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PREDICTING THE FUTURE: HOW DOES A WEATHER FORECAST WORK?

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YOUNG REVIEWERS:

BEN
AGE: 9

CALEB
AGE: 10

COLIN
AGE: 8

EVELYN
AGE: 9

Accurate weather forecasts are very useful, because they tell people what kind of weather to expect in the next few days. But how can we predict what will happen in the future? This article will explain how meteorologists, the people who study and work with the conditions that happen in the atmosphere, predict tomorrow's weather. To help you understand weather predictions, we will first explain how changes in the atmosphere result in various types of weather. In this article, we will tell you how meteorologists turn knowledge of the conditions in the atmosphere into a weather forecast, just like you see in the news or on a weather app!

WHAT INFORMATION CAN A WEATHER FORECAST PROVIDE?

Every day in the news, we can see the weather forecast for the next few days, telling us if it will be sunny, cloudy, windy, rainy, or cold.

Many people rely on weather forecasts every day—for more than just knowing whether they should bring a raincoat! For example, pilots must be able to fly airplanes safely, farmers need to look after their crops, and local governments need to know whether they should prepare roads for icy conditions. Usually, a weather forecast tells us about a few **weather characteristics** that are most important to us, for example, temperature, cloudiness, **precipitation** (such as rain or snow) and wind. To understand how **meteorologists** predict these conditions, we must first explain how these weather characteristics occur based on what is happening in the atmosphere.

WEATHER CHARACTERISTICS

Things that can be measured in the atmosphere, for example, temperature, pressure, or humidity.

PRECIPITATION

Any form of water, liquid or solid, that falls to the Earth's surface, for example, rain, sleet, or snow.

METEOROLOGIST

A person who works with understanding or predicting the weather.

Temperature

The temperature depends on many things, including cloudiness and which direction the wind blows. In the daytime when the sky is clear, the sun can heat up the air more than it can in cloudy weather. However, during the night the opposite is true. Just as you cover yourself with a blanket to keep warm when you go to sleep, cloud cover helps to keep the air closer to the ground warm. If the sky is clear at night, it will be quite chilly. Temperatures can also be affected by air moving from hotter or colder places. For example, when warm air travels north from northern Africa, Europe can experience very high temperatures.

Clouds

Clouds form when there is enough **water vapor** in the atmosphere. Air can hold a certain amount of water vapor, depending on the air's temperature. The warmer the air, the more vapor it can hold. When there is more water vapor in the atmosphere than the air can hold, then it will **condense**. This means small water droplets will form. These droplets are so light that they float in the air, forming clouds. If it is cold enough, the little droplets of water can freeze. The clouds will then be made up of tiny ice crystals instead of droplets.

WATER VAPOR

Water in the form of a gas.

CONDENSE

The process of a substance (like water) changing from gas to liquid form.

Precipitation (Rain and Snow)

As the water droplets in a cloud swirl around and bump into each other, they merge and grow bigger. Eventually they become so big that they are too heavy to float in the sky, and they fall to the ground as rain. Different types of clouds can lead to different types of rain. For example, think of a surprising, intense summer shower, compared to a light rain that lasts all day. If the cloud consists of ice crystals, snowflakes can form as the crystals bump into each other. If it is cold all the way down to Earth's surface, then there will be snow. Otherwise, the snowflakes melt and turn into rain before they reach the ground.

AIR PRESSURE

The pressure caused by the weight of the air (which has mass) above a certain location.

Wind

To understand how windy it will be, meteorologists must look at the **air pressure** in the atmosphere. Even though we barely notice it, air has mass, and the air pressure tells us the weight of all the air that

is above your head. You can think of this like pumping up a bike tire: as you pump more air in, the pressure in the tire increases. Now let us think of this for the whole atmosphere. If there is high air pressure, that means there is more air than normal sitting above us. This is usually associated with calm conditions and sunny days. On the other hand, if air pressure is low, then there is less air than normal above us. This is typically associated with wet and windy weather. The strength of the wind depends on how quickly the pressure changes between locations.

COMPONENTS OF A WEATHER FORECAST

Now that you know a bit about the atmosphere, we can look at how to predict the weather. Weather prediction requires observations, weather models and of course, meteorologists! Figure 1 shows how information is collected and combined to make a weather forecast. The following three sections will explain the steps in more detail.

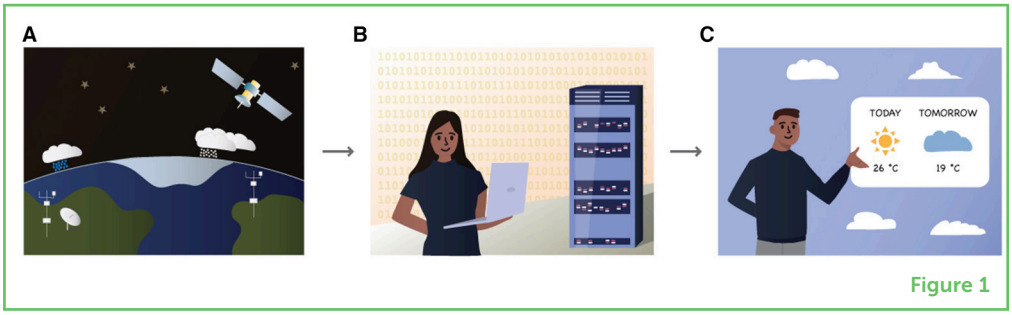

Figure 1

There are three main steps to creating a weather forecast. **(A)** Accurate observations of the current weather and the atmosphere are crucial. These observations can be made from the ground or from satellites. **(B)** Weather models are programs run on supercomputers which perform complex calculations based on equations that describe weather characteristics. **(C)** Meteorologists combine information from weather models with their own experience and knowledge of local effects to create a forecast that they can present to the public.

Measurements at Ground Level and From Satellites

Accurate measurements of the weather are very important for producing an accurate forecast. These measurements come from various types of equipment, which measure lots of weather characteristics including temperature, humidity, precipitation, and wind (Figure 1A). In addition, radar images are very important, particularly for precipitation [1]. Radar works by sending out a light pulse, a bit like flashing a torch, then detecting how the light is reflected back by precipitation. From radar data, it is possible to figure out where there is snowfall or rain, and how intense the precipitation is. Another very important source of information for generating weather forecasts comes from satellites. They provide "photos" of the Earth from space at regular times throughout the day, which are especially useful for collecting information about cloud cover.

Weather Prediction Models

Imagine you are watching a film. The decisions that the main character makes in the beginning will affect how the story ends. This is similar for the weather: changes in the current weather, such as changes in temperature and humidity, will affect the weather in the future [2]. By providing precise information about the current conditions

WEATHER MODEL

A program usually run on a super-computer which simulates the atmosphere and weather.

in the atmosphere to a **weather model** (Figure 1B) meteorologists can calculate how the atmosphere will look each hour, for about a week into the future. They can do this because many processes that happen in the atmosphere are predicted by mathematical equations. For example, there are equations that describe how quickly warm air rises, how raindrops are formed, and how wind creates waves on the ocean, just to name a few examples! A weather model combines these equations and calculates them using a supercomputer. The weather model can cover a large region, like the whole world, or a smaller region, such as one specific country. In a film, we cannot change the character's decisions and, similarly, we cannot make a weather model always predict sunny weather, or snow on Christmas!

Producing a Forecast

Meteorologists combine the measurements and the output from the weather model, along with their own experience, to produce a weather forecast for the public (Figure 1C). The model only gives numbers for certain weather characteristics, for example the temperature and pressure at certain locations, so it is the job of the meteorologist to interpret what these numbers mean, and how they can be expressed and explained. Often, the meteorologist can also improve the forecast further, with local knowledge and experience. The meteorologist then communicates the information to the public, for example during a weather report on the radio or TV, or *via* a weather app.

CAN WE BE CERTAIN ABOUT THE WEATHER?

ENSEMBLE METHOD

A weather model that creates many suggestions for how the weather could evolve, which gives meteorologists information on the chances of certain events, like precipitation, occurring.

Sometimes weather predictions are spot on, but other times they miss by a little. To get a measure of how reliable the forecast is, meteorologists run many weather models to get suggestions about how the weather could evolve. This is called an **ensemble method** [3]. Think of this like throwing a paper plane many times and looking at the path the plane takes each time (Figure 2). The first part of the path will probably look very similar for almost every throw, but the plane could still land in quite different places. If all suggestions from the weather models are similar, then meteorologists can be quite certain of the future weather, but if the models tell different stories, they know that the forecast is uncertain. Meteorologists also get information about what could happen in the most extreme situation, which allows society to prepare for the worst-case scenario and helps keep everyone safe.

SUMMARY

Weather forecasts provide vital information to the public, helping societies to run smoothly. Forecasts are much better now than they were just a couple of decades ago [4], and today we have access to lots

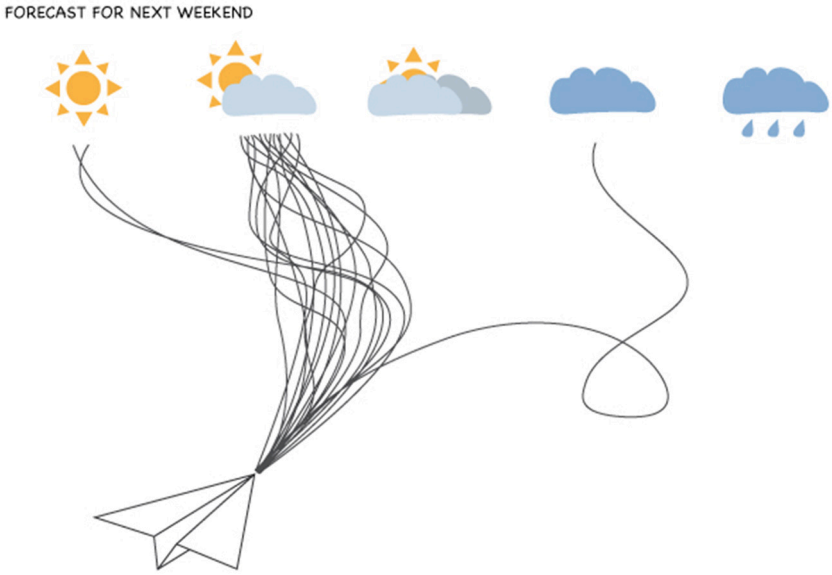

Figure 2

If you throw a paper airplane many times, the paths of the plane could represent ways that weather could evolve. Short-term weather forecasts are usually more certain than longer-term forecasts, just like it is difficult to predict exactly where the plane will land, even if you throw it the same way each time. The difference between the forecasts created by various weather models gives a good estimate of how likely various types of weather will be. In this case, we see the most paths going toward the partly cloudy symbol, so the weather is most likely to be partly cloudy next weekend.

of information and knowledge that helps meteorologists understand and model the atmosphere. There is still ongoing research on the physics of the atmosphere and weather modeling, but for such a complicated system, we can forecast the weather incredibly well. So, the next time you hear a weather forecast that says that there might be rain, you should probably pack your raincoat!

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

BEN, AGE: 9
Hi, my name is Ben, and I am 9 years old. I love Science and Math and am interested in playing bowling and chess.

CALEB, AGE: 10
Caleb enjoys all things science, animals, reading, exploring the outdoors, playing the violin, and curling. When he grows up, Caleb wants to be an architect focusing on eco-friendly and animal-oriented buildings. He has tried four sports and is always up for trying something new. Caleb's favorite foods are macaroni and cheese or lasagna. He enjoys traveling and would like to go to an animal reserve.

COLIN, AGE: 8
My name is Colin. I like to draw cartoon characters and play video games but my favorite hobby is to play tennis. My dream is to be an entomologist. This is a scientist that studies insects. I think I really got into it because I read a lot of insect-related books since I was very young and my curiosity about insects never stops!

EVELYN, AGE: 9

Hi my name is Evelyn. I enjoy reading, writing, science experiments, and learning. I have a lot of favorite books, one example is "My Weird School." I also like comics like "What is Up Beanie." When I grow up I would like to be a teacher. One of my favorite places to be is my home, and school. But I do not like summer school. These are some things about me.

AUTHORS

EMMA HOLMBERG

Emma Holmberg is a Ph.D. student in meteorology at Uppsala University, Sweden. Her research and professional interest lies at the interface between mathematics and climate science, in particular, analyzing extreme weather events using techniques from mathematics and statistics. Prior to starting her Ph.D., Emma worked for the insurance industry as a consultant for risk associated with natural hazards, like severe storms. She loves cooking and spending time in nature, either hiking or foraging for berries and mushrooms in the Swedish forests. *emma.allwright@geo.uu.se

CHRISTOFFER HALLGREN

Christoffer Hallgren is a meteorologist with a great love for clouds—as well as for clear skies. Working as a weather forecaster for many years, Christoffer learned the practical craft of forecasting and realized how the challenges in making the perfect forecast change with the seasons. At the moment, Christoffer is working toward his Ph.D. at Uppsala University, focusing on peculiar winds in coastal areas and how to predict them.

GABRIELE MESSORI

Gabriele Messori started out wanting to be a theoretical physicist, but became fascinated by weather and climate at an early stage of his studies. He has now been researching the atmosphere for over 12 years. Gabriele has found himself in lots of interesting weather during these years, from severe storms in the Southern Ocean to an extratropical cyclone on the Norwegian coast and a record-breaking heatwave in Italy. Gabriele is currently a professor of meteorology at Uppsala University in Sweden, and is still fascinated by weather every day.