This is a story about the immediate relationship between our bodies and our spinning planet, as well as the proximate ties between the sea and the sky. Through the examination of a peculiar, sub-surface wave—the Rossby Wave—it will focus on the properties of balance, movement, dynamism and unrivaled stamina. If I have done my job well, reading this will remind you of the closeness of far apart things, the doggedness of time and the ever-abiding mysteries of nature. It might also remind you of why so many children aspire to be astronauts or marine biologists, two disciplines that present the unique possibility of waging adventure into an uncharted void. Though most of them will take on more practical careers when of age, it's an innate curiosity that informs this story all the same. Who, at any point in their lives, wouldn't want to go where maps cannot follow or lead?

In order to examine the Rossby wave, we must start with the fact that there are many varieties of waves from which to choose. Prior to researching this story, I was oblivious to the fact that wave classification existed. It's a strange oversight in our elementary school curriculum that otherwise teaches children to differentiate between all sorts of systems in nature. Clouds may be categorized based on their altitude and storms are numerically rated based on velocity. Why was I left to naively assume that the same mysterious cocktail of gravity and lunar energy created all forms of tide? Here are a few taxonomic varieties, in alphabetical order:

Elastic wave
Electromagnetic wave
Harmonic wave
Internal wave
Kelvin wave
Matter waves
Mechanical wave
Seismic wave (Love wave, Rayleigh wave, Stonely wave)
Shock wave
Surface gravity wave
Transverse wave

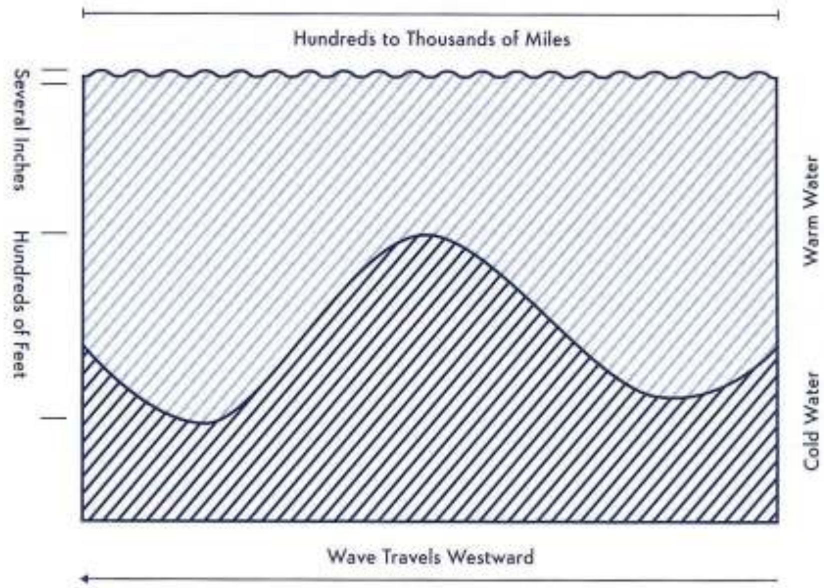
Different as waves are from one another, they have one characteristic in common: they all depend on a mechanism that returns them consistently to their starting point, a process that oceanographers describe as restorative force. Imagine if affection behaved this way.

Rossby waves are no exception to this rule. However, they have other unique characteristics that, arguably, make them the strangest of all. Says distinguished professor of physical oceanography Dudley Chelton — who, along with biological oceanography doctoral student Sam Urmy, was kind enough to speak with me for this story — they are rather of "a strange sort." A bastard cousin to the tidal wave, Rossby's travel far beneath the ocean's surface. Though only several inches tall, they span hundreds to thousands of miles and can reach thousands of feet below. Travelling non-dispersively across long distances, one intact wave can sweep the length of an entire ocean basin. At their slowest, Rossby waves move at about an inch per second, and can then take up to a decade to travel from California to Japan.[1] This is twice as fast as an ant can walk, or one-hundredth the speed of a human being. Picture a toddler, and then imagine her again 10 years later as a burgeoning adolescent (maybe even developing like one, with all the hormones in milk these days). This is the duration of time that it could take a single, determined Rossby wave to journey from shore to distant shore.

Rossby waves only travel in one direction, as if on pilgrimage. It's a route — east to west — that is specific to the shape and counter-clockwise rotation

1 **In 1996, Dudley Chelton and Michael Schlax carried out a global analysis to investigate some critical properties of Rossby waves that cannot be deduced from regional studies. In particular, they discovered that the westward propagation speed decreases systematically with increasing latitude. For instance: at a latitude of thirty degrees the theoretical propagation speed is about one inch per second. However, along the equator, Rossby waves would travel much faster, taking only about a year to cross the equatorial Pacific Ocean as opposed to seven or ten.**

of Earth. This propagation is similar to the cream whirling through your black coffee, powered by the force of a single spoon: a circulation that moves in the only direction that it knows how. Similarly, everything on our spinning planet is itself spinning; go to sleep tonight and you will wake up facing a different direction (where exactly you fall asleep in the world, of course, will affect just how much you rotate). So, rather than gravity being the force that causes wave motion, as is the case with the kind of waves we surf, "the restoring force for



Rossby waves is a combination of the rotation... and the spherical shape of the Earth," explains Chelton. Earth rotates because it's an imperfect sphere, shaped out of a cloud of debris gradually swirling into a solid from which, once started turning, could never stop. Rossby waves are held hostage by that turning. To understand this abstruse reality, we must visualize something that we all know to be true but can never actually see or feel, like an asymptomatic disease, the assassination of John Lennon, or other people's feelings.

Contrary to geometric law, Rossby waves never travel in a straight, longitudinal line. Rather, they hit constant perturbations—such as crosscurrents—and continually undulate north and south during their westward route.[2] These upward and downward sweeps can be hundreds of miles. "To get any oscillation initially going," says Urmy, "you need to disturb the system. Throw a rock in the water or pluck the guitar string. It's the same for Rossby waves, they need to

2 When the water is displaced to the north, it will start rotating clockwise relative to the earth's surface, and if it is displaced to the south it will start rotating counterclockwise. That means that the east side of this water column will move back towards where it started, while the water on the west side will be pushed away from where it started, propagating the disturbance in that direction, which is, always, westward.

3 Amazingly, these vast, fifty-plus meter northern and southern shifts only move the surface of above water up and down by several inches.

be pushed north or south." Picture a snake moving forward in the grass, its body fluidly zigzagging to propel forward motion; this is the determined course, on a much grander scale, of a Rossby wave.[3] The waves need to continually overshoot in order to move forward. The ocean is steely in this way, and a constant reminder of the inexorability of psychics and intuition.[4]

Although discovered theoretically in the 1920s, there was no tangible proof of Rossby waves until the 1970s, when hints of their presence were detected. Two decades later, they were tracked, and confirmed, from the sky.[5] It's a technical solution that is, as much of modern science appears to me, at once baffling and logical. On August 10th, 1992, the first highly accurate earth-orbiting satellite designed to measure variations in the sea surface height was launched. Named TOPEX for the Ocean Surface TOPography EXperiment, it orbited the earth fourteen times a day.[6] If you are a fast reader, TOPEX might have covered your continent by the time you are finished with this story. The satellite, and those that came afterward in its model, use altimeters (or, altitude meters), radars that bounce a microwave pulse off of the ocean's surface and measure how long it takes to return the pulse. Using this technology, researchers are able to take measurements down to a centimeter. Because the waves are only two to five inches tall, this extraordinary technological achievement is essential to the ability to detect Rossby waves from space. "If you were to scale that down," says Chelton, "it is equivalent to being able to measure the thickness of a sheet of paper from the 35,000 feet altitude of a commercial airliner." Another way to understand this comparison is to note that satellites travel seventy times higher than airplanes, at about five hundred miles high. Jason-2, the most recent satellite to perform this function, monitors 95% of earth's ice-free oceans every ten days. As with its predecessor Jason-1 (which followed TOPEX), it was named after the mythical and heroic Greek mariner whom no one has heard of.

Scientists are interested in using this satellite technology to determine how Rossby waves both sustain and reflect the vital conditions of our environment. As you might imagine, any vortex that fundamentally transmits kinetic energy, intensifies currents, and interacts with large-scale oceanic circulation is bound to influence our increasingly sensitive climate and weather patterns. Says Chelton, "the net result of Rossby waves is that they "pile up" energy at the western sides of ocean basins, which is responsible for the existence of the Gulf Stream," the narrow and intense current of warm water that flows northeastward along the eastern seaboard of the United States. (The Gulf Stream, among other things, is responsible for warming the water between the southeast United States and northern Europe. It also increases the intensity of cyclones, and perhaps most importantly, transmits about 1.4 Petawatts of heat, equivalent to one hundred times the world energy demand. Ocean thermal scientists are currently investigating ways to tap this colossal energy source.) A similar

4 This story is drawn largely from the findings of oceanographers, which is not in fact the same field as marine biography, though the disciplines have substantial overlap. Marine biologists focus on the cellular genetics or organismal biology of life, such as intertidal, near shore, or benthic animals and ecosystems, while oceanographers take interest in the physics of ocean propagation, considering such factors as temperature, salinity, dissolved nutrients, gases, and minerals. These are variables that are never fixed, as the ocean is constantly moving in one direction or another. (It is worth noting that there are also chemical, geological, and biological oceanographers studying those, or similar, aspects of the ocean.) To be an oceanographer is to be a physicist of the ocean, computing its unseen movements and energy.

coastal "pile up" in the western tropical Pacific is also partially responsible for El Niños that occur every three to seven years, most notably in 1982 and 1997. Though they don't generally cause or avert natural disasters on the sensational scale of which makes newspaper headlines, in their slow meanderings, Rossby waves both modify and retain the environment in which we all live, sleep, surf, and work.

Once you have wrapped your head around their oblique propagation habits and resulting environmental affects, consider now that Rossby waves are not unique to our planet. In 2008, researchers discovered that Jupiter's moon Europa has liquid oceans on its surface; it is theorized that Rossby waves exist on that moon, transporting the kinetic energy necessary to keep the liquid from freezing to a solid. In fact, says Chelton, "Any rotating spherical body in the universe that has either a gaseous or liquid surface will have Rossby waves." This indicates that the waves also exist on Jupiter itself; there is suggestive evidence that the giant red spot on the planet is itself a slow-moving Rossby wave. And, if you dare: speculative academic papers have also been published about the possibility of Rossby waves existing on the photospheric surface of the sun.[7]

The solar system is a good, if impossible, place to end. Rossby waves — wildly determined agents, slowly and certainly making due course — are seemingly distant phenomena, detached from the daily upkeep of our lives. In fact, they possess the ability to perpetuate and describe our bodily, environmental, and existential conditions back upon us. Too many people (myself included) regard their bodies as mute containers, or don't regard them at all; similarly, I would argue, the Earth is often considered to be *a thing* apart from the life it houses, a hunk of rock that props us all up. Rossby waves remind us of just how untrue, detached, and even dangerous both of these presumptions are. In fact, our planet and our bodies are continually forming and disintegrating and reforming all over again, and Rossby waves stand as a literal and emblematic reminder of that fact. In every sense, we live on top of, and within, a hotly dynamic process. "We need the tonic of wilderness," wrote Thoreau in *Walden*, it's just often too grand for us to notice.

5 SEASAT would last only 105 days, a relatively short period for a satellite of its kind and cost. Because SEASAT was also unexpectedly able to detect the wakes of submerged submarines, there is an ongoing conspiracy theory that the military shut it down prematurely (rather than NASA, who reported a power supply short). As a result, only around 10% of the total SEASAT data set was recorded before the processor was turned off.

6 Through a process of mathematical reasoning, a meteorologist named Carl Rossy theorized the presence of Rossby waves existed in 1930, but before the advent of satellite oceanography, there was no way to prove to their existence. These are waves named after a dead man who never lived to see his prescient theory realized and speculation proven.

7 The "solar oscillations" would account for and describe the curious rotation of the sun, which is different from that of the earth. The sun's equatorial regions rotate faster than its poles.