Chapter 2

It Is All about the Ice

I have grown accustomed to the quirks of sailing south across the Drake Passage, and I've come to expect the anomalous temporal and spatial qualities of air and sea temperatures, winds, ocean currents, icebergs, sea ice, ice sheets, and glaciers whose synergy defines Antarctica's physical essence. The interplay of these physical attributes becomes an ever-changing stage upon which life performs. The ecological impacts of rapid climate change on the marine life of the Antarctic Peninsula are inseparably linked with the environment and geography. Neither physical nor biological realms exist in a vacuum; rather, the two collectively form a complex web of interactions, some relatively benign and others triggering cascades of ecological consequences. In 2009, I led an Antarctic Climate Change Challenge Mission Cruise for Abercrombie and Kent Travel Company to the western Antarctic Peninsula. Among the participants from my hometown in Alabama were four undergraduate honors students from the University of Alabama at Birmingham. Each had enrolled in my Antarctic Marine Ecology course, and between scholarships, student loans, and artfully approached parents, each student had managed to scrape together the necessary funds for the voyage. Of the remaining two hundred passengers aboard our ship, the *Minerva,* most were well-heeled, retired professionals who had traveled the world over, and they shared my sense that these four students were incredibly fortunate to visit Antarctica at such a tender age.

The first physical attribute of the Antarctic environment that I share with those new to the continent is the abrupt drop in seawater temperature that welcomes one to the Antarctic Circumpolar Current

(ACC). Circling the entire continent of Antarctica in a clockwise direction, the ACC is truly one of the world's greatest geographic wonders. Unparalleled in its volumetric dimensions (the current extends from the sea surface to depths ranging from six thousand to twelve thousand feet), its very presence ensures the refrigeration of Antarctica. This refrigeration is caused by the ACC trapping very cold, less saline surface waters that circulate around the continent and maintain stable cold air temperatures. When the ACC was formed many millions of years ago, the entire continent rapidly cooled. Even more remarkable is its immense breadth, extending at some points as wide as twelve hundred miles. Because the ACC circles the globe (the Southern Ocean is the only ocean to do so), it provides a unifying link to every major ocean basin. Some scientists refer to it as the "mixmaster" because exchanges of water masses across these linkages play a critical role in regulating the climate of our planet.

Strong westerly winds drive the current's eastward motion and have given the ACC its alias: the West Wind Drift. These westerlies are world renowned for their speeds. As such, some are named by combining catchy adjectives with latitudes; examples include the Roaring Forties, the Furious Fifties, and the Screaming Sixties. Such wind-intensified latitudinal gradations are the result of air being displaced from the equator toward Antarctica. As air travels south of thirty degrees latitude, it gradually loses heat garnered over the equator, and as it cools, it sinks closer to the earth's surface while the earth's rotation drives the air from west to east. The growing intensity of winds south of forty degrees latitude is the result of a vast expanse of uninterrupted ocean that permits the winds to build upon themselves relentlessly. I know these winds all too well. I was essentially baptized by wind on my first Antarctic expedition to Kerguelen. In the Northern Hemisphere, land masses interrupt the wind's flow, preventing it from building to great speeds.

One of the projects I assigned the students on the *Minerva* was to locate and identify the ACC by recording surface seawater temperatures and positional coordinates every three hours over the thirty-six-hour Drake Passage crossing. It didn't take the students long to discover a GPS on the ship's bridge that provided our latitude and longitude and also a digital gauge that displayed surface seawater temperature. Determining who would set his or her alarm and get up repeatedly throughout the course of the night to record GPS coordinates and sea temperatures was even more challenging. Halfway across the Passage, my students eagerly approached me at dinner and presented a graph that displayed seawater temperature and latitude. The students explained that as we had approached 57 degrees latitude, the seawater temperatures had transitioned in just six hours from a moderate 46 degrees to a more frigid 38 degrees Fahrenheit. Here, they exclaimed, was irrefutable evidence we had crossed the Polar Front and entered the ACC.

Scientists predict that as rapid climate change increasingly impacts the Southern Ocean, the ACC will act as a conduit to transmit climate changes around the globe. A scientist at the Scripps Institute of Oceanography reported in a groundbreaking paper in the journal *Science* that since the 1950s the average mid-depth temperature of the Southern Ocean (especially within the ACC) has significantly warmed—and done so at a faster rate than temperatures measured in the Pacific, Atlantic, or Indian Oceans.[1] The implications of this Southern Ocean warming trend are profound as the waters surrounding Antarctica spread their influence gradually over the entire globe. Importantly, observations indicate that the ACC has migrated about thirty miles toward the South Pole since the 1950s. In another paper, scientists from the Canadian Center for Climate Modeling and Analysis[2] put this southern migration of the ACC into perspective by using oceanographic models. They concluded that by the end of the twenty-first century the migration (actually, shrinkage) of the ACC could displace a body of water equal to that of the entire Arctic Ocean. As such, the climate influence of a diminished ACC would be felt globally. Marine scientists at the Rosenstiel School of Marine and Atmospheric Science at the University of Miami point out that as the westerlies and ACC continue to move south, the oceanic "gateway" at the southern tip of Africa will expand as warm salty waters from the Indian Ocean leak into the Atlantic Ocean.[3] This enhanced leakage influences patterns of oceanic circulation. Specifically, warm saltwater may disrupt currents climate scientists had predicted would reduce warming in the North Atlantic Ocean.

If my students were to travel south across the Drake Passage in a future world—a world where the ACC and its nutrient-rich water and abundant seabird population had shrunk and was located closer to Antarctica as a result—their second assignment would have been abbreviated. I assigned my students to spend as many daylight hours as possible out on the rear deck recording the numbers and types of seabirds following our ship. When the students reviewed their avian field notes, they discovered that as the *Minerva* had transitioned into the colder, nutrient-rich waters of the ACC, both the abundance and diversity of seabirds had dramatically increased. Black-browed albatross had been joined by their cousins, great wandering albatross and royal albatross; cape petrels now enjoyed the company of giant petrels, sooty shearwaters, and Wilson's storm petrels. The students correctly surmised that increased quantities of avian prey—zooplankton and fish—explained this transition. Off the rear deck, seabirds soar on the westerly winds against a backdrop of sea and sky. Most circle in patterns that take them gradually up the sides of the ship, then out in front of the bow, and with sudden angling of wings, back at breakneck speed to once again soar behind the ship's stern. This pattern of flight provided a perfect opportunity for my students to observe the phenomena of *dynamic soaring*—a flight technique that exploits the ability of birds to gain speed by crossing back and forth between calm and windy air masses. Seabirds dive into the calm air behind a ship or wave and then wheel back up and into a strong headwind. When they emerge like this, the speed of the air flowing across the top of their wings increases—then by shifting their flight to a downwind glide, the birds are propelled, like a high-speed roller coaster over a drop, into yet another calm region. This dynamic process provides an almost effortless means of travel and makes possible such feats as the transoceanic foraging flights of the giant wandering albatross.

No voyage from South America across the Drake Passage to Antarctica is complete without celebrating the first sighting of an iceberg. Usually one can expect to see one about two-thirds of the way across the Passage. On Antarctic cruise ships, a bottle of fine champagne is awarded to the first guest to inform the officer on the bridge of the sighting. Aboard research vessels, scientists are outwardly subdued, as if sighting the first iceberg is routine and benign. But scientists hide their excitement behind their professional demeanor. Icebergs are irrefutably stunning—transcending both science and art. When sunlit on a clear day, they are so brilliantly white they are impossible to look at without squinting. Where snow has melted or blown free, a translucent-light to deep-azure blue emerges from the ice. At the water line and up to twenty or so feet below the sea's surface, the shades of turquoise and lime green can take an onlooker's breath away. As icebergs melt and shrink, they periodically tip over, exposing their underbellies of glassy-smooth or pockmarked surfaces. As a precaution against sudden roll-overs, our vessels give icebergs a wide berth, and the National Science Foundation (NSF) Antarctic dive program prohibits scuba diving in their proximity. But one need not enter the water to enjoy such surreal beauty. One of my favorite places in Antarctica to take nature photographs is from a small boat slowly winding its way through gardens of icebergs. As if sculpted by an artist, their myriad shapes—some reminiscent of animals, castles, or treasures from the world's finest modern art collections—provide a virtual smorgasbord of photographic potential.

Icebergs are large pieces of floating freshwater ice, generally projecting from just a few to around two hundred fifty feet above sea level, and weighing hundreds to millions and occasionally even billions of tons. They can originate from a variety of sources, such as being shed from a snow-formed glacier (known as a *calving event*), or from cracking off an ice sheet. The word *iceberg* itself is derived from the Dutch *ijsberg*, meaning "ice mountain." This term is somewhat ironic considering that 80 to 90 percent of an iceberg is hidden below the surface of the water. If upside down, however, an iceberg would truly be an ice mountain.

Antarctica boasts some of the largest icebergs ever recorded. In 2000, Iceberg B-15 broke free from the Ross Ice Shelf—a floating platform of ice that can be hundreds or even several thousands of feet thick. (Large icebergs are given designations so they can be tracked.) The Ross Ice Shelf is the largest ice shelf in Antarctica and is about the size of France. Remarkably, a vertical ice wall towering 50 to 100 feet fronts 370 miles of the Ross Sea. The ice shelf was named for Captain James Clark Ross who first sighted the shelf on January 28, 1841. Iceberg B-15 measured twenty-two miles wide and 183 miles long, and was estimated to weigh three billion tons. At 4,200 square miles, the iceberg was 8 times the size of the city of Los Angeles. I was fortunate to witness one of these behemoths on a cruise to Antarctica aboard the *Explorer II*—on which I was lecturing with a friend, geologist Henry Pollack—in 2007. We sailed for hours, seemingly within reach of a thirty-one-mile-long iceberg that had grounded itself near Clarence Island off the northern tip of the Antarctic Peninsula. Henry, who had visited Antarctica frequently over a span of eighteen years, was, like me, nonetheless awestruck by this iceberg's grandeur. Emerging one hundred vertical feet from the sea, the immense iceberg towered above us, dwarfing our ship as we passed.

As global temperatures rise, icebergs will more often break off, or calve from, the mainland. Throughout the decade I have worked at Palmer Station, I have witnessed many bergs or smaller pieces of ice calve from their glaciers. About once a week, I would be startled by a loud, thundering crash. Leaping from my desk on the second floor of the Palmer BioLab, I would join others running down the hall to throw open the door and watch the waves rolling up neighboring Arthur Harbor—waves brought on by a house-sized chunk of the Marr Glacier breaking free and plummeting into the sea. Now when I visit Palmer Station, the calving events have become so routine that my colleagues and I in the BioLab don't even bother to move from our desks when we hear the glacier roar. Sometimes, three or four calvings happen in a single day. Indeed, those who have worked at Palmer Station over the past decade don't need to consult journals, television programs, or the Internet to understand how the climate is changing. Furthermore, as the geography changes, so do the names of actual locations. When the receding ice tongue of the Marr Glacier recently revealed an island rather than a seemingly long-established point of land, Amsler Island was officially born.

The frequency of icebergs calving off glaciers and ice sheets breaking up will inevitably increase as waters along the Antarctic Peninsula and other regions of western Antarctica continue to warm. Larger icebergs will also become more common as they are shed from ice sheet break-ups, and their increased mass will permit them to drift farther north before finally melting. They will also begin to show up in odd places. On November 16, 2006, while I was on sabbatical at the University of Otago in the city of Dunedin on the South Island of New Zealand, government officials spotted a large iceberg off the coast—the first iceberg sighted from a New Zealand shoreline in seventy-five years. It turned out to be one of a flotilla of over a hundred icebergs. Immediately, the media was abuzz with news about the impacts of climate change, and the New Zealand icebergs soon became a major tourist attraction. Tourists paid $300 apiece for a helicopter ride over the fields of ice, and for a bit more cash, they could land on the large berg within sight of Dunedin. A tour company quickly organized an iceberg wedding, but had to scuttle it when the helicopter pilot decided it was unsafe to land.

A warming Antarctic Peninsula riddled with icebergs has consequences that are hidden from the casual observer. The increased amount and sizes of icebergs scouring the coastal seafloor disrupt the marine communities there. Marine biologists have long known that near-grounded icebergs behave much like earth movers at construction sites, displacing tens of thousands of square yards of seafloor sediment. The exposed portion of an iceberg acts as a sail, transferring the energy of wind and current to motion, causing the berg's base to plow through soft sediments and scrape over hard bottoms. Massive iceberg scars extend for miles along coastal Antarctic seafloors, and these are devoid of seaweed, sponges, sea anemones, soft corals, sea spiders, starfish, brittle stars, and even fish. Over a period of a few years, the process ecologists refer to as *community succession* will kick into gear along these iceberg scars. Temporary communities of rapidly settling and fast-growing, but short-lived, seaweeds, sponges and sea squirts will give way to more stable "climax" communities comprised of more competitive seaweeds and marine invertebrates that grow slower and have longer life spans. Climax communities are ecological communities in which populations of bacteria, plants, and animals remain stable and exist in balance with each other and their environment. In the big picture, Antarctic seafloors that are subject to intermediate levels of periodic iceberg scour are checkered with short-term opportunistic and long-term stable communities and, as such, sustain higher overall diversities of species. But just as intermediate levels of iceberg disturbance may increase species diversity, too much iceberg disturbance may actually compromise this diversity. Heavily ice-scoured seafloors, like a graded construction site, can be biological deserts. Climate warming could result in an overabundance of coastal icebergs that regionally decimate near-shore seafloor communities.

Icebergs can also have unforeseen impacts on Antarctic marine birds. Following the 2005 break-up of B-15, a massive offspring (renamed B-15A) grounded at the mouth of McMurdo Sound. Its position effectively blocked the outflow of pack ice from the Sound while simultaneously cutting off the Adélie and emperor penguins from their food resources. This blockage diverted the penguins to a route that effectively doubled the distance they would normally travel, from about 60 to 120 miles. Until the massive B-15A iceberg floated free several years later, biologists routinely found emaciated penguin carcasses en route between rookery and sea.

Having completed our crossing of the Drake Passage, my students and I rendezvoused on the ship's bridge and took in the jaw-dropping vistas of icebergs that ranged in size from a Volkswagen Beetle to a large hotel. "Are all icebergs so easy to see?" one of my students asked the ship's captain. The captain explained that the crew manning the bridge can sight small icebergs emerging above sea level (aided by a powerful spotlight at night), and that the ship's radar readily detects the larger icebergs. He further explained that they had to give the large bergs a wide berth because their ice can extend horizontally just below the sea's surface—a significant hazard to ships.

Unfortunately, technology has yet to provide a means of detecting smaller icebergs whose upper portions lurk just barely above the sea surface. Known as *growlers* because of the growling sound they emit as air escapes the ice, these are about the size of a concert grand piano (fifty square feet). Because they have lost most of the air trapped in their ice, they sink low into the water, often protruding only two to three feet above the sea surface. Growlers are too small to be detected by radar and too low on the horizon to be seen from a ship's bridge, yet they're large enough to breach a ship's hull. Ships that routinely ply Antarctic waters are generally designed with ice-hardened (thicker-than-normal) hulls, or even double hulls to prevent a breach should a collision occur. The NSF research ships I sail upon to Antarctica and the small Antarctic tour ships leased by Abercrombie and Kent have ice-hardened hulls. But not all ships that visit Antarctica have reinforced hulls, including the larger cruise ships that carry several thousand tourists at a time. This is a cause for concern, especially as a rapid warming along the Antarctic Peninsula increases the frequency of encounters between ships and icebergs. Over the past twenty years several of the smaller Antarctic cruise ships such as the *M/S Explorer* have had to evacuate their passengers at sea. The *Explorer* collided with an iceberg on November 23, 2007, and sank to the seafloor within fourteen hours. Fortunately, the weather was calm and the passengers and crew were plucked from their lifeboats by a cruise ship that happened to be nearby. But the prospect of evacuating several thousand passengers in heavy seas and foul weather, with assistance perhaps many hours away, portends a disaster of *Titanic* proportions.

Scientists attempting to measure how rapidly the climate along the Antarctic Peninsula is changing are fortunate because they can access Faraday Station (now Vernadsky Station), a small coastal research facility, some twenty-five miles south of Palmer Station on the central western Antarctic Peninsula. The British government established Faraday Station in 1947, where scientists initiated and sustained air-temperature measurements that span a period of six decades. When a scientist plots the mid-winter air temperatures over this period on a line graph, he or she sees an average increase of almost 2 degrees Fahrenheit per decade.[4]

Sea temperatures along the western Antarctic Peninsula are also warming. Scientists have determined from seawater temperature measurements taken from 1955 to 1998 that a 1 to 2 degree Fahrenheit increase has already occurred in surface seawater temperatures.[5] And increased sea and air temperatures are contributing to the rapid retreat and decreased duration of the annual sea ice (ice that accumulates and actually doubles the size of Antarctica every winter), which, over the past thirty years, has seen a reduction of 40 percent along the Peninsula. Some scientists predict that by the middle to end of this century, annual sea ice along the western Antarctic Peninsula will become scarce.[6]

All these factors make the central western Antarctic Peninsula the poster child for climate warming on the planet. While climate scientists originally thought that regions of the Antarctic continent other than the Antarctic Peninsula were less vulnerable to warming, this view has changed dramatically over recent years. Air temperatures along the west coast of the Antarctic continent have been warming according to a recent study published in *Nature*.[7] Using a combination of satellite thermal infrared observations and ground weather stations, the authors of the study have determined that west Antarctica has warmed at a rate exceeding 0.18 degrees Fahrenheit per decade over the past fifty years. These findings were a game changer, as one of the outstanding questions in Antarctic climatology has been whether the dramatic warming on the Antarctic Peninsula had also been going on in West Antarctica. The study answered this question with a resounding "yes." Polar climate scientists attribute the rapid warming of the Antarctic Peninsula to a combination of the buildup of greenhouse gases and, especially during summer months, changes in wind patterns (the westerly jet) due to the hole in the ozone. The authors of the *Nature* paper surmise that West Antarctica seems less influenced by ozone-related changes such as wind patterns and more tied to broad patterns of atmospheric circulation associated with regional changes in sea ice.[8] One intriguing hypothesis to explain why some areas of eastern Antarctica have not warmed is that altered wind patterns generated by the hole in the ozone have postponed warming.[9] Should the ozone hole eventually close, as now predicted by atmospheric scientists, warming in the eastern regions of the continent may make up for lost time. Regardless, Antarctica is warming, and the Antarctic Peninsula is at the forefront.[10] From a scientific standpoint, the dramatic warming of the Peninsula provides an opportunity to study first impacts of unprecedented warming on sea ice, icebergs, ice sheets, and marine life.

Iceberg-studded seas give way to first views of the Antarctic Peninsula and its neighboring islands. Glaciers that extend to the sea from thick land-based Antarctic ice sheets adjoin semi-permanent ice shelves that float on the surface of the sea. Some of the ice shelves along the east and west coasts of the Antarctic Peninsula are mind-boggling in their dimensions. Given the rapid warming of air and sea temperatures over the last thirty years, large sections of at least nine ice shelves have separated from the Peninsula, most of these since 1995. Perhaps the most famous break-up to date is the Larsen Ice Shelf located on the eastern side of the central Antarctic Peninsula. On January 31, 2002, satellite images revealed large numbers of striations running shore to sea in a region known as Larsen Ice Shelf-B. A little over three weeks later, a satellite image on February 23 showed that the striations had led to disintegration, as tiny to massive iceberg-sized chunks now littered the region. Two weeks later, on March 5, a satellite image indicated that Larsen Ice Shelf-B was essentially gone; in its place floated hundreds, even thousands, of icebergs in the Southern Ocean. The magnitude of this event is impossible to put to scale from satellite images alone—without a scale, it may seem like mere tens of miles of ice were affected. But scientists have estimated that the vast region of Larsen Ice Shelf-B that broke out measured a staggering 3,540 square miles, a piece of real estate about the size of Rhode Island.

The breakout of this major section of the Larsen Ice Shelf provided the stimulus for the LARISSA Project. This multinational research program, funded by the U.S. National Science Foundation, involves twenty-three principal collaborators and investigators teamed together to address the dramatic environmental shifts in Antarctica's Larsen Ice Shelf system. In the big picture, the disintegration of this ice sheet is a significant regional problem with global implications. Amy Leventer, a geologist, friend, and colleague from my early days as a polar marine biologist at McMurdo Station in the mid-1980s, was among a group of researchers joining the LARISSA Project from widely varying scientific backgrounds. In addition to Amy, glaciologists, physical and biological oceanographers, marine ecologists, and climate and atmospheric scientists were present. Each individual brought to the table a different set of attributes that, when combined, generated a compelling synergy. As complex problems such as global climate change increasingly challenge humankind, broad interdisciplinary science teams such as those exemplified by the LARISSA Project provide an optimal approach to answering complex questions.

Amy explained to me that the LARISSA Project undertook yearly research cruises to the Larsen Ice Shelf aboard the *Nathaniel Palmer*. The National Science Foundation provided additional logistical support, including the use of two helicopters and a Twin Otter airplane. Each year, once their ship had arrived in the vicinity of the Larsen Ice Shelf, the LARISSA scientists were deployed by small boats, helicopters, or the

Twin Otter to sample seawater and ice and to dredge, core, and record video of the seafloor communities under the former and current ice shelf, and to establish a suite of automated battery-powered monitoring stations both on the surface of the ice shelf and adjoining glaciers as well as on bare rock near glaciers feeding into the ice shelf. The ice monitoring stations, known as *AMIGOS Stations*, each consisted of a GPS unit that provides precise information on the position of the ice shelf or glacier, digital instruments to collect weather information (temperature, humidity, and wind speed), and a computer modem that can store and download data directly in real time to an orbiting satellite. With sufficient ice monitoring stations positioned in key locations, the Larsen Ice Shelf and its adjoining glaciers are like a living organism equipped with sensors to monitor its respiration and heartbeat. Capturing a shelf breakout in real time through these devices would be akin to monitoring a heart attack while it was in progress; scientists could analyze the intricate dynamics of the ice shelf as it broke out, much like doctors in the emergency room use information on the condition of a damaged heart to predict future attacks. As a geologist, Amy was personally involved in establishing a number of the bedrock monitoring stations that scientists deployed on ice-free rock surfaces near the glaciers.

LARISSA scientists also provisioned the monitoring stations with sensitive instruments that record the earth's surface actually rising, or rebounding, in response to the reduction of the weight of the glacial ice. As such, scientists can precisely measure what's known as the earth's *glacial isostatic adjustment.* To envision the earth's rebound, think of the surface of hardened gelatin. When you push on the surface with your finger, it depresses. When you remove your finger, the gelatin readjusts to its original position. Scientists measuring the earth's isostatic adjustment can use this information to determine how Antarctic glaciers will ultimately contribute to global sea level rise.

In January 2010, with Amy and her fellow LARISSA scientists aboard, the *Nathaniel Palmer* departed Punta Arenas, Chile, for the Larsen Ice Shelf. Unfortunately, as the *Nathaniel Palmer* rounded the northern tip of the Peninsula, the captain observed that the annual sea ice had not broken out and the ship would be unable to reach the shelf. The helicopters were useless over the distance from the ship to the Larsen Ice Shelf. Amy summarized the collective feeling of those on board: "The ship, the helicopters, the plane, and the scientists were all dressed up with nowhere to go." They could either return to Chile empty-handed or find another way to reach the ice shelf. Using his ingenuity, the captain repositioned the ship so that the Larsen Ice Shelf was a direct shot to the east across the breadth of the center of the peninsula. The helicopters were now close enough to the ice that they wouldn't run out of fuel. However, they still had to deal with the impressive extension of the Andes that jutted in the middle of the flight path. Most of the peaks are steep, windswept, and extremely rugged, with elevations averaging above 6,000 feet—the highest peak is an impressive 9,186 feet. Amy and her research colleague Gene Domack, a fellow geologist from Hamilton College in New York, loaded their survival gear, food and water, and the modular components of an automated bedrock monitoring station onto one of the helicopters. Amy was comfortable around helicopters—she had flown hundreds of helicopter missions during her years of geological research in the vicinity of McMurdo Station. She even married one of the helo pilots stationed there. Despite all that experience, as Amy and Gene's helicopter lifted off the flight deck of the *Palmer*, she couldn't help feeling a bit nervous about her first flight over the mountainous spine of the central Antarctic Peninsula.

Like Amy, I have flown in helicopters among the stupendous Antarctic Dry Valleys—remarkable landscapes free of snow and ice due to lack of precipitation and high wind scour—that stretch for miles from the Transantarctic Mountains of Victoria Land to the coast of McMurdo Sound. On a crystal-clear austral summer day, flying by helicopter down the gut-dropping length of the Taylor Dry Valley and erupting out of its mouth over the deep-blue waters set against the sparkling white expanse of McMurdo Sound's ice edge is breathtaking. Add in the view of 12,280-foot Mount Erebus with its perennial smoky summit and you have a view Ansel Adams would have made famous in a photograph. How could any panorama on earth be as compelling? Yet Amy described her cross-peninsular flight that day as even greater in grandeur: "Dwarfed by the sheer magnitude of the landscape, our helicopter would climb and climb, only to emerge over seeming summits to reveal yet another even higher ridge to ascend." Amy had never felt as far removed from humanity nor as geographically isolated as the moment she and Gene watched their helicopter depart. As the thumping of the rotor blades faded into the distance, they stood alone in the deafening silence of Antarctica on a patch of bare rock near a glacier adjoining the Larsen Ice Shelf. With nary a research vessel or cruise ship along the entire eastern Peninsula, they were as alone as a human can be barring space travel. With little time to waste, Amy and Gene set about their day-long task of erecting the modular bedrock monitoring station.

The most recent breakup of a major ice shelf along the Antarctic Peninsula was observed March 25, 2008, when a 156-square-mile chunk of the Wilkins Ice Shelf broke apart. In what amounted to the first winter breakout in May 2008, another section disintegrated that measured 62 square miles, leaving the entire Wilkins Ice Shelf dangling from a cluster of islands by a thread of ice (only 1,640 feet at its narrowest point). When the strip eventually breaks it will release the entire ice shelf—a whopping 8,700-square-mile chunk of real estate the size of Connecticut.[11] Adding to the problem is the recent discovery by scientists from the Lamont-Doherty Earth Observatory and the British Antarctic Survey that strengthening currents are bringing more deep, warm water into contact with the underside of the nearby half-mile-thick Pine Island Ice Shelf, causing it to melt.[12] Nineteen cubic miles of the ice shelf's underside melted in 2009 alone, accelerating the flow of ice into the sea from the Pine Island Glacier that feeds into the ice shelf. Since 1974, the Pine Island Glacier has accelerated its flow into the sea by more than 70 percent, and thinned five feet per year between 1992 and 1999.[13] Given the rapid warming that has occurred along the length of the Antarctic Peninsula,[14] one could reasonably conclude that the ongoing disintegration of the Wilkins Ice Shelf is tied to climate warming, an observation that should serve as a warning that the coastal ice sheets lining the western coastal regions of the Antarctic continent may follow suit. Recent satellite-based measurements showing thinning of land-based ice in the western coastal region of the continent suggest that the increased disintegration of sea-born ice shelves along the Antarctic Peninsula may transition farther south. Furthermore, glaciologists estimate that if the land-based ice sheet that covers western Antarctica were to melt, it would raise global sea levels by about ten feet.[15] In such a scenario, Manhattan would be underwater and coastal Florida would be history.

If a silver lining exists on this rash of ice shelf breakouts occurring up and down the length of the Antarctic Peninsula, it is that these ice shelves rest on the surface of the sea. As such, when icebergs break off and drift north, melting along the way, they have no impact on global sea level. The reason for the lack of sea level rise is simple and can be easily illustrated with a glass of ice water. Ice that melts in the glass does so without changing the water level—the volume is consistent. The same principle applies to Antarctica's melting ice shelves: they will not affect the global sea level.

The loss of ice shelves, however, does produce a significant side effect. Ice shelves act as barriers that block land-based glaciers from flowing into the sea. Remove the barrier, and the glaciers flow more rapidly.[16] This increase of glacial ice introduced to the sea contributes directly to increasing global sea levels. Ted Scambos, a LARISSA project lead scientist and glaciologist from the National Snow and Ice Data Center at the University of Colorado, explained to me that when ice shelves are removed it is similar to removing a dam that blocks the flow of water down a stream. Rates of unimpeded glacial ice flow may increase by two to four times the rate of glaciers that interface with intact ice shelves. In the 2007 Intergovernmental Panel on Climate Change report, the scientific committee responsible for writing up the document chose to leave out any estimates of land-based glacial and ice sheet melt for Antarctica or Greenland in their predictions of global sea level rise.[17] At the time, they felt that the information would be premature. However, with new knowledge about the alarming decay of ice in both Antarctica and Greenland,[18] little doubt remains that the IPCC's next report (due out in 2014) will increase earlier predictions for global sea level rise by mid-century to its end.[19]

Scientists and support staff living at Palmer Station know their glaciers well. The Marr Glacier, towering behind the station, is by far the most prominent geographical feature in the region. As the glacier melts, its sea-side flanks on either side of the rocky point of land housing our station shed iceberg-sized chunks of real estate, while behind the station the glacial tongue recedes across the bare ground like a garden snail pulling its foot and head back into its shell. The Marr Glacier provides us with a visual barometer of our earth's rapid warming.

Maggie Amsler, a research associate in my laboratory, and a pioneer among women scientists in Antarctica, has an even more profound relationship with the Marr Glacier. At the crack of dawn, while the rest of the station still sleeps, Maggie extricates herself from a sleeping bag within her bivy sack (short for "bivouac sack," a thin fabric shell that fits over a sleeping bag) in the boulder-strewn landscape behind Palmer Station where she spends most nights. Depending on the weather and snow conditions, she heads off to hike, run, or ski to the summit of the glacier and comes back before breakfast. Her summit forays are mythic, but verifiable as I routinely encounter Maggie in the BioLab dining hall fresh from an early morning glacial assault. In 1979, Maggie arrived to spend the first of many field seasons at Palmer Station. She tells me that she used to be able to open the back door of the station and almost step on to the Marr Glacier. Today, it takes a hike of a third of a mile to reach the glacier's base. With findings that sync with the recessive behavior of the Marr Glacier, glaciologists have now determined that 87 percent of the glaciers along the Antarctic Peninsula are under retreat. Scientists have evaluated its retreat with aerial photographs of the glacier beginning in 1963, and then sporadically over subsequent years. The photographs show a dramatic pattern of glacial recession. Over recent years, improvements in technology have facilitated more precise measurements of the glacier's receding edge.[20]

Brian Nelson, the science technician at Palmer Station in 2010, has a full plate of science projects that he maintains in the TeraLab, a small building perched on the hill behind the main station. These projects include monitoring studies of seismic activity, air quality, ultraviolet radiation, and global measurements of lightning strikes. And there is one more scientific project that requires an annual outdoor adventure. Each year, Brian hikes along the receding edge of the Marr Glacier to map its exact position. By doing so, the rate of the recession of the glacier can be mapped over years and decades. Taking advantage of orbiting satellites and a GPS base station in the TeraLab, Brian can map the receding edge of the glacier to an accuracy of one centimeter. Brian explained to me that the high-tech Trimble surveying GPS unit, GPS receiver, and battery that he carries in his bright orange backpack are incredibly heavy to lug around. Brian operates the receiver using a handheld control unit wired to the GPS, much like a computer game. Brian attaches a circular dish antenna, about the size of a teacup saucer, to the frame of the backpack on a pole extending several feet high. Each year, as the science tech sets out from the station across the rocky backyard wearing his gadget-laden backpack, fellow staff members mock him good-naturedly with comments like, “Hey, Ghostbuster!” Brian explained that despite the unsteady footing at the far ends of the ice, walking the glacier’s terminus is fairly easy in its central region. At the south end, near Hero Inlet, the winter’s snowdrifts persist well into the summer, and the snow is undercut by the water in the inlet below. Brian is at constant risk of punching his foot right through the snow and falling directly into the freezing water. Like a tightrope walker, he carefully tests each footing before applying his body weight. On the north end, the walk is even more exhilarating as the retreating glacier becomes quite steep, eventually forming a near-vertical wall whose base ends in a slippery muddy slope. To properly survey the glacier’s edge in this area, Brian has to sidle up as close to the ice wall as possible before sliding back down the muddy slope then scrambling back up to the base of the wall to repeat the process. In addition to the danger of large pieces of ice falling from the wall, Brian is periodically vulnerable to downbursts of small shards of ice. Once, he nearly lost a shoe where small streams of glacial meltwater had turned the fine-grained soil into a sloppy quicksand. After a couple of hours, Brian returns to the station and downloads the GPS data to a computer. With a few keystrokes, he adds another year’s profile to a historical map of the Marr Glacier that tells a tale of glacial retreat as rapid as anywhere on the planet.

One of my first encounters with an Antarctic glacier was in the Taylor Valley, a desolate but beautiful dry basin in the Transantarctic Mountains of Victoria Land some fifty miles west of McMurdo Station.

Our helicopter pilot took us on a brief tour of the eighteen-mile valley to see the receding tongue of the glacier before he dropped us off at the New Harbor tent camp. During my stay at New Harbor, I wandered up the Taylor Valley, admiring the grandeur of the landscape and the glistening polished stones sculpted by the glacier and dust and sand blown by the notorious Antarctic katabatic winds. The term *katabatic* is derived from Greek and means "going downhill." Katabatic winds increase due to gravity and are comprised of dense air flowing from high to low elevation. These winds build to blistering speeds as they descend. In Antarctica, the katabatic winds plummet off the high ice sheets of the polar plateau down snow- and ice-covered terrain, glaciers, and dry valleys, whipping fine sand and dry snow into stinging blizzards and peeling the very surface of the sea skyward. British Antarctic heroic-era (the period from 1897 to 1922 marked by intense scientific and geographic exploration of Antarctica) scientists Edgeworth David and Raymond Priestley write that the steep grade in slope and decrease in temperature from the Polar Plateau to the sea and the vast surrounding ocean combine "to make the Antarctic the home of winds of a violence and persistence without precedent in any other part of the world."[21] Yet katabatic winds are not restricted to cold places. For example, growing up in Santa Barbara, California, I grew accustomed to the hot dry Santa Ana katabatic winds that howled relentlessly down the canyons toward the Pacific Ocean in the fall and early winter. Caught in their spell, the pine trees behind my home in the coastal foothills would moan and howl and bend, and the occasional Southern Californian forest fire would become an inferno. Yet Santa Ana katabatics pale in comparison to those in Antarctica.

My friend Sid Bosch, a marine biologist at the State University of New York at Geneseo, and his research technician Tom Gast experienced the wrath of katabatic winds on an austral spring October day near Palmer

Station. The two researchers were in a zodiac boat—an oblong, sixteen-foot rubber boat built of a series of rigidly inflated tube-shaped sections that are pressurized just like automobile tires—in Arthur Harbor, towing plankton nets for marine invertebrate larvae. Zodiacs are the workhorses for marine scientists at Palmer Station. Importantly, given the unpredictability of Antarctic weather, the small boats are seaworthy in sloppy swells and they maneuver effectively through the basketball- to table-sized chunks of sea and glacial ice known collectively as brash ice. Tom and Sid received a sudden radio call from the communications dispatcher at Palmer Station alerting them that the winds at the station had shot up from a normal range of about five to ten knots to twenty-five knots (about thirty miles per hour), the wind speed at which all zodiacs are recalled, and that they should return to station ASAP. Out of sight of the station and on the leeward side of nearby Janice Island, Sid and Tom were only experiencing mild wind. Yet as the two researchers cleared the leeward side of the small island, they were blasted by the offshore winds. Sid later estimated that it had to be blowing at least forty knots.

The wind lifted the bow of Sid and Tom's zodiac, threatening to flip it. With Tom operating the engine at the helm, Sid threw his body as far forward as possible to weigh down the bow. Had wind been the only issue, Sid and Tom would have probably made it back to station. However, the brute strength of the sudden burst had broken out the fast ice that had been attached to the shoreline, sending a flotilla of large chunks in their direction. Sitting high on the bow, Sid pointed his outstretched arm toward gaps in the encroaching army of car-sized ice chunks. Yet each time Tom gunned the zodiac's engine to propel the boat through, the gap in the ice closed, forcing a hasty retreat.

Helpless against the wind and ice, the researchers realized that making it back to the station was not an option. The situation was made all the more stressful because both researchers knew that if they were blown out to sea, rescue was unlikely. (The station manager admitted as much, as he would not have risked additional station personnel by ordering a rescue.) Sid and Tom turned their full attention to a last-ditch effort to secure a landing on one of the small islands adjacent to Palmer Station. At the last minute, Tom was able to gun the zodiac through a gap in the sea ice and land at Torgerson Island, the last island that remained in their path before the open ocean. After Tom had yanked the outboard engine up into its locked position, the two frantic researchers dragged the zodiac up and on to the rocky shore of Torgerson and secured the bow line to a boulder. With no chance of returning to station until the winds dropped, Sid and Tom located the island's chest-high emergency blue survival barrel. They removed from the barrel a small cache of emergency supplies including a mountain tent, two sleeping bags, fuel, and a backpacking stove, a medical kit, and dried food and bottles of water. They secured a site that was somewhat protected and set up camp for the night. Ever since Palmer Station opened in 1968, survival caches have been maintained on the small neighboring islands. Presently, nine of the islands have blue survival barrels.

By first light, the wind had died down, and the sea ice had dispersed enough that Sid and Tom could attempt passage back to Palmer. The two sleep-deprived researchers packed up their camp, launched their zodiac, and returned the short distance to station. Contributing to the long history of human survival, Sid and Tom's adventure had allowed Antarctica to serve up yet another poignant reminder of its fickle nature. The explorer and geographer Paul Siple, who represented the Boy Scouts of America during the famous Antarctic expeditions led by Adm. Richard E. Byrd in 1928–30 and 1933–35, is likely to have been the first person to utter the scout motto, "Be prepared," on the Antarctic continent. The intent of this simple but poignant statement remains an essential ingredient of Antarctic survival.

I had a memorable encounter with katabatic winds while aboard a cruise ship that had planned to travel through the Lemaire Channel (also known as Kodak Alley), just southeast of Palmer Station. About halfway down the channel we suddenly encountered seventy-mile-per-hour hurricane-force gusts. Those of us on the ship's bridge watched a stunning display of nature's energy as the blistering winds lifted the upper inch of the sea's surface skyward to dissolve in a rainbow of spray and mist. Fortunately, our ship was headed directly into the prevailing wind and we were in little danger of being driven into the rocks on either side of the narrow channel. By the time we exited the Lemaire Channel an hour later, the winds had abated, but it wasn't the end of them.

Our cruise ship was equipped with twelve rubber zodiac boats that would be used to take guests to shore and back and closer to the dramatic scenery. I was in charge of operating one of the boats myself. The crane operator lifted the first zodiac off the top deck of the ship, hoisted it over the side, and brought it to an abrupt stop suspended about twenty-five feet above the water. From this position, a boat operator could hop into the suspended boat and hang on to the boat's ropes as it was then lowered by cable to the sea. As we watched, the first operator hopped aboard the dangling rubber boat and grasped the ropes attached to the deployment cable. At that very instant, a sudden burst of katabatic wind caught the zodiac in a ferocious gust, flipped it sideways like a child's toy, and effectively turned it into a kite. The woman who was in the boat now found herself dangling above the icy sea, clinging to the ropes for dear life. Fortunately, an attentive ship's crew jumped to the boat operator's assistance, and in the blink of an eye she was standing back among us, dazed but unharmed. As the katabatic winds continued to blast down the adjacent valley, the small boat was hoisted back to its stowed position on the ship's upper deck, and tour operations wisely aborted for the day.

The physical attributes of the Antarctic Peninsula—its icebergs, annual sea ice, ice shelves, glaciers, winds, and currents—are important players in a rapidly warming environment. Some are increasing in size and abundance (icebergs), some are diminishing in duration, size, or extent (annual sea ice, ice shelves, and glaciers), and others (winds and currents) are subject to regional variation. All are subject to change. When considered collectively, they portray a dynamic ecosystem undergoing remarkable transition in a relatively short period of time. These incredible changes affect the myriad of Antarctic marine organisms that over the millennia have adapted to survive in one of the world's most stable locations. Some of these organisms may adapt, but the majority of species here have become so finely tuned to their surroundings that they don't have much wiggle room.