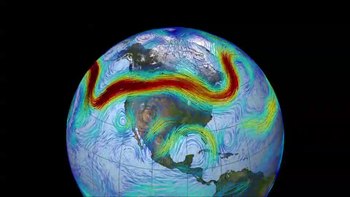
***JET STREAM***

**Jet streams** are fast flowing, narrow, meandering [air currents](https://en.m.wikipedia.org/wiki/Thermal_wind) in the [atmospheres](https://en.m.wikipedia.org/wiki/Atmosphere_of_Earth) of some planets, including [Earth](https://en.m.wikipedia.org/wiki/Earth). On Earth, the main jet streams are located near the altitude of the [tropopause](https://en.m.wikipedia.org/wiki/Tropopause) and are westerly winds (flowing west to east). Their paths typically have a [meandering](https://en.m.wikipedia.org/wiki/Meander) shape. Jet streams may start, stop, split into two or more parts, combine into one stream, or flow in various directions including opposite to the direction of the remainder of the jet.



The polar jet stream can travel at speeds greater than 180 km/h (110 mph). Here, the fastest winds are coloured red; slower winds are blue.

The strongest jet streams are the **polar jets**, at 9–12 km (30,000–39,000 ft) above sea level, and the higher altitude and somewhat weaker **subtropical jets** at 10–16 km (33,000–52,000 ft). The [Northern Hemisphere](https://en.m.wikipedia.org/wiki/Northern_Hemisphere) and the [Southern Hemisphere](https://en.m.wikipedia.org/wiki/Southern_Hemisphere) each have a polar jet and a subtropical jet. The northern hemisphere polar jet flows over the middle to northern latitudes of [North America](https://en.m.wikipedia.org/wiki/North_America), [Europe](https://en.m.wikipedia.org/wiki/Europe), and [Asia](https://en.m.wikipedia.org/wiki/Asia) and their intervening [oceans](https://en.m.wikipedia.org/wiki/Ocean), while the southern hemisphere polar jet mostly circles [Antarctica](https://en.m.wikipedia.org/wiki/Antarctica) all year round. The southern hemisphere mid-latitude jet[[*clarification needed*](https://en.m.wikipedia.org/wiki/Wikipedia:Please_clarify)] is a relatively narrow band of strong winds stretching from the Earth's surface to the top of the troposphere at about 12 km increasing steadily in strength with height.

Jet streams are the product of two factors: the atmospheric heating by [solar radiation](https://en.m.wikipedia.org/wiki/Solar_radiation) that produces the large-scale [Polar, Ferrel, and Hadley](https://en.m.wikipedia.org/wiki/Atmospheric_circulation) circulation cells, and the action of the [Coriolis force](https://en.m.wikipedia.org/wiki/Coriolis_force) acting on those moving masses. The Coriolis force is caused by the planet's [rotation](https://en.m.wikipedia.org/wiki/Planet#Rotation) on its axis. On other planets, [internal heat](https://en.m.wikipedia.org/wiki/Internal_heat) rather than solar heating drives their jet streams. The Polar jet stream forms near the interface of the Polar and Ferrel circulation cells; the subtropical jet forms near the boundary of the Ferrel and Hadley circulation cells.

Other jet streams also exist. During the Northern Hemisphere summer, easterly jets can form in tropical regions, typically where dry air encounters more humid air at high altitudes. Low-level jets also are typical of various regions such as the central United States. There are also jet streams in the [thermosphere](https://en.m.wikipedia.org/wiki/Thermosphere).

Meteorologists use the location of some of the jet streams as an aid in [weather forecasting](https://en.m.wikipedia.org/wiki/Weather_forecasting). The main commercial relevance of the jet streams is in air travel, as flight time can be dramatically affected by either flying with the flow or against, which results in significant fuel and time cost savings for airlines. Often, the airlines work to fly 'with' the jet stream for this reason. Dynamic [North Atlantic Tracks](https://en.m.wikipedia.org/wiki/North_Atlantic_Tracks) are one example of how airlines and [air traffic control](https://en.m.wikipedia.org/wiki/Air_traffic_control) work together to accommodate the jet stream and winds aloft that results in the maximum benefit for airlines and other users. [Clear-air turbulence](https://en.m.wikipedia.org/wiki/Clear-air_turbulence), a potential hazard to aircraft passenger safety, is often found in a jet stream's vicinity, but it does not create a substantial alteration on flight times.

## ***Discovery of the Jet Stream***

The exact first discovery of the jet stream is debated today because it took some years for jet stream research to become mainstream around the world. The jet stream was first discovered in the 1920s by Wasaburo Ooishi, a Japanese [meteorologist](https://www.thoughtco.com/what-is-a-meteorologist-3444385) who used weather balloons to track upper-level winds as they ascended into the Earth's atmosphere near Mount Fuji. His work significantly contributed to knowledge of these wind patterns but was mostly confined to Japan.

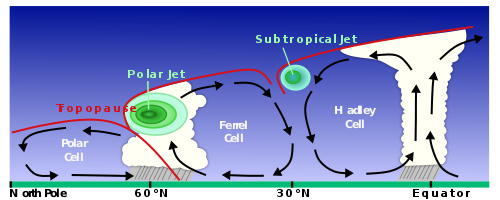
In 1934, knowledge of the jet stream increased when Wiley Post, an American pilot, attempted to fly solo around the world. To complete this feat, he invented a pressurized suit that would allow him to fly at high altitudes and during his practice runs, Post noticed that his ground and airspeed measurements differed, indicating that he was flying in a current of air.

Despite these discoveries, the term "jet stream" was not officially coined until 1939 by a German meteorologist named H. Seilkopf when he used it in a research paper. From there, knowledge of the jet stream increased during [World War II](https://www.thoughtco.com/overview-of-world-war-ii-105520) as pilots noticed variations in winds when flying between Europe and North America.

## ***Description***

[](https://en.m.wikipedia.org/wiki/File:Jetstreamconfig.jpg)

General configuration of the polar and subtropical jet streams

[](https://en.m.wikipedia.org/w/index.php?title=File:Jetcrosssection.svg&lang=en)

Cross section of the subtropical and polar jet streams by latitude

Polar jet streams are typically located near the 250 [hPa](https://en.m.wikipedia.org/wiki/Pascal_(unit)) (about 1/4 atmosphere) pressure level, or seven to twelve kilometres (23,000 to 39,000 ft) above [sea level](https://en.m.wikipedia.org/wiki/Sea_level), while the weaker subtropical jet streams are much higher, between 10 and 16 kilometres (33,000 and 52,000 ft). Jet streams wander laterally dramatically, and changes in their altitude. The jet streams form near breaks in the tropopause, at the transitions between the [Polar, Ferrel and Hadley circulation cells](https://en.m.wikipedia.org/wiki/Atmospheric_circulation), and whose circulation, with the Coriolis force acting on those masses, drives the jet streams. The Polar jets, at lower altitude, and often intruding into mid-latitudes, strongly affect weather and aviation. The polar jet stream is most commonly found between latitudes 30° and 60° (closer to 60°), while the subtropical jet streams are located close to latitude 30°. These two jets merge at some locations and times, while at other times they are well separated. The northern Polar jet stream is said to "follow the sun" as it slowly migrates northward as that hemisphere warms, and southward again as it cools.

The width of a jet stream is typically a few hundred kilometres or miles and its vertical thickness often less than five kilometres (16,000 feet).

[](https://en.m.wikipedia.org/wiki/File:Jetstream_-_Rossby_Waves_-_N_hemisphere.svg)

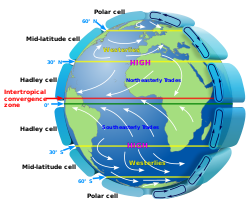
Meanders (Rossby Waves) of the Northern Hemisphere's polar jet stream developing (a), (b); then finally detaching a "drop" of cold air (c). Orange: warmer masses of air; pink: jet stream.

Jet streams are typically continuous over long distances, but discontinuities are common. The path of the jet typically has a meandering shape, and these meanders themselves propagate eastward, at lower speeds than that of the actual wind within the flow. Each large meander, or wave, within the jet stream is known as a [Rossby wave](https://en.m.wikipedia.org/wiki/Rossby_wave) (planetary wave). Rossby waves are caused by changes in the [Coriolis effect](https://en.m.wikipedia.org/wiki/Coriolis_effect) with latitude.[[*citation needed*](https://en.m.wikipedia.org/wiki/Wikipedia:Citation_needed)] [Shortwave troughs](https://en.m.wikipedia.org/wiki/Shortwave_(meteorology)), are smaller scale waves superimposed on the Rossby waves, with a scale of 1,000 to 4,000 kilometres (600–2,500 mi) long, that move along through the flow pattern around large scale, or longwave, "ridges" and "troughs" within Rossby waves. Jet streams can split into two when they encounter an upper-level low, that diverts a portion of the jet stream under its base, while the remainder of the jet moves by to its north.

The wind speeds are greatest where temperature [differences](https://en.m.wikipedia.org/wiki/Gradient) between air masses are greatest, and often exceed 92 km/h (50 kn; 57 mph). Speeds of 400 km/h (220 kn; 250 mph) have been measured.

The jet stream moves from West to East bringing changes of weather. Meteorologists now understand that the path of jet streams affects [cyclonic](https://en.m.wikipedia.org/wiki/Cyclonic) storm systems at lower levels in the atmosphere, and so knowledge of their course has become an important part of weather forecasting. For example, in 2007 and 2012, Britain experienced severe flooding as a result of the polar jet staying south for the summer.

## ***Cause***

[](https://en.m.wikipedia.org/wiki/File:Earth_Global_Circulation_-_en.svg)

Highly idealised depiction of the global circulation. The upper-level jets tend to flow latitudinally along the cell boundaries.

[***Extratropical cyclone***](https://en.m.wikipedia.org/wiki/Extratropical_cyclone)***and***[***Thermal wind***](https://en.m.wikipedia.org/wiki/Thermal_wind)

In general, winds are strongest immediately under the [tropopause](https://en.m.wikipedia.org/wiki/Tropopause) (except locally, during [tornadoes](https://en.m.wikipedia.org/wiki/Tornado), [tropical cyclones](https://en.m.wikipedia.org/wiki/Tropical_cyclone) or other anomalous situations). If two air masses of different temperatures or densities meet, the resulting pressure difference caused by the density difference (which ultimately causes wind) is highest within the transition zone. The wind does not flow directly from the hot to the cold area, but is deflected by the [Coriolis effect](https://en.m.wikipedia.org/wiki/Coriolis_effect) and flows along the boundary of the two air masses.

All these facts are consequences of the [thermal wind](https://en.m.wikipedia.org/wiki/Thermal_wind) relation. The balance of forces acting on an atmospheric air parcel in the vertical direction is primarily between the gravitational force acting on the mass of the parcel and the buoyancy force, or the difference in pressure between the top and bottom surfaces of the parcel. Any imbalance between these forces results in the acceleration of the parcel in the imbalance direction: upward if the buoyant force exceeds the weight, and downward if the weight exceeds the buoyancy force. The balance in the vertical direction is referred to as [hydrostatic](https://en.m.wikipedia.org/wiki/Hydrostatic). Beyond the tropics, the dominant forces act in the horizontal direction, and the primary struggle is between the Coriolis force and the pressure gradient force. Balance between these two forces is referred to as [geostrophic](https://en.m.wikipedia.org/wiki/Geostrophic). Given both hydrostatic and geostrophic balance, one can derive the thermal wind relation: the vertical gradient of the horizontal wind is proportional to the horizontal temperature gradient. If two air masses, one cold and dense to the North and the other hot and less dense to the South, are separated by a vertical boundary and that boundary should be removed, the difference in densities will result in the cold air mass slipping under the hotter and less dense air mass. The Coriolis effect will then cause poleward-moving mass to deviate to the East, while equatorward-moving mass will deviate toward the west. The general trend in the atmosphere is for temperatures to decrease in the poleward direction. As a result, winds develop an eastward component and that component grows with altitude. Therefore, the strong eastward moving jet streams are in part a simple consequence of the fact that the Equator is warmer than the North and South poles.

### ***Polar jet stream***

The thermal wind relation does not explain why the winds are organized into tight jets, rather than distributed more broadly over the hemisphere. One factor that contributes to the creation of a concentrated polar jet is the undercutting of sub-tropical air masses by the more dense polar air masses at the polar front. This causes surface low pressure and higher pressure at altitude. At high altitudes, lack of friction allows air to respond freely to the steep pressure gradient with low pressure at high altitude over the pole. This results in the formation of planetary wind circulations that experience a strong Coriolis deflection and thus can be considered 'quasi-geostrophic'. The polar front jet stream is closely linked to the [frontogenesis](https://en.m.wikipedia.org/wiki/Frontogenesis) process in midlatitudes, as the acceleration/deceleration of the air flow induces areas of low/high pressure respectively, which link to the formation of cyclones and anticyclones along the polar front in a relatively narrow region.

### ***Subtropical jet***

A second factor which contributes to a concentrated jet is more applicable to the subtropical jet which forms at the poleward limit of the tropical [Hadley cell](https://en.m.wikipedia.org/wiki/Hadley_cell), and to first order this circulation is symmetric with respect to longitude. Tropical air rises to the tropopause, and moves poleward before sinking; this is the Hadley cell circulation. As it does so it tends to conserve angular momentum, since friction with the ground is slight. Air masses that begin moving poleward are deflected eastward by the [Coriolis force](https://en.m.wikipedia.org/wiki/Coriolis_force) (true for either hemisphere), which for poleward moving air implies an increased westerly component of the winds (note that deflection is leftward in the southern hemisphere).

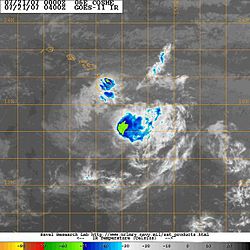
### ***Other planets***

[Jupiter](https://en.m.wikipedia.org/wiki/Jupiter)'s atmosphere has multiple jet streams, caused by the convection cells that form the familiar banded color structure; on Jupiter, these convection cells are driven by internal heating. The factors that control the number of jet streams in a planetary atmosphere is an active area of research in dynamical meteorology. In models, as one increases the planetary radius, holding all Clouds along a jet stream over Canada.

parameters fixed,[[*clarification needed*](https://en.m.wikipedia.org/wiki/Wikipedia:Please_clarify)] the number of jet streams decreases.[[*citation needed*](https://en.m.wikipedia.org/wiki/Wikipedia:Citation_needed)]

## ***Some effects***

## Hurricane protection

[](https://en.m.wikipedia.org/wiki/File:Jet_Stream_Rigs_Apart_Flossie_2.jpg)

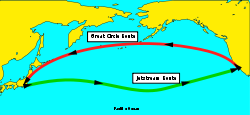
[Hurricane Flossie](https://en.m.wikipedia.org/wiki/Hurricane_Flossie_(2007)) over [Hawaii](https://en.m.wikipedia.org/wiki/Hawaii) in 2007. Note the large band of moisture that developed East of [Hawaii Island](https://en.m.wikipedia.org/wiki/Hawaii_Island) that came from the hurricane.

The subtropical jet stream rounding the base of the mid-oceanic upper trough is thought  to be one of the causes most of the Hawaiian Islands have been resistant to the long [list of Hawaii hurricanes](https://en.m.wikipedia.org/wiki/List_of_Hawaii_hurricanes) that have approached. For example, when [Hurricane Flossie (2007)](https://en.m.wikipedia.org/wiki/Hurricane_Flossie_(2007)) approached and dissipated just before reaching landfall, the U.S. [National Oceanic and Atmospheric Administration](https://en.m.wikipedia.org/wiki/National_Oceanic_and_Atmospheric_Administration) (NOAA) cited vertical [wind shear](https://en.m.wikipedia.org/wiki/Wind_shear) as evidenced in the photo.

## ***Uses***

## On Earth, the northern polar jet stream is the most important one for aviation and weather forecasting, as it is much stronger and at a much lower altitude than the subtropical jet streams and also covers many countries in the [Northern Hemisphere](https://en.m.wikipedia.org/wiki/Northern_Hemisphere), while the southern polar jet stream mostly circles [Antarctica](https://en.m.wikipedia.org/wiki/Antarctica) and sometimes the southern tip of [South America](https://en.m.wikipedia.org/wiki/South_America). The term *jet stream* in these contexts thus usually implies the northern polar jet stream.

## ***Aviation***

[](https://en.m.wikipedia.org/wiki/File:Greatcircle_Jetstream_routes.svg)

Flights between [Tokyo](https://en.m.wikipedia.org/wiki/Tokyo) and [Los Angeles](https://en.m.wikipedia.org/wiki/Los_Angeles,_California) using the jet stream eastbound and a [great circle](https://en.m.wikipedia.org/wiki/Great_circle) route westbound.

The location of the jet stream is extremely important for aviation. Commercial use of the jet stream began on 18 November 1952, when [Pan Am](https://en.m.wikipedia.org/wiki/Pan_Am) flew from Tokyo to Honolulu at an altitude of 7,600 metres (24,900 ft). It cut the trip time by over one-third, from 18 to 11.5 hours. Not only does it cut time off the flight, it also nets fuel savings for the airline industry. Within North America, the time needed to fly east across the [continent](https://en.m.wikipedia.org/wiki/Continent) can be decreased by about 30 [minutes](https://en.m.wikipedia.org/wiki/Minute) if an [airplane](https://en.m.wikipedia.org/wiki/Airplane) can fly with the jet stream, or increased by more than that amount if it must fly west against it.

Associated with jet streams is a phenomenon known as [clear-air turbulence](https://en.m.wikipedia.org/wiki/Clear-air_turbulence) (CAT), caused by vertical and horizontal [wind shear](https://en.m.wikipedia.org/wiki/Wind_shear) caused by jet streams. The CAT is strongest on the cold [air](https://en.m.wikipedia.org/wiki/Air) side of the jet,  next to and just under the axis of the jet. Clear-air turbulence can cause aircraft to plunge and so present a passenger safety hazard that has caused fatal accidents, such as the death of one passenger on [United Airlines Flight 826](https://en.m.wikipedia.org/wiki/United_Airlines_Flight_826).

### ***Possible future power generation***

[***High-altitude wind power***](https://en.m.wikipedia.org/wiki/High-altitude_wind_power)

Scientists are investigating ways to harness the wind energy within the jet stream. According to one estimate of the potential wind energy in the jet stream, only one percent would be needed to meet the world's current energy needs. The required technology would reportedly take 10–20 years to develop. There are two major but divergent scientific articles about jet stream power. Archer & Caldeira claim that the Earth's jet streams could generate a total power of 1700 [terawatts (TW)](https://en.m.wikipedia.org/wiki/Watt#Terawatt) and that the climatic impact of harnessing this amount would be negligible. However, Miller, Gans, & Kleidon. claim that the jet streams could generate a total power of only 7.5 TW and that the climatic impact would be catastrophic.

### ***Unpowered aerial attack***

Near the end of [World War II](https://en.m.wikipedia.org/wiki/World_War_II), from late 1944 until early 1945, the Japanese [Fu-Go balloon bomb](https://en.m.wikipedia.org/wiki/Fu-Go_balloon_bomb), a type of [fire balloon](https://en.m.wikipedia.org/wiki/Fire_balloon), was designed as a cheap weapon intended to make use of the jet stream over the [Pacific Ocean](https://en.m.wikipedia.org/wiki/Pacific_Ocean) to reach the west coast of [Canada](https://en.m.wikipedia.org/wiki/Canada) and the [United States](https://en.m.wikipedia.org/wiki/United_States). They were relatively ineffective as weapons, but they were used in one of the few [attacks on North America during World War II](https://en.m.wikipedia.org/wiki/American_Theater_(1939%E2%80%931945)#Fire_balloon_attacks), causing six deaths and a small amount of damage. However, the Japanese were world leaders in biological weapons research at this time. [Unit 731](https://en.m.wikipedia.org/wiki/Unit_731) had killed many hundreds of thousands of people in China with biological weapons, developed by conducting experiments on live human subjects that were as appalling as those conducted by Nazi Germany in Jewish concentration camps. The Japanese Imperial Army's Noborito Institute cultivated [anthrax](https://en.m.wikipedia.org/wiki/Anthrax) and plague [*Yersinia pestis*](https://en.m.wikipedia.org/wiki/Yersinia_pestis); furthermore, it produced enough [cowpox](https://en.m.wikipedia.org/wiki/Cowpox) viruses to infect the entire United States. The deployment of these biological weapons on fire balloons was planned in 1944. Emperor Hirohito did not permit deployment of biological weapons on the basis of a report of President Staff Officer Umezu on 25 October 1944. Consequently, biological warfare using Fu-Go balloons was not implemented.