

When Our Heads Are in the Clouds

The fog comes on little cat feet.

It sits looking over harbor and city on silent haunches and then moves on.

Carl Sandburg



Creative Commons: glemaharpe

The problem is, where does the fog go next? And how long until it gets there? The ability to detect this foggy behavior from space would help a lot of people.

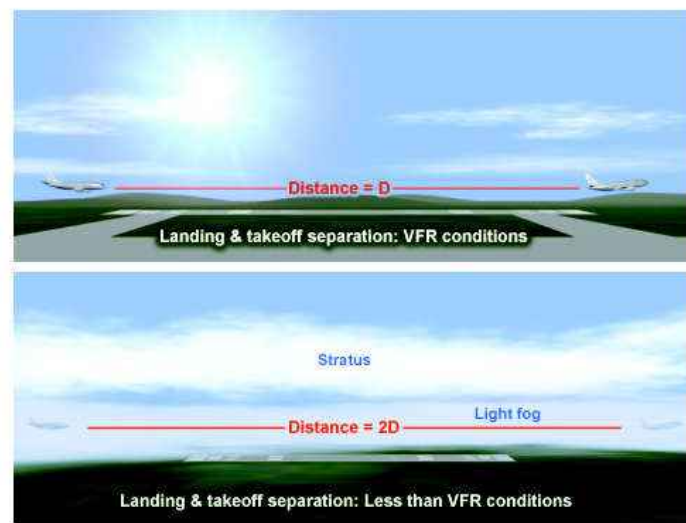
Fog and low clouds as troublemakers

Fog and low stratus clouds are a hazard to public and personal transportation. Visibility under foggy conditions can be drastically reduced, creating dangerous situations for vehicles on roadways as well as airplanes, trains, boats, and other means of transportation.

From 1995 to 2005, the National Highway Traffic Safety Administration (NHTSA) found that in the U.S. each year, an average of 38,700 vehicular accidents were directly related to fog. These accidents caused 16,300 injuries and 600 deaths. In the same period, the National Transportation Safety Board (NTSB) reported an annual average of 81 airplane crashes caused by reduced visibility due to clouds, fog, or low ceiling. Sixty-one of these accidents each caused at least one fatality. In addition, commercial airlines lose millions of dollars each year from cancellations, delays, and rerouting forced by low visibilities at airports due to fog and low stratus clouds.

Where are the clouds?

Clouds can be found as high as 60,000 feet (18,000 meters), or over 11 miles high. They can also be found around your feet on the ground—the road, or the runway. No matter where they are, we humans take a great interest in them because they often dictate what we will do—and do not do.



During poor visibility conditions, planes taking off and landing must be spaced out farther apart than usual, if they are allowed to take off and land at all.

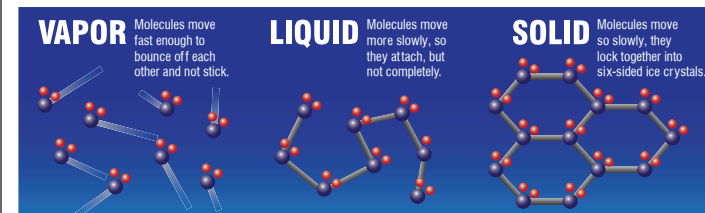
The highest clouds are cumulonimbus, and they often produce severe storms, with lots of rain and lightning, and sometimes tornadoes, hail, and other dramatic events.

The lowest clouds are stratus, below about 6,000 feet (about 2,000 meters, or a bit over a mile). If they are very low, say below 1,000 feet, they can interfere with an airplane pilot's visibility when it comes time to find the runway and land. That is when the pilot must switch from Visible Flight Rules (VFR) to Instrument Flight Rules (IFR).

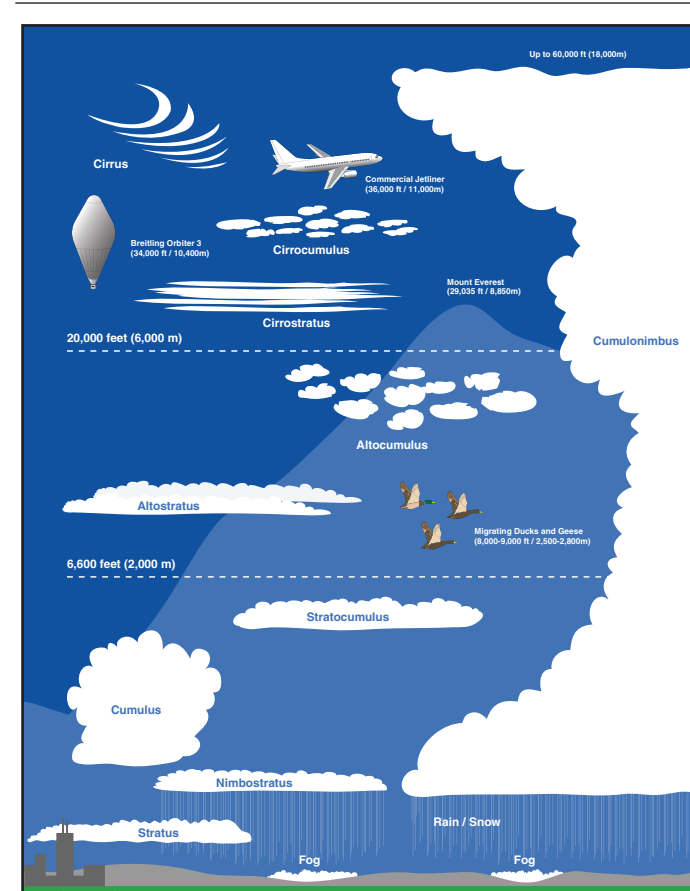
Fog is a little different from other clouds, because it generally forms as a direct effect of the atmosphere and the surface (whether land or water) interacting at their boundary. Another reason fog, as well as low stratus clouds, are different is that they interfere in all kinds of ways with human activity.

The faces of fog

As all clouds do, fog forms when water vapor condenses into water droplets suspended in the air. It's important to remember that water vapor needs a tiny particle of dust or soot, or another water drop, or ice crystal, or a surface of something solid upon or around which to condense.



The three main phases of water are gas (vapor), liquid, and solid. We say "main," because other in-between phases occur under certain circumstances.



Altitudes of common clouds.

The warmer the air, the more water vapor it can hold. If the warm air is saturated—that is if it is holding as much water vapor as it possibly can—and then the air cools, some of the water vapor turns to liquid water. If the air drops below freezing, the water droplets freeze, become ice crystals, snow, sleet, or hail.

Sometimes if saturated air cools suddenly to below freezing, the water can go directly from gas (water vapor) to solid (ice crystals). This condition is called **ice fog**.



Ice fog.

Sometimes water droplets do not freeze in below-freezing temperatures. This happens if they do not have a surface (like a dust particle or an ice crystal) upon which to freeze. This below-freezing liquid water becomes "supercooled." Then when it touches a surface whose temperature is below freezing, such as a road or sidewalk, the water will freeze instantly, making a super-slick icy coating on whatever it touches. This condition is called **freezing fog**.



Freezing fog.

A condition that makes for even worse visibility is **super fog**. This dense, almost zero-visibility fog occurs during wildfires. Since water is a product of combustion, the air above the ground is not only hot, it is also very saturated with water vapor. In a humid climate, the air will be even more likely to be saturated. As the air in the fire area cools off at night, the moisture has an abundance of soot particles to condense onto. The resulting fog in the morning is at times so dense you cannot see your hand in front of your face. Drivers can suddenly find themselves engulfed in this type of fog, and huge chain-reaction vehicle pile-ups can occur.

Fog and smoke from a brush fire combined to make a superfog, causing this pileup of about 50 cars between Tampa and Orlando, Florida, in 2008. Used with permission of the Orlando Sentinel, copyright 2008.



Detecting fog from space

Weather satellites operated by the **National Oceanic and Atmospheric Administration (NOAA)** collect data on clouds and storms.

NOAA operates two different types of satellites. **Geostationary satellites** orbit at about 22,236 miles (35,786 kilometers) above sea level at the equator. At this altitude, the satellite makes one Earth orbit per day, just as Earth rotates once per day. Thus, the satellite seems to hover over one spot below and keeps its "birds-eye view" of nearly half the Earth at once.

The other type of NOAA satellites are **polar satellites**. Their orbits pass over, or nearly over, the North and South Poles. They orbit at a much lower altitude, about 435 to 500 miles (700-800 kilometers) than the "geo" satellites. With Earth rotating under them, these satellites pass over nearly every point on Earth each day.

The satellites' imagers collect data that can be processed to give a picture of low clouds and fog, apart from other types of clouds, thus providing warning to pilots and drivers.

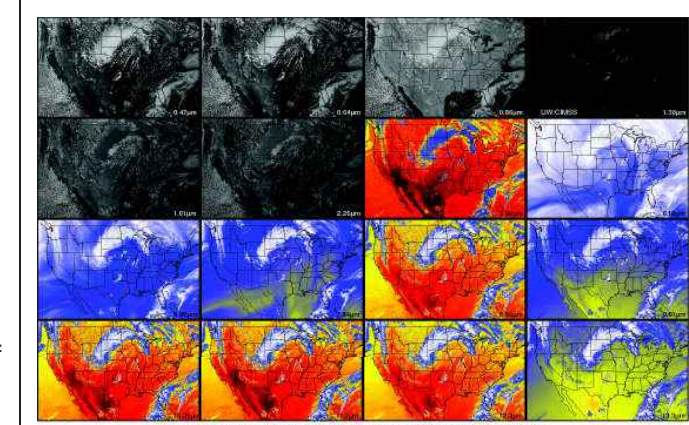
Cloud layers that are close to the ground most often exhibit the following properties.

- The temperature difference between the cloud and ground is small.
- The size of the cloud droplets are small relative to those produced in the formation of other cloud types. Satellite measurements can be used to help identify clouds that exhibit these properties. There are some limitations. For example, the fog layer cannot be overlapped by higher cloud layers. Overlapping clouds are a limitation because the satellite will only see the highest cloud layer and can therefore not take cloud measurements from the low clouds below. The limitations can be significantly reduced when satellite data are combined with other data sources, such as weather prediction models and surface observations.

The imagers

One great difficulty in detecting fog is that it can occur on very small scales, such as in small river valleys, and form rapidly in small patches or narrow bands. For these reasons detecting its location accurately from space requires an imager with high resolution (that is, the ability to see small-scale features). This feature is called spatial resolution. It must also be able to detect different wavelengths of light separately, because different kinds of weather phenomena reflect light differently. This feature is called spectral resolution. And the imager must also be fast, able to cover an area quickly. This feature is called temporal (time) resolution.

Using specific spectral wavelengths (kind of like different colors) satellites can detect whether clouds contain



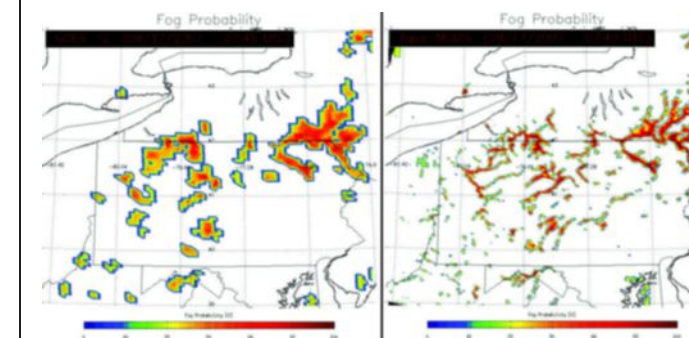
ABI band data for 2005 June 04 22:00 UTC

Clear and cloudy regions over the U.S. on June 4, 2005, as shown here in each of the 16 simulated separate bands, or "colors," detectable by the GOES-R Advanced Baseline Imager. Credit: Cooperative Institute for Meteorological Satellite Studies (CIMSS).

the properties expected to be seen in fog and detect where it is most likely to be found.

The imager on the current **Geostationary Operational Environmental Satellites (GOES)** is limited in spatial, spectral and temporal resolution, making the resulting fog maps less accurate than what is needed, requiring additional information from surface visibility reports.

The next generation of GOES, called **GOES-R** (for series R) will carry the **Advanced Baseline Imager (ABI)**, which will be able to view the Earth in 16 different spectral bands (better than only 5 on the current GOES). It is as if the imager had 16 different kinds of sunglasses, each one allowing only a certain wavelength—also called a band or channel—of light to come through. The imager detects two



The advanced imagers on the new geostationary (GOES-R) and polar-orbiting (JPSS) weather satellites will show much more accurately where fog is probable. On left is the result of using GOES-R processing on data from the current GOES, while on the right the same processing is applied to GOES-R data. These images show that greater detail can be obtained using the higher spatial resolution from GOES-R.

visible, four near-infrared, and ten infrared bands. Each band is like a separate "color" of light, except that all but two of the 16 colors are invisible to human eyes. These are the infrared bands. Although we cannot see infrared, we feel it as heat.

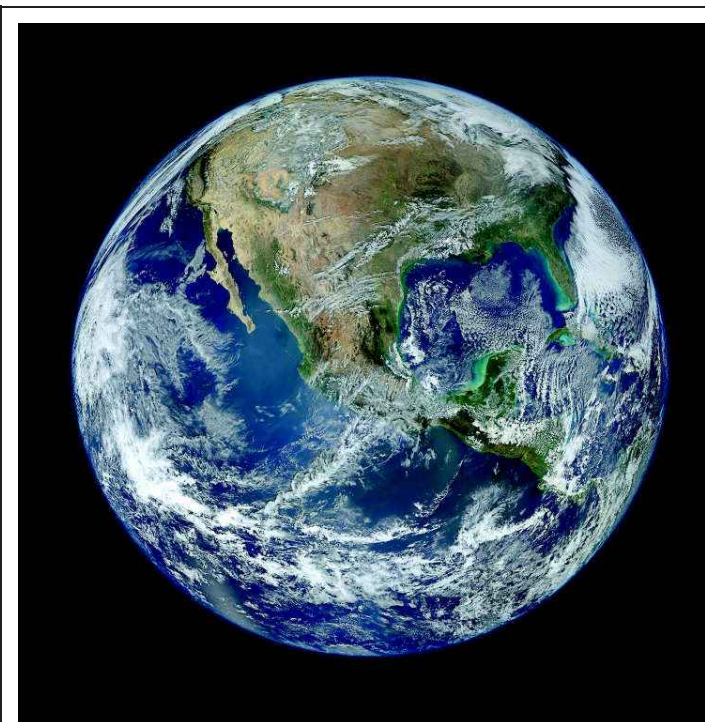
The ABI will be a huge advance over the current system. It will provide three times more information on the separate wavelengths of light being reflected from the atmosphere, have four times the spatial resolution and will cover the same area five times faster than the current technology. Forecasters will be able to use the higher resolution images to track the development of storms in their early stages.

The next generation of polar-orbiting weather satellites is called the **Joint Polar Satellite System (JPSS)**. It also carries an advanced imager, the **Visible Infrared Imager Radiometer Suite (VIIRS)**. VIIRS offers 22 different spectral bands of information, from visible light to infrared. It can detect and characterize cloud and fog properties both day and night. One new spectral band on the VIIRS is the **Day-Night Band**. It not only views clouds by the sunlight they reflect during the daytime, but also by the moonlight they reflect at night! The sensor can even detect light from a single street lamp!

When the Moon is up, the Day-Night Band sees low clouds and fog in the same way as the daytime visible sensor. In fact, moonlit images from the Day-Night Band look much like a daytime visible image, except for little details that give away the sensor's extreme sensitivity to the nighttime environment—such as city lights, lightning flashes, forest fires, and aurorae. The Day-Night Band can even sense the faint glow of light produced by Earth's upper atmosphere (called airglow) and use it as a source of light to see clouds on completely moonless nights.



These nighttime valley fog images were made by the VIIRS instrument on the Suomi National Polar-Orbiting Partnership satellite, which is giving a preview of the new JPSS satellites.



This image of Earth was made by the VIIRS instrument on the Suomi National Polar-orbiting Partnership (SNPP) satellite.

The final product

The computer program that creates the fog and low clouds data product will use the same wavelengths, or channels, of data from both types of satellite imagers. The program also uses other cloud products created for each satellite that often use additional channels (such as a cloud mask that detects where all clouds are located). The final fog and low cloud detection program (developed in preparation for GOES-R) does not use satellite data alone. Several other data sets, including mathematical models for forecasting weather, are combined with the satellite data to find out where hazardous fog and low clouds are most likely to be.

The beauty of these multi-spectral, high-resolution, fast imagers is that these data can be combined and processed in ways that give much more information and more accurate information about atmospheric conditions and their probable evolution than were possible with previous generations of satellites. This information can then be conveyed to pilots and motorists, potentially saving hundreds of lives each year.

More about GOES-R and JPSS

The next generation GOES-R and JPSS satellites are built by the National Aeronautics and Space Administration (NASA). Once NASA has launched them and made sure everything works perfectly, NOAA takes over their daily operation.

The first next-generation polar-orbiting satellite launched in October 2011. It is called the NOAA/NASA Suomi National Polar-orbiting Partnership (SNPP) and it carries the same instrument suite that will be used for JPSS-1, scheduled for launch in 2017.

The first satellite in the GOES-R series is planned for launch in 2016. Besides the Advanced Baseline Imager, it will carry five other new instrument technologies.

NOAA and NASA have successfully partnered on these types of satellites for more than 40 years.



Geostationary Operational Environmental Satellite, R Series (GOES-R). Credit: Lockheed-Martin



Suomi National Polar-orbiting Partnership, the first Joint Polar Satellite System (JPSS) mission. Credit: Ball Aerospace & Technology Corp.

Follow their progress

Find out some other capabilities of these advanced satellites. Their instrument technologies and new data processing techniques on the ground will provide dozens of new data products that will make weather event forecasting more timely and accurate than ever before.

Visit these websites to learn more:

- GOES-R: <http://www.goes-r.gov>
- JPSS: <http://www.jpss.noaa.gov>
- NOAA Satellite and Information Service: <http://www.nesdis.noaa.gov>
- SciJinks (NOAA/NASA weather and Earth science for middle-school students): <http://scijinks.gov>
- Space Place (NASA Science Mission Directorate website for upper elementary age students) <http://spaceplace.nasa.gov/weather>

Abbreviations

- ABI:** Advanced Baseline Imager (on GOES-R)
- CIMSS:** Cooperative Institute for Meteorological Satellite Studies
- GOES-R:** Geostationary Operational Environmental Satellite, R Series
- IFR:** Instrument Flight Rules
- JPSS:** Joint Polar-orbiting Satellite System
- NASA:** National Aeronautics and Space Administration
- NOAA:** National Oceanic and Atmospheric Administration
- SNPP:** Suomi National Polar-orbiting Partnership
- VFR:** Visual Flight Rules
- VIIRS:** Visible Infrared Imager Radiometer Suite (on JPSS satellites, including the SNPP satellite)

Activity

Make fog in a bottle

This activity shows water in all of its phases (gas, liquid, and solid) at once. You need a clear, wide-mouthed glass jar or vase, some very hot water, some ice, and a strainer or bag to contain the ice.



Fill up a **wide-mouthed jar or vase** completely with **very hot water** and let it stay there for about 65 seconds.

- Pour out all but about an inch of the hot water.
- Put a **strainer or bag** over the top of the jar.
- Place **ice cubes** in the bag or strainer.

Water vapor from the bottom of the bottle contacts the cold air created by the ice cubes and begins condensation.

Make fog in a bottle with rubbing alcohol

Making fog in a bottle with rubbing (isopropyl alcohol) is the same basic technique of making it with hot and cold water and air. The alcohol speeds up the process by vaporizing faster than the water.

NOTE: Isopropyl alcohol is poison! Do not drink!

- Fill up a jar or bottle completely with very hot water and let it stay there for about 65 seconds.
- Pour out enough to leave the container 1/3 full with hot water.
- Add a few drops of **alcohol**. Rubbing alcohol works well and is available to everybody.
- Put ice over the top of the bottle and watch the fog form.

How long did it take to form fog using only water? How about when you added a bit of alcohol?

Try the experiment again, using cold or room temperature water in the bottle. What happens? Why?

Discussion questions

Clouds and fog:

- What are the three main phases of water? What determines the phase of water at any particular place in Earth's atmosphere?
- If warm air is saturated with water vapor, what happens if the air is cooled to freezing temperature very suddenly?
- Suppose water droplets in the air become "supercooled" (cooled below freezing), but remain liquid because there are no particles or ice crystals in the air upon which to freeze. Suddenly the water droplets come in contact with a surface such as a road or sidewalk. What happens? What is this phenomenon called?
- How is a "superfog" formed? What kind of climate is likely to produce a superfog?
- How can low clouds and fog affect aviation?
- How can fog affect road transportation?

Weather Satellites:

- How many orbits of Earth does a geostationary satellite make in one day? What is the advantage of this type of orbit for weather forecasting?
- What is the advantage of a polar orbit for studying Earth's weather and climate?
- Why is it hard for satellites to detect fog?
- How do weather satellite imagers tell the difference between low-altitude clouds and fog and higher-altitude clouds?
- Most of the wavelengths—or bands—of light that the Advanced Baseline Imager on the new GOES-R satellite are invisible to humans. Why is this "invisible" infrared light good for detecting information about clouds?
- How will the imagers on the new generation of geostationary- and polar-orbiting satellites improve prediction of fog and low clouds? Why is it important for these imagers to detect so many different wavelengths (or bands) of light (12 for JPSS and 16 for GOES-R)?
- What do the acronyms NASA and NOAA stand for? How do these two U.S. governmental agencies work together in the weather satellite program?
- Do scientists just look at the raw images from the satellite imagers to detect where the fog and low clouds are? If not, what has to happen to get the information?

Answers are available at <http://scijinks.gov/posters/fog-q-and-a.pdf>.