

Chapter 11

Hurricanes

Few phenomena in nature compare to the destructive force of a hurricane. Called the greatest storm on Earth, a hurricane is capable of annihilating coastal areas with sustained winds over 100 mph, intense areas of rainfall, flooding ocean waters, and huge waves. In fact, during its life cycle a hurricane can expend as much energy as 10,000 nuclear bombs!¹ The term hurricane is derived from *Huracan*, a god of evil recognized by the Mayan civilization in Central America and the Tainos of the Caribbean.²

Beyond the soft winds and tranquil north shore waters of Hawaii, the late summer and fall ushers in threatening tropical storms and hurricanes. Hurricanes, tropical storms, and typhoons are collectively known as *tropical cyclones*. These disturbances are among the most devastating, naturally occurring hazards in coastal areas of the tropics and middle latitudes. Constant media reminders that it is “Hurricane Season” keep us all on guard and stimulate a somewhat closer watch among residents on the weather forecast portion of the evening news.

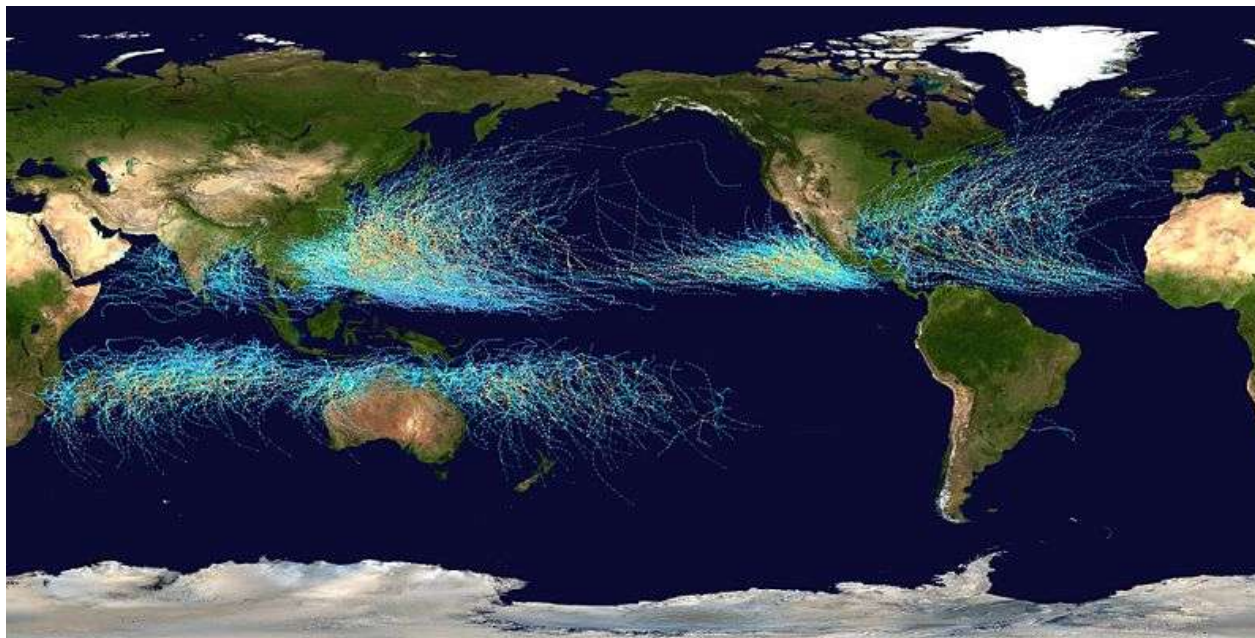
Tropical cyclones³ are classified as follows:

- Hurricane - An intense tropical weather system with a well-defined circulation and maximum sustained winds of seventy-four miles per hour or higher. In the western Pacific, hurricanes are called *typhoons*. Similar storms in the Indian Ocean are called *cyclones*.

- Tropical Storm - An organized system of strong thunderstorms with a defined circulation and maximum sustained winds of thirty-nine to seventy-three mph.
- Tropical Depression - An organized system of clouds and thunderstorms with defined circulation and maximum sustained winds of thirty-eight mph or less.

Hurricanes tend to form around a pre-existing atmospheric disturbance (an area of low pressure) in warm tropical oceans where there is high humidity in the atmosphere, light winds above the storm, and a high rate of condensation in the atmosphere. If the right conditions last long enough, a hurricane can produce violent winds, incredible waves, torrential rains, and floods.

There are on average six Atlantic hurricanes each year; over a 3-year period, approximately five hurricanes strike the United States coastline from Texas to Maine. The Atlantic and Gulf of Mexico coasts of the U.S. are famous for their vulnerability to hurricane damage but other areas are also vulnerable. In fact, there are three regions in the Northern Hemisphere known for their tendency to spawn hurricanes: the tropical Atlantic, the eastern tropical Pacific, and the western tropical Pacific. In the Southern Hemisphere there are two primary areas: the western tropical Pacific, and Indian Ocean.



Saffir-Simpson Hurricane Scale

| | | | | | | |
|----|----|---|---|---|---|---|
| TD | TS | 1 | 2 | 3 | 4 | 5 |
|----|----|---|---|---|---|---|

This map shows the tracks of all Tropical cyclones which formed worldwide from 1985 to 2005. The points show the locations of the storms at six-hourly intervals and use a color scheme shown from the Saffir-Simpson Hurricane Scale. Notice that Hawai'i lies in the corridor between the east Pacific spawning grounds and the west Pacific.⁴ [2 page spread]

Hurricanes in Hawaii

Hurricanes are relatively rare in Hawai'i, but should they run ashore on any of the islands their impact is so devastating that they top the list of local meteorological hazards. Not only is their immediate impact overwhelming but the high winds, heavy rainfall, storm surge, and large surf they generate trigger a domino effect of other hazards, including flash flooding, mudslides and other forms of mass wasting, coastal erosion, and coastal flooding. Usually it is our shoreline that receives a hurricane's most immediate and immense blow. Sitting in the crosshairs of an approaching storm, the shoreline endures the first and most severe pummeling from the wind, waves, and floods.

Hawai'i lies in the Central Pacific, which, on average, has four to five tropical cyclones (depression, storms, and hurricanes) every year. These numbers can range as high as 11 a year, such as in the 1992 and 1994 seasons, or as low as zero such as in 1979. History shows that strong winds associated with hurricanes have struck all major islands, but true landfalls are not frequent. Hurricane Dot in 1959 and Iniki in 1992 are the only two that have actually run ashore in the past half-century. Hurricane Iwa came close as it passed to the northwest of Kauai in 1982. However, a hurricane passing offshore does not have to make landfall to cause catastrophic damage. The passing glance of a nearby system can generate large waves that erode beaches and sweep onto low-lying roads and properties causing significant damage, and high winds that accelerate up and down Hawaii's steep slopes.

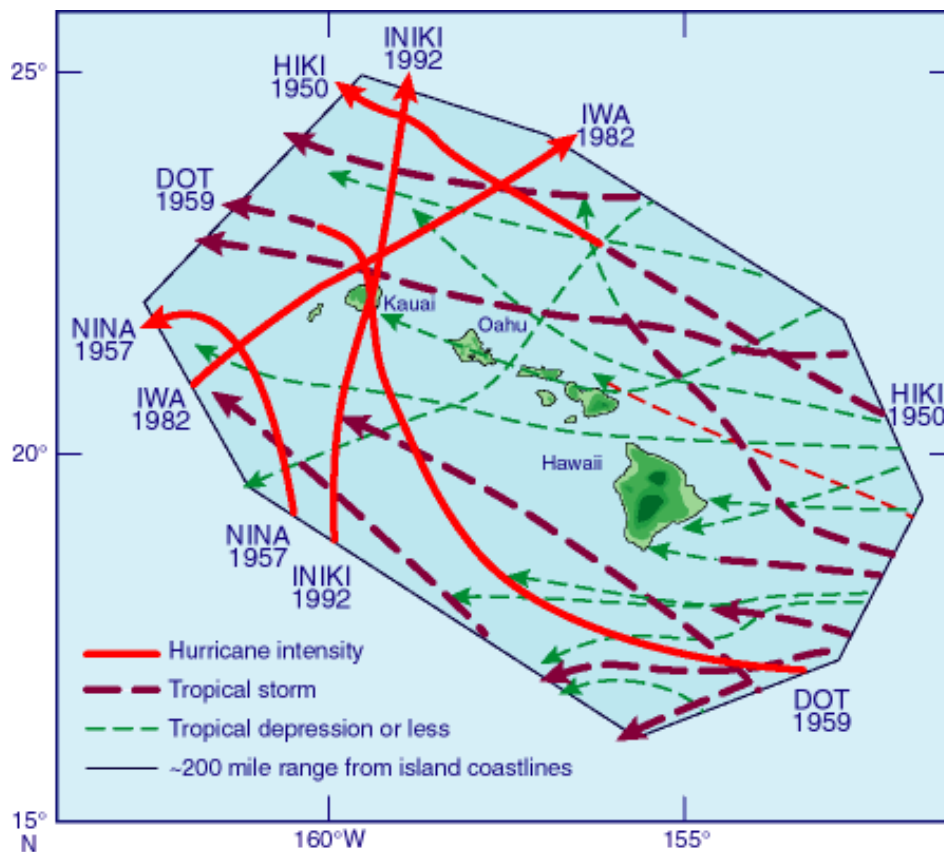
Prior to the launch of the first weather satellite in April of 1960 storm history in the trackless waters of the Pacific is sketchy and built mostly from aircraft and ship reports. The first officially recognized hurricane in Hawaiian waters was Hurricane Hiki which passed to the northeast of Oahu and Kauai in August of 1950.

Since 1950 four hurricanes have caused serious damage in Hawaii. These include: Hurricane Nina (1957) which clocked record winds in Honolulu as it passed to the southwest of the state; Hurricane Dot (1959) which made landfall on Kauai; Hurricane Iwa (1982) which passed north of Kauai on November 23rd and caused over \$200 million in damage; and most recently Hurricane Iniki (1992) which made landfall on Kauai and caused \$2.4 billion in damage to the main islands.

When They Hit

When hurricanes move onto land, the heavy rain, strong winds and large waves can damage buildings, trees, and cars. Accompanying the large waves is a high sea-level phenomenon called *storm surge*. Storm surge is a combined effect that includes low atmospheric pressure above the ocean surface causing a bulge of water that travels beneath a hurricane as well as the effect of wind shearing the water surface in the direction of hurricane forward movement. *Sea-level set-up* due to wave momentum also contributes to storm surge. The combined processes of wind shear, low pressure, and set-up can raise the water level several yards along a coastline. Add to this waves, 30 to 60 ft high (or more) formed by the winds of a hurricane, and it is easy to see why these storms are very dangerous when they intersect the shore, especially a shoreline with low topography. Storm surge causes massive damage and flooding of low-lying coastlines. Damage is compounded if a hurricane should hit at high tide, as hurricane Iniki did when it ran ashore on Kauai.

| 1971-2005 Tropical Cyclones in the Central Pacific ⁵ | | | | |
|---|------------|-----------------|----------------------|-------|
| | Hurricanes | Tropical Storms | Tropical Depressions | Total |
| Total Number | 48 | 57 | 48 | 153 |
| Average Per Year | 1.4 | 1.6 | 1.4 | 4.4 |
| Percent of All Systems | 31% | 36% | 33% | |



Hurricane tracks around the Hawaiian Islands since 1949.⁶

Hurricanes are not the only type of storm to cause damage in coastal areas, but they are the most damaging. High winds and storm surge are a primary cause of hurricane-inflicted loss of life and property damage. When a hurricane makes landfall on low-lying coastal lands, ocean waters sweep across beaches, roads, and into adjacent communities. Houses float, or are blown off their foundations. Debris torn loose is carried by the water and wind to smash into neighboring dwellings. Entire blocks of homes can be brought down in the hours that a hurricane batters the coast. Winds blow onshore at first, and when the eye of the storm passes, they blow from the opposite direction, often completing the total damage to structures severely weakened by the first winds. Heavy rains compound the coastal flooding by saturating the ground and forcing nearby streams to overtop their banks. Coastal erosion compromises any buffering effect

that beaches and wetlands may have because high waves and storm surge can strip a beach of its sand and undermine homes, roadways, and businesses.

How can damage be mitigated? The simplest and most direct way is to *avoid the hazard* by not developing the shoreline. If we stopped putting communities on the edge of the ocean, we would greatly reduce the suffering, loss of life, and enormous damage caused by hurricanes and other types of coastal hazards.

Hurricane Intensity

All hurricanes are ranked by the *Saffir Simpson Scale* according to the power of their winds.⁷ Yet, a storm’s strength fluctuates. What appears to be a weak approaching tropical disturbance may intensify into a full-blown hurricane. The vigilant National Weather Service’s Central Pacific Hurricane Center (CPHC) monitors weather patterns and tropical low-pressure centers, and tracks any suspect tropical storms.⁸ If need be, the CPHC is able to issue storm warnings at least several hours before a gale hits. When the shrill sirens blare out a state of emergency and call for evacuation, citizens are encouraged not to second-guess the CPHC’s judgment, especially because high winds and flooding may occur before the storm’s landfall.

| Saffir Simpson Scale | | | |
|-----------------------------|------------------------------|---------------------|----------------------------|
| Hurricane Category | Sustained Winds (mph) | Damage Level | Typical Storm Surge |
| 1 | 74-95 | Minimal | 5-7 ft |
| 2 | 96-110 | Moderate | 7-12 ft |
| 3 | 111-130 | Extensive | 12-15 ft |
| 4 | 131-155 | Extreme | 15-20 ft |
| 5 | >155 | Catastrophic | 20-24 ft |

Coastal flooding almost always accompanies hurricanes. In Hawai‘i, the threat is doubled because floodwaters arrive from the sea and the land. The heavy rainfall that accompanies most hurricanes can overwhelm our tiny watersheds in a blink, and narrow streams turn into flooding hazardous torrents. Standing water collects in poorly drained areas. This is especially the case where a low-lying coastal plain is flooded by high ocean waters accompanying a storm. Run-off simply cannot drain into the ocean when the storm drain system is already overwhelmed by high sea level. Compounding the situation, unlike continental coastal areas, the islands of Hawai‘i do not have a continental shelf, which makes them prone to bigger waves and marine flooding that overwhelms coastal lands.

As if flooding and high winds were not enough, hurricanes may be accompanied by bursts of extremely intense winds. These concentrated winds, called *microbursts*, can reach over 200 mph and literally blow apart any structure in their path.⁹ Another dangerous feature of hurricanes in our mountainous topography is the tendency for winds to accelerate as they climb steep slopes.

As hurricane force winds blow across the flat ocean and low-lying coastal plains they will encounter a sudden increase in elevation on the slopes of the high shield volcanoes. To maintain the volume of airflow within the storm system these leading winds must accelerate to climb the steep slopes. The wind gusts created by this process can approach and exceed 150 mph. Houses perched on ridgelines, the edge of steep slopes, and even typical valley hillsides can have their roofs torn off, leading to wall collapse and total structural failure.

These same winds can further accelerate as they cross the palis and hurtle downhill along steep contours. During Hurricane Iwa in 1982, the highest wind speeds were measured in Kāneʻohe even though the hurricane passed on the other side of the island.¹⁰ In either case of upslope or down slope winds, homes among the hills get it coming and going. A good dictum for siting your house: “If you have a nice view, you are vulnerable to wind damage.”

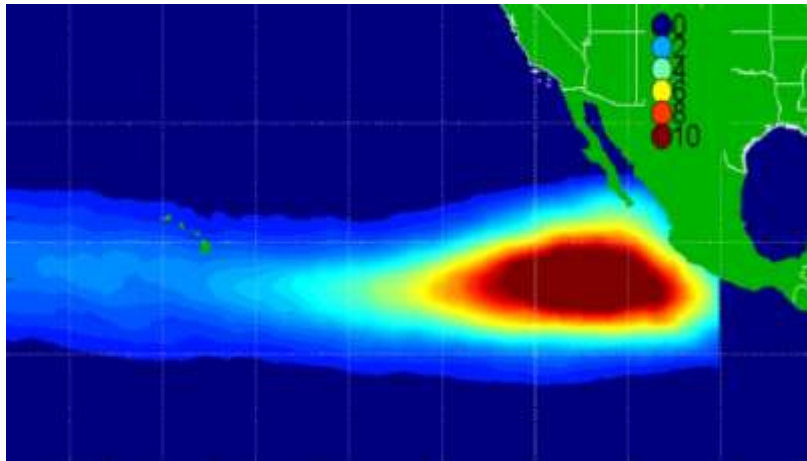


Winds during Hurricane Iniki in Kauaʻi reached Category 4 strength. The airborne wooden pallet weighs approximately forty pounds.

Storm Formation

Tropical storms that arrive in the Hawaiian Islands usually form off western Mexico and Central America in the warm coastal waters of the eastern Pacific. The hurricane season officially starts on May 15th and extends through November. However, the stormiest period generally falls from July through September.

Hurricanes forming off the Americas are designated *eastern Pacific hurricanes* when they occur east of 140 degrees west longitude. Storms occurring between 140 degrees and the International Date Line are *central Pacific hurricanes*. This distinction distinguishes which weather office tracks and forecasts the storms; eastern Pacific storms are tracked by the National Hurricane Center in Miami, and central Pacific storms are tracked by the Central Pacific Hurricane Center in Honolulu. West of the International Date Line, the hurricanes are called typhoons, and tracking is performed by the U.S. Joint Typhoon Warning Center and the Japan Meteorological Agency.



*Contours show relative hurricane risk for the Hawaiian Islands, the number of times a hurricane passes within seventy-five nautical miles in a ten year period.*¹¹

Tropical storms have been identified using both men's and women's names since 1978. A mix of English and Spanish names is used in the eastern Pacific Region, and Hawaiian names in the central Pacific Region. Storm names in the eastern Pacific are recycled every six years, and in the central Pacific four lists of names are used sequentially.

The conditions that lead to tropical cyclone formation in the eastern Pacific are the same as elsewhere in the world. With the onset of summer, a large area of warm water, high humidity, and light winds forms between 8° and 20° north of the equator with a temperature that exceeds 80° F. This heat fuels the energy of the storm.

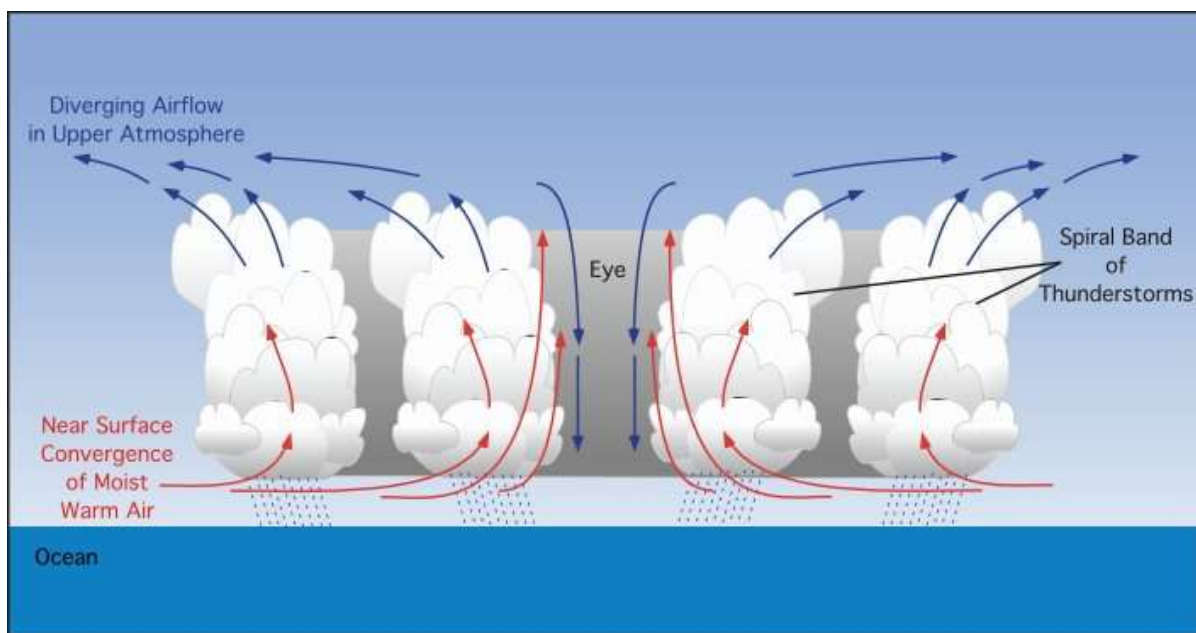
The first sign of hurricane development is the appearance of a cluster of thunderstorms over the tropical oceans, called a *tropical disturbance*. Tropical disturbances most commonly form where surface winds (such as trade winds) converge near the equator, accelerate, and develop turbulences. Given favorable conditions, a tropical disturbance can grow, indicated by falling surface pressure in the area around the storm and the development of a counter-clockwise circulation of air. Surface pressure falls as water vapor condenses and releases heat into the air causing it to rise. This lowers air pressure on the ocean surface and surrounding air flows inward toward the area of low pressure.

As the warm air rises, it expands and cools triggering more condensation, the release of more heat, and a further increase in upward air flow. This process essentially becomes a chain reaction as the rising column of air in the center of the storm causes surface pressure to lower even more, drawing air (wind) into the storm center. As the air flows in, it develops counter-clockwise circulation in the northern hemisphere and clockwise circulation in the southern hemisphere – a consequence of the *Coriolis Effect* caused by Earth's rotation. As the process of condensation, heat release, and air circulation continues, it generates more thunderstorms, more heat, lower surface pressure, stronger winds, and so on. In the right circumstances, this process can build and gain strength.

At the top of the storm, atmospheric pressure begins to rise in response to the rising column of warm air. This causes air to flow outward (diverge) around the top of the disturbance. Like a

chimney, this upper-level area “vents” the tropical system and prevents the air converging on the ocean surface from piling up around the center. If it did, surface pressure would rise inside the base of the storm and ultimately destroy it.

As a hurricane gathers strength, the center develops into a five to forty mile-diameter cloud free area of sinking air and light winds, called the *eye*. The eye is the calmest part of the storm. This is because the strong cyclonic winds that accelerate towards the center never actually reach the exact center of the storm. Instead, the winds form a cylinder of intensely fast airflow, called the eye wall, surrounding a cylinder of relatively calm, downward flowing air. Like an ice skater whose body spins faster as her arms are drawn inward, air near the center speeds up as it spirals in towards (but never reaching) the eye. Hence, the winds form an intense high velocity band ringing the eye characterized by tall thunderstorms, heavy rain, and destructive winds.



*Vertical cross-section of air circulation, clouds, and precipitation in a hurricane*¹².

The most dangerous section of the storm is in the eye wall on the right side of the eye. This is where the wind blows in the same direction as the storm's forward motion adding the forward speed of the storm to the speed of the wind. For example, in a hurricane moving due north at twenty mph with eye wall winds at 125 mph, the most intense airflow is found on the eastern side of the storm where the winds blow north at 145 mph. On the west side of the eye the same winds would be southerly at 105 mph.

Even when conditions are ripe for storm formation on the ocean surface, high altitude winds or descending columns of air can prevent a disturbance from developing. For example, in the region of 20° to 30° latitude, the air aloft is often sinking because of the presence of a semi-permanent high pressure system called the *North Pacific High*.¹³ As the air in the North Pacific High sinks, it warms. This prevents the formation of an upward-moving column of air necessary

to make a storm. In addition, strong upper-level winds in some areas tend to “decapitate” thunderstorms by dispersing rising air and preventing a storm from getting organized.

Three conditions usually cause a hurricane’s death:

- 1) the storm moves over cooler water that can't supply warm, moist tropical air;
- 2) the storm moves over land, also cutting off the source of warm, moist air; and
- 3) the storm migrates into an area where high altitude air flow disrupts storm circulation.

Tracking Hurricanes

Tropical storms formed in the eastern Pacific tend to drift westward or to the north into the open North Pacific. As the season progresses, more hurricanes steer northward paralleling the American Pacific Coast and ultimately meeting their fate in the colder waters. It is the trade winds that steer most Pacific hurricanes from their place of birth westward into the open ocean. This track ensures that few hit land.

The storms that do make landfall usually strike along the Mexican coast. If a storm were to curl back toward the coast of California, its impact would be muted by the cold waters of the California Current that flow southward along the coastline with temperatures that rarely exceed 60° F. In fact, because it is protected by the current of cold water, hurricanes are unlikely to hit California.¹⁴ The same cannot be said of tropical storms however. In September 1939, winds of fifty mph struck the Los Angeles–Long Beach area as part of a tropical Pacific storm that produced 5.6 inches of rain in Los Angeles and over 11.6 inches at Mount Wilson. The storm claimed forty-five lives (mostly at sea) and caused two million dollars of damage to crops and coastal development.¹⁵ Has California ever been hit by a hurricane? The answer is “sort of.” In 1858 the coastline from San Diego to Long Beach was raked with damaging winds, some reaching hurricane strength, generated by a low pressure system that tracked offshore, probably without the eye actually making landfall.¹⁶

The majority of central Pacific hurricanes that capture our attention also originate in the warm, tropical waters off the Mexico coast. Every few years a storm will move along a path that is west by northwest toward Hawai‘i. However, most of these diminish before reaching the islands because waters to our east and northeast are generally too cool to sustain a hurricane’s intensity.

Figuring out the history of hurricanes in the Pacific has been complicated by the lack of direct observations prior to the modern era of satellites. Most hurricanes spend their lives over trackless waters of the east Pacific where few ships and even fewer islands are available to report their position and intensity. The majority of hurricanes went undetected prior to the 1960s. But as global weather satellites came on-line, meteorologists were surprised to learn that eastern Pacific hurricanes are rather frequent phenomena with patterns of movement that follow semi-predictable pathways.

Eastern Pacific hurricanes can make landfall along the Central American coast potentially hitting the nations of Mexico, Guatemala, El Salvador, Nicaragua, Costa Rica, and Panama. When these storms do make landfall they bring with them strong winds, raging surf, storm surge, and heavy rains. These of course often lead to flash flooding, landslides, mudslides and other associated hazards. In downgraded form as tropical storms, East Pacific hurricanes can lead to

heavy rainfall and gusty winds in the southwest states of California, Arizona, New Mexico and as far east as Oklahoma and Texas.

Hurricane John in 1994 is the longest living Pacific hurricane on record.¹⁷ Over thirty-one days it tracked across 4,000 miles of eastern and central Pacific waters. On two different occasions John's winds reached the alarming speed of 170 mph, it crossed the international date line twice (becoming "Typhoon John" in the process), and thankfully skirted the Hawaiian Islands to the south and west in the process.

Lest you think there is no relationship between Atlantic and Pacific hurricanes, a few storms have tracked across from the Gulf of Mexico into the Pacific, and (more rarely) from the Pacific into the gulf. Hurricanes that cross the Central American landmass typically lose energy quickly and degrade to tropical storms. But on occasion, a weakened storm re-entering the ocean can strengthen and gather energy if it encounters a warm pool of water. Hurricane Cosme left the Eastern Pacific in 1989 to become Atlantic Tropical Storm Allison.¹⁸ There was even a "hurricane with three names" in 1961 when an Atlantic storm crossed into the Pacific, regained hurricane strength in the east Pacific warm pool, and doubled back into the Gulf of Mexico again!¹⁹

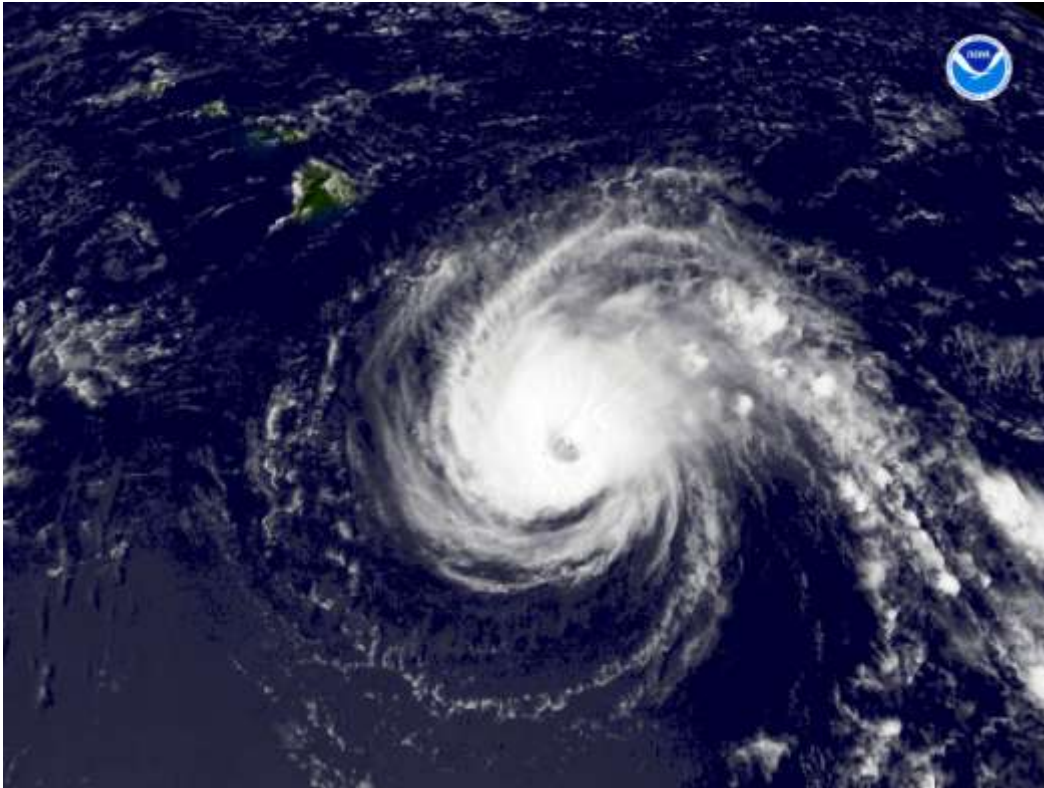
El Niño and Hurricanes

El Niño, in addition to controlling episodes of major drought, plays an important role in the location of hurricane genesis in the Pacific. During the onset year of an El Niño, changes in the wind pattern of the central Pacific create a zone of disturbances between equatorial west-flowing winds and subtropical east-flowing winds. Under the right conditions, these disturbances can grow into hurricanes.

El Niño warm phases in the Southern Oscillation have corresponded to some of the largest annual storm counts in the central Pacific.²⁰ However, the relationship is not unique because although 1972, 1982, and 1992 were warm phase years and major storm years, 1978 was not an El Niño year, yet it still had as many storms as the warm phase years, and 1977 was a warm phase year and the central Pacific storm count was zero.

Pao-Shin Chu, a University of Hawai'i meteorology professor, reported in a 1997 study of tropical cyclones that El Niño years produce more Pacific tropical storms, and that with some exceptions, their tracks are more erratic than in non-El Niño years.²¹ If this is the case, then terms like "100-year storm" or "50-year storm" are misleading, and may lull people into thinking Iniki or Iwa, the last two hurricanes to strike Hawai'i, warrant our safety for many years to come.

Unfortunately, more often than we like or plan for, the path of a hurricane clips or intersects the islands. Four hurricane-strength tropical cyclones have moved across the Hawaiian Islands since statehood in 1956: Nina in 1957, Dot in 1959, Iwa in 1982, and Iniki in 1992.²² Kauai's position is located further west than the other islands and therefore is more likely to lie in the path of a hurricane hooking to the north after passing south of the Big Island. This effect was seen in Hurricanes Dot, Iwa, and Iniki, all of which passed over the Kaua'i and Ni'ihau Island zone.²³ More recently, hurricane Flossie, a category 4 storm when it began life in the east Pacific, passed south of the Big Island in a downgraded state in August of 2007. The storm produced strong swell that hit exposed shores of all the islands and heavy rainfall on the Big Island and triggered a flash flood watch.



Hurricane Flossie on August 14, 2007; Flossie passed approximately 100 miles south of the Big Island. In a typical year, four to five tropical cyclones form or cross into the central Pacific, two of which on average reach hurricane intensity.²⁴

Global Warming and Hurricanes

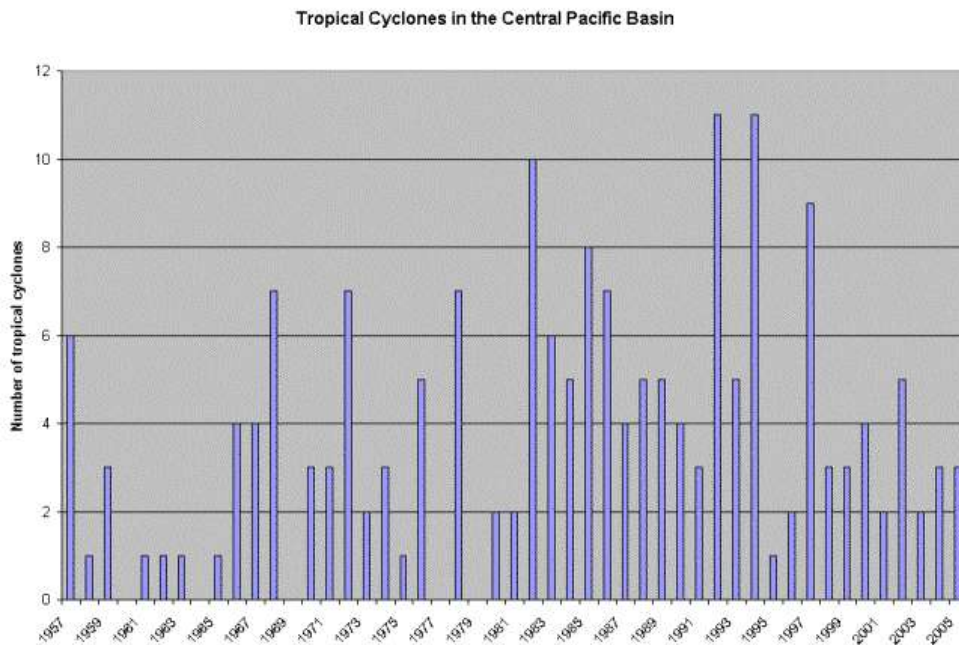
The theory that global warming will spawn more hurricanes and that more of them will be big storms is well accepted. Proving it with direct observations of hurricane history, however, is turning out to be vexing. Warmer air should lead to warmer water which should provide more heat to both build and supercharge storms. The problem is that the history of instrumented observations recording hurricanes is only as old as the global satellite network, and this is not long enough to confirm an unequivocal link to global warming.

For example, one study in 2005 concluded that hurricanes and typhoons have become stronger and longer-lasting over the past thirty years and that these changes correlate with a rise in sea surface temperatures over the same time period.²⁵ Kerry Emanuel, a professor of atmospheric science at the Massachusetts Institute of Technology, reported that the duration and strength of hurricanes increased by about 50% in the past three decades. This observation revised existing models for measuring storm strength, which suggested that the intensity of hurricanes and typhoons should only increase by 5% for every 1°C (1.8°F) rise in sea surface temperature. Emanuel said “We’ve had half a degree [Celsius] of warming, so that should have led to a 2.5% increase [in intensity], which is probably not detectable. What we’ve seen is somewhat bigger than that, and we don’t really know why.”²⁶ Emanuel speculated that ocean temperatures may be

increasing more quickly than atmospheric temperatures. “When that happens we've shown theoretically you get an increase in the intensity of hurricanes,” he said.

However, by April of 2008, Emmanuel was changing his stand. He unveiled a novel technique for predicting future hurricane activity suggesting that, even in a dramatically warming world, hurricane frequency and intensity may not substantially rise during the next two centuries.²⁷ “The results surprised me,” Emanuel said of his work, adding that global warming may still play a role in raising the intensity of hurricanes. What that role is, however, remains far from certain.

Another study by scientists at the Georgia Institute of Technology and the National Center for Atmospheric Research in Boulder, Colorado, suggested that the number of category four and five hurricanes has almost doubled globally over the past three decades.²⁸ These results indicate that a substantial increase has occurred in all the major tropical storm basins of the world with the greatest increases in the north Pacific, Indian, and southwest Pacific oceans. However, a key question for all studies of the relationship between hurricanes and global warming is the quality and degree of agreement in the storm intensity and frequency data being used, a subject of vigorous debate in the hurricane research community. Indeed the Georgia study has been criticized for drawing conclusions from a historical database that may suffer from sampling errors.



Is global warming changing the intensity or frequency of hurricanes? According to the 2007 Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC-AR4), it is “more likely than not” (better than even odds) that there is a human contribution to the observed trend of hurricane intensification since the 1970s. In the future, “it is likely [better than 2 to 1 odds] that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of

tropical [sea surface temperatures].” According to the IPCC-AR4, on a global scale, “[t]here is no clear trend in the annual numbers [i.e. frequency] of tropical cyclones.” However, the frequency of tropical storms has increased dramatically in the North Atlantic and this tends to drive public awareness of the potential role of global warming. Reasons for the North Atlantic increase are subject to intense debate among climate scientists. At least one peer-reviewed study indicates a significant statistical link between increasing intensity of the strongest storms and global warming²⁹, but research to identify a mechanism explaining this link is ongoing. Notably, this study does not show a significant trend of growing storms in the Pacific, only in the Atlantic and the Indian oceans.

Relevant to this discussion is the actual number of tropical cyclones happening in recent years in the central north Pacific. In 2004, the total activity was slightly below normal, with three cyclones occurring compared to the annual average of four to five. One tropical cyclone developed within the central Pacific and the other two, Darby and Estelle, moved into the area from the eastern Pacific. Estelle was the strongest of the three systems and the only one of tropical storm intensity. There were no deaths recorded or property damage reported in the central north Pacific due to these three tropical cyclones.

With three systems in 2005, the total activity for the tropical cyclone season was below normal. One tropical cyclone developed within the central Pacific and the other two, Jova and Kenneth, moved into the area from the eastern Pacific. Jova was the strongest of the systems, maintaining category 3 strength for 36 hours, and the strongest tropical cyclone in the central Pacific since Ele in 2002. Although two storm remnants contributed to some locally heavy rainfall across Hawaii, there were no deaths recorded or significant property damage reported in 2005.

In 2006, the central Pacific tropical cyclone season had near normal activity despite the development of a relatively weak El Nino in September 2006. A total of five tropical cyclones occurred during the season, including two hurricanes. One of the hurricanes, Ioke, reached category 5 intensity and set several central Pacific tropical cyclone records. The other three systems only reached tropical depression intensity.

Although the average number of hurricanes between 1995 and 2006 is probably unprecedented on a global basis, there has not been a long-term increase in hurricane frequency overall. Instead, there have been periods of high hurricane activity that last for several decades, followed by decades of low activity. The 1920s-30s and 1950s-60s were active periods.³⁰ In 1995, we entered and are currently in the latest natural phase of high hurricane frequency, which is expected to persist for another decade or two. What is the last word on the connection between global warming and hurricanes? Leave it to the experts, they haven’t figured it out yet.

Hurricane Iniki: The wake-up call.

Hurricane Iniki engulfed Kaua‘i on September 11, 1992, with 130 mph winds and gusts up to 160 mph.³¹ Iniki’s winds, waves, and flooding destroyed 1,421 buildings, and damaged another 6,292, totaling 90% of all houses, buildings, and structures on the island. An additional 607 buildings on other islands were damaged or destroyed from the pounding surf.³² This level of damaged proved to be crushing to the economy of Kauai which was not seen to recover for another decade.

The hurricane's devastating waves penetrated well beyond the shoreline, smashing buildings, ripping up roads, tearing down power lines, filling swimming pools with sand so that they disappeared from view, and spreading boulders, gravel, and debris across properties and roads. Survey parties measured watermarks higher than fifteen feet above sea level on interior walls of demolished homes, trees, and among the vegetation in open fields. At eye level, the trunks of coconut trees were bruised, smashed, and had been laid open to their core by cobbles and coral heads suspended in the swirling flood waters and surging waves. However, the most severe cause of property damage from Iniki was its turbulent wind.

The wind sucked roofs and walls off of houses, leaving the interiors exposed to torrential rains, and contributing to the wind-borne debris hurtling into adjacent buildings. Many houses were uprooted and pulled from their footings by the strong winds or floodwaters. Almost mysteriously, while one house blew to shreds, the next-door neighbor would survive with minor damage – the product of proper engineering and careful construction. In some cases, the margin between total structural failure and only moderate damage was determined by whether a single line of roofing nails was well aimed and found the underlying joist, or missed and failed in its job of anchoring a plywood roofing sheet to the frame of the house.³³

Although there were only six fatalities, Iniki was the most costly natural disaster in Hawaii's recorded history. At \$2.4 billion in losses, it ranks as one of the top ten costliest hurricanes in U.S. history.³⁴ Thousands of people were left homeless, 100 injured, and many lives were disrupted for years after, as Kaua'i struggled to recover. For a decade following the event, Kaua'i remained in the grip of a recession as tourism shifted to the less damaged islands.³⁵ Iniki was neither a particularly large hurricane nor unusual in terms of frequency of occurrence yet its impact was still devastating over an extended period of time. The shock and destruction are indelibly printed in the memory of those who experienced the storm and suffered through its aftermath.

How Much Damage Can a Hurricane Cause?³⁶

If a Category 1 storm as strong as Hurricane Iwa, with sustained winds at 74 mph, strikes any of the islands in the state, we can estimate from past experience that about 12% of the houses and apartments will be destroyed or heavily damaged and about 18% will experience minor damage.

If a Category 4 storm strikes any island with the force of Iniki, with winds raging at over 130 mph, we can estimate that about 38% of the homes will be heavily damaged or destroyed. An additional 40% will probably have minor damage.

The following information was extrapolated from Kaua'i Damage in 1982 and 1992.

Potential Hurricane Damage in Hawai'i (billions of \$)

| | O'ahu | Maui | Hawai'i | Kaua'i |
|-----------------------------|--------------|-------------|----------------|---------------|
| Iwa-Strength Storm | \$4.5-7.5 | \$0.8-1.4 | \$0.8-1.4 | \$0.3-0.6 |
| Iniki-Strength Storm | \$13.9-23.3 | \$2.7-4.5 | \$2.6-4.4 | \$1.1-1.9 |

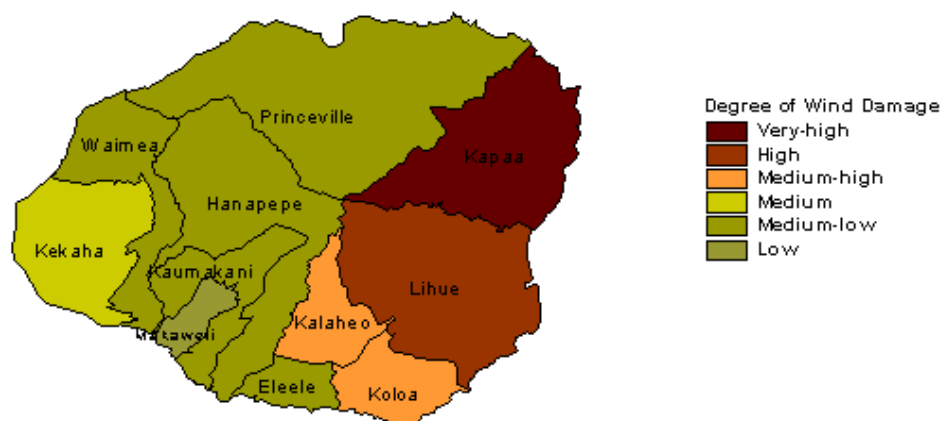
What Determines the Level of Damage During a Hurricane?

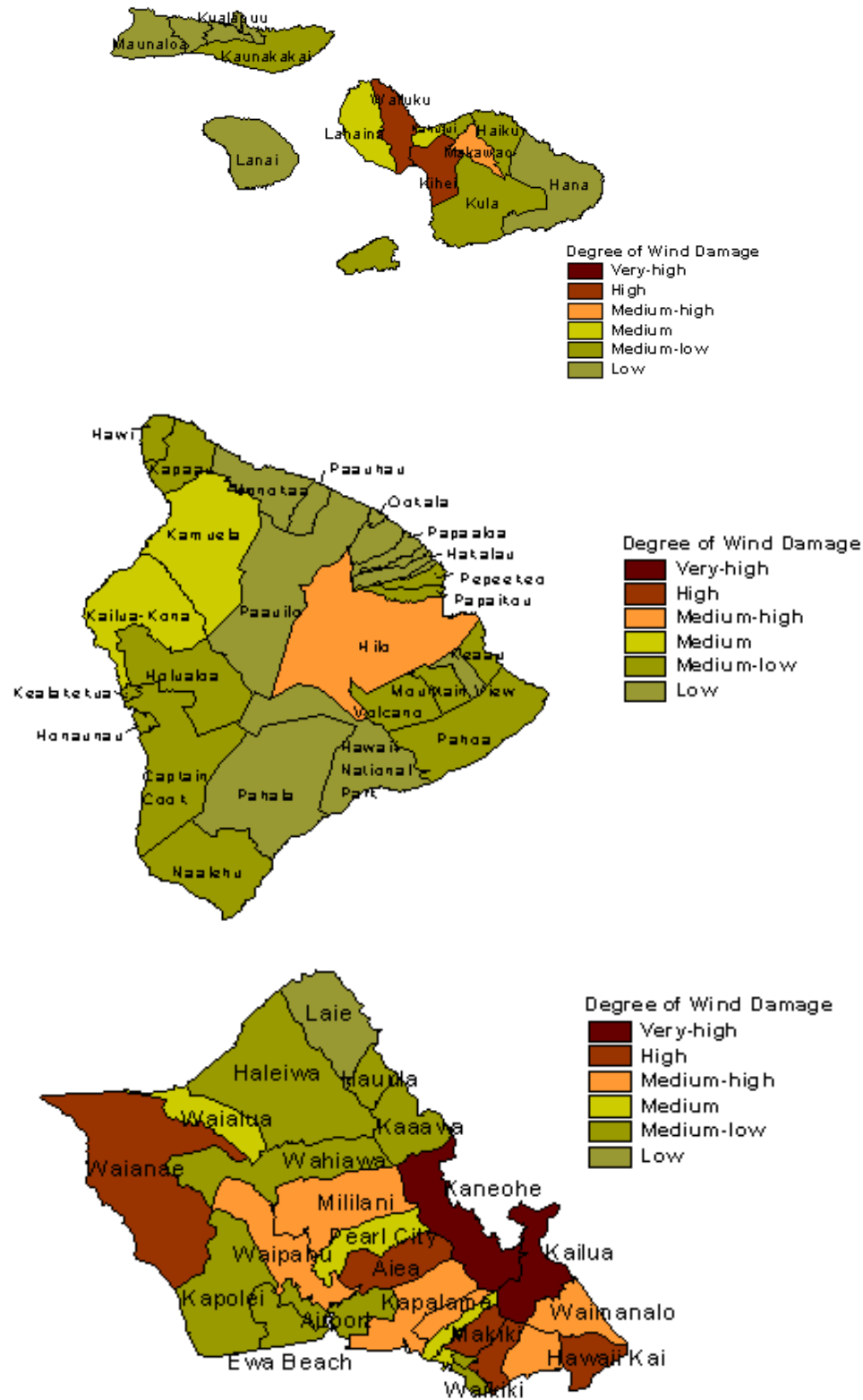
Although warning systems and evacuation procedures have improved over the years, the best way to mitigate damage is to build in areas less susceptible to high winds and flood waters and their associated hazards, and to upgrade building codes as new construction materials and techniques become available. The single most important step to mitigate hurricane damage is to build away from the coast, ridgelines, and exposed hillsides, to build homes with continuous load paths from the foundation to the uppermost components of the roof, and to minimize external features such as eaves, balconies, and other structural components that are easily ripped off by high winds. These breach the envelop of a building and render it vulnerable to further destruction by the high gusts associated with winds near the eye wall of the storm as it passes across an island.

The greatest building damage during a hurricane occurs in the area of highest winds and strongest storm surge. However, it is not so obvious where highest winds and storm surge will occur. The damage a building may experience depends on several factors: the track of the storm, position to the left or right of the eye, exposure to the open ocean and free or accelerated airflow, the topography of the surrounding landscape, and the construction and design of the building.

There is no way of knowing the chances of a hurricane damaging a particular home. We can only go on past history. Almost no one expected a hurricane as powerful as Iniki to strike Hawai'i. The best we can guess is that hurricanes in the future will probably hit Hawai'i as frequently as they have in the past. Unfortunately, this is like driving down the highway looking in the rearview mirror, not the most desirable way to predict what lies ahead – especially since the conditions of Pacific climatology appear to be changing with global warming.³⁷ In addition, increased development, increased alteration of watersheds, and increased loss of beaches add up to the likelihood of increased property losses in future storms.

These maps show insurance claims island by island. Although they are no predictor of the future, they do reveal regions on each island that have been subject to the greatest wind-related damage claims for insurance in the past.





Homeowner insurance policy claims 1989 to 1999 – by island.³⁸

STAY OUT OF HARM'S WAY³⁹

Recommendations on what to do before, during, and after a hurricane:

Stay or leave?

- When a hurricane threatens your area, you will have to decide whether you should evacuate or whether you can ride out the storm in safety at home. If local authorities recommend evacuation, you should leave!
- If you live on the coastline, an offshore island, near a stream/river or in a flood plain, a high-rise or mobile home, plan to leave.
- If you live in a sturdy structure and away from coastal and rainfall flooding, consider staying.

At the beginning of hurricane season

- Learn the elevation and the flooding and wind damage history of your area.
- Learn safe routes inland if you live near the coast.
- Learn location of official shelters.
- Determine where to move your boat in an emergency.
- Trim back dead wood from trees.
- Check for loose rain gutters and downspouts.
- If shutters do not protect windows, stock tape and boards to cover glass.

When a hurricane watch is issued

- Check often for official bulletins on radio, television, or National Oceanic and Atmospheric Administration Weather Radio.
- Fuel car.
- Moor small craft or move to safe shelter.
- Stock up on canned provisions.
- Check supplies of special medicines and drugs.
- Check batteries for radio and flashlights.
- Secure lawn furniture and other loose material outdoors.
- Tape, board or shutter windows to prevent shattering.
- Wedge sliding glass doors to prevent their lifting from their tracks.

When a hurricane warning is issued

- Stay tuned to radio, TV or NOAA Weather Radio for official bulletins.
- Stay home if sturdy and away from the coast.
- Board up garage and porch doors.

- Move valuables to upper floors.
- Bring in pets.
- Fill containers (bathtub) with several days' supply of drinking water.
- Turn up refrigerator to maximum cold and don't open unless necessary.
- Use phone only for emergencies.
- Stay indoors on the downwind side of the house, away from windows.
- Beware of the eye of the hurricane.
- Leave areas that might be affected by storm tide or stream flooding.
- Leave early, in daylight if possible.
- Shut off water and electricity at main stations.
- Take small valuables and papers, but travel light.
- Leave food and water for pets (shelters will not take them).
- Lock up house.
- Drive carefully to nearest designated shelters using recommended evacuation routes.

After the "all-clear" is given

- Drive carefully; watch for dangling electrical wires, undermined roads, flooded low spots.
- Don't sight-see.
- Report broken or damaged water, sewer and electrical lines.
- Use caution when re-entering home. Check for gas leaks. Check for food and water spoilage.

Mitigation Activities at Home⁴⁰

Homes can be destroyed by high winds. Flying debris can break windows and doors, allowing high winds and rain into your house. High winds can also cause weak places in your home to fail. Strengthen these areas in your house: roofs, exterior doors, windows, and garage doors. Other mitigation activities include clearing debris from the area and building a safe room in your home.

Roof:

Gable roofs need additional truss bracing to make your roof system stronger. Truss bracing consists of 2x4s running the length of your roof and gable-end bracing consists of 2x4s in an X pattern. Hurricane straps and clips can also keep your roof attached to your walls and are very inexpensive. For a 1,200 square foot house, hurricane clips might cost between \$400 and \$600. Learn more about protective measures from your local home improvement store.

Exterior Doors:

Most double-entry doors have an active and inactive door. Check to see if the fixed door is secure enough. Some door manufactures provide reinforcing bolt kits or you can buy and install door bolt materials. Check with your local home improvement store.

Windows:

There are many types of manufactured storm shutters or you can make your own plywood shutters. Plywood shutters should be made of 5/8 inch exterior plywood and installed using bolts and masonry anchors. Remember to cover all exposed windows and glass, even French doors and skylights. Hurricane shutters cost between \$1.67 per square foot to \$50.00 per square foot for motorized roll-up shutters. Check with your local home improvement store.

Garage Doors:

Two-car garage doors pose a problem because they wobble in high winds and can blow out of their tracks and collapse. Some garage doors can be strengthened with retrofit kits. Installing horizontal bracing on each can reinforce some garage doors. Backing a car up against the inside of the garage door in the event of a hurricane can also help resist strong winds. Check with your local home improvement store.

Clear Debris:

Clear debris away from structures, so they do not become airborne missiles. Check with local officials about tree pruning and clearing for additional information.

Safe Rooms:

There are several options for building a safe room. A safe room made of concrete would have 8-inch mortar-filled tile walls and a 4-inch concrete ceiling, all supported with iron reinforcing rod. A wood-framed safe room would have doubled 2-by-4 studs, set 16 inches on center, faced on one side with ¾-inch plywood and on the other with 12-gauge steel, and sheathed inside and out with ½-inch gypsum board. Go to your local library for additional information. (*mothernature-hawaii.com*)

¹ Joseph A. Angelo, Space Technology, pg 213 (Greenwood Publishing Group 2003).

² Kerry A. Emanuel, Divine Wind: The History and Science of Hurricanes, p 18 (Oxford University Press 2005).

³ See Wikipedia entry for a discussion of Tropical Cyclones: http://en.wikipedia.org/wiki/Tropical_cyclone

⁴ Image from Wikipedia: http://en.wikipedia.org/wiki/Tropical_cyclone

⁵ National Weather Service, Climatology of Tropical Cyclones in the Central Pacific Basin: <http://www.prh.noaa.gov/cphc/pages/climatology.php>

⁶ Charles Fletcher et al., Atlas of Natural Hazards in the Hawaiian Coastal Zone, Geological Investigations Series I-2761 (U.S. Government Printing Office 2002).

⁷ For more information about the scale, see the National Hurricane Center <http://www.nhc.noaa.gov/aboutshs.shtml>.

⁸ The CPHC is run by the National Weather Service at NOAA. For more information, see <http://www.prh.noaa.gov/hnl/cphc/>.

⁹ See Tetsuya Theodore Fujita, The Downburst: Microburst and Macrobust (University of Chicago 1985).

¹⁰ City and County of Honolulu, Hawaii Hazard Mitigation Forum, O'ahu, http://www.mothernature-hawaii.com/county_honolulu/hurricane_what_are-O'ahu.htm.

¹¹ O'ahu Civil Defense Agency, 2003

¹² See Physical Geography.net Fundamentals eBook. Illustration from <http://www.physicalgeography.net/fundamentals/7u.html>

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- ¹³ See Chapter 5.
- ¹⁴ Jack Williams, Background: California's Tropical Storms, USA Today (May 17, 2005).
- ¹⁵ Tropical Storms, *supra* note 14.
- ¹⁶ Chenoweth, M., and Landsea, C., The San Diego hurricane of 2 October, 1858. *Bulletin of the American Meteorological Society*, v. 85, Issue 11, p. 1689-1697.
- ¹⁷ NOAA, CPHC, The 1994 Central Pacific Tropical Cyclone Season, <http://www.prh.noaa.gov/cphc/summaries/1994.php>.
- ¹⁸ To see the course Tropical Storm Allison took, see <http://www.hpc.ncep.noaa.gov/tropical/rain/allison1989.html>.
- ¹⁹ Bryon Norcross, Hurricane Almanac: The Essential Guide to Storms Past, Present and Future, p 74 (Macmillan 2007).
- ²⁰ Fletcher et al., *supra* note 6.
- ²¹ P.S. Chu and J.X. Wang, Tropical Cyclone Occurrences in the Vicinity of Hawaii: Are the Differences Between El-Nino and non-El-Nino Year Significant?, *J. Climate* 10, 2683-89 (1997).
- ²² Dennis Hwang, Hawaii Coastal Hazard Mitigation Guidebook, p 43 (January 2005).
- ²³ Guidebook, *supra* note 22.
- ²⁴ National Oceanic and Atmospheric Administration, NOAA expects slightly below average Central Pacific hurricane season, May, 19, 2008: http://www.noaanews.noaa.gov/stories2008/20080519_pacific.html
- ²⁵ Kerry Emanuel, Increasing Destructiveness of Tropical Cyclones Over the Past 30 Years, *Nature*, Vol. 436 (Aug. 4, 2005).
- ²⁶ Increasing Destructiveness, *supra* note 25.
- ²⁷ Emanuel, K., Sundararajan, R., Williams, J., 2008 Hurricanes and global warming: Results from downscaling IPCC AR4 simulations; *American Meteorological Society*, v. 89, issue 3, p. 347-367.
- ²⁸ P.J. Webster et al., Changes in Tropical Cyclone Number, Duration, and Intensity in a Warming Environment, *Science*, Vol. 309, No. 5742, pp 1844-46 (Sep. 16, 2005).
- ²⁹ The increasing intensity of the strongest tropical cyclones. James B. Elsner, James P. Kossin & Thomas H. Jagger *Nature* 455, 92-95(4 September 2008) doi:10.1038/nature07234
- ³⁰ See NOAA, Central Pacific Hurricane Center, Climatology of Tropical Cyclones in the Central Pacific Basin, <http://www.prh.noaa.gov/cphc/pages/climatology.php>
- ³¹ County of Kauai, Hawaii Hazard Mitigation Forum, Hurricane, http://www.mothernature-hawaii.com/text_only/kauai/hurricane_what_are-kauai.htm.
- ³² Cyclone Season, *supra* note 17.
- ³³ FEMA, Building Performance: Hurricane Iniki, FIA-23 (Mar. 1993).
- ³⁴ Cyclone Season, *supra* note 17.
- ³⁵ Anthony Sommer, A Decade After the Disaster Iniki, *Star Bulletin* (Sep. 8, 2002).
- ³⁶ See: <http://www.mothernature-hawaii.com/index.html>
- ³⁷ See Chapter 8 for information on climate change.
- ³⁸ See: <http://www.mothernature-hawaii.com/index.html>
- ³⁹ See: <http://starbulletin.com/2002/05/19/news/story2.html>
- ⁴⁰ See: <http://www.mothernature-hawaii.com/index.html>