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The refraction of light as it passes between layers of air at different temperatures also produces mirages. In the lower layers, atmospheric gases are well mixed by turbulent winds. At about 62 miles (100 km) above Earth gravitational effects become larger than the turbulent mixing and gases begin to separate based on their mass. A small fraction of the lightest gases, hydrogen and helium, achieve escape velocities and leave Earth.

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Thunder continued

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Hailstorms

Severe thunderstorms generate wild, gusty winds and damaging hailstones. Hailstorms are most common in the mid-latitudes, particularly in spring and summer. While most hailstones are the size of a pea, some grow as large as golf balls or even oranges. Lobes and asymmetric shapes occur for rare, extremely large hailstones.

Hail damage Hailstones can damage cars, smash windows and roofs, and, most serious, they destroy crops. They also present an aviation hazard, although the advent of onboard radar has lessened this risk.

Threats from hailstones include:

- **Crop damage**: A single hailstorm can reduce a farmer’s annual income to nothing.
- **Busted nose**: This aircraft en route from Geneva to London was unfortunate to get caught in hailstorm. Aircraft are designed to withstand such punishment.
- **Busted skylight**: A hailstorm in Stavropol, southern Russia left this woman’s roof peppered with holes. Hundreds of homes were damaged in the city.
- **Box head**: The largest hailstone ever recorded (illustrated head) fell at the town of Aurora, Nebraska, U.S.A. on June 23, 2012. Its circumference measured 18.75 inches (47.62 cm).
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CHAPTER 156

EXTREMES

EXTREMES CHAPTER

A small fraction of the light of the sun is scattered by dust particles, cloud droplets, and gas molecules in the atmosphere. These coarse particles reflect incoming light, causing clouds that seem white, gray, or almost black. While cloud droplets are colorless, when large masses of droplets reflect incoming light, they create clouds that seem white, green, or almost black. Cloud patterns are monitored from satellites and meteorologists to track weather. Dust particles, cloud droplets, and the Earth's atmosphere are composed of heterogeneous mixtures. The atmosphere is divided into five layers, with all of Earth's weather occurring in a region of these layers called the troposphere. All weather phenomena result from interactions between solar energy, air, and water vapor carried within the weather system.

The lowest layer of the atmosphere, the troposphere, is the region where all weather events occur. This layer is divided into several sub-layers, each with its own characteristics and processes. The troposphere is the layer that we interact with most directly, as it is the layer where weather phenomena such as clouds, precipitation, and turbulence occur. The troposphere is also the layer where most of the Earth's weather events occur, with around 90 percent of all weather events taking place in this layer.

MIXED LAYERS

In the lower layers, the atmosphere's air and layers are turbulent, but as the air descends, the air becomes more dense and the air layers become more stable. The turbulence and mixing of air and gases become larger than the gravitational forces that hold Earth's atmosphere in place. These forces become larger than the gravitational forces that hold Earth's atmosphere in place. These forces are called escape velocities and leave Earth. The lowest layer of the atmosphere, the troposphere, is the layer where all weather events occur. This layer is divided into several sub-layers, each with its own characteristics and processes. The troposphere is the layer that we interact with most directly, as it is the layer where weather phenomena such as clouds, precipitation, and turbulence occur. The troposphere is also the layer where most of the Earth's weather events occur, with around 90 percent of all weather events taking place in this layer.

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Tornado Structure

A supercell thunderstorm is a severe storm characterised by a strong, rotating updraft. Under the right conditions, the system elongates downstream to become more compact, causing it to rotate faster, finally reaching the ground as a tornado. Within the body of the tornado, incredibly intense mini tornadoes, called suction vortices, sometimes form.

Inside a tornado Warm moist air entering the updraft (1) interacts with cool air from the downdraft (2). Air rises on the outside of the tornado (3) while the whole column of air rotates (4). Inside the tornado the air pressure is very low. This creates the visible condensation funnel and causes air in the core to sink (5). Because the winds around each suction vortex (6) are much faster than the winds around the tornado (4), each suction vortex carves its own looping path into the ground (7) as it circulates the outside of the tornado.

FACT FILE

Building rotation
Wind speed increasing with height, a gust front diving under the inflow, or a wall cloud downdraft meeting an updraft are three ways wind shear is created. When an updraft raises air only on one end of that band of shear, the shear turns into rotation about a vertical axis.

FACT FILE

Suction vortices
Some large diameter tornadoes develop as many as six suction vortices within them. They form within the chaotic winds by a process known as vortex breakdown.

Moving music
Tornado suction vortices are astonishingly powerful. This grand piano was picked up and hurled one quarter of a mile (400 m).

Rope tornado
This photogenic tornado soars across an Oklahoma field on May 22, 1981. As the gap between top and base of the tornado narrows, the funnel cloud narrows until it breaks apart and dissipates.

Angular momentum conservation
Increasing the column draws air in. Spiraling inward air gains speed as its angular momentum is conserved, causing the tornado to narrow. This is why a skater can spin faster by pulling her arms in.

FACT FILE

5 Surface inflow (blue arrows) converge and rise inside the tornado (orange). The net motion is a spiral (green).

2 The air pressure inside drops as the tornado grows stronger. The air in the core starts to sink (yellow).

3 The tornado continues to intensify, further lowering the air pressure inside. The air in the core sinks even farther.

4 When the downward moving air reaches the ground and spreads out, suction vortices form from the complex interaction with the inflow.
Tornado Climatology

Tornadoes form where thunderstorms grow in the presence of wind shear. Tropical thunderstorms are numerous and powerful but form where there is little shear. In midlatitudes, only certain regions have cool dry air moving perpendicular to warm moist air beneath. That combination triggers huge thunderstorms and the right kind of shear for tornadoes. 

U.S. tornado map Over the U.S., central plains tropical moist air from the Gulf of Mexico collides with cold, dry air from the Rockies to the west. The result is the greatest concentration of tornadoes on Earth.

Tornadoes around the world

<table>
<thead>
<tr>
<th>Year</th>
<th>Place</th>
<th>Deaths</th>
</tr>
</thead>
<tbody>
<tr>
<td>1984</td>
<td>Ivano-Volzhsky, Russia</td>
<td>400</td>
</tr>
<tr>
<td>1977</td>
<td>Madaripur, Bangladesh</td>
<td>500</td>
</tr>
<tr>
<td>1964</td>
<td>Magura and Narail, Bangladesh</td>
<td>500</td>
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<tr>
<td>1984</td>
<td>Valtellina, Italy</td>
<td>600</td>
</tr>
<tr>
<td>1973</td>
<td>Manikganj, Bangladesh</td>
<td>681</td>
</tr>
<tr>
<td>1925</td>
<td>&quot;Tri-state&quot; U.S.A.</td>
<td>689</td>
</tr>
<tr>
<td>1996</td>
<td>Madarganj to Mrizapur, Bangladesh</td>
<td>700</td>
</tr>
</tbody>
</table>

Tornadoes occur where warm moist air can move at an angle to cool dry air above. This occurs mostly in the midlatitudes near the eastern sides of continents.

Enhanced Fujita scale (right) This scale classifies the intensity of tornadoes by analyzing the nature of the wreckage they leave behind.

- **EF0** (65–85 (105–137)) Light damage. Some roof covering lost, some glass breakage, light damage.
- **EF1** (86–110 (138–177)) Considerable damage. House roof stripped off, some exterior walls collapse. Trees stripped of leaves. Tornados can toss cars.
- **EF2** (111–135 (178–217)) Structural damage. One-story frame houses have roofs torn off, exterior walls collapse.
- **EF5** (more than 200 (323–)) Incredible. Commercial jet airplanes tossed. Buildings loose exterior walls.

In the field This mobile Doppler radar can be moved into close proximity to a severe thunderstorm.

watchful eye Meteorologists monitor data captured by advanced instruments. Computer programs highlight features that signal severe weather.

Tornadoes by the hour Tornadoes can occur any time of day but most occur in the afternoon because solar heating often builds up more and more vigorous convection over the day.

Tornadoes by the month Tornadoes can occur in any season but are most common in spring when stronger contrasts develop between cold and warm air masses. Thus, stronger fronts develop more powerful thunderstorms.
NOTABLE TORNADOES

Thousands of tornadoes touch down somewhere on Earth every year, however few of these are very destructive and some go unreported. While most tornadoes have been lost to history, some are remembered decades or even centuries later because of their unusual strength or duration, because they strike where they are uncommon or because they happen to strike a heavily populated area and cause great loss of life and destruction. Just a few of these notorious twisters are discussed here.

SUBHEADERS

The earliest recorded tornado in history struck the village of Rosdalla, Ireland on April 30, 1550. A shipping armada was destroyed by a waterspout on the harbor at Valetta, Malta with the loss of about 600 lives. On December 28, 1879 two or three waterspouts brought down the Tay Rail Bridge in Scotland. A passenger train plunged into estuary 305 miles (491 km) downwind. On March 12, 1996 a Missouri teenager earned an unenviable record when he was tossed by a tornado 1,307 feet (402 m) with only minor injuries. A tornado important in the history of meteorological science passed down a Lubbock Texas street in 1915. It demolished a substantial brick church while sparing a wooden shack just a few steps away. This counter-intuitive event inspired research that uncovered previously unrecognized structures within some tornadoes: a suction vortex had skipped the shack but hit the church.

1974. 148 tornadoes touched down in 13 states. On May 3, 1999, 22 tornadoes spawned near Oklahoma City, including an EF5 within city limits that destroyed 2,200 homes. The greatest one-week outbreak was May 4-10, 2003 when 400 tornadoes tore through 19 states; one crossed a path taken in 1999. Tornadoes tore through 19 states; was May 4-10, 2003 when 400 tornadoes touched down in 13 states. On May 3, 1999, 22 tornadoes spawned near Oklahoma City, including an EF5 within city limits that destroyed 2,200 homes. The greatest one-week outbreak was May 4-10, 2003 when 400 tornadoes tore through 19 states; one crossed a path taken in 1999. The most deadly tornado in history ripped across Manikganj District, Bangladesh on April 26, 1989 killing about 1,300 people and leaving 80,000 homeless along a 10-mile (13 km) path. Bangladesh has witnessed many more devastating tornadoes including an outbreak that struck south of Dhaka on May 13, 1996, though some of the 700 fatalities were from blows by extremely large hailstones. Anecdotes abound of things sent flying. A 1915 tornado tossed a flour sack 110 miles (177 km), a 1970. It demolished a substantial brick church while sparing a wooden shack just a few steps away. This counter-intuitive event inspired research that uncovered previously unrecognized structures within some tornadoes: a suction vortex had skipped the shack but hit the church.

Among ruins a man searches through his brother’s home looking for salvageable items. The neighborhood was razed by a powerful tornado, one of the Infamous twisters that barreled into Oklahoma City on May 3, 1999.
There are other kinds of rotating winds apart from tornadoes. A dust devil is a spiraling, dust-filled vortex of air. They vary in height from only a few feet to over 1,000 feet (300 m). A waterspout can be a tornado that happens to be over water, but are normally much weaker, and do not require a supercell thunderstorm to form.

**Fact File**

**Waterspout dynamics**

Non-tornadic waterspouts form where there is a pre-existing rotation near the surface of the water, combined with some form of updraft. This produces a funnel of rotating air that extends from the water to the base of the cloud.

**Spreading the dust**

Dust devils occur mainly in desert and semi-arid areas, where the ground is dry and high surface temperatures produce strong updrafts. This photo shows a dust devil in the Atacama Desert in Chile. Towering dust devils have been observed on the desert planet Mars.

Richard, these captions are adapted from the original captions in a previous book. Stage 3 didn’t make so much sense in the new context. How can we link the sinking air displacement (2) to the rotational movement seen in (3). The original caption spoke of eddies resulting from topography but hat is not relevant here.
Hurricanes

A tornado may produce the strongest winds on Earth, but for destructive power nothing matches a hurricane. These spiraling storm systems can measure up to 500 miles (800 km) in diameter and can produce torrential rain, winds up to 190 miles per hour (300 km/h) and an enormous high tide called a storm surge. “Tropical cyclone” is the generic meteorological name and also the name by which they are known in Australia and around the Indian Ocean. They are called hurricanes in the Atlantic, Caribbean, and Eastern Pacific, apparently from Hurakan, a god of the indigenous Caribbeans. In the western Pacific they are called typhoons, from a Cantonese word tai fung meaning “big wind.”

Super storms

All mature hurricanes have certain features in common. In the center is an eye—a clear, almost calm area bordered by a ring of extremely vigorous convection known as the eye wall. The extreme updrafts within the ring are fed by lines of converging winds that in turn form bands of thunderclouds and heavy rain. The clumps of storms that produce hurricanes occur only where sea temperatures are at least 79°F (26°C). This means that they usually originate in the tropics. To develop its distinctive rotation, a system must be at least 5 degrees from the Equator, because this is where the Coriolis effect begins to have an influence (see page 39).

The warm ocean initiates the process of energy exchange and release that powers the hurricane. First, the warm ocean heats the air above it, thus increasing the amount of vapor the air can hold before reaching saturation. Because the ocean is warm, a copious amount of water is evaporated into the air (much more than is possible over land). The heat that caused the water to evaporate is released when the moisture condenses into clouds, particularly rain clouds. That heat warms the atmosphere, especially in the center of the storm, causing the air to expand, and the pressure to drop. The lower the pressure, the faster the wind blows around the storm. The stronger the wind blows over the ocean surface, the greater the rate of evaporation, so, as the tropical storm spins faster, the storm grows stronger. This positive feedback process continues for as long as conditions are favorable for hurricane development.

Once spinning, a storm system tends to move farther away from the equator where it tends to become more powerful, although it is unlikely to continue beyond 30 degrees north or south. If a hurricane returns toward the equator, it usually begins to weaken. Hurricane tracks are erratic because their wind speeds greatly exceed the weak “steering winds” of their surrounding environment. If a hurricane strikes land, its storm surge and rains may flood large areas and its winds create a wide path of devastation. But when a hurricane leaves the ocean, it also leaves behind its supplies of heat and moisture. So as it moves inland it weakens rapidly and soon dies out.

Hurricane Rita (right) Hurricane Rita churns across the Gulf of Mexico on September 21, 2005. Rita was one of three, rare, category five hurricanes to roar across the Gulf during the most active hurricane season ever in the Atlantic.

New Orleans after Katrina (right) The flooding in the wake of a hurricane is usually more destructive than the high winds. For days after Hurricane Katrina people were stranded in flooded neighborhoods. Houses were ruined by floodwater and the growth of mold.

Dumped ashore (left) This yacht was swept several miles across a section of the Florida Everglades during Hurricane Andrew in 1992.
Hurricanes continued

As a tropical storm builds up to hurricane force, several characteristic structures appear. As air spirals inward, it accelerates in a way similar to the motion seen in a tornado. The dynamic is revealed by lines of converging air masses that produce bands of cloud of varying density in the center of this revolving spiral of clouds is a mostly cloud-free “eye”.

**Eye**

Eyeinking is in the hurricane center suppresses all but the lowest clouds in the eye and winds are weak. The eye can be 5–50 miles (8–80 km) in diameter.

**Eye wall**

Winds and rain are strongest in the eye wall. Horizontal wind speeds decrease with height so the lower cloud rotates faster than the upper cloud.

**Rainfall bands**

Bands of intense rain spiral in toward the eye wall. Often, two bands are more prominent and can extend for 1,000 miles (1,600 km).

**Rainfall revealed**

A radar mounted on an orbiting satellite shows individual convective cells of intense rainfall as green columns.

**Anatomy of a hurricane**

A mature hurricane consists of bands of thunderclouds (spiraling about the eye), a clear almost calm area at the center of the storm. Each band is fed by updrafts of warm, wet air. The air is warmest and circulates fastest at the base of the hurricane. The air spirals (counter-clockwise in the northern hemisphere and clockwise in the southern hemisphere) into the center, accelerating as it does so. The air then spirals upward in the torrential rain-producing eyewall cloud that surrounds the eye of the storm. In the upper levels the air spirals outward the opposite direction away from the hurricane’s center. As the hurricane approaches the coast a storm surge can drive seawater deep inland.

**Hurricane Katrina (above)**

When a tropical disturbance first forms (1), the clouds are asymmetric and there is no eye. It intensifies into a tropical depression (2), with an irregular, partial ring of cloud. The storm becomes a hurricane (3) with deep convection, a prominent eye, symmetric ring, and spiral arms. If it reaches land (4) it loses its supply of warm oceanic air and quickly weakens.

**Hurricane anatomy**

All hurricanes share several characteristic structures. Many of these are revealed by satellite photography, but high clouds can obscure some features. Radar can unmask many of these complex internal structures.
Hurricane Climatology

Tropical cyclones form over ocean areas that are warm enough to provide the huge quantities of water vapor that power the storm. Other factors need to be in place as well. The location must be sufficiently distant from the equator for the rotating winds to form and the surrounding atmosphere must have weak winds.

Tropical cyclone tracks The map shows tropical cyclone tracks from 1985 through 2005. Warmer colors indicate stronger storms. Individual tracks are irregular, but most head west then polewards.

In the firing line Fishermen in Yehliu, Taiwan repair their boats after the passage of a typhoon. Being surrounded by very warm water and weak summertime wind shear makes Taiwan a frequent target of typhoons.

Hurricane conditions Hurricanes are powerful storms but they form only where the air is warm enough to hold sufficient water vapor. Typically, this occurs where ocean surface temperatures are greater than 79°F (26°C). Most tropical oceans are warm enough, but the ocean off Chile and Peru is too cold.

2 Convergence/divergence A hurricane forms from a pre-existing group of thunderstorms that is maintained by the presence of surface convergence and upper level divergence. In the Atlantic this commonly occurs with a line of thunderstorms, known as an “easterly wave” that moves westward out of Africa.

3 Off the equator Hurricanes cannot form on the equator because the Coriolis force is zero there (see page 38). The Coriolis force determines the rotation around the cyclone. Tropical cyclones rotate counter-clockwise and clockwise in the northern and southern hemispheres, respectively.

4 Deep convection Hurricanes are organized deep convection, so an environment favoring tall convective clouds is needed. That environment occurs where temperature decreases rapidly with increasing elevation through the troposphere, such as from heating of the air in the lower atmosphere, cooling of the air aloft, or both.

5 Low wind shear In conditions of high wind shear the upper and lower parts of a thunderstorm complex will move differently and the group will never organize into a coherent cyclone. Too much wind shear suppresses hurricanes in the central Pacific and southern Atlantic oceans.

Hot water This map shows sea surface temperatures on August 29, 2005 when Hurricane Katrina reached its peak intensity over the Gulf of Mexico. Temperatures above the critical threshold of 79°F (26°C) for tropical cyclone formation are colored yellow and orange.

Saffir-Simpson scale The intensity of a hurricane, as determined by its maximum sustained wind speed, is given by a five-point scale. Sustained wind speed also defines earlier stages: disturbance, 23–39 mph (37–64 km/h); depression, 39–54 mph (63–87 km/h); and tropical storm, 40–74 mph (65–119 km/h).
NOTABLE HURRICANES

H urricanes are given names so there is no confusion when talking about a particular storm. A consequence of this practice has been the clear identification of notorious storms. Just saying “Katrina” in the United States or “Nargis” in Burma evokes a cascade of images and emotions. Notorious storms uncover weaknesses in our preparedness but ultimately lead us to better practices.

NOTORIOUS STORMS

Tropical cyclones span a range of sizes and intensities. Some storms are fleeting, while others are remembered for their unusual behavior or meteorological extremes.

The deadliest cyclone on record slammed into what is now Bangladesh in 1970. The combination of primitive prediction and warning systems and a dense population living in a low lying region was particularly deadly.

The 1955 “Bhola” cyclone was estimated to have killed more than 300,000 people, nearly all by drowning as the storm surge. Relief efforts were hampered by political and logistical factors that added to the death toll. Disastrous with the central government’s reaction contributed to the succession of Bangladesh from Pakistan a year later.

Today, satellite images are far superior and ubiquitous and computer models that predict storm tracks are infinitely better, but hurricanes can still cause large loss of life when warnings are not disseminated or relief efforts are mishandled. In 2008, Cyclone Nargis struck the Irrawaddy Delta in Burma, causing more than 140,000 deaths, a toll made worse by delays in accepting foreign relief.

Katrina’s storm surge breached levees in New Orleans. Because some of the city lay below sea level it felt like a bowl resulting in astronomical damage costs.

Other hurricanes are noted for their meteorological factors. Wilma (2005) holds the record for the lowest estimated sea level pressure (882 hPa) in the Atlantic though the deepest pressure occurred in the Western Pacific when Typhoon Tip reached 850 hPa. Tip (1979) packed sustained winds greater than 190 mph (310 km/h) in have some other storms, notably Hurricane Camille (1969). Camille struck land with those ferocious winds a little east from where Katrina struck. Tip was very large, with hurricane force winds extending for over 1,300 miles (2,000 km).

Hurricane Mitch (1998) caused the greatest loss of life by a hurricane in the western hemisphere during modern times. Mitch was a very powerful storm that dropped record rainfall on Honduras over a six day period. The storm surge was unremarkable, but the incredible flooding coupled with landslides made Mitch so devastating.

The costliest hurricane on record was Katrina (2005), with damage exceeding $125 billion, about five times as costly as the second most damaging hurricane in U.S. history, Hurricane Andrew in 1992. Extreme winds were the primary factor in fast moving Andrew’s trashing of south Florida. Katrina eclipsed Andrew with massive destruction along the Louisiana, Mississippi, and Alabama coast.
Hurricane Watch

The ability to forecast and issue warnings of hurricanes has improved greatly in the past 50 years. The number of deaths from hurricanes has generally declined, but exceptions occur mainly due to human activities and poor planning. While fatalities have decreased, damage costs have soared, primarily due to expanded development in areas impacted by hurricanes.

Seen inside radar gives a detailed picture of the structures hidden within the cloud mass of a hurricane. Meteorologists use ground-based, aircraft-based, and satellite-based radars to study and predict hurricane development and movement.

Looking ahead (below) Modern tools have improved forecasting. Video loops from satellite images can predict where a storm’s heading. A composite image shows Hurricane Andrew over the Gulf of Mexico on three successive days in August 1992.

No barrier (right) When Hurricanes Barne and Yancy hit Texas barrier island in 2008, hundreds of homes were completely destroyed. This home survived because the owners built it using construction practices designed to withstand a moderate hurricane.

Improved forecast (below) Satellite data and computer modeling are the primary tools used to track and forecast severe storms. Computer models solve mathematical equations that represent each of the weather processes.

Public warnings (below) Storm forecasts are disseminated over the internet and broadcast media to alert the public to possible danger. The black line shows the most probable track of the storm at 12-hourly intervals. The white area shows the uncertainty in the track.

Evacuation (below) Proximity to the forecast track of a hurricane triggers either a voluntary or mandatory evacuation. Roads near the Gulf of Mexico and Atlantic coasts of the U.S.A. are often signposted to indicate evacuation routes, which generally head inland and to higher ground.

Safe house (below) If evacuation is not possible, residents must be prepared to live without basic utilities, such as electricity and running water. Essential items include battery-powered radios, flashlights, food, and water.

Crowding People were stranded for days at the Superdome and Convention Center. Facilities were overwhelmed and lawlessness emerged.

Poor infrastructure Bridges that failed during Hurricane Camille in 1969 and were rebuilt to a similar standard, also failed during 2005’s Hurricane Katrina.

Bad planning Much of New Orleans lies in a low basin. Buses intended to evacuate people were rendered useless when parked in areas below sea level.

Weak spots Erosion and canal-building reduced the natural protection of the Mississippi delta. Katrina’s storm surge flooded large tracts of New Orleans.

What went wrong Hurricane Katrina, which hit New Orleans in August 2005, was a calamity many expected. Katrina was a very powerful storm, but the damage it inflicted was exacerbated by poor preparation and inadequate emergency response.

HURRICANE WATCH EXTREMES

EXTREMES HURRICANES
FLOODS

Floods are the most deadly and damaging of weather events. Flash floods normally result from unusually intense rainfall from thunderstorms. The type and condition of the land surface along with topography, greatly influence the severity of these floods. Large-scale floods occur primarily as a result of persistent rainfall or from rain falling upon snow and melting it. Flooding can also be a benign seasonal event essential for revitalizing soil fertility.

AIR AND ITS LAYERS

Large-scale floods can be months in the making. Persistent rain can saturate the soil driving all further rainfall into rivers that may break their banks and overflow into the surrounding countryside. Over the summer of 1993, a persistent circulation built thunderstorms day after day over the north-central U.S. Severe flooding developed and became the second most costly weather disaster in U.S. history. Persistent extratropical cyclone tracks can also deliver unusual amounts of rainfall. During the fall of 1966, rainfall saturated soils in Tuscany, Italy. On November 4, after two days of particularly intense rainfall, the river flooded in the city’s history inundating Florence. Irreplaceable documents and art were damaged.

Warm rain falling on snowfall melts the snow, creating snowmelt that combines with rainwater flowing into streams and rivers. A 1936 flood that destroyed thousands of buildings in Pittsburgh, Pennsylvania resulted from this combination.

The deadliest floods in human history affected China’s Yellow, Yangtze, and Huai rivers during much of 1931. They were the product of heavy snows followed by warm spring rains and finally the passage of several typhoons. The death toll may be as high as or four million people.

The Po River rages through Turin, Italy on October 16, 2000. A front had stalled over the Piedmont region and rain over a three day period saturated the soil. The rain finally culminated in thunderstorms over most of the region on this day. This frightening deluge was a once in 200 year event.

In December 1999, intense rainfall saturated the steep hills behind Caraballeda, Venezuela. The resulting landslides flowed out of the narrow valleys as large alluvial fans and buried much of the town.

Some floods are at least partly caused by human activity. The town of Johnstown, Pennsylvania was devastated by a notorious flood on May 13, 1889 when heavy rains breached an earthen dam upstream. In early August, 1975 an extratropical trough merged with spent Typhoon Nina over central China to produce record rainfall. The rains exceeded the design capacity of several dams, most notably the Banqiao dam. A cascade of several dozen dam failures caused with the loss of thousands of lives.

Dry soil in rocky canyons, saturated soils, frozen soils, and burned over areas, cannot absorb moisture and flood more easily. Flash floods are common in deserts that experience summer thunderstorms. It is impossible to outrun a flash flood, even in a car. A number of motorists drowned during to escape the 1976 Big Thompson Canyon flood in Colorado U.S.A. Now, road signs throughout the Rocky Mountains, implore people to park and climb up to safety.

However, sometimes human memory is too short. Intense rainfall pounded northern Venezuela in late 1999. Massive landslides spilled out of coastal mountains and buried many coastal communities. A similar, smaller magnitude event struck the same area in 1951, but development and population mushroomed in the years in between and the danger had been forgotten.

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While flash floods can be devastating, they are usually short-lived, confined to a small area, and depend quickly on contrast, large-scale floods can take weeks to develop and can inundate thousands of square miles. Such flooding often begins along a river, which may break its banks and overflow. At other times, tides and storm surges bring water from the sea over land.

**Fact File**

**Flood protection**

Areas at risk of flooding can be protected by strong barriers built to hold or restrict floodwater. But protective structures in one location may raise water levels in a nearby place without safety measures.

**Maps to come x 6**

1. The Netherlands Much of The Netherlands is below sea level and for centuries the Dutch have struggled against the threat from the sea. On February 1, 1953 a powerful storm surge combined with a high tide overwhelmed flood defences and 1,836 people drowned. Parts of the Belgium and England were also affected.

The Netherlands, 1953

2. Mississippi In 1927, after several months of exceptionally heavy rain, the waters of the Mississippi River and many of its tributaries flooded over and inundated 27,000 square miles (70,000 km²) of land. It remains the most damaging river flood in U.S. history.

Mississippi, 1927

3. Yellow River The Yellow River is often referred to as “China’s sorrow.” Major floods along this river have been recorded 1,500 times over the last 3,500 years, often with enormous loss of life. A flood in 1887 may have killed up to 2.5 million people.

Yellow River, 1887

4. Mozambique On February 22, 2000, Tropical Cyclone Eline reached Mozambique. The country, which was already suffering from disastrous flooding and heavy rainfall, was hit by a series of flash floods. Nearly one million people were left destitute.

Mozambique, 2000

5. Paris After three months of heavy rain and snow the Seine burst its banks in January 1910 bringing the French capital to a standstill. The floodwaters peaked at over 20 feet (6 m) above the normal level. About 50,000 buildings were flooded in the city with further damage upstream and downstream.

Paris, 1910

**Elbe River**

The image at top shows the Elbe River, upstream of Wittenberg, Germany, as it is normally seen by satellite. The second image was captured on August 20, 2002 when the worst floods to hit Central Europe in over 100 years were at their peak.

**Fact File**

**Levee** Reinforced earthen walls contain rivers that change course often or overflow regularly.

**Tidal barrier** In low-lying coastal regions, barriers stop abnormally large waves and control tide. Sluices provide normal flow.

**Sandbagging** Sandbags are an effective, if labor-intensive, means to hold back floodwaters. In this case they are protecting Dresden, Germany, from the rising waters of the River Elbe.
EXTREME FRONTAL SYSTEMS

Frontal systems, also known as extratropical frontal cyclones, are the dominant weather generators in the midlatitudes. No other weather system can produce such a diversity of extreme conditions: strong winds, flash floods, hail, and tornadic phenomena. Frontal systems may spawn vigorous convection, forming thunderstorms along a front, or as an intense squall line ahead of the front. Contrasting polar and tropical air masses provide the energy to bring heavy rains and leave blizzards that blanket large areas. This may drive frigid air toward the Equator, outside its normal boundaries, developing bands of disruptive freezing rain.

**Agents of Change**

Masses of warm and cold air are moved around the globe by winds, with one main air mass displacing another. The boundaries between warm and cold air masses are called fronts. These are the zones where the atmosphere is most active and that cause changes in weather. The interaction of warm and cold air masses may produce systems of low pressure that give rise to storms. Unlike a hurricane, a frontal system has a cold core. Its main energy source is the large temperature difference across the system. A hurricane has a warm core, its energy comes entirely from the sun. Unlike a hurricane, the frontal cyclone has a cold core. Its main energy source is the large temperature difference across the system. A storm. A hurricane has a warm core, its energy comes entirely from the sun. Unlike a hurricane, the frontal system has a cold core. Its main energy source is the large temperature difference across the system. A storm.

**Cold fronts**

Cold fronts are the leading edges of cold air masses that move into warm air. They are typically associated with strong winds, heavy rain, and thunderstorms. Cold fronts can also bring significant snowfall, particularly in the northern latitudes. The passage of a cold front can be marked by a sharp drop in temperature, a rise in pressure, and a shift in wind direction.

**Warm fronts**

Warm fronts are the leading edges of warm air masses that move into cold air. They are typically associated with light to moderate precipitation, often in the form of drizzle or light rain. Warm fronts can bring mild temperatures, with a slow increase in pressure and a gentle shift in wind direction.

**Occluded fronts**

Occluded fronts are formed when a warm front overtakes a cold front, creating a zone of mixed air masses. They are characterized by a transition from warm to cold, often leading to precipitation and thunderstorms.

**Extratropical systems**

Extratropical systems, also known as extratropical frontal cyclones, are the dominant weather systems in the midlatitudes. No other weather system can produce such a diversity of extreme conditions: strong winds, flash floods, hail, and tornadic phenomena. Frontal systems may spawn vigorous convection, forming thunderstorms along a front, or as an intense squall line ahead of the front. Contrasting polar and tropical air masses provide the energy to bring heavy rains and leave blizzards that blanket large areas. This may drive frigid air toward the Equator, outside its normal boundaries, developing bands of disruptive freezing rain.
Blizzards and Ice Storms

Blizzards are caused by a combination of heavy snow, low temperatures, and strong winds. They can dramatically reduce visibility. A typical blizzard occurs behind an intense surface low-pressure area. When a layer of warm air is sandwiched between two layers of sub-freezing air, freezing rain can develop and an ice storm may form. These storms can cause severe damage.

Ice glaze (above) Liquid rain falls on an object of sub-freezing temperature and freezes as a layer of ice. An accumulation of glaze can cause structural damage, bringing down tree branches and power lines.

Ice storm (below) Frozen water droplets first melt as they pass through a layer of warmer air. They then fall into sub-freezing air—as occurs along a warm front—to form freezing rain and produce an ice storm.

Fact File

1. Southern China Ice storms and the worst blizzards in 10 years paralyzed much of southern China from late January to early February 2008. Hundreds of thousands of impenetrable workers attempting to return to their home towns and villages for Chinese New Year were left stranded.

2. Iran A blizzard in early February 1972 covered parts of Iran with such a volume of snow that the single event ended a four-year drought. Drifts of snow 10–20 feet (3.0–6.1 m) deep were reported near the capital, Tehran. An estimated 4,000 people perished in the snow and subsequent cold.

3. Great Plains The Children’s Blizzard of January 12, 1888 had one of the largest 24-hour temperature ranges ever recorded. The storm in the Great Plains was so named because the extreme cold, strong winds, and heavy snow trapped children in small schools.

NEW YORK CITY

The Great Blizzard of 1888 dumped over 40 inches (102 cm) of snow that hurricane-force winds then piled into 40-foot (12 m) drifts. It changed New York’s landscape. Communication and power lines were put underground and the subway system was initiated.

Disorder (above) Blizzards can disrupt daily life: snarling traffic, closing airports, and stopped trains. Strong winds can pile snow into drifts that far exceed the amount of actual snowfall.

Big chill (right) A heavy blanket of snow was left over Afghanistan after a blizzard crossed the region on January 31, 2006. While such snowfall is disruptive, it is essential in providing sufficient water for the long dry summers.

Traffic flow Even during a blizzard, keeping the roads open is a high priority. Municipalities in snowy areas allocate significant resources for plowing roads.

Building design In cold climate areas, roofs are steep to help shed snow and reinforced to withstand the weight of a thick layer of snowfall.

Electricity Freezing breaks in power lines caused by falling branches is a high priority after an ice storm.
Cold-air Outbreaks

A potent frontal cyclone may drag a cold air mass over a region that rarely experiences cold weather. This anomaly can have serious consequences when the local population and infrastructure are not adapted to the cold. Temperatures of 14°F (–10°C) during a central Siberian winter may be a heat wave, but in central Florida this would be a record cold spell.

Wind chill—The combination of strong wind and low temperature can produce much greater loss of body heat than the air temperature alone would suggest. The figure often used to express this is the wind-chill temperature.

Exposure to cold—Loss of heat from the body can lead to hypothermia. The elderly are at particular risk from extremes of heat and cold.
Drought is the oddest form of extreme weather. It does not shout in presence with fierce winds, flashing lightning, or lashing rains. Quite the opposite, drought is the absence of something, namely, precipitation. Drought develops slowly and silently. The withering effects of drought may also bring along a heat wave and maybe a duststorm where one rarely occurs. Heat waves and duststorms occur in the absence of drought, of course. Heat waves happen when a hot air mass is displaced far from its normal location. Heat waves are often associated with warmer temperatures.

Drought is one of several factors that contribute to the severity of a heat wave. In addition to heating by compression, the suppression of clouds allows more sunlight to strike the ground. Ground heated by the sun can release heat either by heating the air above or indirectly through the evaporation of water. During a drought, there is less water, hence more of the solar heating must be removed by directly heating the air. Finally, winds during such conditions are often (but not always) light; light winds can’t mix the heating so easily through a deep layer of the atmosphere.

There is no universal definition of a heat wave. People have adjusted their lifestyle and expectations to fit the normal range of temperatures expected in the place where they live. A summer maximum temperature of 100°F (38°C) in London would be headline news, whereas the same temperature in Marrakesh, Morocco would hardly be mentioned. Local definitions incorporate knowledge of the local norms and may use thresholds that measure the amount of heat stress a person feels, such as the “apparent temperature.”

Duststorms may be associated with drought, as vegetation holding the soil withers away.

Drought hazard map: This drought hazard map is derived from the length of time rainfall was less than half of its long-term median value for three or more consecutive months between the years 1982 and 2000. Areas with less than 0.04 inch (1 mm) average rainfall per day are excluded.

Caption head: A woman carries water back to a camp in Ogaden province, Ethiopia, April 2000. Drought is all too frequent in the region.

Dust and bones: A farmer near Leigh Creek, Australia, surveys the bones of horses and cattle that perished in a prolonged drought that gripped much of Australia from 2003. Scant vegetation is seen for miles in this photo from June 7, 2005.
Heat Waves

Heat waves are periods of higher-than-average temperature. They occur when an air mass is displaced from its normal location for several days or weeks. Other factors can make the heat more severe, including lack of cloud and dry ground. People can adapt to constant heat, but an unexpected heat wave can make people sick and can even kill.

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Maps to come x 5

1. Dallas During the summer of 1980, a drought and heat wave gripped the central and southern U.S.A. In Dallas, high temperatures exceeded 100°F (38°C) for a record 42 consecutive days. This event was one of the costliest disasters in U.S. history because of crop losses and buckled roads.

2. Victoria In January 1999, the state of Victoria endured a punishing heat wave following a protracted drought. On “Black Friday,” January 13, Melbourne recorded a high of 111°F (43.8°C) and 71 people lost their lives in wildfires that swept the state.

3. Southeastern Europe The summer of 2007 brought record-breaking temperatures and fires to southeastern Europe. In Bulgaria, 500 deaths were attributed to the heat wave. In Athens, the electricity system almost collapsed due to the demand for air-conditioning.

4. India In 2003, the monsoon rains were late to arrive in India and temperatures soared to unusual highs over fifty days. Temperatures exceeded 116°F (47°C) across much of the country and as many as 1,900 people died from its effects.

Deadly summer The 2003 European heat wave claimed an estimated 35,000 lives. The elderly kept in areas (like Prague) where such heat were particularly at risk. Five French workers in a refrigerated warehouse to store corpses.

Scorched Earth This satellite view from August 4, 2003 records infrared radiation emitted from the ground or from the tops of clouds. France and the Iberian Peninsula sizzle with scorched earth.

Cooperating with heat There are several ways to keep cool on a very hot day. Drinking lots of water, seeking in a cool pool, and sheltering in an air-conditioned building all help to beat the heat.

Water replacement Dehydration is a danger in hot weather, when the body keeps cool by sweating. It is important to drink water.

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Heat index chart Actual temperature and humidity are combined to produce a temperature related to physical comfort. For example, 80°F (27°C) feels like 115°F (46°C) in 60 percent humidity.

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Heat stroke highly likely with continued exposure
Sunstroke, heat cramps, and heat exhaustion possible
Exhaustion likely; heat stroke possible
Sunstroke, heat cramps, and heat exhaustion likely
Fatigue possible with prolonged exposure

Heat waves

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Strong winds are capable of lifting topsoil and scattering it over wide areas, but occasionally certain conditions combine to produce huge walls of moving dust that carry thousands of tons of soil, sand, and debris. Dust storms are most common in deserts but can occur in other places such as where glaciation has ground rocks into fine, dry sand.

When lifted by strong winds and convection, the dust can rise two miles (3 km) into the sky, and travel for several thousand more miles.

FACT FILE

1. Haboob A dust storm caused by the vigorous gust front of a thunderstorm, a haboob is common in the Sahara and the Arabian Peninsula. The term comes from an Arabic word for “strong wind.” Haboobs can also occur in other desert regions that have thunderstorms, such as the U.S. southwest.

2. Shamal These strong northwest winds occur over a large area of Iraq, Iran, and the Arabian Peninsula. Shamals develop either in front of or behind a cold front, most commonly in summer. Dust and sand can cover the entire Persian Gulf and Iraq.

3. Dust Bowl The Dust Bowl of the 1930s affected the prairies of Canada and the U.S.A. Dry plowing and lack of cover crops or wind breaks exposed soil to prolonged drought. When strong winds blew, huge dust storms developed, causing catastrophic fertility loss and migration from the regions.

4. Drought On February 8, 1983, Melbourne, Australia, was enveloped in a dramatic dust cloud. Earlier, one of the strongest El Niño events brought record drought to eastern Australia. Around 55,000 tons (50,000 tonnes) of topsoil was carried by the storm.

WEATHER WATCH

When the dust settles Each year, millions of tons of dust blows off the Sahara and travels as far as the Caribbean and Florida. The dust can fertilize the oceans and bring microbes that cause disease outbreaks downwind. Some scientists believe Saharan dust can suppress Atlantic hurricanes.
Particular combinations of circumstances produce extreme weather conditions. For example, Vostok Station is exposed to temperatures lower than those found anywhere else on Earth because of its latitude—78.46ºS—and high elevation. Other extreme phenomena develop by chance. The biggest hailstone that formed inside a storm cloud could have grown in any of a number of places, while the strongest sustained winds could blow in any part of the world that is exposed to tropical cyclones.

## Extreme Weather

Full dates and true values have been told about the weather for as long as there have been people around to tell them. Sorting the tall from the true is not easy—few accounts have been confirmed by reliable meteorological measurements. Systematic observations started only in 1814, when the Radcliffe Meteorological Measurements were introduced in Oxford, England, beginning recording changes in weather. In the United States, daily records started in 1885, in an observatory founded by Abbott Lawrence Ronch in Milton, Massachusetts. This observatory—the Blue Hill—continues to keep the longest continuously operating weather station at the same location. Extremes of weather can be officially cited as records only if the weather station that recorded them has a long-term set of weather measurements. The extremes recorded during the first year of readings should generally not be cited records. Just how long weather stations should maintain data before declaring records remains a subject of debate, but the consensus is that at least 10 years’ measurements are required before an extreme reading is declared to be a record.

The accurate records maintained by today’s weather stations across the world enable comparisons to be made and extremes of weather to be documented. Together, these extremes reveal the enormous power of the forces that contribute to our weather.

### Extreme Cold

The Russian weather station is located on the Severnaya Zemlya archipelago off the north coast of Siberia. Winters are long, dark, and extremely cold.

### Extreme Dry

The Little Valley of the Alazan in the Alazan-Alakul Desert is part of the northern steppe desert. The constant wind ends the rock to form a Blaue-like landscape.

### Record-Breaking Weather

<table>
<thead>
<tr>
<th>AUR</th>
<th>STORMY WEATHER</th>
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<tbody>
<tr>
<td>1. Highest surface wind speed, world</td>
<td>244.7 mph (393 km/h)</td>
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<tr>
<td>2. Highest average wind speed, world</td>
<td>139 mph (224 km/h)</td>
</tr>
<tr>
<td>3. Highest air pressure, world</td>
<td>30.29 inHg (1032.5 hPa)</td>
</tr>
<tr>
<td>4. Lowest seaward air pressure, world</td>
<td>29.52 inHg (986.6 hPa)</td>
</tr>
<tr>
<td>5. Lowest average luminosity, world</td>
<td>Gold Coast, Australia</td>
</tr>
</tbody>
</table>

### Temperature

| 1. Highest temperature, Asia | 129°F (53.9ºC) | Death Valley, California, U.S.A. |
| 2. Highest temperature, Europe | 118.4°F (48ºC) | Rivadavia, Salta, Argentina |
| 3. Highest temperature, North America | 112.4°F (44.6ºC) | Fairbanks, Alaska |
| 4. Lowest temperature, Asia | –56.7°F (–49.2ºC) | Ust-Shchugor, Russia |
| 5. Lowest temperature, Europe | –51.2°F (–46.2ºC) | Sarmiento, Chubut, Argentina |
| 6. Lowest temperature, North America | –71.4°F (–57.5ºC) | Amundsen–Scott South Pole Station |

### Precipitation

| 1. Highest annual average rainfall, world | 468.7 in (1189 mm) | Mount everest, Nepal |
| 2. Highest annual average rainfall, North America | 41.1 in (1042 mm) | Henderson Lake, British Columbia, Canada |
| 3. Highest annual average rainfall, South America | 40.4 in (1026 mm) | Uruyen, Bolivia |
| 4. Highest annual average rainfall Africa | 39.3 in (1000 mm) | Soldado, Colombia |
| 5. Highest annual average rainfall, Europe | 24.4 in (620 mm) | Crakow, Poland |

### Extreme Dryness

| 1. Greatest number of thunderstorm days, world | 409 strikes per square mile per annum | Bogor, West Java, Indonesia |
| 2. Greatest number of thunderstorm days, United States | 372 days per year | Yearly average for the U.S. |

### Extreme Winds

| 1. Highest surface wind speed, world | 244.7 mph (393 km/h) | Mt. Washington, New Hampshire, U.S.A. |
| 2. Highest average wind speed, world | 139 mph (224 km/h) | Cape Hanga, Antarctica |

### Extreme Hail

| 1. Greatest number of hailstorms, world | 109.6 per square mile | Juneau, Alaska, U.S.A. |
| 2. Greatest number of hailstorms, United States | 409 strikes per square mile per annum | Bogor, West Java, Indonesia |

### Extreme Snowfall

| 1. Greatest one-year snowfall, world | 1,140 inches (28.95 m) | Mount Baker, Washington, U.S.A. |
| 2. Greatest one-year snowfall, United States | 222 inches (5.62 m) | Mount Rainier, Washington, U.S.A. |

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Earth’s Coldest Places

Antarctica is Earth’s capital of cold. It is noted for its long, savage, and perpetually dark winters when freezing temperatures and hurricane-force winds make it dangerous to venture outside. However some locations in the Northern Hemisphere, within the Arctic Circle and further south, come close to matching Antarctica’s coldest temperatures.

1. Yakutsk This city of 270,000 people in the Russian Far East is the coldest on Earth. The average high temperature in January is –40°F (–40°C). Children are excused attendance at school if the temperature is below –40°F (–50°C).

2. Vostok Station On July 21, 1983, the coldest temperature ever recorded on Earth of –128.6°F (–89.2°C) was observed at the Russian Vostok Station, near the South Magnetic Pole. About thirteen staff brave the winter at this remote outpost opened in 1957.

3. Oymyakon, Russia Although it is located 209 miles (336 km) south of the Arctic Circle, Oymyakon is believed to be the coldest place in the Northern Hemisphere. This village is 2,625 feet (800 m) above sea level and in 1926 the temperature here dropped to a bitter –96.2°F (–71.2°C).

4. Snag, Yukon In February 1947 the temperature at Snag Airport fell to –81.4°F (–63°C). This small village and military airfield in Canada is the coldest place in North America, within one of the two cold poles, or coldest parts, of the northern hemisphere.

5. Ifrane, Morocco Situated 5,364 feet (1,636 m) above sea level in the Middle Atlas Mountains, Ifrane is the coldest place in Africa. It is surrounded by forests and offers winter skiing in the nearby hills. On February 11, 1935, the temperature was –11°F (–23.9°C).

Greenland (below) The Greenland Ice Sheet is the coldest place in the Western Hemisphere. A record low of –87°F was (–66°C) was recorded at the North Ice Research Station in 1954.

Yakutsk bus queue (above) A group of women wait for a bus protected from the cold with reindeer coats and fur hats. It is January, midday, and the temperature is about –49°F (–45°C).

Maps to come x 5

Antarctica (below) The Antarctic Plateau has an average elevation close to 10,000 feet (3,000 m) which compounds the cold experienced there. Coastal Antarctica has a considerably warmer climate than the interior.

Winter world This satellite image shows daytime surface temperatures in January (Northern Hemisphere) and August (Southern Hemisphere). Outside of Antarctica, southern winters are comparatively mild, the landmasses are all outside the polar region and the predominance of ocean water moderates temperatures.

Fact File

Polar clothing Traditionally, polar clothing is made from the fur of animals such as reindeers and polar bears. Modern polar explorers and scientists wear clothes made mostly of synthetic materials.

Eye protection The small slits in Inuit snow goggles and the tinted lenses of modern goggles protect the eyes from snow blindness.

Modern materials: Modern synthetic fabrics allow moisture from sweating to escape but does not let water in, keeping the wearer dry.
Earth’s Hottest Places

Equatorial regions are hot, and continental climates far from the ocean experience scorching summers, but the highest temperatures occur in subtropical deserts. These places of extreme heat and scarce rainfall are inhospitable to life. Only a few plants and animals with special adaptations can survive.

Surviving the heat (night) The Tuareg are nomads who thrive in the Sahara. Their loose clothing, traditionally blue, shades their bodies and traps cool air.

Death Valley (below) Death Valley in California, U.S.A. is the hottest place in North America. It has an average summer temperature of 98°F (36.7°C). It also contains the lowest point in the Americas, 282 feet (86 m) below sea level.

Death Valley Depression, Ethiopia, has the world’s highest average temperature, of 94°F (34.4°C). In places it is 380 feet (116 m) below sea level. Air sinking down to it warms by compression as it descends. The area is volcanically active. The landscape pictured is a field of eroded lava.

Desert travelers Sidewinder snakes, which exist in most sandy deserts, move in loose, hot sand by throwing their bodies in loops.

Heat transfer Blood vessels near the surface of a desert-dwelling jackrabbit’s large ears release excess body heat efficiently.

Heat keepers A camel’s body can withstand large differences in temperature. During the day, it acts as a heat sink. During the cool desert night, the body heat is dissipated.

1. Al Aziziyah The highest air temperature ever recorded—admittedly questioned by some—with a possible 136°F (57.8°C) at Al Aziziyah, Libya on September 13, 1922. Surprisingly, this town is not located deep in the Sahara; in fact, it is only about 20 miles (32 km) from the Mediterranean coast.

2. Oodnadatta Located in the heart of the desert 628 miles (1,011 km) north of Adelaide, this is the hottest place in Australia. On January 2, 1902, the temperature rose to 123°F (50.7°C), the highest ever recorded there. It was an important railhead town until the rail was relocated in 1983.

3. Catenanuova On August 10, 1999, the temperature at this town in inland Sicily reached 119°F (48.5°C), the highest ever recorded in Europe. Summer days can be very hot in Sicily when the Sirocco wind carries hot, dry air from North Africa to the island.

4. Padidan Average maximum temperatures are above 100°F (37.8°C) from April to September, but the temperature has been known to reach 122°F (50.0°C). Though hot in summer, winter temperatures can drop close to freezing at night.

5. Tirat Tsvi This town in Israel’s North District is about 50 miles (80 km) from Jerusalem, near the Jordan border, and 722 feet (220 m) below sea level. On June 6, 1942, the temperature rose to 129°F (53.9°C), the highest ever recorded in Asia. Despite the hot climate, the area is cultivated.

Earth’s Hottest Places

-25 10 45°C F° –13 50 113

Fact File

Coping with heat Animals living in hot deserts seek shelter during the middle of the day, to prevent overheating and to conserve fluid. Some obtain all their water from the food they eat.

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Earth’s Wettest Places

Rainfall is not distributed evenly around the world. Mount sea ar, rising as it crosses mountains, delivers heavy rain to the windward side of coastal ranges. In southern Asia the summer monsoon brings torrential rain, while heavy rainstorms batter islands near the equator. In the future, rising global temperatures may increase the rainfall in such places.

**Fact File**

1. **Llunis** This small town in Colombia, located approximately 1,200 feet (366 m) above sea level, is the wettest place in South America and certainly one of the wettest in the world. Its estimated average annual rainfall is 452.6 inches (11,520 mm).

2. **Pohnpei Island** This Micronesian island receives more than 400 inches (1,029 mm) of rain a year. Pohnpei is the tip of an extinct volcano, lying in the oceanic warm pool, where the water temperature is almost 90°F (29°C).

3. **Debundscha Point** This is on the coast at the foot of the southwest side of Mount Cameroon, Cameroon, West Africa. It receives an annual average rainfall of 600 inches (15,240 mm), mostly between May and October. The upper slopes of Mount Cameroon lie above the clouds and dry air.

4. **Cherrapunjee** Located 4,500 feet (1,370 m) above sea level on the windward side of India’s Khasi Hills, Cherrapunjee receives monsoon rain over a few short periods, the heaviest rain falls from intense thunderstorms. Records from one to several days are associated with tropical cyclones. The wettest places by annual average are receive either heavy monsoon rain over a few months or steady year-round orographic rain.

5. **Mawsynram** This village in the Khasi Hills, Meghalaya State, India, reportedly receives 468 inches (11,972 mm) of rain a year. However, this figure is unofficial. As there is no meteorological office, the village cannot claim to be wetter than its neighbors, Cherrapunjee.

**Place** | **Rainfall** | **Intensity per/hr**
--- | --- | ---
1. **Bali**, Malaysia | 1.5 in (38 cm) | 89.76 in (228 cm)
2. **Muluocaidang**, China | 1.17 in (2.98 cm) | 9.50 in (24.13 cm)
3. **Shangdi**, China | 1.49 in (3.73 cm) | 3.86 in (9.81 cm)
4. **Cherrapunjee**, India | 1.23 in (3.1 cm) | 2.96 in (7.58 cm)
5. **Mawsynram**, India | 0.94 in (2.39 cm) | 1.17 in (2.98 cm)
6. **Foc-Foc**, Réunion | 0.94 in (2.39 cm) | 1.17 in (2.98 cm)
7. **Commerson**, Réunion | 0.86 in (2.19 cm) | 1.17 in (2.98 cm)
8. **Commerson**, Réunion | 0.49 in (1.25 cm) | 0.49 in (1.25 cm)
9. **Plumb Point**, Jamaica | 0.49 in (1.25 cm) | 0.49 in (1.25 cm)

**Record Rainfall**

Over short periods, the heaviest rain falls from intense thunderstorms. Records from one to several days are associated with tropical cyclones. The wettest places by annual average receive either heavy monsoon rain over a few months or steady year-round orographic rain.

**Mount Waiakea, Hawaii**

Mount Waiakea, Kauai, Hawaii (above) With an average rainfall of more than 460 inches (11,680 mm), this mountain is one of the wettest places on Earth.

**Bergen, Norway (right)**

Bergen, Norway (right) With an average annual rainfall of 88 inches (2,210 mm) Bergen is far from the world’s wettest place, but its relatively year-round rainfall can make it feel that way. It once rained on the city for 85 consecutive days.

**Cherrapunjee, India**

This town receives 90 percent of its extraordinary rainfall between March to October.

**Mount Waiakea, Hawaii**

Mount Waiakea, Hawaii This round conical Hawaiian peak is exposed on all sides to moist ocean winds. It receives rain almost every day of the year.

**Quibdo**

Quibdo’s rainfall chart

Quibdo, Colombia This town is located where prevailing warm moisture-laden winds meet the Andes. The nearby town of Lloro is even wetter but it does not have an official weather station.

**Wettest no more?**

There are indications that Cherrapunjee—the wettest town in the world—is becoming drier. Since the turn of the century, rainfall has been consistently below average and the monsoon has been arriving later. Climate change and intense deforestation may be to blame.
Earth’s Driest Places

The driest climates are found in large subtropical deserts, continental interiors, and at the Poles. In deserts, dry, subsiding air flows outward at a low level and prevents moist air from entering. Continental interiors are dry because of their distance from the ocean, and polar air is too cold to hold moisture. A warmer climate may increase rainfall in some deserts.

Antarctic dry valley

Virtually no snow falls on the McMurdo Dry Valleys in Antarctica. They are kept bone dry by the action of strong, cold katabatic winds that evaporate all traces of moisture.

Fact File

Conserving water Plants and animals that live in very dry areas have developed ways of making the most of every drop and of surviving dry times. Some species store water. Others remain mostly dormant, reviving after rain.

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Antarctic dry valley

Fleeting beauty

When rain does come to the desert, a profusion of colorful wildflowers may appear. These plants only germinate after rain and complete their life cycle within a few months.

South Pole

This is a long way from the ocean and the air is too cold to hold much water vapor. Permanent high pressure means surface air flows outward, producing frequent gales and preventing milder, warmer air from generating into the interior.

Fleeting beauty

South Pole, Antarctica

Arica

In the north of the Atacama Desert, the city of Arica experiences prevailing winds that blow from the northeast. Before reaching Arica, air crosses the South American continent and the Andes Mountains, losing its moisture and producing extreme aridity with an average annual rainfall of just 0.03 inches (0.76 mm).

South Pole, Antarctica

Arica, Chile

Mojave Desert

This arid region lies to the south and east of the Sierra Nevada mountain range and in its rain shadow. As air from the ocean crosses the mountains, it loses its moisture. As a result, the desert receives 5 inches (127 mm) of rain a year.

Mojave Desert, U.S.A.

San Pedro Springs

Deep underground water flows to the surface as an oasis, which supports palm trees and sometimes crops and other vegetation. For centuries oases were critical links on important trade routes.

Oases

Brine shrimp

Eggs of desert brine shrimp can lay dormant for several years before conditions are suitable for hatching.

Brine shrimp

Thorny devil

A network of channels in the skin of this Australian lizard directs water toward its mouth.

Cactus

Cacti have a shallow but extensive root system to collect as much water as possible from dew or infrequent rains.

Cacti

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Antarctic dry valley

Parts of the Atacama Desert in Chile have not seen rain in recorded history. However more than a million people live in the region today, mostly along the Pacific coast.

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Atacama desert

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Earth’s Driest Places

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Fact File

Conserving water Plants and animals that live in very dry areas have developed ways of making the most of every drop and of surviving dry times. Some species store water. Others remain mostly dormant, reviving after rain.

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