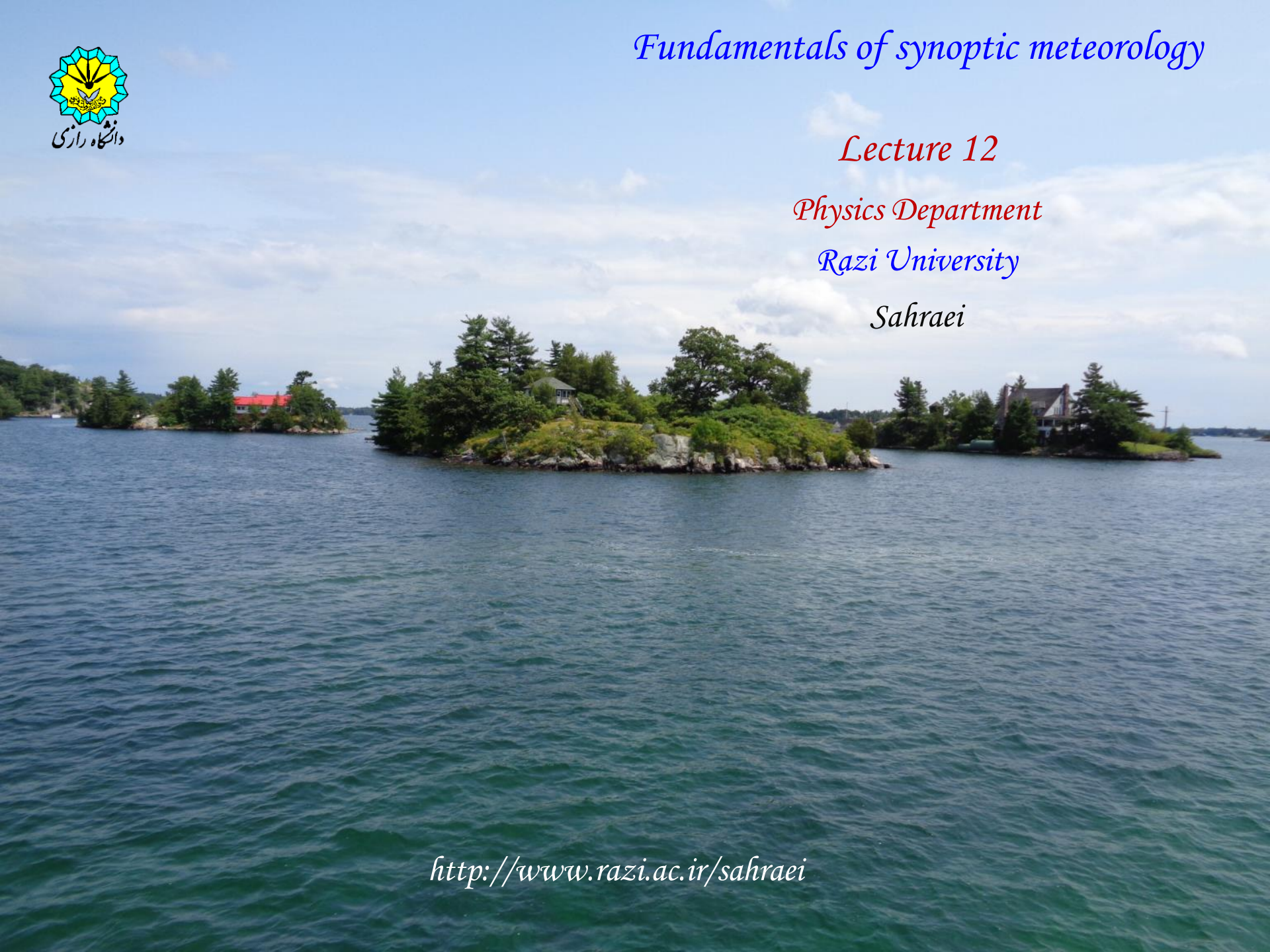


Fundamentals of synoptic meteorology

Lecture 12

Physics Department

Razi University

Sahraei

http://www.razi.ac.ir/sahraei

GENERAL CIRCULATION OF THE ATMOSPHERE

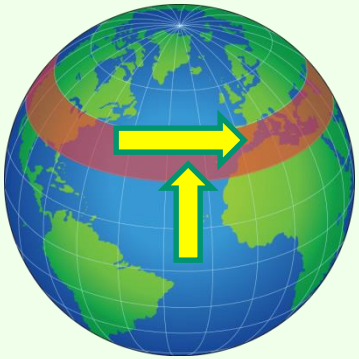
Introduction

Well-defined pressure patterns exist across the globe
These define the general circulation of the planet

In describing wind motions:

Zonal winds are those which blow parallel to lines of latitud

Meridional winds move along lines of longitude



The general circulation of the atmosphere may be examined

through a single-cell or three-cell model

General Circulation of the Atmosphere

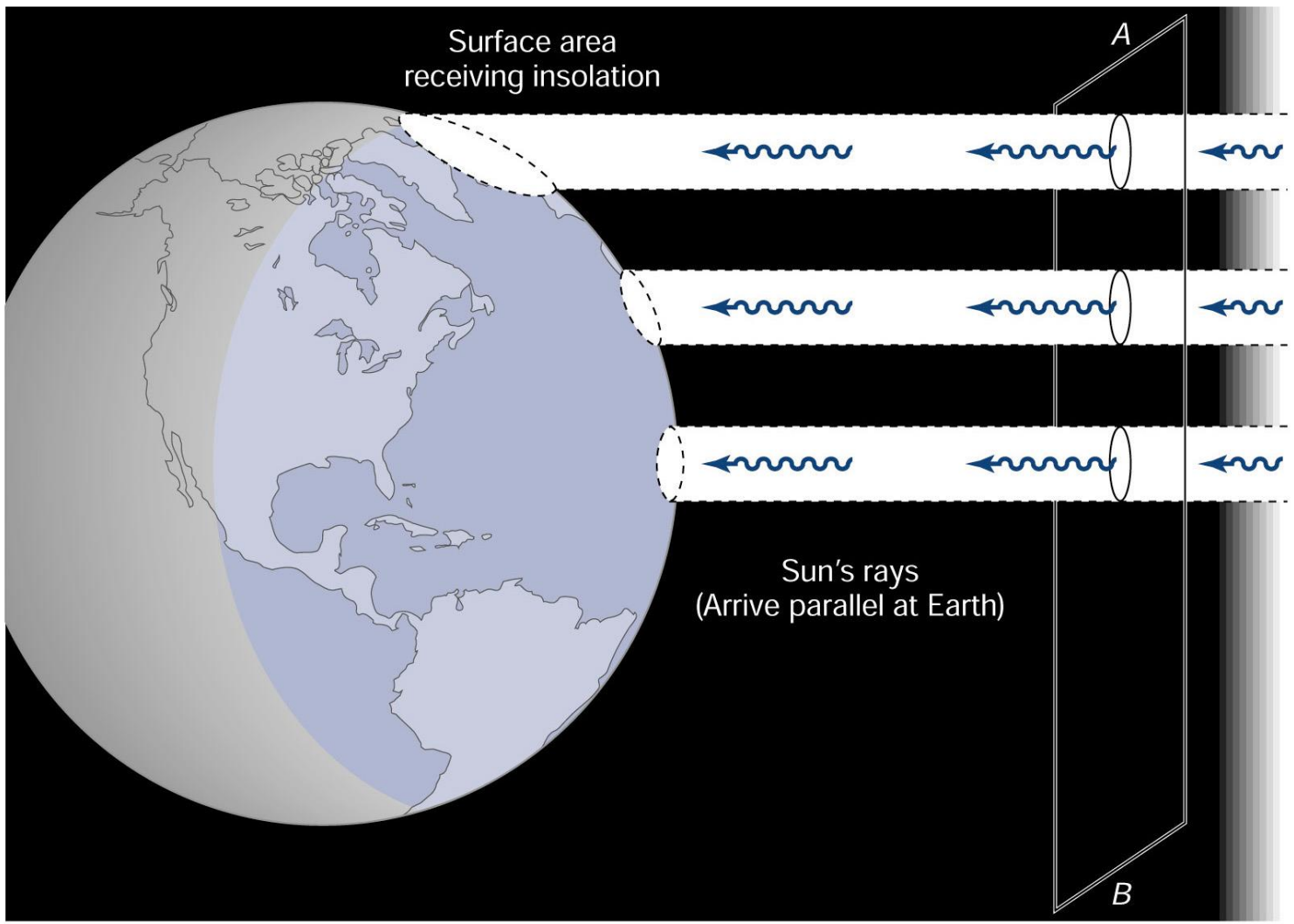
General refers to the average air flow, actual winds will vary considerably

The basic cause of the general circulation is unequal heating of the Earth's surface

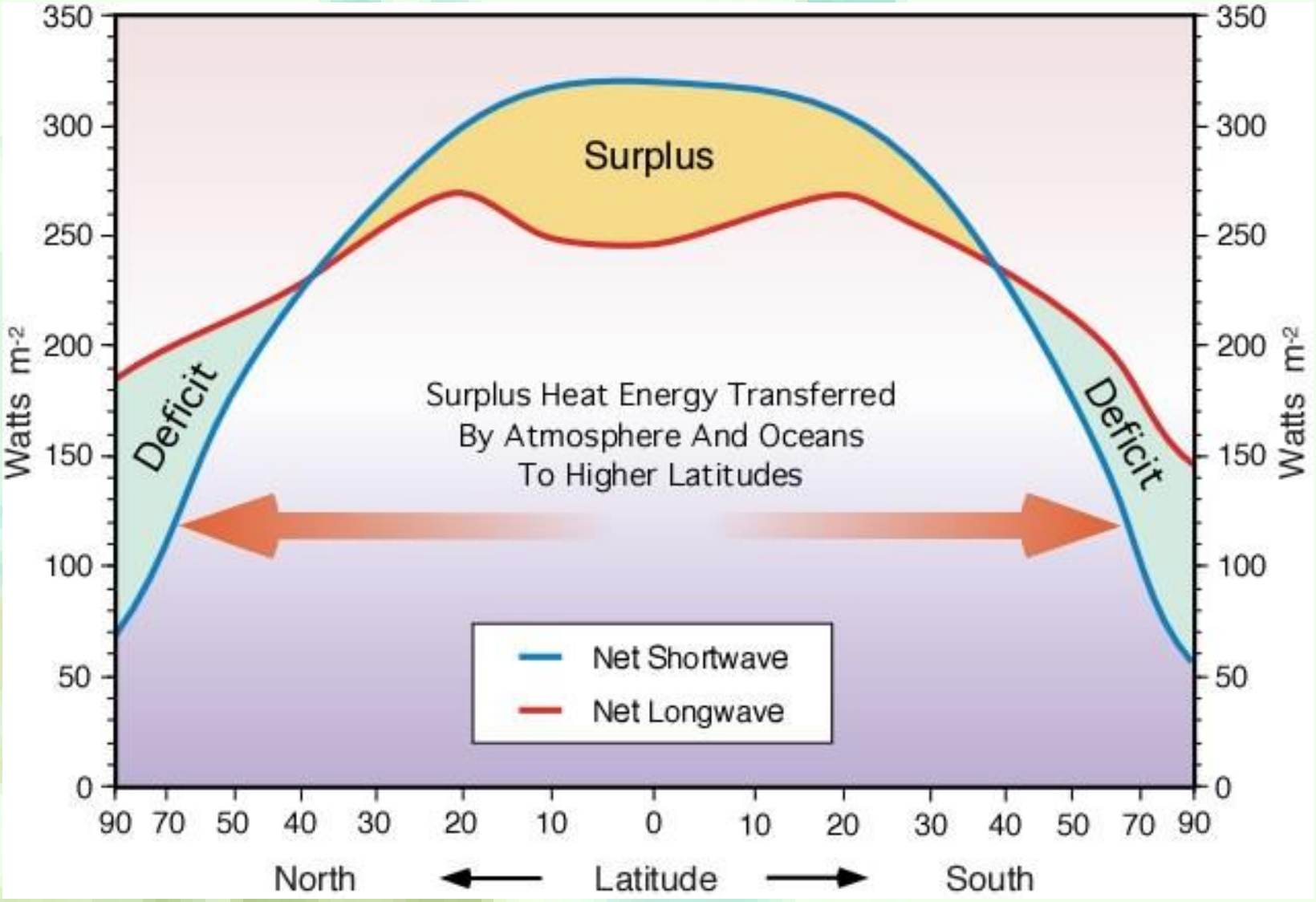
Warm air is transferred from the Tropics to the Poles

Cool air is transferred from the Poles to the Tropics

Flux of solar radiation less at higher latitudes; max. at equator



GLOBAL HEAT BALANCE



Global Heat Balance

Figure illustrates the annual values of net shortwave and net longwave radiation from the South Pole to the North Pole.

On closer examination of this graph one notes that the lines representing incoming and outgoing radiation do not have the same values.

From 0-35 ° latitude North and South incoming solar radiation exceeds outgoing terrestrial radiation and a surplus of energy exists.

The reverse holds true from 35-90° latitude North and South and these regions have a deficit of energy.

Surplus energy at low latitudes and a deficit at high latitudes results in energy transfer from the equator to the poles.

It is this meridional transport of energy that causes atmospheric and oceanic circulation. If there were no energy transfer the poles would be 25° Celsius cooler, and the equator 14° Celsius warmer!

Single Cell Model

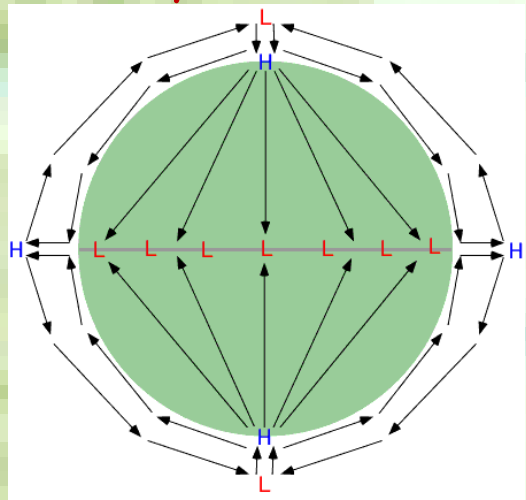
Assume

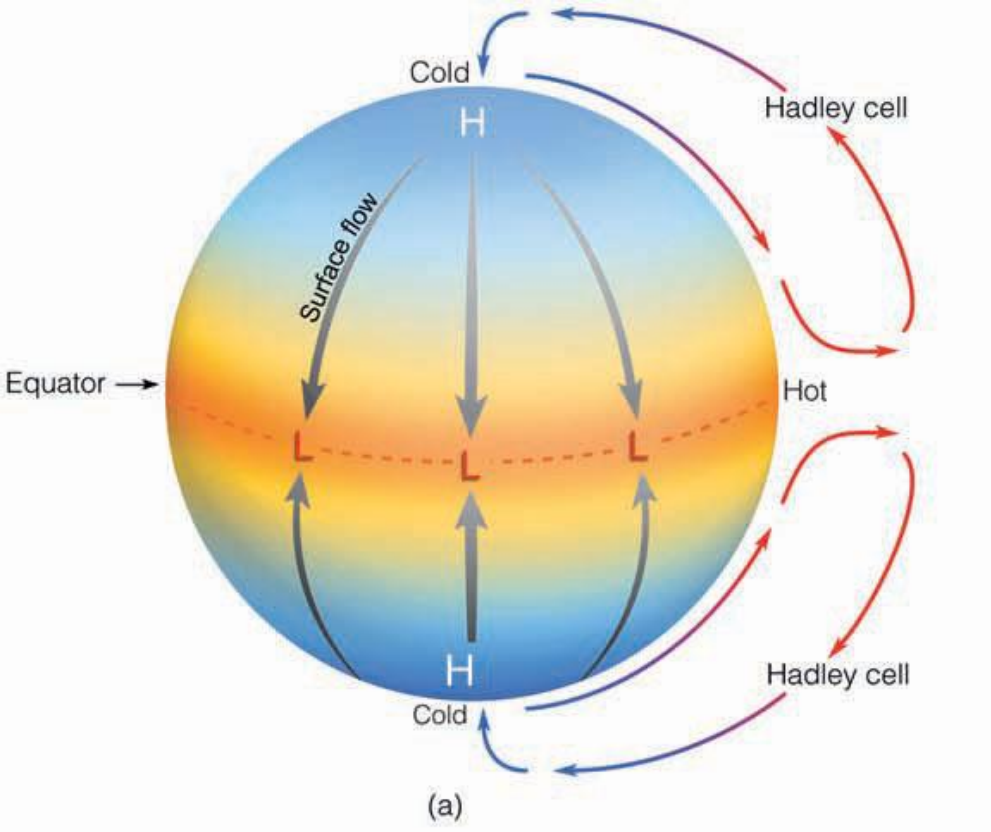
1. The earth's surface is uniformly covered with water (so that differential heating between land and water does not come into play).

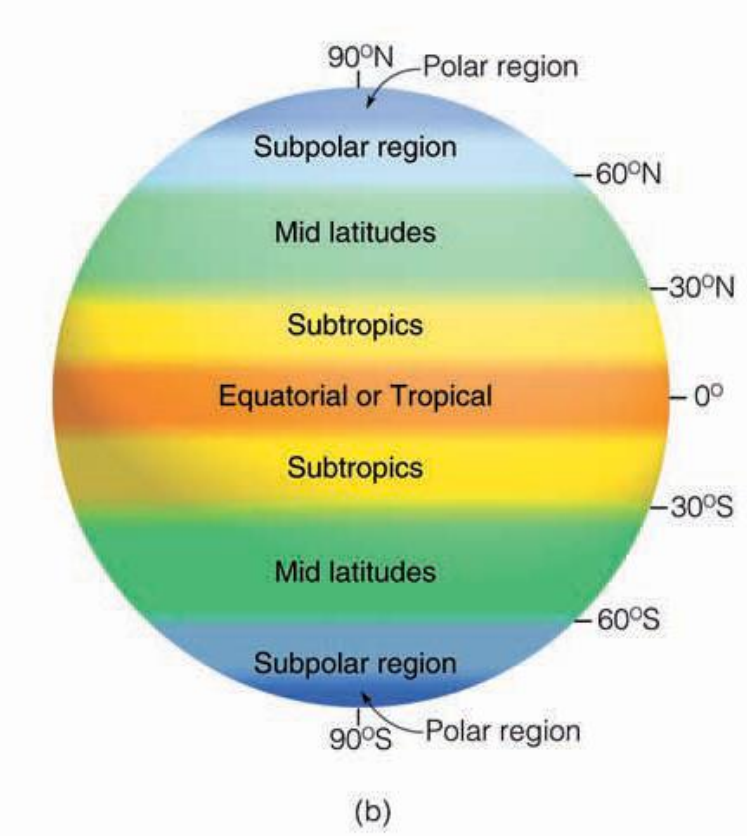
2. The sun is always directly over the equator (so that the winds will not shift seasonally). On the Equinoxes, which are generally on March 21 and September 21.

3. The earth does not rotate (so that the only force we need to deal with is the pressure gradient force).

Result: huge thermally direct convection cell (Hadley)







A single convection cell per hemisphere would redistribute heat from the equator to the poles under such conditions

THREE-CELL MODEL

Each hemisphere is divided into three pressure cells

The first is the thermally driven:

Hadley cell

In the tropics air is heated through high solar angles and constant day length.

Air becomes heated, expands, and diverges toward higher latitudes

The equatorward boundary of the Hadley cell is characterized by expanding and ascending surface air that forms the equatorial low, or intertropical convergence zone (ITCZ).

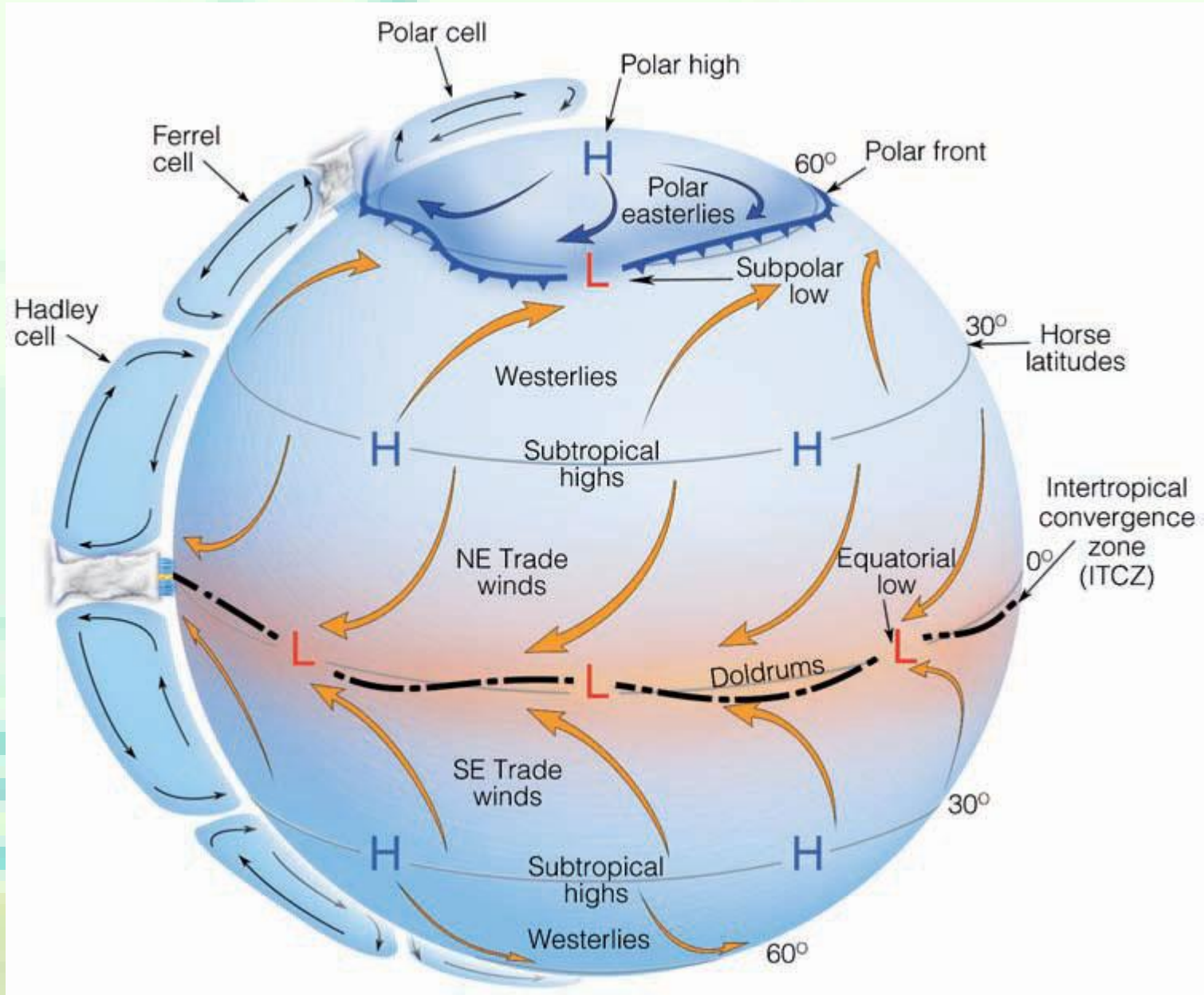
The ITCZ (or doldrums) is usually found near the vertical solar ray.

It is usually characterized by clouds and heavy precipitation .

Reflects some of the wettest areas on Earth .

Ascending air diverges poleward aloft.

Air gains considerable westward momentum and descends in the subtropics

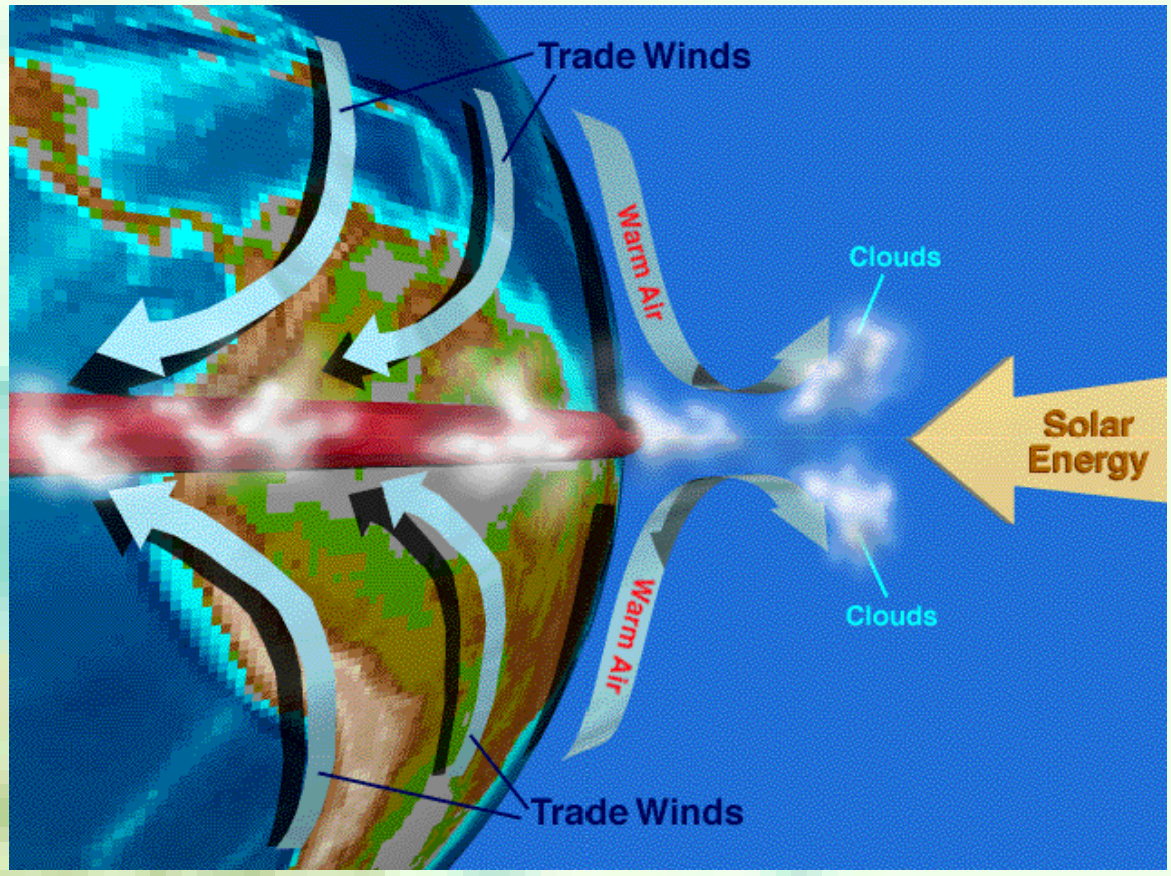

Polar cell
Polar high
Ferrel cell
H
60°
Polar front
Polar easterlies
L
Subpolar low
Hadley cell
30°
Horse latitudes
Westerlies
H
Subtropical highs
H
Intertropical convergence zone (ITCZ)
NE Trade winds
Equatorial low
0°
L
L
Doldrums
L
SE Trade winds
30°
H
Subtropical highs
H
Westerlies
60°

منطقه همگرايی درون حاره اي: در منطقه آرامگان (Intertropical Convergence Zone (ITCZ دور تا دور كره مين را كمربندي از كم فشار فرا گرفته است. به دليل اينكه كم فشار حاره اي اغلب در شمال استوا واقع مي شود بادهاي تجارتي جنوب شرقي دچار انحراف به سمت راست مي گردد، به نحوي كه براي رسيدن به منطقه كم فشار به شكل قلاب در مي آيد. اين موضوع خصوصا براي مناطق هندوستان و شرق ارام قابل توجه است.به دليل همگرايي باد تجارتي در كمربند كم فشار حاره اي يا آرامگان، اين منطقه به عنوان منطقه تراكم درون حاره اي شناخته مي شود.

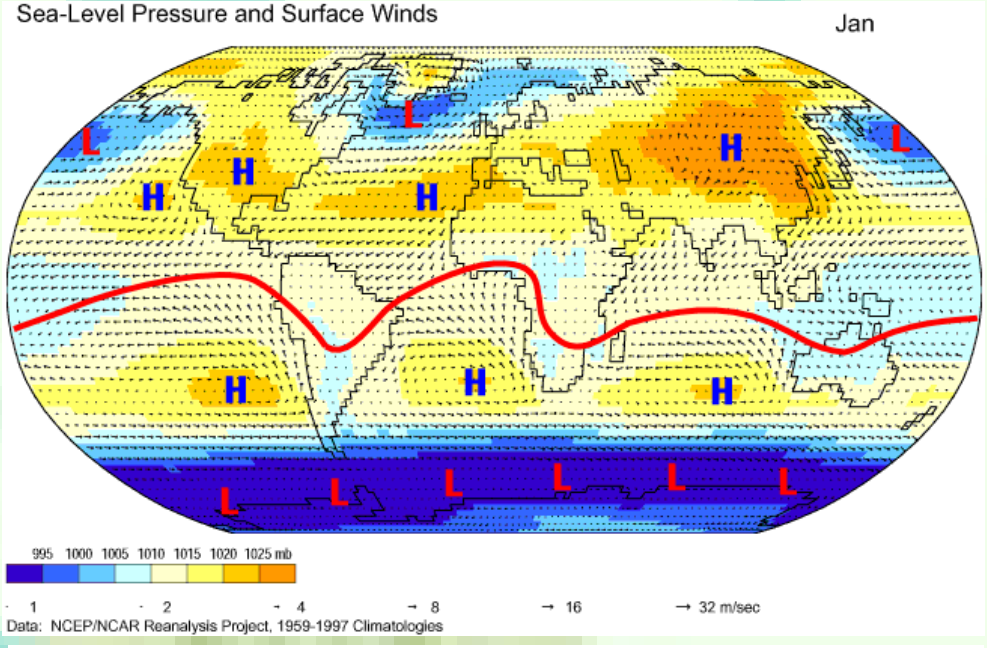
با كمي دقت متوجه بر عكس شدن فشار از كم فشار به پرفشار در روي منطقه آسيا در فاصله زماني زمستان تا تابستان مي شويم. از اين جهت باد هاي موسمي هند بسيار مشهور شده اند كه در طول مدت زمستان يك سيستم پرفشار بر منطقه آسيا حاكم است و بادهاي اين منطقه از سمت شمال شرق مي وزد، در حالي كه در تابستان بر روي اين منطقه ك سيستم كم فشار حاكم شده و بادها از جهت جنوب غربي، يعني دقيقا بر عكس زمستان مي وزند. البته بعد از آن كه استوا را به صورت قلاب قطع مي كند. اين حركت هوا در جنوب عرضهاي اسبي وجود دارد و در نتيجه ارائه گراديان فشار در آسياي مركزي است. بنابر اين بادهاي موسمي و بادهاي تجارتي در اين ناحيه تركيب مي شوند. بادهاي موسمي جنوب غربي پس از عبور از روي آبهاي آزاد منطقه حاره اي تقريبا گرم و مرطوب هستند. بر فراز مناطق مرتفع و كوهستانهاي هندوستان، هواي گرم و مرطوب به صورت بي درو صعود كرده و سرد مي شود،و كاهش برودت هوا تا زير نقطه شبنم باعث ايجاد بارانهاي مشهور فصلي به هنگام تابستان در اين منطقه مي گردد.

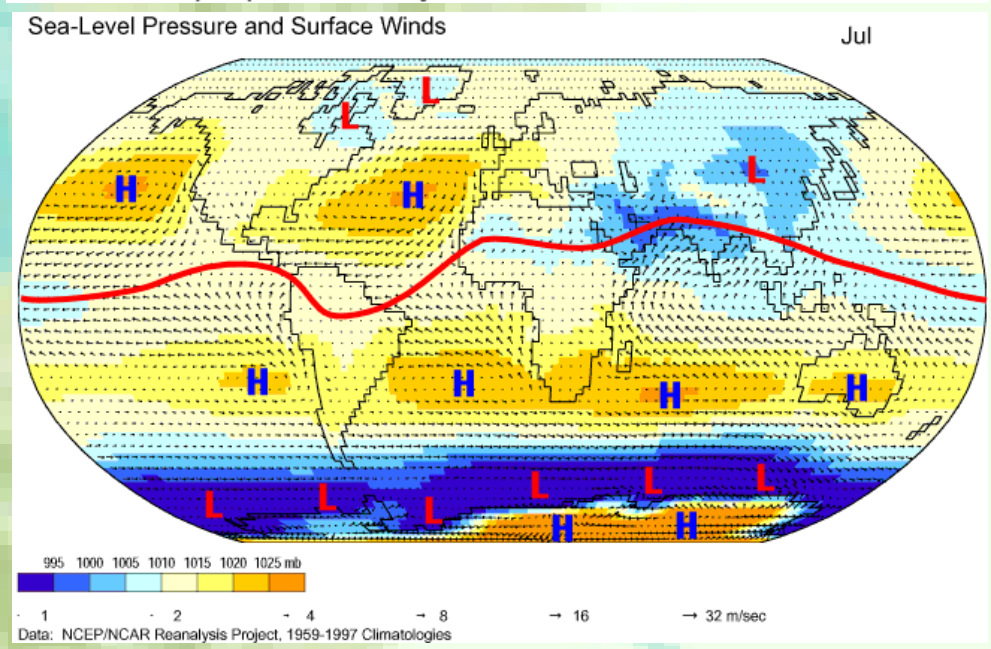
TRADE WINDS
and the Intertropical Convergence Zone (ITCZ)

ITCZ



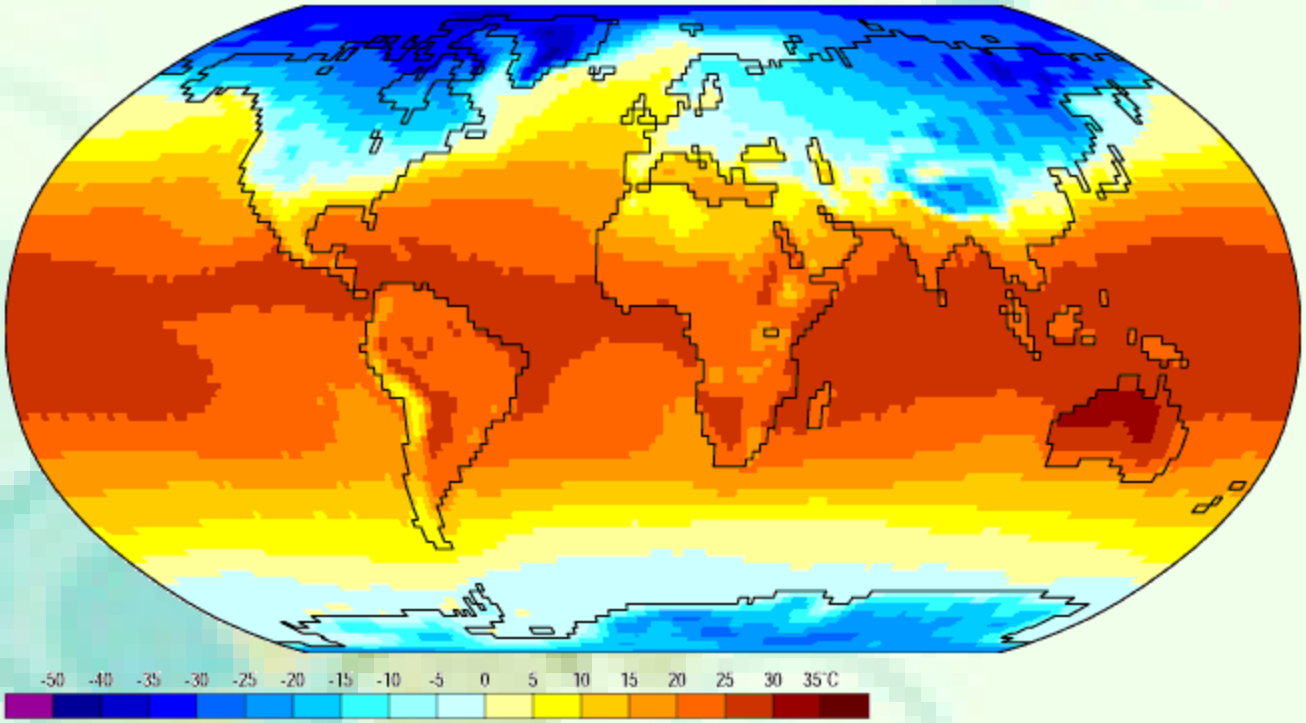
THE INTERTROPICAL CONVERGENCE ZONE(ITCZ)



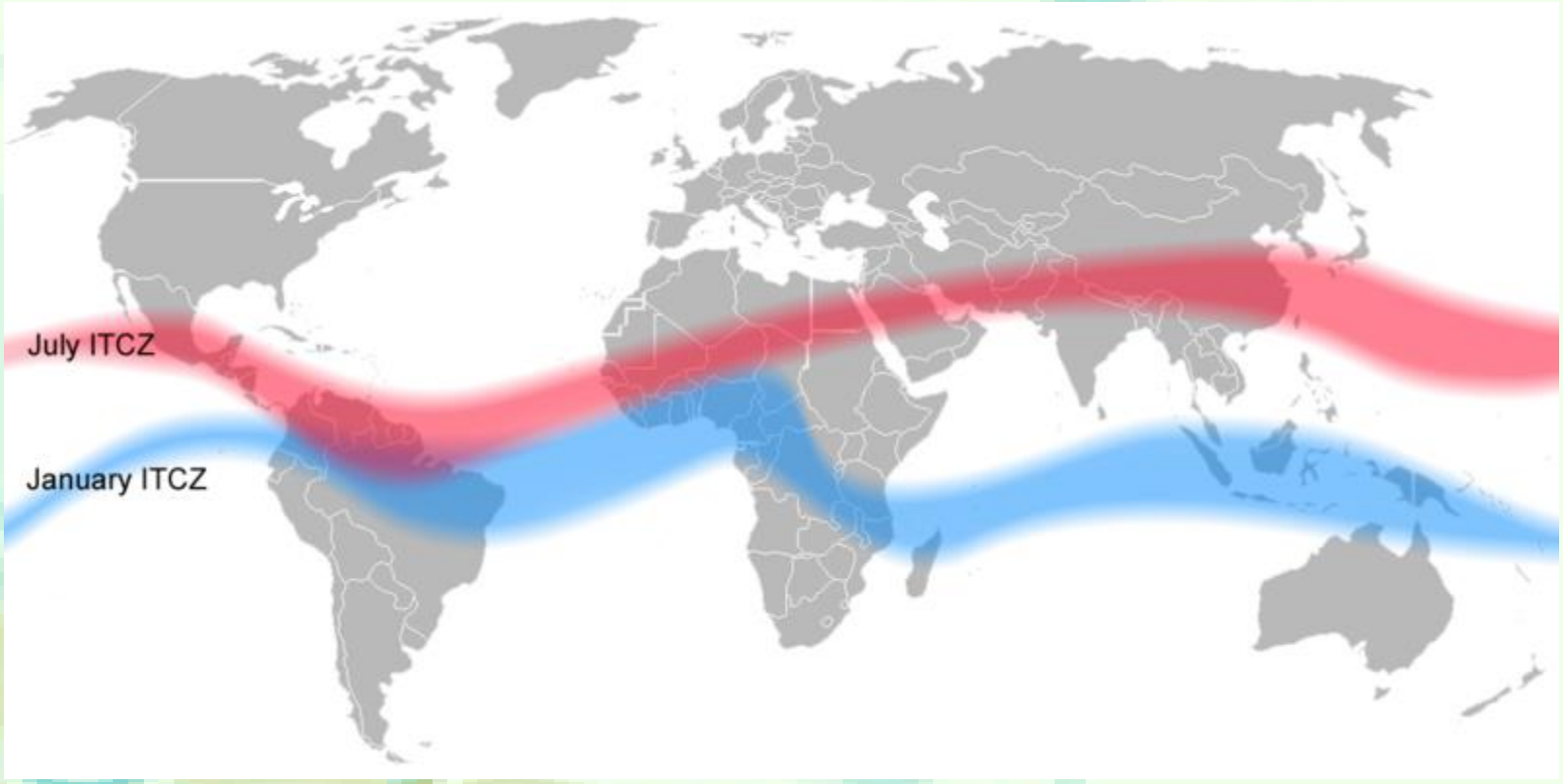


Air Temperature

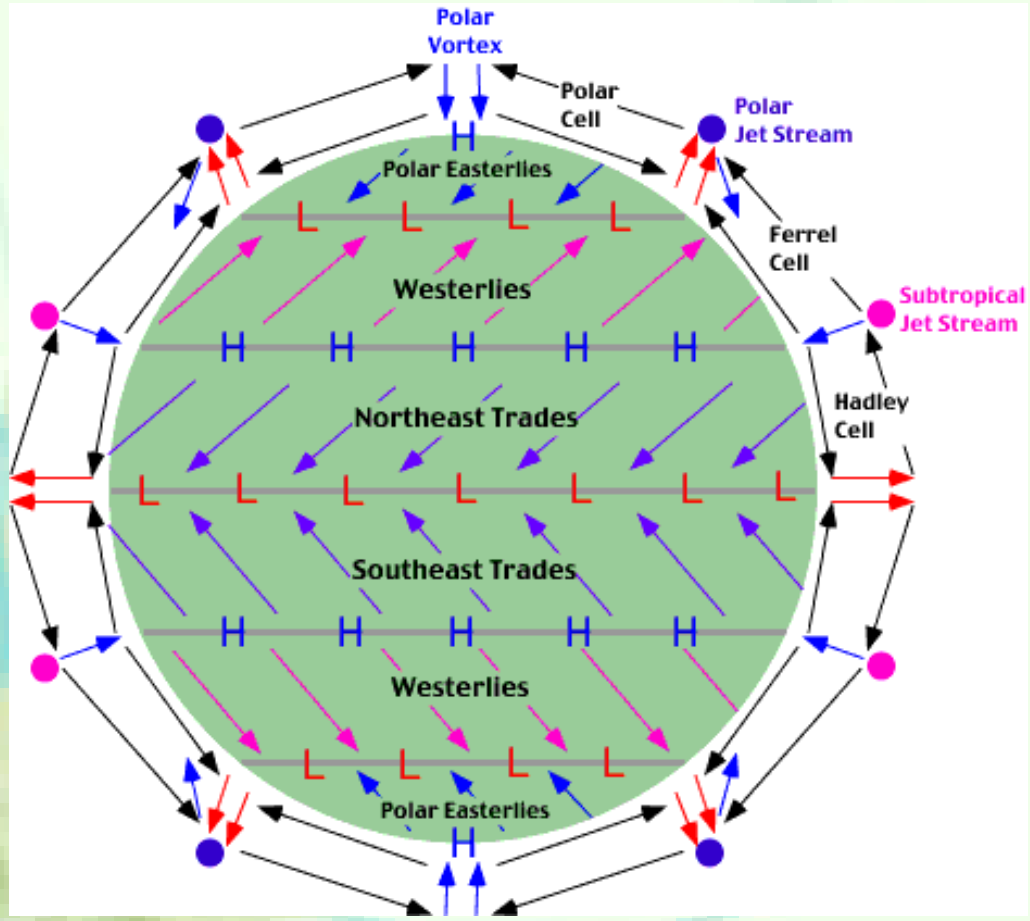
Dec



Data: NCEP/NCAR Reanalysis Project, 1959-1997 Climatologies
Animation: Department of Geography, University of Oregon, March 2000


July ITCZ
January ITCZ

Simplified Global Three-Cell Surface and Upper Air Circulation Patterns



Between 20 and 30° latitude, air descends forming the subtropical highs, or horse latitudes .

Compressional warming creates clear, dry conditions near the centers of the highs .

Surface air flow is primarily from the subtropical highs towards the ITCZ .

The addition of Coriolis deflection results in the northeast (southeast) trade winds in the northern (southern) hemisphere .

Hadley cell strength increases during the cool season when thermal contrasts are maximized .

Ferrel and Polar Cells

Constitute the remaining hemispheric cells

Ferrel cells lie poleward of each Hadley cell

They circulate air between the subtropical highs and the subpolar low

The subpolar lows result from surface air converging from the equatorward subtropical high and the poleward *polar high* .

The Ferrel cell is an indirect cell as it is formed from air motions initiated by adjacent cells .

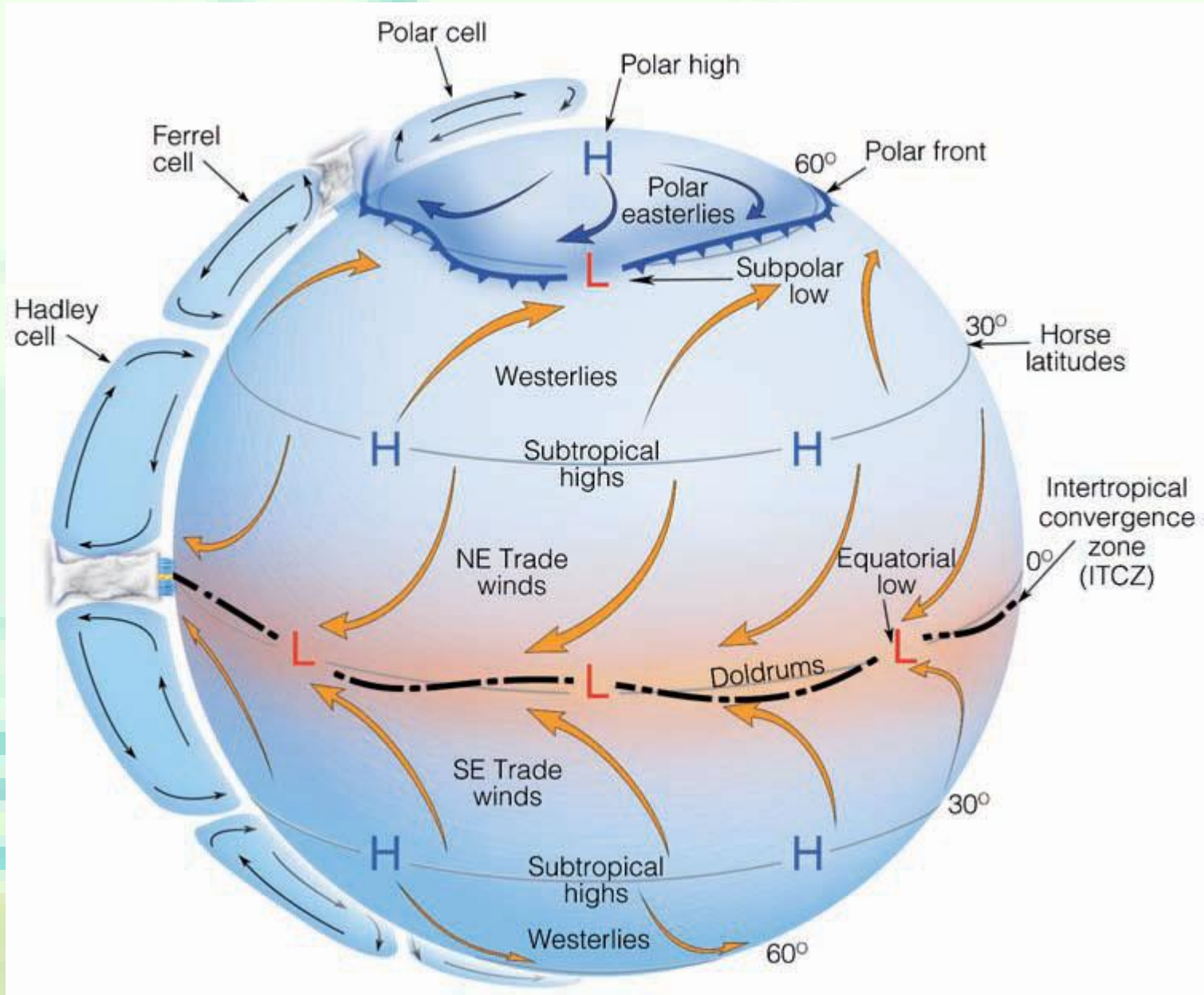
Air moving from the subtropical highs towards the subpolar lows undergoes Coriolis deflection causing the ***westerlies*** in both hemispheres .

Polar Highs

Thermally direct cells formed by very cold temperatures near the poles .

Air in these locations becomes very dense resulting in sinking motions indicative of high pressure .

Air moving equatorward is deflected by Coriolis creating the *polar easterlies* in both hemispheres


Polar cell
Polar high
Ferrel cell
H
60°
Polar front
Polar easterlies
L
Subpolar low
Hadley cell
30°
Horse latitudes
Westerlies
H
Subtropical highs
H
Intertropical convergence zone (ITCZ)
NE Trade winds
Equatorial low
0°
L
L
Doldrums
L
SE Trade winds
30°
H
Subtropical highs
H
Westerlies
60°

Average Surface Wind and Pressure
The Real World

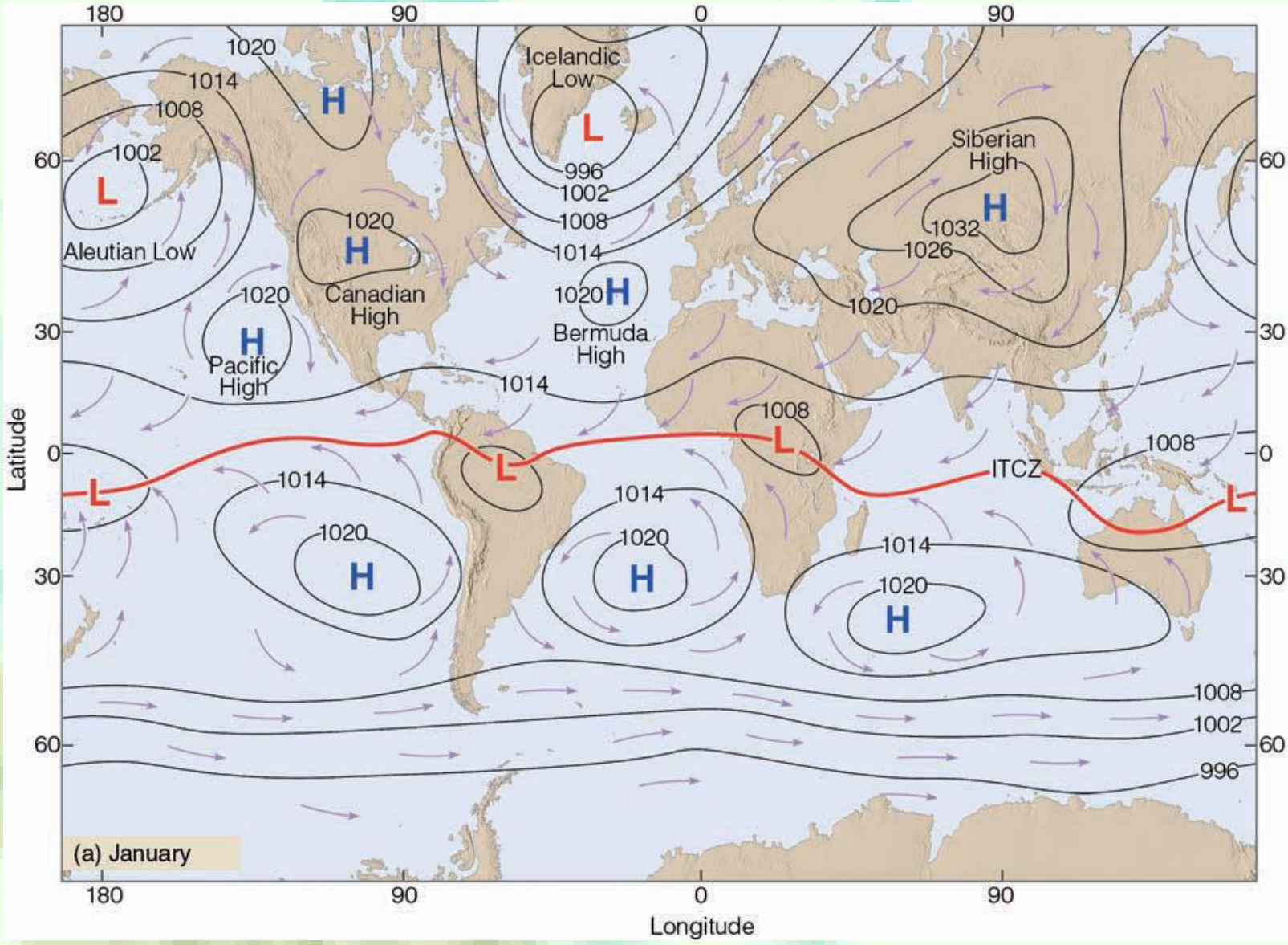
Semi-permanent high and lows

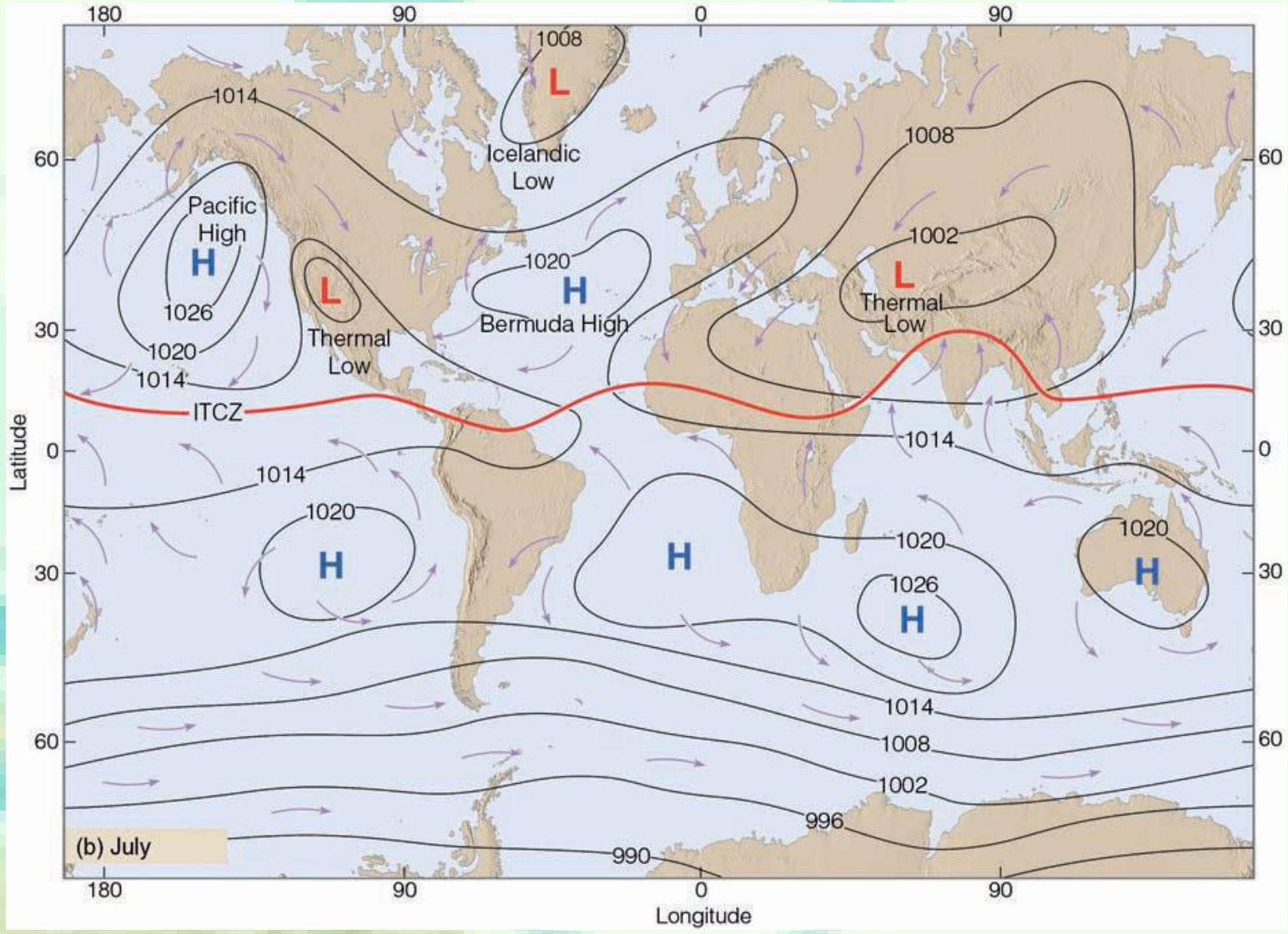
Northern vs. Southern Hemisphere

Major features shift seasonally with the high sun

North in July

South in December


180
90
0
90
60
30
0
30
60
Latitude
Longitude
Icelandic Low
Siberian High
Aleutian Low
Canadian High
Bermuda High
Pacific High
ITCZ
1020
1014
1008
1002
996
1032
1026
(a) January


180
90
0
90
1008
L
Icelandic
Low
1014
1008
60
60
Pacific
High
H
1002
1020
H
L
1026
Thermal
Low
Bermuda High
Thermal
Low
30
30
1020
1014
ITCZ
1014
Latitude
0
0
1014
1020
1020
H
H
1020
H
1026
H
30
30
1014
60
1008
60
1002
996
990
(b) July
180
90
0
90
Longitude

MID-LATITUDE CYCLONES

Low pressure systems are a characteristic feature of mid-latitude temperate zones.

They form in well defined zones associated with the polar front – which provides a strong temperature gradient – and convergent flow resulting from the global circulation.

What is a mid-latitude cyclone?

The mid-latitude cyclone is a synoptic scale low pressure system that has cyclonic (counter-clockwise in northern hemisphere) flow that is found in the middle latitudes (i.e., 30^0N-55^0N)

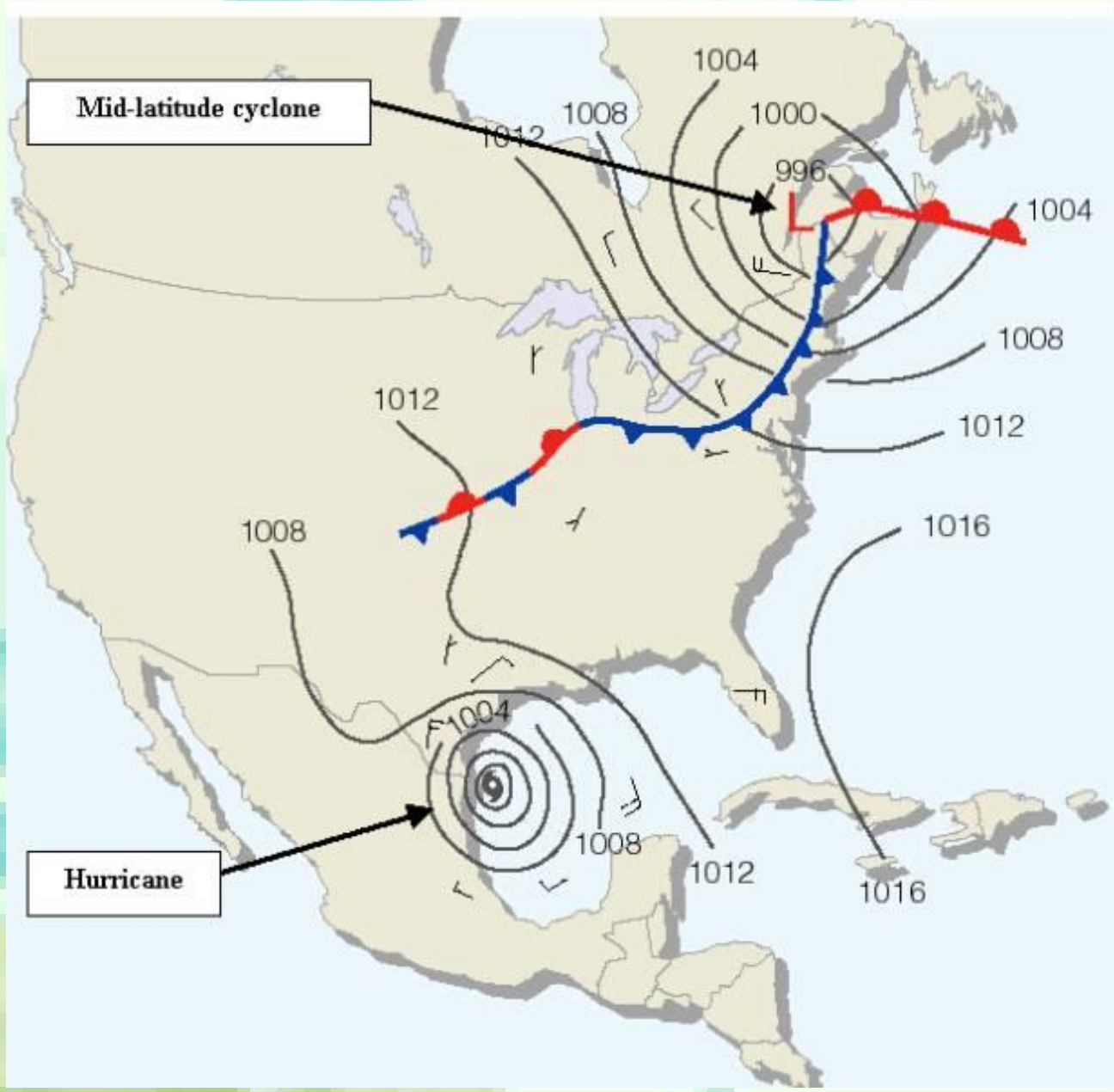
IT IS NOT A HURRICANE OR TROPICAL STORM

There is a location (tropics vs. mid-latitudes) and size difference between hurricane and mid-latitude cyclone

Typical size of mid-latitude cyclone = 1500-5000km in diameter.

Typical size of a hurricane or tropical storm = 200-1000km in diameter

Here is a picture of a typical mid-latitude cyclone and hurricane. Notice the size difference.


Mid-latitude cyclone
1004
1008
1000
1012
996
1004
1008
1012
1012
1008
1016
1004
1008
1012
1016
Hurricane

MID-LATITUDE CYCLONES

The Norwegian Cyclone Model

1. Development & intensification of a midlatitude cyclone is explained in terms of the "polar-front" theory .

2. Cyclones form along fronts. Life cycle last about 3 to 7 days.

Six stages:

1) Formation (cyclogenesis)

2) Development of wave in the front

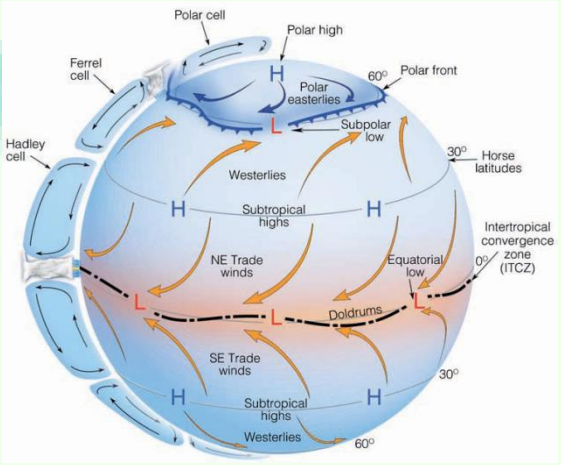
3) Cyclonic circulation established

4) Occlusion begins

5) Occluded front develops

6) Cyclone dissipates

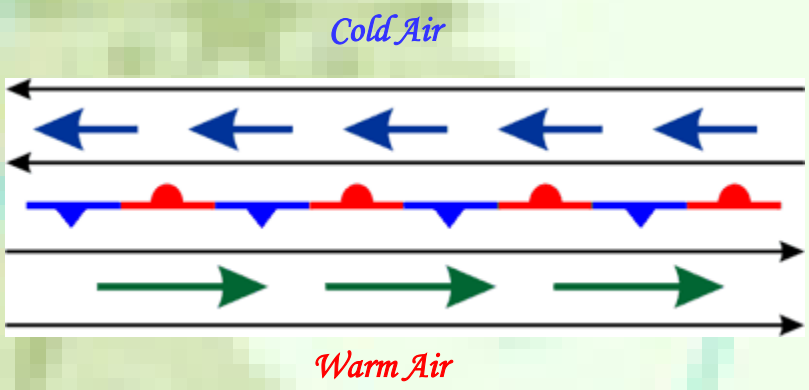
STAGE 1 - FORMATION (CYCLOGENESIS)



Two air masses of different densities & temperatures are moving parallel to the front, and in opposite directions.

Typically - cP associated with polar easterlies on the north of the front, mT driven by westerlies on the south.

(This causes counterclockwise rotation of the air mass.)

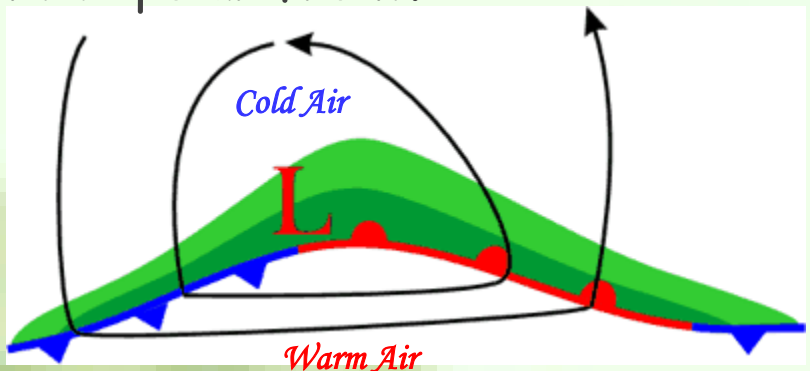


The Stationary Front

STAGE 2- DEVELOPMENT OF WAVE IN THE FRONT

Under suitable conditions, the front takes on a wave shape that is usually several hundred km long.

Movement of the air masses forms the cold and warm fronts; a 'wave' develops on the polar front.



cloud

A region of upper level divergence moves over the front and forms an area of surface low pressure (Upper Level Support).

Friction effects cause surface flow around low to converge

Mass balance: inward flow compensated by

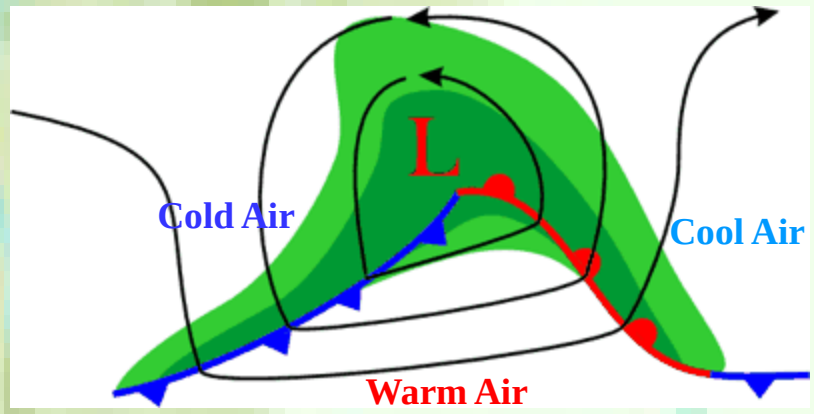
large scale lifting ⇒ cooling ⇒ cloud formation

Stage 3- Cyclonic Circulation Established

Enhanced upper-level divergence continues to strengthen the surface low.

As the low strengthen (pressure drop), the fronts become better organized

The stronger winds around a stronger low allows more cold and warm air advection to occur.

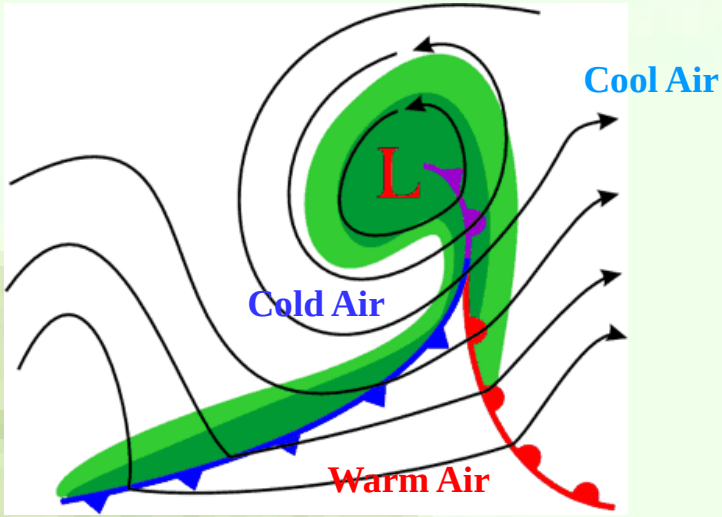


This sets up a circular flow pattern in a counterclockwise direction - the cyclone.

Stage 4: Occlusion Begins (Maturity)

Cold front normally travels about 50% faster then the warm front, and overtakes it, causing occlusion.

Ends of the fronts in center of cyclone occluded first.



The surface low reaches its lowest pressure.

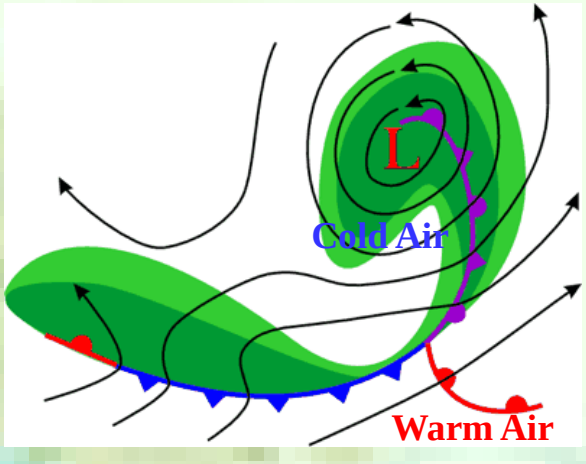
In the occluded front, the cold air undercuts the "cooler air" ahead of the warm front, so lifting still occurs but it is less vigorous (stratiform clouds and precipitation).

Stage 5- Occluded Front Develops

The size of the occluded front grows in length, displacing the warm front aloft.

The storm usually intensifies, the central pressure falls, and wind speeds increase.

During Winter, can get heavy snowfalls and blizzard-like conditions (because of the high winds).



Once the occlusion forms, the low pressure is separated from the warm air mass and thus the warm air advection.

The motion of the surface system slows. maximum intensity 12-24 hours after the start of occlusion.

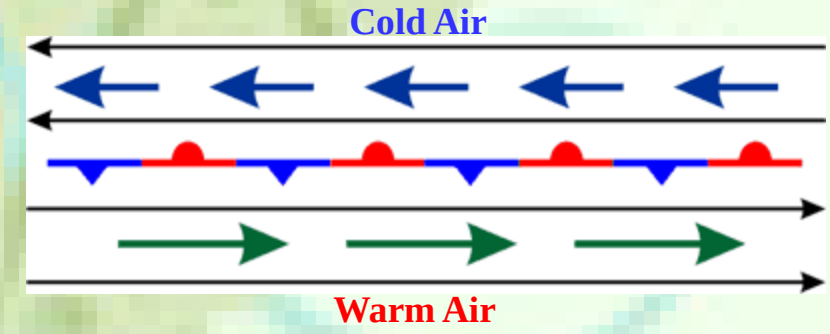
Stage 6: Cyclone Dissipates

With the upper-level low and its associated convergence directly above the surface low, the surface low begins to "fill-in" and eventually dissipates.

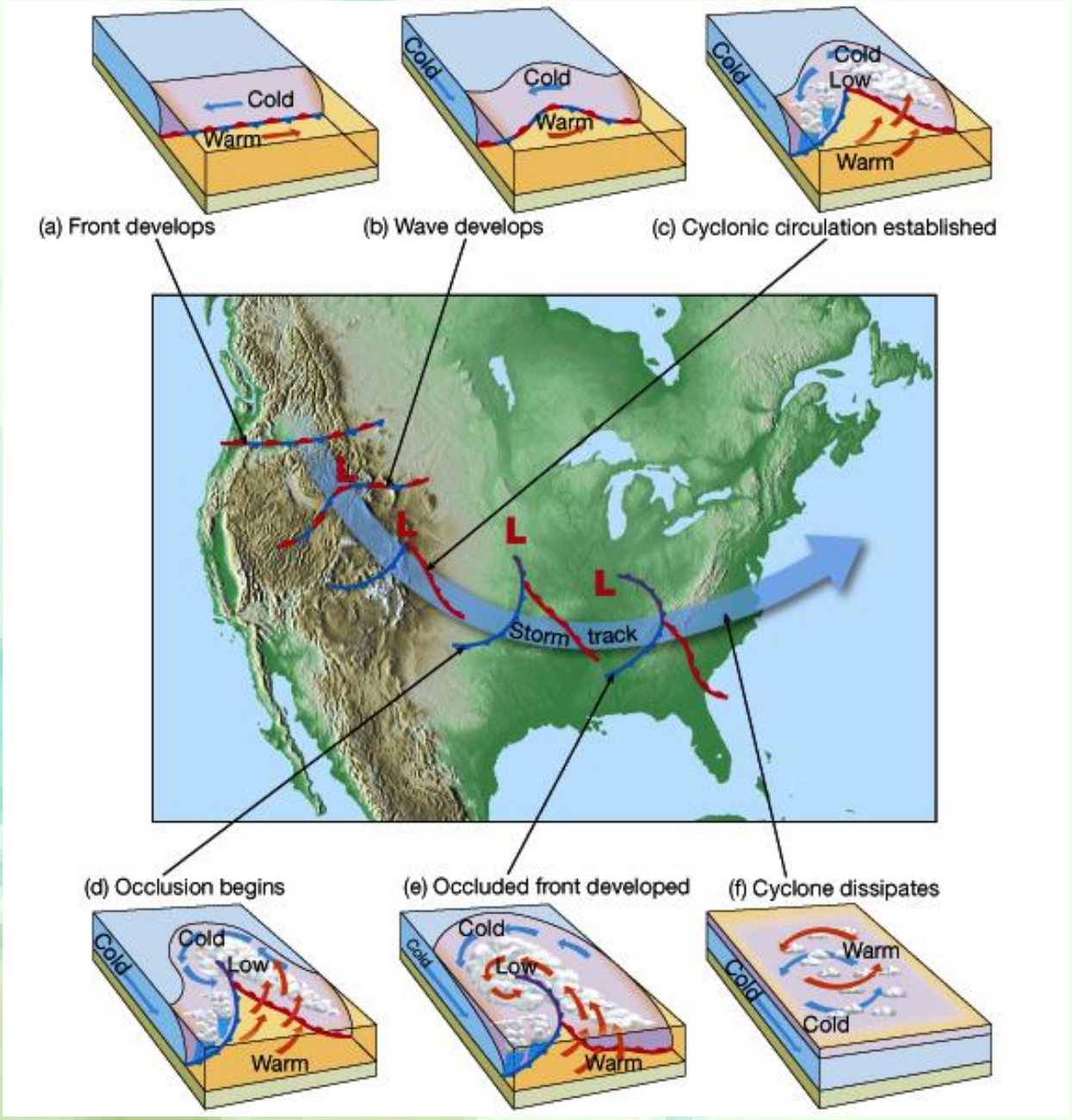
The remains of the warm and cold front will form a stationary boundary and await the next upper-level trough….

Once all the warm air has been displaced, we have just the cold air and no temperature gradient.

There is thus no energy left to drive the cyclone, which therefore dissipates.



Low continues to weaken, clouds break up


Cold
Warm
(a) Front develops
Cold
Cold
Warm
(b) Wave develops
Cold
Cold
Low
Warm
(c) Cyclonic circulation established
L
L
L
L
Storm track
(d) Occlusion begins
Cold
Cold
Low
Warm
(e) Occluded front developed
Cold
Cold
Low
Warm
(f) Cyclone dissipates
Cold
Warm
Cold