Jet stream

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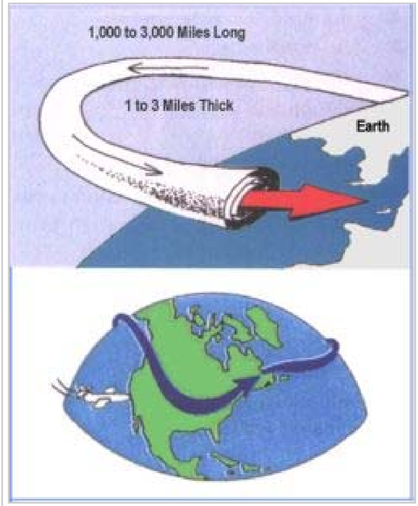

Jet streams flow from the west in the upper portion of the troposphere

Jet streams are fast flowing, relatively narrow air currents found at the tropopause, the transition between the troposphere (where temperature decreases with height) and the stratosphere (where temperature increases with height),[1] and are located at 10-15 kilometers above the surface of the Earth. They form near boundaries of adjacent air masses with significant differences in temperature, such as the polar region and the warmer air to the south.[2] The path of the jet typically has a meandering shape, and these meanders known as Rossby waves. Rossby waves propagate westward with respect to the flow in which they are embedded, which translates to a slower eastward migration across the globe than smaller scale short wave troughs. The major jet streams are westerly winds (flowing west to east) in the Northern Hemisphere.

During the summer, low-level easterly jets can form in tropical regions. A southerly low level jet in the Great Plains of North America helps fuel overnight thunderstorm activity, normally in the form of mesoscale convective systems. A similar northerly low-level jet can form across Australia, instigated by cut-off lows which develop across southwest portions of the country.

Meteorologists use the location of the jet stream as an aid in weather forecasting. The main commercial use of the jet stream is during airline travel, as flight time can be dramatically affected by either flying with or against the stream. One type of clear-air turbulence is found in the jet stream's vicinity, which can be a hazard to aircraft. One future benefit of the jet stream could be to power airborne wind turbines, if technological hurdles can be overcome.

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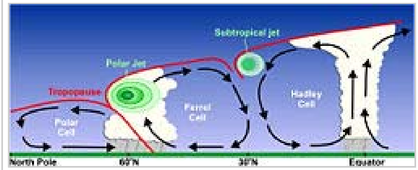
Discovery

The existence of the jet stream may have been first detected in the 1920s by Japanese meteorologist Wasaburo Ooishi.[3] From a site near Mount Fuji, he tracked pilot balloons, also known as pibals (balloons used to determine upper level winds using a theodolite and the balloon's known ascension rate due to its internal gas),[4] as they rose into the atmosphere. Ooishi's work largely went unnoticed outside of Japan. American pilot Wiley Post, the first man to fly around the world solo in 1933, is often given some credit for discovery of the jet stream. Post invented a pressurized suit that let him fly above 6,200 metres (20,000 ft). In the year before his death, Post made several attempts at a high-altitude transcontinental flight, and noticed that at times his ground speed greatly exceeded his air speed.[5] German meteorologist H. Seilkopf is credited with coining the term "jet stream" (Strahlströmmung) in a 1939 paper.[6] Many sources credit real understanding of the nature of jet streams to regular and repeated flight-path traversals during World War II. Flyers consistently noticed tailwinds in excess of 100 mph in flights, for example, between the US and UK.[7]

Description



Cross section of the subtropical and polar jet streams by latitude

There are two main jet streams north of subtropical latitudes, with a weaker subtropical stream closer to the equator. The polar jet stream is typically located near the 250 hPa (7.38 inHg) pressure level, or 7 kilometres (4.3 mi) to 12 kilometres (7.5 mi) above sea level, while the subtropical jet is much higher, between 10 kilometres (6.2 mi) and 16 kilometres (9.9 mi) above sea level. Both upper-level jet streams form near breaks in the tropopause, which is at a higher altitude near the equator than it is over the poles, with large changes in its height occurring near the location of the jet stream.[8][9] The streams are most commonly found between latitudes 30°N and 60°N, with the subtropical jet stream located close to latitude 30° N. The upper level jet stream is said to "follow the sun" as it moves northward during the warm season, or late spring and summer, and southward during the cold season, or autumn and winter.[10][11]

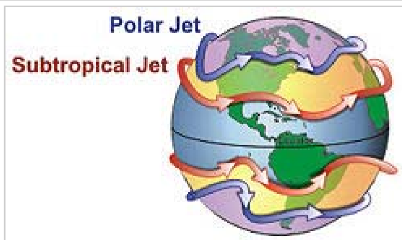
Jet streams are typically continuous over long distances, but discontinuities are common.[12] The path of the jet typically has a meandering shape, and these meanders themselves propagate east, at lower speeds than that of the actual wind within the flow. Each large meander, or wave, within the jet stream is known as a Rossby wave. Rossby waves are caused by changes in the Coriolis effect with latitude, and propagate westward with respect to the flow in which they are embedded, which slows down the eastward migration of upper level troughs and ridges across the globe when compared to their embedded shortwave troughs.[13] Shortwave troughs are smaller packets of upper level energy, on the scale of 1,000 kilometres (620 mi) to 4,000 kilometres (2,500 mi) long,[14] which move through the flow pattern around large scale, or longwave, ridges and troughs within Rossby waves.[15] Jet streams can split into two due to the formation of an upper-level closed low, which diverts a portion of the jet stream under its base, while the remainder of the jet moves by to its north.

The wind speeds vary according to the temperature gradient, exceeding 92 kilometres per hour (50 kn),[12] although speeds of over 398 kilometres per hour (215 kn) have been measured.[16] Meteorologists now understand that the path of the jet stream steers 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, Britain experienced severe flooding as a result of the polar jet staying south for the summer.[17][18]

Cause

Upper-level variety

See also: Extratropical cyclone and Thermal wind



General configuration of the polar and subtropical jet streams

In general, winds are strongest just under the tropopause (except during tornadoes, hurricanes or other anomalous situations). If two air masses of different temperatures or densities meet, the resulting pressure difference caused by the density difference (which 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 and flows along the boundary of the two air masses.[19] The polar front and subtropical jets merge at some locations and times, while at other times they are well separated.

All these facts are consequences of the thermal wind relation. The balance of forces on an atmospheric parcel in the vertical direction is primarily between the pressure gradient and the force of gravity, a balance referred to as hydrostatic. In the horizontal, the dominant balance outside of the tropics is between the Coriolis effect and the pressure gradient, a balance referred to as geostrophic. Given both hydrostatic and geostrophic balance, one can derive the thermal wind relation: the vertical derivative of the horizontal wind is proportional to the horizontal temperature gradient. The sense of the relation is such that temperatures decreasing polewards implies that winds develop a larger eastward component as one moves upwards. 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.[19]

The thermal wind relation does not immediately provide an explanation for why the winds are organized in tight jets, rather than distributed more broadly over the hemisphere. There are two factors that contribute to this sharpness of the jets. One is the tendency for developing cyclonic disturbances in midlatitudes to form fronts. A front is a sharp localized gradient in temperature. The polar front jet stream can be thought of as the result of this frontogenesis process in midlatitudes, as the storms concentrate the north-south temperature contrast into relatively narrow regions.[12]

An alternative explanation is more appropriate for the subtropical jet, which forms at the poleward limit of the tropical Hadley cell. One can visualize this circulation as being symmetric with respect to longitude. Rings of air encircling the Earth move polewards beneath the tropopause from the equator into the subtropics. As they do so they tend to conserve their angular momentum. But they are also moving closer to the axis of rotation, so they must spin faster in the direction of rotation, implying an increased eastward component of the winds.[20]

Jupiter's atmosphere has multiple jet streams, forming the familiar banded color structure, caused by internal heating.[16] 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 other parameters fixed, the number of jet streams increases.

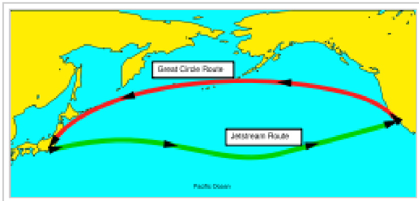
Low-level variety

There are low-level wind maxima in the atmosphere that are referred to as jets, such as the African easterly jet which occurs during the Northern Hemisphere summer between 10°N and 20°N from the Indian Ocean across Africa, and the nocturnal poleward low-level jet in the Great Plains. The easterly jet out of Africa is formed because of heating of the Tibetan plateau and subsequent anticyclogenesis.[21] The equatorward divergence takes the form of easterlies, embedded in the form of easterly jets. This jet stream is considered to play a crucial role in the southwest monsoon of Africa,[22] and helps form the tropical waves which march across the tropical Atlantic and eastern Pacific oceans during the warm season.[23] A southerly low-level jet in the Great Plains helps fuel overnight thunderstorm activity during the warm season, normally in the form of mesoscale convective systems which form during the overnight hours.[24] A similar phenomenon develops across Australia, which pulls moisture poleward from the Coral Sea towards cut-off lows which form mainly across southwestern portions of the continent.[25]

Uses

Airplanes

The location of the jet stream is extremely important for airlines. Commercial use of the jet stream began on November 18, 1952, when Pam Am flew from Tokyo to Honolulu at an altitude of 7,600 metres (25,000 ft). It cut the trip time by over one-third, from 18 to 11.5 hours.[26] Not only does it cut time off the flight, it also nets fuel savings for the airline industry.[27] Within North America, the time needed to fly east across the continent can be decreased by about 30 minutes if an airplane can fly with the jet stream, or increased by more than that amount if it must fly west against it.



Flights to and from Tokyo and Los Angeles using the jet stream eastbound and a great circle route westbound.

Associated with jet streams is a phenomenon known as clear air turbulence (CAT), caused by vertical and horizontal windshear connected to the jet streams.[28] The CAT is strongest on the cold air side of the jet,[29] next to and just underneath the axis of the jet.[30] Clear air turbulence can be hazardous to aircraft, and has caused fatal accidents, such as with BOAC Flight 911 and United Airlines Flight 826.[31][32][33]

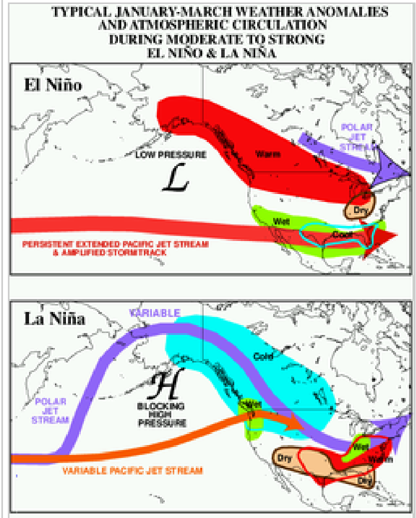
Future power generation

Scientists are investigating ways to harness the wind energy within the jet stream using airborne wind turbines. Kite-like wind generators have been proposed, which would transmit its electricity back to the ground via either aluminum cables, copper cables, or beams of microwave energy. Tethered balloons, which reach heights of 4,500 metres (15,000 ft) have been used to monitor drug trafficking over many years, with no reported airplane incidents. According to one estimate, only 1 percent of the potential wind energy in the jet stream could meet the world's current energy needs. The required technology would reportedly take 10–20 years to develop.[34]

Changes due to climate cycles

Effects of ENSO

The changing of the normal location of upper-level jet streams can be anticipated during phases of the El Niño-Southern Oscillation (ENSO), which leads to consequences precipitation-wise and temperature-wise across North America, affects tropical cyclone development across the eastern Pacific and Atlantic basins. Combined with the Pacific Decadal Oscillation, ENSO can also impact cold season rainfall in Europe.[35] Changes in ENSO also change the location of the jet stream over South America, which partially effects precipitation distribution over the continent.[36]



Impact of El Niño and La Niña on North America

El Niño

During El Niño events, increased precipitation is expected in California due to a more southerly, zonal, storm track.[37] During the El Niño portion of ENSO, increased precipitation falls along the Gulf coast and Southeast due to a stronger than normal, and more southerly, polar jet stream.[38] Snowfall is greater than average across the southern Rockies and Sierra Nevada mountain range, and is well-below normal across the Upper Midwest and Great Lakes states.[39] The northern tier of the lower 48 exhibits above normal temperatures during the fall and winter, while the Gulf coast experiences below normal temperatures during the winter season.[40][41] The subtropical jet stream across the deep tropics of the Northern Hemisphere is enhanced due to increased convection in the equatorial Pacific, which decreases tropical cyclogenesis within the Atlantic tropics below what is normal, and increases tropical cyclone activity across the eastern Pacific.[42] In the Southern Hemisphere, the subtropical jet stream is displaced equatorward, or north, of its normal position, which diverts frontal systems and thunderstorm complexes from reaching central portions of the continent.[36]

La Niña

Across North America during La Niña, increased precipitation is diverted into the Pacific Northwest due to a more northerly storm track and jet stream.[43] The storm track shifts far enough northward to bring wetter than normal conditions (in the form of increased snowfall) to the Midwestern states, as well as hot and dry summers.[44][45] Snowfall is above normal across the Pacific Northwest and western Great Lakes.[46] Across the North Atlantic, the jet stream is stronger than normal, which directs stronger systems with increased precipitation towards Europe.[47]

Global warming

Between 1979 and 2001, it has been found that the position of the jet stream has been moving northward at a rate of 2.01 kilometres (1.25 mi) per year across the Northern Hemisphere. Across North America, this type of change could lead to drier conditions across the southern tier of the United States and more frequent and more intense tropical cyclones in the tropics. A similar slow poleward drift was found when studying the Southern Hemisphere jet stream over the same time frame.[48]

The Dust Bowl

Evidence suggests the jet stream was at least partially responsible for the wide drought conditions during the 1930s Dust Bowl in the Midwest United States. Normally, the jet stream flows west over the Gulf of Mexico and turns northward pulling up moisture and dumping rain onto the Great Plains. During the Dust Bowl, the jet stream weakened and changed course traveling farther south than normal. This starved the Great Plains and other areas of the Midwest of precious rain creating dusty conditions.[49]

See also

- Surface weather analysis
- Tornado
- Wind shear
- Japanese balloon bombing of the United States during World War II
- Sting jet

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External links

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