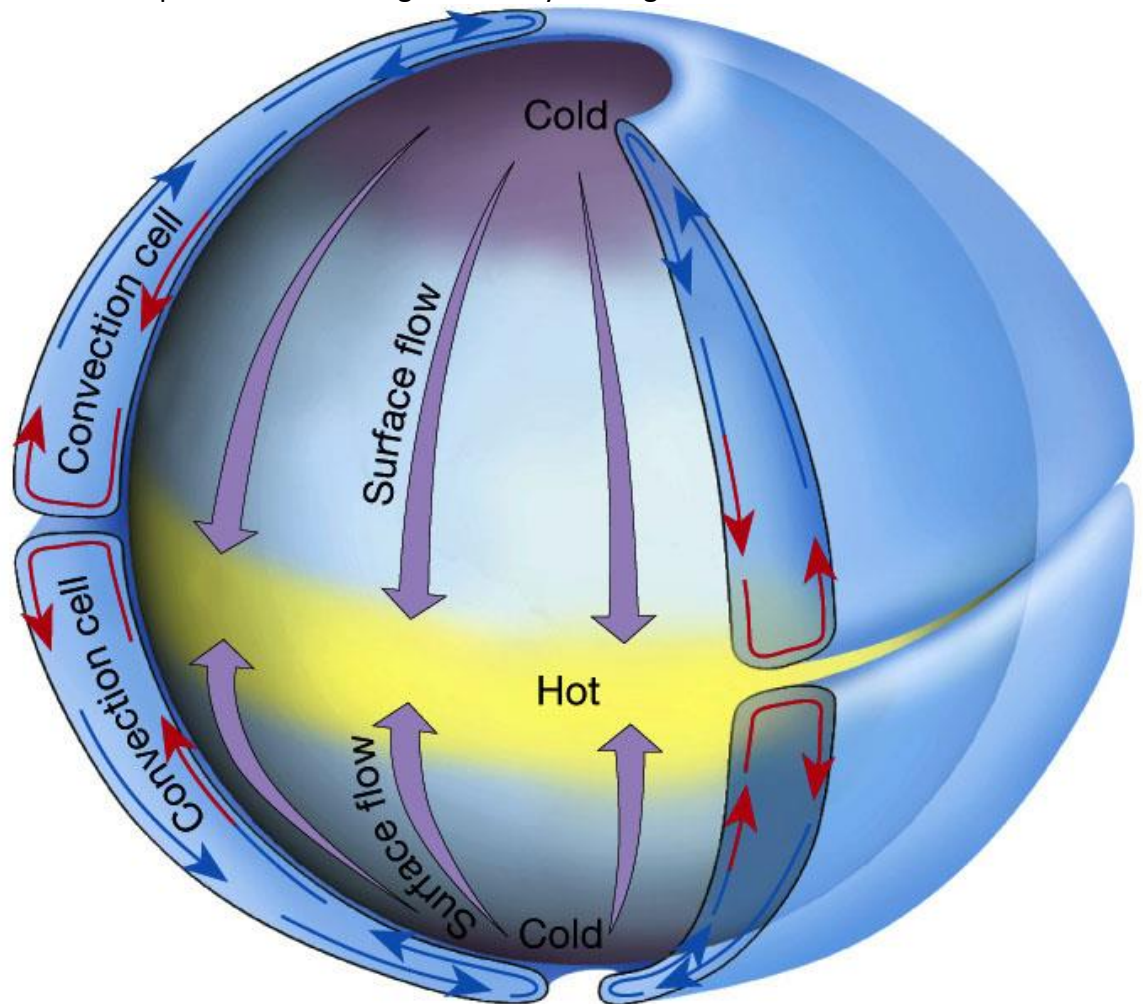


X. GLOBAL CIRCULATION:

A. One Cell Model:

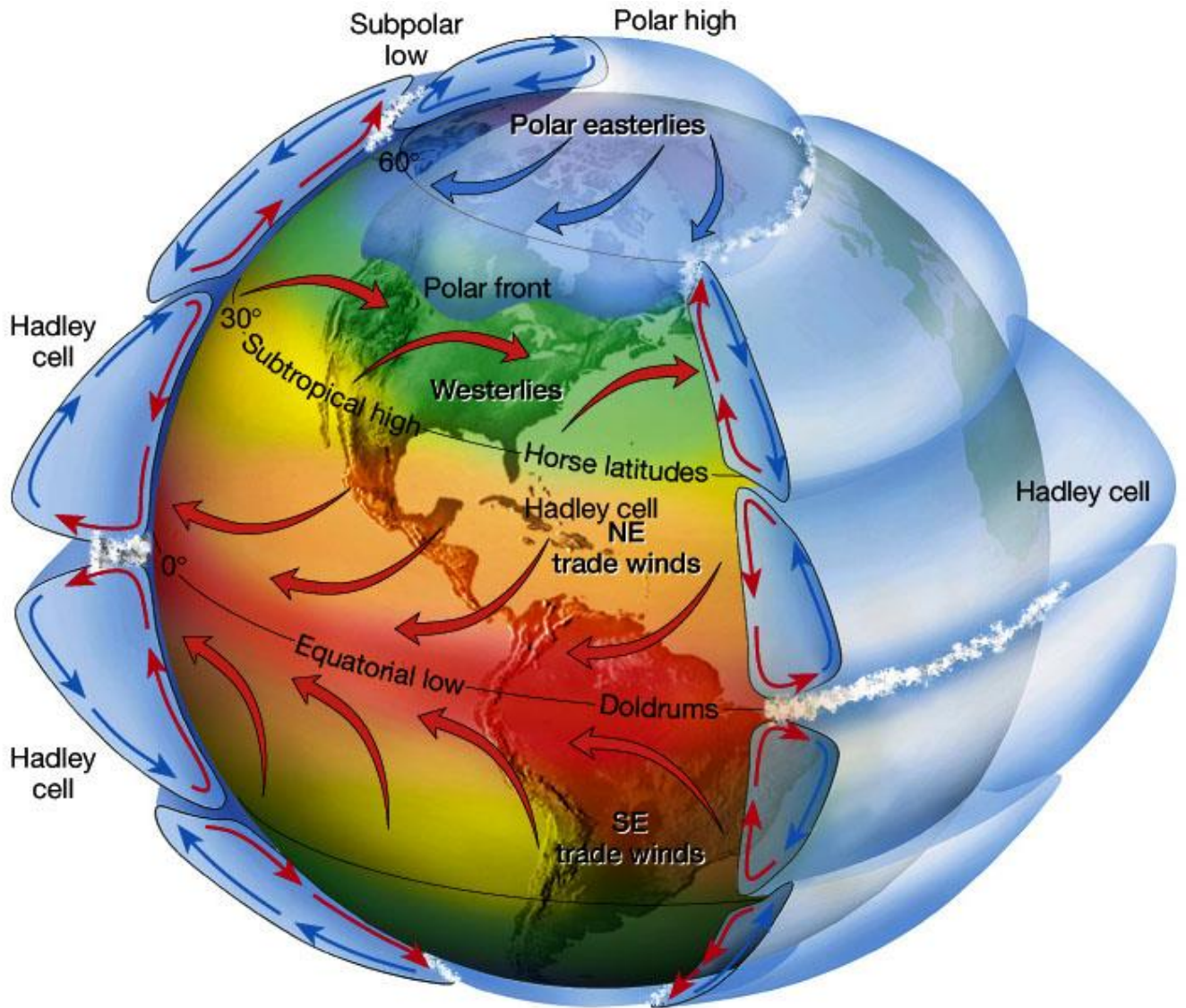
- 1) If the basic sea and land breeze ideas were applied to the entire hemisphere, we would have sinking air at the North Pole above surface high pressure and rising air at the equator above surface low pressure.
 - a. We call the result the 1-cell model.
 - b. It would represent 1 cell per hemisphere, which would also be thermally direct.
 - c. The cold air at the pole is sinking which helps increase its temperature through compression.
 - d. The warm equatorial air is rising and slowly cooling due to latent heat release.



B. Three Cell Model:

- 1) The Coriolis force breaks the single thermally direct cell into 3 cells.
- 2) From north to south, the 3 cells are called Polar, Ferrel, and Hadley.
- 3) Looking at the Ferrel cell, it's colder at 60 and 30 degrees north, but the cooler air is rising and the warmer air is sinking.
 - a. Expansion cooling and compression warming increase the horizontal temperature gradient in mid-latitudes, so this cell is thermally indirect.

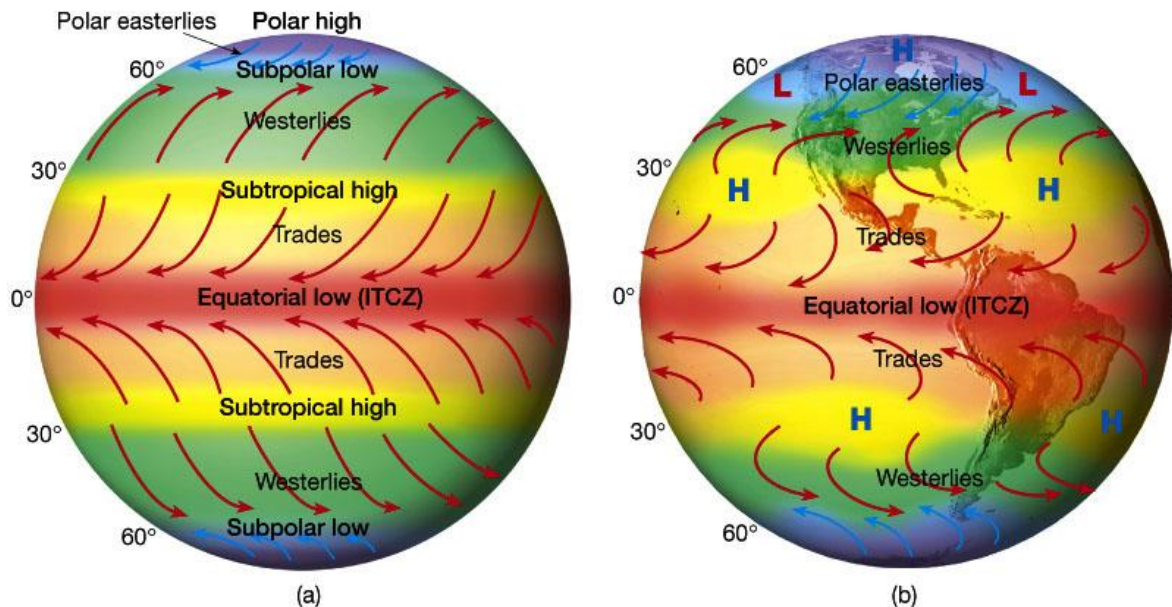
- b. The Ferrel cell is forced to operate as thermally indirect by the Polar and Hadley cells.



- c. The Ferrel cell is like the middle gear in a set of 3 interlocking gears.
 d. It's forced to go into the opposite direction of the other 2.
- 4) The 3-cell model predicts surface lows at 60° north and the equator and surface highs at the pole and 30° north.
- Rising moist air saturates, so we expect storm and precipitation at 60° north, as well as the equator.
 - Sinking air is clear and potentially hot, so deserts would be expected there.
 - What, then, would the geostrophic winds be?
 - In the Northern Hemisphere, with the wind at our backs, lower pressure is to the left. Therefore, in mid-latitudes, the geostrophic wind is

westerly. And we call these winds the “prevailing **mid-latitude westerlies**”.

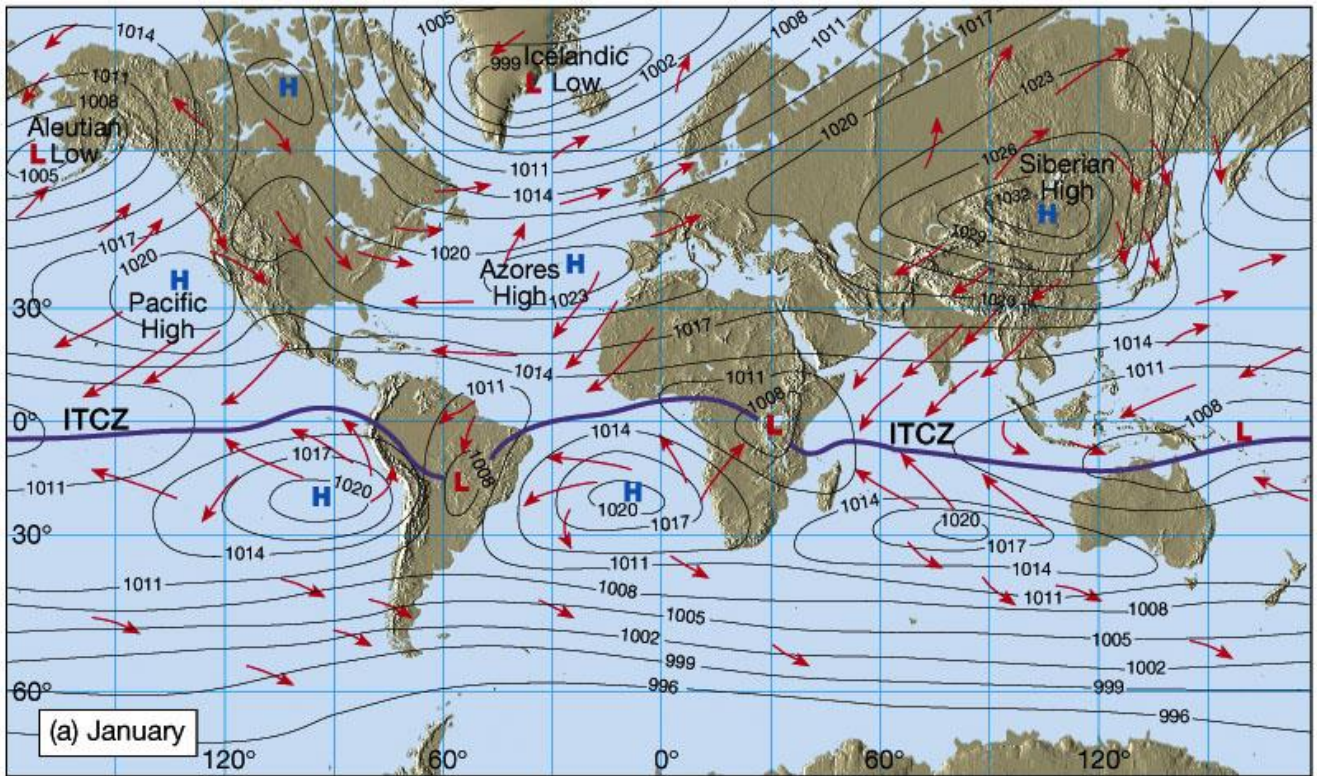
- ii) Closer to the pole, the wind are easterly, the polar easterlies.
 - iii) These are geostrophic winds, neglecting friction. And friction would allow these winds to turn a little bit towards lower pressure.
- 5) Recall that the Coriolis force vanishes at the equator; thus, the wind there cannot be in geostrophic balance.
- a. With the weaker Coriolis force near the equator, we get southeast trade winds between the equator and 30° south, also with a component directed toward the equator.
 - b. As a result, there is a convergence of surface air at the equator from both hemispheres.
 - c. This force is sustained rising motion at the **inter-tropical convergence zone (ITCZ)**, a ring of deep convective storms where Northern and Southern air meets.
 - i) The ITCZ is not a continuous band of storms, and it isn't usually located exactly on the equator either.
 - ii) Its precise location actually varies with the seasons.
 - d. We have westerly winds in mid-latitudes and easterly near the poles in both hemisphere.
 - e. The only difference is in the tropics, where air is pushed toward the equator from both sides.



C. So let's quickly recap our Northern Hemisphere surface winds.

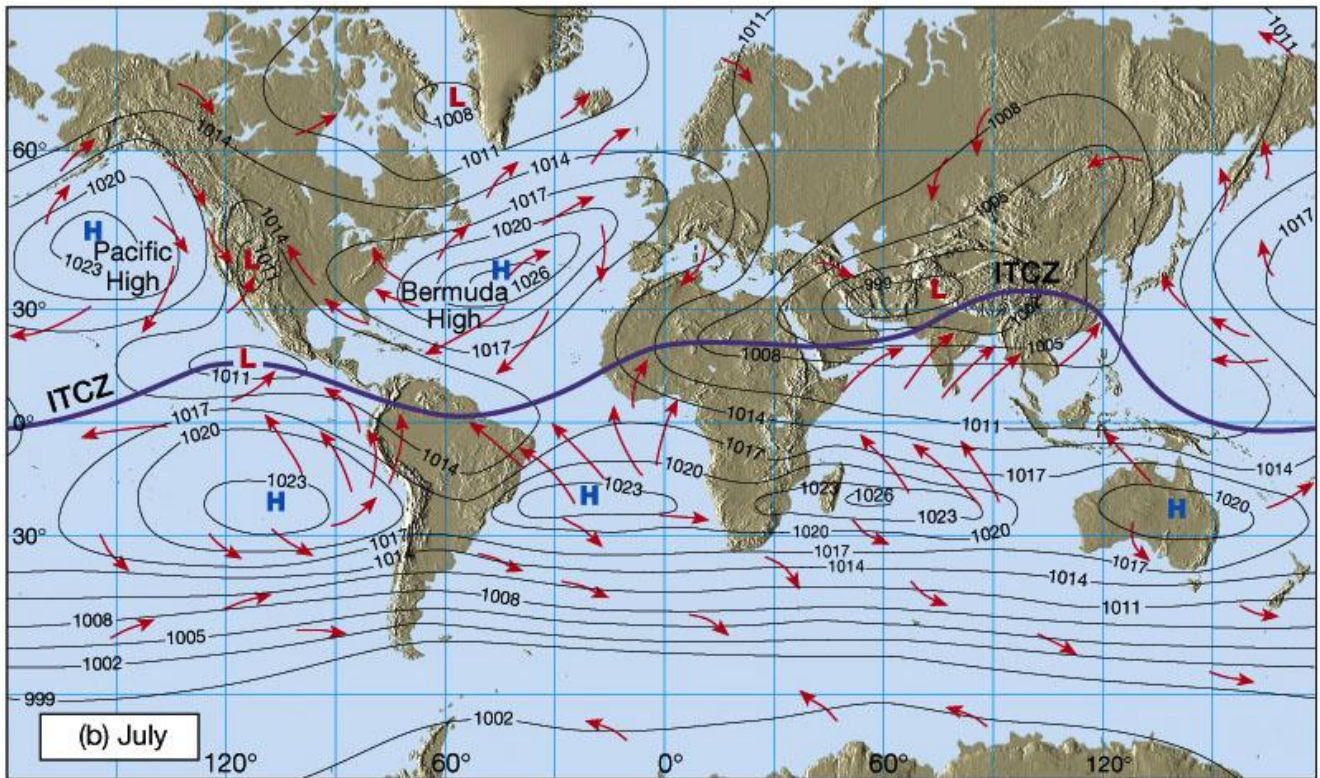
- 1) We have westerly winds between 30° and 60° north, easterlies closer to the pole, north-easterlies in the tropics.

- 2) This is a very idealized model, presuming no complications from land surfaces and topography, and we might wonder how well does this hold up in reality, so let's check it out.
- D. How well does this model hold up in reality?
- 1) We expect to see low sea level pressure at the equator and at 60° north and south.
 - a. This shows up well in the Southern Hemisphere, where there's a lot less land to complicate the picture, especially at 60° south, which lies over the Southern Ocean, ringing the Antarctic continent.
 - 2) We expect to see high pressure at 30° north and south and at the poles.
 - a. Indeed, the pressure is higher at 30°, but the picture is also complicated by land/sea arrangements.
 - b. Over the eastern Pacific and Atlantic Oceans, these are our sub-tropical highs, which we'll be calling the "Pacific High" and the "Bermuda High."



- 3) In the Northern hemisphere winter, the low pressure areas at 60° north over the North Pacific and Atlantic oceans are prominent. These are our Aleutian and Icelandic lows.
 - a. These semi-permanent features of the winter season are the weath-makers, creating storms and sending them off into the mid-latitude westerlies on collision courses with the North American and European continents.

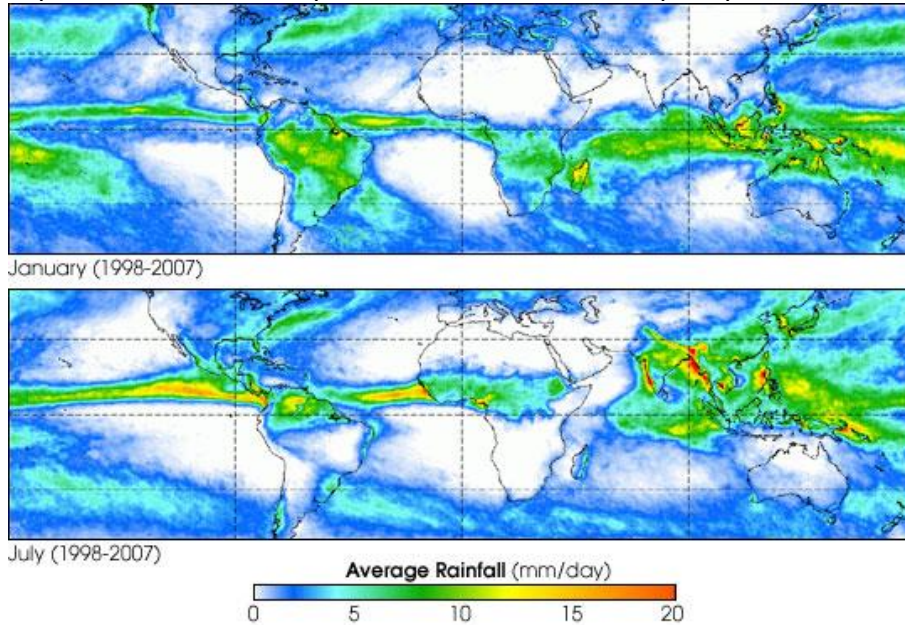
- b. The subtropical highs at 30° north are weaker, and the highest pressure is over the Asian interior, which is very cold.



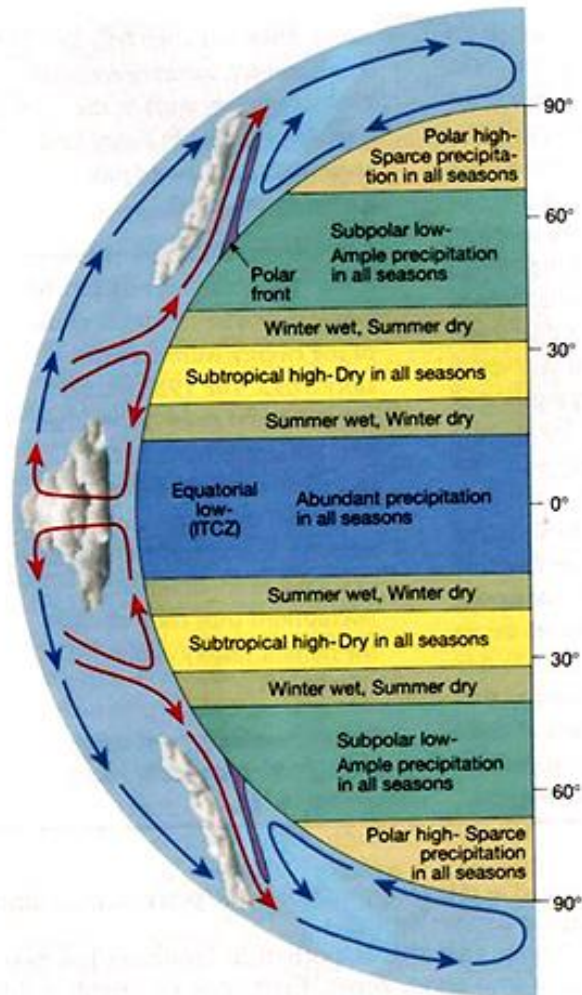
- 4) In the Northern Hemisphere summer, the Aleutian and Icelandic Lows are absent, and the subtropical Pacific and Bermuda Highs are dominant.
- Notice the lowest pressures are over the land areas.
 - This reflects warm season heating as in the land and the sea breeze circulation.
 - Let's zoom in on Southern Asia, where the sea level pressure is particularly low over a wide area.
 - We'll discover later that we're seeing an important element of the monsoon here.
 - Despite the complications of Coriolis, this deep low pressure over land is pulling extremely moist air from the Indian Ocean onshore, leading to terrific rains, especially when and where aided by topographic lifting.
- 5) In both models, we associate high pressure areas with descending motion, and on the 3 cell figure above, we see that air is sinking in the mid-troposphere, near both sub-tropical highs.
- The ascent seems shifted eastward, rather than in the apparent centers of these 2 highs.
- 6) At the equator, we see a globe-straddling band of ascent; this is the ITCZ.
- By adding surface vector winds, we confirm that the ITCZ represents the convergence of the Northern Hemisphere's northeast trades and the Southern Hemisphere's southeast trades.

- 7) In the United States, the Rocky Mountains create a barrier to surface mid-latitude westerlies.
 - a. We also see mid-tropospheric air descending, subsiding over Tornado Alley.
 - b. That's making the midlevel air over these states hotter and dryer.
 - c. Meanwhile, note the surface winds are bringing warm moist Gulf air far into the Great Plains, thanks to the Rockies blocking the winds from the west, and thanks to the clockwise motion around the Bermuda High.

E. Let's compare Northern Hemisphere summer and winter precipitation.



- a. We see winter storm tracks associated with the Aleutian and Icelandic Lows in the northern Pacific and Atlantic oceans.
- b. In the summer, rising motion over heated land helps create rain in central South America. Meanwhile, let's look over in Africa. The rain has followed the Sun south of the equator.
 - i) There is still an ITCZ in the equatorial north Pacific, but a southern branch is also now more apparent, and this is helping to stretch rainfall in the central South Pacific, an area that might otherwise be barren of precipitation if the simple 3-cell mode were strictly correct.



ii) Earth's sphericity has made a temperature difference that Earth's rotation preserves by preventing the ready flow of warm and cold air between places with different temperatures.

F. An air mass is a large body of air that forms over a particular region, acquiring particular characteristics: temperature, humidity, and so on.

- 1) Where air masses meet, we have fronts and convergence; not all convergence zones, however, are fronts.
- 2) There are 2 primary types of air masses, continental and maritime.
- 3) There are 2 primary source regions, polar and tropical.
- 4) The 4 air mass categories are combinations of these: continental polar (cP), continental tropical (cT), maritime (mP), and maritime tropical (mT).

Table 8-1 Weather characteristics of North American air masses

Air Mass	Source Region	Temperature and Moisture Characteristics in Source Region	Stability in Source Region	Associated Weather
cA	Arctic basin and Greenland ice cap	Bitterly cold and very dry in winter	Stable	Cold waves in winter
cP	Interior Canada and Alaska	Very cold and dry in winter	Stable entire year	a. Cold waves in winter b. Modified to cPk in winter over Great Lakes bringing "lake-effect" snow to leeward shores
mP	North Pacific	Mild (cool) and humid entire year	Unstable in winter Stable in summer	a. Low clouds and showers in winter b. Heavy orographic precipitation on windward side of western mountains in winter c. Low stratus and fog along coast in summer; modified to cP inland
mP	Northwestern Atlantic	Cold and humid in winter Cool and humid in summer	Unstable in winter Stable in summer	a. Occasional "nor'easter" in winter b. Occasional periods of clear, cool weather in summer
cT	Northern interior Mexico and southwestern U.S. (summer only)	Hot and dry	Unstable	a. Hot, dry, and cloudless, rarely influencing areas outside source region b. Occasional drought to southern Great Plains
mT	Gulf of Mexico, Caribbean Sea, western Atlantic	Warm and humid entire year	Unstable entire year	a. In winter it usually becomes mTw moving northward and brings occasional widespread precipitation or advection fog b. In summer, hot and humid conditions, frequent cumulus development and showers or thunderstorms
mT	Subtropical Pacific	Warm and humid entire year	Stable entire year	a. In winter it brings fog, drizzle, and occasional moderate precipitation to N.W. Mexico and S.W. United States b. In summer this air mass occasionally reaches the western United States and is a source of moisture for infrequent convective thunderstorms.

G. Summary:

- 1) WE started by looking at the thermally direct 1-cell model and why it doesn't work for the entire hemispheric circulation, driven largely by equator to pole temperature gradients.
- 2) Instead, we wound up with a 3-cell per hemisphere structure, with ascent above surface low pressure at 60° north, as well as the equator, and descent above surface highs at 30° north, as well as over the pole.
- 3) The Coriolis force combined with these newly established pressure gradients to establish westerly and easterly geostrophic winds in the mid-latitudes and polar regions of both hemispheres.
- 4) In the tropics, the situations were a little different.
 - a. The trade winds that converged on the equator were established, a consequence of the fact the Coriolis force is relatively weaker there.
 - b. And the trade wind convergence at or near the equator produced the ITCZ, a sustained band of lifting, leading to rainfall that straddles the globe.
 - c. Like the 3-cell model itself, the ITCZ is complicated by the arrangement of continents and oceans, and wanders with the seasons.

- 4) If Earth rotated more rapidly, the Coriolis force would be stronger. How would a faster rate of rotation affect the location (latitude) of Earth's belts of sub-tropical high pressure?

- 5) Referring to the idealized three-cell model of atmospheric circulation, most of the United States is situated in which of prevailing winds?
- 6) Briefly explain each of the following statements that relate to the global distribution of surface pressure:
 - a. The only true zonal distribution of pressure exists in the region of the subpolar low in the Southern Hemisphere.

 - b. The subtropical highs are stronger in the North Atlantic in July than in January.

 - c. The subpolar low in the Northern Hemisphere is represented by individual cyclonic storms that are more common in the winter.

- 7) Explain the cause of the Asian monsoon. In which season (summer or winter) does it rain?

- 8) Why is the flow aloft predominantly westerly?

- 9) What is the ITCZ? Where is it formed? How does it change seasonally?

- 10) What latitude is the following: Subtropical high and the Subpolar Low

