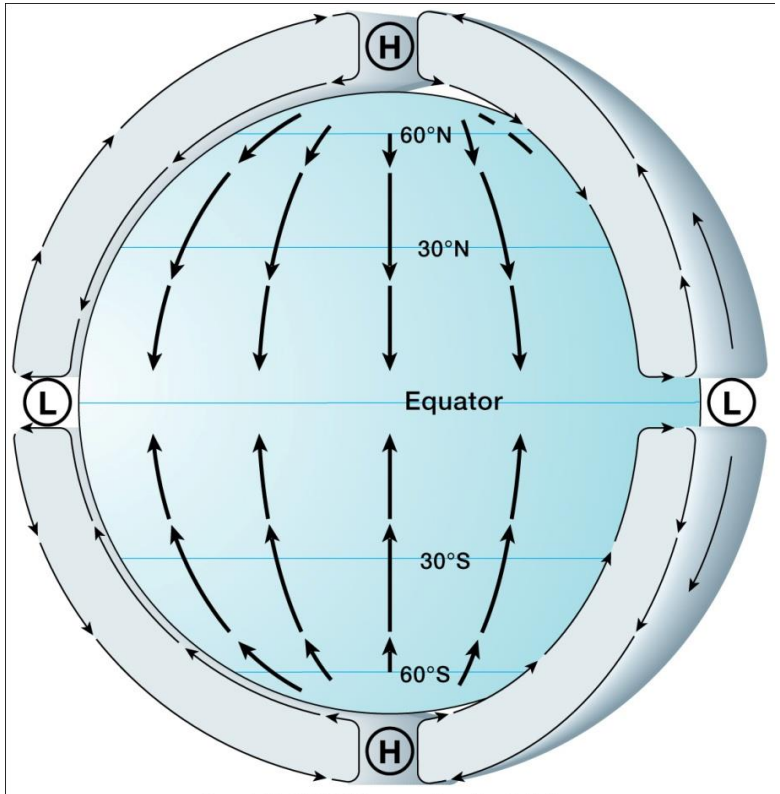
General Circulation of Atmosphere

June 23rd, 2021

Idealized Pattern: Uniform surface and No Earth rotation

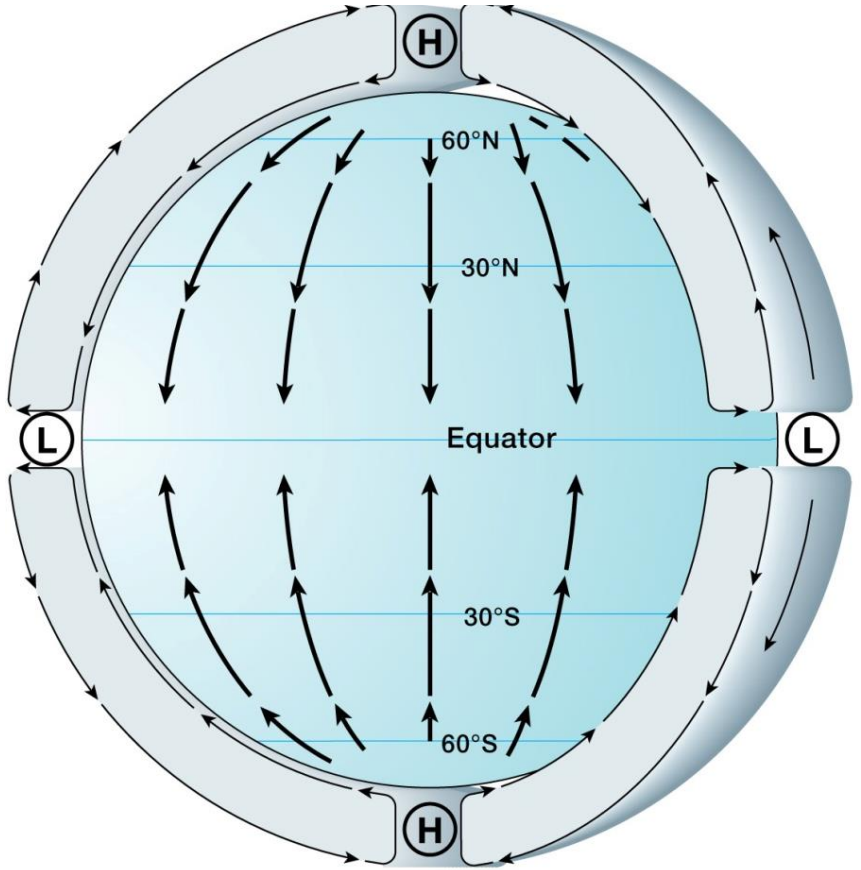
•Circulation of the atmosphere is the principal mechanism for both longitudinal and latitudinal heat transfer – **exceeded only by the global pattern of insolation – in determining world climates.**
•If the Earth had **no rotation and was a smooth sphere** with a uniform surface, we would have a simple circulation pattern.
•The greater heating in the equatorial region would produce low pressure around the world, and cooling at the poles would produce a cap of high pressure in those areas.



Idealized Pattern: Uniform surface and No Earth rotation

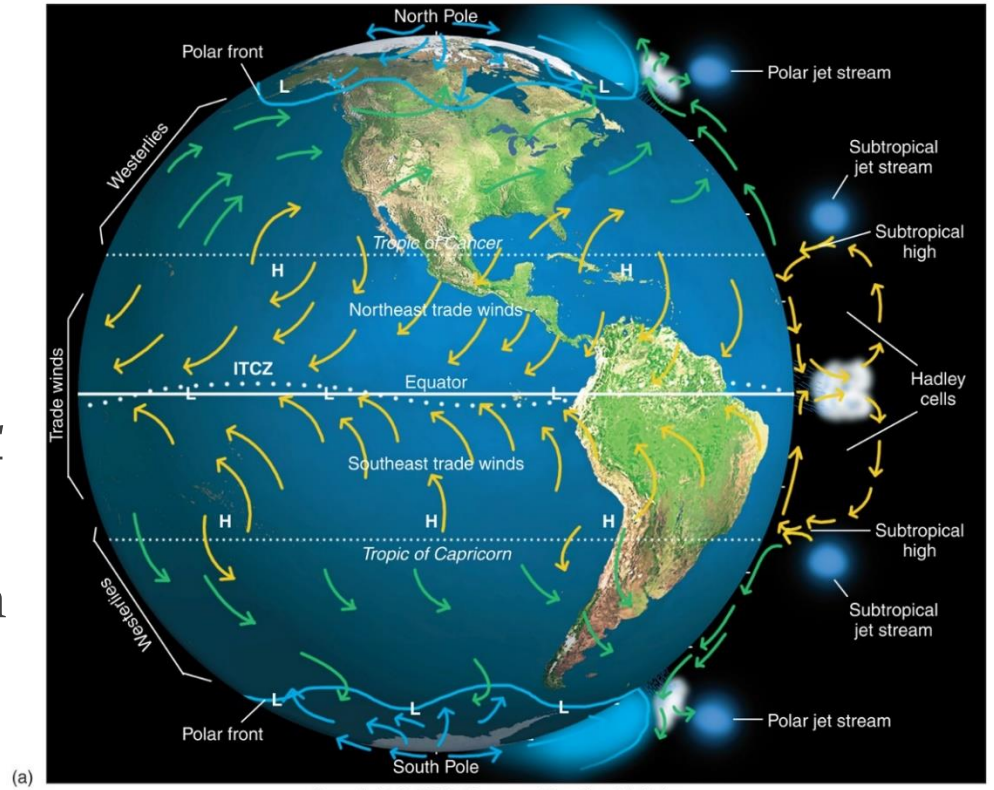
•Surface winds in the Northern Hemisphere would flow directly down the pressure gradient from north to south, whereas those in the Southern Hemisphere would follow a similar gradient from south to north.

•Air would rise at the equator in a large convection cell and flow toward the poles (south to north in the Northern Hemisphere and north to South in the Southern Hemisphere), where it would subside into the polar highs.



But……

- The earth does rotate and has a extremely varied surface. As a result, broadscale circulation pattern of the atmosphere is very complex
- Apparently, only the tropical regions have a **complete vertical convective circulation cell** (similar cells have been postulated for the mid and high latitudes but they either do not exist or are weak and sporadically developed)
- The low-latitude cells – one north and one south of the equator – can be thought of as gigantic convective systems
- **These circulations are called Hadley cells (after George Hadley, 1685-1768)**



But……

- Around the world in equatorial latitudes, warm air rises, **producing a region of relative low pressure at the surface**. This air ascends reaching the upper troposphere at elevations of ***around 15 kilometers (50,000 feet)***, where it is cooled
- The air then spreads north and south and moves poleward, eventually descending at latitudes of about 30 degrees North and South, where it forms bands of high pressure at the surface
- One portion of the air diverging from these surface high-pressure zones flows towards the poles, while another portion flows back toward the equator – where the Northern and Southern Hemisphere components converge and the warm air rises again.
- **This is a simplification of the circulation patterns**, but is a good starting point for understanding general circulation of the atmosphere.

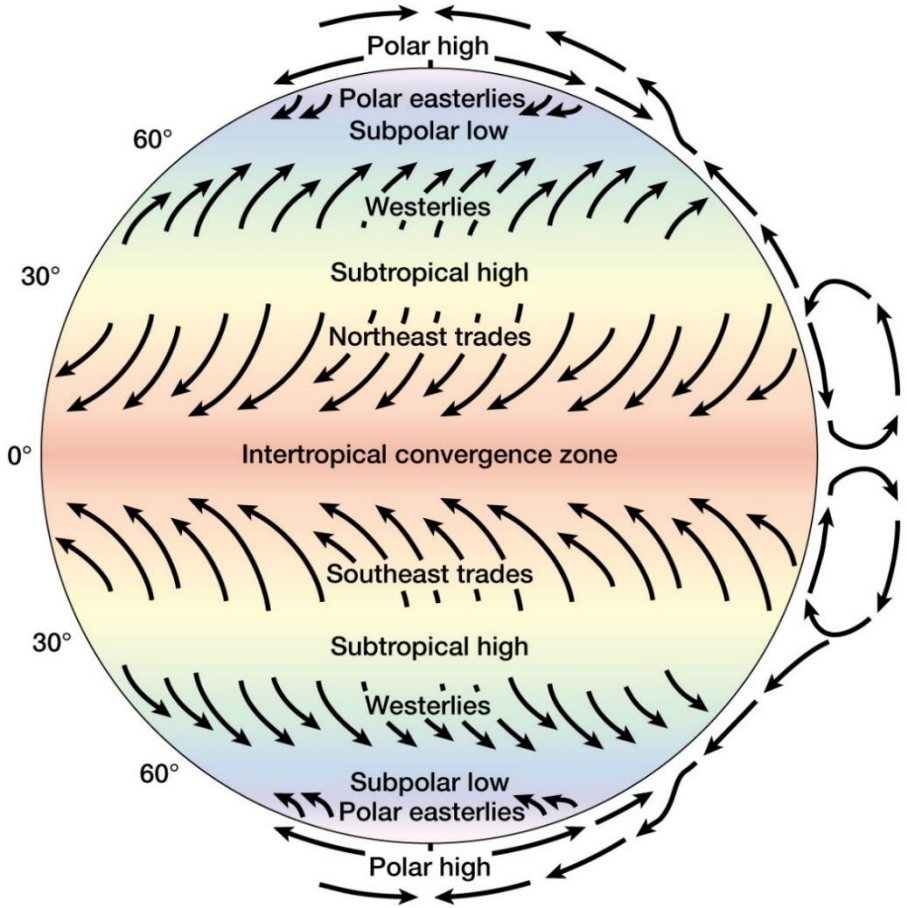
General Circulation of the Atmosphere

Circulation in the troposphere is essentially a closed system, with neither a beginning nor an end, so we can begin describing it anywhere.

There are seven surface components of pressure and wind, which are replicated north and south of the equator.

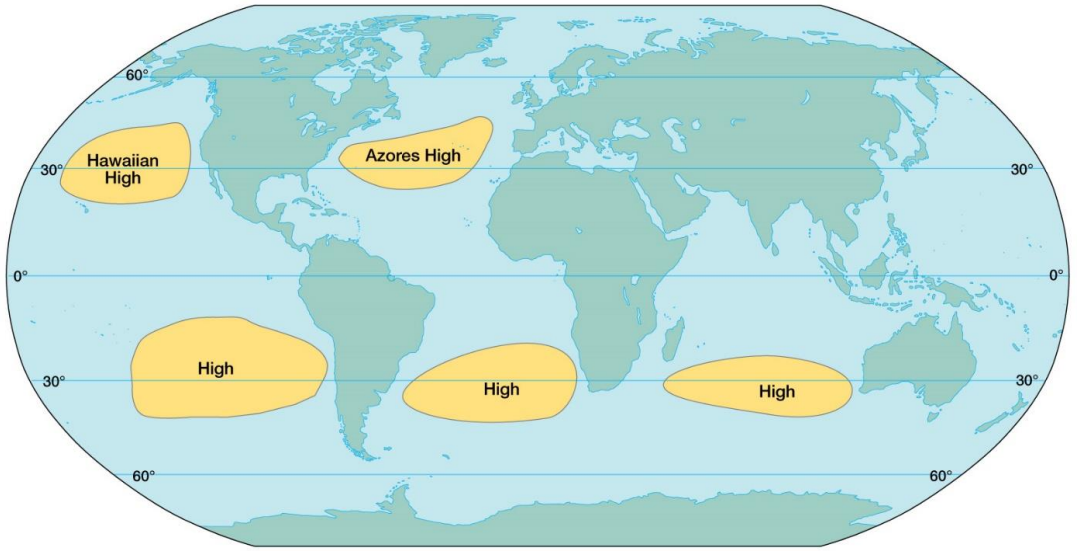
These are (from the equator to the poles):

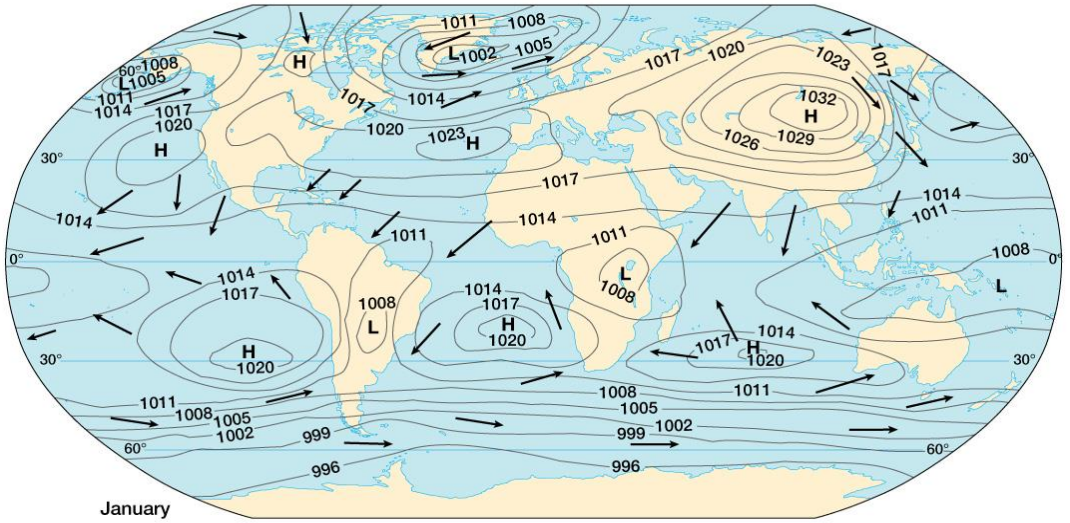
1. Intertropical convergence zone (ITCZ)
2. Trade winds (Wind)
3. Subtropical highs
4. Westerlies (Wind)
5. Polar front (Subpolar lows)
6. Polar easterlies (Wind)
7. Polar high

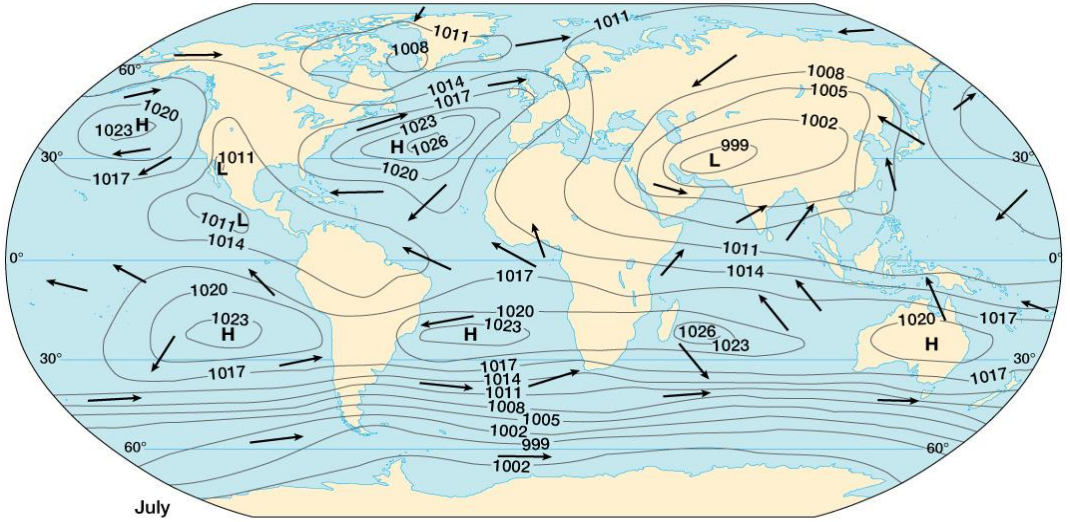


Sub-Tropical Highs

- **Subtropical highs— (STHs)** large semi permanent high-pressure (anticyclone) **cells centered at about 30° latitude over each ocean basin (just off the west coast of continents)**
- **They have average diameters of 3200 kilometers (2000 miles) and are usually elongated east–west.**
- They develop from the cool descending air of the **Hadley cells**.
- Their latitudinal positions vary from time to time, shifting a few degrees poleward in summer and a few degrees equatorward in winter.
- Subtropical latitudes serve as the source of the major surface winds of the planet.
- So permanent they have proper names.



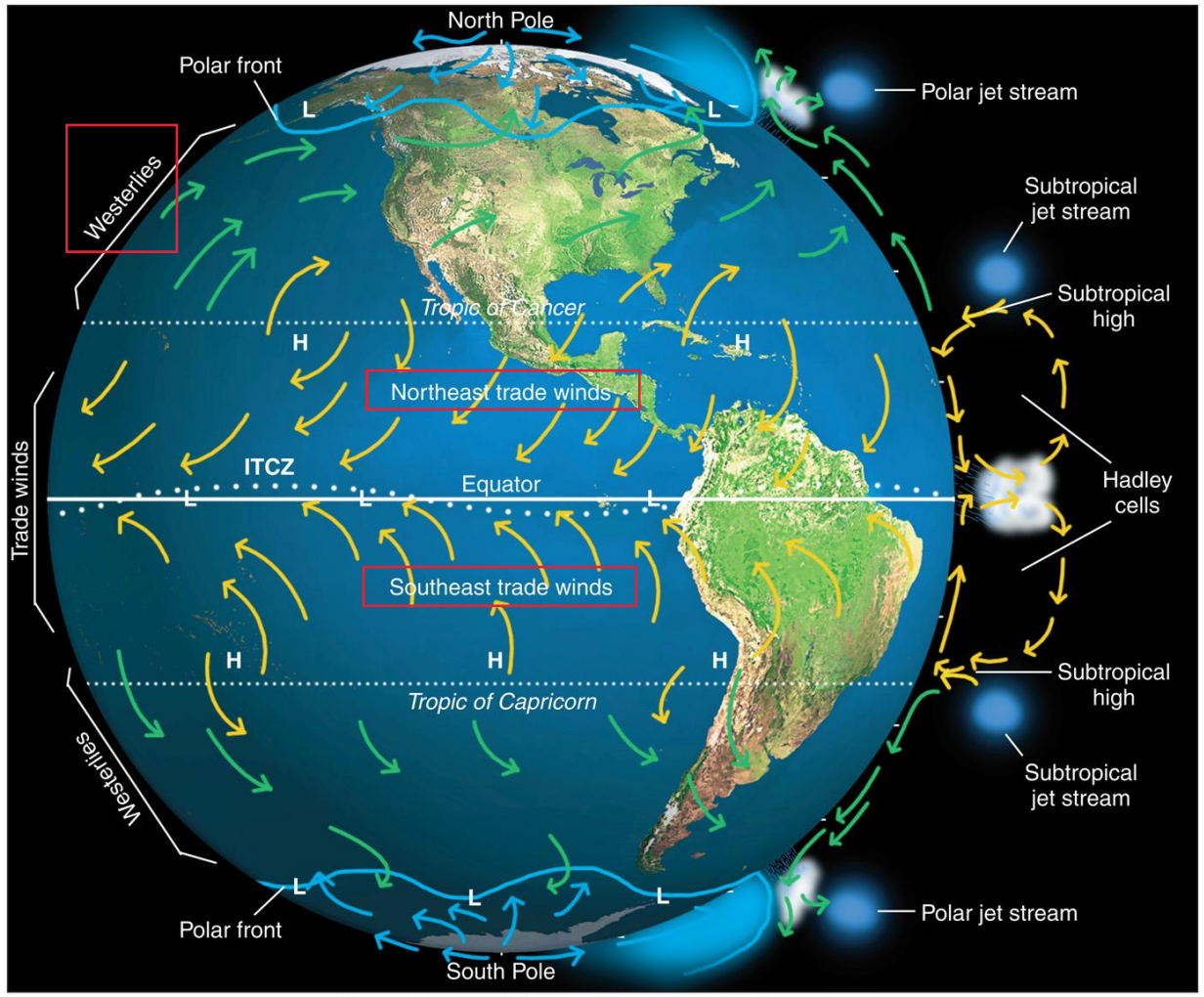




Sub-Tropical Highs

Sub-Tropical Highs

- **Weather is nearly always clear, warm and calm, tropical sunshine = no clouds.**
- In the center of the STH air is primarily subsiding; **horizontal air movement and divergence begin toward the edges == can be thought of as gigantic wind wheels.**
- **Horse latitudes—sixteenth - and seventeenth - century ships were becalmed and often offloaded their horse cargo to conserve on water because of the absence of wind.**
- **STHs also coincide with most of the world's major deserts.**
- STHs serve as source for two of the world's three major surface systems: **Trade winds and Westerlies.**



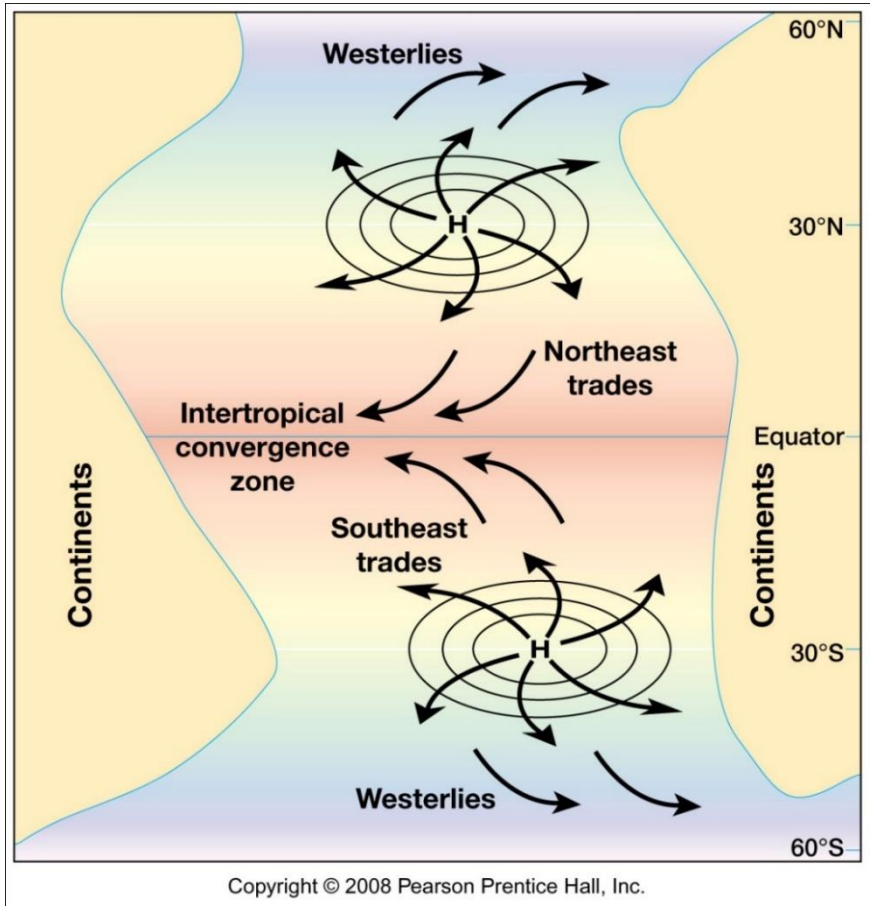
(a)

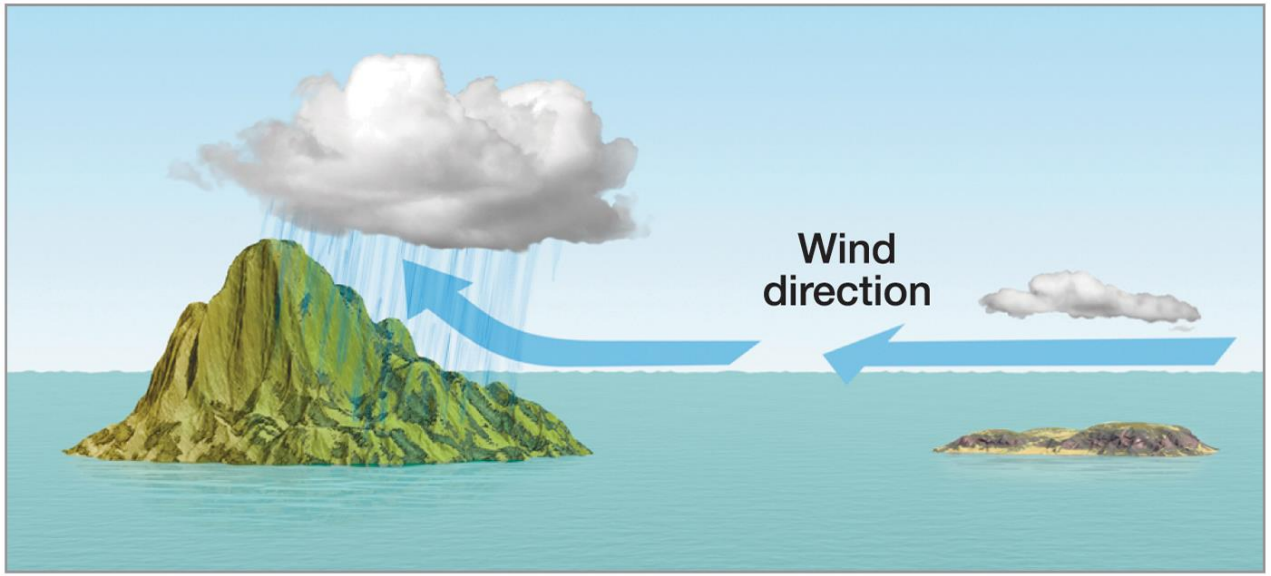
Trade Winds

- Trade winds—the major wind system of the tropics, issuing from the equatorward sides of the subtropical highs and diverging toward the west and toward the equator.
  - Covers most of the Earth between 25°N and 25°S
  - Most reliable of all winds, being extremely consistent in both direction and speed
  - Prominent over oceans, but disrupted or modified over landmasses
- Winds are named for the direction from which they blow
  - Trade winds' origin depends on which hemisphere they are in.
  - In Northern Hemisphere, originate in northeast, so are sometimes called *northeast trades*.
  - In Southern Hemisphere, originate in southeast, so are sometimes called *southeast trades*.
  - These blow from east to west and are called easterlies.

Trade Winds

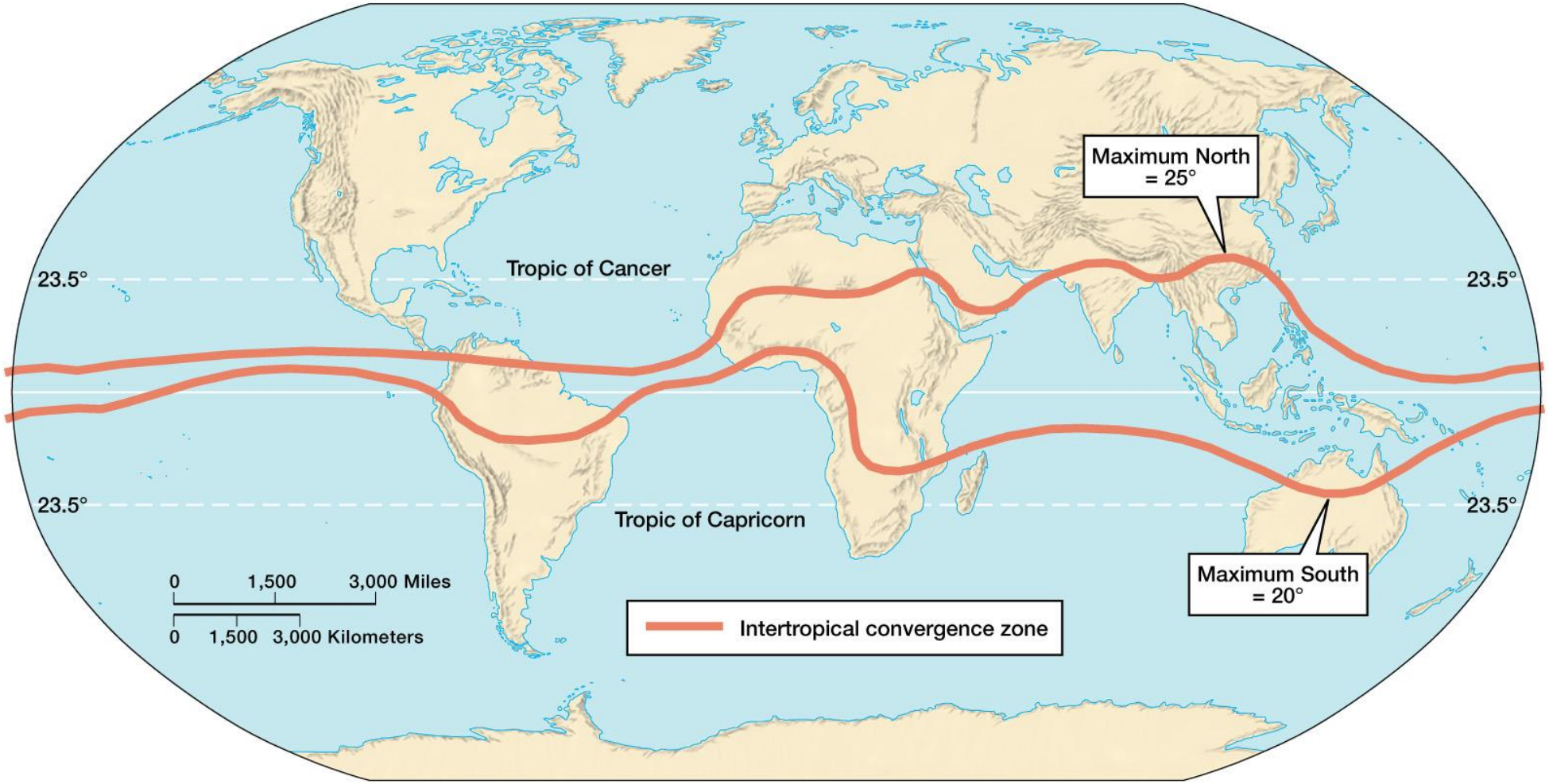
- Winds of commerce – sixteenth century mariners noted the reliability of these winds for sailing from Europe to the North Atlantic
- Warming, drying winds capable of holding enormous amounts of moisture.
- High evaporation from the ocean associated with these winds = high potential for storms and rain
  - Do not release moisture unless forced by a topographic barrier or pressure disturbance.
  - Passes over low-lying islands, which thus are desert islands.
  - Windward slopes in trade winds, as in Hawaii, are some of the wettest places on Earth.

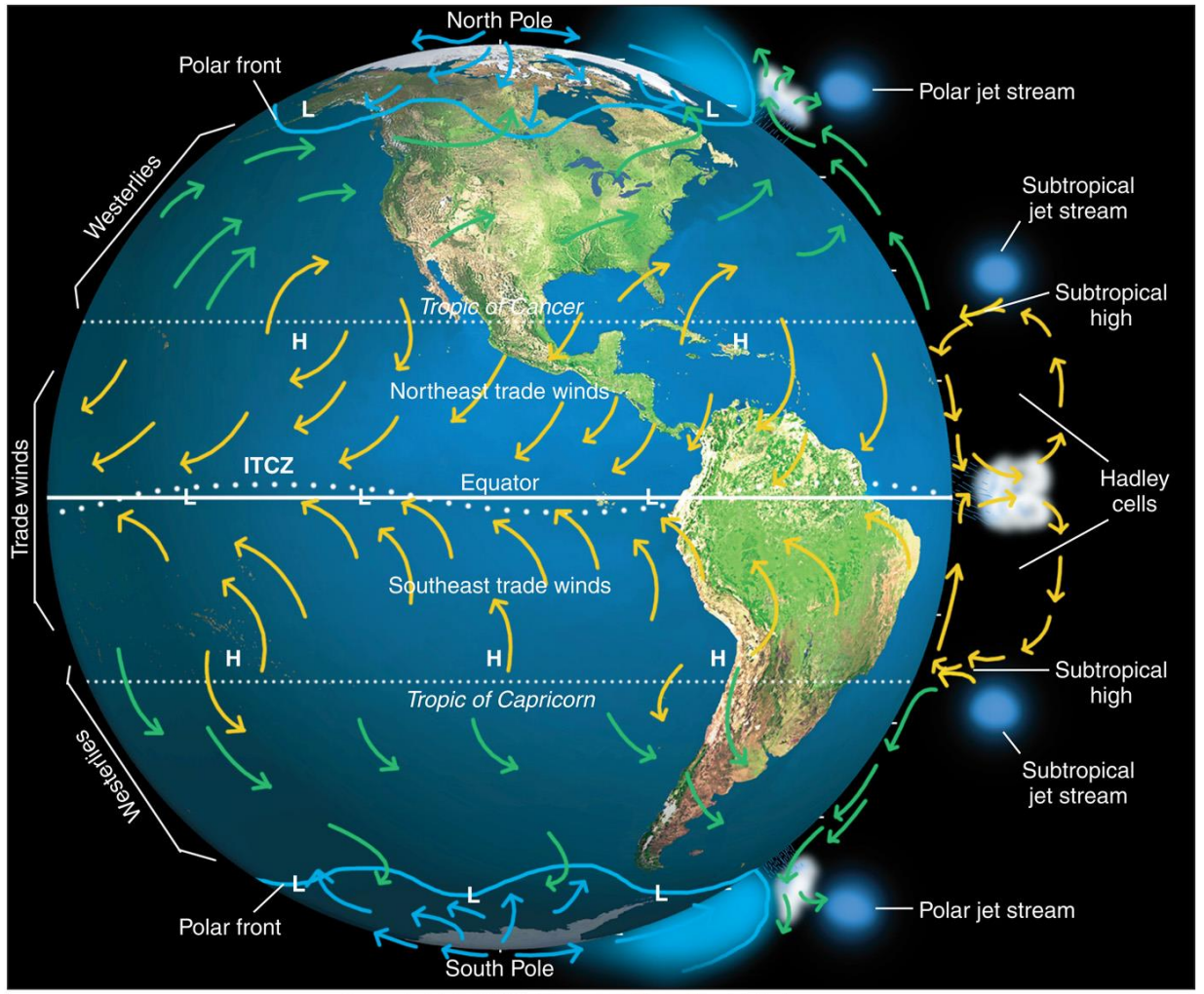



Wind
direction

Intertropical Convergence Zone (ITCZ)

- A belt of calm air where **northeast trades and southeast trades converge, generally in the vicinity of the equator**.
  - Latitudinal position shifts seasonally northward or southward following the Sun.
- Shift is **greater over land than water** because land heats up more. Often appears as a narrow band of clouds over the oceans, but it is less distinct over the continents.
- Also called the **doldrums** (sailing ships often becalmed in these latitudes), **equatorial front, intertropical front.**
- ITCZ is a area of convergence and weak horizontal airflow characterized **by feeble and erratic winds**
- It consists of warm surface conditions, **low pressure associated with high rainfall**, **atmospheric instability, and rising air in the Hadley cells.**
- Almost all rising air in the tropics comes from here during thunderstorms through latent heat of condensation in the upper troposphere, where much of it spreads polewards.
- **Thunderstorms are common**





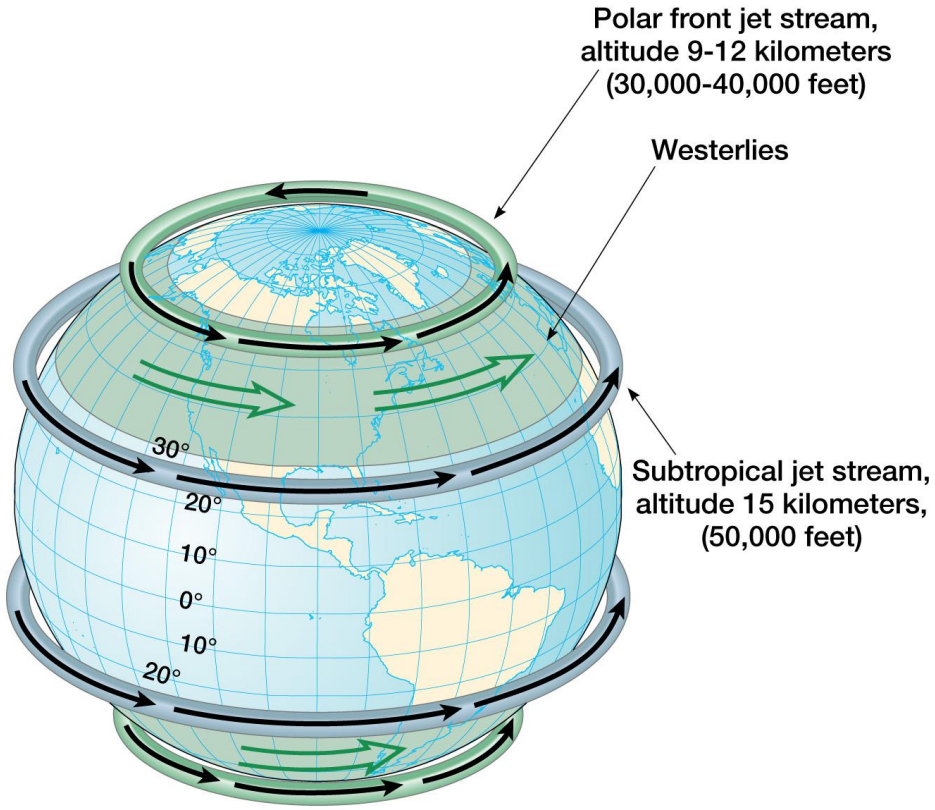
(a)

The Westerlies

- These are the winds **that blow from the STH polewards between latitude 30 degrees to 60 degrees (both north and south)**
- The Westerlies are less extensive than the trades, because the globe is smaller at these latitudes, nevertheless they cover much of the earth and are the great wind system of the midlatitudes.
- Near the surface, the **westerlies** are less constant than the trades, meaning they do not always flow from the west but may come from any point on the compass
  - Near the surface there are interruptions caused by friction, topographic barriers, and migratory pressure systems, which produce airflow that is not westerly.
- The belt of westerlies can be thought of as a meandering river of air moving generally from west to east around the world, with the jet streams as its fast-moving cores.

The Westerlies

- There are two 'cores' of high speed winds in each hemisphere ALOFT (upper atmosphere) called ***Jet Streams.***
  - *Polar Front Jet Stream –simply polar jet stream*
  - *Subtropical Jet Stream - are also **Rossby Waves***

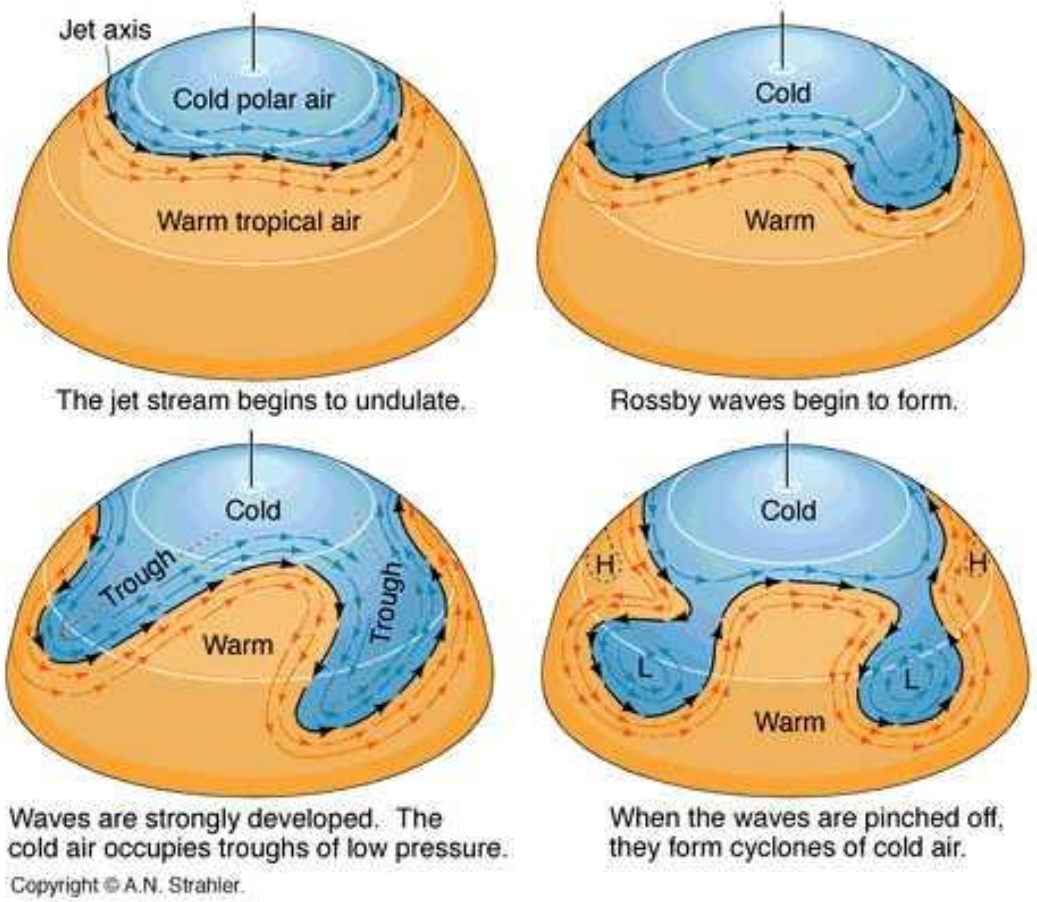


Jet Streams

- **Polar front jet stream: 9 -12 km high (30-40 thousand feet) is not centered on the band of the westerlies but displaced polewards**;
- **Subtropical front jet stream: 15 kilometers high (50,000 feet) is more in the subtropics**.
- **Note:** commercial aircrafts tend to fly at these altitudes, therefore encountering the Jet Streams. As a result it generally takes longer to fly **east to west** across North America that is does to fly west to east.
- Travelling from the east takes you into a headwind which impedes progress, traveling west gives you a tailwind aiding progress.

Rossby Waves

- **Rossby Waves**: the underlying direction is west to east, but when polar jet streams shift latitude and undulations produce **a meandering jet stream path that wanders widely north to south**.
- These curves are very large and are called Rossby waves.



Polar Highs

Situated over both polar regions – high pressure cells – polar highs.

The Antarctica high, forms over an extensive, high elevation, very cold continent – very strong, persistent, and almost permanent above the continent.

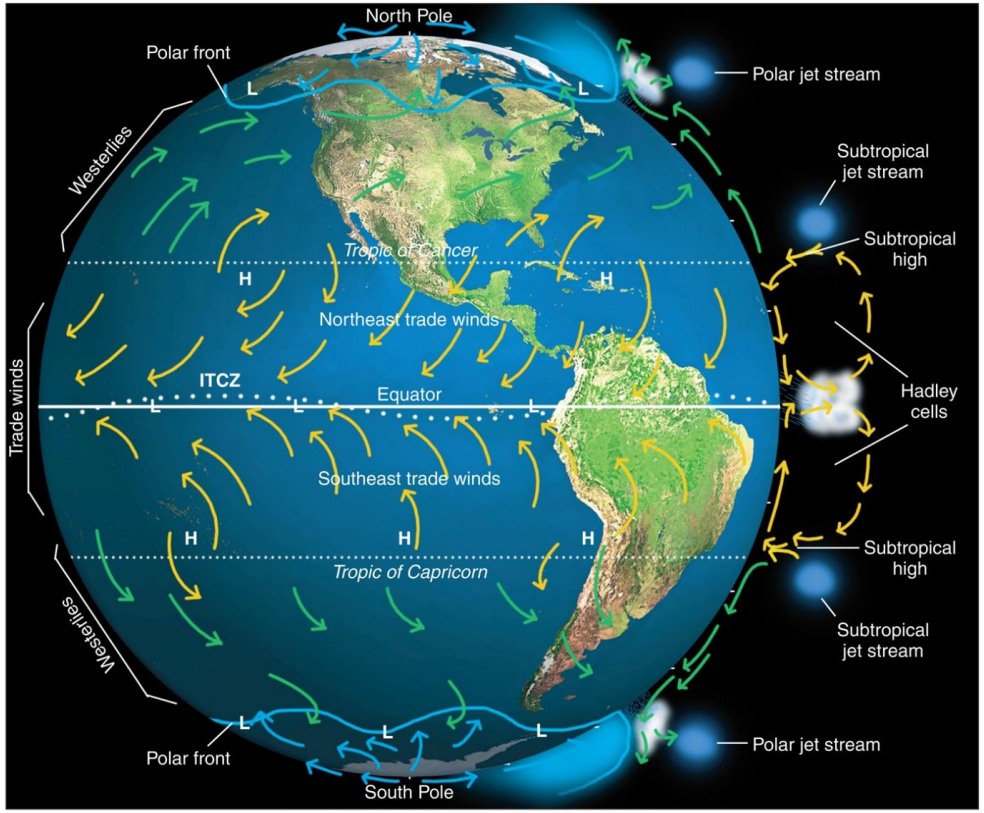
Arctic high is less pronounced and more transitory, especially in winter – tends to form over the continental areas rather than the Arctic Ocean.

There are typically anticyclone air systems.

Air from above sinks down into the high and diverges horizontally near the surface, clockwise in the North and counterclockwise in the South, forming the third of the world's wind systems, the **Polar Easterlies.**

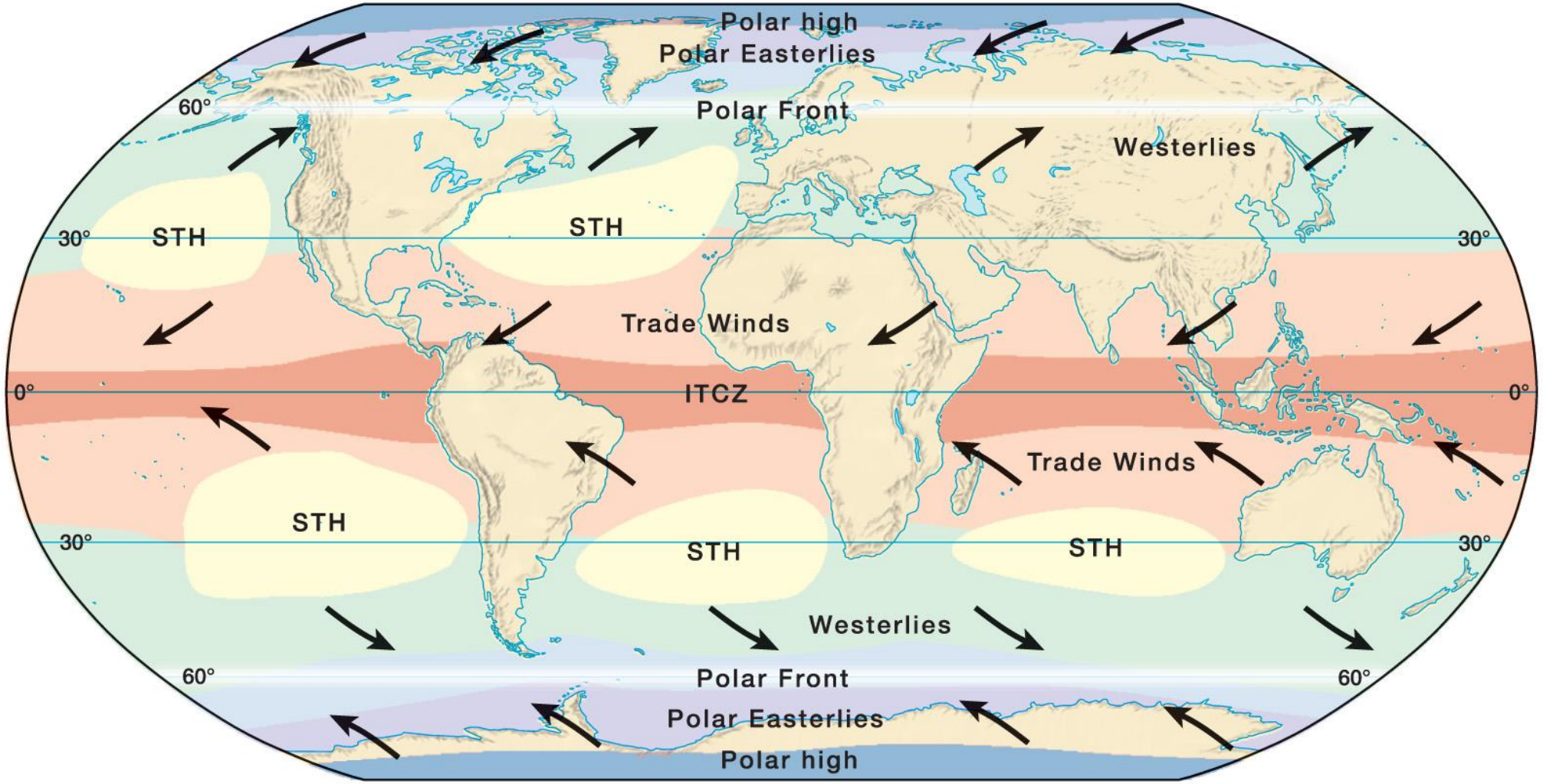
Polar Easterlies

- The third broad-scale global wind system.
- Occupies most of the area between the polar highs and about 60° latitude.
- The winds move generally from east to west and are typically cold and dry.



Polar Fronts

- **Front**—a zone of discontinuity between unlike air masses.
- Polar Front: **semi-permanent zone of low pressure** at about **50° to 60° latitude** North and South Hemisphere -- *subpolar lows*.
- The polar front is the meeting ground and zone of conflict between the cold winds of the polar easterlies and relatively warmer **westerlies**.
- These are almost continuous over the uniform ocean surface of the cold seas over Antarctica. Tend to be less continuous in the Northern hemisphere being interrupted by land masses.
- Much more prominent in winter than summer over the Pacific and Atlantic forming the ***Aleutian low*** and ***Icelandic Low*** respectively.
- **Polar front areas:** rising air, widespread cloudiness, precipitation, unsettled and stormy weather conditions.



Summary

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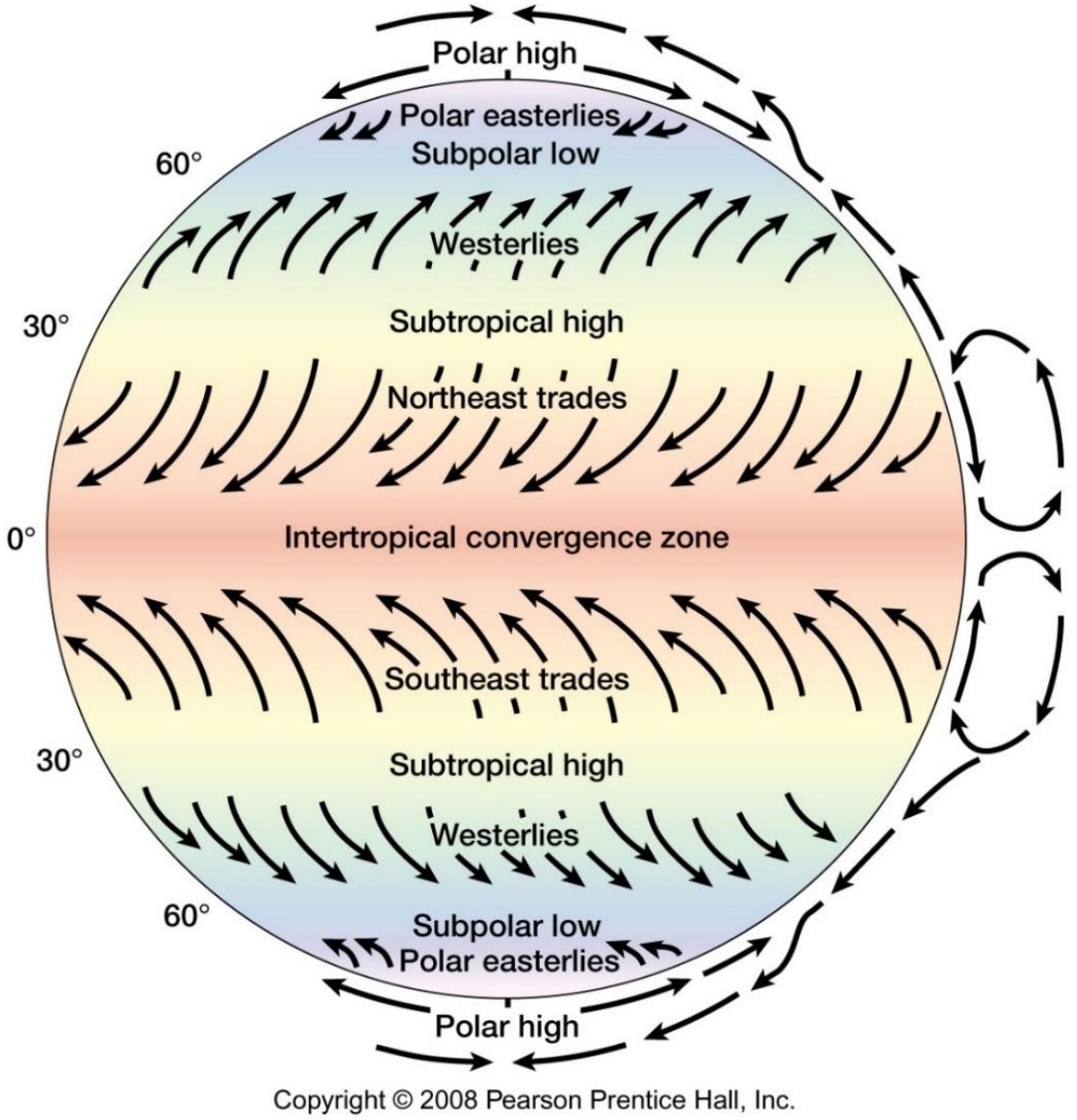
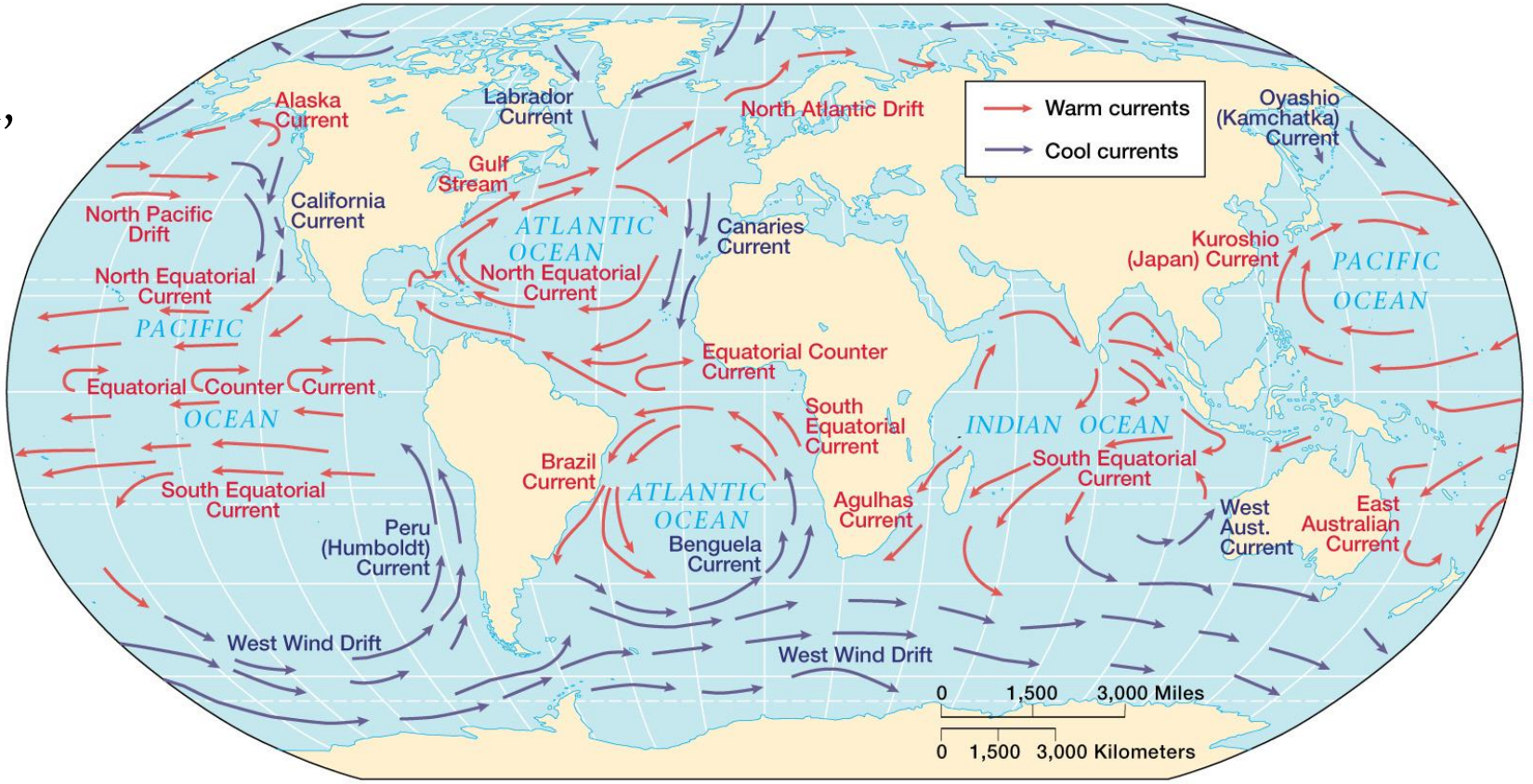


Atmosphere-Ocean Interactions

The Oceans

All Earth's five ocean basins are interconnected, but it is easier to think of them as separate entities:
North Pacific
South Pacific
North Atlantic
South Atlantic
South Indian



The Basic Pattern

Ocean Currents

- Surface Currents
- Deep Currents

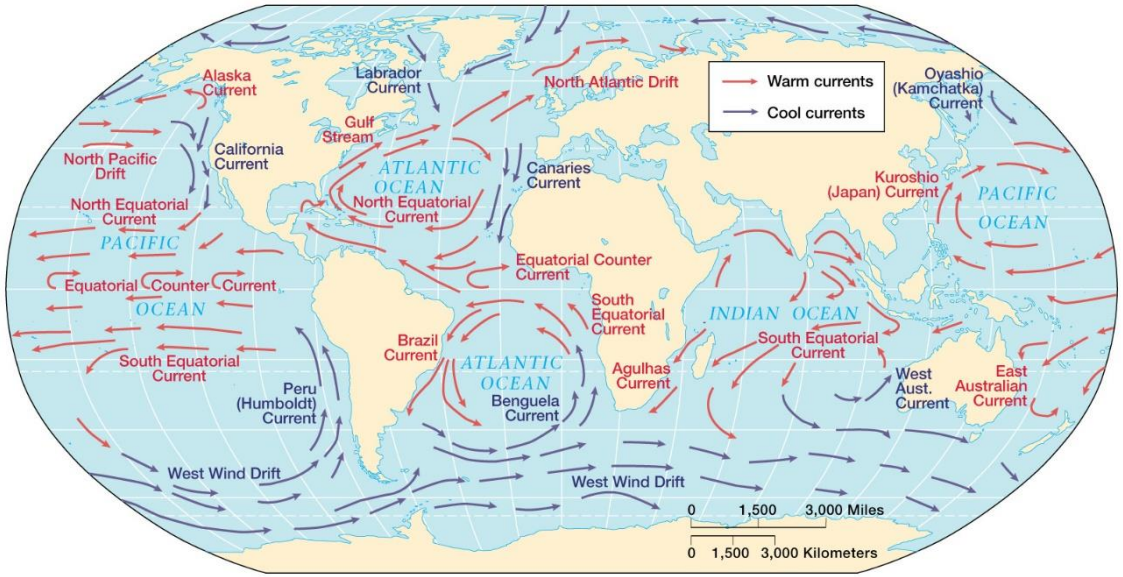
All the basins have a single simple pattern of surface currents:

- A series of enormous elliptical loops elongated east-west and centered approximately at 30° latitude (except in the Indian Ocean, where it is centered closer to the equator)
- The loops, called **subtropical gyres**, flow **clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere**
- Basically, warm tropical water flows poleward along the western edges of each ocean basin, and cool high-latitude water flows equatorward along the eastern margin of each basin

Surface Currents: Ocean Gyres

Near the western margin of each ocean basin, the general current curves poleward; as the currents approach the poleward margins of the ocean basin they curve east; as they reach the eastern edges they curve back toward the equator, producing an incompletely closed loop for each basin.

Note that these patterns ensure that the **west** coasts of continents tend to have cold currents offshore; whereas **east** coasts have warm currents (**hence people swim at the Jersey shore, but not on the beaches of the Pacific Northwest**).

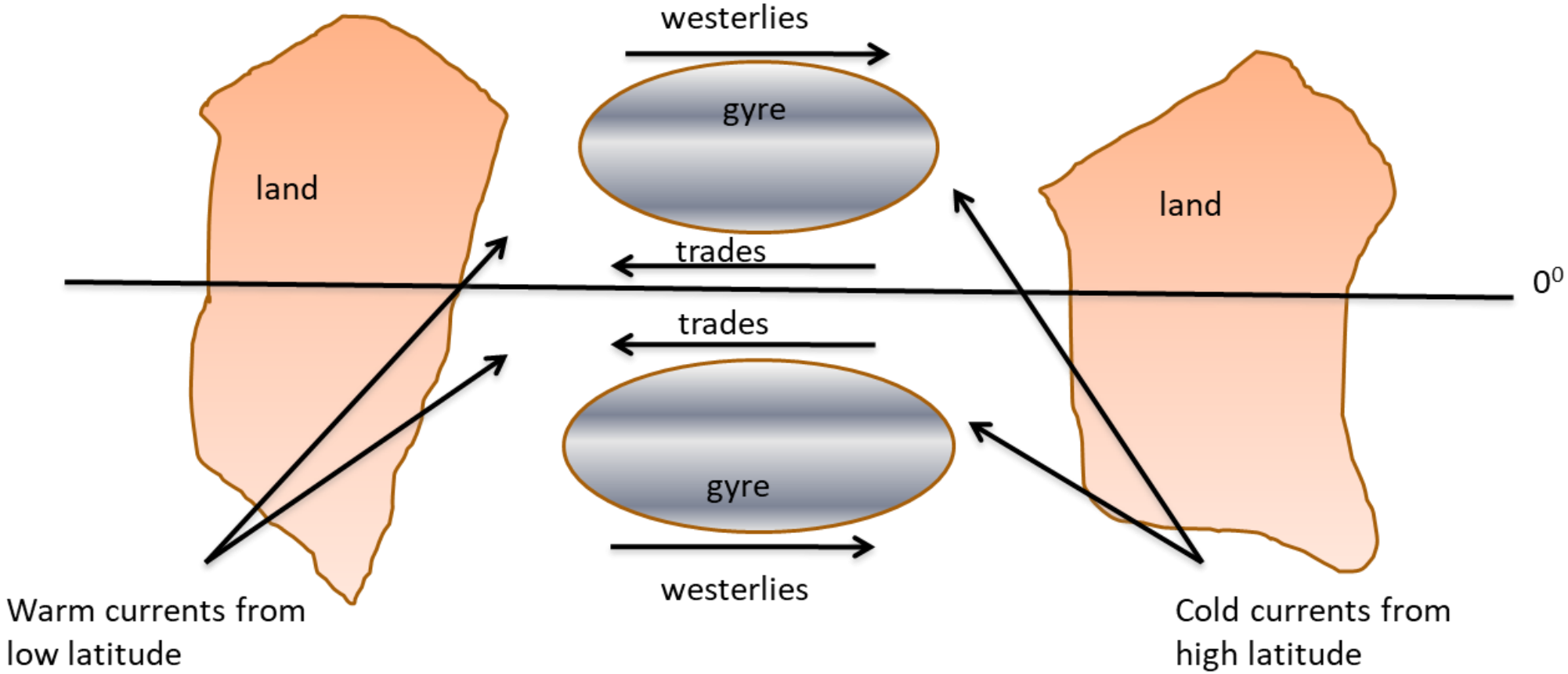


Surface Currents: Ocean Gyres

Within each ocean basin (actually, within each hemisphere in each ocean basin) the Easterly Trade Winds **cause a low-latitude current from east to west**, while the Midlatitude Westerlies **cause a Midlatitude current from west to east.**

This tends to create an overall spinning pattern within the basin (or again really two in each basin, one N of the equator, the other S).

These spinning patterns of currents are called "**ocean gyres**"

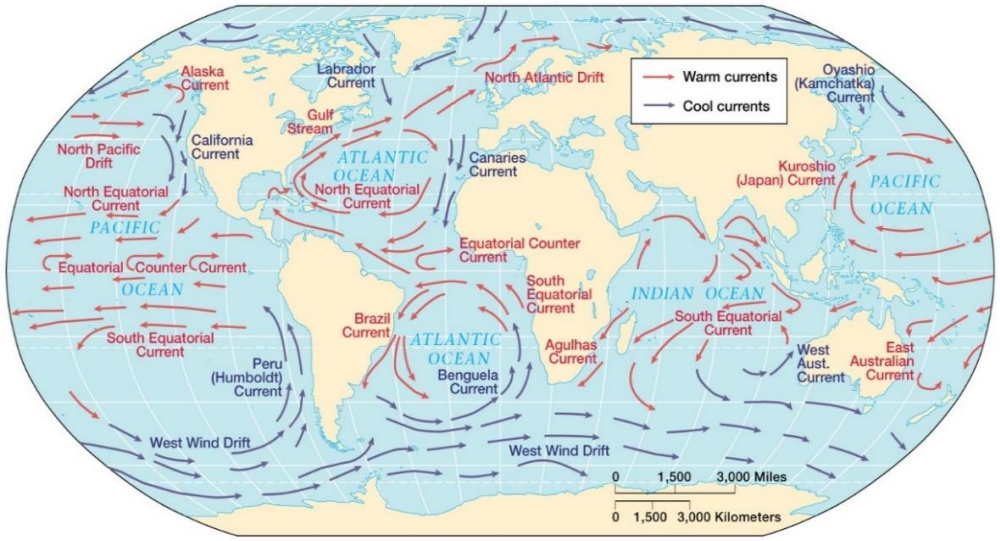

westerlies
gyre
land
land
trades
0⁰
trades
gyre
westerlies
Warm currents from low latitude
Cold currents from high latitude

Surface Currents: Ocean Gyres

On the equatorward side of each subtropical gyre is the **Equatorial Current** which moves steadily towards the west. The two equatorial currents have an average position 5° to 10° north or south of the equator and are separated by the **Equatorial Countercurrent**, which is an **east-moving flow approximately along the equator in each ocean**.

The equatorial currents feed the Equatorial Countercurrent near its western margin in each basin.

Water from the Equatorial Countercurrent in turn **drifts poleward to feed the Equatorial Countercurrent near the eastern end of its path**.



Northern and Southern Variations

In two Northern Hemisphere Basins - North Pacific and North Atlantic – current flow is prevented from entering the Arctic Ocean because continents are close together

This effect is more pronounced in the Pacific than in the Atlantic

Flow is more limited in North Pacific because Asia and North America are very close together

In the Southern Hemisphere, distance between continents permits continuous flow around the world

- ***West Wind Drift***—circumpolar flow around latitude 60° S.

Temperatures of the Currents

1. Low-latitude currents (Equatorial Current, Equatorial Countercurrent) have **warm water**
2. Poleward-moving currents on the western sides of ocean basins carry **warm water toward higher latitudes**
3. High-latitude currents in the Northern Hemisphere gyres **carry warm water toward the east**, and high-latitude currents associated with the Southern Hemisphere gyres (generally combined into the West Wind Drift) **carry cool water to the east**
4. Equatorward-moving currents on the eastern sides of ocean basins carry **cool water toward the equator**

Ocean Circulation

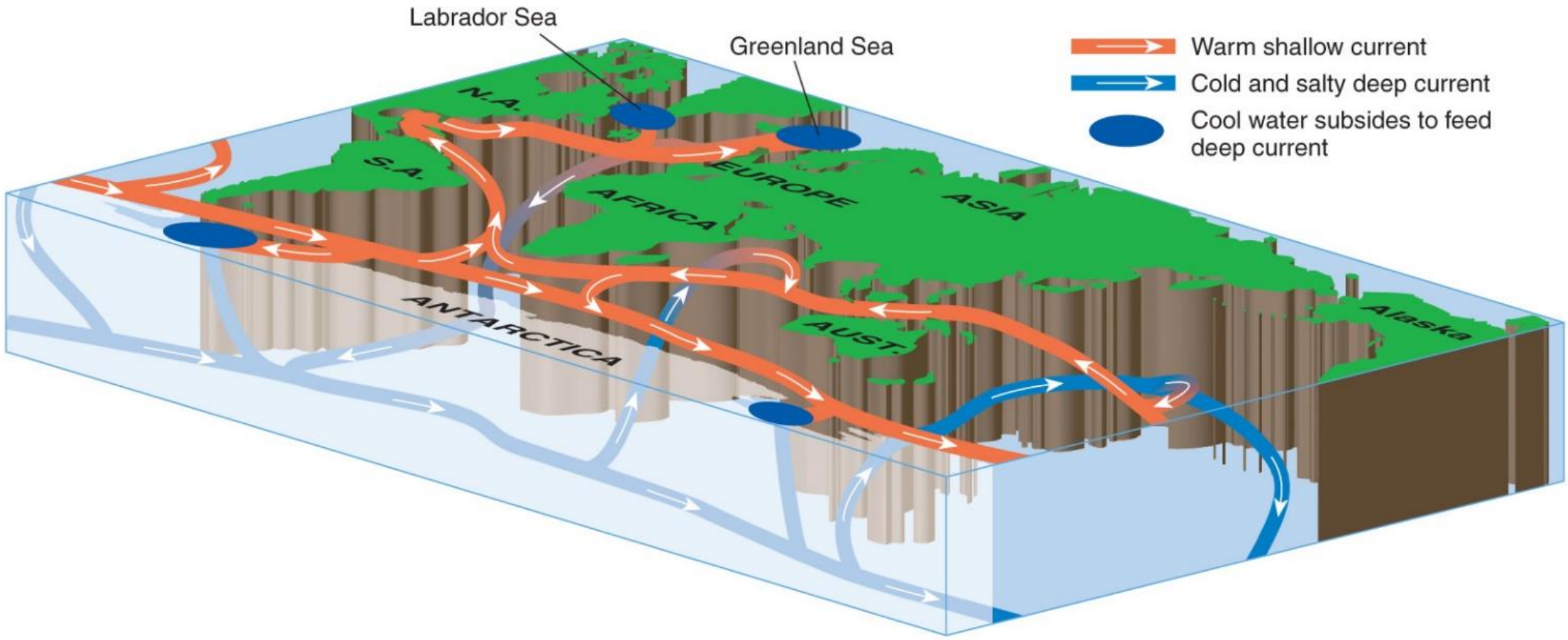
Surface currents – to 400m -- 10%

Deep Water – below 400 m – 90%

Deep Currents – Thermohaline Circulation Or *Global Conveyor Belt Circulation*

•The ocean's physical structure and profiles of **temperature, salinity, and dissolved gases** drive deep currents;

•Differences **in temperatures and salinity** produce density differences important to the flow of deep currents.

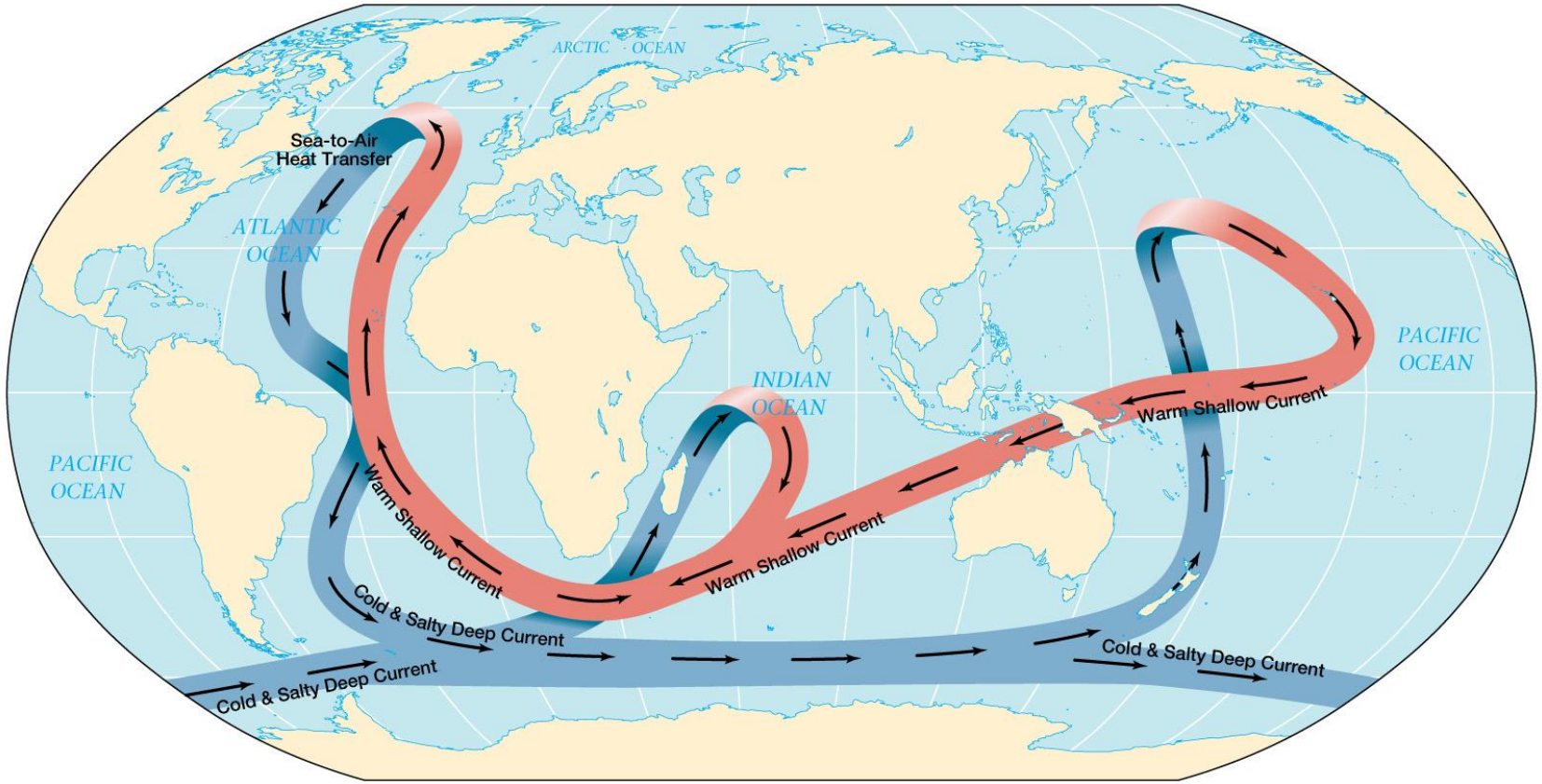


•This is Earth's Thermohaline circulation, and it is different from wind-driven surface current, the thermohaline circulation hauls larger volumes of water.

In the North Atlantic Ocean warm water sinks and moves to the south as a deep subsurface flow.

It joins cold deep water near Antarctica, eventually moving into the Indian and North Pacific Ocean where the water rises slowly, eventually flowing back into the North Atlantic where it again sinks.

One circuit may take many hundreds of years



Land and Sea Breezes

- Sea breeze = during the day
- Land breeze = night
- Name tells where these winds come from
- Land/water contrast:
- During day land warms faster than sea, therefore a pressure gradient – **high over sea, low over land**
- This reverses at night as land cools faster (radiate) – cool air flows offshore.