



# Weather Basics

## Unit 2

### The basics about the main circulation systems and El Niño

Wind power plants, or 'Wind Farms', are, for good reasons, often located close to the sea. When at the seaside we have all felt the seabreeze blowing around our nose and disheveling our hair. But why is the wind at the seaside always so strong? And why there are so often thunderstorms in the mountains on summer afternoons?

Local air circulation and pressure systems define the weather depending on the landscape. However, prevailing wind systems, such as the trade winds around the equator, affect the weather over a much larger area. The El Niño effect has an impact on many continents and recurs every few years but irregularly. In this unit we read about air circulation and where and why it occurs on our planet.



"Seabreeze"  
Giclee on canvas © Gary George  
[www.garygeorge.com](http://www.garygeorge.com)



## Part 1: Local circulation

**Why does air circulate and what are the driving forces for this movement?**

Energy from the Sun heats different parts of the Earth differently and this causes pressure differences to develop across the globe. These pressure differences cause air to move. The air moves from regions of high pressure to regions of low pressure to try to smooth out the pressure differences. Air movement occurs on different scales, on a global scale (global circulation of the Earth), over a medium scale (tornadoes) and on a local scale (mountain winds).

In some zones around the Earth, the winds blow predominantly in one direction and this is known as the prevailing wind direction. This direction can change with the seasons. Winds over most areas are variable in direction from day to day. A wind is named according to the point of the compass from which it blows, i.e., a wind blowing from the north is a north wind.

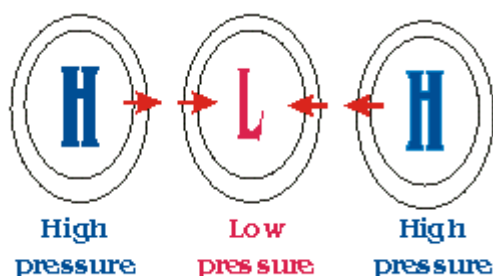


1. Windmill (c) FreeFoto.com

Energy from the Sun is the most important driving force for winds but there are other forces, which are also important:

### 1. Pressure Gradient Force (PGF)

- this causes horizontal pressure differences and winds.



2. In absence of other forces, air moves from high to low pressure due to the "Pressure Gradient Force"

We know that winds are generated by differences in air pressure. The greater the difference in pressure, the stronger the force. The distance between the area of high pressure and the area of low pressure also determines how fast the moving air is accelerated. Meteorologists refer to the force that starts the wind flowing as the "pressure gradient force".

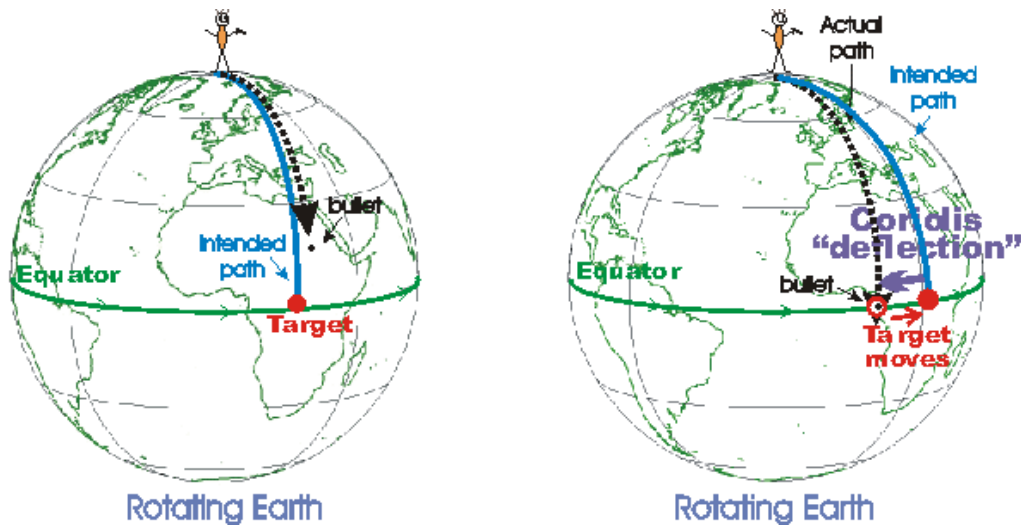


## 2. Gravity

— this causes vertical pressure differences. The force of gravity is constant for a given altitude.

## 3. Coriolis Force

— once the wind begins blowing, the rotation of the Earth affects its direction. This is the Coriolis effect.



3. Figure by Schlanger ©

The Coriolis effect results in the deflection of all objects to the right in the Northern hemisphere and to the left in the Southern hemisphere. The Coriolis force moves large objects such as airmasses considerable distances. Small objects, for example ships at sea, are too small to experience significant deflections in their direction due to the Coriolis Force.

## 4. Friction

— this has very little effect on air in the atmosphere, but is more important close to the ground. The effect of friction on air motion decreases as the altitude increases to a point (usually 1-2 km above the ground) where it has no effect at all. The layer of the atmosphere where friction affects atmospheric motion is referred to as the boundary layer.

## 5. Centrifugal Force

— An object traveling in a circle behaves as if it experiences an outward force. This force, known as the centrifugal force, depends on the mass of the object (the heavier the object, the greater the force), the speed of rotation (the greater the speed of the object, the greater the force), and the distance from the center (the closer an object is to the center, the smaller the force).



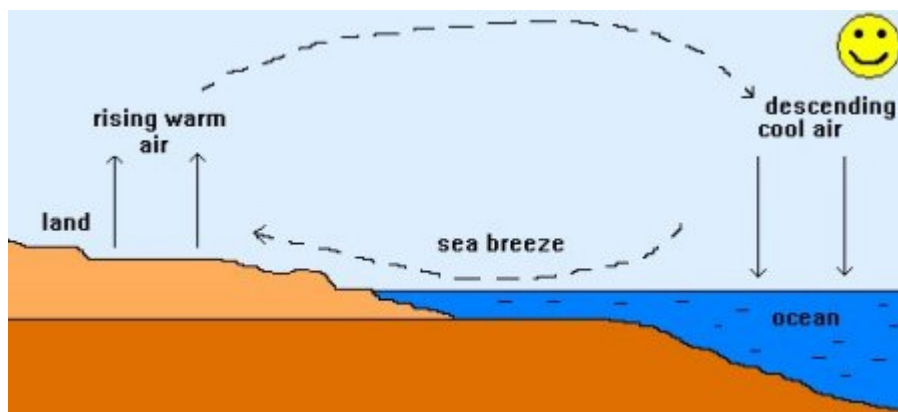


4. We experience centrifugal force when we ride on a merry-go-round, when we go round a curve in a car or when we make a sharp turn on a bike.

Photo by Patricia Marroquin  
 © <http://www.betterphoto.com/gallery/dynoGallByMember.asp?mem=2083>

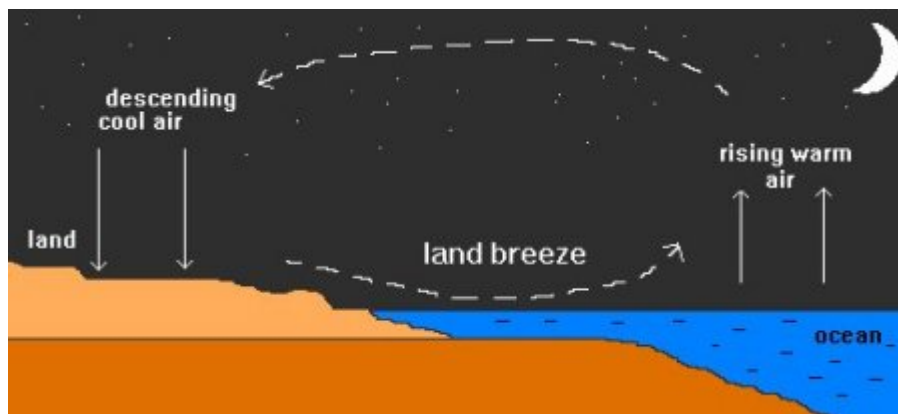
## Land and Sea Breezes

Water has a much greater heat capacity than land and, as a result, it warms up slower than the land and also cools down slower. So during the day, there are significant temperature differences between a water body such as a lake or the sea and the surrounding ground. This temperature difference causes pressure differences and, as a result, the development of local winds. Close to the coast, these winds are known as the sea breeze.



A sea breeze develops on sunny days when the land becomes much warmer than the sea. As the land warms up, the air above it expands and begins to rise. To replace the rising air, cooler air is drawn in from above the sea surface.

5. Source: <http://www.ace.mmu.ac.uk/eae/> ©



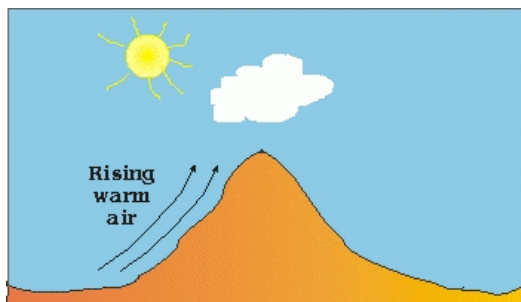
At night the water cools down slower than the land and the air circulation reverses and air moves from the land to the sea. This is called a land breeze.

6. Source: <http://www.ace.mmu.ac.uk/eae/>

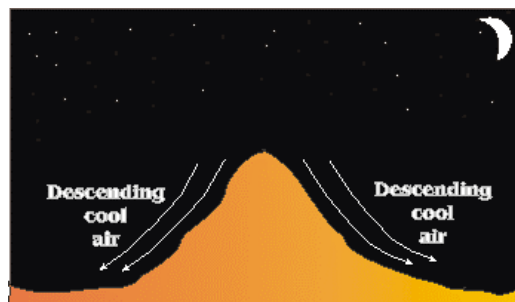


## Mountain and Valley Breezes

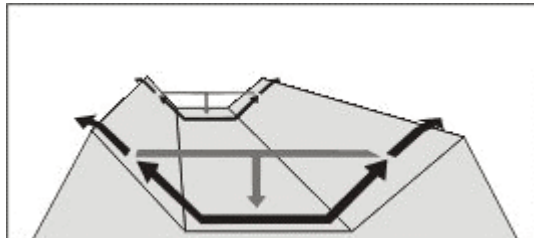
Special wind systems develop in mountainous regions. The slopes of the mountains and the narrow parts of the valley are more intensively heated by the Sun than the open valley floor. This leads to the generation of valley breezes during the day and mountain breezes during the night.



7. a) During the day the air close to the mountain sides becomes warmer than the surrounding air. This warm air rises up the mountains and is replaced by air from within the valley. So during the day valley air moves up the mountain sides. This process leads to clouds and rain in the mountains in the summer, particularly in the late afternoon. Figure: Vera Schlanger.



7. b) At night the sides of the mountain cool down and cool air is pulled down by gravity. In the morning, the coldest air is, therefore, often found within the valley. If the air is moist enough, valley fog may form. Figure by Vera Schlanger.



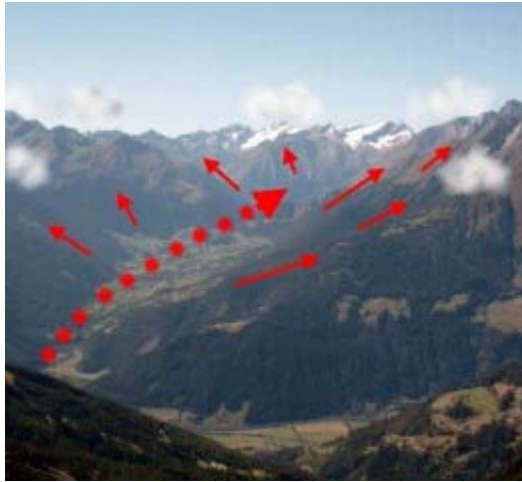
8. Simple slope wind circulation © Dept. for phys. geography, Univ. of Kiel

So slope winds go up the mountains in the day and down during the night and the moving air has to be replaced with air from elsewhere. A simplified picture of the air circulation is shown in Figure 8. However, this *slope wind circulation* is only seen for a short time during the day. The air circulation in a typical valley is a bit more complicated than this!

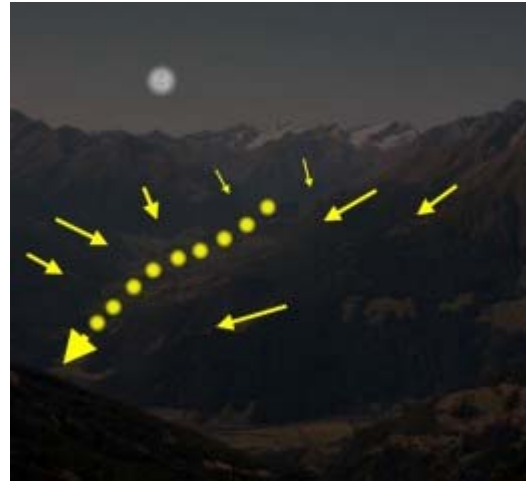
The narrower the valley is, the more air that rises. This rising air is replaced from the valley floor or the plains. So the wind during the day usually comes from the lower and flatter parts of the valley system and then rises up the mountains. As the name of the wind is always given by the place or direction from where it comes from, we call this wind the *valley breeze*. During the night, the air cools and descends along the mountain slopes into the valley. So the breeze moves in the opposite direction, it comes from the mountains and moves into the valley floor and plains. As a result, this wind is known as the *mountain breeze*.



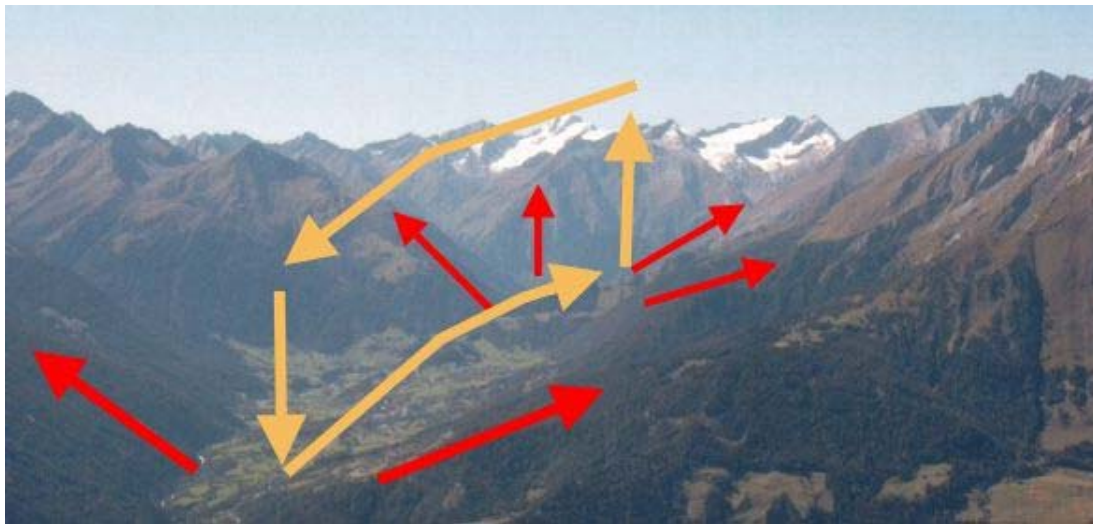




9. a) Valley breeze during the day (large dotted arrow). Photo: Elmar Uherek.



9. b) Mountain breeze during the night (large dotted arrow). Virgen Valley, Austria.



10. Local circulation during a valley breeze.

This local circulation scheme is a bit simplistic as mountains are not smooth and have many side valleys. However, this gives a basic idea of the wind movement in a mountainous area.

## Part 2: Global Circulation

### Global Atmospheric Circulation

**Energy from the Sun heats the entire Earth, but this heat is unevenly distributed across the Earth's surface. Equatorial and tropical regions receive far more solar energy than the midlatitudes and the polar regions.**



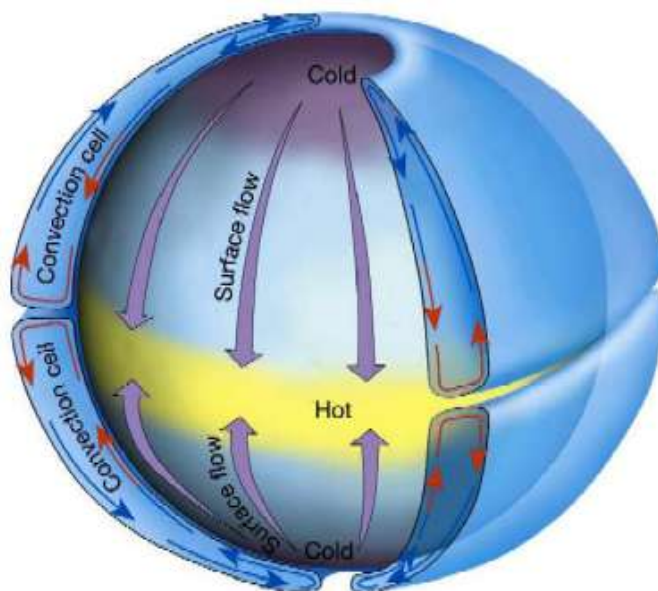
The tropics receive more heat radiation than they emit, while the polar regions emit more heat radiation than they receive. If no heat was transferred from the tropics to the polar regions, the tropics would get hotter and hotter while the poles would get colder and colder. This latitudinal heat imbalance drives the circulation of the atmosphere and oceans. Around 60% of the heat energy is redistributed around the planet by the atmospheric circulation and around 40% is redistributed by the ocean currents.



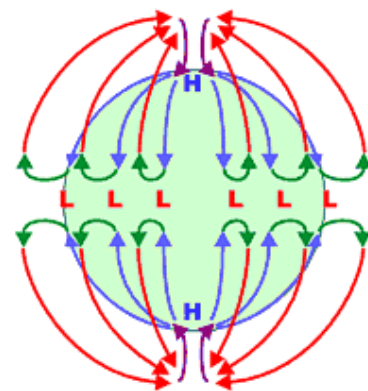
1. Planet Earth from Space.

### Atmospheric Circulation

One way to transfer heat from the equator to the poles would be to have a single circulation cell where air moved from the tropics to the poles and back. This single-cell circulation model was first proposed by Hadley in the 1700's.



2. Air circulation around the globe would be simple (and the weather boring) if the Earth did not rotate and the rotation was not tilted relative to the Sun.



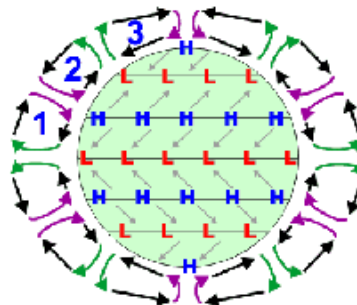
3. Hypothetical circulation for a non-rotating Earth.  
Source: National Weather Service, Southern Regional Headquarters - USA.



Since the Earth rotates, its axis is tilted and there is more land in the Northern Hemisphere than in the Southern Hemisphere, the actual global air circulation pattern is much more complicated. Instead of a single-cell circulation, the global model consists of three circulation cells in each hemisphere. These three cells are known as the tropical cell (also called the Hadley cell), the midlatitude cell and the polar cell.



4. Rotating Earth  
source: <http://www.math.montana.edu/~nmp/materials/ess/atmosphere/expert/activities/circulation/>



5. Idealised global circulation.  
Source: National Weather Service, Southern Regional Headquarters - USA.

1. **Tropical cell (Hadley cell)** - Low latitude air moves towards the Equator and heats up. As it heats it rises vertically and moves polewards in the upper atmosphere. This forms a convection cell that dominates tropical and sub-tropical climates.
2. **Midlatitude cell (Ferrel cell)** - A mid-latitude mean atmospheric circulation cell for weather named by Ferrel in the 19th century. In this cell the air flows polewards and towards the east near the surface and equatorward and in a westerly direction at higher levels.
3. **Polar cell** - Here air rises, spreads out and travels toward the poles. Once over the poles, the air sinks forming the polar highs. At the surface, the air spreads out from the polar highs. Surface winds in the polar cell are easterly (polar easterlies).

Although still oversimplified, this three cell model can describe the main features of atmospheric circulation.

## Surface Features of the Global Atmospheric Circulation System

### Main wind belts:

Because the Coriolis force acts to the right of the flow (in the Northern Hemisphere), the flow around the 3-cells is deflected. This gives rise to the three main wind belts in each hemisphere at the surface:

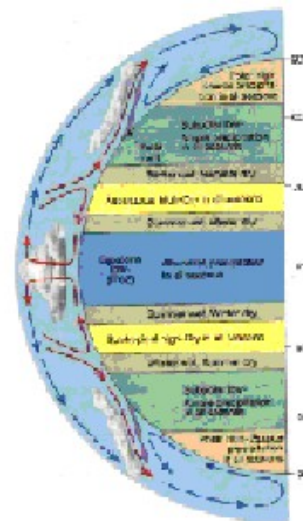
- The easterly trade winds in the tropics
- The prevailing westerlies
- The polar easterlies

### Doldrums, ITCZ:

The doldrums are the region near the equator where the trade winds from each hemisphere meet. This is also where you find the intertropical convergence zone (ITCZ). It is characterized by hot, humid weather with light winds. Major tropical rain forests are found in this zone. The ITCZ migrates north in January and south in July.

### Horse latitudes:

The horse latitudes are the region between the trade winds and the prevailing westerlies. In this region the winds are often light or calm, and were so-named because ships would often have to throw their horses overboard due to lack of feed and water.



6. Global Circulation. Source: <http://www.geocities.com/CapeCanaveral/Hall/6104/atmosphe.html>





Polar front:

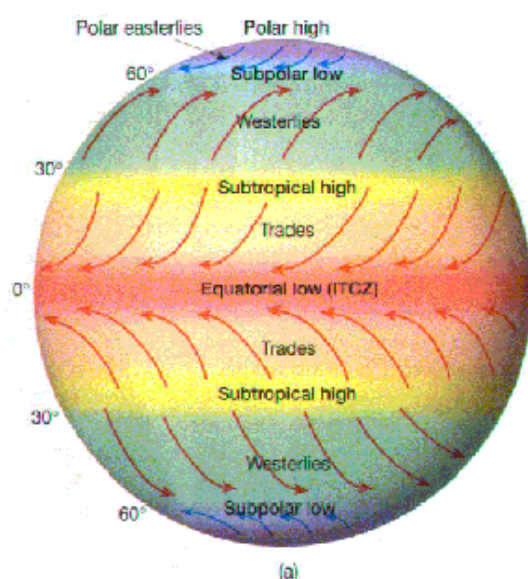
The polar front lies between the polar easterlies and the prevailing westerlies.

Pressure belts:

The three-cell circulation model has the following pressure belts associated with it:

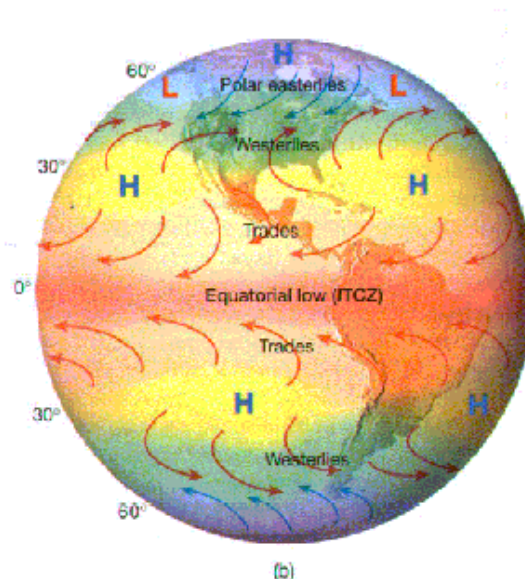
- **Equatorial low** – A region of low pressure associated with the rising air in the ITCZ. Warm air heated at the equator rises up into the atmosphere leaving a low pressure area underneath. As the air rises, clouds and rain form.
- **Subtropical high** – A region of high pressure associated with sinking air in the horse latitudes. Air cools and descends in the subtropics creating areas of high pressure with associated clear skies and low rainfall. The descending air is warm and dry and deserts form in these regions.
- **Subpolar low** – A region of low pressure associated with the polar front.
- **Polar high** – A high pressure region associated with the cold, dense air of the polar regions.

In reality, the winds are not steady and the pressure belts are not continuous.



7. "Ideal" Zonal Pressure Belts

An imaginary uniform Earth with idealised zonal (continuous) pressure belts.



8. Actual Zonal Pressure Belts

Large landmasses disrupt the zonal pattern breaking up the pressure zones into semipermanent high and low pressure belts.

There are three main reasons for this:

- The surface of the Earth is not uniform or smooth. There is uneven heating due to land/water contrasts.
- The wind flow itself can become unstable and generate "eddies."
- The sun doesn't remain over the equator, but moves from 23.5 °N to 23.5 °S and back over the course of a year.

Instead, there are *semi-permanent high- and low-pressure systems*. They are semi-permanent because they vary in strength or position throughout the year.

Wintertime

- Polar highs develop over Siberia and Canada
- The Pacific High, Azores High (parts of the subtropical high pressure system) Aleutian Low and Icelandic Low form



Summertime

- The Azores high migrates westward and intensifies to become the Bermuda High
- The Pacific high also moves westward and intensifies
- Polar highs are replaced by low pressure
- A low pressure region forms over southern Asia

## Part 3: El Niño

### El Niño, La Niña, global impacts

#### El Niño

**El Niño is a large-scale ocean-atmosphere climate phenomenon in the tropical Pacific. It represents the warm phase of the periodic warming of the sea-surface. It typically appears around Christmas time (and this is why it is called El Niño, as this is Spanish for the 'Christ Child'). It can last for up to a year.**

#### El Niño affecting the world

...

*1. Flood in San Francisco. During the winter of 1997/98, wind-driven waves and abnormally high sea levels significantly contributed to hundreds of millions of dollars in flood and storm damage in the San Francisco Bay region. Recent analyses by U.S. Geological Survey (USGS) scientists of nearly 100 years of sea-level records collected near the Golden Gate Bridge found that these abnormally high sea levels were the direct result of that year's El Niño atmospheric phenomenon.*

from: USGS Fact Sheet



2. Flood in Lima. © Reuters

*2. More than 35,000 people have been evacuated and nearly 7,000 people remain isolated by the flooding of the Paraguay river. Abnormally heavy rains associated with the El Niño phenomenon have caused flooding affecting 60,000 people in Paraguay's capital, Asuncion, and the provinces of Concepcion, Alberdi, San Pedro, Presidente Hayes and Alto Paraguay.*

from: UNDP Disaster Protection, 1998 Jan, 8th

*LIMA, 2002 May 9 (AlertNet) - In April, the normally calm Piura River turned overnight into a raging torrent. More than 3,500 families in northern Peru escaped but lost their homes and livelihoods. Scientists disagreed over whether the dramatic weather was connected to the climate phenomenon El Niño, due to make a reappearance this year.*

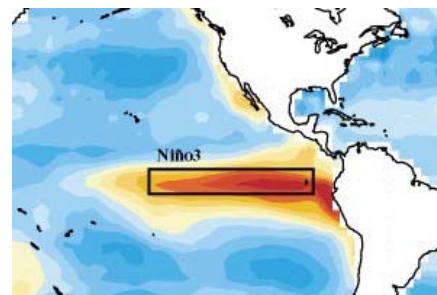
from: Reuters alert net



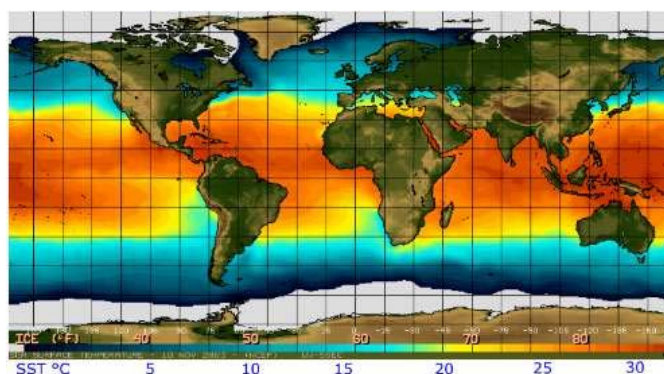
The warm ocean current which flows during El Niño influences the weather around the globe. El Niño events cause increased rainfall, flooding and storms, but also drought and sometimes devastating fires.

### What drives El Niño?

During non-El Niño conditions, the sea surface temperature (SST) in the tropical Pacific is between 6 and 8 °C higher in the west than in the east. This temperature difference is caused mainly by the easterly trade winds. These blow warm surface water across the tropical Pacific from east to west. The surface water gets progressively warmer as it moves west because it is exposed to longer solar heating.

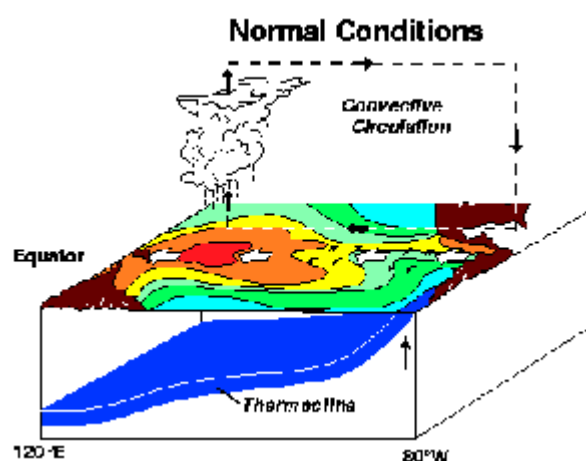


3. The picture does not show the ocean temperature but rather shows how much warmer (in red) or how much cooler (in blue) the sea is during El Niño compared to its normal state. West of South America in front of the Peruvian coast, the water is a lot warmer than normal. © clivar.org / Mojib Latif, MPI Hamburg



4. Sea surface temperatures in absolute values, °Celsius and °Fahrenheit, in November 2003. This image shows normal conditions with cool water from the Humboldt Stream along the South American west coast. Source: SSEC University of Madison, Wisconsin, USA.

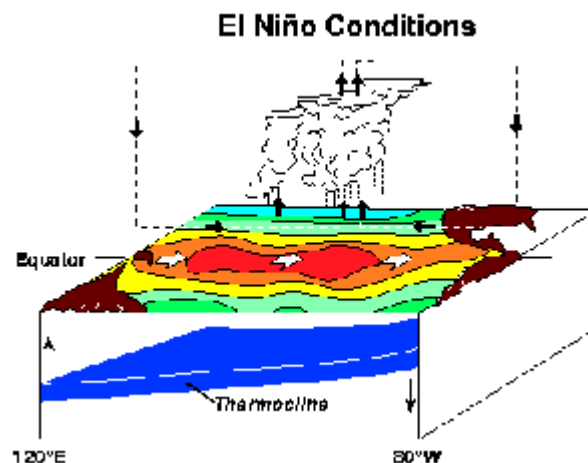
The wind blows the seawater west and, as a result, the sea surface is about half a metre higher at Indonesia than at Ecuador. Because of this difference in seasurface height, water is upwelled from deeper in the ocean in the east to reduce the disparity in height (Figure 4a.). This cool, nutrient-rich sea water is very important in terms of fishing.



5 a) 3-D model of the Pacific Ocean with the South American continent on the right and Australia on the left. This shows the normal conditions in the Pacific.



During El Niño years, weakened winds reduce the flow of water from the east to the west and less nutrient rich cold deep water is upwelled to the surface along the South American coast. So surface waters are warmer than normal but also contain less nutrients. As a result, a dramatic reduction in marine fish and plant life is seen during El Niño events. Most importantly, the warmer than normal water makes the atmosphere unstable and this causes changes in rainfall and weather around the globe.



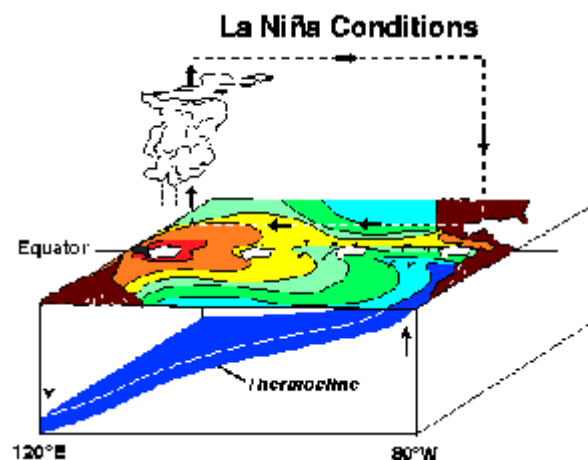
5 b) El Niño conditions in the Pacific  
source: <http://www.pmel.noaa.gov>

El Niño episodes occur every 2-7 years.

### La Niña

Compared to El Niño, La Niña (the female child) events are characterised by cooler than normal sea-surface temperatures in the central and eastern tropical Pacific Ocean.

During La Niña, the easterly trade winds strengthen and upwelling of cold deep water along the equator and the west coast of South America intensifies. Sea-surface temperatures drop as much as 4 °C below normal. The event also called anti-El Niño, or simply "a cold event" or "a cold episode". La Niña conditions make the atmosphere very stable and tend to cause opposite climatic effects to El Niño.



5 c) La Niña conditions in the Pacific  
source: <http://www.pmel.noaa.gov>

Between 1950 and 1997, El Niño events occurred 31% of the time, La Niña events occurred 23% of the time and normal conditions were seen around 46% of the period. El Niño and La Niña events occur, on average, every 3 to 5 years. Based on the historical record, the interval between events has varied from 2 to 7 years. Since 1975, La Niña events have been only half as frequent as El Niño events. A La Niña episode may, but does not always, follow an El Niño. La Niña conditions typically last for 9-12 months, but some episodes may persist for as long as two years.

La Niña events do not negatively affect fisheries in the same way as El Niño events and so are less well known. However, both affect global climate.

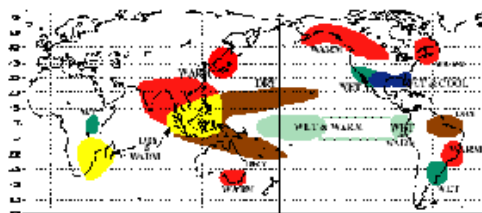




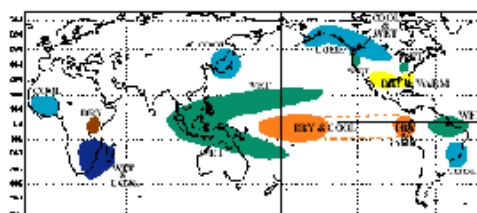
## The global impacts of El Niño and La Niña

The impacts of El Niño and La Niña are seen mostly in the Pacific Ocean and along the Equator. Their effects on temperature and rainfall are roughly opposite and are shown in the figures below.

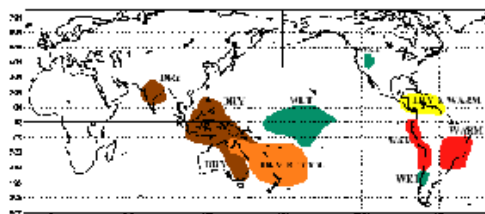
WARM EPISODE RELATIONSHIPS DECEMBER - FEBRUARY



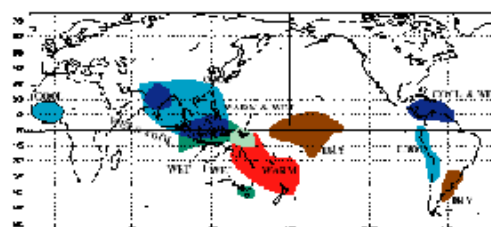
COLD EPISODE RELATIONSHIPS DECEMBER - FEBRUARY



WARM EPISODE RELATIONSHIPS JUNE - AUGUST

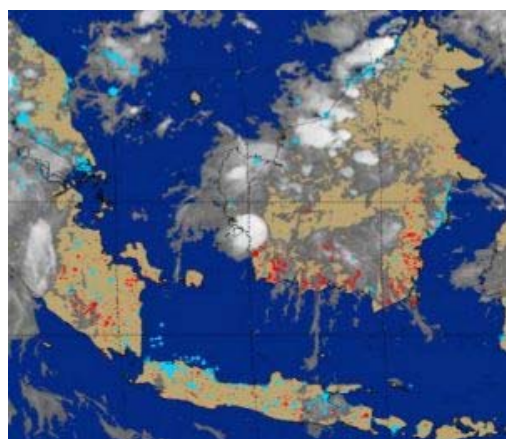


COLD EPISODE RELATIONSHIPS JUNE - AUGUST



6. a) El Niño changes the weather conditions nearly everywhere on the world and lead to severe problems in some regions. Source: NOAA.

6. b) Source: NOAA



7. Fires in Indonesia - Sept. 30th, 1997. The strong El Niño event from mid 1997 to mid 1998 increased the incidence of dangerous fires in Indonesia in this year. © NOAA / significant event imagery.

In the tropics, the eastward shift of thunderstorm activity from Indonesia into the central Pacific during warm episodes results in abnormally dry conditions over northern Australia, Indonesia and the Philippines in both seasons. Drier than normal conditions are also observed over southeastern Africa and northern Brazil during the northern winter season. During the northern summer season, Indian monsoon rainfall tends to be less than normal, especially in northwest India where crops are adversely affected. Wetter than normal conditions during warm episodes are observed along the west coast of tropical South America and at subtropical latitudes of North America and South America.





During a warm episode winter, mid-latitude low pressure systems tend to be more vigorous than normal in the eastern North Pacific. These systems pump abnormally warm air into western Canada, Alaska and the extreme north of the United States. Storms also tend to be more vigorous in the Gulf of Mexico and along the southeast coast of the United States resulting in wetter than normal conditions in that region.

No one clear impact has been detected in Europe yet. This does not mean that El Niño and La Niña do not influence the weather in Europe, but that the connection between these processes is not very strong.

