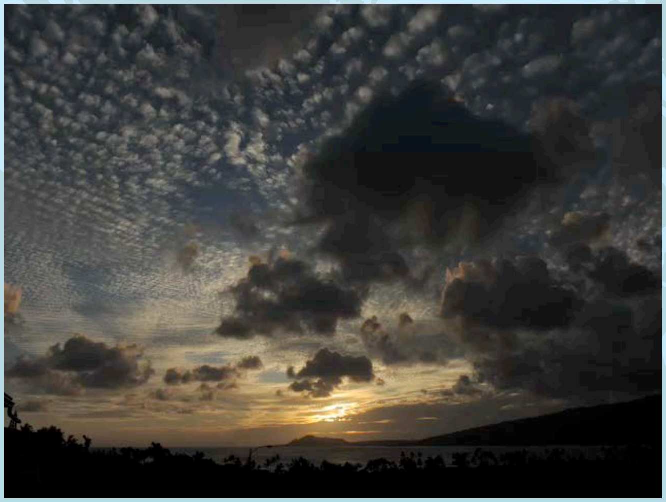
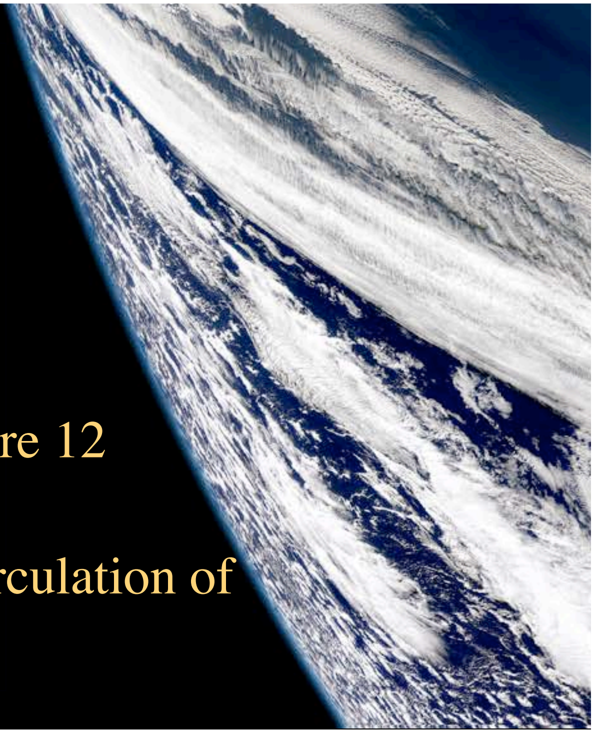
Hadley Circulation in Action



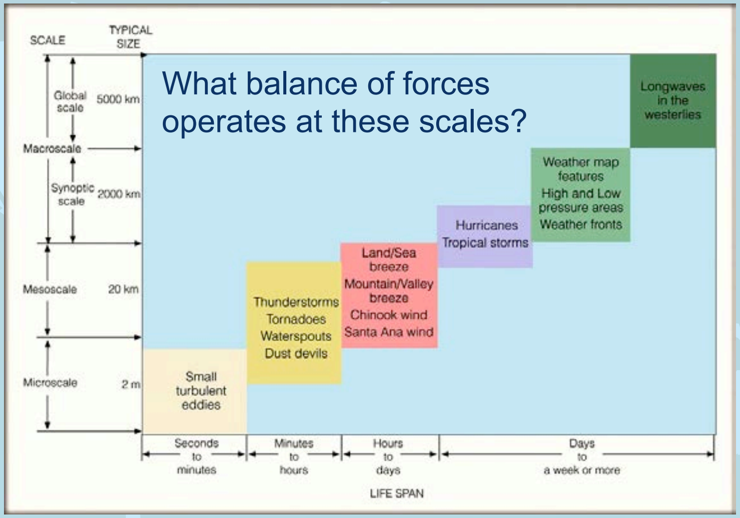
MET 200 Lecture 12 Global Winds: The General Circulation of the Atmosphere



Previous Lecture   Local Winds

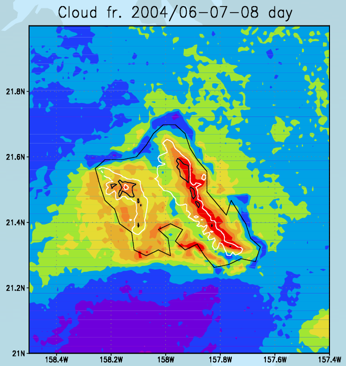
- Scales of Motion
- Eddies
- Sea Breeze
- Mountain-Valley Circulations
- Chinook - Snow Eater
- Drainage Wind - Katabatic Wind

Scales of Motion



Phenomena with large length scales occur over long time scales and vice versa.

Hawaii has Combined Sea Breeze and Mountain - Valley Circulations

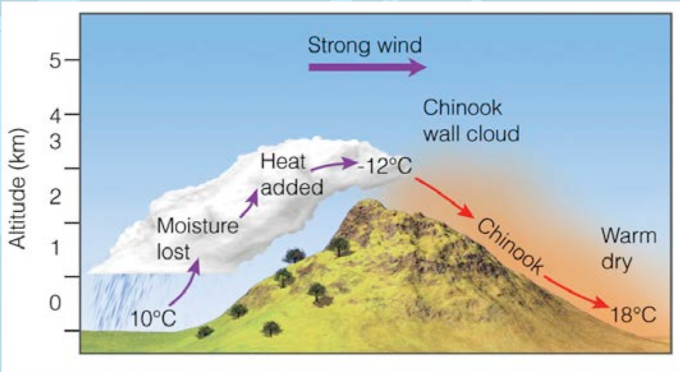


In Hawaii, the sea-breeze and mountain-valley circulations are combined to produce an island scale circulation that can be quite vigorous, especially when trade winds are light.

Kona Sea-breeze Front

Hawaii sea breeze has insufficient kinetic energy to overcome the large altitude of the Big Island's volcanoes.

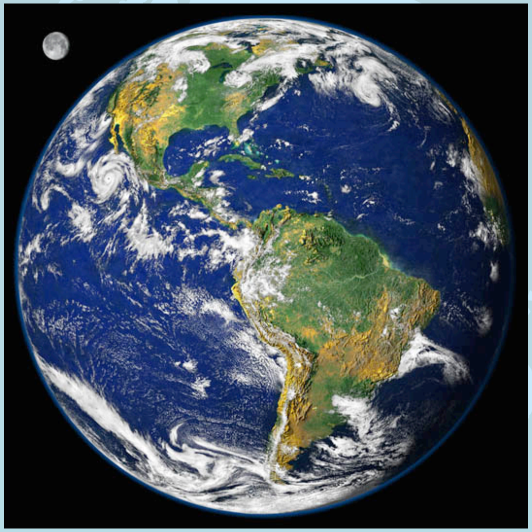
Chinook Downslope Winds



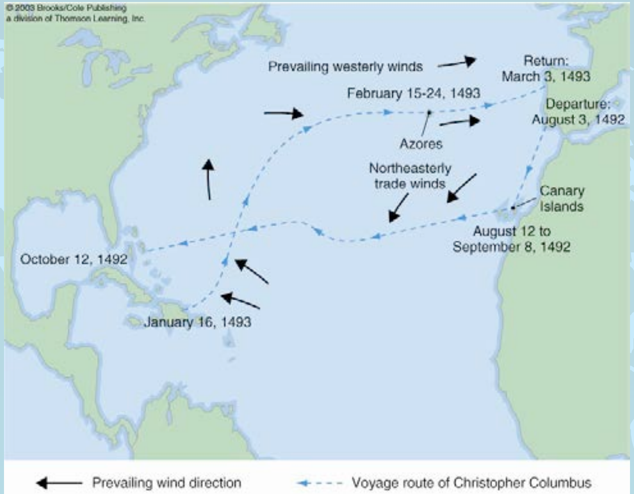
- Main source of heating is compression during downslope flow
  - Key is loss of moisture on upwind slope so downslope heating occurs at higher dry adiabatic rate
- Latent heat release from condensation during upwind ascent also contributes
  - If condensed water is removed as precipitation on upwind slope

Lecture 12 Global Winds

- General Circulation of winds at the surface and aloft
- Idealized 3-cell model of the winds
- ITCZ & Monsoons
- Subtropical & Polar Jet Streams



Global Wind Circulation

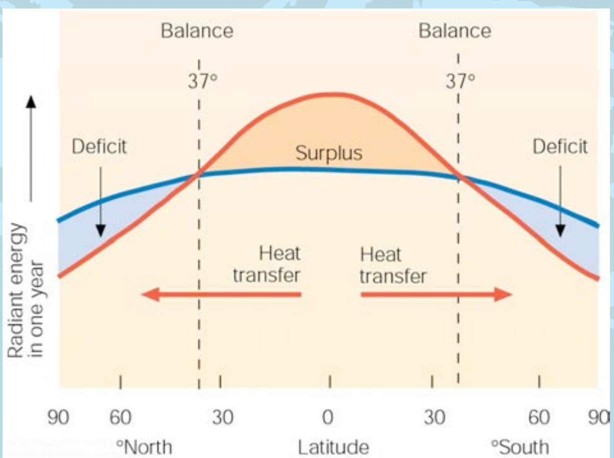


Early explorers were very familiar with the global circulation and used their knowledge in planning their voyages.

Global Wind Circulation

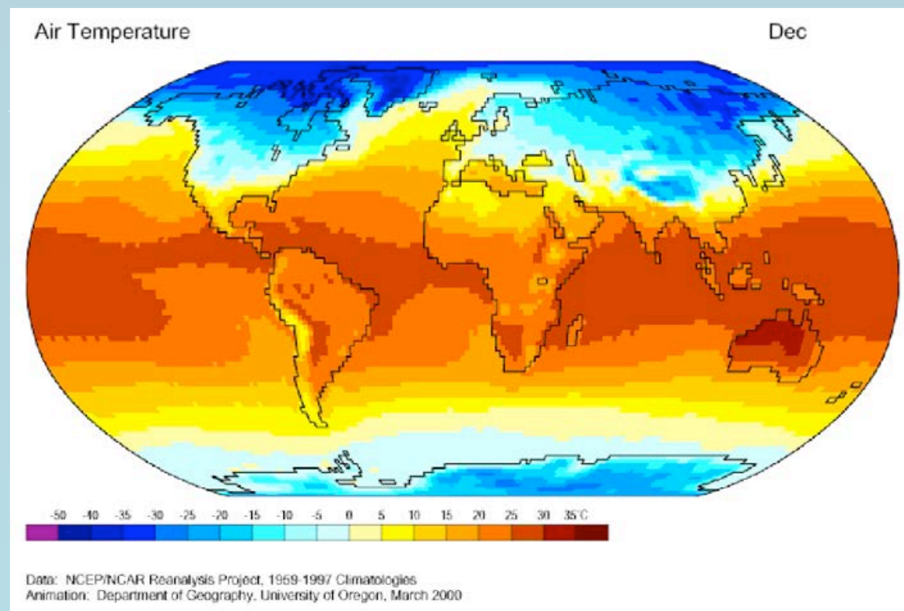
The circulations of the atmosphere and oceans are ultimately driven by differential solar heating and the local radiation imbalance between incoming solar (short wavelength) radiation and outgoing terrestrial (long wavelength) radiation.

Radiation Budget at the top of the Earth's Atmosphere

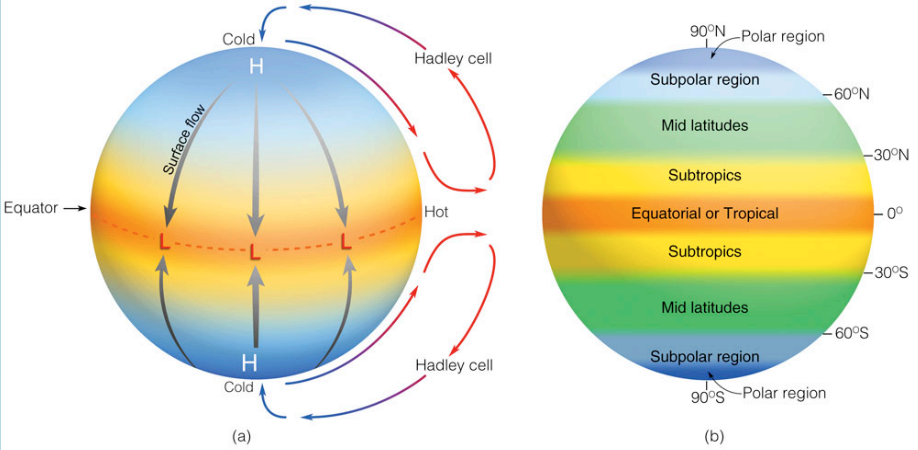


Red Line is incoming radiation from the sun
Blue Line is outgoing radiation emitted by the earth

Global Surface Temperature

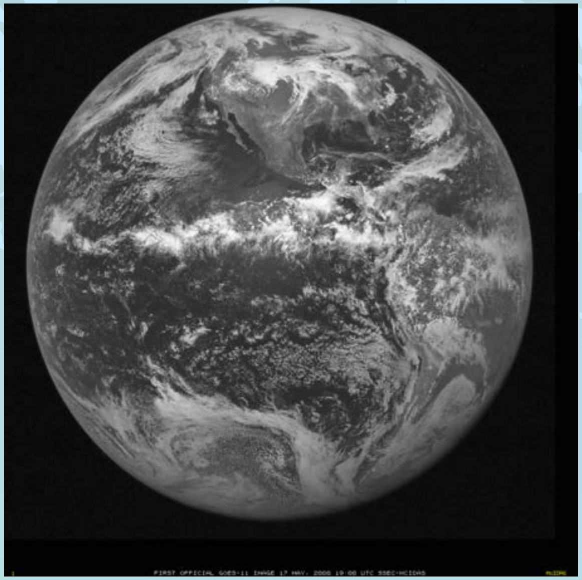


A Single Cell Convection Model

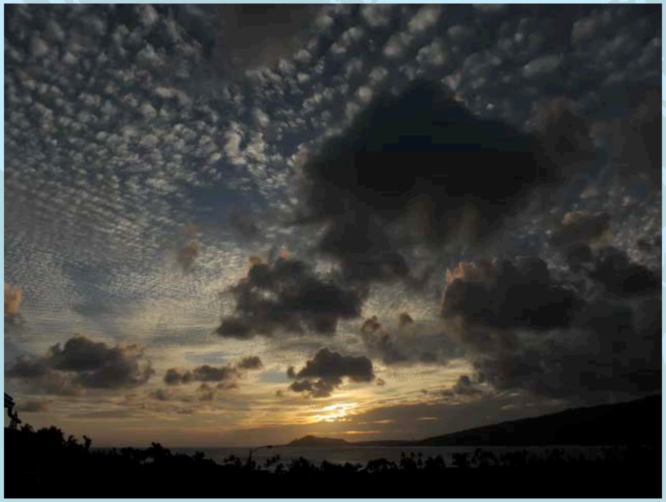


- Solar heating leads to formation of a convection cell in each hemisphere
- Energy transported from equator toward poles
- What would prevailing wind direction be over N. America with this flow pattern on a rotating earth?

Does the Earth Exhibit a Single Cell?

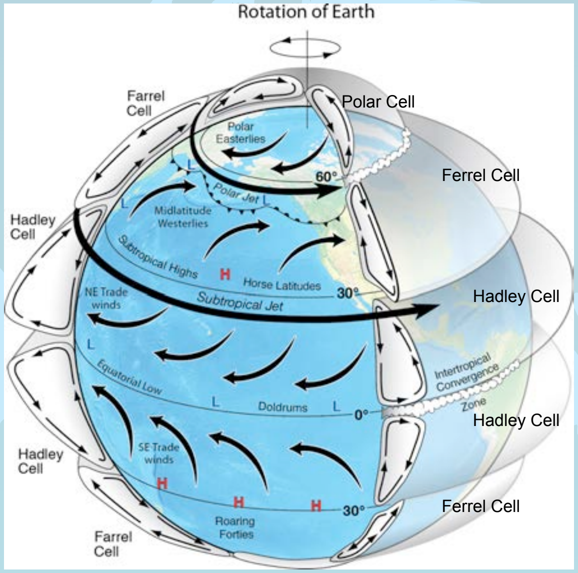


Hadley Circulation in Action



Idealized 3-Cell Model

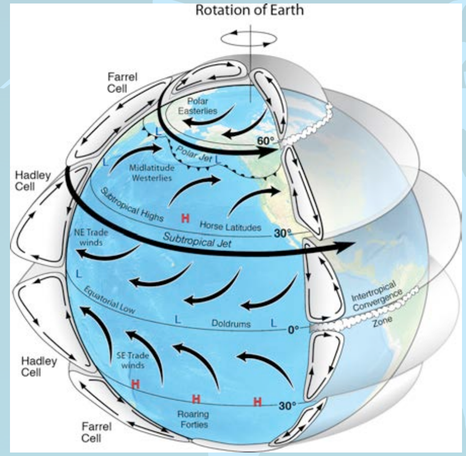
A schematic of the Earth's weather machine bringing warm moist air northward and cold dry air southward (latent and sensible heat).

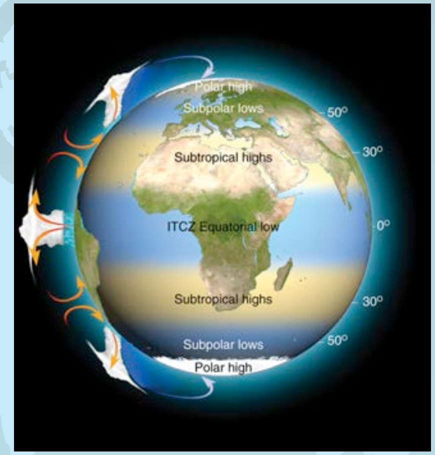


Key features of 3-Cell Model

- Hadley cell
  - driven by differential heating by the sun
  - air rises near equator and descends near 30˚
  - explains deserts, trade winds, ITCZ, and subtropical jet
- Ferrel Cell
  - driven by heat transports of winter storms
  - air rises near 60˚ and descends near 30˚
  - explains surface westerlies from 30˚-60˚, and polar jet
- Polar Cell
  - driven by radiational cooling
  - air sinks over the pole and rises near 60˚
  - explains surface easterlies from 60˚- pole
  - explains why polar regions are as dry as deserts

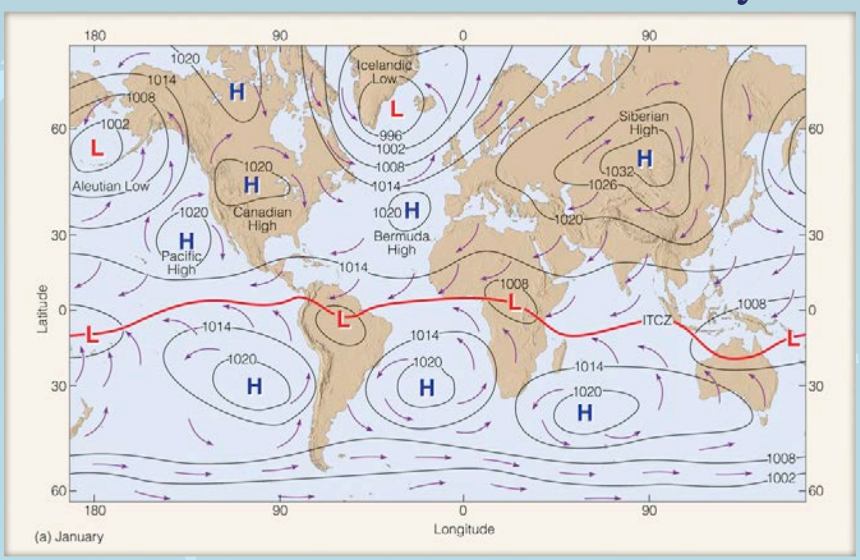
Idealized 3-Cell Model





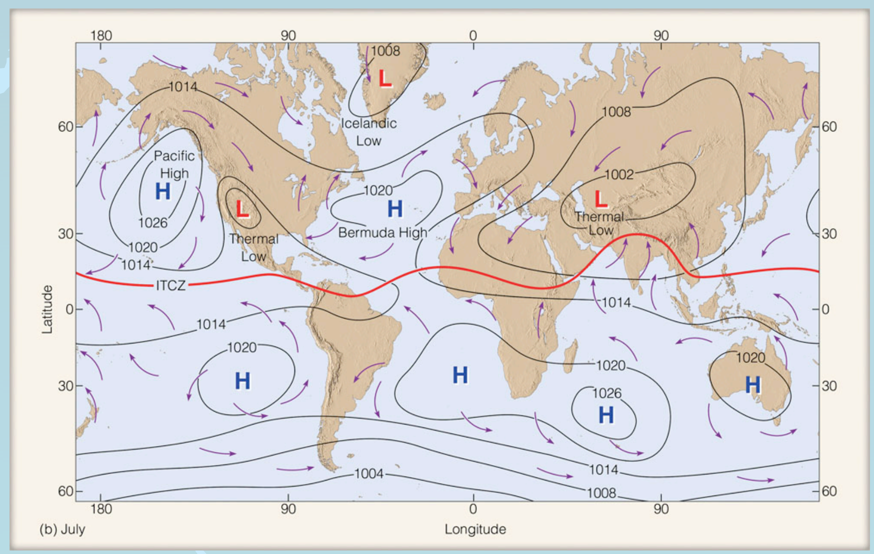
- Weak winds found near Equator (doldrums), 30 degrees (horse latitudes), and over poles.
- Boundary between cold polar air and mid-latitude warmer air is the *polar front*

The Real World is More Messy



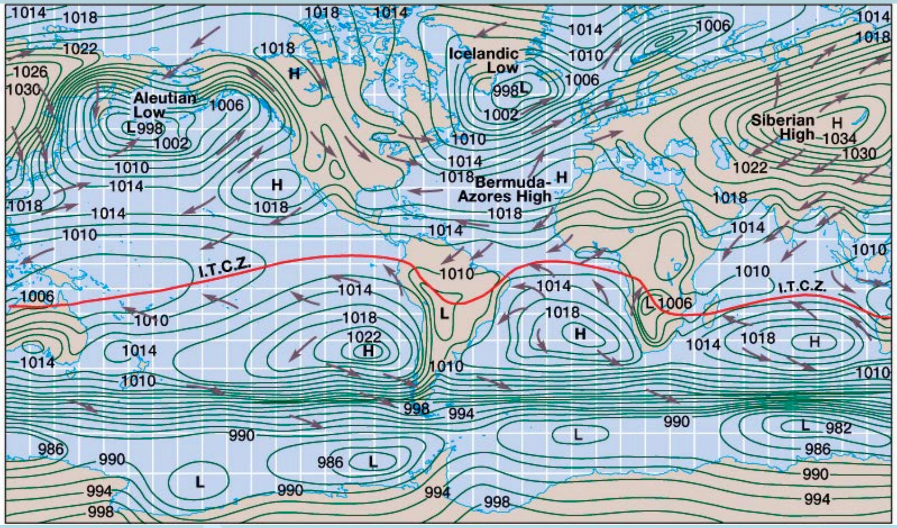
The presence of continents, mountains, and ice fields alters the general circulation from the ideal 3-cell model.

General Circulation - July



During winter, highs form over land; lows over oceans. Vice versa during summer. Consistent with differences in surface temperature.

General Circulation - January



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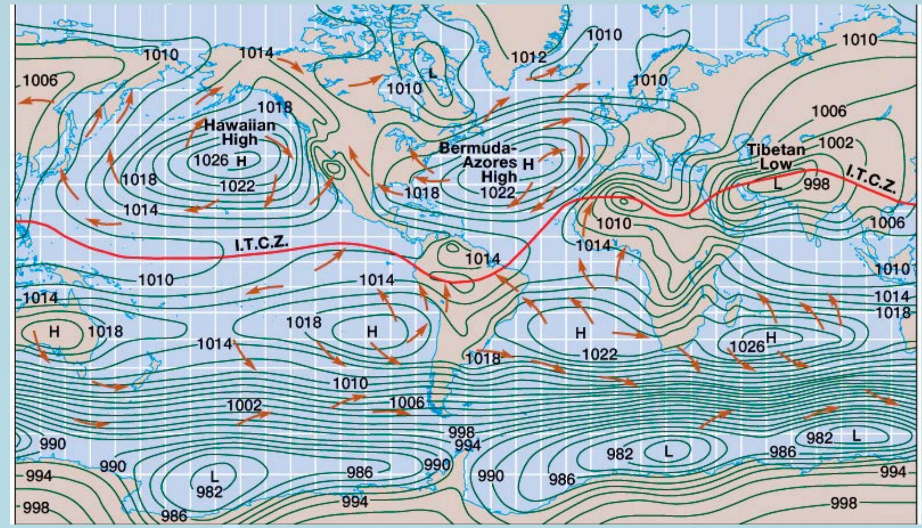
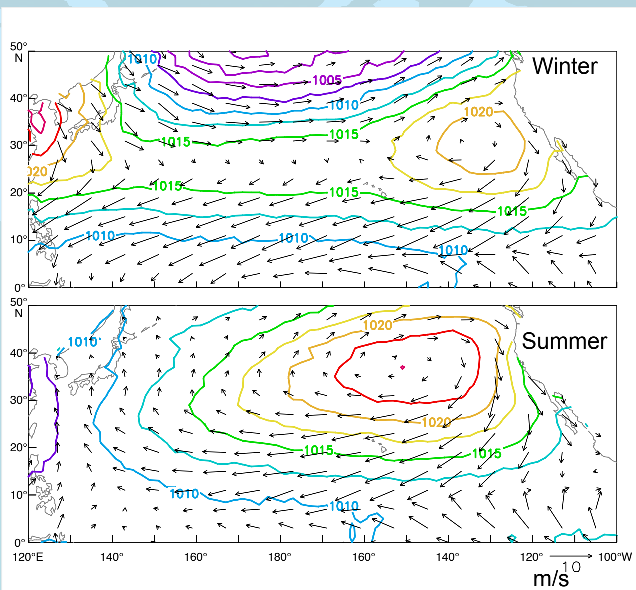
General Circulation - July



The general circulation shifts N and S with the sun.

Surface Pressure & Wind over the North Pacific
Based on historical ship reports



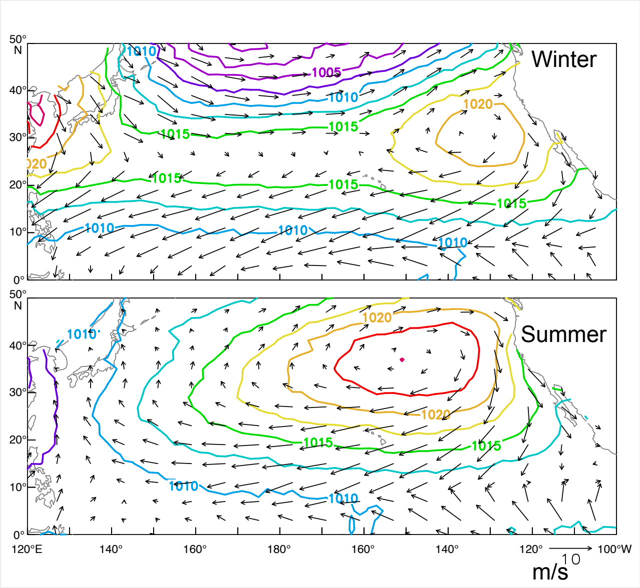
Trade Winds

Trade winds are the most common winds over Hawaiian waters, accounting for 70% of all winds in Hawaii.

These persistent winds, which blow from a NE to ENE direction, became known as trade winds centuries ago when trade ships carrying cargo depended on the broad belt of easterly winds encircling the globe in the subtropics for fast passage.

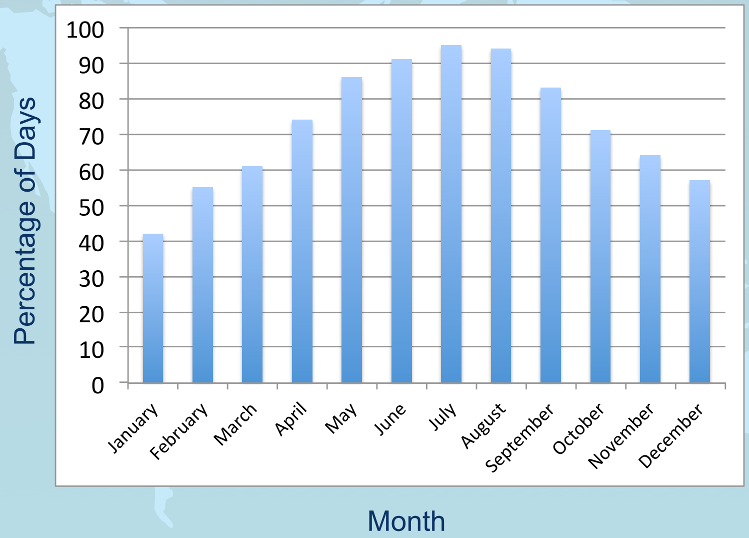
Winds blow from each of the other quadrants (SE, SW, and NW) 10% of the time.

Surface Pressure & Wind in Summer and Winter

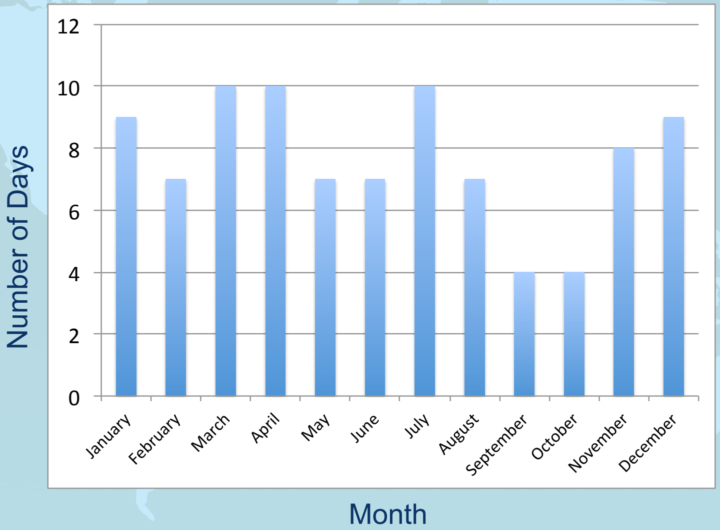


Based on ship reports

Frequency of Trade Wind Days



Strong Trade Wind Days (25-33 kt)



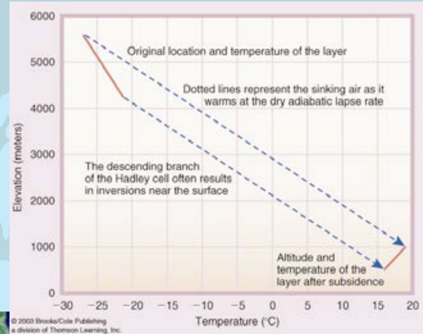
Trade Winds

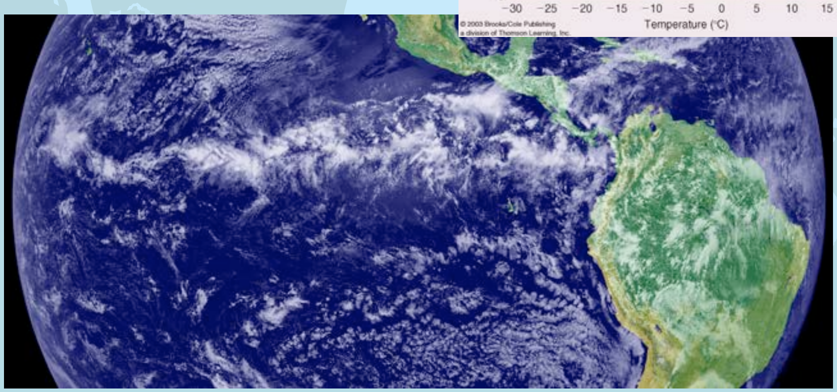
Though often refreshingly cool, strong, gusty trade winds can cause problems for Hawaii.

Blowing from the NE through East direction, these strong trades funnel through the major channels between the islands at speeds 5-20 knots faster than the speeds over the open ocean.

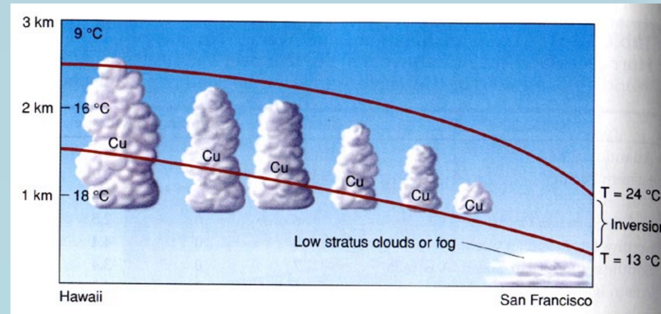
In addition, terrain enhancement of trade winds can cause even greater acceleration to more than hurricane force.

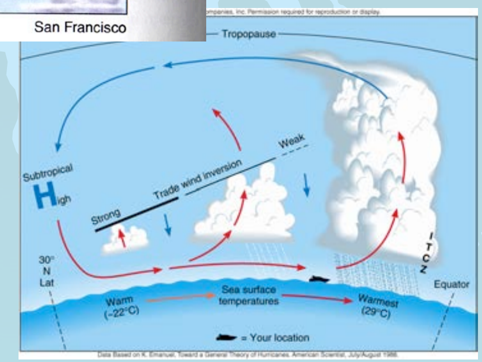
Hadley Cell, Cumulonimbus, and Marine Stratus



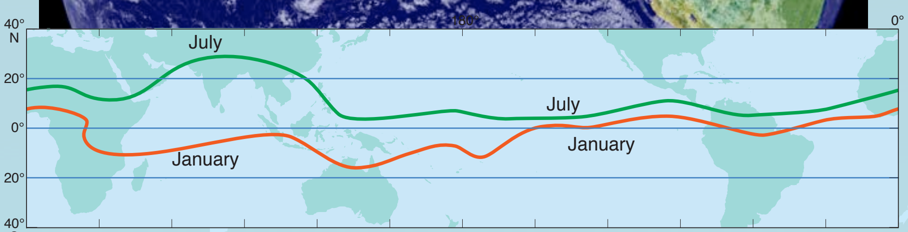


Evolution of Trade Wind Inversion





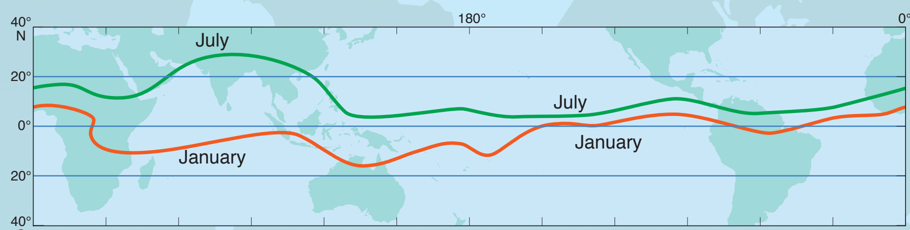
Intertropical Convergence Zone



The Intertropical Convergence Zone (ITCZ) shifts southward in January and northward in July. Why?

The Monsoon

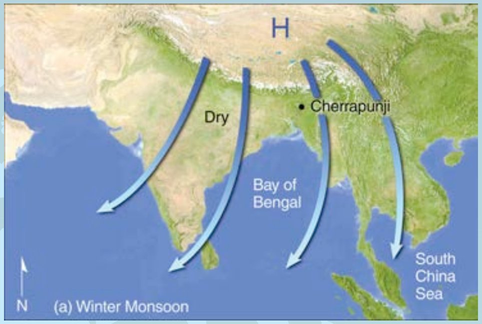
- The Monsoon is
  - Seasonal
  - Common in eastern and southern Asia
  - Similar to huge land/sea breeze systems



The Monsoon

During winter strong cooling produces a shallow high pressure area over Siberia

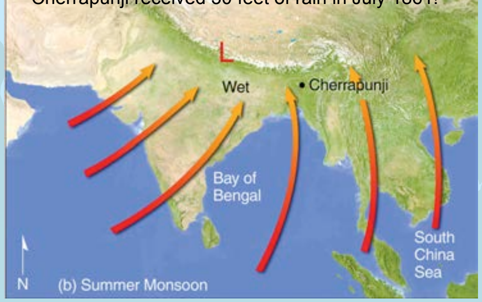
Subsidence, clockwise circulation and flow out from the high provide fair weather for southern and eastern Asia



During summer, air over the continent heats and rises, drawing moist air in from the oceans

Convergence and topography produce lifting and heavy rain.

Cherrapunji received 30 feet of rain in July 1861!



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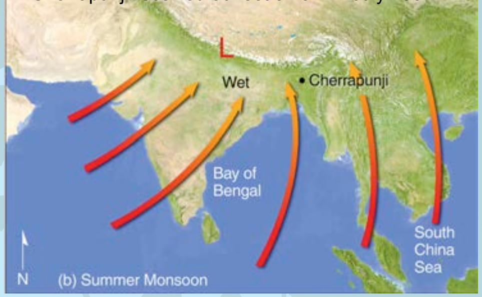
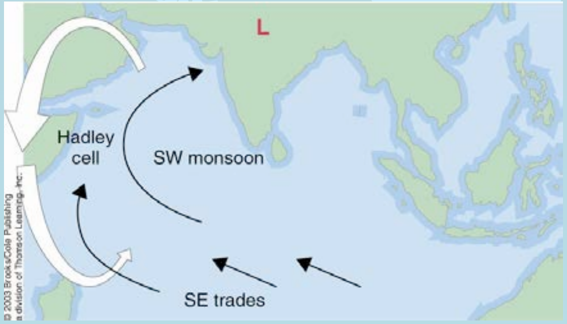
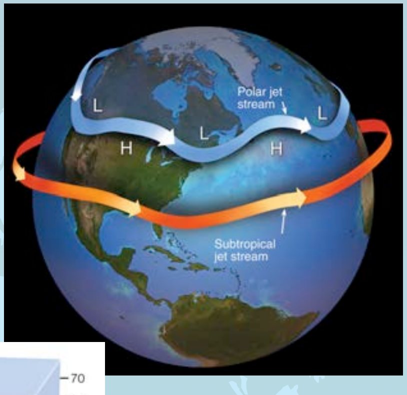


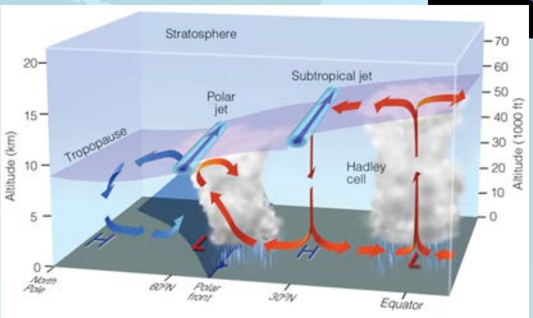


Jet Streams

Fast air currents in the upper troposphere, 1000's of km's long, a few hundred km wide, a few km thick

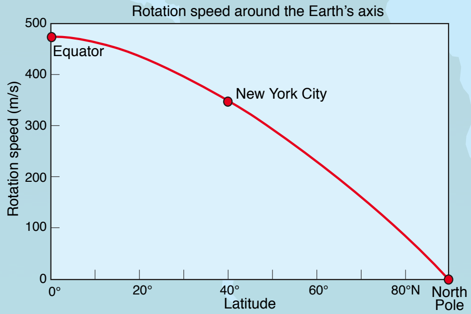
Typically find two jet streams (subtropical and polar front) at tropopause in NH



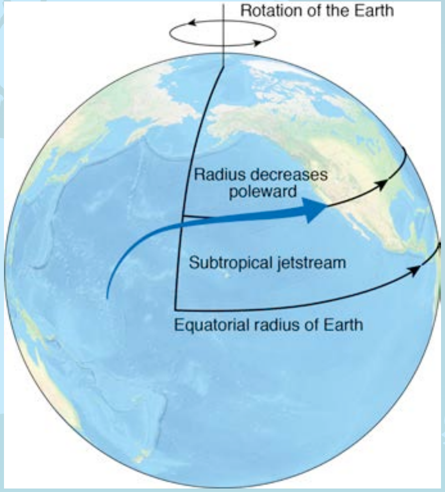


Subtropical Jet Stream

The subtropical jet stream results from the Coriolis acceleration of the poleward branch of the convection (Hadley) cell.



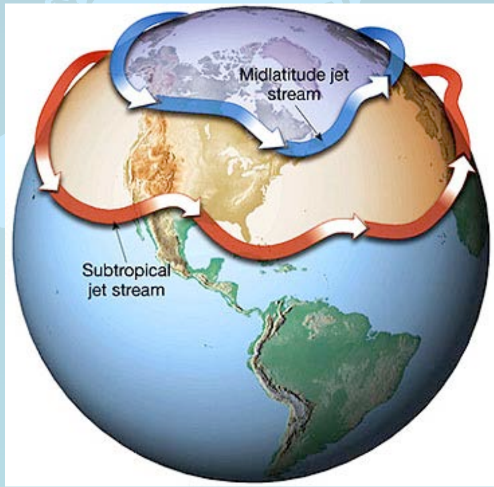
Rotation speed due to rotation of the earth



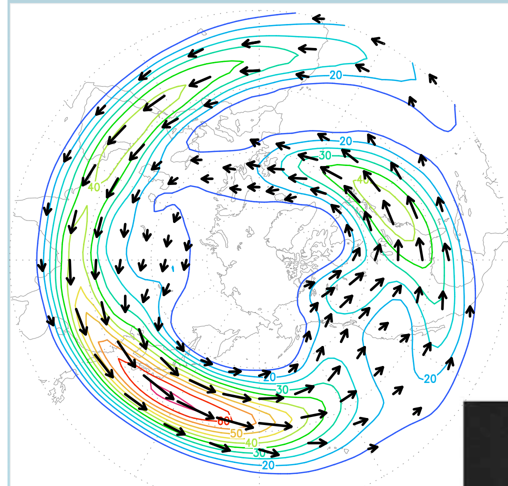
Pressure Patterns and Winds Aloft

The subtropical jet stream results from the Coriolis acceleration of the poleward branch of the Hadley(convection) cell.

How does the polar jet stream form?

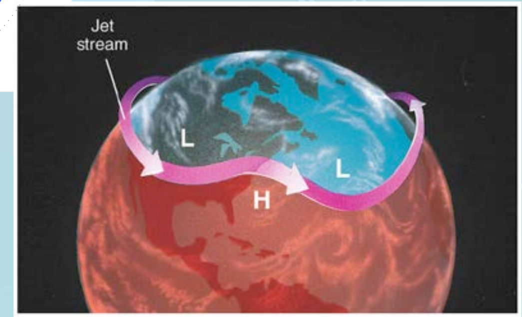


Westerly Jet Streams

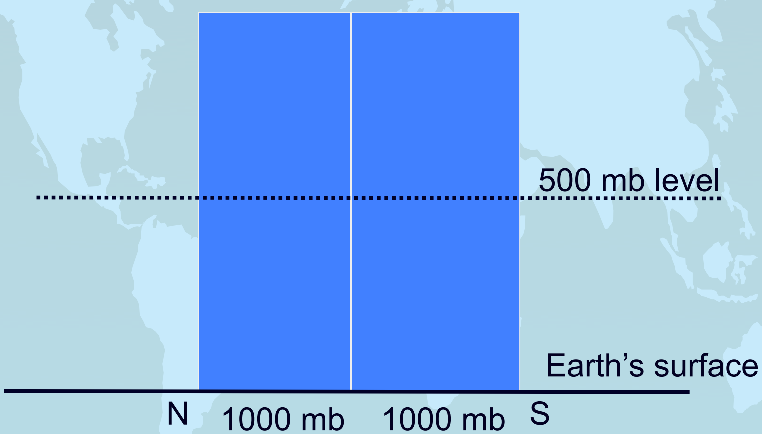


- Maximum (> 60 m/s) near Japan & secondary max (40 m/s) along the US east coast.
- Responsible for longer return flights to Japan from North America.

Wind velocity (m/s) at 300 hPa in January, viewed from the North Pole

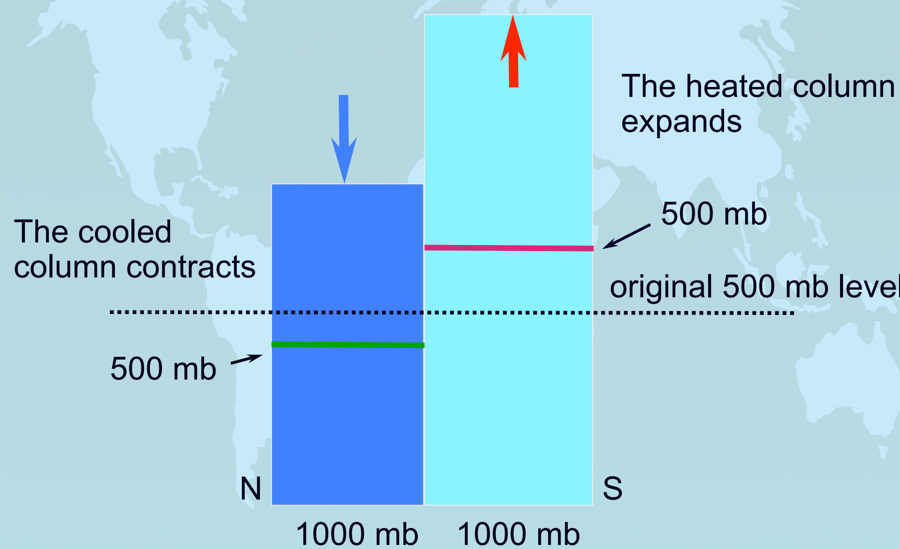


Heating, Pressure Patterns, and Winds

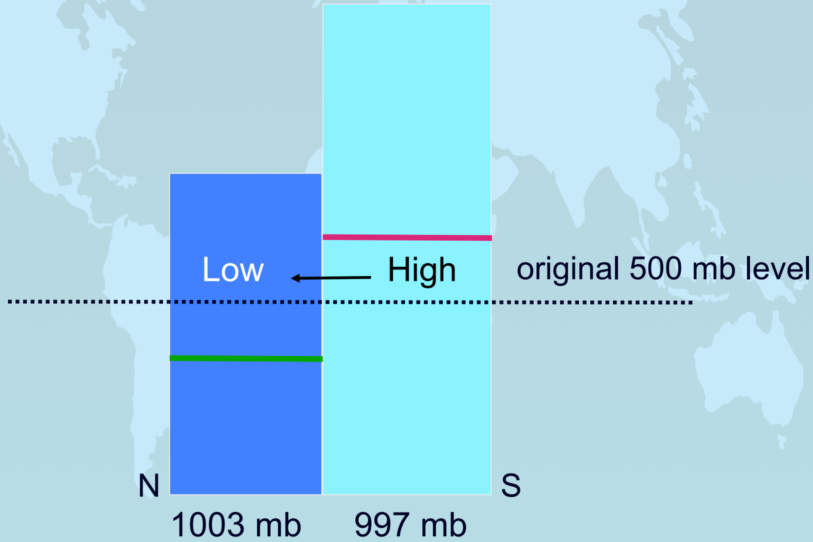


Start with two columns of air with the same temperature and the same distribution of mass

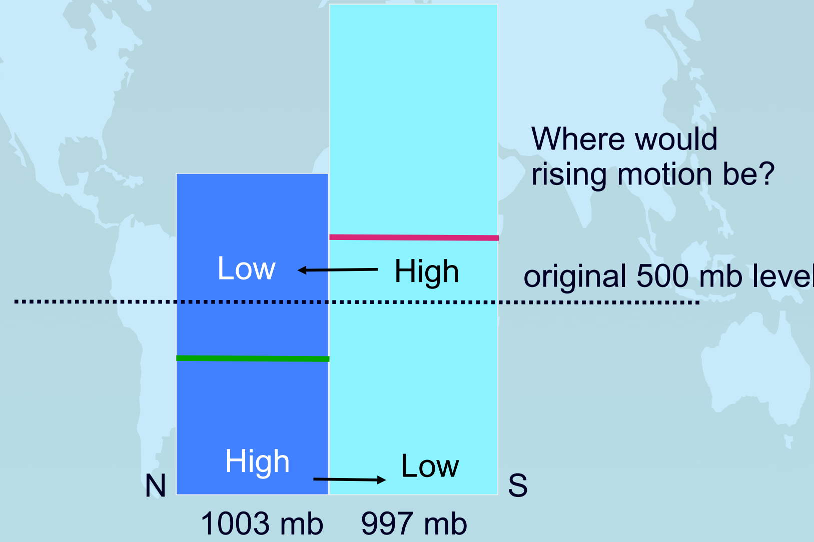
Cool the left column & Warm the right column



Air moves from high to low pressure in middle of column, causing surface pressure to change.



Air moves from high to low pressure at the surface



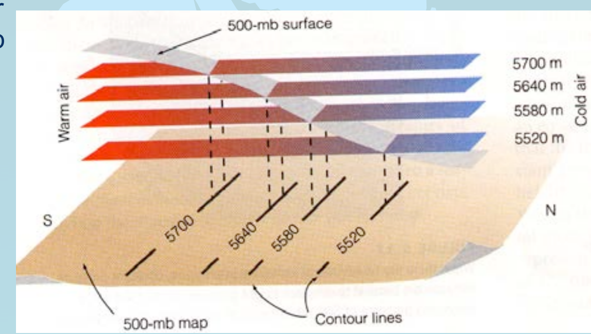
What have we just observed?

- Starting with a uniform atmosphere at rest, we heat the tropics and cool the poles.
- The differences in heating cause different rates of expansion in the air (warm air takes up more space).
- The differing rates of expansion result in horizontal pressure gradients (differences).
- The pressure gradients produce wind.
- This is a simple model of how the atmosphere turns heating into motions.

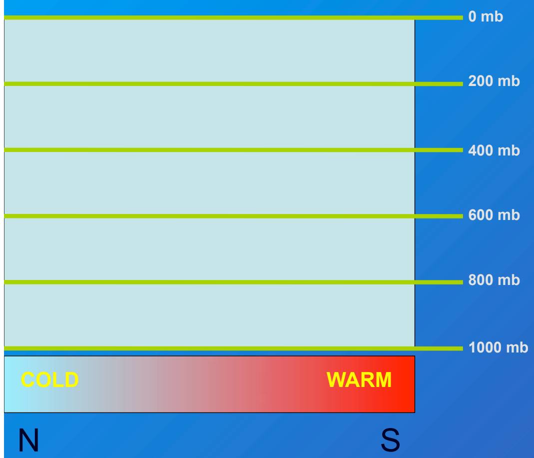
Constant Pressure Charts

Constant pressure charts are often used by meteorologists. Constant pressure charts plot variation in height on a constant pressure surface (e.g., 500 mb).

- In this example a gradient between warm and cold air produces a sloping 500 mb pressure surface.
- Pressure decreases faster with height in a colder (denser) air mass.
- Where the slope of the pressure surface is steepest the height contours are closest together.



The Polar Jet Stream

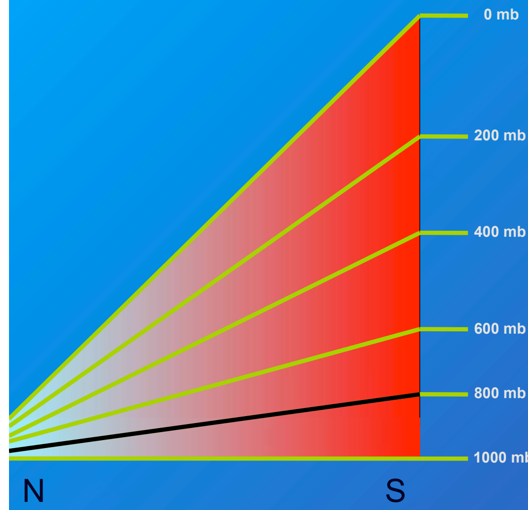


Imagine the atmosphere is a 'block' of air that pushes down with 1000 mb of pressure at the bottom.

The block starts out at a **uniform temperature** – the thickness of the atmosphere is the same everywhere.

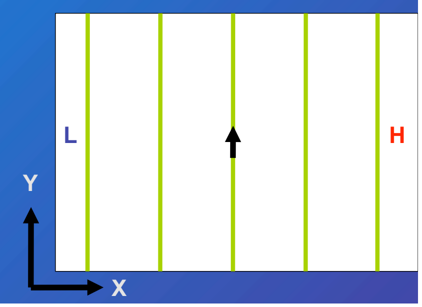
Now we make the block **cold** on the north side (polar night) and **warm** on the south side (tropical sun).

The Polar Jet Stream

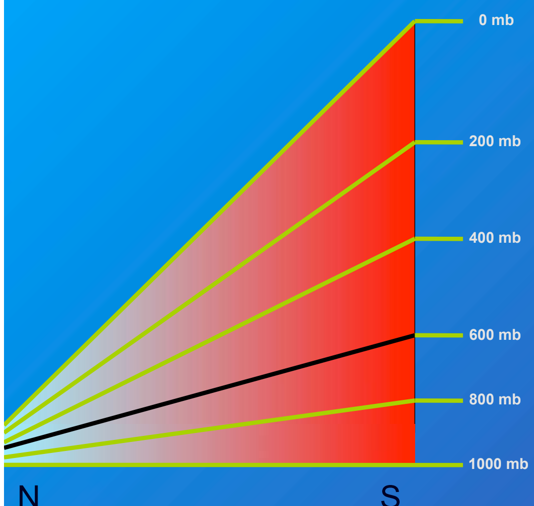


The 1000 mb pressure surface is still flat – there is the same amount of fluid above the surface whether you are on the cold side or the warm side.

But above the surface a **pressure gradient** appears, which drives wind.



The Polar Jet Stream



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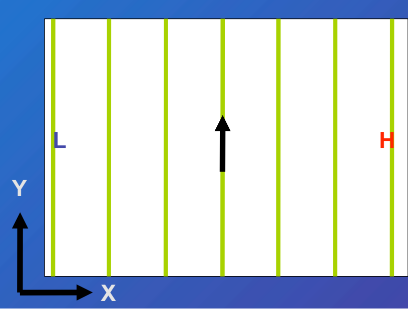
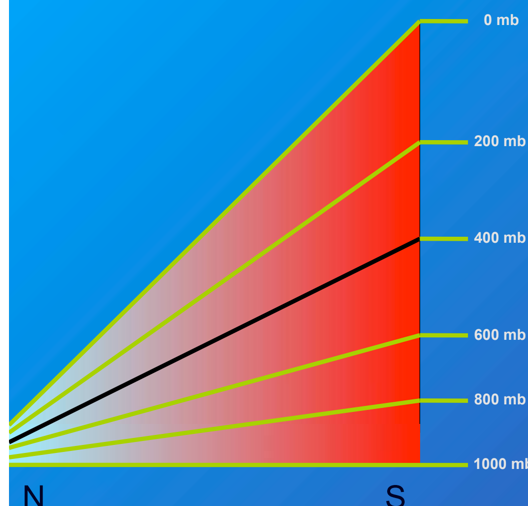
But above the surface a **pressure gradient** appears, which gets **stronger** as you go **up**. So the wind gets stronger as you go up.



The Polar Jet Stream



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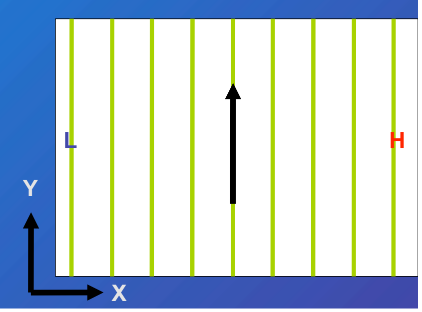
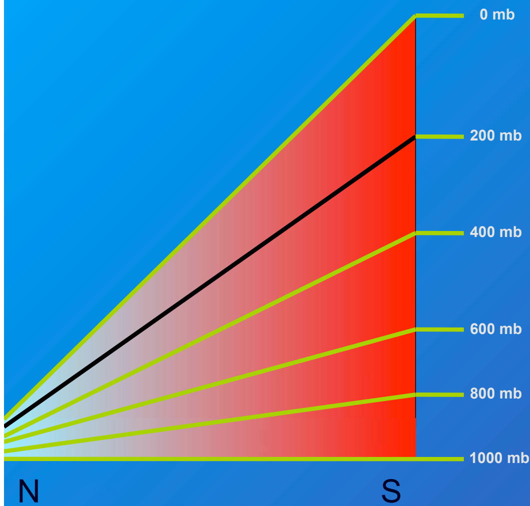


The Polar Jet Stream



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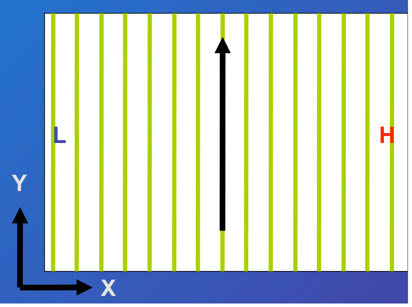
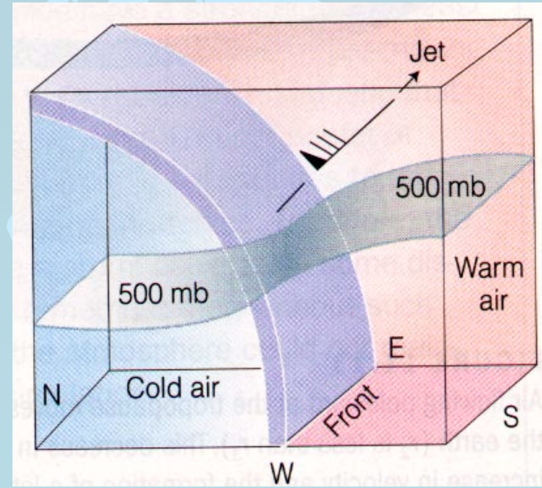


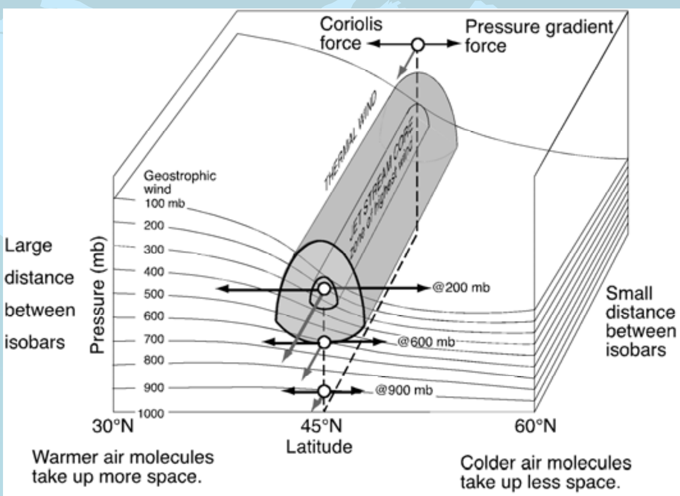
Polar Front Jet Stream

Polar front jet stream forms along polar front where strong thermal gradient causes a strong pressure gradient

Strong pressure gradient force and Coriolis force produce strong west wind parallel to contour lines. The jet stream is nearly in geostrophic balance.



Polar Jet Stream and the Thermal Wind



The jet stream associated with the polar front owes it existence to the differential solar heating from equator to pole. Thus, the jet is stronger in winter than in summer and moves north and south with the sun.

Deriving the Thermal Wind Relationship

If we differentiate the geostrophic wind, $V_g = \frac{1}{f} k \times \nabla_p \Phi$

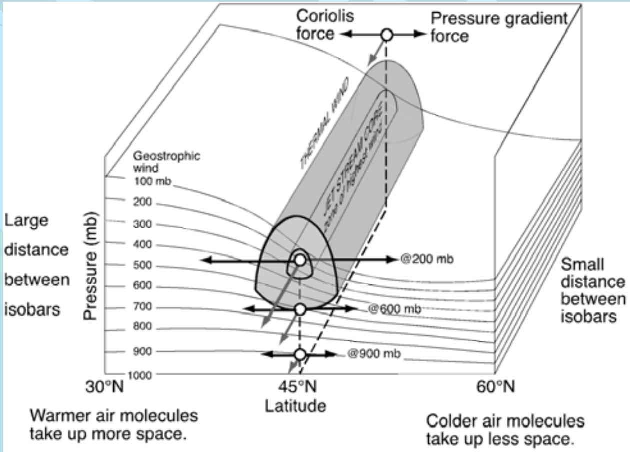
(where *f* is the Coriolis parameter, *k* is the vertical unit vector, and the subscript "*p*" on the gradient operator denotes gradient on a constant pressure surface) with respect to pressure, and integrate from pressure level from p_0 to p_1, we obtain the thermal wind equation:

$$V_T = \frac{1}{f} k \times \nabla_p \left(\Phi_1 - \Phi_2 \right)$$

Substituting the hypsometric equation, one gets a form based on temperature, $\Phi_2 - \Phi_1 = R\overline{T} \ln \left[\frac{p_1}{p_2} \right]$

$$V_T = \frac{R}{f} \ln \left[\frac{p_1}{p_2} \right] k \times \nabla_p \overline{T}$$

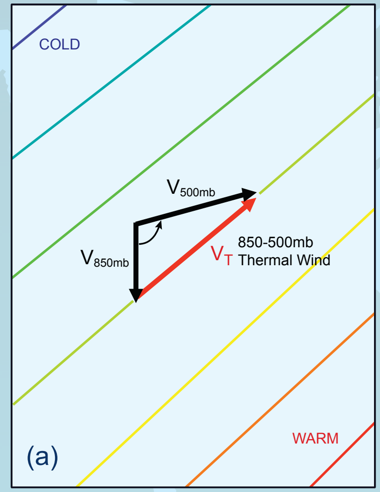
Thermal Wind in Component Form

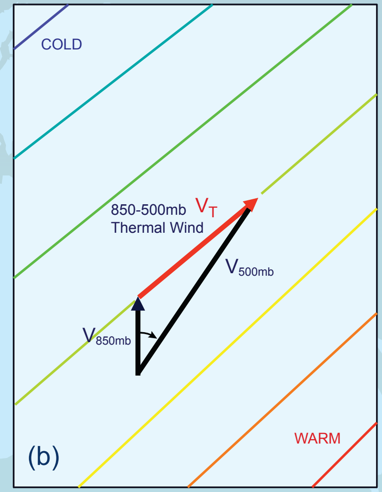


$$u_T = -R/f\ (\partial T/\partial y)_p \ln(P_1/P_2)$$

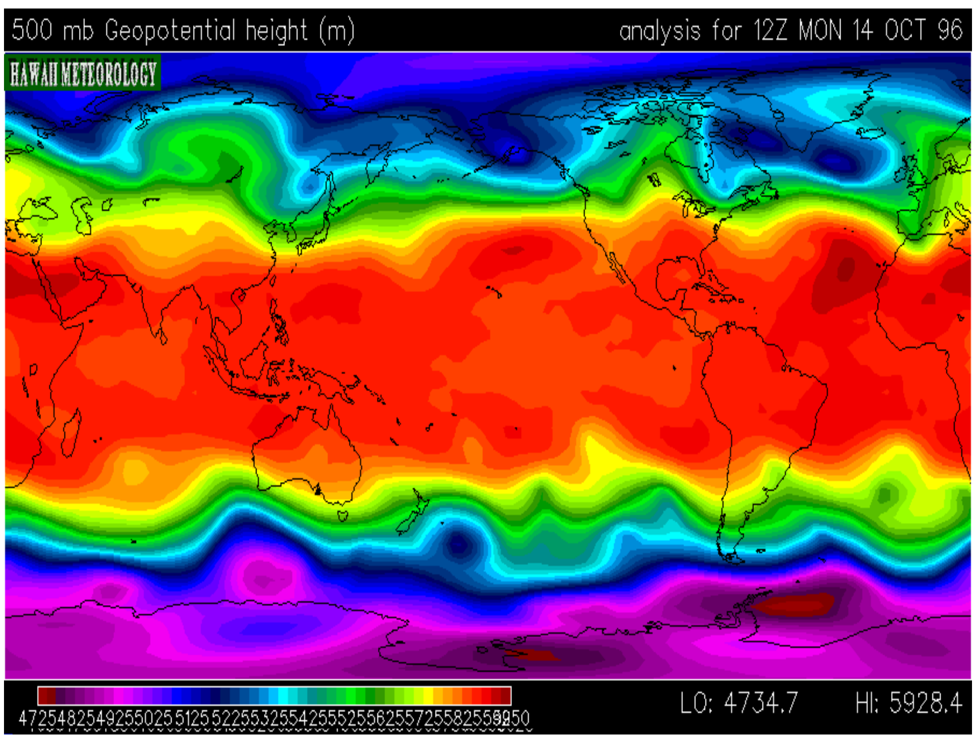
$$v_T = -R/f\ (\partial T/\partial x)_p \ln(P_1/P_2)$$

Thermal Wind and Advection

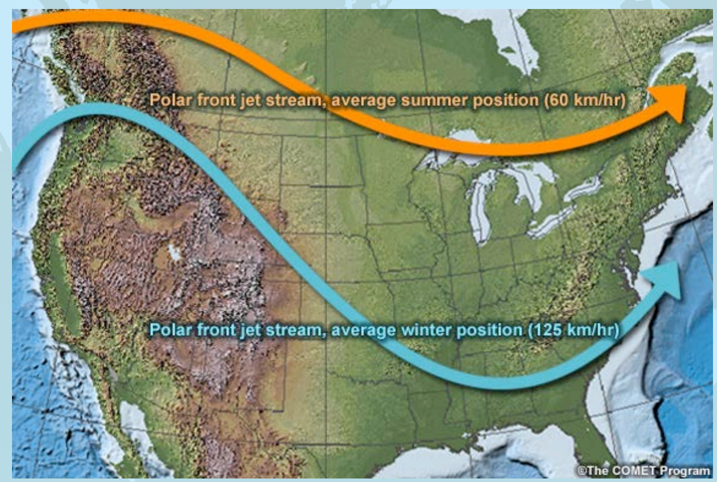




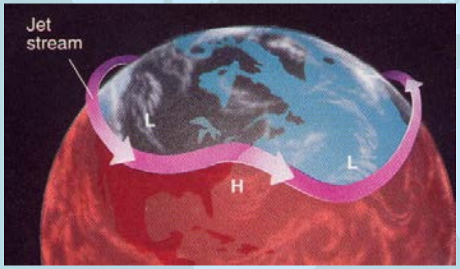
Wind vectors at 500 and 850 mb and the wind shear vector or thermal wind for (a) cold advection: wind direction is backing with height and (b) warm advection: wind direction is veering with height.

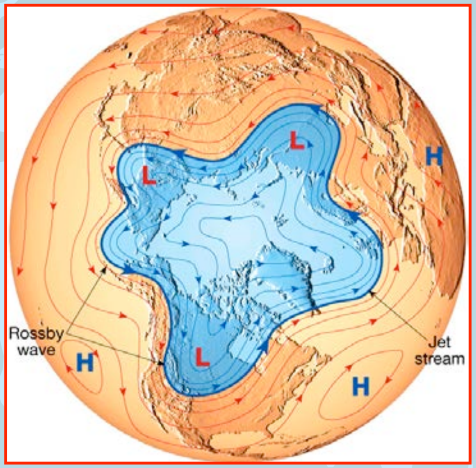


Polar Jet Stream - Shifts with the Sun



Waves form along Jet





Temperature gradients lead to pressure gradients.
Height contours decrease in value toward cold air.

Troughs and Ridges

- Contour lines are usually not straight.
  - Ridges (elongated highs) occur where air is warm.
  - Troughs (elongated lows) occur where air is cold.

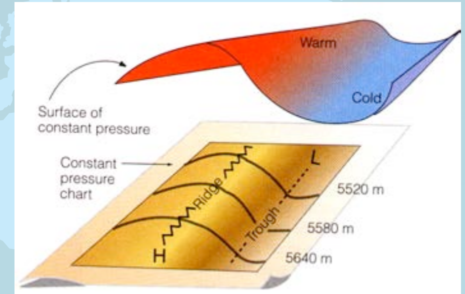
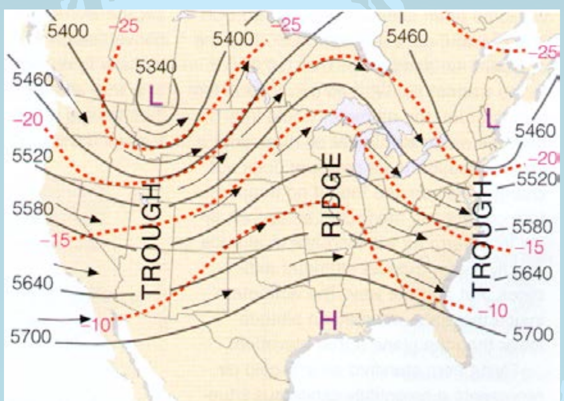


FIGURE 9.14
The wavelike patterns of a constant pressure surface reflect the changes in air temperature. An elongated region of warm air aloft shows up on a constant pressure chart (isobaric map) as higher heights and a ridge; the colder air shows as lower heights and a trough.

Pressure patterns and winds aloft

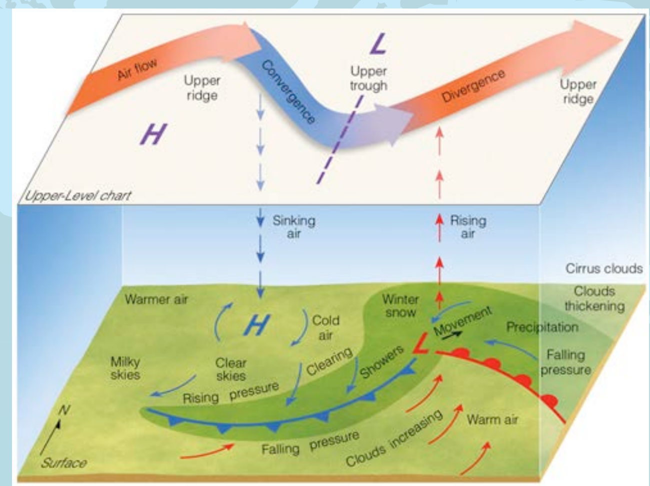
At upper levels winds blow parallel to the pressure/ height contours.

Troughs are cold, ridges are warm.



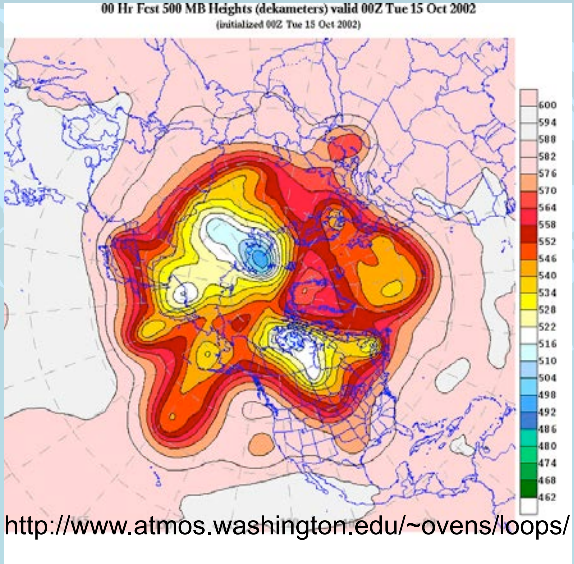
http://ProfHorn.meteor.wisc.edu/wxwise/kinematics/jetcore2.html

Waves determine Track and Intensity of Winter Storms



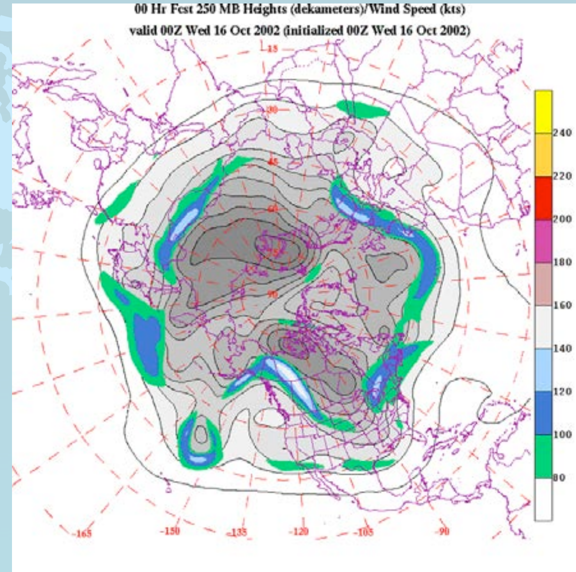
Temperature gradient across the polar front determines the strength of the polar jet stream.

Jet Stream has Waves



500-mb heights

Jet Stream has Wind Maxima

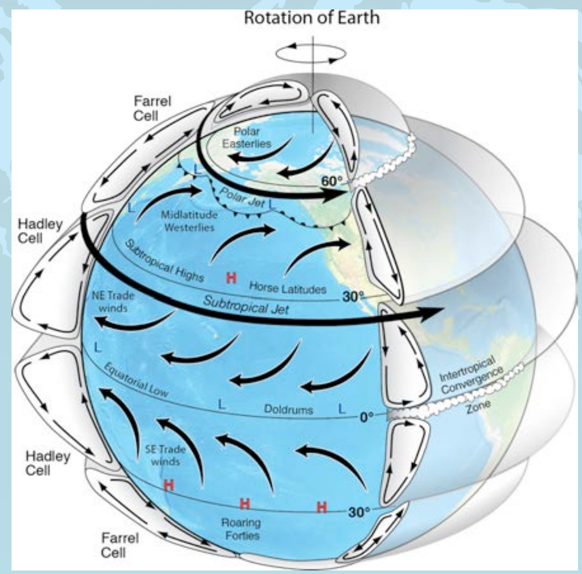


250-mb heights and isotachs (contours of constant wind speed)

Global Wind Circulation

- General Circulation of winds at the surface and aloft
- Idealized 3-cell model of the winds
- ITCZ & Monsoons
- Subtropical & Polar Jet Streams

Idealized 3-Cell Model is Still Useful



Summary of General Circulation

1. Driven by differential solar heating between the equator and poles, atmospheric winds generally act to move heat poleward.
2. In Hadley cell, warmer air rises and moves poleward.
3. Ferrel cell is driven by heat and winds in winter storms.
4. In the Northern Hemisphere, air is deflected to the right as it moves; in the Southern Hemisphere, air is deflected toward the left as it moves - Therefore rotation yields trade winds; midlatitude westerlies; subtropical jet, polar easterlies, etc.
5. Along axes of of high pressure light winds and low precipitation prevail.

Questions?