Fundamentals of Earth's Atmosphere: **Catch-Up**

AOSC / CHEM 433 & AOSC / CHEM 633

Ross Salawitch

Class Web Sites:
http://www2.atmos.umd.edu/~rjs/class/fall2020
https://myelms.umd.edu/courses/1291919

Goal:

1) Review a few items that may have been confusing in Lecture 3

2) Geostrophy (balance of pressure force & Coriolis Force ⇨ storms)

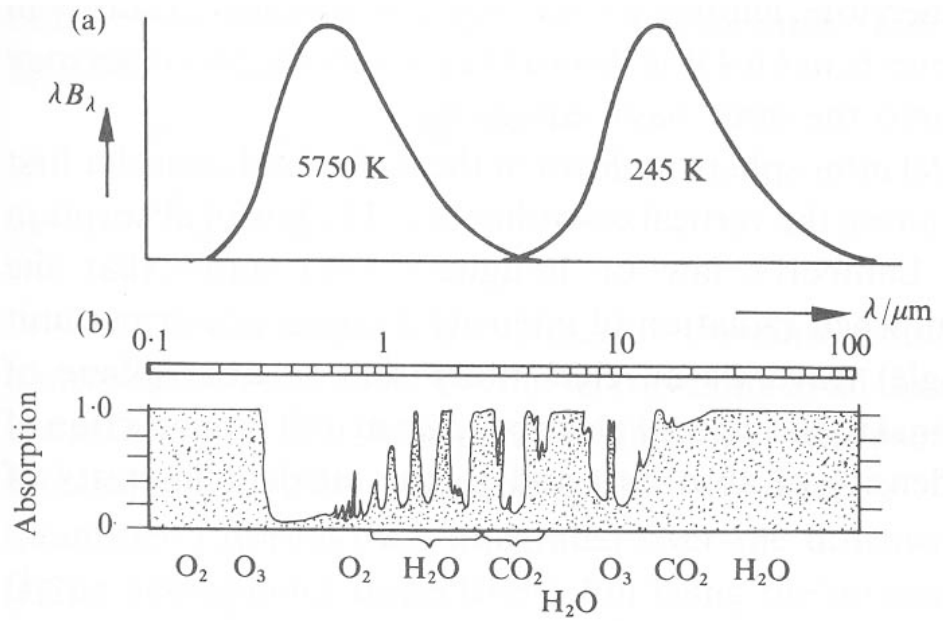
3) Ferrel Circulation (mean circulation Earth's atmosphere ⇨ climate regimes)

Lecture 3: Catch-up

12 September 2020

Atmospheric Radiation

- Solar irradiance (downwelling) at top of atmosphere occurs at wavelengths between ~200 and 2000 nm (~5750 K "black body" temperature)
- Thermal irradiance (upwelling) at top of the atmosphere occurs at wavelengths between ~5 and 50 μm (~245 K "black body" temperature)



Panel (a): Black-body energy versus wavelength for 5750 K (Sun's approx T) and 245 K (Earth's mean atmospheric T). Curves are drawn with equal area since integrated over entire Earth, at top atmosphere, solar downwelling and terrestrial upwelling fluxes are in close balance.

Panel (b): absorption by atmospheric gases: 1.0 represents complete absorption.

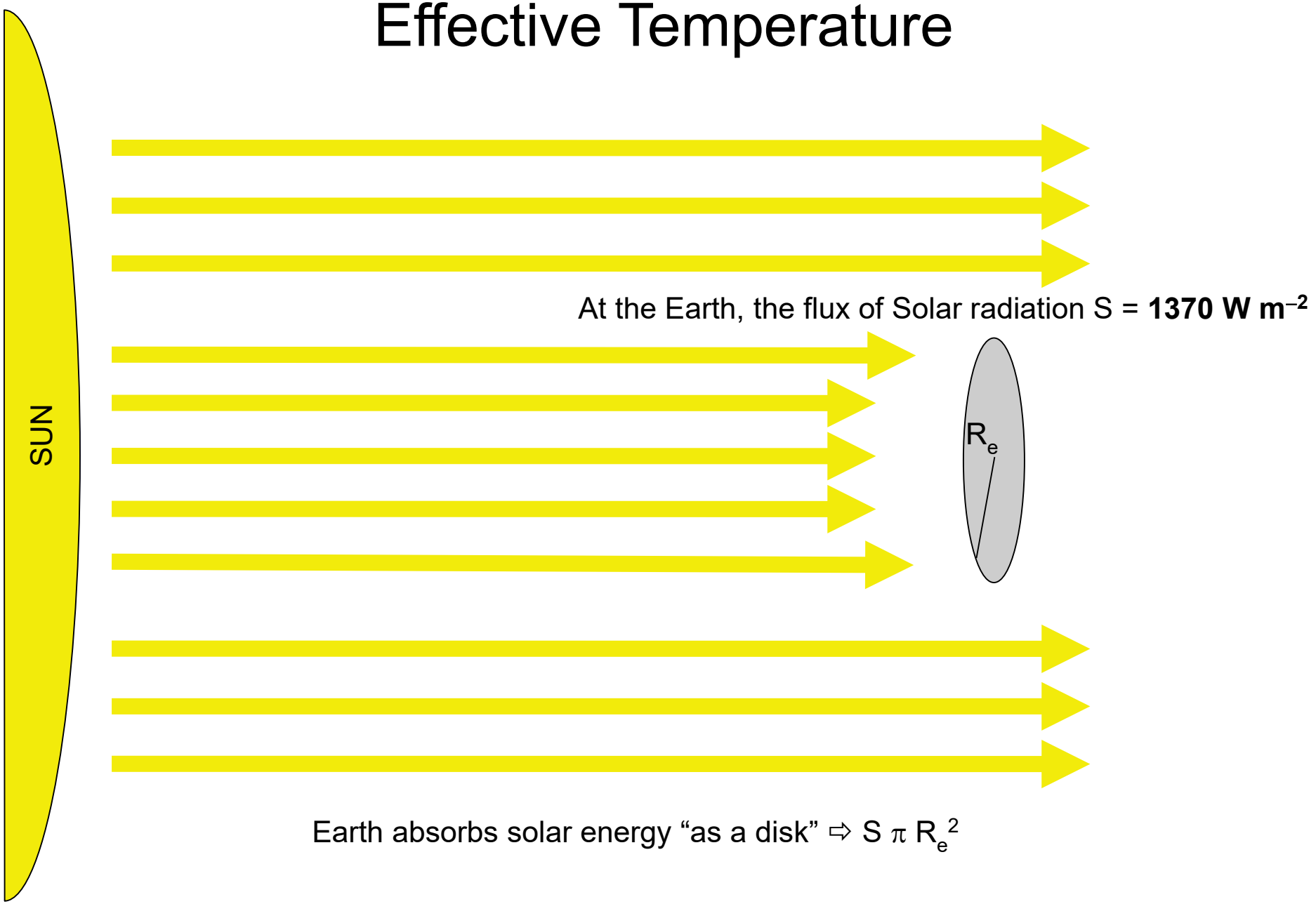
From Houghton, *Physics of Atmospheres*, 1991

Effective Temperature

My Favorite Planets

Venus:	Earth:	Mars
$T_{SURFACE} \approx 753$ K	$T_{SURFACE} \approx 288$ K	$T_{SURFACE} \approx 217$ K
$T_{EFFECTIVE} \approx ???$	$T_{EFFECTIVE} \approx ???$	$T_{EFFECTIVE} \approx ???$

Effective Temperature



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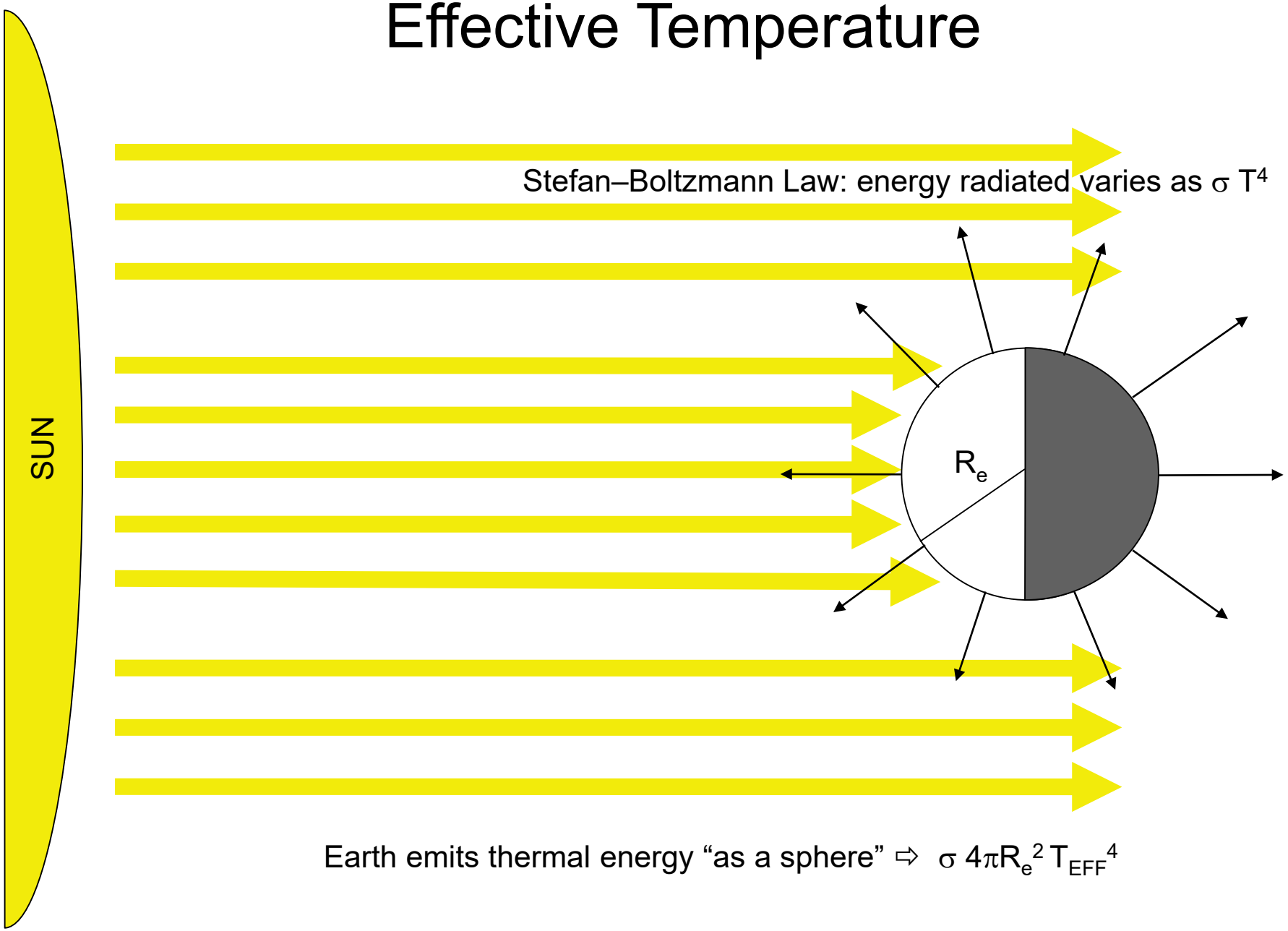


Earth emits thermal energy "as a sphere" ⇨ $\sigma\, 4\pi R_e^2\, T_{EFF}^4$

Effective Temperature

Earth absorbs solar energy "as a disk" ⇨ $(1 - \text{Albedo}) \times S \, \pi \, R_e^2$

Earth emits thermal energy "as a sphere" ⇨ $\sigma \, 4\pi R_e^2 \, T_{EFF}^4$

$$(1 - \text{Albedo}) \times S = 4 \, \sigma \, T_{EFF}^4$$

or

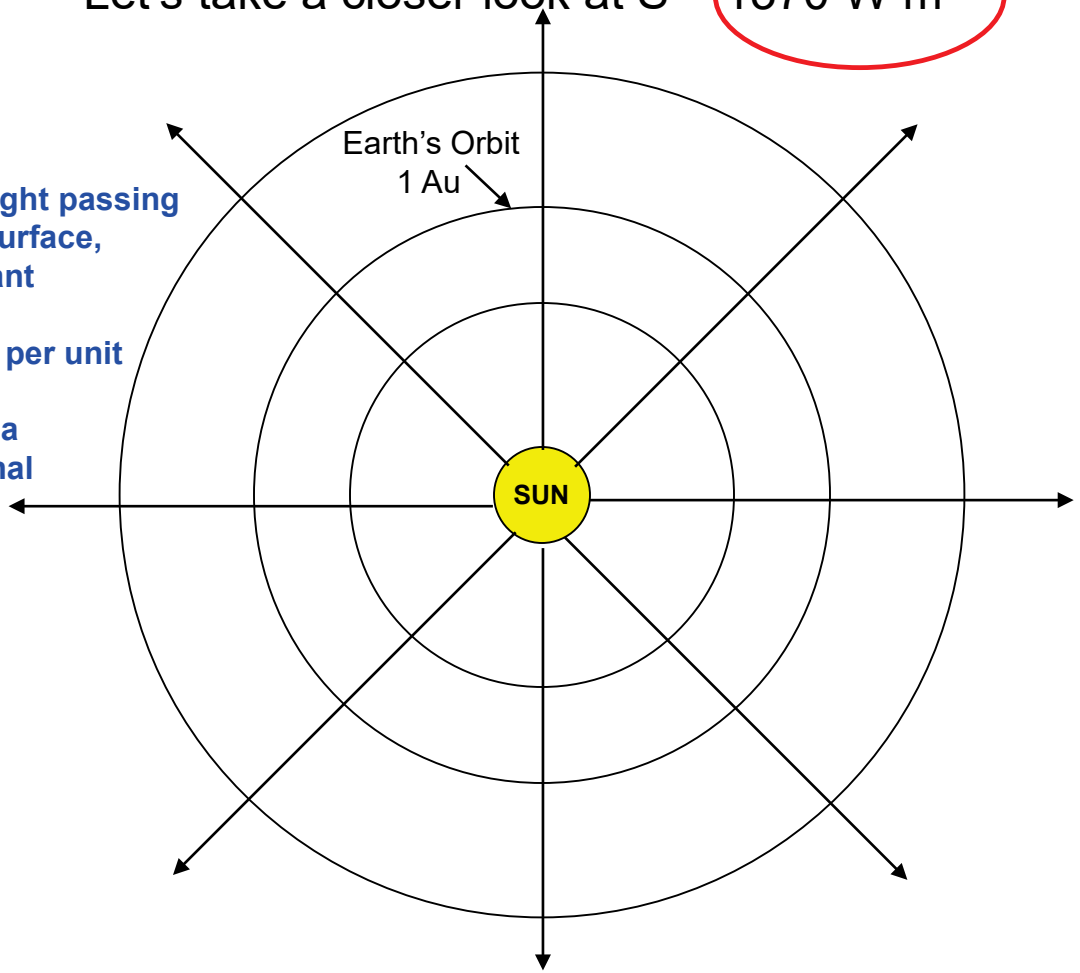
$$T_{EFF} = \{ (1 - \text{Albedo}) \times S \, / \, 4 \, \sigma \}^{1/4}$$

Effective Temperature

Let's take a closer look at S = 1370 W m^{-2}

The total amount of sunlight passing through each spherical surface, of various radii, is constant

Therefore the energy (W) per unit area (m^{-2}) decreases wrt distance from the Sun in a manner that is proportional to 1 / (Distance)^2



Notes: 1) Au, or Astronomical Unit, is a measure of the distance of a planet from the Sun, normalized by the mean distance of Earth from the Sun. So by definition, **Earth's orbit is 1 Au from the Sun**

2) The diagram above represents orbits as perfect spheres, which is suitable for our study of effective temperatures. In reality, of course, planets orbit the Sun in an elliptical manner.

$$T_{EFF} = \{ (1 - \text{Albedo}) \times S \ / \ 4\,\sigma \}^{1/4}$$

633 students: find T_{EFF} for Earth, using:

$\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}

$S = 1370$ W m^{-2}

Albedo = 0.3

433 student whose last name begins with letters A-M:

Find T_{EFF} for **Mars** using:

$\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}

$S = 1370$ W m^{-2}

Albedo = 0.17

Distance from Sun = 1.5 AU

433 student whose last name begins with letters N-Z:

Find T_{EFF} for **Venus** using:

$\sigma = 5.67 \times 10^{-8}$ W m^{-2} K^{-4}

$S = 1370$ W m^{-2}

Albedo = 0.75

Distance from Sun = 0.72 AU

Effective Temperature

My Favorite Planets

Venus:	Earth:	Mars
$T_{SURFACE} \approx 753$ K	$T_{SURFACE} \approx 288$ K	$T_{SURFACE} \approx 217$ K
$T_{EFFECTIVE} \approx 232$ K	$T_{EFFECTIVE} \approx 255$ K	$T_{EFFECTIVE} \approx 217$ K

Effective Temperature

My Favorite Planets

Venus:	Earth:	Mars
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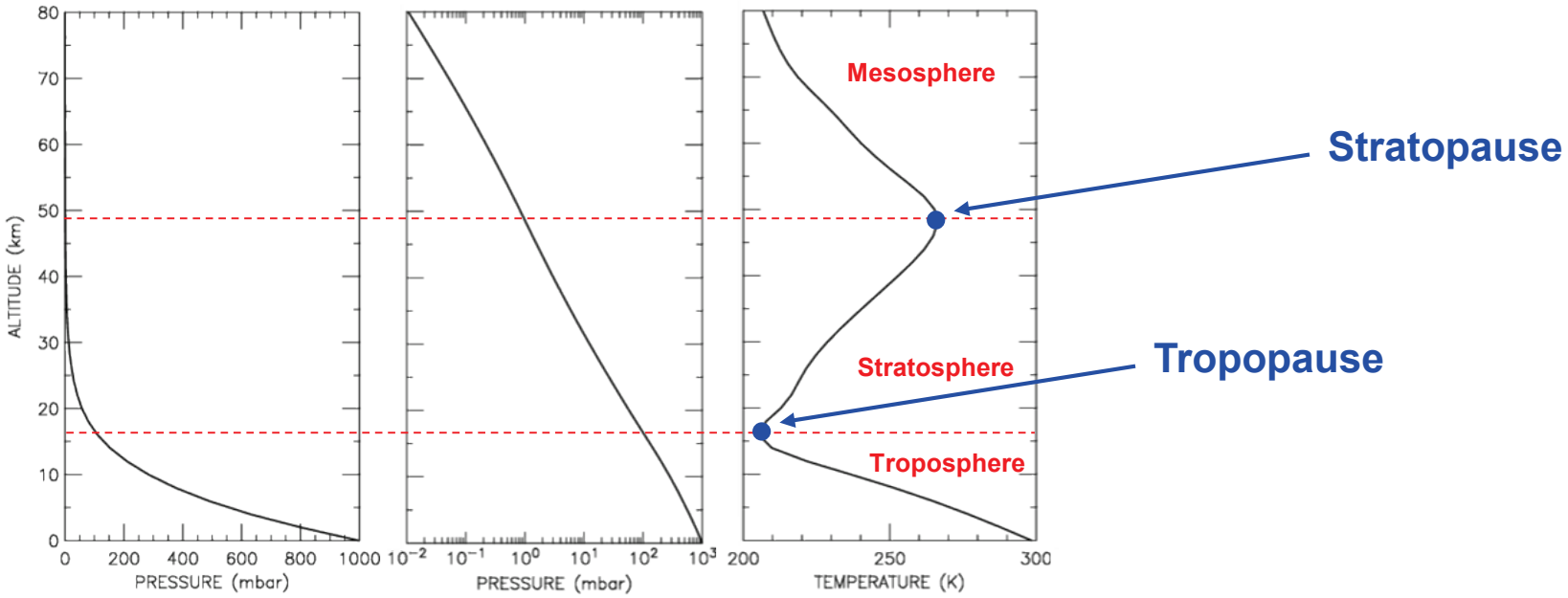
What is going ?

Temperature versus Altitude



- **T falls wrt increasing altit until the tropopause, then rises wrt altit until the stratopause, then falls wrt to rising altitude**

If the troposphere is dry, $dT/dz = -\,grav / c_p$

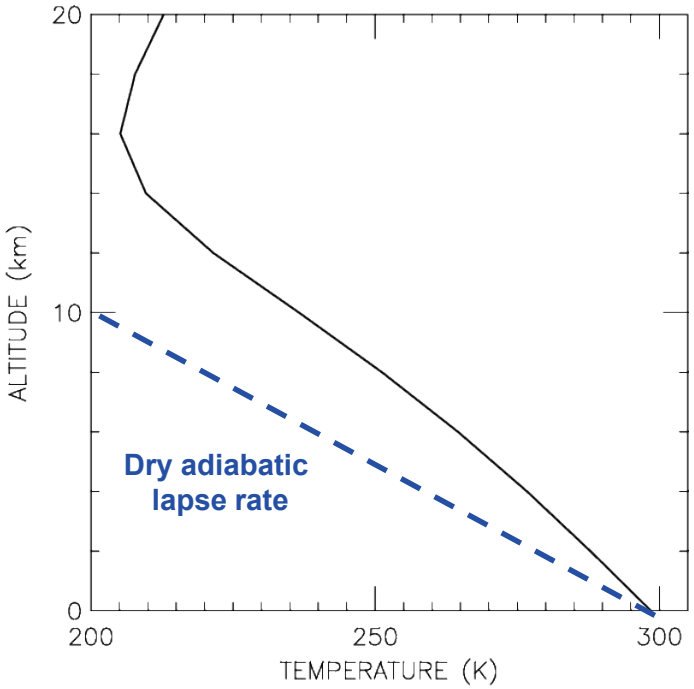
where c_p is specific heat of air at constant pressure = 1×10^7 erg gm^{-1} K^{-1}

Note: 1 erg = 1 dyne cm = gm cm^2 sec^{-2}

⇨ $dT/dz^{DRY} = -\,981$ cm $sec^{-2} / (10^7$ cm^2 sec^{-2} $K^{-1}) \times 10^5$ cm/km = 9.8 K / km

Dry adiabatic lapse rate

Temperature versus Altitude



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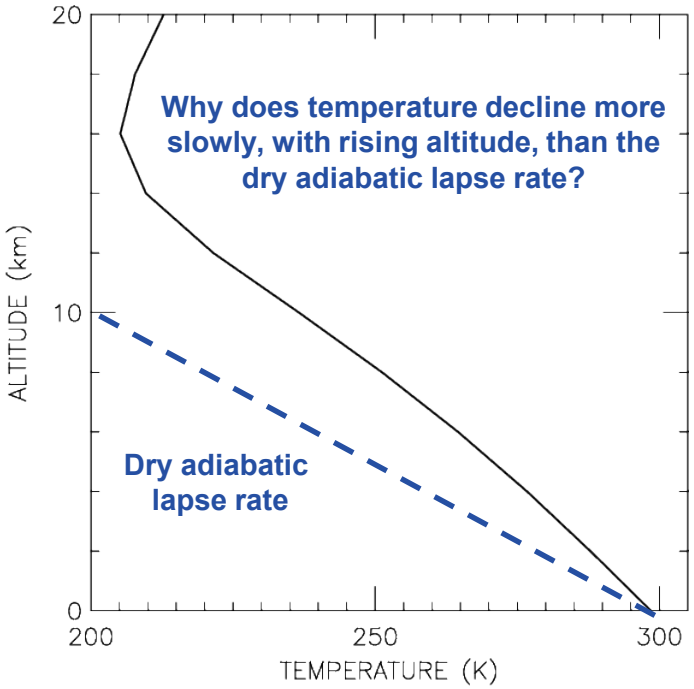

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Dry adiabatic lapse rate

Back to the ATs

AT3, Q4:

According to *Chemistry in Context*, if all of the ozone in Earth's atmosphere could be isolated and brought to the surface at a pressure of 1 atmosphere and a temperature of 15°C), the resulting gas would have a thickness of how many inches?

0.25 inch

AT3, Q5:

If all of the molecules in the entirety of Earth's atmosphere could be isolated and brought to the surface (at a pressure of 1 atmosphere and a temperature of 15°C), the resulting gas would have a thickness of about 7.4×10^5 cm. This equals 7.4 km, about 4.6 miles, or 2.9×10^5 inches.

Compute the mean mixing ratio of ozone throughout Earth's atmosphere (this is a simple ratio of two numbers), ***express the answer in parts per million.***

Mean mixing ratio of ozone: 0.25 inch / 2.9×10^5 inch = 6.8×10^{-7} (no units!)

Note: mixing ratio has used throughout this class means number mixing ratio or: $\frac{\text{moles of a particular gas}}{\text{moles of all gases in the air sample}}$

To convert 6.8×10^{-7} to ppm, need to realize 1 ppm corresponds to: $\frac{1 \text{ moles of a particular gas}}{10^6 \text{ moles of all gases in the air sample}}$

Hence, $6.8 \times 10^{-7} \times 1 \text{ ppm} / 10^6$ = **0.68 ppm** ***OR*** **0.68 ppm × (1000 ppb / ppm) = 680 ppb**

NAAQS for O_3 given is 70 ppb, about a factor of 10 lower than about number

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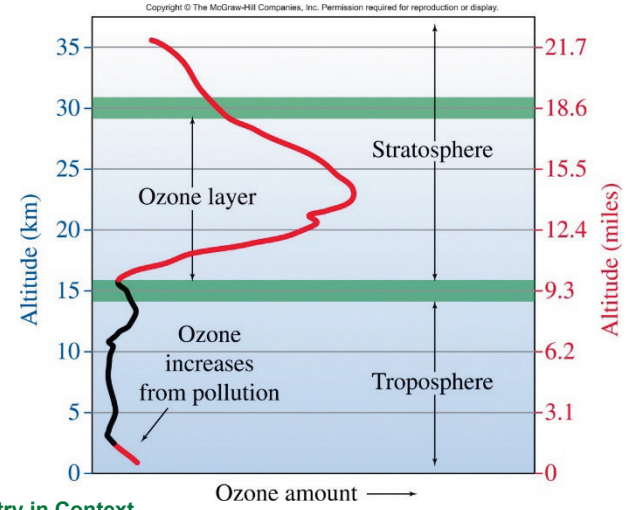
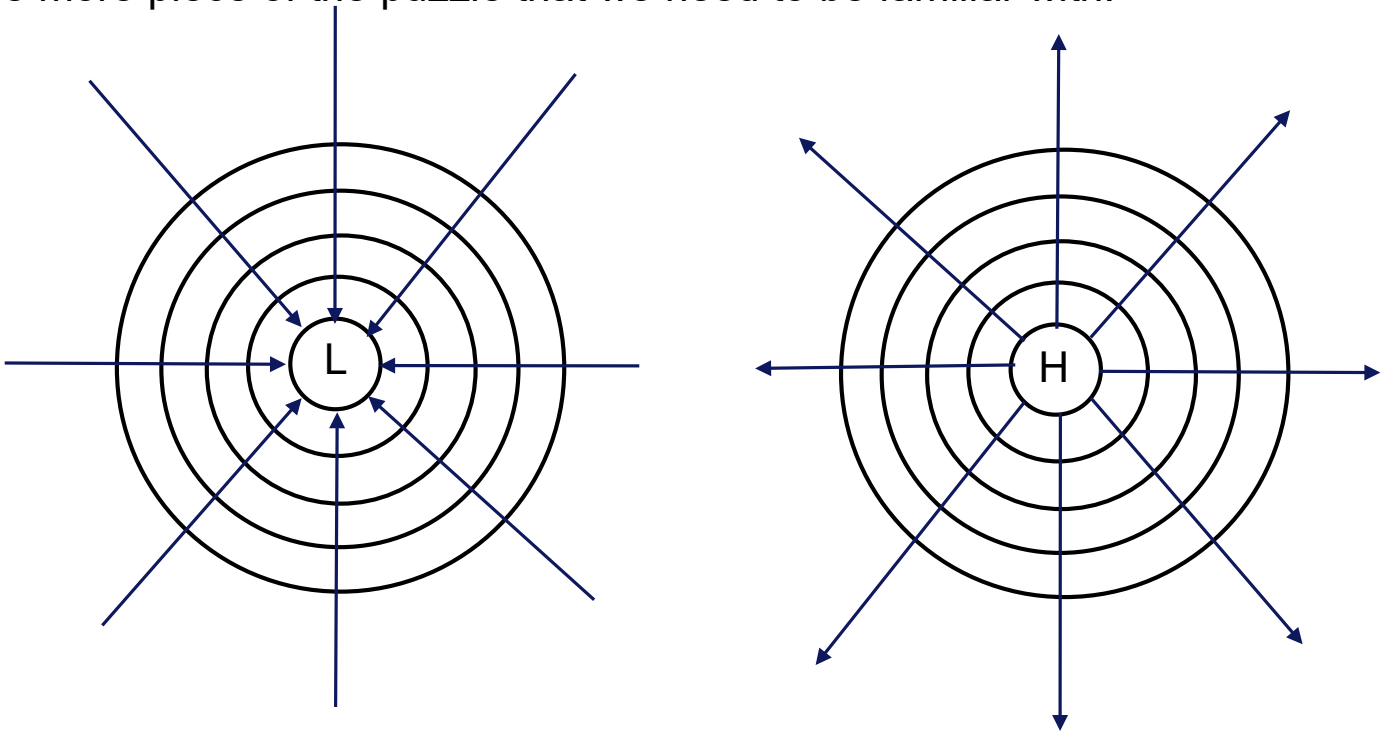


Figure 2.2, Chemistry in Context

Coriolis Force

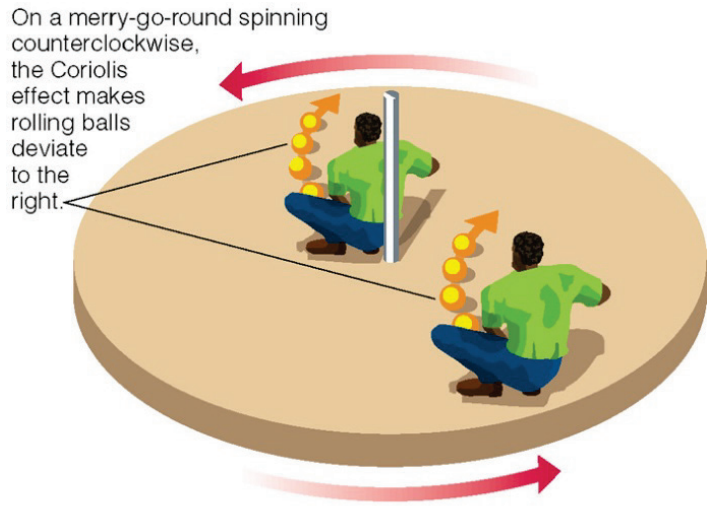
So far, we've reviewed temperature, pressure, and the balance between solar energy input to the atmosphere and terrestrial radiation leaving the atmosphere.

There's one more piece of the puzzle that we need to be familiar with.



In general, air moves from areas of high pressure to areas of low pressure. In the absence of external forces, air will move in a straight line, following pressure gradients

Coriolis Force



http://lasp.colorado.edu/~bagenal/3720/CLASS15/15EVM-Dyn1.html

Earth's rotation provides an apparent force that deflects air
to the right in the Northern Hemisphere,
to the left in the Southern Hemisphere.

Force is proportional to sin(latitude), so vanishes at the equator

Geostrophy

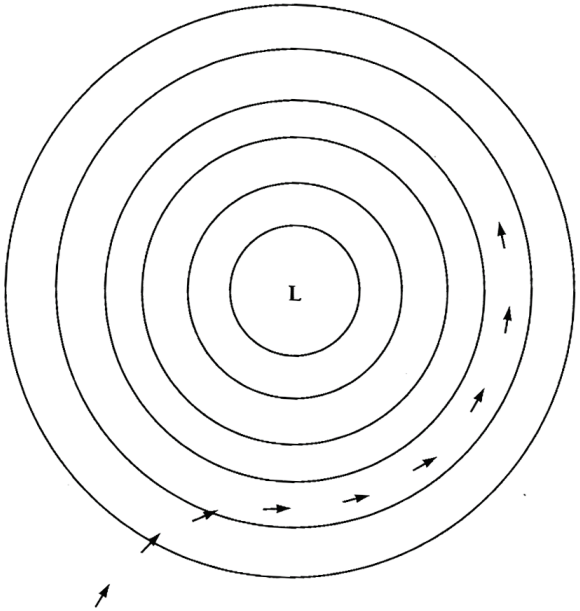


Figure 8.16 Track of an air parcel in the vicinity of a low pressure region in the Northern Hemisphere. The parcel is initially at rest but then adjusts to the pressure gradient force and the Coriolis force to achieve geostrophic balance.

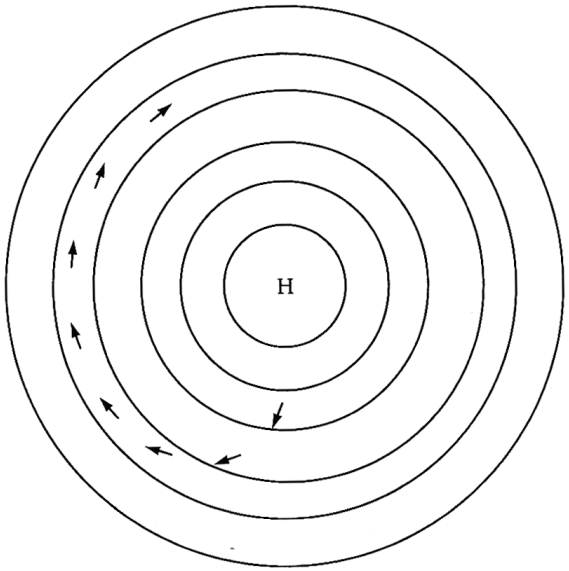


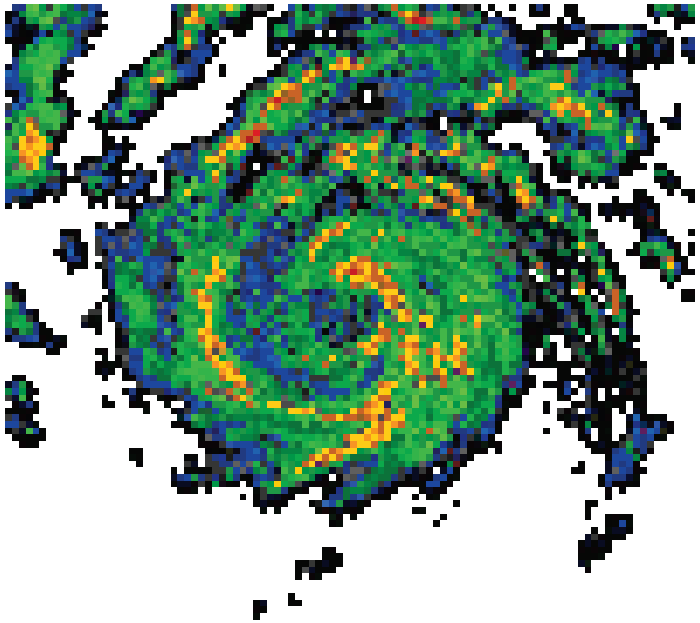
Figure 8.17 Same situation as in 8.16, except that the parcel is in the vicinity of a high pressure region in the Northern Hemisphere.

From "The Atmospheric Environment", M. B. McElroy

Geostrophic balance: balance between Coriolis Force and pressure gradient

Geostrophy

NH Weather System:

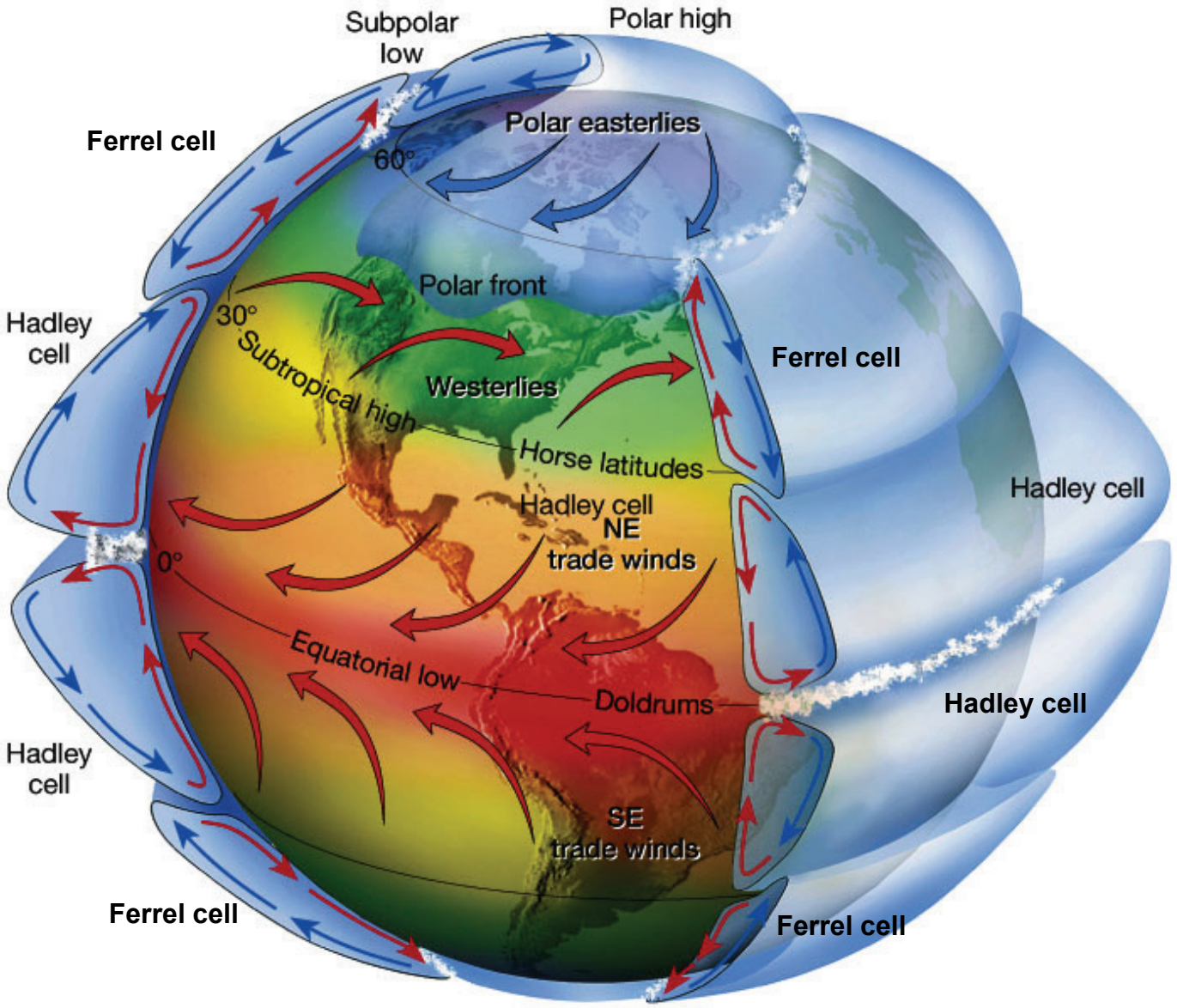


Cyclonic Flow: when the wind swirls
counter-clockwise in the NH

Hurricane: Cyclonic flow occurring in the N Atlantic or NE Pacific Ocean east of the dateline.

Typhoon: Cyclonic flow occurring in the NW Pacific Ocean, west of the dateline.
Cyclones: Cyclonic flow occurring in the South Pacific and Indian Ocean.

Ferrel Circulation (Modern View)



http://www.ux1.eiu.edu/~cfjps/1400/circulation.html

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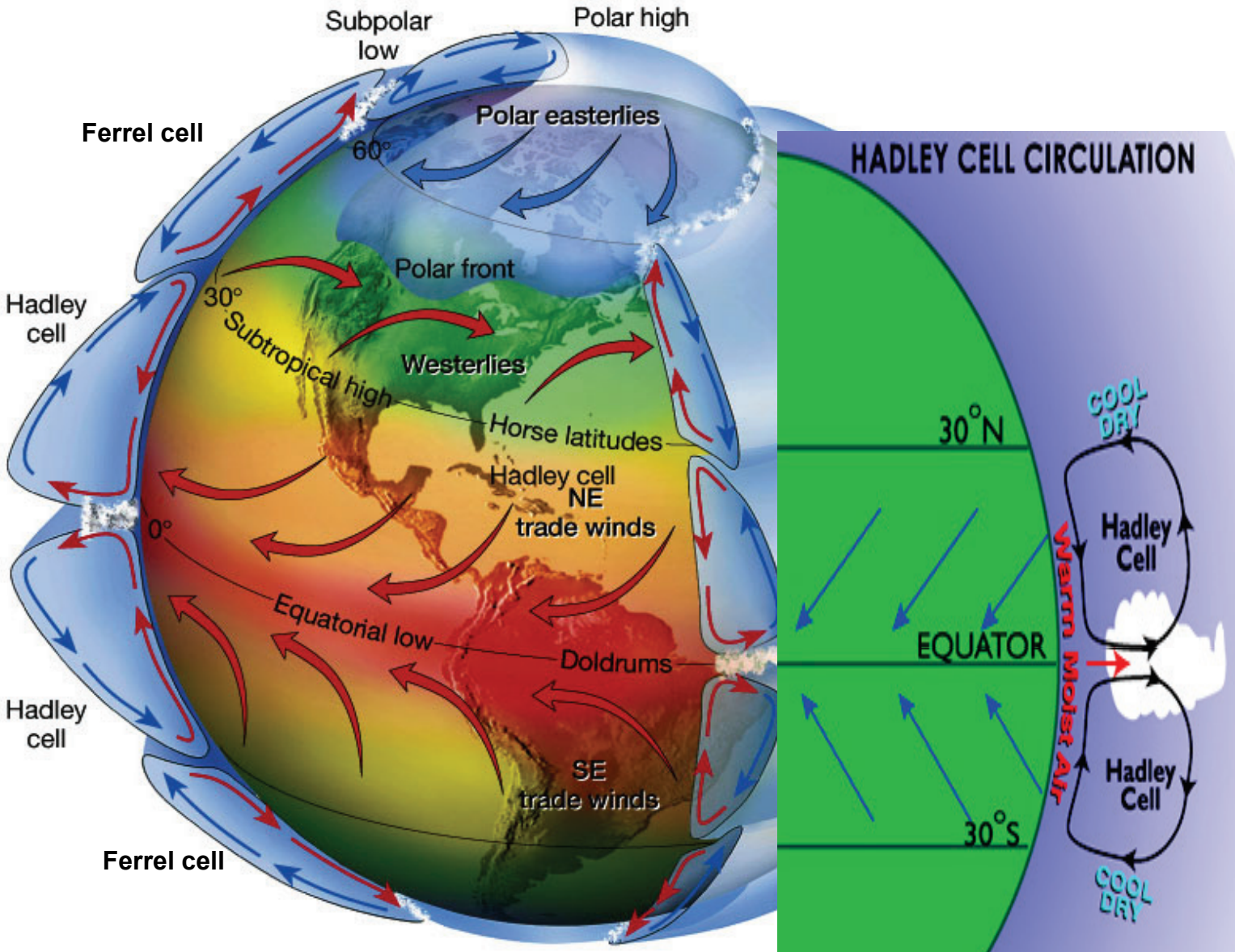

Next Lecture: Climates of the Past

Next Reading:

Chemistry in Context, Secs 2.2, 3.0, 3.1, 3.2 (~14 pgs)

as well as 8 pages from *Global Warming: The Complete Briefing* by Houghton
7 pages from *Paris Beacon of Hope*

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