell boundaries. Indeed, a hurricane can be thought of as a mechanism for heat distribution—a violent, short-lived atmospheric counterpart to the great equatorial ocean currents such as the Gulf Stream and the Kuroshio Current, which are the greatest heat-transfer mechanisms of all.

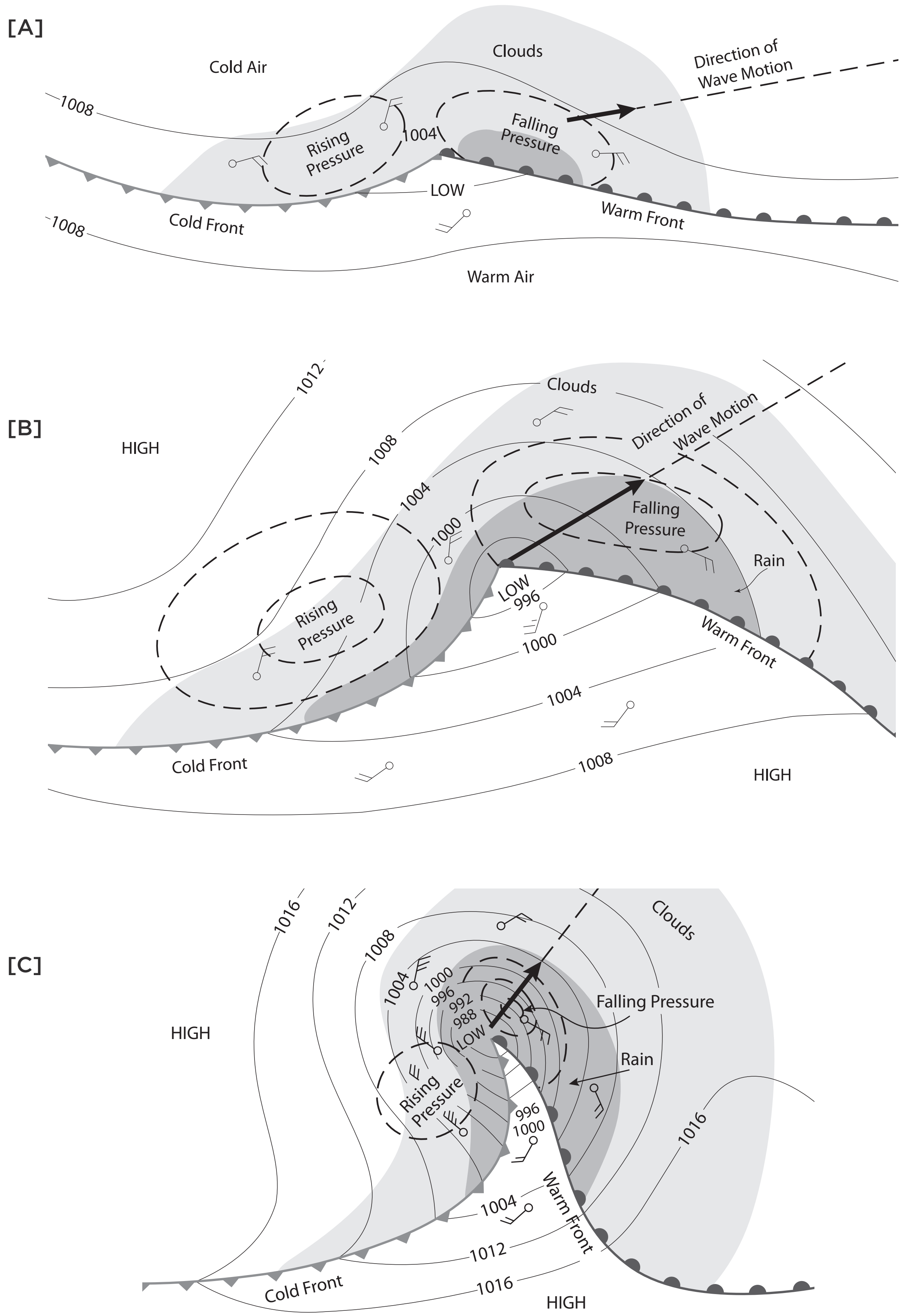
Frontal Boundaries and Low-Pressure Systems

Because warm and cold air masses are reluctant to mix, frontal boundaries—zones of rapid transition in temperature and pressure—occur wherever they meet. Such boundaries are prevalent in middle-latitude regions (30 to 60 degrees north and south), where warm and cold air masses most often meet, which is why temperate-zone weather is so dynamic. In particular, warm air masses meeting cold air along the polar fronts generate most of the strongest middle-latitude storms.

Imagine, for example, a cold continental air mass moving southeastward from the Canadian Shield and meeting a warm, moist, maritime air mass that is moving northeastward from the Gulf of Mexico. In this familiar scenario, at the frontal boundary between the two air masses—which is in fact along the polar front—the cold, dense polar air burrows beneath the warm, moist air, forcing it aloft, and clouds and precipitation develop. The boundary is not vertical; rather it slopes gently upward when viewed in cross section, gaining anywhere from a half mile to 2.5 miles of altitude across 100 miles of horizontal distance. Nor is the boundary sharply defined, although, for convenience, meteorologists speak as if it is; rather, there is substantial mixing along the boundary. Still, it is a boundary.

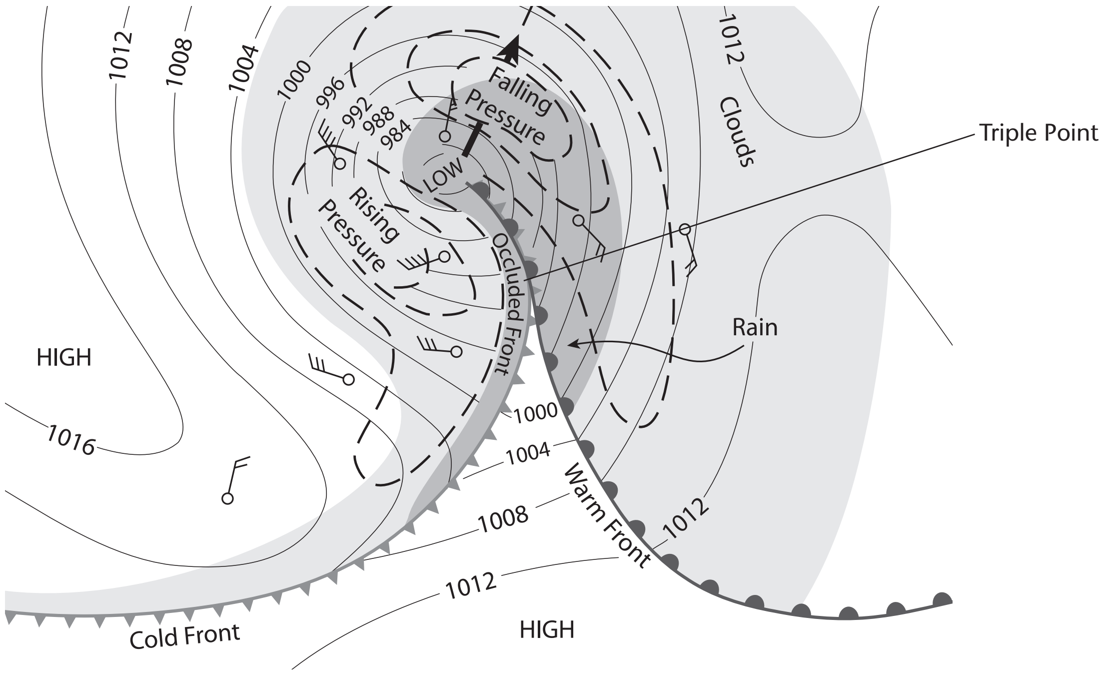
What happens next is determined in significant measure by wind streams aloft, at midheight in the troposphere, about 18,000 feet above the planet's surface (near the 500-millibar level, as we'll see later in the chapter). This band of high-speed winds flows west to east in a series of waves, with troughs extending toward lower latitudes and crests projecting toward higher latitudes. These are not the infamous jet stream that makes an airline flight from New York to London significantly faster than one in the opposite direction; the main axis of the upper jet stream lies at 30,000 feet, near the top of the troposphere, and also flows west to east. The jet stream links to these midlevel steering currents, which link in turn with surface frontal boundaries, intensifying them. It is these midlevel steering currents that are tracked by 500-millibar weather charts.

When these midlevel streamlines move smoothly west to east without pronounced troughs, the flow is called zonal. The associated surface weather systems can be expected to be relatively weak and will move quickly west to east at one-third to one-half the wind speeds in the overlying steering currents. But sweeping dips in these streamlines toward lower latitudes—creating meridional (north-south) flow and upper-level troughs—are not just a harbinger of bad weather but one of the contributing causes, because the southward-dipping loops in the flow (north-



[A]
Cold Air
Clouds
Direction of Wave Motion
1008
Rising Pressure
1004
Falling Pressure
LOW
Cold Front
Warm Front
1008
Warm Air
[B]
1012
Clouds
HIGH
1008
Direction of Wave Motion
1004
Falling Pressure
1000
Rain
Rising Pressure
LOW
996
1000
Warm Front
1004
Cold Front
1008
HIGH
[C]
1016
1012
1008
Clouds
1004
1000
996
992
988
LOW
Falling Pressure
HIGH
Rain
Rising Pressure
996
1000
1016
Warm Front
1004
1012
Cold Front
1016
HIGH

[D]



(Facing page and above) The birth of a midlatitude low. A. With a little twist induced by upper-level dynamics, the boundary between two air masses pinches into a wave shape and gathers a cloud field indicative of falling pressure in front with rising pressure behind. This is the first step in extratropical cyclogenesis, the formation of a midlatitude low. B. As the central pressure deepens and winds start to flow counterclockwise (clockwise in the Southern Hemisphere) around the developing low, distinct warm and cold fronts develop and are drawn along with the developing system. This frontal formation is termed frontogenesis. Isobars begin to pack in tighter, a sure sign of a developing low with a core of cold air pinched off from the polar air mass. C. As the low matures, the cold front catches up with the warm front, a process known as occlusion. Winds strengthen (up to 30 knots, as shown by the increasing number of tails on the wind arrows) and the central pressure continues to drop (down to 988 mb). When such a low develops at sea and a nearby high-pressure system lies just to the northwest (southwest in the Southern Hemisphere), a steep pressure gradient can result, causing the clockwise winds around the high to be turbocharged by the counterclockwise flow around the low, resulting in storm-force conditions and hazardous seas. D. A fully developed extratropical (cold-core) gale has a comma-shaped occluded front. The area near the center of the low, the origin point of the comma-shaped cold front, is the spot a mariner most wants to avoid. As the storm grows more intense and the pressure rapidly drops (now at 984 mb), warm air twists around the cold core (which has been pinched off from the cold air mass), and winds in this region are often the highest, reaching gale, storm, and occasionally even hurricane strength. There can also be violent squalls at the "triple point," the location in a mature low-pressure system where the cold front is occluding (overtaking) the warm front and where new secondary lows can develop.

ward-dipping in the Southern Hemisphere) jumpstart surface low-pressure systems.

Let's return to the frontal boundary between our cold polar and warm subtropical air masses. The boundary runs more or less west to east, and if the overlying steering currents are likewise flowing smoothly west to east, lows are less likely to develop along the boundary, and those that do develop are likely to be comparatively weak. But a trough in the overlying steering current can instigate a kink in the frontal boundary, twisting it into a closed cell in which air flow wraps around a low-pressure core. That wind circulation is counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere.

As the surface low matures, its central pressure drops and the isobars that connect areas of equal pressure move closer together. When coupled with an upper-level trough, the low can deepen rapidly and become a dangerous middle-latitude storm system.

Cyclogenesis is the term for the formation of an extratropical low, and the result is a low-pressure cell with a cold core pinched from the cold air mass. A warm frontal boundary and trailing cold front are formed (in the process called *frontogenesis*) as the low matures and the central pressure drops. In contrast, a typical warm-core low forms on an easterly wave (also known as a tropical wave), usually in tropical latitudes north or south of the ITCZ. Warm-core lows lack frontal boundaries and, when fully developed as tropical storms and hurricanes, reach into the stratosphere. Indeed, new research shows that the vertical development of a tropical low can be rapid enough to eject ice crystal cirrus clouds through the tropopause and beyond the earth's atmosphere, causing the moisture to dissipate in space.

Pressure Gradients and Surface Winds

A high-pressure system develops through a process called *subsidence*, in which cooler air aloft falls to the surface, increasing the density of the air on the ground. As air molecules are compressed by this process they tend to warm adiabatically, and clear skies and fair weather result from this high-pressure, or anticyclone, cell formation.

Together, highs and lows form giant air-shuffling machines that operate in a coupled relationship. Air converges aloft, subsides, and diverges at the surface in a high, while a low is like a stack in which air converges at the surface, rises, and diverges aloft. Wind blows from high to low pressure in a manner reminiscent of water spiraling around a bathtub drain, with the low acting like the drain (but ejecting its in-gathered air upward rather than downward). The wind would blow parallel with the isobar curves in a frictionless world, but due to friction with the ocean surface, it crosses the isobars at a 15-degree angle, bent inward toward a low and outward from a high. The steeper the gradient, the stronger the flow.

When meteorologists refer to a gradient, they are speaking of the magnitude of pressure differential over a given distance. Tightly packed isobars can occur within a high-pressure or low-pressure system, and in either case the result is strong winds. Some of the worst conditions of all occur when a deep low develops just to the east of a large high-pressure system, creating a very steep gradient. A vessel caught in the squeeze zone between the two can encounter hurricane-force winds caused by the rapid change in pressure over a very small horizontal distance.

Meteorologists measure atmospheric pressure in millibars (mb), and each isobar line on a map represents a 4 mb change in pressure. Unfortunately, the United States still clings to inches of mercury for pressure measurements, and many boaters have barometers that read in both scales. The most important measurement, however, is not the absolute value of a single reading but the change in atmospheric pressure over time. A rapidly falling barometer is another sure sign of strong wind and bad weather on the way.

A rapidly rising barometer is likewise predictive of strong wind, though this is less intuitive because rising pressures herald fair weather. But sunny gales can occur without a cloud in the sky. The California coast from Santa Barbara northwest is notorious for strong high-pressure gales, and in Southern California, off Mexico's Gulf of Tehuantepec, and elsewhere, high pressure inland and the effects of mountains can create a turbocharged wind that can gust to 100 knots without a cloud in the sky. High winds are most often associated with low-pressure systems and cold fronts, but not always, and fair-weather gales can be a big obstacle to progress to windward.

Thunderstorms and Squalls

Thunderstorms offer a vivid display of atmospheric forces at work. A local thunderstorm cell often arises independently of larger-scale weather systems, usually quickly and with little warning. Thunderstorms constitute the worst weather many sailors will ever experience.

A thunderstorm develops when warm, moist, unstable air rises. When cooled at high altitudes, the now-denser moisture-laden air plunges back to the surface. This updraft-downdraft conveyor belt transfers huge amounts of energy, and the interface between the updraft and downdraft is the most dynamic part of a thunderstorm. If you're in the presence of a fully vertically developed cumulonimbus cloud and notice intermittent pulses of cold air—even if rain, lightning, and thunder have yet to materialize—you should realize that you are likely only seconds, or minutes at the most, from a potentially hazardous outflow of wind. Strong wind gusts —"microbursts"—can reach hurricane force, and these dense cold outflow winds often precede torrential rain and hail. The storm's onset can occur with little or no warning. Given such harbingers, it makes sense to deeply reef or drop sails and lash down whatever is loose on deck.

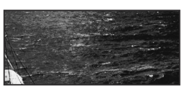
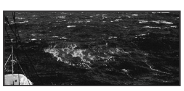
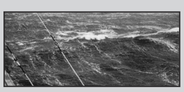
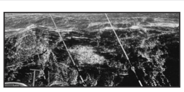
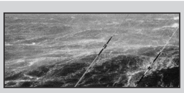
A thunderstorm cell is also a conveyor belt for moisture, which is carried aloft in the warm, moist updraft and then returns to earth as precipitation. The result is a rain signature on radar that causes the cell to show up clearly. Mature storms carry warm, moist air to astounding heights—35,000 to 50,000 feet—and they not only convert water vapor into rain but in many cases cause raindrops to coalesce into icy pellets of hail that grow larger and larger as the pellets shuttle up and down in vertical loops. Eventually the towering anvil-shaped thunderhead becomes unstable, and the vast amounts of water and ice held aloft yield to gravity, causing powerful downbursts and outrushings of rain- and hail-laden wind that can momentarily exceed 100 knots. These terrific bursts of energy often occur in the vicinity of what's called a shelf cloud, and except for a direct lightning strike, they constitute the most destructive feature of a thunderstorm.

When an isolated thunderstorm is spawned on a hot summer day, it is usually *(continued page 287)*

WIND AND SEA STATE

The Beaufort scale links wind strength with resultant sea state, an important consideration for those headed offshore because swells and breaking waves must be reckoned with. Sustained 28- to 33-knot winds (Beaufort Force 7) may raise only 4-foot seas, short-period chop, and spray in a protected bay where fetch is limited, but similar wind velocities at sea, where the fetch can be measured in hundreds of miles rather than hundreds of meters, can raise 13- to 20-foot seas. The Beaufort scale depicts sea states on the open ocean with unlimited fetch, and it further assumes that the wind blows long enough from a given direction at the given velocity for the seas to become fully developed. Tables of significant wave height (the average height of the highest one-third of waves) as a function of wind velocity, fetch, and time are also useful but don't seem to account for background swell effectively. The Beaufort scale is useful because it's more descriptively qualitative than deceptively quantitative. It worked for the sailing navies, and it still works.

THE BEAUFORT WIND SCALE

Force		Wind (knots)	Classification	Appearance of Wind Effects on the Water
0		Less than 1	Calm	Sea surface smooth and mirror-like
1		1–3	Light Air	Scaly ripples, no foam crests
2		4–6	Light Breeze	Small wavelets, crests glassy, no breaking
3		7–10	Gentle Breeze	Large wavelets, crests begin to break, scattered whitecaps
4		11–16	Moderate Breeze	Small waves, 1–4 feet, becoming longer, numerous whitecaps
5		17–21	Fresh Breeze	Moderate waves, 4–8 feet, taking longer form, many whitecaps, some spray
6		22–27	Strong Breeze	Larger waves, 8–13 feet, whitecaps common, more spray
7		28–33	Near Gale	Sea heaps up, waves 13–20 feet, white foam streaks off breakers
8		34–40	Gale	Moderately high waves (13–20 feet) of greater length, edges of crests begin to break into spindrift, foam blown in streaks
9		41–47	Strong Gale	High waves (20 feet), sea begins to roll, dense streaks of foam, spray may reduce visibility
10		48–55	Storm	Very high waves (20–30 feet) with overhanging crests, sea white with densely blown foam, heavy rolling, lowered visibility
11		56–63	Violent Storm	Exceptionally high (30–45 feet) waves, foam patches cover sea, visibility more reduced
12		64+	Hurricane	Air filled with foam, waves over 45 feet, sea completely white with driving spray, visibility greatly reduced

Nothing demonstrates the volatile dynamics of the atmosphere-ocean interface better than a classic thunderstorm cell. Each of these independent air circulations is a thermal engine transferring heat energy vertically, creating massive static electrical buildups, and triggering blinding displays of high-voltage cloud-to-cloud and cloud-to-water energy transfers. The gust front emanating from a single cell can stir a flat, calm sea instantly to life. A thunderstorm at sea is a lesson in storm genesis on a microscale.

A lightning strike is not comprised of a single arc of current but rather involves a series of leaders arising from the ground or sea surface as well as originating in a cumulonimbus cloud.

LIGHTNING STRIKES AND GROUNDING YOUR VESSEL

If thunderstorms have been spotted on Doppler radar and you are in their path but not yet underway, stay put, go below, and remain clear of the mast and chainplates. If the boat is struck by lightning, check the crew first, and then look in the bilge for any sign of a leak. When lightning strikes, your vessel becomes part of the conductive pathway. The strike ionizes a column of air normally so high in resistance that it's a good insulator. At such extreme voltages, lightning can jump gaps and find its way all around the boat. Providing as direct a pathway to the water as possible seems to lessen damage.

Most cloud-to-cloud and cloud-to-ground (or sea) lightning bolts are massive static electrical discharges caused by the friction associated with air movement in a thunderstorm cell. Oppositely charged particles array themselves on cloud surfaces, and as the charge differential increases, a point is reached at which the insulating property of the intervening air is overcome by the voltage between the charges. A leader, an ionized pathway through the air, bridges the gap, followed by a huge energy transfer over that path linking the two opposite charges.

The American Boat and Yacht Council (ABYC) recommends that all boats have a grounded and bonded electrical system that drains all static charges to a common ground point in contact with the sea. The purpose of this wiring is to make the charge state of the vessel electrically identical to the surrounding sea surface rather than standing out as a statically charged hotspot. As a secondary safety feature, this wiring also helps to guide a direct strike toward the sea, but because lightning can ionize an 8-inch-diameter column of air, it is ridiculous to think that it will be carried safely to ground via 8- or 10-gauge wire. At best, the grounding system may help guide the lightning along a path of least resistance, thus causing less damage.

short-lived due to its fast rate of advance and the relatively short lifespan of most individual cells.

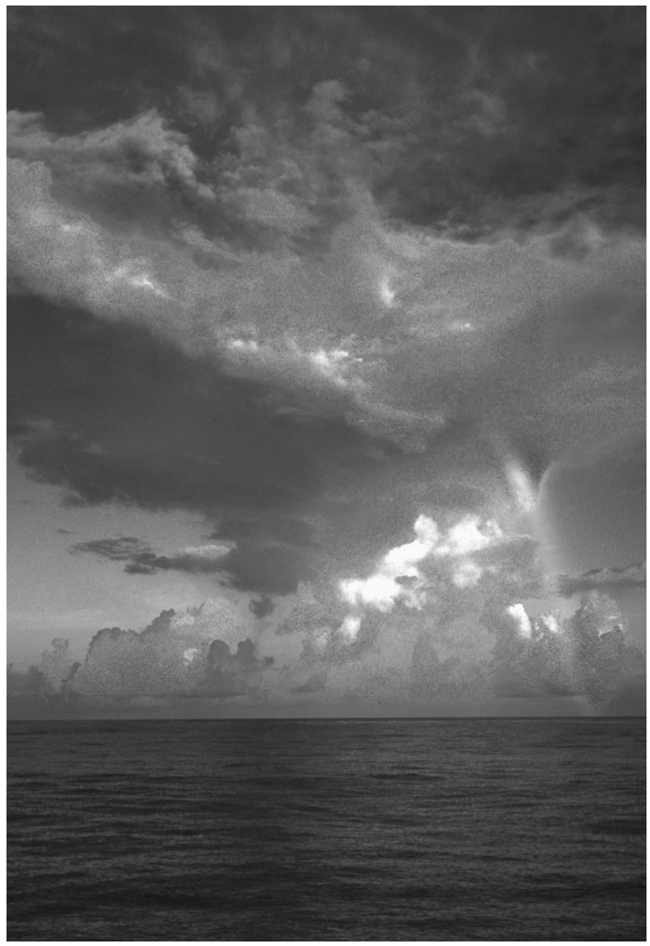
Thunderstorms can also be embedded in warm fronts in the summer and in cold fronts year-round, and they are also a component of troughs (on NWS forecast maps), tropical waves, depressions, storms, and hurricanes. When associated with fronts or systems, thunderstorms can become both more numerous and more violent than an isolated cell developing from local heating of surface air. The cold air/warm air interface along an advancing cold front turbocharges the instability upon which thunderstorms thrive, as the cold wedge bulldozes under the warm, moist air ahead and forces it aloft. A fast-moving cluster of storms is referred to as a line squall and is usually found in the warm sector ahead of the advancing cold front. The involvement of multiple cells can prolong the bad weather.

The presence of a low-pressure trough is another key factor in the development of severe thunderstorms. People often visualize weather in two dimensions, neglecting the profound impacts of rising and descending air regionally (around highs and lows) and locally (in a thunderstorm cell). Near a surface trough of low pressure, which forms beneath a U-shaped dip (toward lower latitudes) in the upper-level jet stream, the instability of the surface air is increased, and thunderstorms are often more volatile. This is especially true when warm, moist Gulf of Mexico air is drawn into the equation and wind shear (directional changes with altitude) exists. This vertical twist can cause a rotational influence, leading to a tornado or waterspout. Although such twisters can also be generated in bands *(continued page 289)*

When the anvil-like cloud tops of a squall line begin to shear off, it's a sign that the cells are past their peak and the vertical heat transfer is starting to break down. Before heaving a sigh of relief and calling friends over for cocktails, make sure no new cells are building up and the squall line is moving away from your location.

WATCHES AND WARNINGS

One of the least understood facets of a marine weather forecast is the difference between a weather watch and a warning. Severe weather watches are issued when conditions are ripe for thunderstorm development. This does not mean that any storms have developed in the watch area; rather, it's a precautionary advisory justifying extra vigilance. When a warning is issued, it means that severe thunderstorms have been sighted in the watch area, and this should be a red flag to those about to leave the dock and a game-plan changer to those already underway.



Hot, humid, calm summer days are ingredients for local thunderstorm development. More often than not these single cells towering toward the stratosphere peter out at about 30,000 feet, making them relatively minor examples of convective activity that nevertheless pack a big punch in the gust-front region. Storms that continue to develop vertically, reaching as high as 50,000 feet, can deliver microburst gusts of 100 knots. Steering clear of such a cell is worth a substantial diversion from your course. Keep in mind that such cells regularly travel at 35 knots, so taking evasive action does not always result in avoidance.

THE CAPSIZE OF *WINGNUTS*

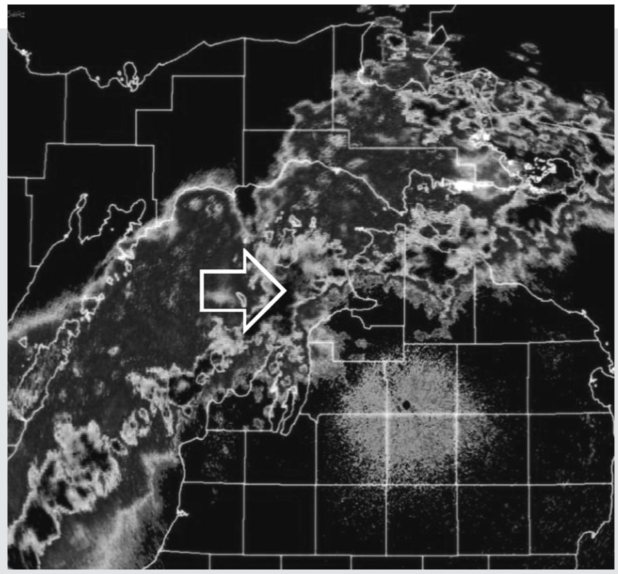
In a thunderstorm in the 2011 Chicago Mackinac Race, the 35-foot sloop *WingNuts* capsized, resulting in the loss of two lives. I was involved in the later analysis of the incident, contributing a weather appendix to the report commissioned by US Sailing. A pair of causal factors rose above the rest: thunderstorm development and vessel design. We'll look at the first now and the latter in Chapter 12.

Localized severe weather was a primary cause of the *WingNuts* capsize at about 11:00 p.m. central daylight time on July 17, 2011. The Independent Review Panel convened by US Sailing noted that the development of thunderstorms in the waters west of Charlevoix, Michigan, generated localized storm-force wind gusts. The squall line was not associated with a low-pressure system or related warm or cold fronts, but formed on a weak surface boundary amidst a very unstable atmosphere.

One of the hardest weather phenomena to forecast a day or more in advance is the severity of the thunderstorms that are likely to track through a given area. On the afternoon of July 17, Doppler radar picked up developing thunderstorm cells over Wisconsin and the Upper Peninsula of Michigan, and forecasters monitored their progress. The forecast for northern Lake Michigan grew worse throughout the day, but the dynamic nature of a thunderstorm's vertical development and the relatively short time interval during which a fully developed cell is at its most destructive made a precise forecast difficult. A severe thunderstorm watch was issued at 7:25 p.m. (about 3½ hours before the capsizing), meaning that conditions were right for wind gusts of gale force and higher to develop. As the cluster of thunderstorms moved over the waters of Lake Michigan, the National Weather Service issued a special marine warning, saying that wind gusts over 35 knots were being recorded and that dangerous cloud-to-water lightning was affecting the area.

WingNuts *under sail. Vessel design was a major factor in her capsize when a fast-moving thunderstorm overtook the fleet of the 2011 Chicago Mackinac Race. Note the wide deck with minimal corresponding hull volume beneath. This design characteristic emphasizes the need for movable crew ballast, rather than buoyancy-induced form stability. The net result is a precipitous drop off in righting moment at angles less than 80 degrees—just when it is needed most. (See Chapter 12 for a fuller discussion of stability and vessel design.) (Courtesy Hubert Cartier)*

It is clear from available NWS data that the duration of the worst weather varied from 10 to 45 minutes for the racing fleet, depending on each vessel's location. The highest gust measured by a calibrated NWS anemometer was 64 knots, and sustained winds of 40 knots or more were reported over a wide area of the Upper Peninsula. According to the meteorologists with whom the Independent Review Panel spoke, a bow echo (a Doppler radar image in the shape of an archer's bow, associated with a line of convective thunderstorms) containing a supercell thunderstorm (the most severe type, characterized by a rotating updraft and often called a rotating thunderstorm) developed west of Charlevoix and likely resulted in a downburst with wind gusts of 70 knots. The cell passed close to the recorded position of *WingNuts* at the time of the capsizing. Wind direction depended upon where a vessel happened to be located in relation to a specific cell, but the general trend was a breeze veering from southwest to northwest. The cells were moving at 30 knots, and not long after midnight the system had exited the region. Severe though it was, this weather event was hardly unusual for this region or, for that matter, for many locations up and down the East Coast and across the Gulf of Mexico.



This Doppler radar image from the time of WingNuts' *capsizing shows a line of thunderstorms moving across northern Lake Michigan. The arrow shows* WingNuts' *location in the heart of a severe thunderstorm cell. The worst of these supercells approached 60,000 feet in height—with that much vertical development the downbursts were of storm- to hurricane-force. (Courtesy National Weather Service)*

of severe thunderstorms, they are more likely to be generated by isolated cells than by bunched cells in a densely packed line squall. A tornado that moves over water becomes a waterspout, and these can cause significant damage to vessels, though such incidents are infrequent. Course changes to avoid these often slow-moving spouts make sense, as does carefully tracking them on radar. Small-craft radar operating on the X-band do a great job of picking up the large water droplets associated with squalls, waterspouts, and thunderstorm cells, not only warning of their presence but also indicating their direction of movement.

An AM radio is a good way to know lightning may be coming, as it picks up the static caused by lightning discharges, with more static indicating a more severe storm. An inexpensive battery-powered portable radio can thus provide an early warning and is a useful piece of safety gear on board. When the underside of towering cumulonimbus clouds take on a rolling, lumpy, or fragmented appearance, sometimes with a visible green tinge, you are in the presence of cumulonimbus mammatus, another strong indicator of an imminent storm that will likely include hail. You may see a descending shelf cloud on a cell's leading edge, and yet another sure sign of an impending gust front is a wisp of noticeably colder air on a hot, sultry day.

Thunderstorm Seamanship

Avoiding a severe thunderstorm is always the best option, but being caught in shoal water or in a nasty inlet while attempting to get to safe shelter can be far worse than encountering the same conditions with sufficient sea room to keep free of collisions or running aground. Attempting to outrace a squall line with a mad dash toward the harbor is a gamble. It may make better sense to head for a part of the bay with less traffic, fewer obstacles, and a fair distance from the nearest hungry lee shore.

Know how fast you and your crew can react. If a blistering hot summer day is already punctuated by cold wisps or gusts, you've probably already waited too long to get rid of the genoa and prepare to reef or strike the mainsail. Prudent sailors often douse the mainsail and let the tempest pass while reaching along with a scrap of unfurled jib, a storm jib, or engine power and bare poles. Powerboaters may power slowly into the wind and developing seas or run before the wind under such conditions. Faster vessels may be able to avoid the worst of these severe thunderstorms by taking evasive action. Short-lived winds in excess of 50 knots can push a moderate-displacement vessel at 6 knots with no sail set. If the seas are flat at the onset of a line squall or an encounter with a single cell, there's little time for seas to build, so the sole threat is the wind itself.

When a cold-air warning bell catches you at anchor, it's time to add more scope and get ready to cope with storm-force gusts. If the lunch hook is down, big problems await, especially if a heavier anchor isn't ready to be released from its bow roller. Running the diesel and shifting into forward during the gusts can take some of the load off the ground tackle. A dive mask (or ski goggles) for the helmsperson may be needed when a gust front or microburst rolls into view.

Along the U.S. East Coast, most of the vigor of these thunderstorms dissipates before they move offshore, but they can be quite intense right along the coast. Typically they won't spin back up until the moist air reaches the thermal boundary along the north wall of the Gulf Stream.

Air-mass thunderstorms are hot air events, not obviously a time to be reminded about hypothermia, but cold fronts can often be punctuated with violent convective activity and the air behind this band of thunderstorms is often much colder. Dressing for the deluge involves foul-weather gear with good seals at the neck and wrists, boots to keep the socks dry, and perhaps a wide-brimmed hat.The post cold-front chill is best warded off with a dry watch cap and gloves. Remaining damp as temperatures drop and the cold dry nor'westerly wind takes hold instigates hypothermia—preventing it from getting a foothold through layering and opting for moisture wicking layers is much easier than trying to warm up after the fact.

Fog

Fog is caused by a stratus cloud formation on the sea or land surface. West Coast and New England boaters have plenty of fog, with its obvious implications for navigation and collision avoidance. Many offshore sailors are surprised to discover that fog doesn't only occur with a calm sea or calm wind. On both U.S. coasts, fog can coincide with winds of 25 knots or greater and significant seas, making watchkeeping even more challenging.

Fog genesis involves an air temperature and dew point that are within 4ºF of each other; water vapor coalesces around tiny dust or salt particles. Fog becomes mist when the dew point is very close to the temperature, affording even lower visibility than fog. The Grand Banks off of the New England Coast has earned the title of the foggiest locale on the planet. California's advection fog is also known for its tenacity and unwillingness to yield, even during warmer summer months.

Radiation fog occurs more often inland and in coastal areas where diurnal cooling (day to night temperature changes) are more extreme. Fall is a classic time for such cooling, and as the air temperature drops during the night and approaches the dew point, fog develops. When this occurs on a bay or in coastal waters, it's often called sea smoke.

Advection fog involves warm and relatively dry air masses moving over cold water. As the air temperature approaches the dew point, fog forms and can become so dense that even a 25-knot breeze will not disperse the surface cloud. Contributing factors such as warm and cold currents meeting exacerbate the situation. Extreme examples include the Labrador Current's confrontation with the Gulf Stream and the collision of the Benguela Current with the Agulhas Current at the tip of South Africa.

New Zealand, Argentina, and Chile, as well as the Arctic and Antarctic waters, all have regions where maritime fog banks are a persistent challenge. Interestingly, breaking waves in an active surf zone put more salt into the air, and these minute hygroscopic particles attract water vapor that thickens the fog in an area that's most threatening to a sailor.

Upper Atmosphere Troughs and Ridges

Thus far we have focused mostly on surface analysis and how surface features impact the world of the mariner. Once the surface maps and their related wind and wave imagery have become familiar friends, it's time to look aloft and see what's happening where the average barometric reading is 500 millibars. This is an active part of the atmosphere, where north-folded ridges of high pressure and south-folded troughs of low pressure move westerly across North America under the influence of a band of high-speed winds traveling west to east. These midlevel steering winds are, in effect, the linkage between the overlying jet stream and the underlying surface air masses. As mentioned earlier, directional changes in these midlevel winds are what fold a straight-line frontal boundary into a classic surface low, and the north-south depth of a midlevel short-wave trough exercises great influence over how violent a surface storm will become and where it will go.

500 Millibar Charts

To better understand what's going on in the mid-level atmosphere, meteorologists map the atmosphere with isoheights, or curves of equal altitude—essen-

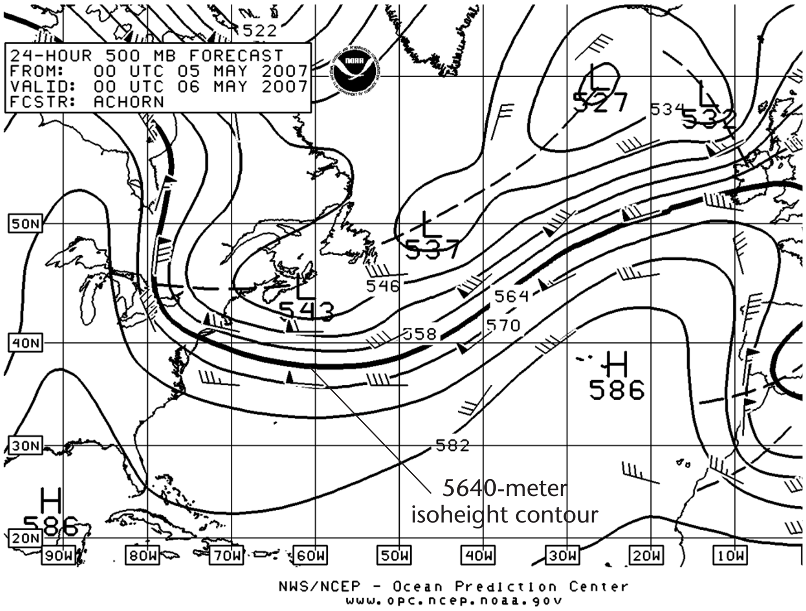
Advection fog, a dominant feature of West Coast boating, is caused by the cold California Current flowing south down the coast. (This cold flow is the descending portion of the Pacific gyre fed by Japan's Kuroshio and Oyashio merging currents.) The prevailing westerlies arrive on the coastline cool and dense after blowing over this cold water, keeping warm desert air from moving offshore.

tially the mirror image of the contours of equal depth shown on nautical charts. Meteorologists sample the atmosphere with weather balloons equipped with sensors that transmit pressure, temperature, altitude, wind speed and direction, and other data to receiving stations—and use these data to make what amounts to an atmospheric topographic map (see the sidebar Unlocking the Mystery of the 500 mb Chart). Tighter gradients mean stronger winds—just as with the isobars on surface maps—but the streamlines or flow directions of these midlevel winds more closely follow their contour lines.

The flow is called zonal when these streamlines move west to east, and if the flow is not strong, bad weather on the surface is reduced. Winds of 100 knots or more do occur in zonal 500 mb flows, however, and when they do, hurricane-force surface lows—called right-movers by meteorologists—can result. More commonly, though, pronounced upper-level troughs in the 500 mb charts—dipping deep to the south—cause surface lows to develop and intensify. These upper-level troughs often appear as a rather innocuous dashed line on surface analysis and forecast maps; lacking the shark's teeth-like jagged triangles of a cold front notation, the symbol seems rather benign. But a steep isoheight gradient aloft associated with a deep-dipping trough intensifies a surface low and can turn run-of-the-mill bad weather into a gale-, storm-, or hurricane-force low. See the sidebar for rules of thumb for using the 500 mb chart as a weather routing tool.

One look at the map shows that the regions north of 40 degrees north have a justified reputation for bad weather. Adventure sailors seeking record-breaking east-to-west transatlantic runs often try to place themselves smack in the middle of this heavy-weather superhighway to harness the nor'easters spawned there. Those headed in the other direction attempt to stay below the lows, looking for the southerlies in the warm-core segment between the warm and cold fronts. The high pressure that follows the cold front delivers a favorable westerly breeze, dries out the crew, and allows spinnakers to fly. But most crews know to head more northerly to avoid being caught in the windless center of these systems.

The upper-level flow shown on a 500 mb chart also features ascending (north-curving) loops that form ridges, and these are associated with surface high-pressure cells and fair, tranquil weather. Ridges develop between troughs in a 500 mb chart, and troughs develop between ridges. Such meanders in the flow move eastward in two separate wave patterns, featuring long- and short-wave troughs. Long-wave troughs have a lot to do with seasonal pattern changes (and sometimes with El Niño or La Niña climate cycles). Short-wave troughs move faster and are

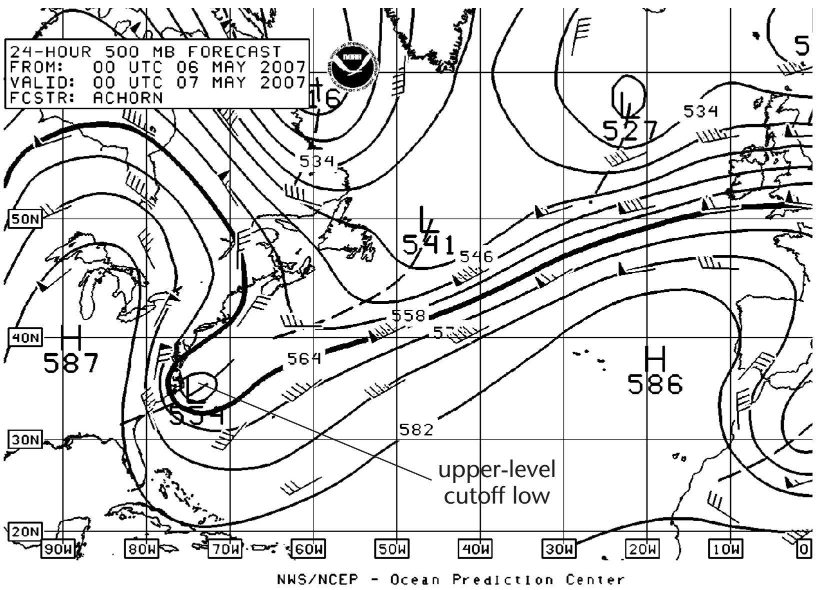


On this 500 mb 24-hour forecast chart the streamlines and wind arrow are exiting the U.S. East Coast in a zonal flow trending west to east, and the midlevel winds are moderate. This chart was issued at 7 p.m. on May 4, 2007. In less than a day a trough will develop, and the map below shows how abrupt a change takes place.

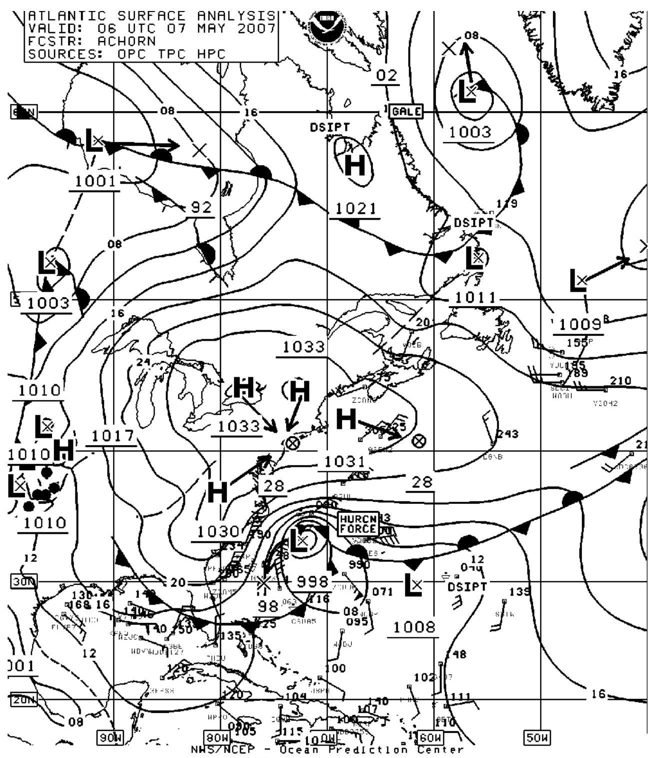
prime instigators of surface weather, directly influencing system formation, movement, intensification, and decay. When long-wave and short-wave troughs get in phase and their wave amplitudes become resonant, the tight band of the midlevel high-speed wind belt is intensified. This condition can give rise to the most violent surface lows, sometimes referred to as meteorological bombs.

Between upper-level short-wave troughs lie upper-level ridges, and the associated dynamics of the atmosphere's midlevel winds are impacted by these north-south twists and turns. Stronger winds occur in the hard bend just east of a deep trough because the left-hand turn about the axis of the trough is enhanced by the Coriolis effect and the energy derived from our spinning planet. Thus, when a surface low lies just a little east of an upper-level trough axis, it will be significantly intensified by its interplay with the trough, which enhances the vertical convection of surface air and resultant instability.

A *cutoff low*, another unwelcome weather development, occurs when an upper-level trough pinches off near its southern extremity *(continued page 294)*



This 500 mb 24-hour forecast chart (above) was issued a day after the one shown at top. In the intervening 24 hours, the zonal flow over the U.S. East Coast has been replaced by a deep-diving upper-level trough, which has been pinched off to form a cutoff low high above Cape Hatteras. When this happens, a developing surface storm quickly begins to intensify. Some 32 hours after this chart was issued, subtropical storm Andrea overwhelmed the 54-foot sailboat Flying Colours, *whose story is told at the end of this chapter. Comparing this chart with the surface analysis (next chart), revealing the actual weather that evolved, we can see that it is already too late to be seeking shelter. Some private weather routers saw this cutoff low developing in the 500 mb chart shown 24 hours earlier and started warning their clients.*



The surface level analysis showing the low that Flying Colours *encountered (see page 314). Note the hurricane-force wind warning, a feature confirmed by local buoy reports.*

UNLOCKING THE MYSTERY OF THE 500 MB CHART

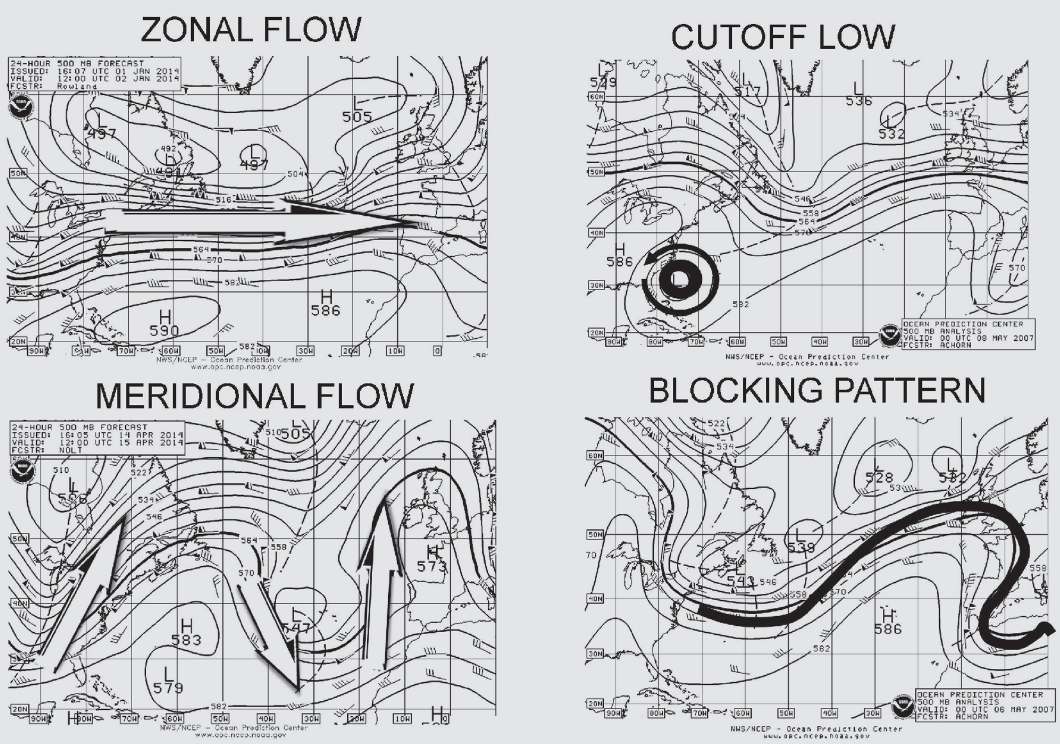
Lee Chesneau

Safe and prudent navigation decision making at sea begins with a fundamental understanding that weather is a dynamic three-dimensional process. The 500 mb atmospheric pressure level is about halfway up the atmosphere at roughly 18,000 feet (5,487 meters), and the air flow at this altitude can be considered as the basement layer of the jet stream. The jet stream core is higher, between 300 (polar jet stream) and 200 (subtropical jet stream) mb, but both jet streams are mirrored at 500 mb, especially in the winter months, and the impact of 500 mb dynamics on surface weather is quite significant.

A 500 mb chart is simply a map of the elevation contours in a surface of constant pressure. These elevation lines reflect the north-to-south temperature differences of their underlying air masses. A 5,400-meter-tall column of cold high-latitude air and a 5,700-meter-tall column of warm low-latitude air may weigh the same, both exerting 500 mb of pressure on the underlying sea surface. The elevation lines are called isoheights and are drawn at intervals of 60 meters. Winds of 30 knots or more are displayed between the isoheight contours on Ocean Prediction Center (OPC) 500 mb charts at intervals of 5 degrees of latitude and 10 degrees of longitude. These symbols are displayed as if the winds were horizontal, when in actuality their stronger component is vertical, especially when the isoheight gradient is steep (i.e., the isoheights are close together). A horizontal display makes it easier to locate strong wind belts or corridors aloft and thus to determine the location and track of a surface storm and its breadth across the ocean surface. This enables a navigator to plot a route that will avoid the heaviest winds and seas.

In this way, 500 mb charts provide important information about how the major synoptic-scale surface-weather systems (i.e., the everyday low- and high-pressure areas seen on surface maps) will form, move, and weaken or dissipate. Providing a macro picture of the wind energy aloft, its orientation, where the resultant worst surface conditions will be, and what changes to expect as much as 120 hours into the future, 500 mb charts comprise an important tool for weather forecasting and routing decisions.

Rules of thumb have developed *(continued next page)*



Characteristic flow patterns on 500 mb charts. Counterclockwise from top left: west to east zonal flow; north to south meridional flow; a blocking pattern and a cutoff low. The blocking pattern, a classic Omega block in the midlevel of the atmosphere, initiates a flow pattern that looks like the Greek letter Ω. Its main significance to surface weather is the way in which it impedes the movement of surface systems, resulting in high and low pressure cells making little westward progress. A midlevel cutoff low can enhance the volatility of a nearby surface low.

UNLOCKING THE MYSTERY OF THE 500 MB CHART, CONTINUED

from decades of observation and practice, beginning in the 1950s when commercial weather routing services were established. These rules are built around the following recognizable flow patterns in the embedded upper-level short-wave troughs and ridges: west-to-east zonal flow, north-to-south meridional flow, blocking ridge patterns (which deflect wind energy and storms north and south), and cutoff lows (which are at lower latitudes than blocking ridges—say 25 to 40 degrees latitude—and move little over days to a week or more). There may be more than one flow pattern overlying any given ocean basin at a given time.

A primary rule of thumb is that surface storms will track parallel with the isoheight contours above and will blow at one-third to one-half of the 500 mb wind speeds in a corridor ranging from 300 to 600 nautical miles poleward of the 5640-meter isoheight contour, which is always highlighted in bold on a 500 mb chart. The 5640 contour therefore reflects the southern extent of Beaufort Force 6/7 westerlies in summer and Force 7/8 westerlies in winter. As used here, the term "westerlies" indicates that the only part of the storm track impacting the 5640 isoheight will be the cold front that usually extends north-south across latitude lines, producing a wind shift from southwest, to west, to northwest as it passes. The strongest winds (gale-, storm-, and hurricane-force) and heaviest seas are very likely to be north of the 5640 isoheight line in the Northern Hemisphere. (Captain Ma Li Chen, who with me coauthored the book *Heavy Weather Avoidance,* uses the more conservative 5700-meter contour rather than the 5640-meter contour to define the poleward edge of the "available zone" within which vessels can safely navigate.)

A second rule of thumb is that up to 50% of the 500 mb wind speeds behind a short-wave trough (i.e., to the west of the trough in the colder air) can be expected to translate to the sea surface. If you see 80 knots on the 500 mb chart, prepare for 40 knots on the sea in the west-to-southwest quadrant of a Northern Hemisphere middle-latitude extratropical cyclone, where the tightest pressure gradients and the strongest winds and heaviest sea states are located.

Lee Chesneau is a marine meteorologist who for years signed many of the Ocean Prediction Center's weather fax charts that scrolled out of printers aboard sailboats, powerboats, and commercial ships. On one particularly lumpy transatlantic, Chesneau charts won our crew's "Gifted Meteorologist" award for nailing the intensity and duration of the gales and storm that stalked our route. In later years, I worked with Lee at sailing seminars, and he proved as gifted at teaching weather awareness as he was at divining where the nasty lows were headed. He holds the view that every sailor benefits from understanding what lies ahead.

(in the Northern Hemisphere), and the short wave that spawned it separates, shifts north, and moves on to the east, leaving the pinched-off low behind. To understand the dynamics of a cutoff low, one must think in three-dimensional terms. Like uneven ground, the atmosphere arranges itself in mounds of air with valleys between, as depicted in upper-level (500 mb) charts. The cutoff low can remain nearly stationary, and a trough of low pressure on the surface will be turbocharged by this reluctant-to-move upper-level low. In the mid-Atlantic region of the United States, surface lows often form on these trough boundaries and move eastward over coastal waters, intensifying as they reach the warmer north wall of the Gulf Stream. This pesky, slow-moving weather feature can spawn a week's worth of bad weather. During some summers, the effect sets up over the Great Lakes and extends a surface trough along a line from 30 to 40 degrees north about halfway to Bermuda, creating a gray, lumpy sea passage all the way to or from the island.

Sailors in the Northern Hemisphere seeking kinder, less gale-ridden adventures know that when they see a deep hitch in the 500 mb chart, setting up a trough over the East Coast, it's best to find a safe haven or be ready for a dose of heavy weather. When this happens in the early spring or late fall, low-pressure systems developing off Cape Hatteras or elsewhere along the East Coast mix cold continental air with the warm, moist air over the Gulf Stream, turbocharging an already eruptive atmosphere. Phrases such as "rapidly intensifying low" and "developing storm" are often associated with such preconditions.

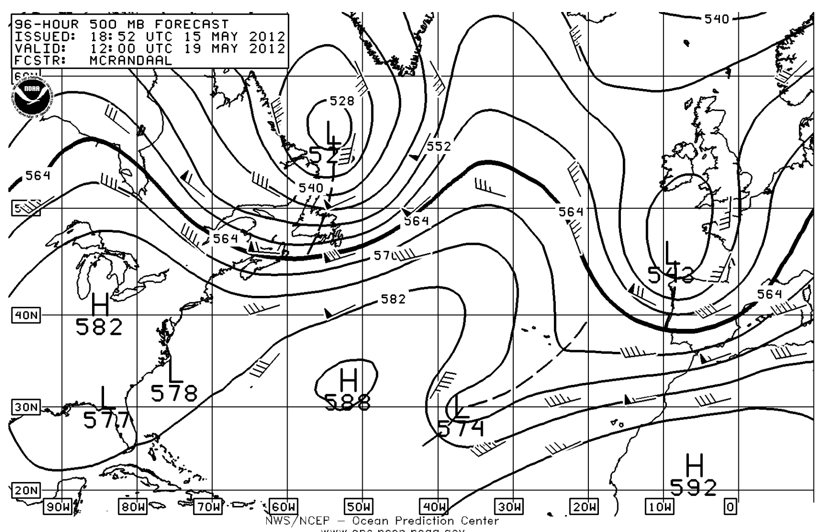
Tropical Weather Patterns

One of the best bits of weather news for those headed for trade-wind latitudes is the farewell they can bid to the unending march of cold fronts and baroclinic lows across the temperate regions of the globe. The tropics are dominated by easterly trade-wind belts. As mentioned earlier in this chapter, the northeasterly trades of the Northern Hemisphere and the southeasterly trades of the Southern Hemisphere are separated by the Intertropical Convergence Zone (ITCZ) and are bounded on their higher-latitude edges by

Persistent squally weather, as seen here, can last for several days. As the trough or cutoff low strengthens and an interacting surface low deepens, the wind increases, turning calm seas into gale-force conditions. An upper-level cutoff low behaves like its creator, the upper-level trough; both are linked to unsettled weather. Surface low-pressure systems often develop on an upper-level trough and move in a northeasterly direction in the Northern Hemisphere. This weather pattern can set up and remain stalled over coastal waters for days, often linked with an upper-level atmospheric phenomenon known as an Omega block*—a ridge bounded by two upper-level lows near its base that create the shape of the Greek letter omega: Ω.*

the semipermanent subtropical high-pressure belts known as the horse latitudes, where upper-level air subsides and spreads equatorward to feed the trade winds and poleward to feed the temperate-latitude westerlies. The ITCZ is a band of low-pressure troughs (the doldrums) extending around the globe near the equator where the convective rising of heated equatorial air produces widespread showers, thunderstorms, and frequent lightning.

The aptly named easterly trades act like a conveyor belt across the oceans. In the Northern Hemisphere they fill in around Christmas and remain steady in direction (though not in velocity) for months at a time. Atypical conditions caused by El Niño and La Niña events can alter the pattern, resulting in a cessation of the easterlies in one area and a strengthening in another. These climatic perturbations can also change the dynamics of the flip side of tropical paradise. Summer in the trade-wind belt brings a lessening of the prevailing easterly, a decrease in wind shear, and sea surface temperatures of 80°F or higher to depths of 150 to 200 feet. These hot, humid conditions, a thunderstorm-ridden atmosphere, a lack of wind shear aloft, and a maritime

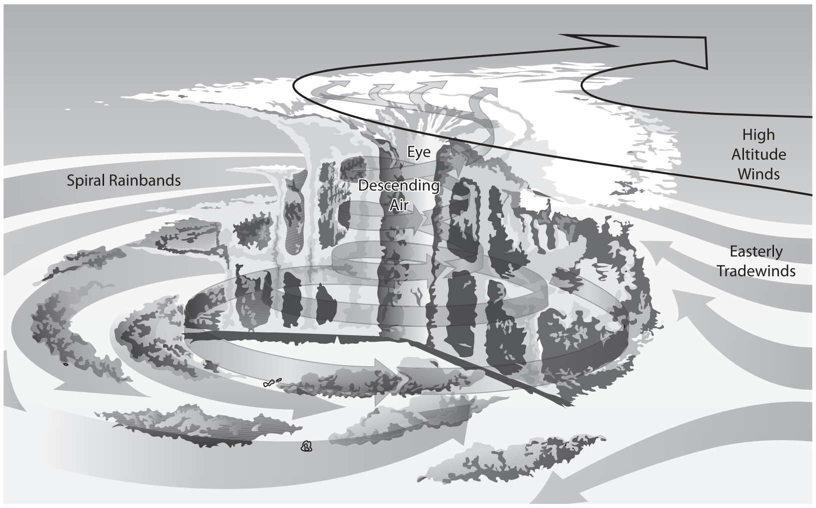


This 96-hour 500 mb forecast from May 2012 shows the development of an upper-level ridge in the mid-Atlantic, with isoheight lines warped from a west-to-east zonal flow into a more meridional configuration with north- and south-flowing legs. We can expect an Omega block to develop in the midlevel atmosphere, slowing the progress of surface weather systems and tending to move bad weather into higher latitudes.

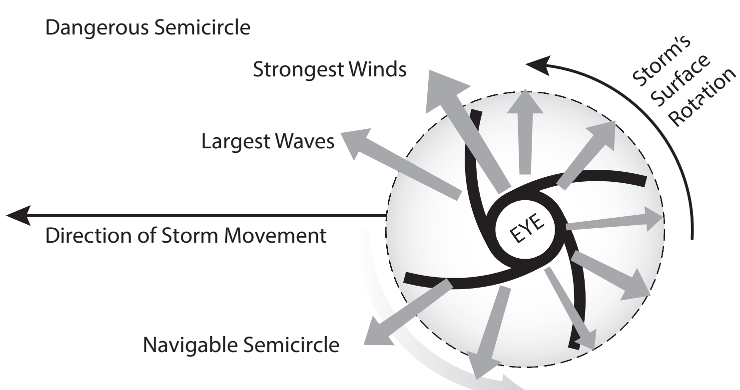
heat source are the required conditions for tropical storm development.

Tropical Cyclone Genesis

Tropical waves can be thought of as upper-level disturbances that cause an increase in thunderstorm activity at the surface and more often than not are linked to the creation of tropical depressions, the fledgling phase of a hurricane. These swirling masses of low pressure have a warm-air core and are not associated with a front—unlike extratropical lows. Like extratropical lows, however, they rotate counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. Called typhoons, cyclones, and hurricanes in different parts of the world, their effects are felt in every trade-wind region except the South Atlantic, which is *almost* completely hurricane-free. (Note the emphasis on "almost;" in March 2004, cyclone Catarina proved that, contrary to the prevailing assumption, even the tropical South Atlantic is not immune.)



Like a giant vortex in the atmosphere, a tropical storm reaches upward to the tropopause, establishing an eye wall and a central region of extremely low pressure and calm wind. In the Northern Hemisphere, the highest wind gusts in the cyclonic (counterclockwise) flow are usually found just outside the eye wall on the right-hand (northeasterly) side of the advancing storm, where the speed of advance is added to the embedded wind speed. In the Southern Hemisphere the flow is clockwise, and the strongest winds are found on the left-hand (southwesterly) side of the advancing storm.



Waves generated by a hurricane rush out in all directions, organizing into deep ocean swells that move much faster than the storm itself. When a hurricane speeds up, its forward progress reinforces the waves moving ahead of it along the storm track, creating much larger seas in that direction.

Anatomy of a Tropical Storm or Hurricane

As mentioned earlier, hurricanes are really thermal-transport mechanisms that transfer poleward heat energy generated in the tropics. Although a complete understanding of these devastating weather events still lies well down the road, meteorologists have a good idea about what must be present for tropical cyclone formation to take place. A handful of key criteria can be directly linked to summer conditions in the hemisphere.

The stage is set for tropical storm formation when the water temperature is above 80°F to a depth of 150 to 200 feet. An unstable atmosphere with high humidity also needs to be in place, as occurs during the summer months in the tropics more than anywhere else in the world. Low wind shear is another vital ingredient, because the vertical development that establishes the water vapor condensation heat engine can be torn apart by winds that vary in direction as altitude increases. Strong west winds aloft stifle tropical storm development much as rain stifles a forest fire.

Tropical storm development also requires a preexisting weather disturbance in the form of a band of thunderstorms or an upper-level tropical wave, the latter being linked to most tropical storm development in the Atlantic, while ITCZ thunderstorms are the primary causal agent in the Pacific and Indian oceans. Another fascinating needed ingredient is at least 4 or 5 degrees of latitude for the rotation to begin. The Coriolis effect is zero at the equator, but just a few degrees north or south, the effect of the earth's rotation is strong enough to spin convective activity first into a tropical depression and eventually, if conditions continue to favor, into a tropical storm and finally the infamous eye of a hurricane.

Winds increase as the barometric pressure of a warm-core storm drops. The stages of development are defined by the Saffir-Simpson Hurricane Wind Scale shown in the accompanying table (see the sidebar Tropical Storm and Hurricane Development).

The concentric nature of hurricanes and tropical storms derives from a series of spiral bands wrapped around a central core or eye wall. The heaviest weather and highest wind velocities are found along the perimeter of this cylindrical inner eye wall, the diameter of which can range from 2 to over 100 miles. Eye wall regeneration occurs in stronger hurricanes, sometimes multiple times. What takes place is a significant but short-term abatement of the high winds and convectivity in the eye wall that can be clearly noted in the storm's radar signature. Barometric pressure remains the same or continues to drop and a new, more intense, eye wall develops. Between the concentrically wrapped spiral bands lie gaps of lower wind and less violent convective activity, and in the eye itself are found calm wind, bright sunlight, and clear sky, a result of the massive central downdraft of dry air pumped down by the heat engine effect of the storm. In essence, the very center of the storm is a chimney in reverse.

MOST INTENSE ATLANTIC HURRICANES, BY PRESSURE (NOT PROPERTY DAMAGE)

Rank	Hurricane Name	Year	Pressure (hPa; note 1 hPa = 1 mb)
1	Wilma	2005	882
2	Gilbert	1988	888
3	"Labor Day"	1935	892
4	Rita	2005	895
5	Allen	1980	899
6	Katrina	2005	902
7 (tie)	Camille	1969	905
	Mitch	1998	905
	Dean	2007	905

(Courtesy Hurdat)

TROPICAL STORM AND HURRICANE DEVELOPMENT

Tropical storms can go through four phases of development that are linked to pressure minimums and wind intensities. The diameter of the storm and the area it covers are not as closely associated with storm intensity as one might suppose. Andrew, the brutal Category 5 hurricane that struck south Florida in 1992, had a relatively small footprint, while Gilbert, a Category 4 hurricane upon landfall (Category 5 earlier), impacted a much larger area. The four phases of development are:

- **Tropical disturbance**—an organized cluster of showers and thunderstorms over tropical or subtropical waters.
- **Tropical depression**—a counterclockwise (Northern Hemisphere) closed rotation around a defined low-pressure area with sustained winds less than 34 knots. This weather event is given a number but not a name.
- **Tropical storm**—when a tropical depression increases to maximum sustained surface winds of 34 to 63 knots, it becomes a named storm.
- **Hurricane**—when the wind speeds in a tropical storm intensify to 64 knots or more and the convection becomes better organized with a well-defined eye, the storm becomes a hurricane.

THE SAFFIR-SIMPSON HURRICANE WIND SCALE

Category	Mean Central Pressure (millibars)	Wind Speed	Surge (feet)	Damage	Example
1	980 or more	68–82 kts 119–151 km/h	4–5	Minimal	Agnes 1972
2	965–979	83–95 kts 152–176 km/h	6–8	Moderate	Kate 1965
3	945–964	96–112 kts 177–209 km/h	9–12	Extensive	Elena 1985
4	920–944	113–136 kts 210–248 km/h	13–18	Extreme	Hugo 1989
5	less than 920	> 136 kts > 248 km/h	> 18	Catastrophic	Gilbert 1988

Commercial mariners know the value of a good, carefully calibrated aneroid barometer like this one. Pressure readings provide information regarding the passage of lows—it is the trend, or rate of change, that best predicts wind velocity. Many sailors have added an electronic barometer/barograph that is able to profile the rate of change.

HURRICANE/TROPICAL STORM SEAMANSHIP

When it comes to the threat posed by a hurricane or its little siblings, tropical storms and depressions, the central pressure is an important measuring stick but not the only one. Barometric pressure and wind velocity are indeed directly correlated, and the tighter the gradient, the stronger the wind blows. The size of the storm, its speed of advance, and its fetch and directionality matter as much to a mariner, however.

Tropical storm avoidance depends upon understanding the timing and geographic extent of hurricane season and closely tracking weather developments during the season. Staying out of the tropics during the height of the hurricane season has always been and continues to be the mariner's best bet, but some sailors today, relying on satellite storm tracking and better long-range forecasting, venture into waters visited by hurricanes using some form of weather routing. It may be unwise, but it's not uncommon to see vessels sailing across the Atlantic from Africa and up to the northeastern U.S. during hurricane season (roughly June to November).

Hurricanes behave something like big jellyfish

LA NIÑA AND EL NIÑO

The children, as these two weather events are called, aren't as exact in their arrival and departure as the seasons. These events, referred to as the Southern Oscillation by scientists, involve atmospheric and oceanic factors that are not yet completely understood. Thanks to satellites and data buoys, however, we know more than we did just a few years ago.

El Niño arrives with a subsidence in the Pacific's easterly trade winds and a redistribution of rainfall across the Pacific. There is a cessation of the upwelling of nutrient-rich water along the west coasts of North and South America—a critical loss for the marine food chain in those regions—and warm water invades the western Pacific, causing fish stocks to crash. The phenomenon has been recognized ever since farmers and anchovy fishermen from California to Chile noted that once in about every 10 years their lives and livelihoods were significantly threatened. More recently, the cold cycle La Niña, the flip side of these El Niño events, has come under scrutiny.

These two faces of a climate cycle affect where low-pressure centers track and are associated with a long-term shift in sea surface temperature and midlevel wind patterns. A few general trends are important to mariners. For example, during La Niña events, massive amounts of warm, moist Gulf of Mexico air are advected into low-pressure systems over the United States, causing an increase in the severity of thunderstorms and lows that develop along the East Coast. There is often a split in the jet stream, and the lower, subtropical portion can dip all the way down to the Gulf and then snake its way northward just off the East Coast. The warm moist air it ushers up toward cold-core lows can turn such storms into what forecasters call a "bomb." With the Gulf Stream further instigating this eruptive cyclogenesis, there's good reason for sailors to have deep respect for Cape Hatteras. These conditions can last for over a year. El Niño conditions, on the other hand, warm up the eastern portion of the Pacific and move tropical cyclone activity farther eastward. They clamp a lid on the conveyor-like reliability of the Pacific trade winds and place those hiding from tropical cyclones in the eastern Pacific more at risk. Such major climate shifts impact passage planning and up the ante for long-distance cruisers attempting to avoid heavy weather. "Safety valve" passagemaking, comprised of shorter hops between all-weather anchorages, can be a viable option during periods of increased volatility.

VOYAGE PLANNING BASED ON CLIMATE AND WEATHER CYCLES

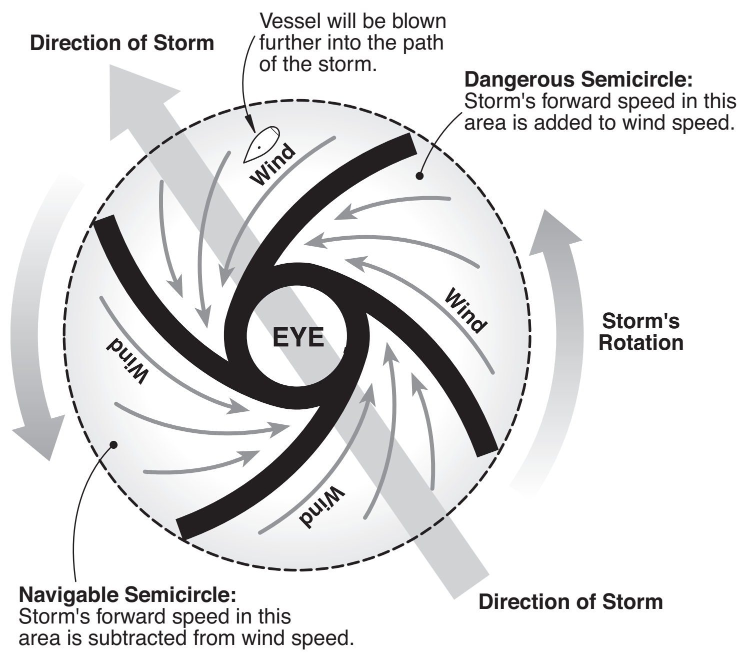
During my family's westabout voyage around the world, we handled ocean-to-ocean passage planning in a finish-to-start process. Arrival dates at landfalls were planned before the onset of the hurricane or cyclone season in that part of the world, and from there we worked back to our starting point to set departure dates that would allow us ample time to make trade-wind transits avoiding hurricane seasons. For our passage across the Indian Ocean from Darwin, Australia, we set up a timetable that would get us into Durban, South Africa, in early November, which marked the onset of the summer cyclone season in the south tropical Indian Ocean. Each stop we made along the way was governed by a timeline that held us to that arrival date.

Then the rudder failed 300 miles from the island of Mauritius, and we made landfall in the independent island republic under jury-rigged steering. Extracting the rudder with the boat in the water was easy, but rebuilding the rudder with little material available was a lot harder. Long days, a few engineering shortcuts, and a local shipyard's willingness to do some welding solved the problem and let us keep on schedule. The sprint around Madagascar to Durban took us through a storm-tossed Southern Ocean, but we were not yet into the cyclone season. The same good fortune did not hold for the crew of the Cal 34 *Drambuie*—whom we met in Chapter 2—a small sloop a month behind us, who chose to chance a cyclone-season passage through the western Indian Ocean. Their last radio message spoke of mountainous seas and knockdowns. At the time they were 400 miles from the center of cyclone Claudette, a storm that would eventually cross their track. Friends waited for them at the dock in Durban, but *Drambuie* never made landfall.

in the atmosphere, except that they are steered by upper-level winds rather than sea currents. The direction they take is determined by the trade winds in the tropics and weather systems in the temperate zones, and forecasters have gotten good at predicting and computer-modeling their tracks. Even so, gambling on your ability to route your boat away from a developing storm can make Vegas odds look good.

The wind field around a tropical storm or hurricane is unbalanced because of the storm's own speed of advance, which lessens the wind velocity on one side of the storm and increases it on the other. Add to this the snowplow effect of storm-generated seas, and it's easy to understand why the right-hand forward quadrant of a Northern Hemisphere tropical storm or hurricane is the most dangerous. If the counterclockwise circulation (Northern Hemisphere) generates wind speeds of 50 knots and the storm is moving westward at 25 knots, a vessel caught in the forward right-hand quadrant of the storm would experience winds close to 75 knots and the largest seas associated with the system. Furthermore, if the boat sets a drogue and runs off before the wind (see Chapter 13), it will be drawn deeper into the heart of the advancing storm in this quadrant. On the other hand, a vessel in the left-hand rear quadrant will find the wind closer to 25 or 30 knots and the seas less dangerous. This is why one of the mariner's golden rules in the Northern Hemisphere is never to sail into the right-hand semicircle of a tropical weather system.

Things get dicey when a storm reaches the western basin of the North Atlantic and in many cases become "extratropical," or what the National Hurri-



In the dangerous semicircle of a tropical storm or hurricane, wind strengths are enhanced by the storm system's speed of advance. A 70-knot wind blowing from the south in a northern-hemisphere hurricane moving northward at 20 knots will feel like 90 knots to any boat unfortunate enough to experience it. Where the rotational wind is blowing from the north in the hurricane's navigable semicircle ("navigable" being a relative term here), the effective wind strength will be 50 knots. What makes the leading quadrant in the dangerous semicircle even more dangerous is that a vessel running before the onslaught in that quadrant is actually heading into the heart of the storm.

cane Center now calls "post-tropical." During such a change, the intense hurricane wind speed seen only at the eye wall lessens, but as the warm core characteristic of the storm dissipates, warm and cold fronts develop and a cold core transition takes place. The result is a much larger diameter storm with high wind readings over a wider area. These transitioned cold core storms can cause horrific damage ashore and at sea—post-tropical storm Sandy was a classic example of such a transition. This in no way is equivalent to falling apart. In fact, many a weak tropical storm has become turbocharged while losing its warm core, and has subsequently spread out, picked up fronts, and gone on to shred the maritime interests of temperate latitudes.

WEATHER PREDICTIONS

The first half of this chapter has only summarized some of the key factors and variables that influence weather. Meteorologists study these plus additional factors, employing sophisticated computer modeling to arrive at forecasts issued to mariners and the public. But it's important still for sailors to understand these basic causes of weather—and to understand that forecasts at best are only more and more accurate estimates of the weather that may actually arrive. Still, government and private forecast services play an important role in safe voyaging.

Government Forecasts

The Ocean Prediction Center (OPC) is a branch of the U.S. National Weather Service (NWS), an agency under the administrative control of the National Oceanic and Atmospheric Administration (NOAA), and it's the boater's best friend. Forecasters in the Camp Springs, Maryland, NOAA Science Center analyze a stream of data from buoys, weather stations, direct satellite feeds, and ships at sea, massaging this information into a variety of forecast products that offer mariners reliable short-, medium-, and long-range looks at the weather ahead. This is a great example of tax dollars at work for the good of all boaters, commercial mariners, and coastal residents.

Weather forecasting and atmospheric sampling are generally conducted nation by nation, although there are many independent sources that compile an array of global forecast data. A good rule of thumb, however, is to always include information from the internationally recognized weather forecast source for each area in which you sail.

Like most scientific endeavors, the meteorologist's tradecraft has been revolutionized by computer technology. Rather than replacing human forecasting, however, computers have enhanced it. Today's forecaster uses data-crunching programs that offer a big picture as well as small snapshots of what's going on from the sea surface to the roof of the atmosphere. With such detail come more accurate and specific forecasts, a big plus for those poised to take advantage of a weather window or preparing to cope with a storm at sea.

Unfortunately, there are so many dynamic factors involved in weather that computer forecasting models cannot address all possible variables. Different computer models also produce different results. The forecaster plays a vital role in tweaking and interpreting the model output.

For example, when a steep-gradient high-pressure system follows a vigorous cold front over the mid-Atlantic region of the U.S. East Coast, the breeze builds and veers from southeast to southwest to west-northwest, and the intensity of the shift is impacted by temperature and pressure differences as well as by the rate of advance of the weather system. An accurate prediction of whether the worst winds will be encountered in a pre-front trough, in the cold-front boundary itself, or during the cold insurgence of northwest winds behind the front requires that the data be decoded with the experience and intuition of an expert. When raw model output is downloaded as a GRIB file by the mariner (see below), the meteorologist's interpretation is missing.

Sometimes a computer model produces a forecast that's well off the mark. These hiccups are most often manifest as mistakes in predicted wind velocities, which can be disconcerting or worse to sailors. A sustained 20-knot sea breeze on a day when 5 to 10 knots was forecast can be caused by a fairly small change in the pressure gradient or by a thermal enhancement to the sea breeze that's greater than what was expected. In some areas, high islands or coastal mountains will cause an orographic wind increase, and a skilled forecaster will know when such conditions are likely to occur.

Ship reports still play a vital role in evaluating computer-generated forecasts, and an array of coastal sea buoys provides further direct feedback and model input. Sea state reports from satellite radar imagery also help with real-time feedback to the prognostications of computer algorithms. Meteorologists have developed a reliable system that uses satellite radar images to correlate sea-surface texture with wind strength and direction. The result is a real-time ability to measure wind and sea conditions associated with specific weather events, another great tool to help evaluate a forecast. Using such techniques, meteorologists have raised model tweaking to a fine art. Trend

ONLINE SOURCES OF WEATHER INFORMATION (NORTH AMERICA)

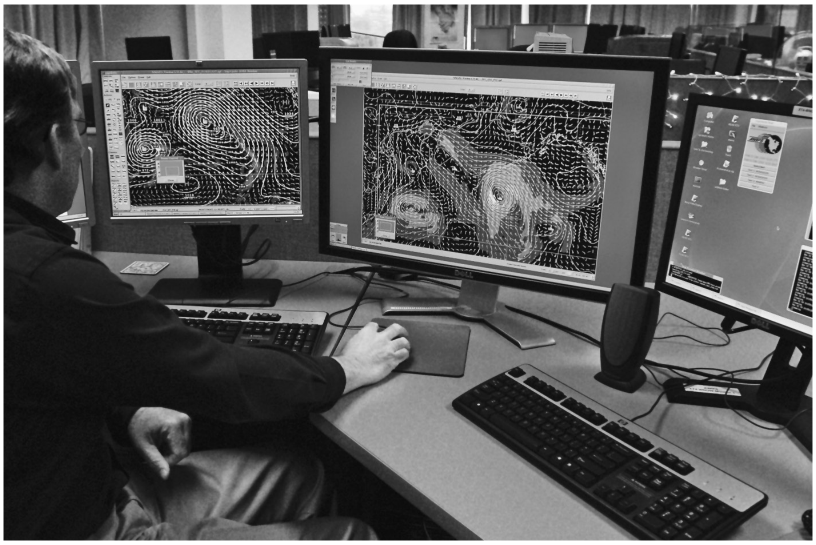
Ocean Prediction Center
http://www.opc.ncep.noaa.gov/
National Hurricane Center
http://www.nhc.noaa.gov/
National Data Buoy Center
http://www.ndbc.noaa.gov/
Weather Underground Marine Weather
http://www.wunderground.com/MAR/
Oceanweather Inc.
http://www.oceanweather.com/data/
Storm Prediction Center
http://www.spc.noaa.gov

analysis from these forecast/feedback loops also helps programmers improve the computer models and lessen the effects of inaccurately weighted variables. As time goes on, forecast models will become even more reliable, but for now the OPC forecast is a blend of human and machine.

One of the best services of the OPC is its continued commitment to providing online and at-sea weather fax forecasts. A full range of graphic and text products can be downloaded from the OPC website (www.opc.ncep.noaa.gov), with detailed current weather conditions as well as 24-, 48-, and 96-hour forecasts for East and West Coast offshore sailors.

This suite of weather forecast products can also be received at sea without costly satellite Internet equipment and service charges. Thanks to USCG communications stations in Marshfield, Massachusetts, and Point Reyes, California, all it takes to get these graphic and text forecasts at sea is a single-sideband (SSB) receiver and a laptop with an inexpensive weather fax decoding program or a dedicated marine weather fax receiver. This service shouldn't be taken for granted; funding was in question just a few years ago, and some private forecast interests lobbied to keep the detailed forecasts from being offered to the public free of charge. Hopefully, no future efforts will be made to limit access to this vital information.

The staff at the Ocean Prediction Center evaluate the weather picture unfolding in the Atlantic and Pacific oceans. Forecasters feed satellite, ship, and other data to various model algorithms, interpreting the results with a human awareness of an algorithm's attributes and potential shortfalls. They fine-tune GRIB file information and send forecasts and analyses to the OPC website, to fax broadcasting stations, and to numerous other consumers of their work.



OPC personnel developing a wintertime forecast for the North Pacific—a lesson in isobar compaction. Low-pressure systems dominate this part of the Pacific, and the waves generated by these storms torment mariners from Hawaii to the Gulf of Alaska. Avoiding midlatitude storm seasons as well as hurricane season is a key component of sensible passage planning.

The National Buoy Data System

The National Buoy Data System is another means of checking a forecast and learning more about what the graphics on the screen or on a printed chart mean for those at sea. All you have to do is point and click your way through the National Buoy Data System website, covering U.S. coastal waters, to get a feel for how conditions at sea are affected by the proximity of a front or a low-pressure system. Use the wind speed, wind direction, and sea state information from a buoy to verify the location of the fronts and the high- or low-pressure system. You'll soon notice that short-range forecasts are more accurate than mid- to long-range forecasts, but the accuracy of the latter two has greatly improved in the past few years thanks to the efforts of teams like the meteorologists at OPC and the global recognition by SOLAS and other international bodies that weather forecasts are a vital safety link for those at sea.

GRIB Weather Data and Files

The acronym GRIB stands for gridded binary files, referring to a compressed information format favored by meteorologists for transmitting weather information digitally. GRIB has become the favored buzzword of the weather-worried, but experts continue to debate the value of GRIB interpretation by nonprofessionals. Lee Chesneau, an ex-OPC meteorologist and now an engaging weather seminar speaker (and contributor to this chapter), tells mariners to be very careful with the raw model data that GRIB files graphically provide. First look closely at the forecasts, surface analyses, and 500 mb information broadcast by the U.S. Coast Guard, downloaded free from the web, or received via SSB or weather fax receiver. The GRIB files most often used by sailors are computer model generated graphics that show wind speed and direction as wind barbs overlaid on a chart and designated for a specific time and date. The data is derived from mathematical models, and the forecast has not been developed by a team of meteorologists. GRIB forecasts derived from different models often differ significantly, and a forecaster using the data develops a "feel" for which model tends to yield the most reliable information under a specific set of conditions. Sailors tapping into these data sources seldom have the same level of insight. Forecasters looking at major storms often allude to diverging model data or converging information. The latter indicates that storm tracks shown on various GRIB sources are coming together, that is, are in better agreement as to a likely storm track.

GRIB data are based solely upon model-driven calculations using complex algorithms—they reflect absolutely no human intervention, not even a look out the window. What's amazing is how accurate these computer-crunched projections can be. In fact, those cruising in remote Southern Ocean regions have been shocked by how often the GRIB file forecast matches local conditions even though weather stations and sampling are scarce. This fact alone is a great testimony to how good the models are getting, but despite this glowing upside, there are times when the models are 180 degrees out of sync with each other, one calling for calm seas and sunshine and another placing a rousing gale in your path. The GRIB charts generated will be equally contradictory, and there's no human element ready to add an expert's opinion.

Forecast Models. NOAA sifts data from the atmosphere via weather stations, weather balloons, ship reports, satellites, and ground radar. Their models (GFS, AVN, and the Wave Watch 3 wave model, also known as WW111) give a shorthand digital summary of the information tweaked by weighted mathematical formulas. For example, the GFS model covers land and sea areas and generates wind vectors at a 10-meter height over a grid with a resolution of 0.5×0.5, 1.0×1.0, or 2.5×2.5 degrees. The data include wind speed and direction, temperature, pressure, humidity, and much more.

WW111 offers high-seas data in a much smaller file, limited to oceanic wind waves and ocean current data. It's updated at 3-hour intervals, and the model is run four times a day. Its grid size is 1.0×1.25 degrees, meaning that each data point is for a rectangular area of sea surface roughly 60 miles by 45 to 75 miles (depending upon the latitude of the cell).

The navy has also put models such as NOGAPS and COAMPS in the public domain, and more and more data are being shared worldwide.

Acquiring GRIB files. People with a high-speed Internet connection can snappily download GRIB files, but it's a much slower world at sea with baud rates that make a 1990s dial-up connection seem impressive. Sailors either spend a huge amount on satellite phone, Inmarsat, or other provider of air time, or purchase a plan with a provider such as WeatherNet, which compresses GRIB files and provides them via SSB or satellite service. A few competitors in a recent race from California to Hawaii spent as much as $2,000 on air time for weather information downloads!

Also needed is a GRIB file reader, a software program that turns the binary files into a color chart depicting wind velocity and sea state as well as other vital meteorological data. GRIB Explorer or another Windows program running on your PC is linked to your communication gear. Ashore, GRIB files can be downloaded by a landline, cell phone, or wi-fi. At sea, an SSB with a digital Pactor III modem can do the job, as can Sailmail and other email/SSB links. Inmarsat and Iridium and other satellite systems also can connect the GRIB file reader in a laptop with a service provider. Ham operators use products such as Ugrib and Pactor-equipped transceivers to circumvent the costs of a commercial service, but the process is less user-friendly and the products are not quite as easy to handle.

Ideally, GRIB files should be used as one more input for forecast development, much like a trend in barometric readings or a shift in wind direction. Basing a forecast solely on a *(continued page 304)*

WEATHER ADVICE IN THE CARIBBEAN 1500 RALLY

In lieu of reading Hiscock, Street, and Moitessier (see A Ship's Library) and using their cumulative wit and wisdom as a primer to traditional voyaging, Caribbean 1500 event organizers offer entrants a fast track to the fun and fraternity of passagemaking en masse, from Hampton, Virginia, to Tortola, British Virgin Islands. This approach to leaving winter astern and fetching up at a landfall surrounded by blue water and palm trees holds much appeal. The pitch is compelling, and the package promises much more than token handholding and a little help getting your boat from here to there. The predeparture shoreside support process includes a vessel inspection for readiness, a chance to gain knowledge in formal lectures, and the weather wisdom of Ken Campbell, one of the best storm guessers in the business. The rally also has a safety-in-numbers appeal for many first-timers anxious about ocean voyaging.

November's weather near Cape Hatteras, like its springtime sequel, is a fickle crapshoot that features two extremes—calms and gales—the only sure thing being that current conditions won't last long. The answer is to clear out on the heels of a cold front with a high-pressure system and westerly winds hopefully hanging around for a while. During these precious few days of good weather, the herd stampedes east and south. There's no dilly-dallying in light air; instead, you crank the diesel and push on toward lower latitudes anytime progress drops below your normal cruising speed. The secondary challenge complicating this plan is the need to put as much easting in the bank as possible before reaching 25 degrees south, at which point you'll likely encounter easterly trade winds that have pushed waves all the way across the Atlantic and can turn an eastward slog into an unwelcome ordeal.

You may not be able to outwit Mother Nature, but if you're a gifted meteorologist you can gauge her mood shifts, and that's just what Ken Campbell of Commander Weather did the day before the scheduled start of the 2006 Caribbean 1500.

A week before the start, a brutal cold front had plunged southward out of a low-pressure system punishing the Northeast. The cold, unstable air mass left a remnant of its ferocity sitting aloft over Texas. This upper-level cutoff low looked to Ken like a candidate for intensification, and despite the fact that on the day before the start of the Caribbean 1500 this undeveloped weather system had hardly any clouds and moisture, one of the computer models was hinting of significant development. Unfortunately, another major weather model and source of GRIB data showed a high-pressure system in its place and nearly optimum conditions for a great getaway.

Campbell staked his call on the Canadian model and his wealth of weather experience. He understood how cold air and warm water off Cape Hatteras can behave like a match in an almost-empty gas tank. Facing a room full of cruisers eager to hit the road, he explained why he had advised race organizers to postpone the start for three days and demonstrated how he had used web-based data to keep current on conditions. Two vessels, *Between the Sheets* (a Hallberg Rassy 62) and *Faraway Eyes* (an Amel 53) shoved off anyway, seeing a 24- to 36-hour window of light, favorable winds in which to sprint south and east, but the rest of the fleet heeded Campbell's warning and stayed put for the next three days.

In retrospect, staying put *(continued next page)*

A 30-knot northwest wind at Cape Hatteras. This view is westward into Albemarle Sound, well away from the reach of ocean swells.

WEATHER ADVICE IN THE CARIBBEAN 1500 RALLY, CONTINUED

turned out to be the right choice for the majority of the fleet. The phantom low materialized, and 24 hours after the postponement the buoy off Cape Hatteras showed south-southeast winds at 20 knots; the next day at 2130 EST, a southeast headwind had freshened to 33 knots, gusting to 42, and seas were approaching 20 feet. As Campbell had predicted, by Wednesday the low was on its way to New England, and a northwesterly brought clearing skies and a good reason to get going.

Such weather guidance is worth its weight in diesel fuel. It makes little sense for most cruising boats to beat into 25- to 35-knot winds; progress is poor at best, and the toll on gear and crew morale can be significant. It's one thing to cope with a gale during a passage, but sailing into one that can be avoided makes little sense at all.

Professional routers like Rich Shema and Ken McKinley also provide commercial and recreation clients with custom-tailored forecasts, and as long as one realizes the need for solid communications gear and a backup plan in case communication is lost, engaging a weather guru can make sense.

When a well-prepared vessel and crew head to sea, the forecast has been checked and the departure date is based on the weather rather than a mark on a calendar. Decks are ready for breaking seas, and the sail plan is matched to the passage at hand.

GRIB file is dangerous. For example, as mentioned already, models that are spot on with wind velocity predictions for one type of weather system often miss the wind velocity implications associated with another. Information garnered from the GFS model are regularly tweaked by meteorologists when developing a forecast. They look at satellite photos of the Gulf Stream's constantly changing north wall conditions, for example, and check ship reports and note how other models read the situation. Leaving a forecaster entirely out of the loop is a gamble with a serious downside. GRIB files should be another tool in the box—not the only tool available.

Private Weather Services

Do-it-yourself amateur weather forecasters believe that NOAA/NWS has done a pretty fine job of sampling and evaluating the dynamics of the atmosphere and putting that information at the fingertips of the boating community. So why pay others to process the same model data and charts? Unfortunately, this argument only holds water for those who have done their homework and can decipher the information on weather fax 24-, 48-, and 96-hour forecast charts and understand why a teardrop-shaped isoheight line on a 500 mb chart is an alarm bell for the formation of a cutoff low. For predeparture planning, if you want GRIB files, satellite radar analysis of the sea surface, and its associative relationship to wind speed, it's all on the web, but Ben Franklin's wisdom quoted at the start of this chapter about the "weather wise and the other wise" seems to sum it all up. It is best to be informed and to have an onboard decision-making process whether or not you plan to sign up for a weather router's service. At sea, a ship with a 22-knot cruising speed can steer clear of a lot of developing weather, but the sailor plugging along at 6 knots may need to prepare to be in harm's way as well as learn how to avoid the worst weather. A satellite weather radio receiver networked to a multifunction device makes sense, and if a private weather-routing service is in the budget, so much the better. Just don't use the money for the new storm jib and trysail to pay for a weather router.

Most professional weather routers willingly admit that they base their advice on the same model information and forecast data that NOAA/NWS provides for free in voice and digital format. Their added value can be twofold: they focus on conditions in their client's vicinity, and they are often experienced small-craft mariners themselves. Their understanding of weather model shortfalls and their familiarity with the unique conditions of a specific water body can be of considerable value. Such expertise is exactly what's missing from every GRIB file.

PUTTING IT ALL TOGETHER: INTERPRETING YOUR WEATHER AND GAUGING OTHER FACTORS INFLUENCING WEATHER AND SEA STATE

Even when you understand what causes weather and know how to obtain forecasts, you still need to know what to do with this information—how to interpret forecasts and use what you see in your local conditions. This includes interpreting clouds and other weather signs, understanding local impacts on wind and sea conditions, and the nuances of forecasts.

Clouds and Other Weather Signs

We have seen how, as a cold-core low develops in the temperate regions of the world, it folds what was a more or less straight-line frontal boundary between warm and cold air into a twisted boundary. As the developing system moves west to east, comparatively warm, moisture-saturated air is in the vanguard. Due to the characteristic slope of a frontal zone, that moisture-laden air will be high overhead long before the warm front arrives at ground level, and it will announce its approach with a distinctive cloud cover. Looking west, a boater can often see high cirrus clouds and cirrostratus mare's tails that are made up of ice crystals and foretell the approach of severe weather.

As the warm front draws closer at ground level, it is usual to see a descending deck of gray stratus clouds. You may see a sun dog—a refraction of light that can mimic a second, usually smaller, sun-like disk—through this gray veil, often accompanied by a rainbow-like arc or halo around the true sun. Growing cloud cover and gentle rain typically follow. A warm front's benign demeanor should not be taken for granted, however; volatile air masses can sometimes

Most manufacturers of network-capable multifunction displays offer a satellite weather service that can display forecasts, GRIB files, and other useful weather information.

spawn severe thunderstorms or even tornadoes along a warm-front boundary, though fortunately this is an infrequent exception (more likely in late spring and early summer) rather than the rule.

When a low-pressure system, approaching from the west, will pass to your north, and you are in the Northern Hemisphere, you can expect a veering easterly to settle in the southeast. It will often remain light during the approach of the warm front, as moist air and rising temperatures make the atmosphere more volatile. And as you move into the warm sector between the warm and cold fronts the veering breeze moves to the SW just ahead of the cold front passage (signified by an abrupt wind shift to the NW). (When an extratropical low passes to your south in the middle southern latitudes—the equivalent Southern Hemisphere scenario—you are likely to experience a northeast wind backing into the north and northwest as the warm front approaches.)

Warm fronts often arrive unnoticed. Occasionally, local heating provides the lift needed for cumulonimbus clouds and squally rain showers to develop; the more vigorous the heating, the higher the clouds rise, and thunderstorms with pronounced anvil tops can develop. These taper off quickly, however, with the passage of the warm front and the arrival of the warm sector.

The cold front in a well-developed low races to catch up with the warm front that precedes it. The classic baroclinic low (i.e., a middle-latitude low with its characteristic associated fronts) features a central point of lowest pressure from which two comma-like legs extend toward the south. These represent the folded warm-front and cold-front boundaries

A high layer of thickening cirrus and cirocumulus clouds align with upper-level winds and indicate the direction from which the next low-pressure system is approaching. These clouds usually precede a warm front by a day or so, and after the warm sector passes by a cold front will usher in the next high-pressure system. This west-to-east flow pattern is typical in the temperate latitudes, but a variety of twists and turns modify this pattern. (One dramatic example is the retrograde movement of a coastal low discussed earlier in this chapter.)

separating the air masses that spawned the low. At times, when a powerful high lies to the west and the temperature differential is large, a low-pressure system can grow very deep (with a central pressure less than 975 millibars) and the associated cold front can be very long; over the U.S. East Coast during the winter, the cold front associated with one of these "mega–lows" can stretch all the way to Cuba or even, occasionally, to Panama. Such turbocharged fronts can bring the dangerous conditions known in various parts of the world as bombs, southerly busters, black nor'easters, or equally descriptive titles.

As a cold front approaches, pre-front squalls can be vicious. The worst example of this scenario plays out along the north wall of the Gulf Stream in early spring and late fall, when cold continental air masses push volatile fronts quickly over warm Gulf Stream waters. Avoiding such encounters should rank right up there with avoiding tropical storms and hurricanes. Heaving-to away from the Gulf Stream—essentially parking your boat to allow a cold front to cross the Stream—is better than meeting the front in the middle of the Stream.

The good news is that the cold front's approach is usually well telegraphed, and knowing what to look for can lessen the chance of being overwhelmed. As one sails or powers through the warm sector, the wind continues to veer to the south, and by the time it reaches a southwesterly heading, meanwhile increasing in velocity and ushering in more numerous squalls, it will be clear that the cold front is close at hand and its passage may be minutes, not hours, away. The worst weather may precede the frontal passage, especially if an upper-level trough has set up in the vicinity to complicate the issue. More often, however, a cold front's fury is focused on the minutes-long passage of the cold front—i.e., the boundary between the warm and cold sectors of

EARLY INDICATIONS OF WEATHER CHANGES (NORTHERN HEMISPHERE)

Approaching warm front: high cirrus, mare's tails, wind backing or veering to south, falling barometer.

Weather as the warm front passes: increasing humidity, showers, overcast, may have scattered thunderstorms (can be volatile especially if there's an upper-level trough).

Weather to expect in the warm sector: southeast winds veering to the south and southwest, rising temperature and humidity.

Weather as a cold front passes: increasing squally winds southwest veering abruptly west and northwest; rapid drop in humidity and temperature, strong thunderstorms on frontal boundary, potentially violent weather when temperature/pressure gradient is steep.

What to expect with an occluded front: the worst weather is at the triple point where the cold front catches up with the warm front.

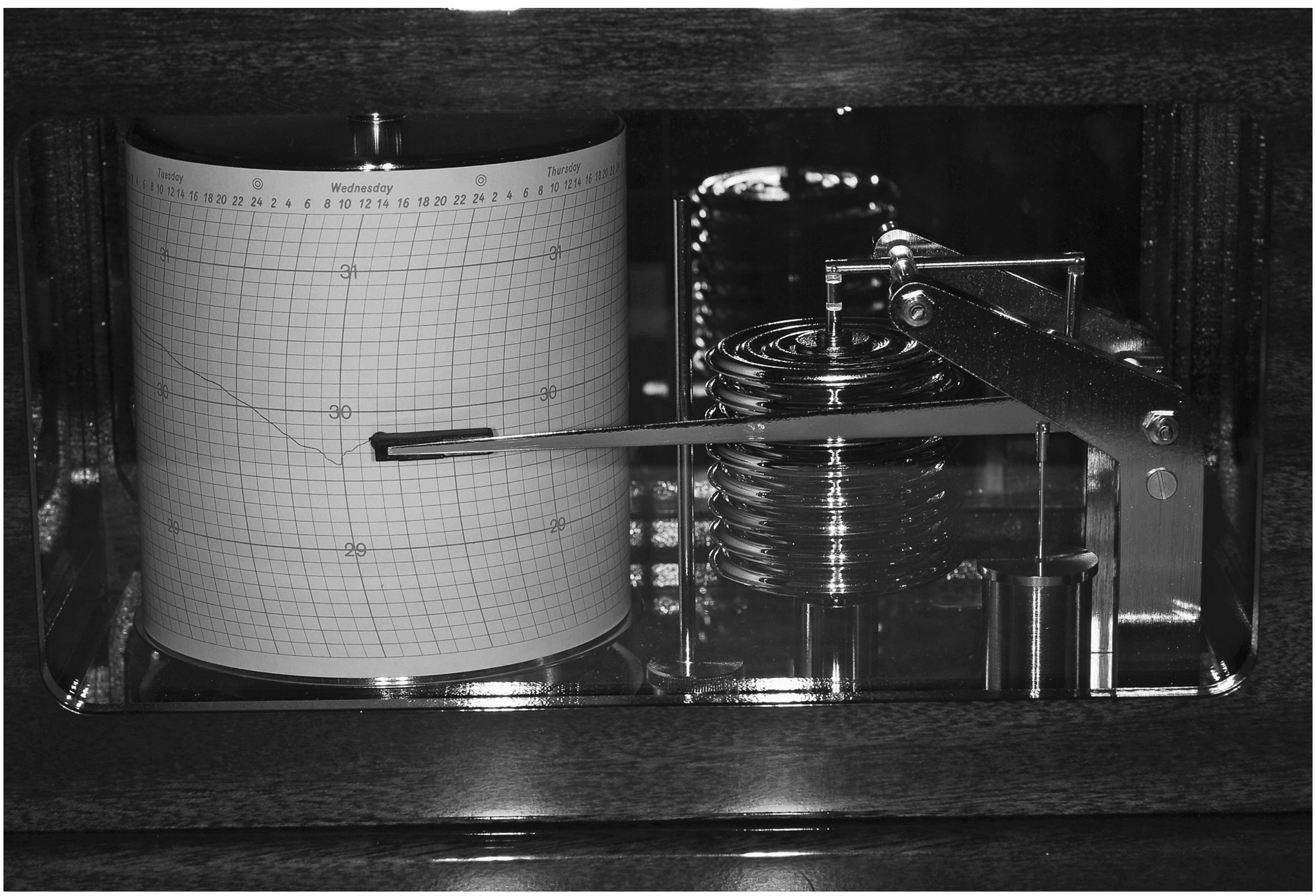
First sign of a new low: a falling barometer, red sky in the morning.

the low. Screaming winds that double the velocity of the sustained winds experienced an hour before, whiteout conditions caused by blown spume, spray, and torrential rain, and thunderstorms with 50,000-foot cloud tops capable of 100-knot downbursts and hail occur in the very worst of these conditions.

With the frontal passage can come an immediate shift in wind direction to the northwest at a velocity equivalent to the punishing gusts that preceded the shift. In open ocean conditions, this can be an awe-inspiring sight. In an instant the seas generated by pre-front winds are blown flat before your eyes, while sunshine dominates a fractocumulus-dominated sky. In the Gulf Steam, the spectacle can be a crescendo announcing that things are about to go from bad to worse because that northerly wind blowing directly against the north-flowing current will cause waves to stand on end. Waves weighing as much as a bulldozer can drop on a vessel caught in such conditions. This is another good reason to cross the Stream in stable weather if you possibly can.

The progression is very different when a low approaches to your south in the Northern Hemi-

A circle around the sun and the formation of a sun dog (to the right of the sun) are prime indicators of the approach of a warm front. Normally less volatile than a cold front, this boundary normally ushers in warm, moist air, and gentle rain. Infrequently, in the presence of sufficient upper-level instability, powerful thunderstorms can arise.



A recording barometer (barograph) tracks the approach of a low-pressure system. The more precipitous the fall, the stronger the expected gale. The tiny uptick shown for Wednesday at 1200 local time coincided with the passage of a cold front and a shift in wind direction from southwest to northwest at 45 knots.

sphere. The wind will back from the east into the northeast as the low approaches. You are likely to experience steady rain, and the cool air preceding the low may cool further as it passes south of you. You will experience no frontal passages. The wind will slowly back into the northwest and the pressure will climb as the low departs.

Low-pressure systems can settle over an area and make boating a rough-weather experience for several days in a row. Deep low-pressure systems are more common in the late fall, winter, and early spring but can occur at any time of the year. On the U.S. East Coast, pay special heed to forecasts that allude to nor'easters and alter your sailing plans accordingly. On the West Coast, keep a weather eye on wintertime Aleutian Gulf lows that can cause gale-force conditions in Southern California. Savvy Florida and Gulf Coast boaters watch every easterly wave that heads across the tropical Atlantic during the hurricane season, and Great Lakes sailors and power cruisers check the pressure gradients of the fall lows that stalk their waters starting in August.

Local Oceanographic Impacts on Wind and Sea

We voyagers tend to think of the sea as a two-dimensional construct and plot our progress with the X/Y coordinates of latitude and longitude. But we should also consider the Z axis, the vertical dimension of the sea beneath us. The configuration of a basin, for example, changes the behavior of the water it contains, defining its tidal range and period as well as current set and drift. Wave development is directly related to seafloor topography. In this section we'll look at how coastal and inshore sailors as well as ocean passagemakers can be influenced by an unseen seafloor or bottom feature. Just imagine what a midocean range of completely submerged seamounts, some nearly as tall as Mt. Everest, can do to a deep ocean current and its influence on nearby surface waters. Or envision what happens when gale-spawned seas rushing westward collide with shallow water and an outgoing tidal current over the sandy shoals off the mouth of the Delaware Bay. Benthic configurations can have a dramatic effect upon wave dynamics.

Wave Dynamics

Sailors nearing the Gulf Stream, rounding Cape Hatteras, or transiting Georges Bank are often shocked at how quickly a friendly rolling swell changes into a vessel-threatening seaway. In the first instance the root cause is a wave train in opposition with a vigorous current; in the latter two instances, a shoaling seafloor is to blame.

But we should begin where waves begin, at the air/ocean interface. Energy is transferred from the atmosphere to the sea surface by wind, and partially because water cannot be compressed, the energy radiates efficiently away from the source, organizing into geometrically ordered swells. This is similar to what happens when a large rock or calving iceberg enters the sea. The initial chaotic splash indicates potential energy becoming kinetic, but thanks to gravity, surface tension, and the viscosity of water, this kinetic energy is quickly reshaped into organized waves moving away from the initial source. The bigger the rock, iceberg, or wind, the larger the swell. In the wind-driven energy transfer, there's a frictional relationship between air and water, and fluid dynamic principles prevail: the stronger the wind, the longer the fetch, and the greater the time duration, the larger the waves. Mariners need to keep in mind that storm-created waves are shaped not just by the nearby weather event, but also the swell influence from more distant gales.

In deep water away from the storm source, the energy becomes mostly benign, long swells with modestly sloping wave faces. The wave energy in a rolling swell passes through the water column in an almost purely oscillatory manner. As a wave moves past, the water particles themselves move up and down in a vertical circle and wind up almost precisely where they were before the wave arrived. There is almost no net forward movement of water, and a cork floating on the surface would bob but remain in the same location. (The true picture is a little more complicated, of course. In reality, the lead wave in a set will dissipate while another is formed at the trailing end of the set.) As mentioned above, time, distance, and opposing wind and wave energy all affect ocean swells.

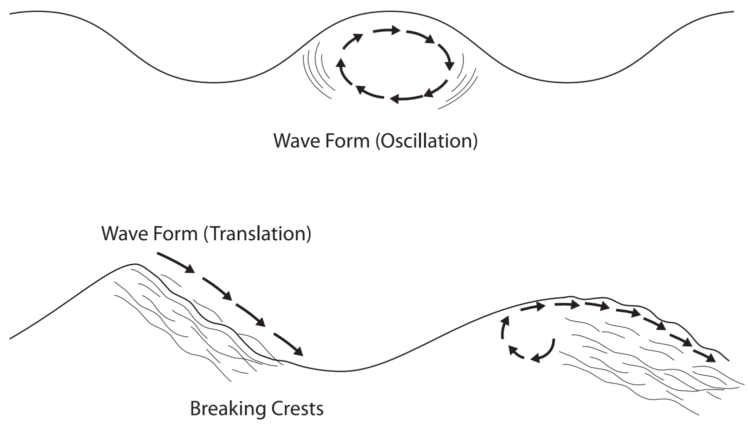
A wave train in deep water is analogous to wave energy moving down the string of a musical instrument; the vibration is a manifestation of energy transfer, but the string remains in place. As long as the water depth remains hundreds or better yet thousands of feet deep and there's no influence from a current or strong breeze moving in the opposite direction, the swell retains an oscillatory nature (not steepening into a breaking wave) and will appear to roll on smoothly. A 15- or 20-foot ocean swell with a long period can be gentle enough to pose little threat. Those who have made the downwind run from the U.S. West Coast to Hawaii probably recall such conditions.

As long as the swells travel over the open ocean's abyssal plain—a monotonously flat seabed devoid of shoals, seamounts, and contravening landmasses—they continue to behave as sinusoidal deepwater waves. But the deep-looping oscillations in a fast-moving long-period swell begin to feel the frictional drag of a shoaling bottom at the outer edges of the continental shelf, when the water is still hundreds of feet deep, and the result is a slowing of wave speed, an elongation of the ocscillations into unstable ellipsoids, and a corresponding heightening and steepening of the seas. As the steeper faces of the once fast-moving ocean swells move toward even shallower water, their speed slows further, and trailing waves crowd the slower, destabilized waves ahead of them. This confluence of energy creates even larger waves. Finally, gravity transforms the steep, overcurling swell into a breaking wave. The highest waves—those magnified to the greatest extent by the amplitude harmonics of overtaking waves or crossing seas from a different wave train—break on the reefs and off-lying sandbars farthest offshore, and when they do, tens of thousands of gallons of water, weighing more than 8 pounds per gallon, plummet downward from the breaking crests at speeds that can exceed 40 knots. In a worst-case scenario that breaking sea can land on the deck of a sailboat caught in the wrong place at the wrong time, and a sailor on such a boat will not be consoled to think that he has just witnessed a transformation of energy of oscillation into the kinetic energy of moving mass.

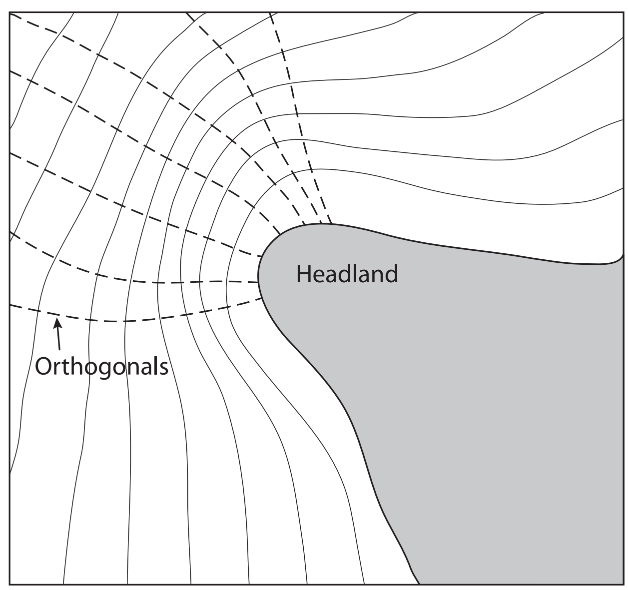
Breaking Seas. Energy of translation is the kinetic energy of water in linear motion—as opposed to the oscillatory motion of gentle swells. It can be seen even when small wavelets crowd into each other as the wind velocity increases. Whitecaps form and dissipate as they splash down the faces of the unstable waves formed by a building breeze. The phenomenon is supersized in the avalanche-like conditions created by large breaking waves. In Beaufort sea states over Force 5 (about 20 knots—see page 285), there's a very noticeable combination of breaking wave faces and oscillatory rolling swells. The more predominant the energy of translation becomes, the more dangerous the sea state. Wave theories vary somewhat, but all show a relationship among three key factors: wave height, H (the vertical distance between trough and crest); wave length, L (the horizontal distance between successive crests); and wave period, T (the time in seconds between the passage of one crest and the passage of the next). The ratio of wave height to wave length is the primary measure of steepness, and when a wave gets steeper than 1:7—or said another way, when its crest angle becomes less than 120 degrees—it will become unstable and start to break.

Breaking seas may also result when an ocean swell's lengthy passage interacts with wave energy from another storm system. When a crest in one wave train meets a trough in another, the two partially cancel one another. But when two crests converge, the result is additive. The overall result is a chaotic sea in which some swells nearly disappear while others grow mountainous in size.

Finally, big waves may break in deep water when slowed and steepened by an opposing current. It has been estimated that a 1-knot opposing current doubles the height of a wave, and this effect is magnified further by stronger currents. Given that the Gulf



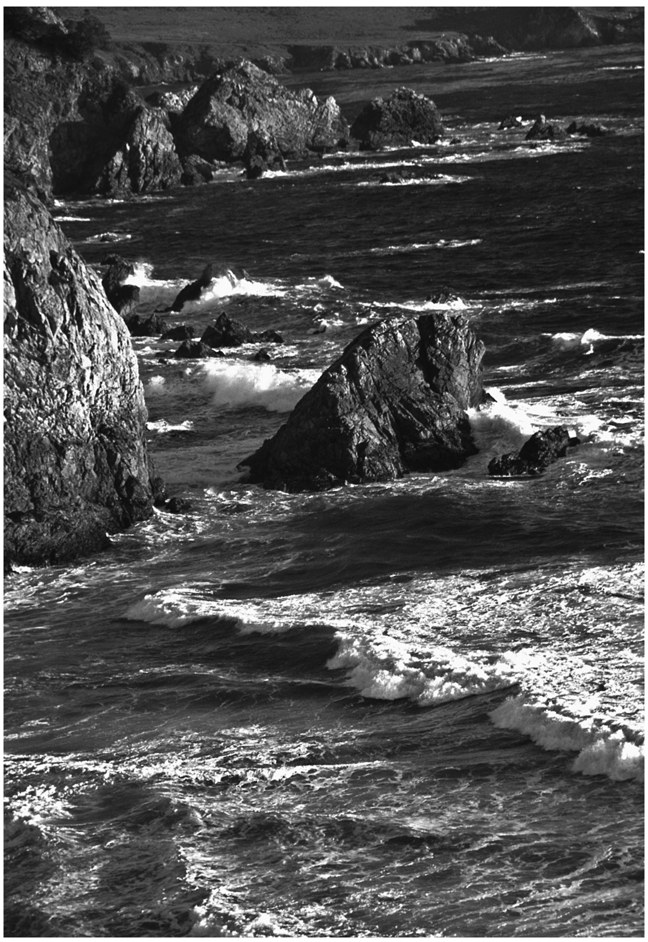
When waves become steep enough to break, the benign energy of oscillation is transformed into the violent kinetic energy of moving mass.



Wave energy is refracted toward a headland—a good reason why bluewater sailors give a wide berth to geographic locations that begin with the word "Cape." The dashed lines are orthogonals, or wave rays, crossing each crest at a 90-degree angle. The ratio of the distance between two adjacent orthogonals offshore to the corresponding distance at the beach is a measure of the degree to which wave energy is focused on a headland or other shore feature.

SHIP KILLER WAVES

In the late 1990s a cruise ship in the North Atlantic east of Cape Cod (nearing Georges Bank) encountered a rogue wave of 90 feet associated with a fairly run-of-the-mill storm of tropical origin. The huge sea would not have been predicted by the storm's central pressure alone, but when its track and rate of advance were added to the equation, the reason for huge waves became clearer. A Category 1 hurricane had dissipated, turning into an extratropical low complete with a cold core and a frontal boundary weather system. Its northerly rate of advance as it turned post-tropical was an extraordinary 35 knots, and its course and speed had kept it resonant with its wave train. The net result was much more energy being imposed upon the swell moving away from the storm, and just as the cruise ship was making her way toward the abruptly shoaling Georges Bank, the swells and the storm arrived together. Massive waves that had been unfettered by the friction of a shallow bottom now stood on end as they piled up on the steeply rising seabed. Such bottom conditions focus wave energy as a lens focuses light. When a mariner faces heavy-weather decision making, avoiding the worst sea conditions becomes paramount; as discussed on page 299, in a tropical storm, deep water and the "navigable-quadrant rule" (the left-hand quadrant in the Northern Hemisphere) are first considerations.



Breaking surf caused by shoaling water is a good example of the oscillatory energy in an ocean swell being transformed into water cascading shoreward in a wave of translation. In 2012, a Sydney 38 in the Farallones Race and a Hunter 376 in the Ensenada Race navigated into the surf zones of offshore islands and were ravaged by the concentrated wave energy unleashed when ocean swells steepen, refract, and break. In the two incidents together, nine crewmembers were lost. A rocky lee shore and a large swell send experienced mariners on a quest for sea room.

Stream flows at speeds up to 4 knots or more, it's little wonder that breaking seas kick up when a strong northerly opposes the Stream.

Wave Refraction. Light is refracted, or bent, as it passes through a concave or convex piece of glass, and when the energy converges on a focal point, there's increased light and heat caused by the increased photon density. Something similar happens when a swell approaches a jutting headland with an associated offshore reef structure. The portion of a swell crest approaching the headland first slows down and steepens due to the frictional effects of the rising bottom. Meanwhile, off to the right and left, the portions of the crest still in deeper water do not slow down and thus outrace the middle portion. This causes the "wings" of the swell crest to bend in toward the headland and in this way focus the energy on the headland.

Wave dynamics in shoal water have been well described by oceanographer Willard Bascomb in his 1964 classic *Waves and Beaches,* a must-read for all serious cruisers coastal sailing or headed for distant landfalls. One of its best explanations is how an orthogonal (also called a wave ray—a curve drawn on a wave diagram so as to cross each successive wave crest perpendicularly) can be used to depict a wave train's energy dispersal or concentration as it approaches a coastline. When waves bend, or refract, toward a prominent headland, the orthogonals converge toward shore, as shown in the illustration on page 309. Dividing the distance between adjacent orthogonals in deep water by the corresponding distance at the beach gives you the refraction coefficient; the higher the coefficient, the more the wave energy is focused. The point of greatest focus of the orthogonals is where the largest waves and the

Cutting corners too closely when a big swell is running can claim a terrible toll. The crew of *Low Speed Chase* passed over shoal water as they rounded the Farallones Islands and were caught by a large breaking wave that capsized the boat, killed five of the crew, and left all sailors to ponder the need for sea room. (Courtesy Sophie Webb)

most dangerous plunging breakers will occur. Reefs lying just off such headlands deserve to be given a wide berth. The Potato Patch off the mouth of San Francisco Bay is just such a situation; swells passing over deep submarine canyons to seaward approach the rocky headlands, and the first shallow spot to intrude on the energy flow is this offshore cluster of reefs covered by as little as 24 feet of water. In light air and flat seas, a fair-weather shortcut nips inside the Potato Patch, but when the swell is up it can be a dangerous gamble to sail there.

Effects of Seabed Topography

Along the U.S. West Coast, submarine canyons over a thousand feet deep come almost to the beach in some areas, and jagged headlands like Point Conception jut seaward. This abrupt sea/land interface concentrates wave energy almost as effectively as the Hawaiian islands, which are actually the tips of volcanic seamounts. These coastlines offer very little wave abatement and do even less to slow down the shoreward progress of powerful ocean swells. In seconds, these huge mounds of dense blue water morph into towering giants as plunging breakers. Big-wave surfers speak with reverence about the power of thick, fast-moving Hawaiian waves or the abundance of energy found in a Northern California winter swell.

The East Coast and its adjacent seafloor are much older geologically than the West Coast, and like the rounded, eroded, worn-down mountains of the East, the seabed has less precipitous peaks and valleys. The East Coast is rimmed by a continental shelf 100 to 200 miles wide—a sandy aggregate of glacial moraine and riverine sediment that has built its way out toward the edge of the abyssal plane or deep oceanic realm—and the submarine canyons are a hundred miles offshore. The wide coastal zone of relatively shallow water causes waves to slow down much farther at sea, dissipating much of their potential energy. Unfortunately, this coastal zone within the 10-fathom depth contour can turn into a tempest when a gale stirs the waters. Building seas become highly unstable, and shallow water increases the likelihood of encountering a breaking crest. Wise mariners seek deep ocean water when they are unable to find a safe harbor.

Currents

The Gulf Stream emanates from the North Equatorial Current and runs northward from the Florida Straits along the U.S. East Coast and then easterly across the North Atlantic. As discussed elsewhere in this book, it is one of the major ocean currents in the world and has a huge impact on local weather systems. One of the reasons that this part of the Atlantic has such a history of savage weather is the confluence of cold and warm air masses meeting just offshore in proximity with the warm water of the Gulf Stream. Hot, moist tropical air from the south is often dragged up the coast in warm fronts associated with rapidly deepening lows, and when dense Canadian cold air forces this warm air aloft, convective activity becomes eruptive, spawning thunderstorms with 50,000-foot cloud tops. Not only does the north wall of the Stream constitute a unique physical boundary between the warm Gulf Stream and cooler inshore and Labrador Current waters, but the heat it radiates also boosts the volatility of warm, moist tropical air and the intruding cold Canadian air associated with each cold front. Satellite imagery reveals towering cumulonimbus buildups along the edge of the gyre and pre-front squalls of epic proportions.

Things get even trickier when a low passes just south of a vessel in the Gulf Stream. The vessel encounters northeast winds, and if the gale or storm has been blowing for a day or two, the resulting seas are mountainous. Their size would be problematic in any event, but the real challenge comes from the opposing current, which steepens the wave faces and makes them dynamically unstable, resulting in dangerous plunging breakers. The prudent mariner

When the wind opposes a surface current, waves develop steeper and higher vertical faces and become more unstable. Breaking crests are more numerous, and the threat of capsize greatly increases

avoids entering the Gulf Stream when such conditions are predicted.

The same phenomenon can occur elsewhere around the globe where strong currents are present—whether an ocean current or tidal current. At sea, wind against the current, especially near a continental shelf, can double the size of the waves and cause them to steepen and become much more dangerous. A strong northerly in the Gulf Stream or when crossing Africa's Agulhas Current is something to avoid—if not, it's an experience one never forgets.

Currents and the Sea Floor. Littoral currents are a wind- and wave-driven sand transport system that scours every coastline. Along the New South Wales coast of Australia, for example, shallow water and a tenacious downcoast current can cause northbound sailors to take note of the relationship between sea and seabed. In this region, the friction between moving water and a shallow bottom diminishes the drift. The sandy bottom also weakens the current by sapping energy as tons of sediment are lifted and carried down the coast. Savvy Aussie sailors take advantage of this region of diminished current and sail with "one foot on the beach." Doing so overnight is far too anxiety provoking for most cruisers headed north toward the Great Barrier Reef, however, and a tack offshore with a dawn return toward shallower water seems to make sense. At least that's what I thought some years ago during a passage from Sydney to the Great Barrier Reef. At dusk we headed offshore, beating into a headwind and a significant downcoast current. Staying clear of land in the darkness and returning on the opposite tack the next morning, I was dismayed to see the same lighthouse that we had bid farewell to the previous evening. The name of the headland was Tacking Point; once again Aussie humor prevailed, and "one foot on the beach" sailing to stay out of the current was the lesson learned.

Today I cope with such situations—whether in Australia, Baja, or just off the New Jersey coast—by short tacking in shallower water with appropriate caution applied to good navigation and a perpetual stare at the depthsounder. Another alternative is to motorsail to weather, staying well inshore and capitalizing on the lighter breezes of early morning. Or you can anchor or visit a new port and wait for a favorable wind—often the cruiser's most delightful prerogative.

Shoals and Inlets

In New England and the Middle Atlantic region, gales mean easterly winds, and many harbor entrances take on a dangerous lee shore demeanor. Waves pile into the coast, causing gutter rips that move sand out to offshore sandbars that are constantly migrating in much the same manner as barrier islands themselves are moved. In an easterly wind the entrances to shallow, sandbar-choked small-craft harbors along this stretch of coast can look like a "ride the wild surf" movie. Sailboats attempting to negotiate these channels are in danger of being spun broadside and in really bad weather can be swamped by breaking seas. The condition is exacerbated by strong shifting winds that steepen already unstable wave faces.

It makes sense to keep careful track of soundings and bottom contours, plot your course on a large-scale chart, and recognize the risk associated with bad weather and breaking seas. Those who cruise the skinny waters of Delmarva and the sand shoals of coastal North and South Carolina should pay special heed to chart updating. Many software programs and apps include free chart updates, and for chartplotters chip updates are often available at reduced price. (See Chapter 8 for more information on digital NOAA charts.)

All navigators learn to pay close attention to coastline features, but experienced voyagers also track bottom contours, soundings, and other benthic features, noting their likely effects on sea state and factoring this into surface and 500 mb weather forecasts. The resultant picture of likely sea-state dynamics is as complete as a sailor can manage. The process blends the sciences of the oceanographer and the meteorologist with the art of seamanship.

Global Weather

Just as American sailors need to understand the weather patterns around North America and the causes of changes in the weather, cruisers elsewhere around the globe should study local weather patterns and possibilities. Following are just a few general examples of other global weather patterns.

Easterly trade winds persist for a good part of the year on either side of the equator in every ocean. They tend to blow a consistent 10 to 20 knots and give rise to equatorial currents that can boost a vessel's daily westerly progress by 20 to 30 miles. The eastern basin trade winds are lighter in all oceans, while those sailing the Caribbean, the western Pacific, and the east side of Africa often find "enhanced trades" (winds over 20 knots) not that uncommon.

The Med is a feast or famine for sailors who prefer to make passages under sail. Local winds coming off the desert of Africa or from higher snow-clad mountains in Europe often play havoc as the crew scurries to take in sail. The best way to avoid being surprised is to read local cruising guides and discern how the northerlies (the tramontana winds of Spain, the mistral of France, and the grigal of Greece) blow during winter and the southerly Sahara sand-carrying sirocco can dust those anchored in France. There's even an easterly levanter that scours mountain passes and blows across the straits of Gibraltar causing rough seas in the western Med. The fickle katabatic meltemi wind of Greece and Turkey slams down from mountain peaks and can easily reach gale force without a storm in sight.

High-latitude sailing is energized by the Roaring Forties and Furious Fifties, a region in the Southern Ocean where waves literally circle the globe ahead of huge low pressure cells. Ice, short days in winter, and snow squalls that blow sideways keep the region's population low and yachts transiting the region to a minimum. *(continued page 317)*

Cape Horn on a moody gray day. The only certainty in these latitudes is that the status quo of weather and wind will not last long.

WEATHER CASE STUDY: THE *FLYING COLOURS* INCIDENT

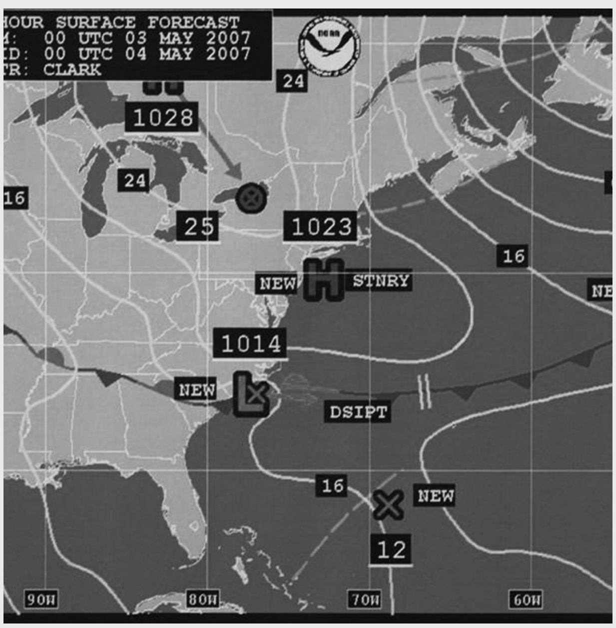
The foundering of *Flying Colours*—and the loss of three other vessels in the same storm—southeast of Cape Hatteras in the spring of 2007 provides a classic lesson in how volatile middle-latitude spring and fall weather can be. We can analyze this incident in hindsight to better understand the weather concepts and realities we have been discussing.

As mentioned throughout this chapter, early spring and late fall weather is highly volatile in the middle latitudes. During seasonal changes, the mid-level streamlines, especially the strong-wind belt, migrate north and south. During the Northern Hemisphere summer, the flow is centered at about 50 degrees north latitude, while in winter it can shift as far south as 30 degrees north in El Niño years. In spring and fall, the main axis is centered around 40 degrees north, just where and when many cruisers are considering a passage north or south between the Caribbean and the U.S.

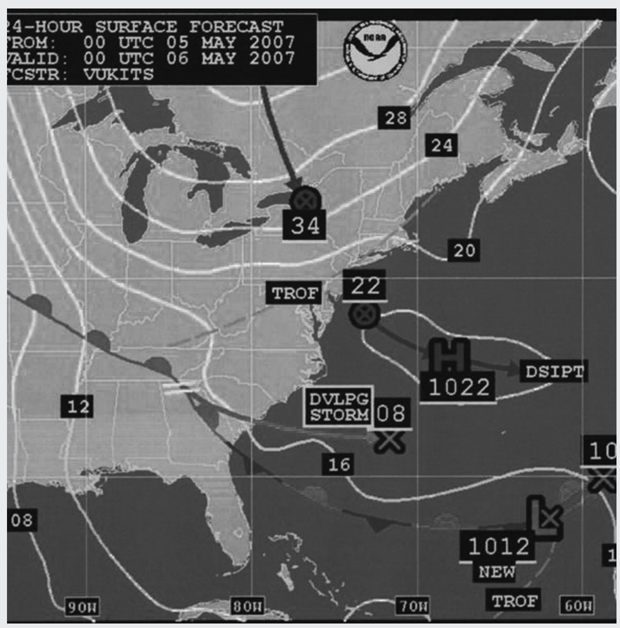
For such passages, one wise precaution is never to put to sea when a tropical storm or hurricane is south of your latitude. Another is to beware of the double-barreled impact of a deepening surface low sliding off the coast of Cape Hatteras when the lower branch of a split jet stream is near the same latitude, as described earlier. And the third caution is to respect the venomous nature of the north wall of the Gulf Stream and its ability to boost convective activity by injecting warm, moist air into already-unstable air masses. Any mariner making a spring or fall sprint between the U.S. East Coast and the Caribbean needs to watch for and guard against these weather-making elements. A crewmember of an Island Packet 38 was lost in late October 2011 when the NARC Rally encountered the unstable boundary between a tropical system and a temperate air mass, turbocharged by the Gulf Stream. But nothing more clearly demonstrates the dangers of this volatile weather brew than the tragedy of the *Flying Colours.*

In May 2007, the crew of *Flying Colours,* a Hood Little Harbor 54, was making a transit from the Caribbean to the vessel's home port in Annapolis, Maryland. The four on board included Trey Topping, the vessel's professional skipper, another licensed captain, and two others who had also worked in the Caribbean charter trade. On May 3, a high-pressure system was moving southeastward from the Great Lakes into New England, and a weak frontal boundary extended west to east off the Carolina coast. A new low-pressure system was forecast to develop on this frontal boundary, but the Ocean Prediction Center indicated that it would dissipate over the next 24 hours as it moved east.

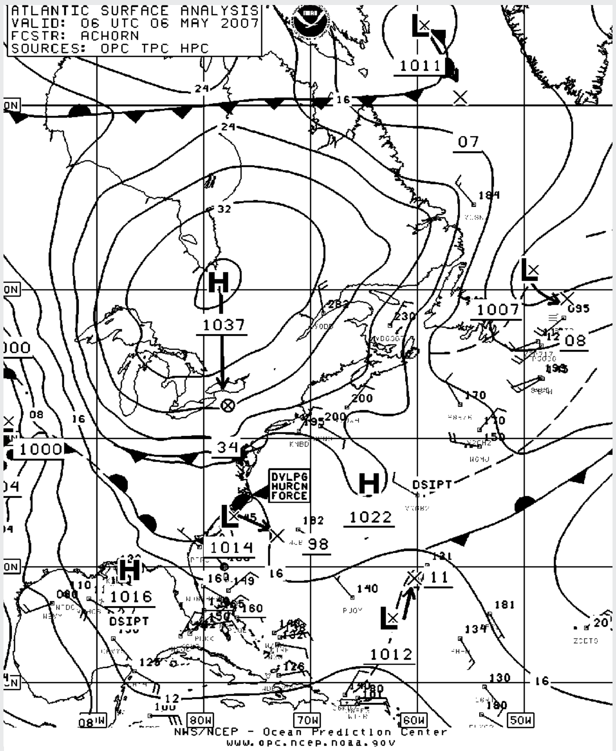
The May 4 forecast retained the weak stationary frontal boundary off the Carolina coast and introduced a new, very weak low (1014 mb) moving eastward out of the area. The high by this time was centered off the mid-Atlantic states, and a modest pressure gradient dominated the region. In a nutshell, there was not



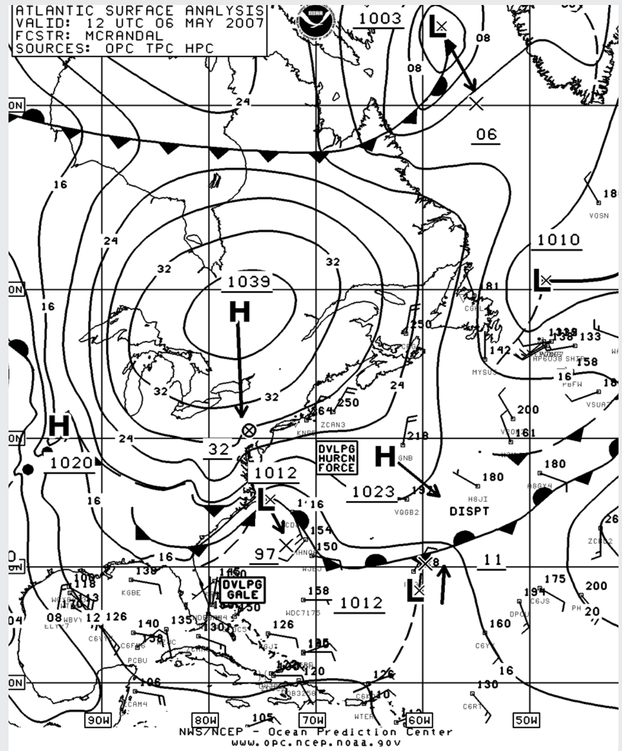
This weather fax of the OPC's 24-hour surface forecast for May 4, 2007, showed a benign weather pattern off the U.S. East Coast. A new low-pressure system off the Carolina coast was expected to dissipate as it moved offshore. (NWS/NCEP)



This 24-hour surface forecast—issued 48 hours after the former one—warned of a developing storm that was forecast to move east. (NWS/NCEP)



This May 6 surface analysis from OPC shows that heavy weather has become even worse as three atmospheric instigators coincide. High pressure to the north has steepened the pressure gradient on the deepening coastal low. An upper-level cutoff low (not visible in this surface analysis) has stopped the eastward movement of the system. A surface analysis is not a forecast; it is a representation of what is actually happening at the time and date indicated. (NWS/NCEP)



This surface analysis issued 6 hours later shows that the rapidly deepening low, the approaching high-pressure ridge, and the Gulf Stream's proximity are creating a veritable weather nightmare. Of the four yachts that issued distress signals off Cape Hatteras, two were driven ashore and their crews rescued by the U.S. Coast Guard, and one was capsized and sunk (its crew also rescued by the USCG). Unfortunately, the 54-foot Flying Colours *was caught in the center of the storm and disappeared along with its four-member crew. (NWS/NCEP)*

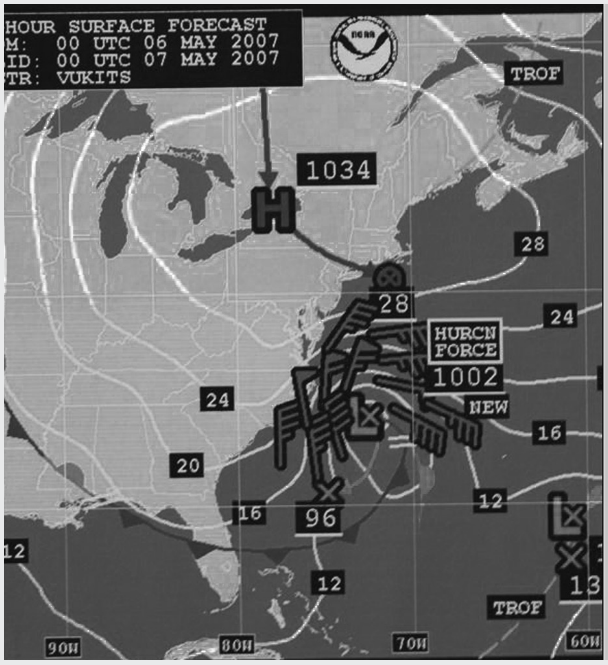
much to make a mariner apprehensive. But seasoned sailors understand that the weather in this region is volatile in early spring and that Cape Hatteras is notorious for its fickle mood shifts. Recall also the influence of the Gulf Stream as described earlier.

On May 5, the OPC reset the stage by placing in its 24-hour surface forecast a small rectangle between the dissipating high-pressure system off the mid-Atlantic states and the pesky frontal boundary now sliding southward into Georgia and off toward the southeast. In the rectangle was printed DVLPG STORM, one of the most unwelcome warnings a sailor can imagine.

On May 6, the 24-hour surface analysis changed the rectangular box warning to HURCN FORCE, leaving no doubt that bad had gone to worse and that anyone caught in the vicinity was in for trouble. This is what forecasters call extratropical cyclogenesis, meaning the development of a middle-latitude (i.e., extratropical) storm with potentially hurricane-force winds. The key culprits were a mid- to upper-level cutoff low, which did not show up on surface charts, and a rapidly building high-pressure system to the north. Some private weather routers recognized as early as May 5 the implications of the cutoff low and how it would interact with the massive 1034-millibar high moving into New England waters, and they began telling their clients to alter course and stay away from the area. The wind field of the counterclockwise-rotating low would be bolstered by the clockwise rotation around the high to the north, and anyone caught in the resulting nor'easter would be in big trouble.

The forecast was vindicated on May 6 and 7. An offshore buoy well away from the worst of the storm reported 65-knot winds and 39-foot seas. *Flying Colours*, the well-built, well-maintained Hood Little Harbor sailed by Trey Topping and his crew, was caught in a very bad part of *(continued next page)*

WEATHER CASE STUDY, CONTINUED



This 24-hour surface forecast—issued 12 hours prior to the surface analysis immediately previous—predicts that the low will deepen even further, from 1012 to 1002 millibars, and winds of storm and hurricane force will engulf the region from Cape Hatteras east to 70 degrees west longitude, some 300 miles offshore. And the worst of the weather will be encountered in enraged Gulf Stream seas. (NWS/NCEP)

the ocean, and early in the morning of May 7, the Coast Guard received an EPIRB distress signal from the vessel. *Flying Colours* was not the only vessel sending distress signals—early on May 7, the U.S. Coast Guard had their hands full with EPIRB signals from vessels across hundreds of miles of storm-swept ocean. A container ship outbound from Savannah, Georgia, en route to Norfolk, Virginia, lost 21 containers in the rapidly growing seas. The delivery crew of the 67-foot alloy cutter *Illusion* was only about 50 miles from the EPIRB signal sent by *Flying Colours*. The crew of *Illusion* was spotted by a C-130 and rescued by a Coast Guard HH-60 helicopter. Closer to the coast, a crew was plucked from a vessel in vicious seas off Frying Pan Shoals. The first distress signal, however, had been issued by an EPIRB the Coast Guard thought was aboard the *Lou Pantai,* although the distressed vessel that actually sent the signal, which was sinking 225 miles southeast of Cape Hatteras, was actually the *Sean Seamour II*.

Sean Seamour II owner Jean Pierre De Lutz and his crew had departed Saint Johns River, Florida, on May 2 aboard a well-equipped Beneteau Oceanis 44 and were headed across the Atlantic. One of the communications upgrades on the vessel was an Iridium satellite phone linked to a computer with MaxSea software. Chopper and OCENS software were also loaded in order to decode weather maps and GRIB files. The skipper had been checking weather patterns since April 25 and did not notice any alarming change in the GRIB data until May 5, when they were approximately 200 miles along their route. The skipper chose to maintain his north-northeast heading, and that fateful decision would put him in a battle for survival two days later.

On May 7, *Sean Seamour II* was 217 miles east of Cape Hatteras, running before mountainous seas with a scrap of inner forestaysail unfurled and a drogue towed astern. As the seas grew larger and more unstable, the vessel was violently driven down by breaking crests. At 0245 hours, a severe knockdown occurred, the drogue parted, and the vessel no longer responded to steering. Less than 10 minutes later the sloop was capsized by an even larger breaking sea, dismasted, and severely damaged. The water in the cabin was up to the knees of the crew, and the life raft was over the side and tangled in the rigging.

To make matters even worse, the ACR GPIRB (an emergency position-indicating radiobeacon, or EPIRB, with a GPS chip) flashed for a short period and then seemingly ran out of battery power and stopped flashing. Fortunately, the owner had brought along a second EPIRB that had belonged to his prior boat, *Lou Pantai,* which apparently had been activated when it was torn from its mount inside the hard dodger when *Sean Seamour II* was first knocked down. The crew knew they were in dire straits and were unable to keep up with water entering the sinking vessel. Hoping to hold off abandoning ship until dawn, they feverishly pumped and bailed, but another breaking wave added 18 inches more water to the downflooding disaster.

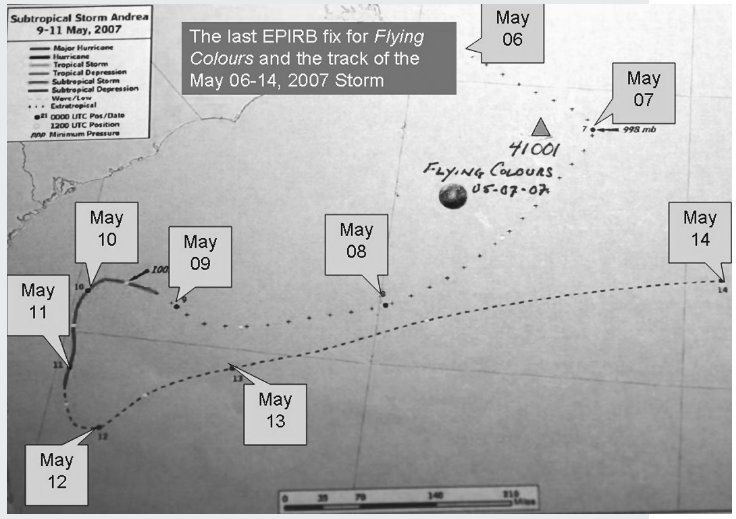
At about 0520, they began the process of abandoning ship. They freed the raft from the tangle of standing rigging, which had damaged the raft's canopy, and clambered into it, watching the Beneteau fill with water and soon sink. The raft was capsized and rolled but was rerighted by the crew. Then the effects of hypothermia began to set in. Between 0600 and 0700, the crew spotted a fixed-wing aircraft, and around 0830, a USCG HH-60 helicopter reached them and rescued all three on board the raft.

During this same period, the crew of *Flying Colours* were also fighting for their lives. Caught in the maw of fierce weather, their larger, more ruggedly built Hood Little Harbor apparently also became a victim of the wind and waves. The rescue coordination center began receiving EPIRB position reports at 0330 on the morning of May 7, but the signals ended abruptly at 0700. At about 0930, a C-130 reached the last known position of *Flying Colours,* initiated a search pattern, and dropped a buoy to track the current. The active sea-and-air search continued until May 12, but no trace of the missing vessel or the crew was ever sighted.

Such tragedies often leave us pondering, but one thing the crew of *Sean Seamour II* was certain of was that the old EPIRB the owner had brought along as a backup saved their lives. The cause of the signal failure in *Sean Seamour II*'s primary GPIRB may yet be discovered, but why the position reports from *Flying Colours* stopped will probably never be known.

The *Flying Colours* incident leaves more questions than answers. The spotty EPIRB transmissions from *Flying Colours* placed the boat near the north wall of the Gulf Stream and in the current's influence when the storm overwhelmed it. No one knows what decision-making process caused the crew to sail into the heart of the rapidly intensifying storm. Did they have a communications system failure that left them unable to receive weather forecasts? Had an engine problem rendered them unable to make a motorsailing sprint to Beaufort during the two days of calm weather preceding the storm? The answers to these and other questions remain a mystery, but this tragedy underscores the risks of rounding Cape Hatteras and other notorious capes worldwide that are confluences of wind, wave, and weather.

Not only was the storm unusually intense, but it was unusual in other respects as well. Instead of behaving like a normal, rapidly developing coastal low and speeding off to the northeast dragging its attendant cold front across the region, this deepening springtime low moved southeastward in its fledgling phase, and on May 7—while at its worst—it made an abrupt 90-degree course change to head southwest (toward *Flying Colours)*, giving it what is termed a retrograde track. On May 8 it veered even more westward, and by May 9 it was headed northwest. Instead of dissipating normally, the low shed its cold front on May 9 and replaced its cold core with warm air, developing a more symmetrical cross section and the vertical profile of a tropical storm. This prompted the National Hurricane Center to open shop a month early and name the storm Andrea, crowning it the first tropical storm of the season—although there was some grumbling among weather agencies as to whether or not this transition from a cold-core low to a warm-core tropical storm (i.e., *baroclinic* to *barotropic)* was quite that complete. (The Ocean Prediction Center handles forecasts for extratropical cold-core lows, but the National Hurricane Center handles tropical and subtropical warm-core storms.)



Note the retrograde movement of the storm to the west-southwest between May 7 and May 12 and its un-usual morphing into a tropical storm on May 9 and 10. The pressure at the center was 998 mb at 0000 UTC May 7, which was 7 p.m. on May 6 for boats off the U.S. East Coast. The EPIRB signal from Flying Colours *was activated at the position shown 8½ hours later, at which point the storm had moved southwest and was almost on top of the boat.*

Turning south on May 10, the storm skirted the Georgia and Florida coastline for two days before turning eastward and leaving the region as, once again, an extratropical weather system. Coastal residents and structures were mostly spared.

The pot of gold at the end of the ordeal is the Antarctic Peninsula, a transition zone with a summer hint of green and a few days when 50-degree temperatures thaw a little ice. Good weather is fleeting, the forecasts are often inaccurate, and risk factors are elevated. Summer in the Arctic is a little less brutal, but a cruise to these waters is an expedition, and one should read about what happened to Shackleton and his crew before even pondering such a voyage.

INTERPRETING FORECAST DATA

By now you should see weather should never be treated lightly—and also that it can be unpredictable and not always follow the forecast. Be cautious and never assume the best, and study weather patterns well before heading out to sea. Even then, stay cautious with how you interpret forecasts.

THE DANGER OF CUTOFF LOWS

The rescue of the crew from *Sean Seamour II* and the tragic loss of *Flying Colours* illustrate several salient points. The first is that a storm at sea can claim even well-found yachts with experienced hands. Another is how important it is to make use of as much weather information as possible and to obtain updates at least daily. Finally, in the case of the May 7 storm, long-range forecasts and model data didn't come into agreement until May 5, and even when the storm's severity was recognized, its retrograde motion and transition into a tropical storm were completely unanticipated.

The bottom line is that cutoff lows are a significant threat, and their development needs to be closely monitored. Looking at surface forecasts right up to May 5 would not have alerted a crew to the imminent danger ahead. The best early warning came from the upper-level, 500 mb behavior of the atmosphere and model predictions of how an upper-level low and the massive high-pressure system to the north would affect the surface low. A close read—a 2-day warning of a very bad storm but not a perfect picture of what lay ahead—reveals there was enough evidence to cause a prudent skipper with the May 5 forecast in hand to head for a safe haven, or at least get clear of the Gulf Stream's influence.

Even when you have the best data-reception capabilities and hired professional guidance, there remains a significant risk of encountering bad weather. The spring of 2007 had been cold and stormy in the mid-Atlantic region, and the volatile start to May was more typical of early April than mid-spring. Atmospheric volatility also increases in areas such as Cape Hatteras, where weather systems and the Gulf Stream meet. An apex of the infamous Bermuda Triangle, this part of the ocean has a deservedly dangerous reputation—but more due to weather extremes than mystical legends.

Getting and Using Forecast Data

A major goal for sailors is to better understand the material generated by the OPC, and as mentioned at the start of this chapter, one of the best ways to improve your skills is to seek confirmation of your weather chart reading. It can be as simple as downloading a set of charts and imagining the weather coming. Then compare your forecast with the Weather Channel forecast. Study weather graphics online to recognize the value of the 24-, 48-, and 96-hour surface forecasts and their associated wind/wave maps. Notice the direct correlation between isobar gradients and the size of the seas that are generated. The tighter or steeper the gradient, the more feathers on the wind arrows and the larger the sea state number. Your skills will grow from such basic observations to a more detailed familiarity as you practice reading these graphic forecasts during your shoreside life. In a way, all this is like installing radar on your boat. Hooking up the unit is only the start, and if you wait until you're in zero visibility to turn it on, you'll probably not gain much benefit from it. But if you practice when it's clear and can confirm what you see on the screen, you'll make better use of the equipment when the time arrives to use it in earnest. The same holds true for the weather information provided by OPC; the more familiar you become with how charts compare with actual weather, the better you'll be able to interpret the new chart scrolling out of the weather fax machine.

During many of my early voyages I looked at the sky and wished I had a large-scale weather map perspective of what an approaching cold front looked like and how fast it was moving. Today, we can print out graphic forecasts and compare the squiggly lines with the cloud cover and trends indicated by the barometer. Add to this the wind speed and direction as well as the sea state and ocean swell dynamics, and you can get a really good feel for the implications of a weather chart. It's a lot like looking at a large-scale harbor chart of a new landfall and feeling as if you already know what the anchorage looks like.

What to Do with Your Forecasts

A forecast means different things to different crews. The gale that a cruising couple wants to avoid at all costs can be just what the crew of an 80-foot transatlantic record breaker is looking for. The first requirement for making optimal use of forecast information is a working understanding of the sea conditions generated by a given weather system and what that means for your vessel and crew.

Some years back I was aboard a 60-foot sloop enjoying the final day of a three-week springtime transatlantic passage to England. We had been tormented by two gales and a storm that hammered us with relentless easterlies, and the prospect of landfall was welcome. As the Lizard came into view, our young-eyed helmsman saw something in the distance: a small speck that looked initially like a rock awash in an angry sea. But as we drew closer, the rock turned out to be a 28-foot pilot cutter slogging upwind with a hardy British crew awash in the cockpit. What to us was a miserable day at sea was a normal sailing day to these voyagers from the storm-tossed Hebrides. Be aware of your crew's comfort threshold.

You should also be aware, of course, of how much punishment your boat can handle and in what weather conditions you're likely to see wind and sea that challenge the boat's survival. This is a matter of sea sense, the point where the meteorologist's expertise leaves off and the sailor's skill takes over. During the transatlantic crossing mentioned above, we received weather guidance from the U.S. Navy, and at one point the forecaster advised us to head 2 degrees (120 nautical miles) south to get away from the 50-knot blow that was assaulting us. The problem was that the wind was out of the south, and the prospect of beating into 50 knots of wind was a lot less appealing than reaching under storm sails and making 9 knots in the direction we wanted to go. An aircraft carrier and a 60-foot sloop have different needs and capabilities when it comes to making way to windward, obviously. We held our course and safely reached on toward our destination.

Picking the best time of year to make a passage remains a sailor's best bet. This is usually summer in temperate parts of the world. But hurricane activity usually ramps up in August and September, and finding your boat in the crosshairs of even a tropical storm can do more than dampen enthusiasm.

As mentioned earlier, the weather window approach to passagemaking can give you a few good days to clear the shoals, cross the Stream, and gain sea room, but if your destination lies a couple thousand miles away and "safety valve" landfalls are few and far between, you and your crew need to be ready to handle heavy weather if and when the need arises. Regardless of your weather router, a 6-knot sailboat will have a hard time avoiding a big low or tropical storm moving at 25 knots. Knowing what lies ahead helps you prepare for the worst. The next chapter discusses how to handle heavy weather.