Translated excerpt with selected illustrations

Stefan Rahmstorf / Klaus Ensikat (Illustrator)
Wolken, Wind & Wetter.
Alles, was man über Wetter und Klima wissen muss

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Stefan Rahmstorf / Klaus Ensikat (Illustrator)
Clouds, Wind, and Weather

Translated by Allison Brown

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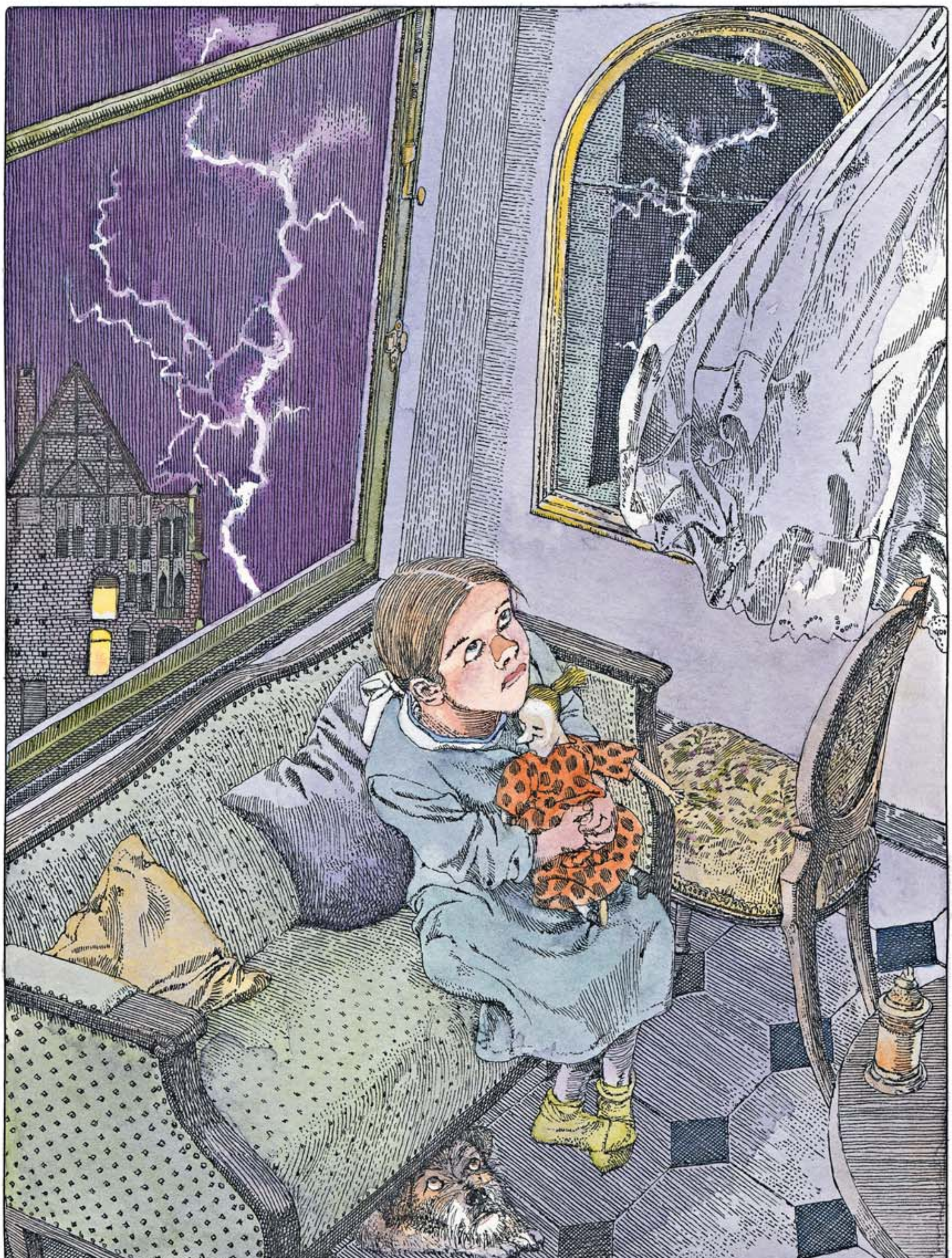

Chapter 1

Who's afraid of thunderstorms?

Who doesn't get scared when lightning flashes and thunder roars? It is probably a primal fear built into human beings—as early as the Neanderthals! Even dogs like to hide under the couch during a thunderstorm. And psychologists have a name for this kind of fear: brontophobia.

On the other hand: Aren't thunderstorms a fascinating act of nature, which we can gaze at in amazement—from the safety of our home or car? With a feeling of excitement in our stomach and of living on an incredible planet.

The atmosphere, that layer of air surrounding the Earth, has a whole arsenal of spectacular tricks on hand, which trigger awestruck wonder in us or teach us the meaning of fear. We'll learn about some of the wildest things in this chapter!

Gray clouds gather at the horizon beyond the lake. Their upper surface is still bright, with the sun shining on them, but towards the bottom they are getting darker and darker. If you watch them for a while you can see how the bright, upper part rises upward, as new cloud formations accumulate. It's is almost like a bubbling pot—but in slow motion. Gradually the dark cloud bank comes ever closer, eclipsing the sun, and the mood of the fair summer afternoon quickly turns ominous. The first rolls of thunder can be heard, at first from a distance. Suddenly strong gusts of wind come over the lake, making the water rough and dark. Storm warning lights start blinking. Lightning bolts flash out of the sky and the clap of thunder follows almost immediately. The wind dies down a bit, and then it starts to rain heavily or even to hail.

I have often observed such a thunderstorm developing from my parents' balcony. There I have a front row seat and can see out over most of Lake Constance. Experiencing a heavy thunderstorm close-up is an impressive natural spectacle. It makes you feel so small in the face of the flashing lightning and the mighty claps of thunder. Many people as well as pets are afraid of thunder and lightning. In olden days, thunderstorms were thought to be a sign of God's wrath. The ancient Germanic tribes believed that Thor, Norse God of thunder, had thrown his hammer down to Earth.

Farmers do not necessarily like thunderstorms, as it can spoil their lettuce or tomatoes. But some windsurfers love the gusts of wind prior to a storm all the more in order to ride quickly over the water. That can definitely be a dangerous activity, however: If lightning and thunder come closer, you should quickly leave the surface of the water. We'll discuss the dangers of a thunderstorm later on. But first let's understand what a thunderstorm is and how is develops.

Why is there thunder and lightning during a thunderstorm?

Every child knows what a thunderstorm is—it is when lightning and thunder fills the sky. A lightning bolt is an electrical discharge. A spark jumps between a cloud and the ground or between two clouds. The famous natural scientist Benjamin Franklin was able to prove that in 1752, when he flew a kite with his son during an approaching storm. He electrically charged a metal key that he had attached to the kite string, so that it threw off sparks. That was a dangerous experiment! If a bolt of lightning had struck the kite, it would have cost Franklin his life. As a practical application he then invented the lightning rod, which in an improved form can be seen on many buildings today. A lightning rod is made of metal and extends above the roof of a building. It attracts the lightning that would otherwise strike the building and cause great damage, and conducts it safely into the ground.

Electricity is comprised of electrons—these are minuscule particles that carry a negative charge. They are in all atoms—also in clouds—flying around the positively charged atomic nucleus. During thunderstorms the positive and negative charges separate. The top of the clouds is usually positively charged and the bottom gets a negative charge. This creates an electrical tension, a sort of attractive force on the electrons, which continues to increase as the difference between the charges also increases. When this tension gets to be unbearably large, it discharges suddenly in a bolt of lightning. It is just like the tension that grows between two siblings, which then discharges in a big fight! Well, actually that is very different. As much as a hundred million volts can accumulate between the ground and a thundercloud! The voltage in an electrical outlet is only between 110 and 220 volts—not more than a mosquito bite in comparison.

No one knows precisely how the charges in a thundercloud actually separate, but it has to do with strong air movements and the accompanying friction in such a cloud. Anyone can experiment to see how friction can lead to an electrical charge: If you rub a wool sweater against a piece of plastic, you can make tiny little sparks. That’s why it crackles sometimes when you take off a sweater.

The electricity in a lightning bolt flows through a so-called lightning channel, which is about half an inch thick. The lightning channel takes a branched zig-zag path from the cloud to the ground, or between two clouds. The air there is unbelievably hot: 54,000°F. That is five times as hot as the surface of the sun! Vapors that hot will glow, thus generating the bright flash of light. The power surge lasts only a fraction of a second. Usually, there is a series of several short discharges through the same lightning channel. That's why lightning appears to flicker.

Thunder also comes from the sudden heating up of the air. In the process the air molecules expand explosively and start vibrating, like a bell does when you strike it. Sound waves are of course nothing more than air vibrations.

The sound rushes through the air at a speed of more than 1000 feet/second (approx. 740 mph); that's about five seconds per mile. That might sound really fast but light moves even faster. Light can encircle the Earth seven times in one second! As a result we can see the flash of lightning almost immediately, but there is a delay before we hear the thunder. If you count the seconds between the lightning and the thunder, and divide that number by five, that is about how many miles away the lightning is. If it takes less than 15 seconds for the thunder to reach your ears, then the storm is less than 3 miles away and you are in the danger zone, within which the lightning could strike next.

How the weather factory makes a thunderstorm

In order to make a real thunderstorm, nature needs only three things: The first is water vapor (that is, moist air) close to the ground. The water vapor is the fuel that gives the thunderstorm its energy. Second, the air has to quickly get colder as it rises, which means that the air must be warmer close to the ground than it is a few miles high. And third, something must cause an updraft, that is, it must lift the moist air from the ground.

What then happens is an exciting chain reaction. A bubble of moist air rises. It thereby cools down since the pressure decreases at higher altitudes and the air expands. You are familiar with the inverse effect from an air pump. When air gets compressed it gets warm. But cold air cannot hold as much water vapor, so some of the vapor condenses into a liquid, forming small drops of water. Those are the clouds that we can see from the ground. When water vapor liquefies, heat is released. Conversely, heat must be added in order for liquid water to evaporate, that is, to vaporize into steam. Heat is a form of energy and the total volume of energy has to be maintained. It never disappears; it only changes its form. We'll talk more about that in the next chapter.

Back to the updraft, or rising air: The heat that is released from the water vapor makes the rising bubble of air warmer than the air around it, which means that it is also lighter. That makes it rise even faster, like a hot air balloon but without the balloon envelope. As a result, more water vapor is converted to drops and even more heat is released. The air then rises even faster—until all the water vapor is gone. Now it is clear why we referred to the water vapor as the source of energy that fuels the thunderstorm factory. At this point the air is bubbling like crazy, and the bubbles and clouds rise intensely.

Aside from lightning and thunder, heavy rains also result, because the many drops of water that develop start falling at some point. Before that happens, the quickly rising air sometimes lifts the drops to such great heights that they freeze, since it is very cold at higher altitudes. When the frozen drops finally fall to the ground, it is hail. Sometimes the hailstones can become dangerously large. The heaviest hailstone that has every been recorded weighed more than a pound and a half and had a diameter of about 5½ inches—as big as a cantaloupe. There were even newspaper reports in 2006 that an entire herd of sheep in Croatia was struck down and killed by hailstones. Sometimes huge icy-cold drops of rain fall. These are hailstones that have melted on their way back down to Earth.

Scientists who study weather are called meteorologists. They distinguish between different kinds of thunderstorms depending on why the air starts rising in the first place. Heat (or air-mass) thunderstorms occur during the summer, usually in the afternoon or evening. They develop because the sun greatly heats up the air close to the ground and also saturates it with moisture through the evaporation of water. At a certain point the warm air bubbles start to rise. The more seldom winter thunderstorms are generated essentially in a similar way, but the necessary large difference in temperature is not achieved through heat on the ground (the sun in the winter is too weak to do that). Instead, it occurs when the higher air layers cool down, for example, when icy polar air flows in at a high altitude. Another kind is the so-called multicell cluster storm; it often occurs before a cold front and thus announces a change in weather. In this case the approaching cold (and thus heavier) air pushes underneath the existing warm, moist air mass like a wedge, pushing it upward, which in turn can trigger the aforementioned chain reaction. The last type is a mountain thunderstorm. When air flows over a mountain range it is necessarily lifted higher, which can also trigger a thunderstorm.

How many lightning bolts are there in the world?

Every second about one hundred lightning bolts are discharged somewhere in the world, since at any moment in time there are between 2000 and 3000 thunderstorms occurring somewhere on Earth. That amounts to more than three billion flashes of lightning in one year! In Germany alone there are about two million. Who counted all of them? Thousands of meteorologists kept watch and recorded all of them day and night for a whole year. No, that's nonsense of course! In fact, two satellites collected the data from their orbit. They had special devices on board in order to automatically register lightning bolts.

These satellites also show where most lightning occurs: namely, close to the equator and most of all in Africa's Congo Basin. At any location there you can experience heat thunderstorms almost daily. The rising bubbles of warm air release into the atmosphere every evening the heat that collects during the day in the tropics. The situation in Germany is rather boring in comparison. If you want to see a lot of lightning there the best place to go is to the south, especially in the Black Forest, and also in the summer since there are far more thunderstorms in the summer than in the winter.

By the way, only about ten percent of all lightning flashes look the way we imagine them and reach down to the ground. Most lightning bolts arc from one cloud to another. Often we cannot see them directly, but only their reflection in the clouds. That is also the case with thunderstorms observed from a great distance. We refer to that as heat (or sheet) lightning.

With a bit of luck it is possible to glimpse some particularly rare thunderstorm phenomena, such as Saint

Elmo’s Fire. High metallic objects such as an antenna mast or a summit cross appear to be on fire.

Are thunderstorms really dangerous?

Many people are very afraid of getting struck by lightning during a thunderstorm. This is in fact known to happen. However, presently only about seven people die each year in Germany due to lightning. In comparison: Of the 80 million Germans, about 5000 die each year in traffic accidents. One could think that the danger posed by thunderstorms is only minimal—that suffering a lethal stroke of lightning is “as probable as winning the jackpot in the lottery,” as is often claimed. But of course you also have to consider the fact that most people hardly ever expose themselves to the danger of a thunderstorm, yet most are constantly active participants in street traffic (and many play the lottery every week). Also, in the nineteenth century the figure was still around 300 deaths due to lightning in Germany each year, because at that time many more people still worked outside on the fields.

Let’s make a rough estimate: Scientists like to do that in cases in which they don’t have any precise data. Based on statistical investigations, the average German spends about 1¼ hours per day in traffic, which is almost 500 hours annually. The odds of being killed in traffic are thus 1 to 8,000,000 (the result of the equation: 80 million Germans x 500 hours ÷ 5000 deaths = 8 million). It is not known how much time the average German spends outdoors during a thunderstorm, but it is possible to try to estimate it by asking ask friends and family. You have to take into account that some people never go outside during a thunderstorm at all, but others, such as hikers, sailors, bicyclists and motorcyclists, golfers, and farmers do in fact get caught outside during a thunderstorm without any shelter nearby—and many people are outside during a storm for at least a few minutes, if they are hurrying from their parking space to their front door, for example. If we assume that each person spends an average of five minutes in a thunderstorm each year, and compute the figure using the same formula as we did for traffic, then the risk of death when spending one hour in a thunderstorm is roughly 1 to 1,000,000, or about ten times as much as in traffic.

With such a rough and thus uncertain estimate of a danger, it is definitely better to play it safe, since we might have even made a mistake in our calculation. To be on the safe side let's assume that the dangers facing someone caught in a thunderstorm might be even more than ten times greater than estimated. In that case, five minutes in a thunderstorm might be just as dangerous as seven hours in traffic. Hardly anyone is afraid of the latter, so we can see that there is no reason for any exaggerated fear of lightning.

But it does make sense to take reasonable precautionary measures to reduce the risk significantly. Lightning likes in particular to strike high, towering objects, such as a tree standing alone. Thus it is smart to keep a distance of several yards from trees and masts. You should also make sure that you are never the highest point in your surroundings. And I would refrain from swimming during a thunderstorm, as water conducts electricity and you can be injured by lightning that strikes even ten to twenty yards away in the water. If you get caught in a thunderstorm when out in an open field, the risk can be minimized by crouching with both feet pressed close together, if possible in a hollow, or ground depression. But don't lie down, because if lightning strikes the ground nearby, it creates a drop in voltage. This means that anyone lying down has a different voltage at his or her head than at the feet, and electricity could then travel through the body.

As a thunderstorm approaches, you should go inside a car or building if possible, where you will generally be safe from lightning. Vehicles are so-called Faraday cages. The famous nineteenth-century English physicist, Michael Faraday, was able to prove that electricity flows along the exterior of a metal cage without being able to be felt in the interior. I myself was once sitting in an Intercity Express train that was hit by lightning in the Rhine valley. I didn't notice anything at all while in the train, except that it suddenly stopped between stations and did not continue for quite some time, after the engine driver had checked that all the electrical systems were still working. Electrical devices, especially highly sensitive computers, can be easily damaged by lightning. When inside a house it is totally safe to talk on the telephone, bathe, or shower during a thunderstorm, provided the telephone lines are underground and the water lines are properly grounded, that is, with an electrically conductive connection to the ground. You cannot be absolutely certain of this in simple mountain cabins or in some other countries, such as in the United States, where many telephone lines are still above ground, attached to telephone poles.

Very few people know that most people survive getting struck by lightning. Only one in four dies. The power surge lasts only a fraction of a second and most of the electricity flows along the exterior surface of the skin and does not penetrate the body. If the person suffers respiratory arrest, resuscitation measures can help get breathing to start up again. If someone is struck by lightning it is important that he or she gets proper treatment from a specialist, as after-effects can occur, such as headaches and memory problems.

p. 12: text in figure:
Ableitung = connection to ground
Blitzableiter = lightning rods or conductors
Auffangsstangen = rods
Erdung = ground

p. 15:
330 m pro Sek. ≈ 1083 ft/s or 740 mph

Boxes:
p. 12: **Make your own lightning flashes**
Blow up a balloon and rub a wool sweater on it. This will give the balloon an electrical charge. Now place the balloon in a stainless steel colander that is resting on a dry glass (for insulation). If you slowly bring your finger closer to the colander, a small spark will arc across the gap—a mini-flash of lightning! You can even see it in the dark.

p. 15: **Thunder experiment**
Using a funnel, fill a balloon with flour. Now blow up the balloon. Stand outside at least 200 paces from a friend. Then burst the balloon with a pin. Your friend will see the cloud of flour—but will not hear the bang until a bit later.

p. 16: **The most expensive hailstorm**
On July 12, 1984, a heavy hailstorm rained down on Munich. Pellets of ice as big as walnuts or even tennis balls plummeted down from the thunderclouds towering as much as seven and a half miles high. After 15 minutes it was all over, having

damaged 70,000 homes, 150 airplanes, and more than 200,000 cars. It was the worst case of damages up to then for German insurance companies.

p. 17: **Ball lightning**

Ball lightning is a rare occurrence that has not yet been thoroughly explained by science. There have been numerous reports of these floating balls of lightning roughly the size of a soccer ball, which appear suddenly near thunderstorms and disappear after a few seconds. During a heavy thunderstorm in Potsdam, my father-in-law once saw a lightning ball roll down the street and then climb the wall of a building up to the roof. Only recently have scientists been able to create something like ball lightning in a laboratory.

p. 19: **Lightning miracle**

There is supposedly one man who was struck by lightning seven times—former park ranger Roy C. Sullivan in Virginia. He reported that each time his hair started crackling two seconds before the strike.