Climate and Climate Change

Fred F. Hattermann
Potsdam Institute for Climate Impact Research

Outline of the three lessons

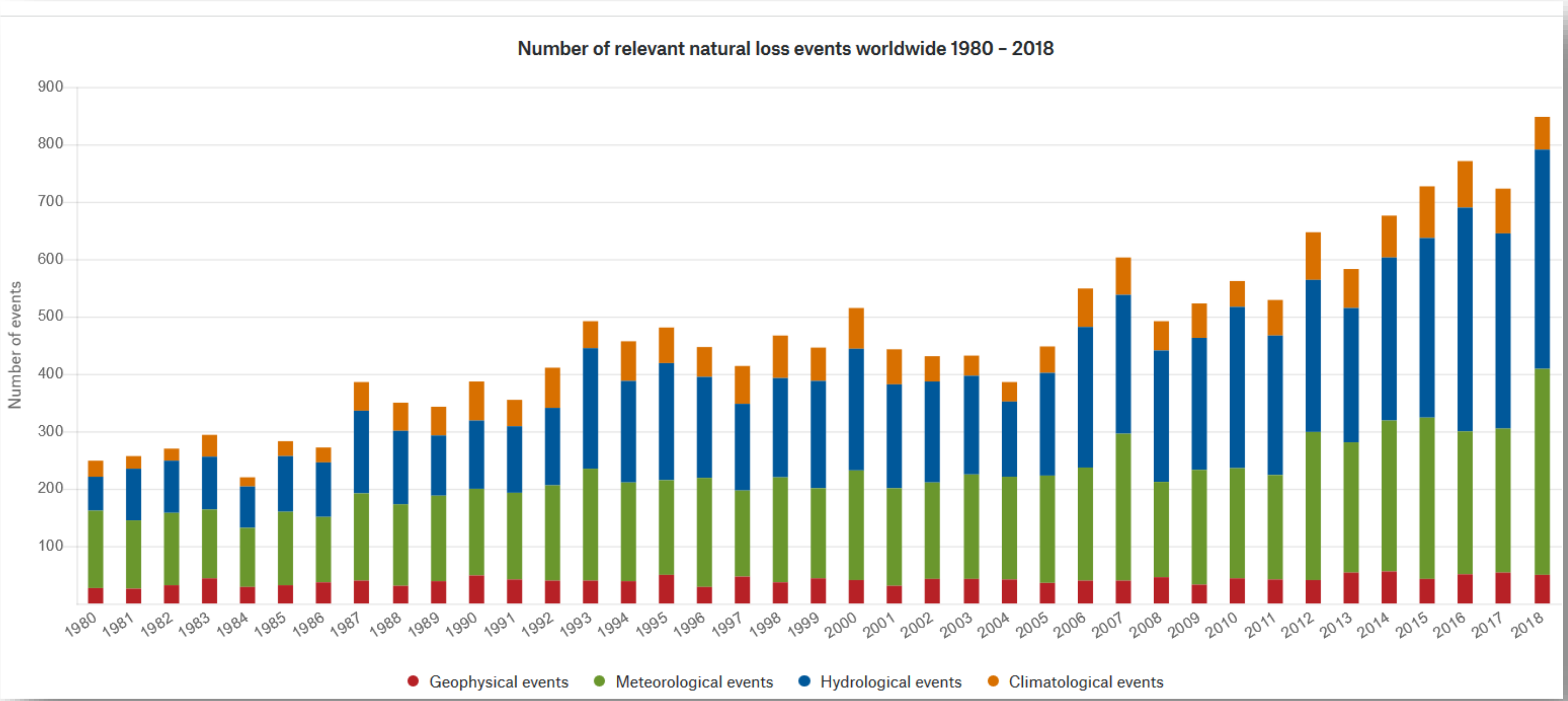
- Introduction
- Climate – drivers and processes
- Climate and live
- Observed climate change and change

Climate change?

Climate change?

Climate change?

Number of events worldwide (Munich Re NatCat)



P I K

UN sustainable development goals

What we will learn

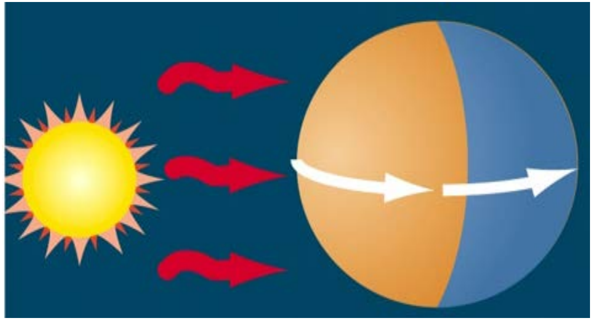
- The climate of earth is driven by solar energy / radiation
- This shapes live on erarth
- Human activities influence the energy budget
- This impacts on climate and live on earth
- Rigid mitigation is necessary to avoid un-manageable impacts

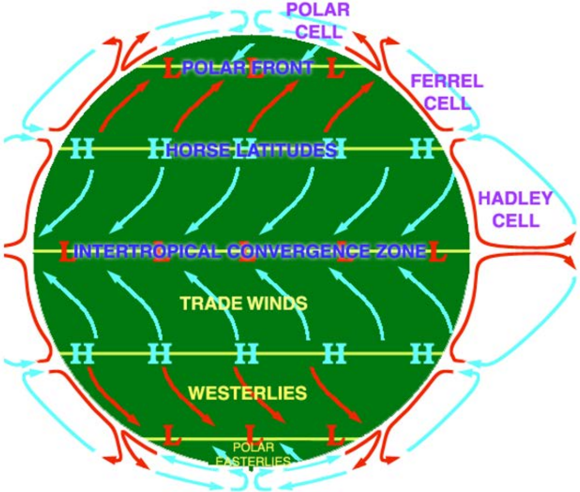
Outline of the three lessons

- Introduction
- Climate – drivers and processes
- Climate and live
- Observed impacts of climate change

I - From Radiative Forcing to Atmospheric Circulation

1. Energy distribution on Earth’s surface
2. Air circulation in the atmosphere
3. Effects of Earth’s rotation
4. The Coriolis effect
5. Global atmospheric flux processes
6. Earth’s resulting circulation cells





Source: James F. Kasting - http://www.powershow.com/view/5a855-YWRmO/Atmospheric_Circulation_flash_ppt_presentation

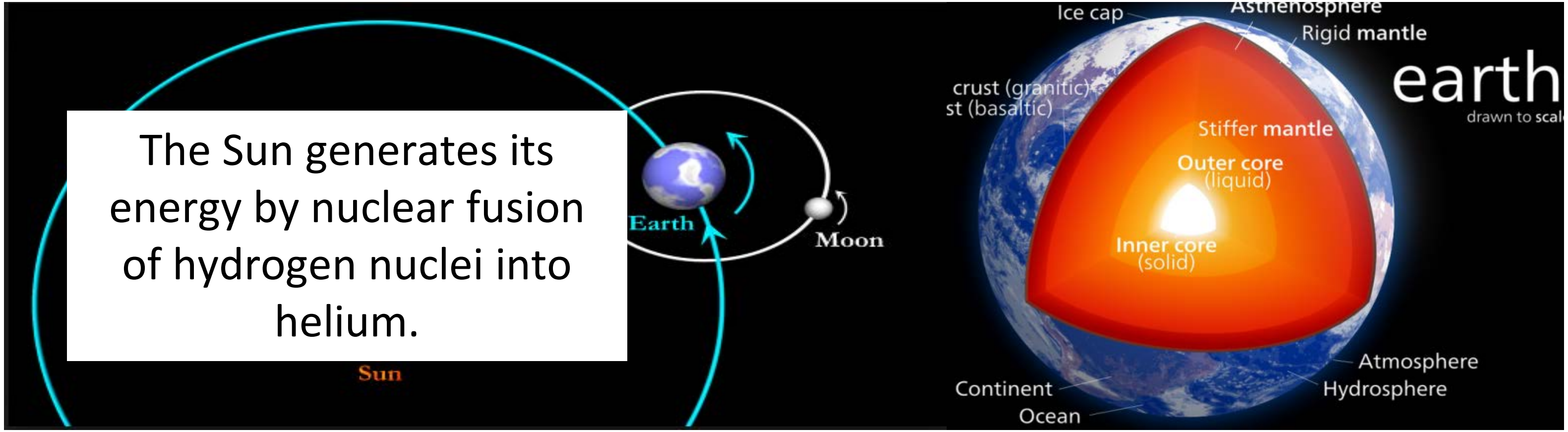
Which Quantities and Units do we use for Energy?

• **Energy**	**E**	**J** (Joule)	
• **Work**	**L**	**W** (Watt)	energy per time
		W = J/s	
• **Energy Flux**	**S**	**W/m²**	work per area

Other Units used

- **Electricity:** **kilowatt-hour** (kWh);
  1 kWh = 3.6×10^6 J
- **Food:** **calorie** (cal) or Calorie (kcal)
  1 cal = 4.184 J

Earth's Energy Sources



Sun's surface temperature (5780 K) ~ Earth's core temperature (6300 K)

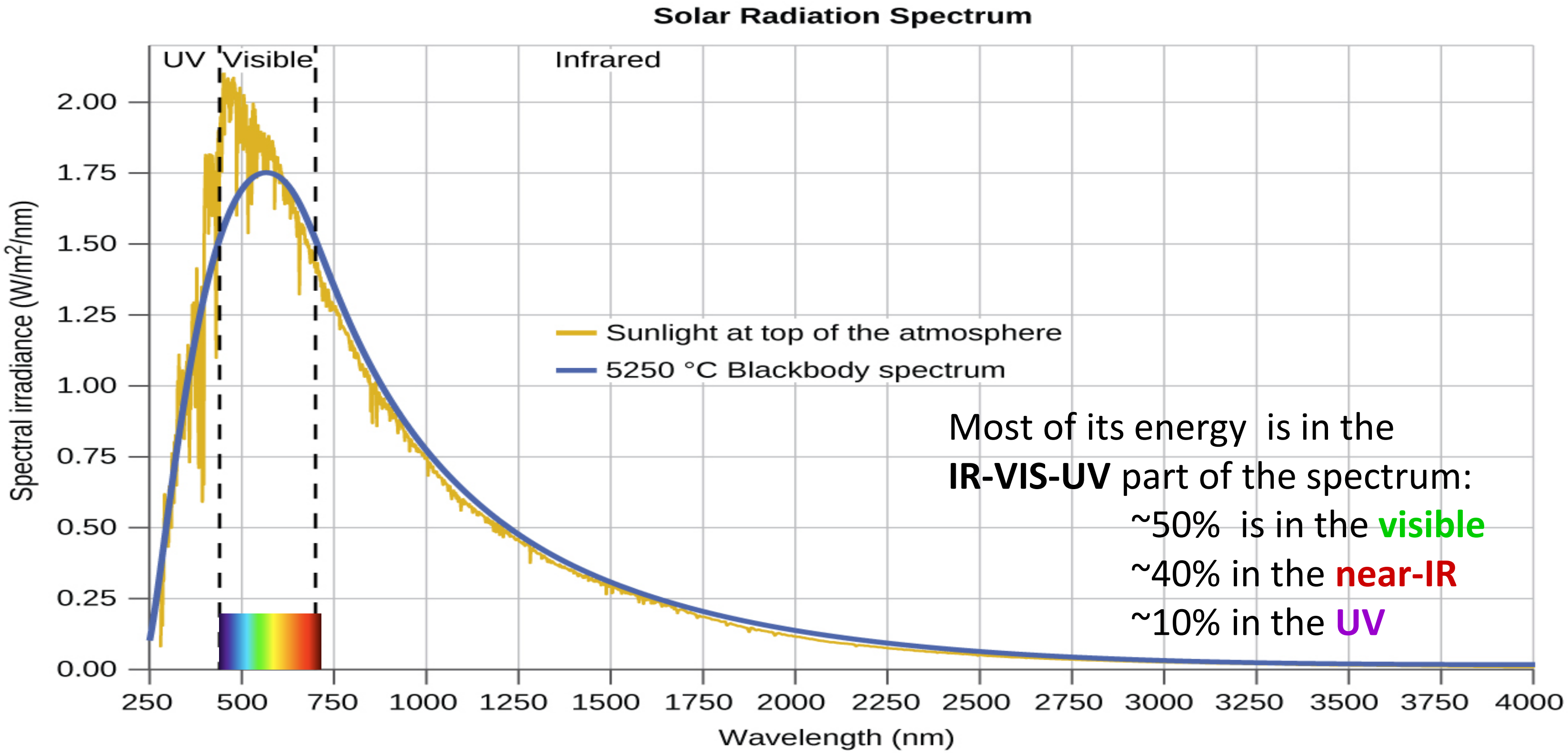
Question	Answer
Are the Earth's surface and its lower atmosphere warmed up by a) geothermal heat flux from the Earth's interior? b) incoming radiant energy from the Sun?	Its the radiation from the Sun (nearly 100%). a) = 47 Terawatts b) = 173,000 Terawatts

1 Terrawatt = 10^{12} Watt ; 1 Watt = 1 Joule/s

Longwave and shortwave radiation

- **Short-wave radiation** is the radiation coming from the 5,500 °C hot sun with a **wavelength of 0.2 to 3 µm** (micrometres), which humans partially perceive as light.
- The earth's surface and atmosphere, which are around 15 °C warm, radiate energy into space in the form of **long-wave thermal radiation (wavelength 3-60 µm)**.

Solar Radiation - Wavelength and Energy



Most of its energy is in the **IR-VIS-UV** part of the spectrum:

~50% is in the **visible**

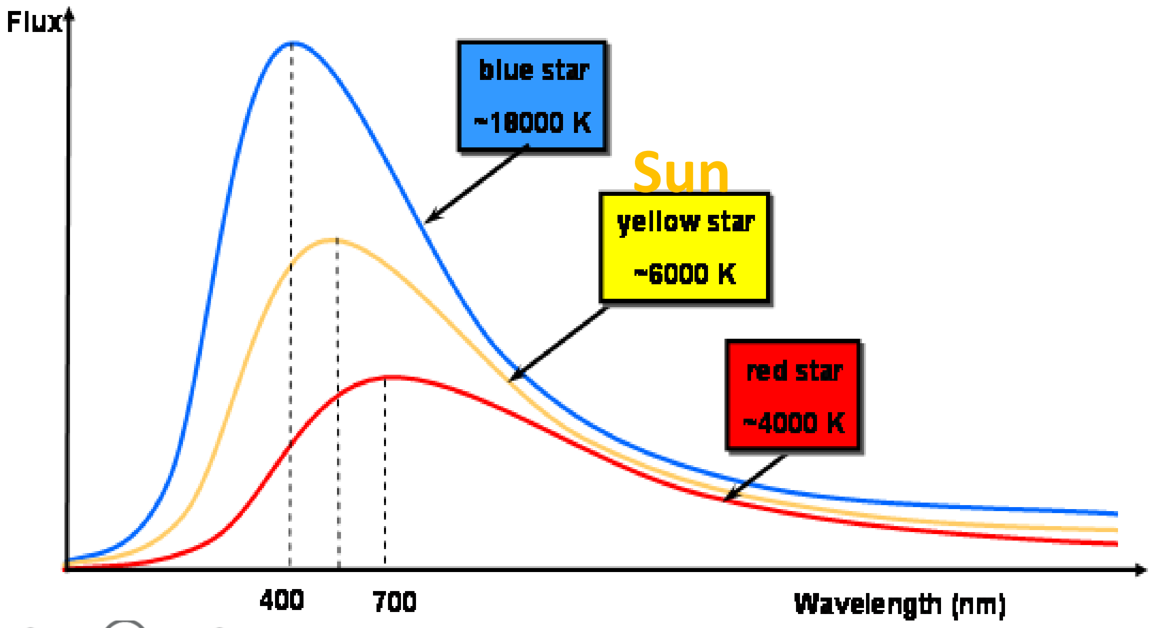
~40% in the **near-IR**

~10% in the **UV**

https://opentextbc.ca/chemistry/chapter/6-1-electromagnetic-energy/

The Relation between Radiation and Temperature

The **radiation energy flux** of light from a star
(energy per area, per time, and per wavelength)
increases with the **surface temperature T** of the star

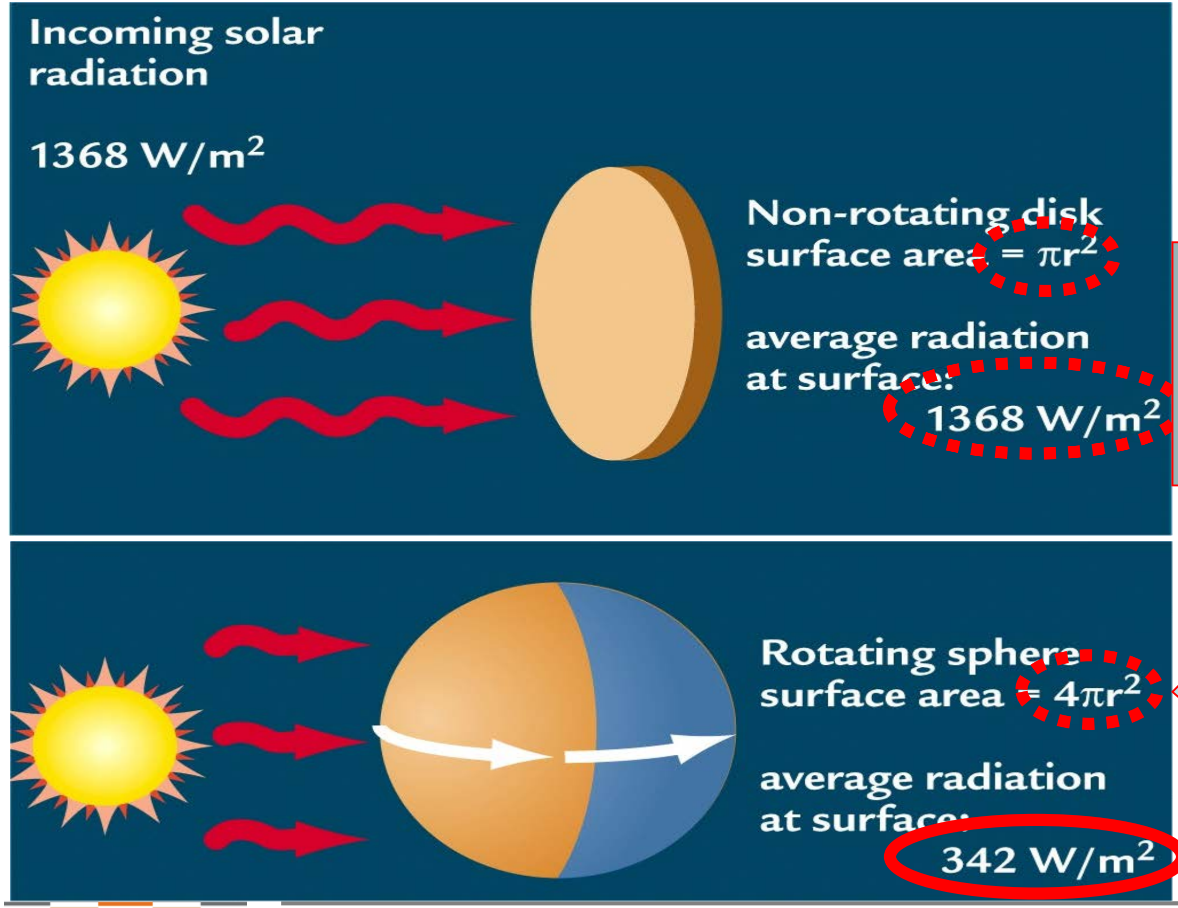


The total energy flux **S** radiated per unit area per unit time is related to temperature **T** in K as follows:

$$S = \sigma T^4$$

with $\sigma = 5.67 \; 10^{-8} \; Wm^{-2}K^{-4}$
(Stefan-Boltzmann constant)

Energy Input and Energy Distribution on Earth



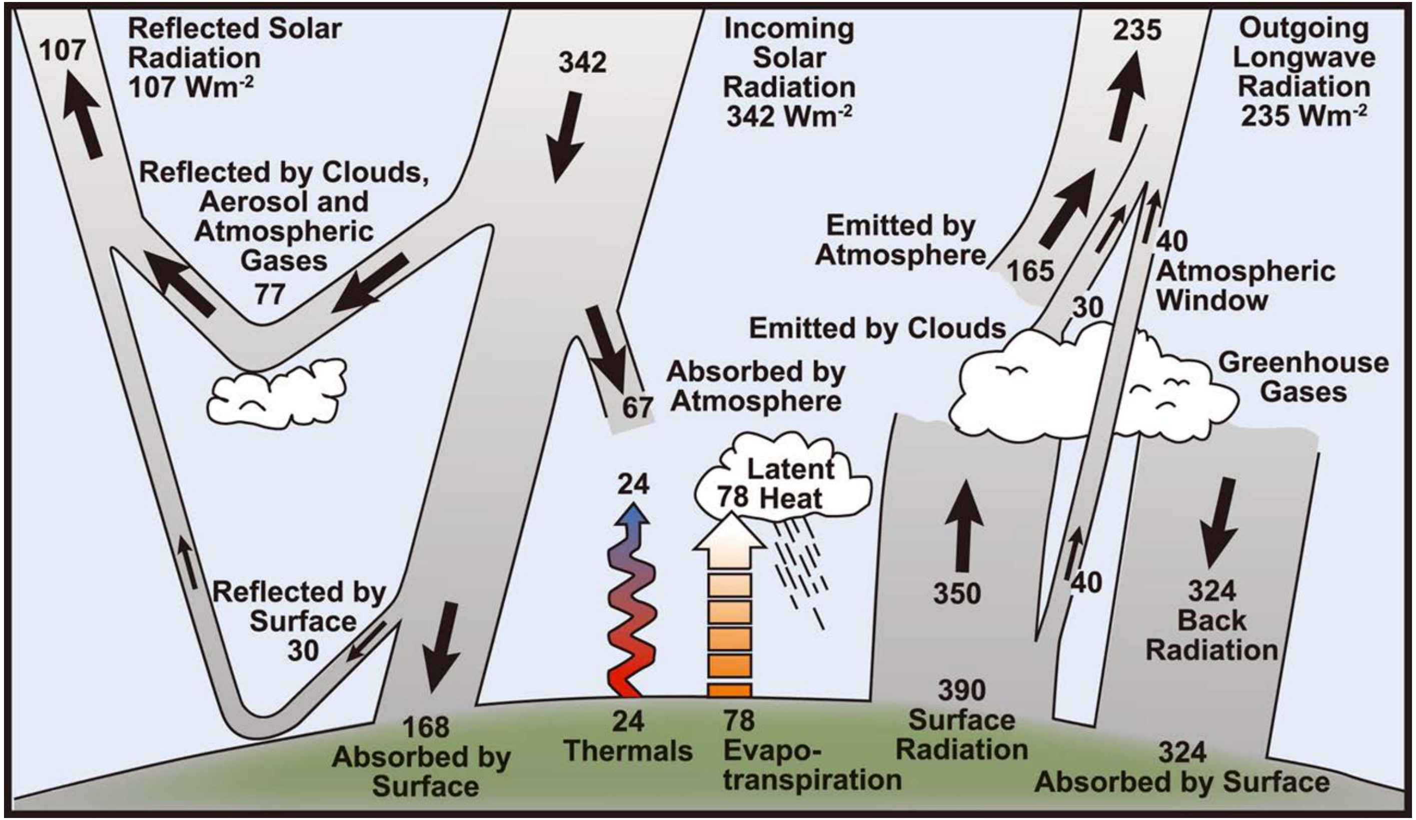
The total energy input per second at top of the atmosphere is

1368 W/m²

During a days rotation of Earth the energy is distributed over the four times larger surface area

= 1368 / 4 W/m²

Earth's Energy Balance (in W/m², ± 20% uncertainty)



First law of thermodynamics: conservation of energy

Quelle: Kiehl and Trenberth, 1997

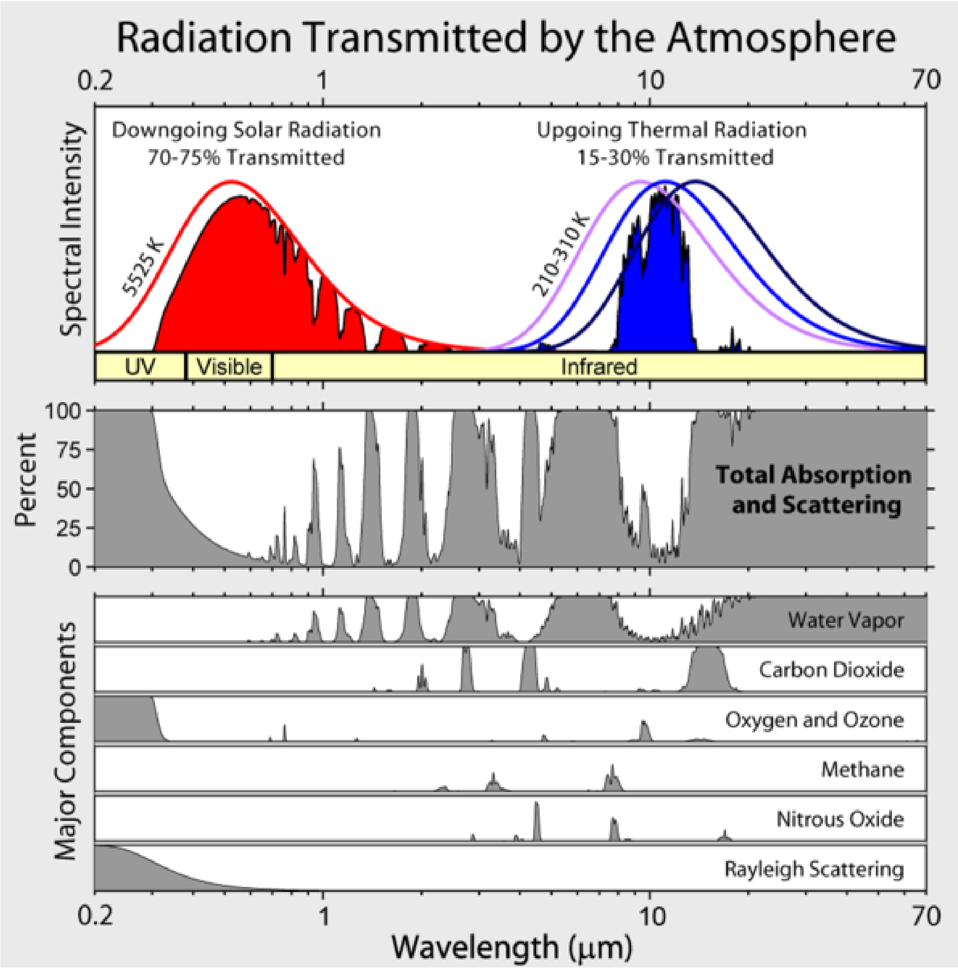
Example: 168 + 324 = 492 = 24 + 78 +390 and 342 = 107 + 235 and 165 + 30 + 40 = 235

P I K

Long-wave radiation and the greenhouse effect

- The earth's surface radiates 390 W/m² in the form of long-wave thermal radiation. Only about 40 W/m² can escape unhindered through the atmosphere into space. The remaining 350 W/m² are absorbed by the atmosphere due to the absorption properties of the atmosphere and the natural greenhouse gases it contains.
- **The property of greenhouse gases to allow short-wave radiation to pass through unhindered, but to absorb long-wave radiation, results in the much-cited greenhouse effect.**
- The resulting atmospheric counter-radiation is 324 W/m², which is radiated back towards the earth's surface. This naturally occurring greenhouse effect is a decisive prerequisite for life-friendly climatic conditions on Earth.
- **Without the natural greenhouse effect, the earth would not have a pleasant average temperature of 15°C, but an icy -18°C!**

Radiation transmitted by the atmosphere and the greenhouse effect



http://de.wikipedia.org/wiki/Datei:Atmospheric_Transmission.png

Earth's Latitude and Longitude Lines

- Latitude and Longitude lines divide up the Earth into a usable coordinate system
- Lines from W to E
  = meridians of Longitude
- Longitude measures how far E or W a location is from the Prime Meridian (through Greenwich, England)

- Lines from N to S (parallel to equator) are meridians of Latitude
- Latitude measures how far N or S a location is from the equator.

Values of Longitude
go from 180°W to 180°E

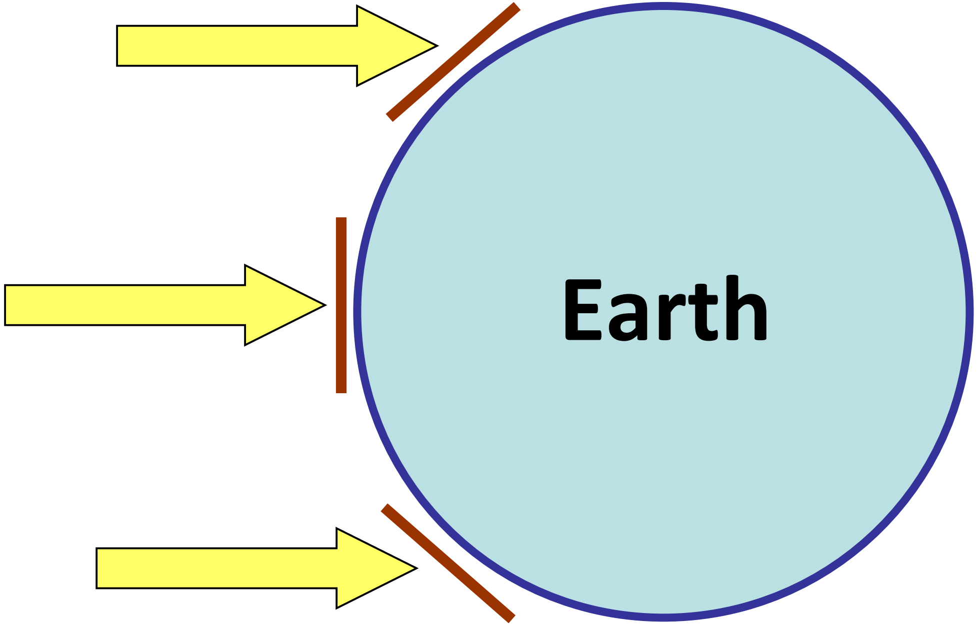
Values of Latitude
go from 90°S to 90°N

1. Energy distribution on Earth's surface

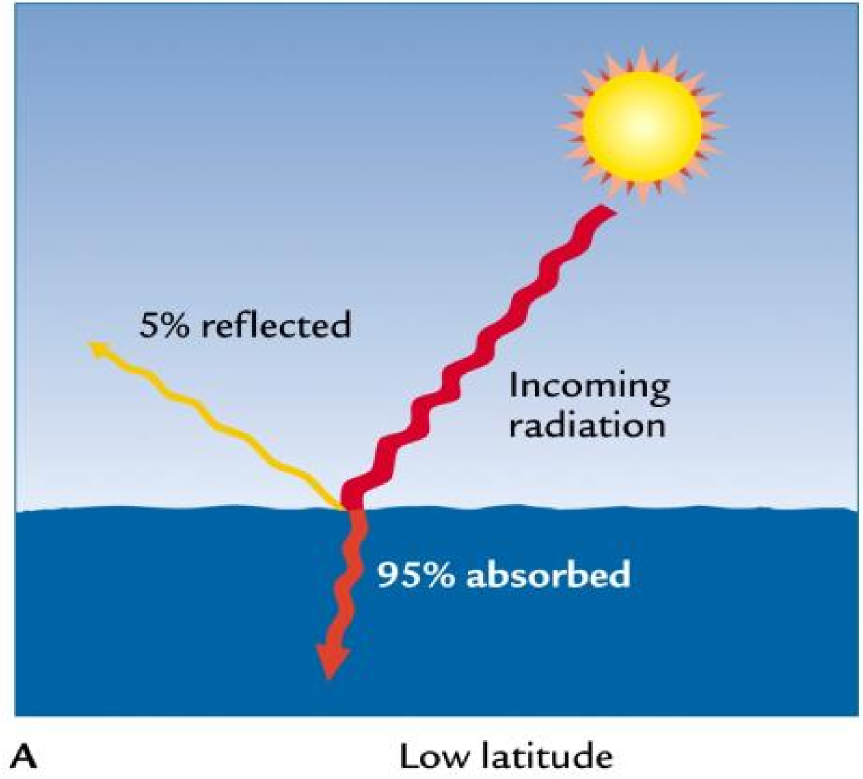
High latitudes receive light at low angles

Regions near the equator receive light at 90º

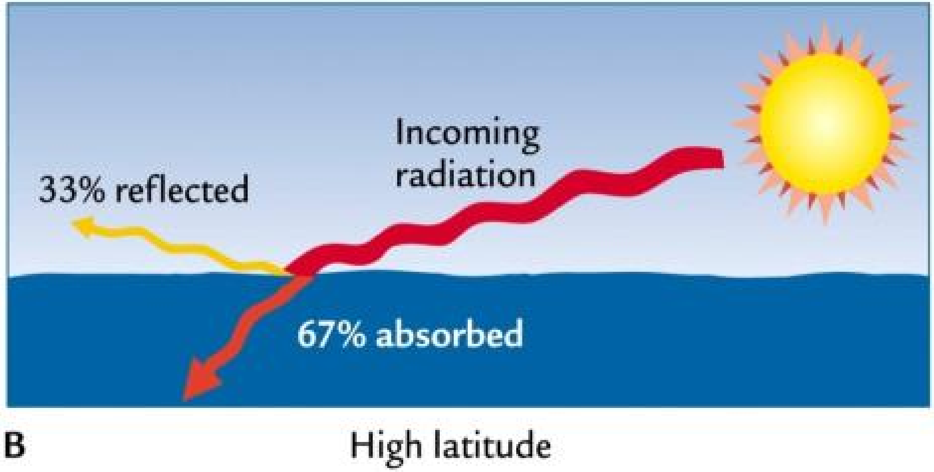
-> Light energy is more concentrated near the equator. In other words, there is a greater flux per unit area (W/m²)



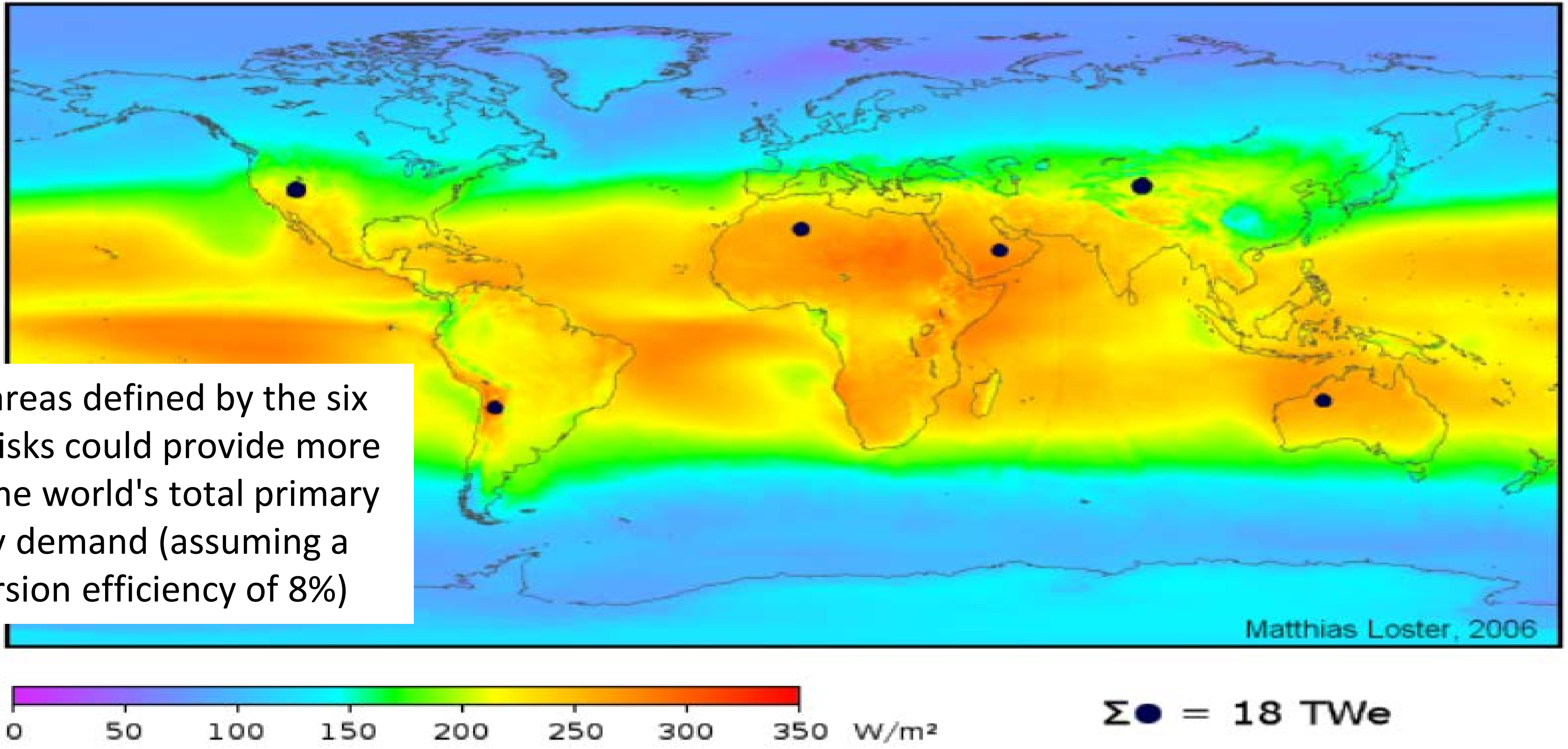
Radiation Differences at Low and High Latitudes



In low latitudes is a greater flux per unit area (W/m^2) than in high latitudes

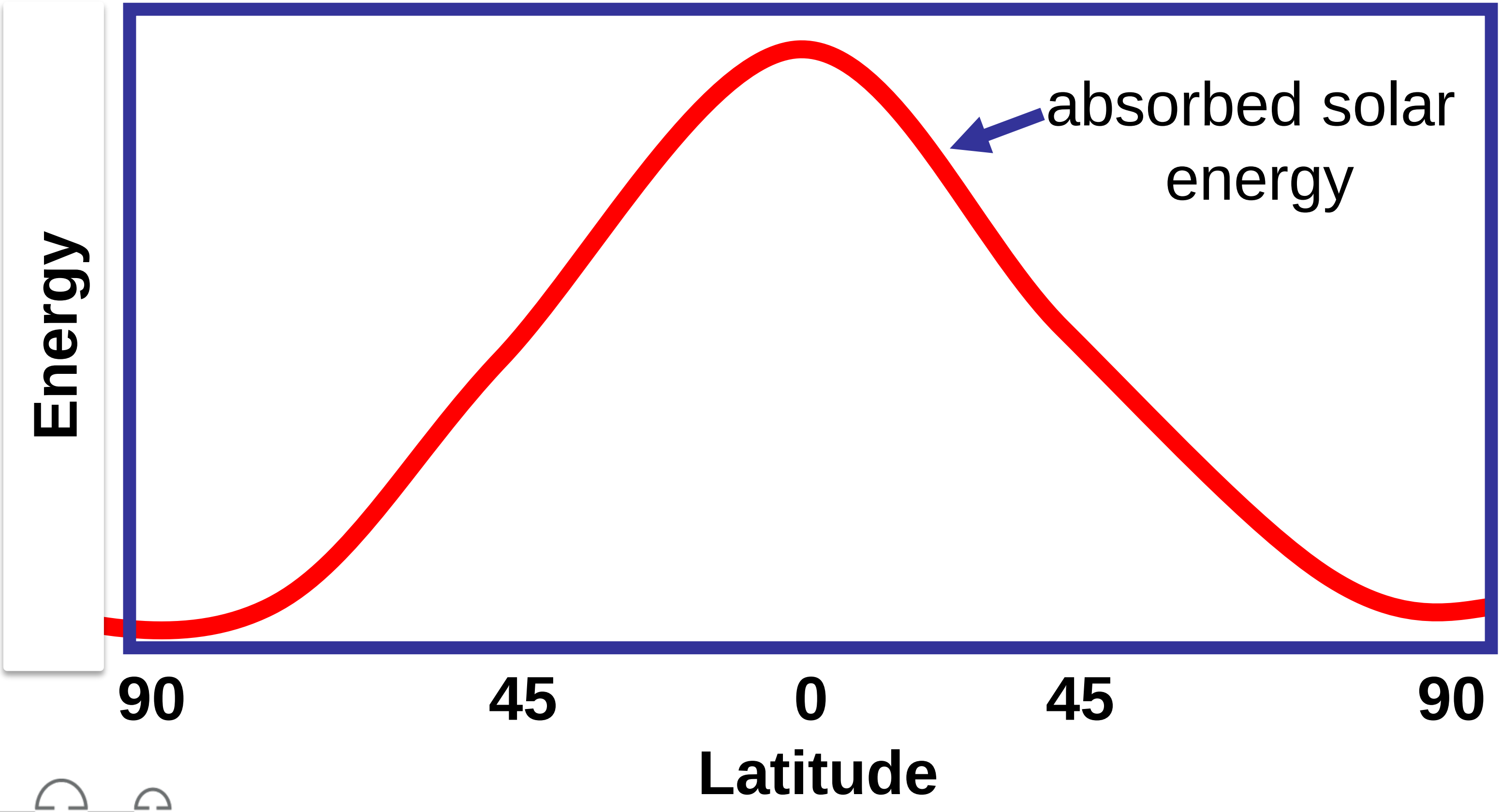


Average Incoming Solar Radiation

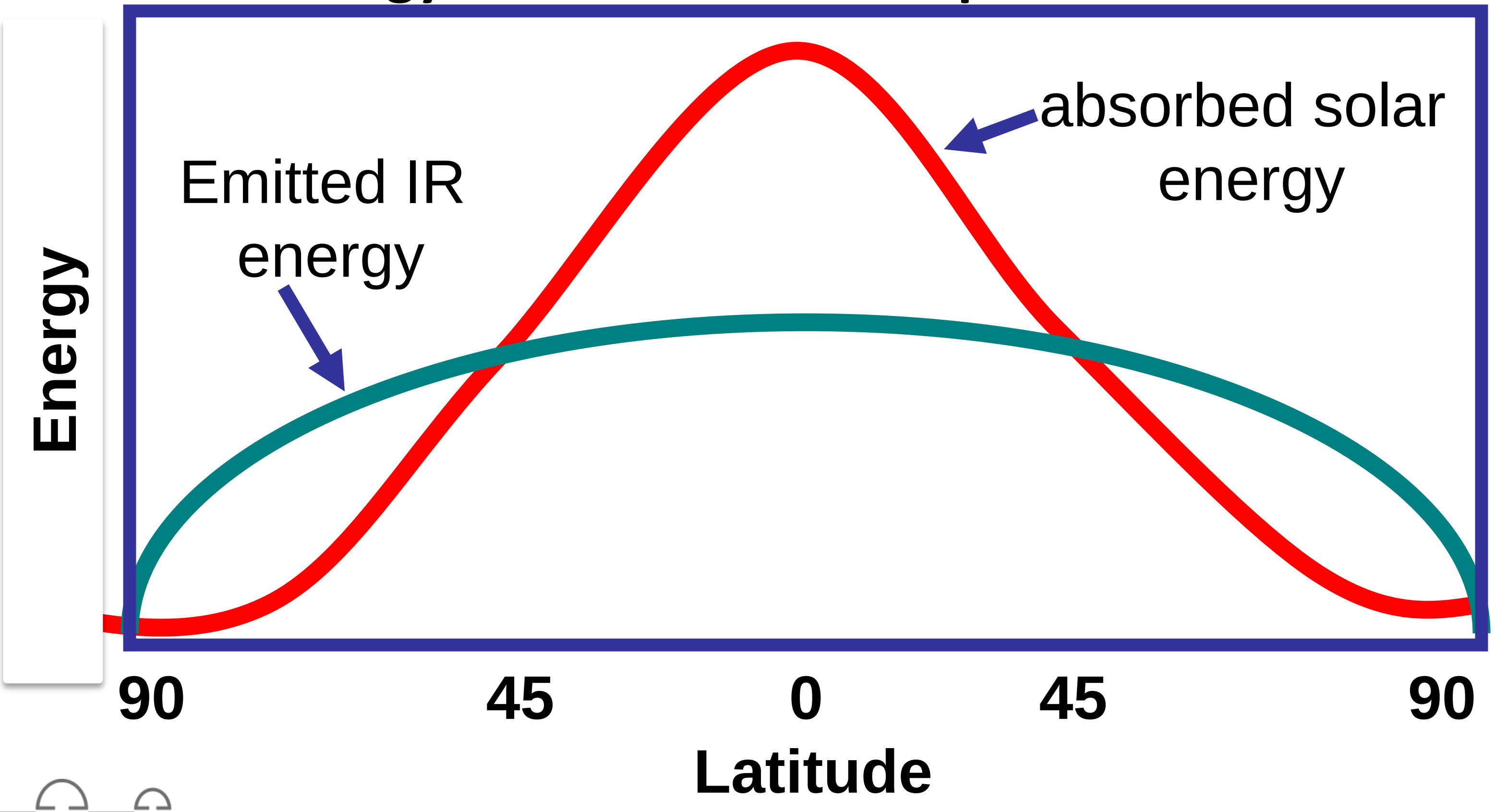


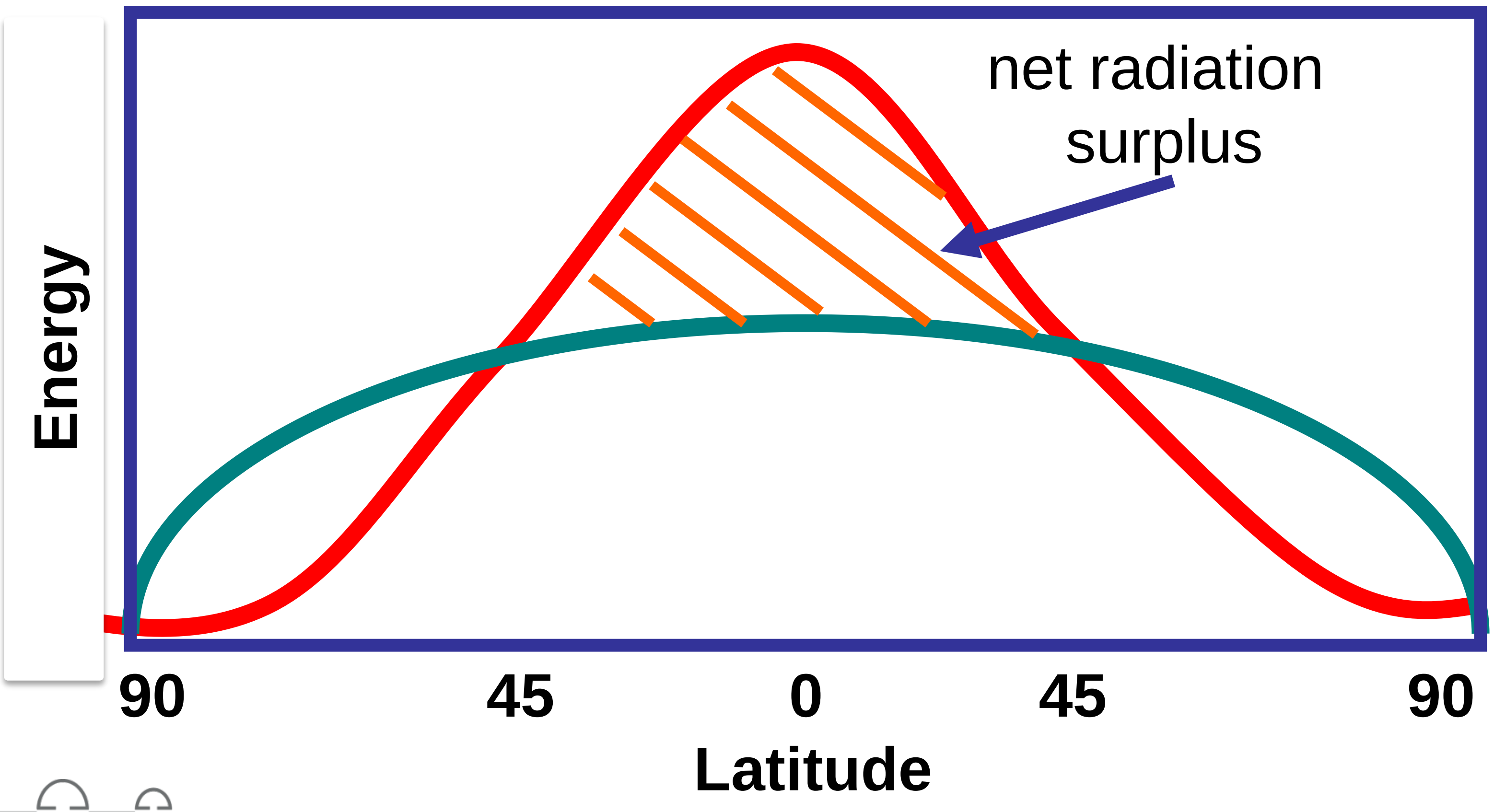
Solar areas defined by the six dark disks could provide more than the world's total primary energy demand (assuming a conversion efficiency of 8%)

http://en.wikipedia.org/wiki/Solar_energy

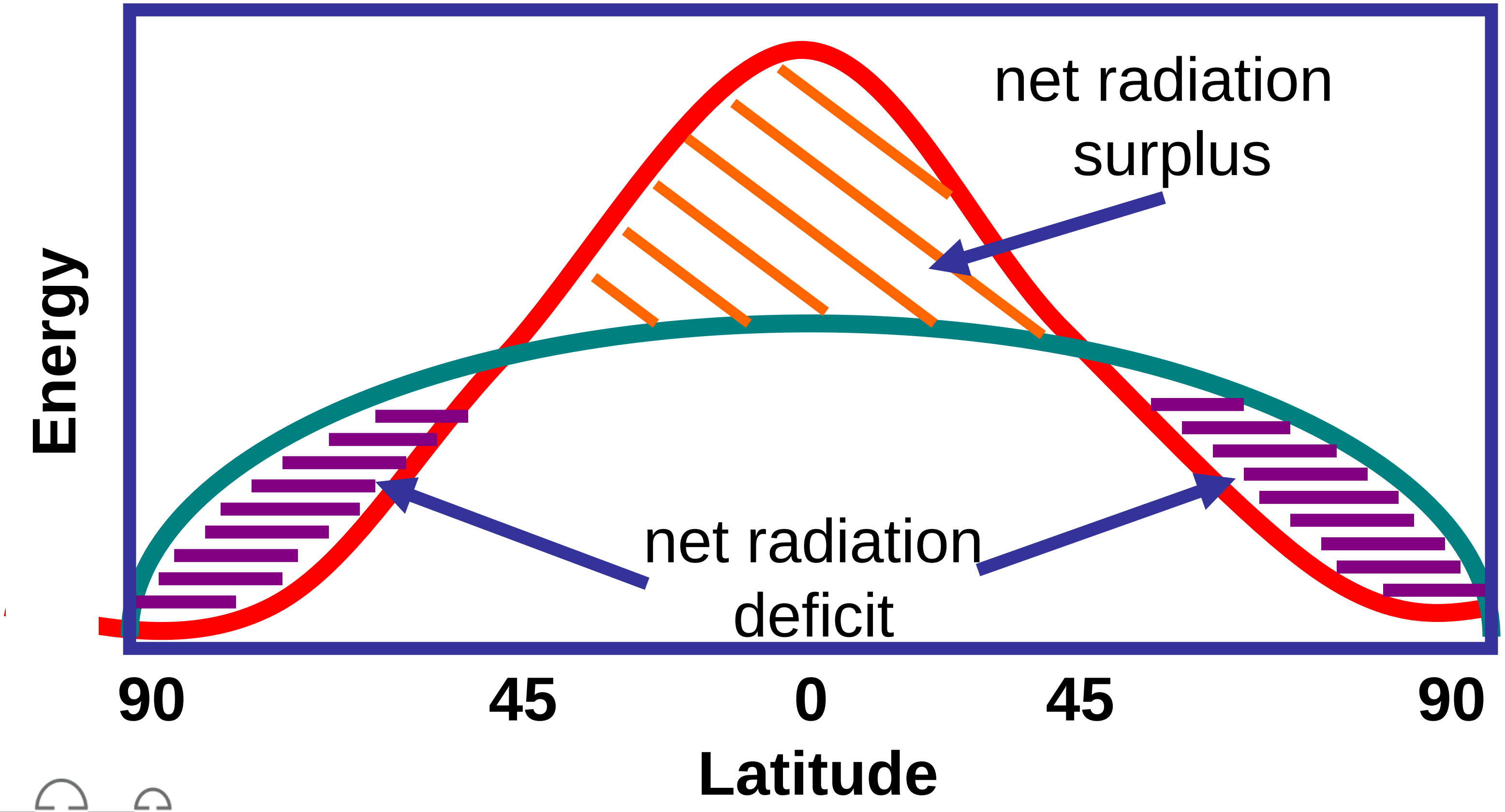

absorbed solar energy
Energy
90
45
0
45
90
Latitude

More energy is absorbed near the equator than emitted and more energy is emitted near the poles than is absorbed.



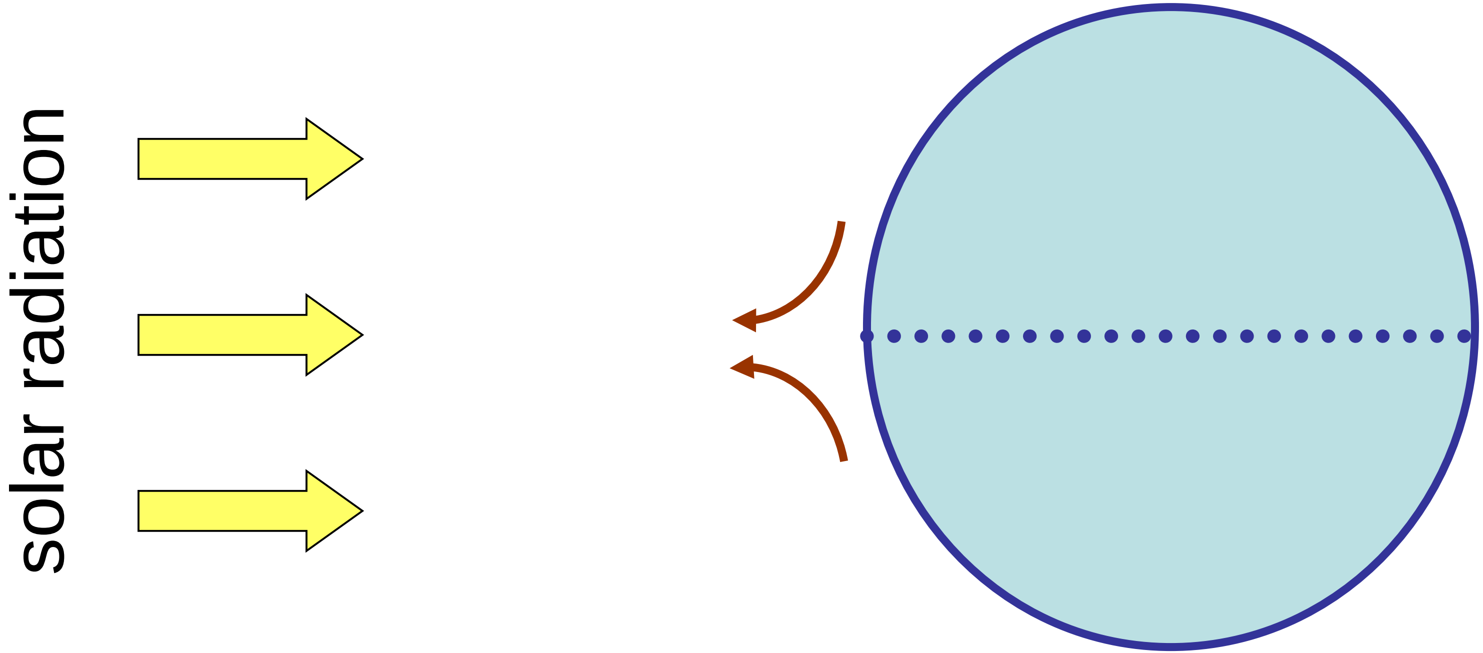

net radiation
surplus
Energy
90
45
0
45
90
Latitude

Excess energy at the equator is transferred towards the poles by convection cells

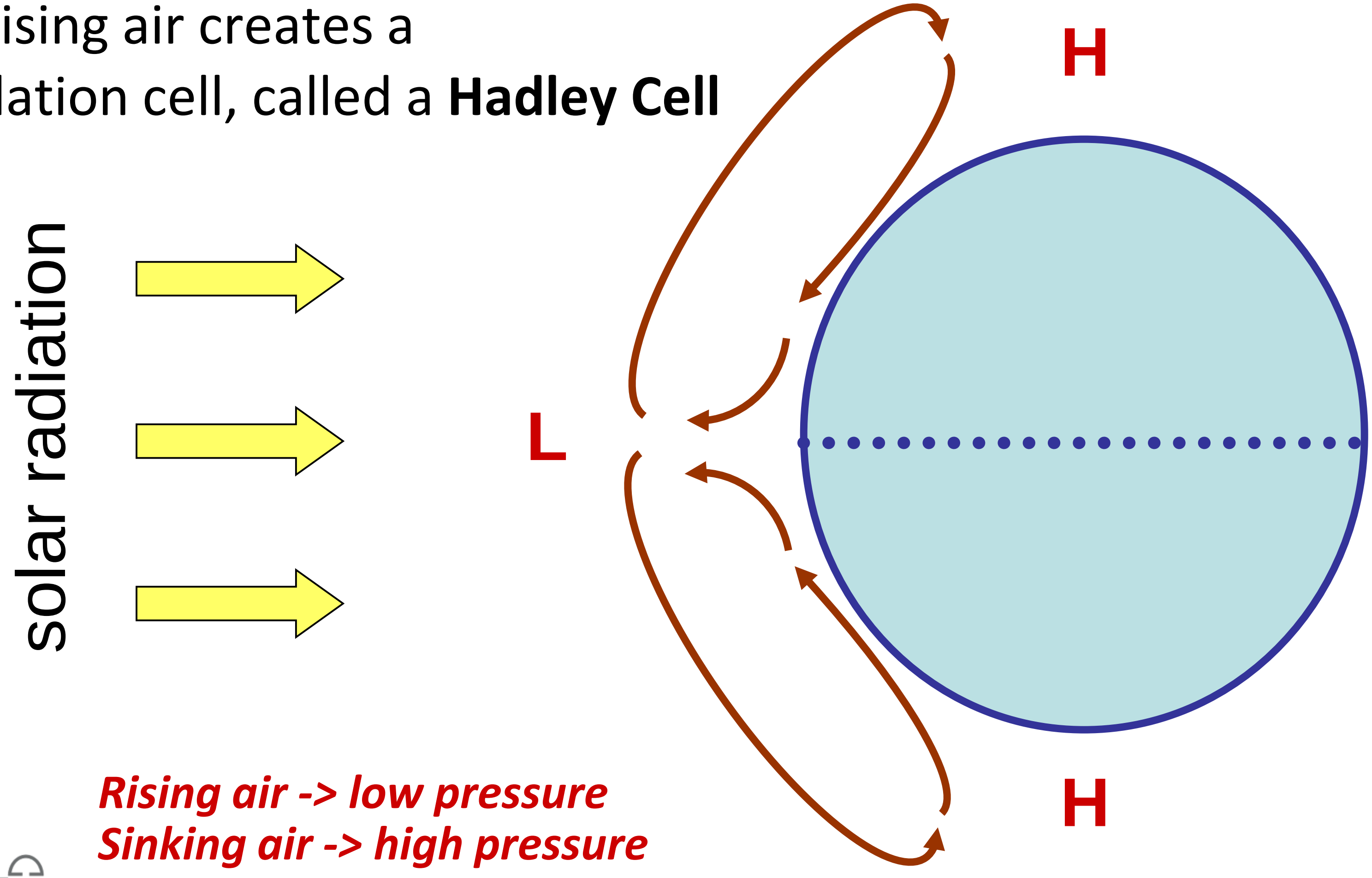


2. Air circulation in the atmosphere

Air near the equator is warmed, and rises

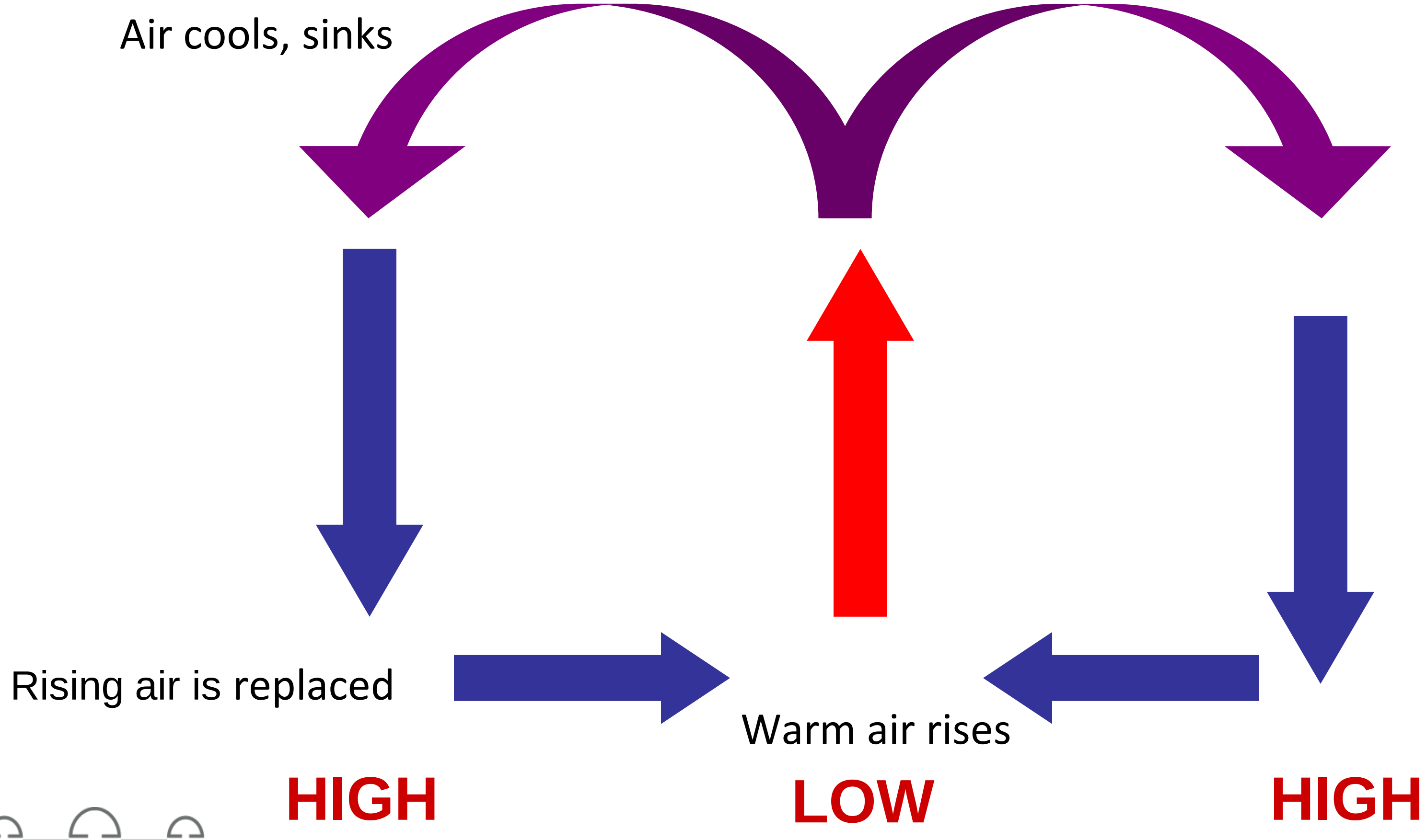


The rising air creates a circulation cell, called a **Hadley Cell**

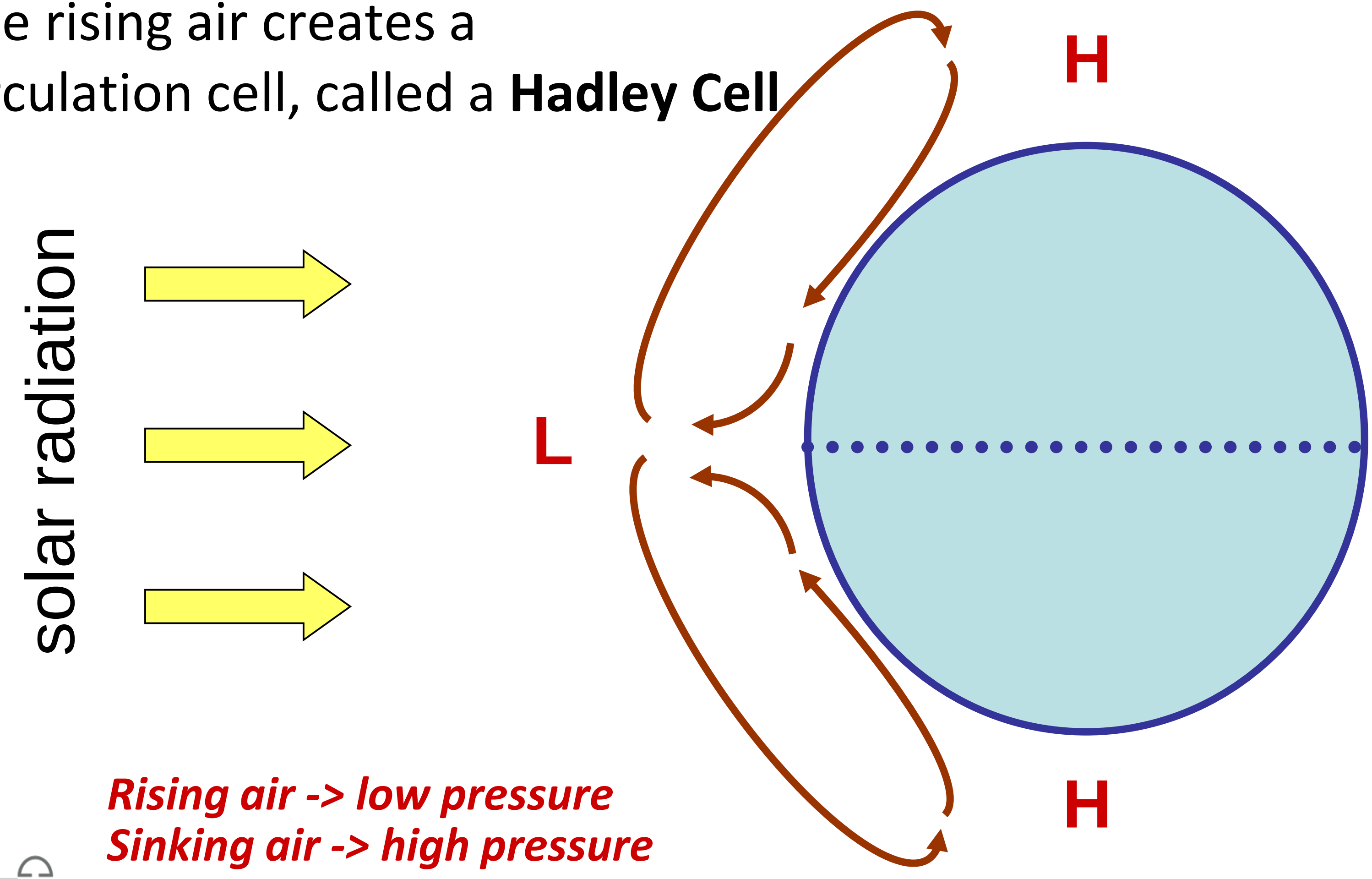


Rising air -> low pressure
Sinking air -> high pressure

Hadley Circulation Cell

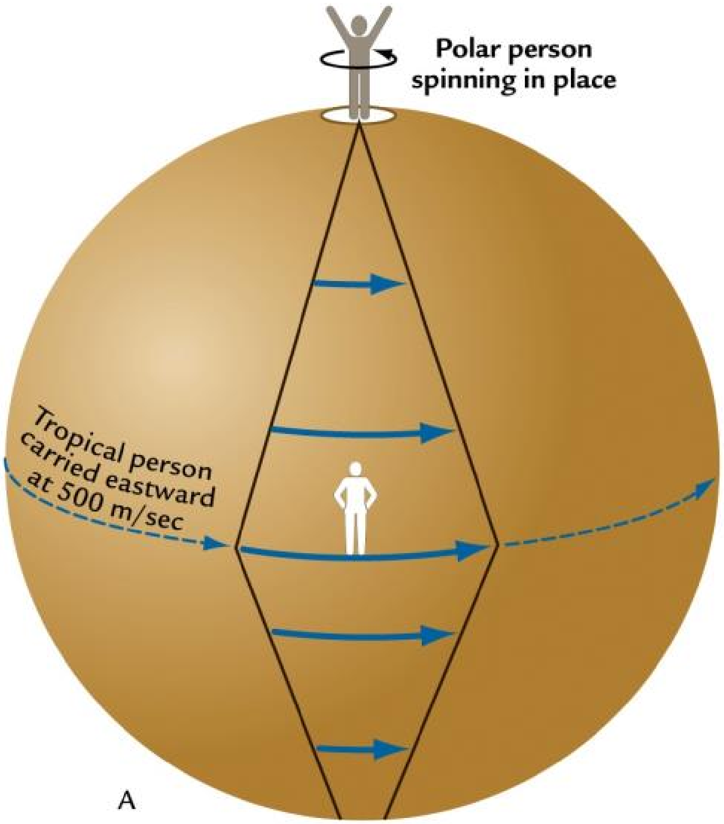


The rising air creates a circulation cell, called a **Hadley Cell**



Rising air -> low pressure
Sinking air -> high pressure

3. Effects of Earth rotation



The Earth would have two large Hadley cells, if it did not rotate.

--This is exactly what we think occurs on Venus (which rotates very slowly)!

Rotation of the Earth leads to the Coriolis Effect

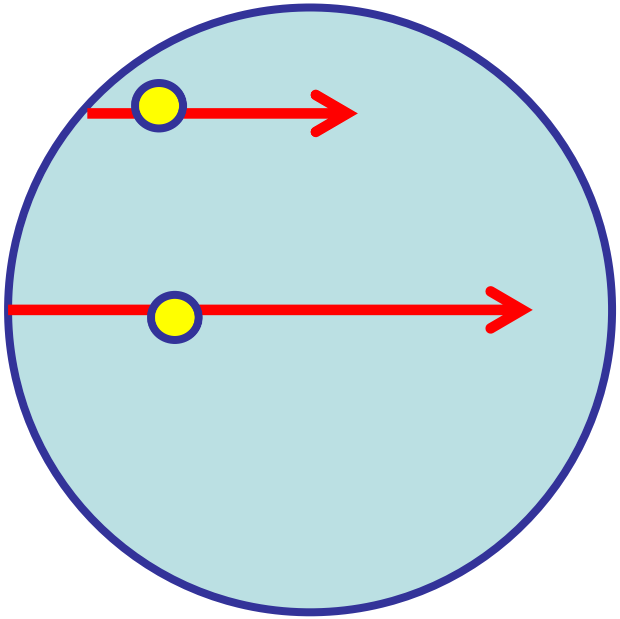
This causes winds (and all moving objects) to be deflected:

- **to the right in the Northern Hemisphere**
- **to the left in the Southern Hemisphere**

The Earth as a rotating system

Planet Earth rotates once per day.

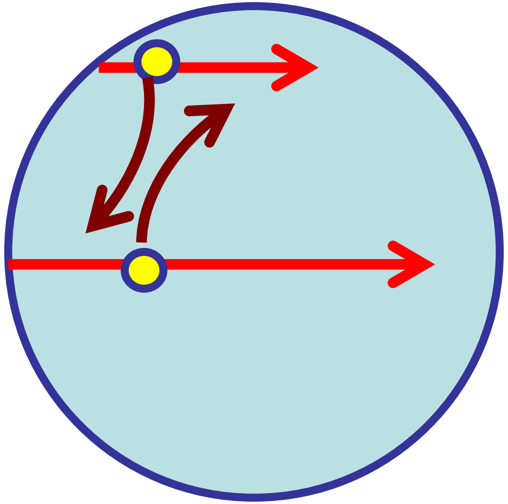
Objects near the poles travel slower than those near the equator.



4. Coriolis effect

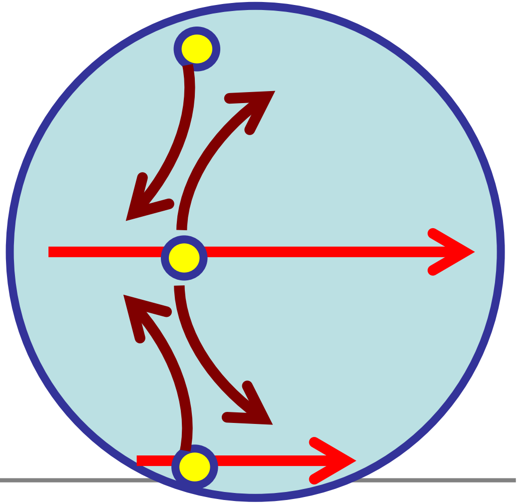
Objects near the poles have less angular momentum than those near the equator.

When objects move polewards, their angular momentum causes them to go faster than the surrounding air. Conversely, they slow as they move towards the equator.

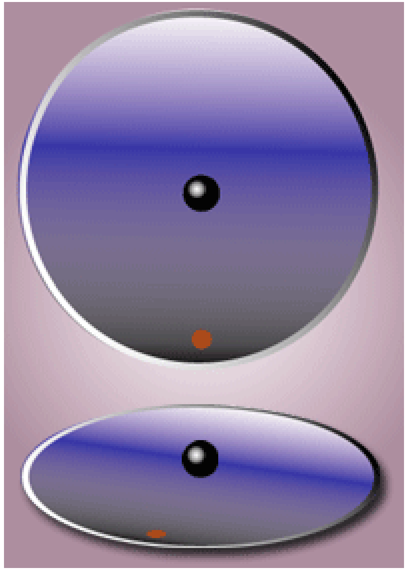


When objects move north or south, their angular momentum causes them to appear to go slower or faster.

This is why traveling objects (or air parcels) deflect to the right in the northern hemisphere and to the left in the southern hemisphere.



Coriolis effect seen from in- and outside



In the inertial frame of reference (upper part of the picture), the black object moves in a straight line.

However, the observer (red dot) who is standing in the non-inertial frame of reference (lower part of the picture) sees the object as following a curved path due to the Coriolis and centrifugal forces present in this frame.

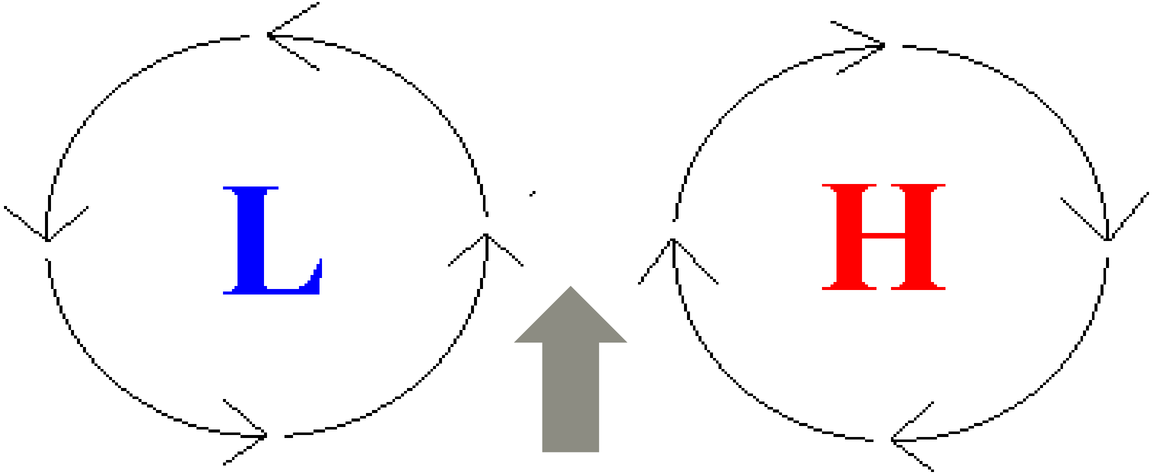
http://en.wikipedia.org/wiki/Coriolis_effect

The Coriolis effect is a large-scale effect!

Coriolis force is a large-scale effect!

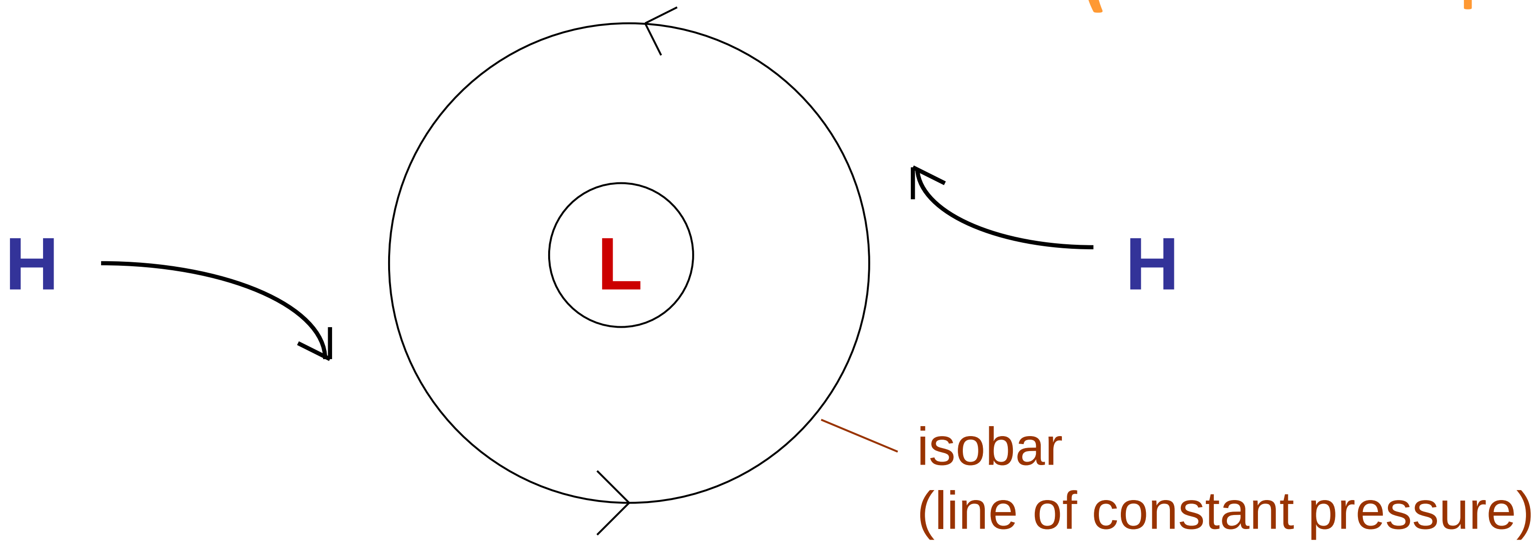
Winds around High's and Low's

- **If the wind is at your back in the Northern Hemisphere, high pressure is always on your right, low pressure always on your left!**
  (Remember *L*ow pressure = *L*eft!)



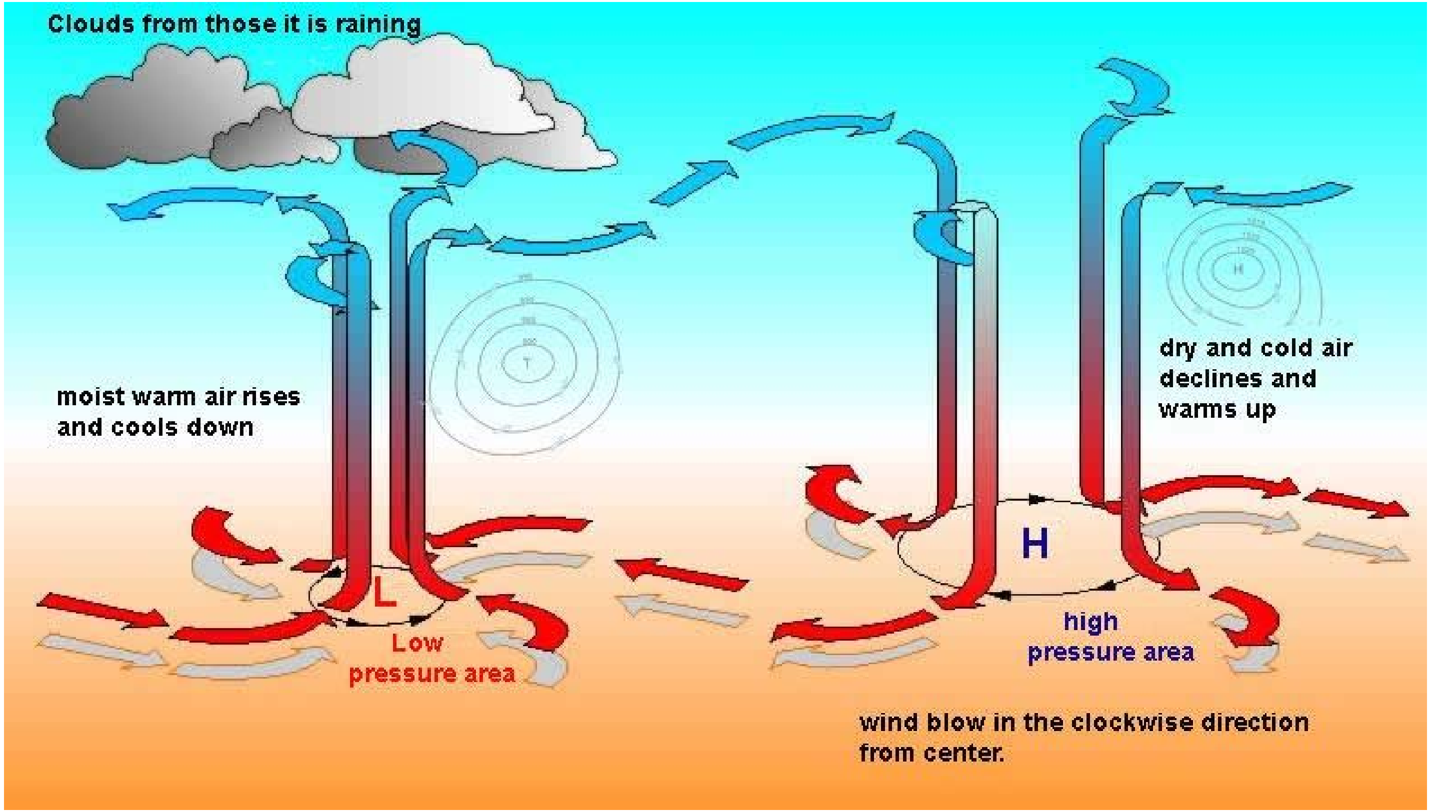
- Because of the Coriolis force winds in the Northern Hem:
  - blow counterclockwise (or cyclonically) around Low Pressure
  - and blow clockwise (or anti-cyclonically) around High Pressure

Example of Coriolis effect: Hurricanes (North. Hemisph.)



- **Hurricanes are low pressure centers (cyclones)**
- **Air moves from high pressure towards low pressure**
- **As the air moves in, it is deflected towards the right in the NH**
- **Resulting circulation is counter-clockwise**

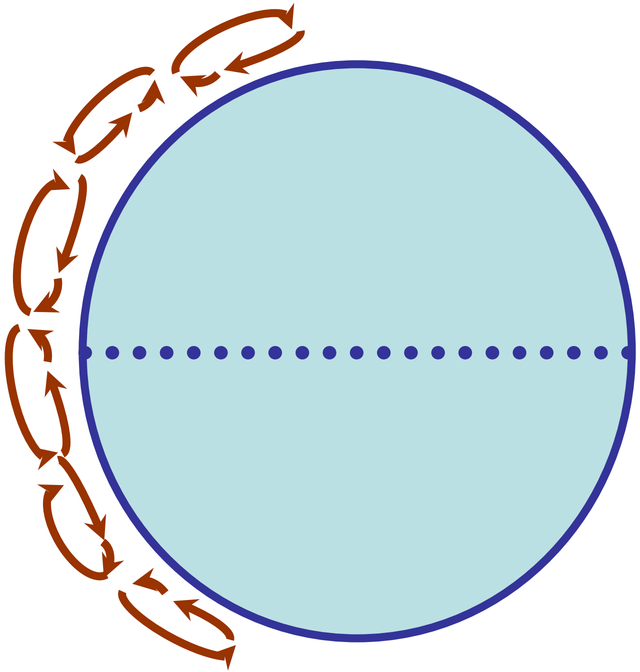
Highs and Lows and the resulting Wind



5. Global Atmospheric Flux Processes

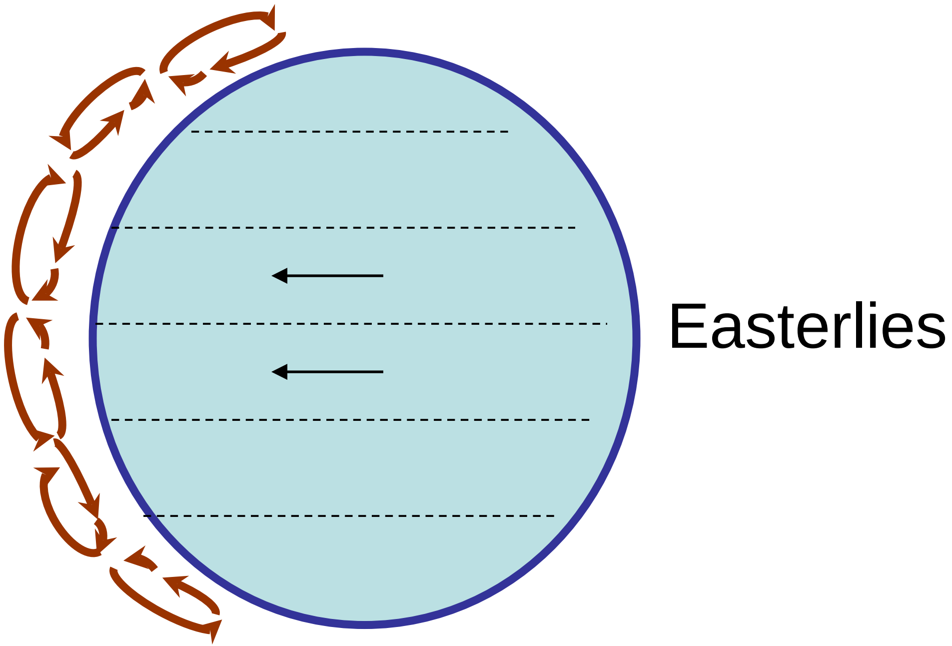
The Coriolis effect causes winds to deflect as they travel within circulation cells

This breaks up the two large Hadley cells into six smaller cells.



In the tropics, surface air is moving equatorwards.

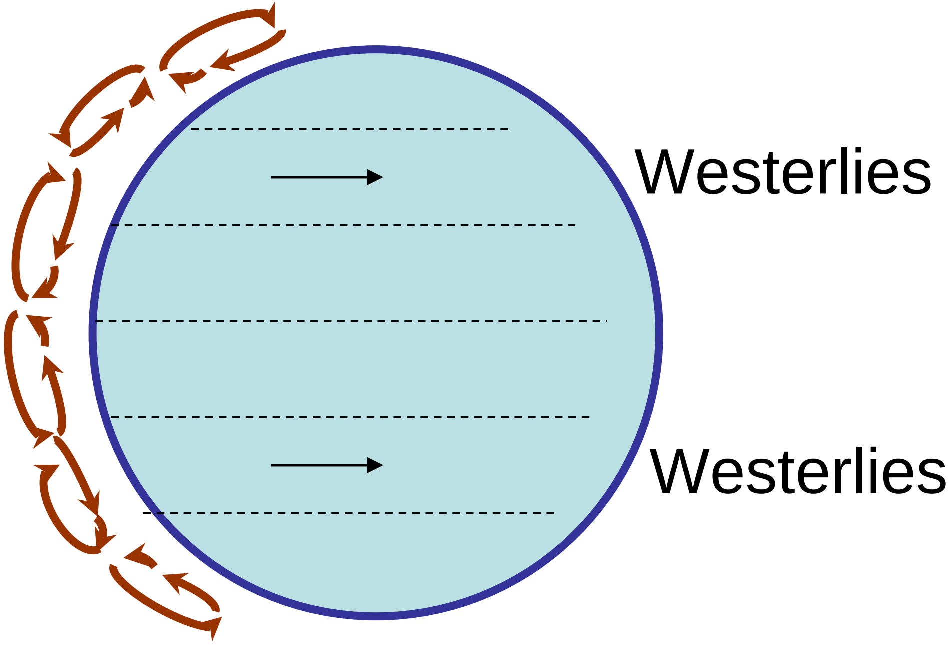
It is deflected to the right in the NH (left in the SH), giving rise to easterly flow (the trade winds)



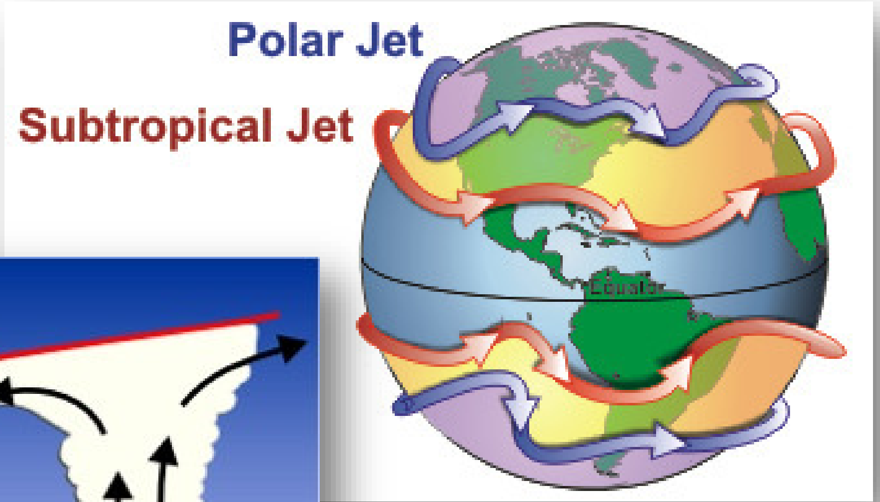
At midlatitudes, surface air is moving poleward.

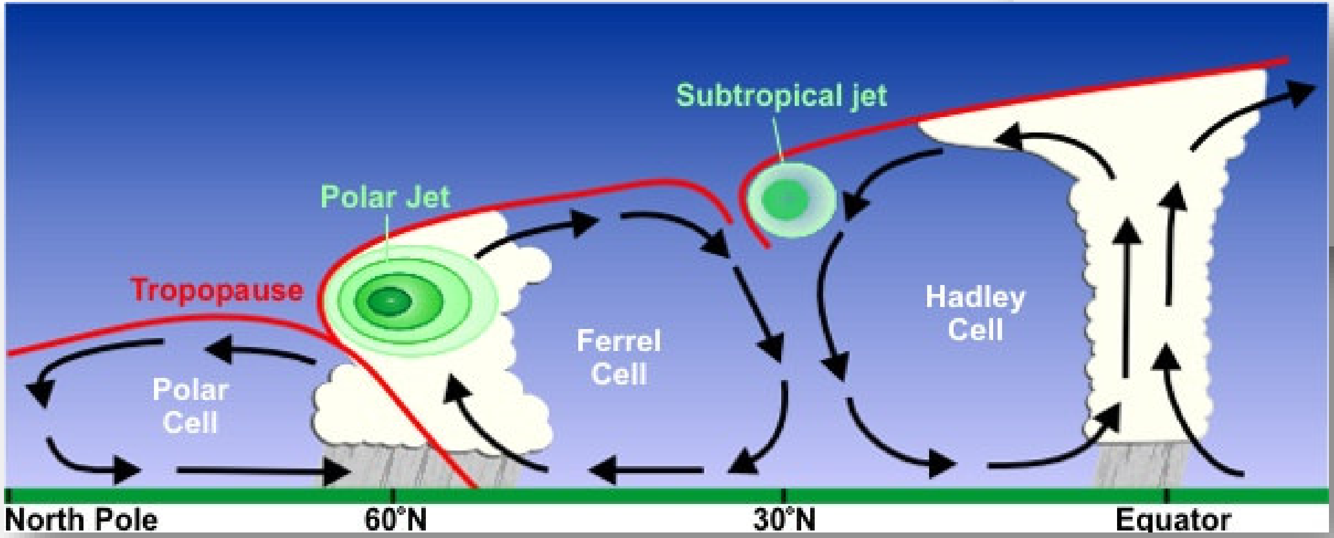
It is deflected to the right in the NH (left in the SH),

Giving rise to westerly flow (the prevailing westerlies)

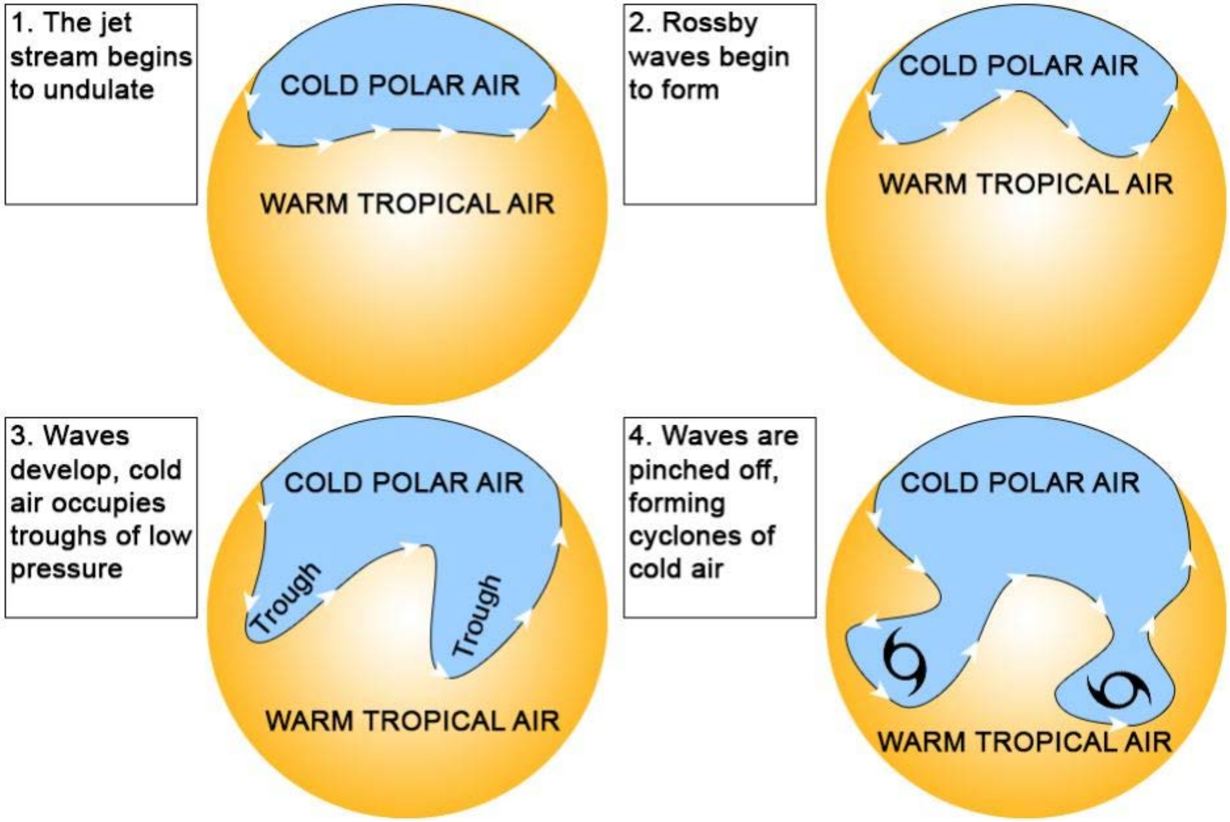


The Jet Streams



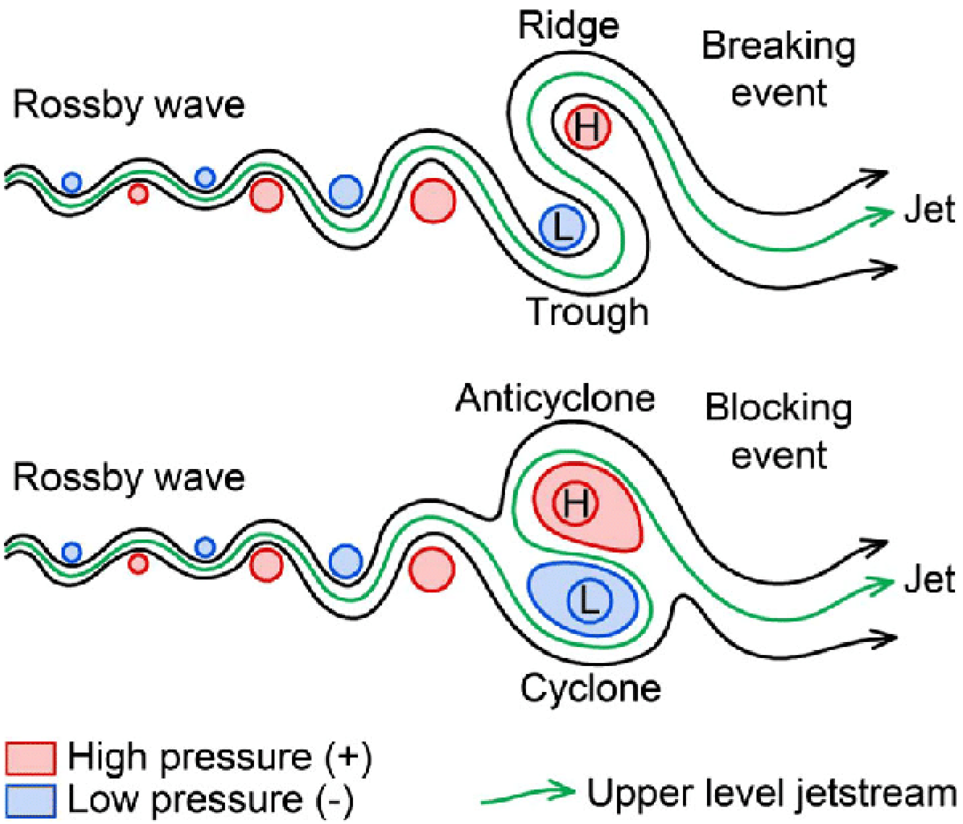


Dynamical development of highs and lows, NH



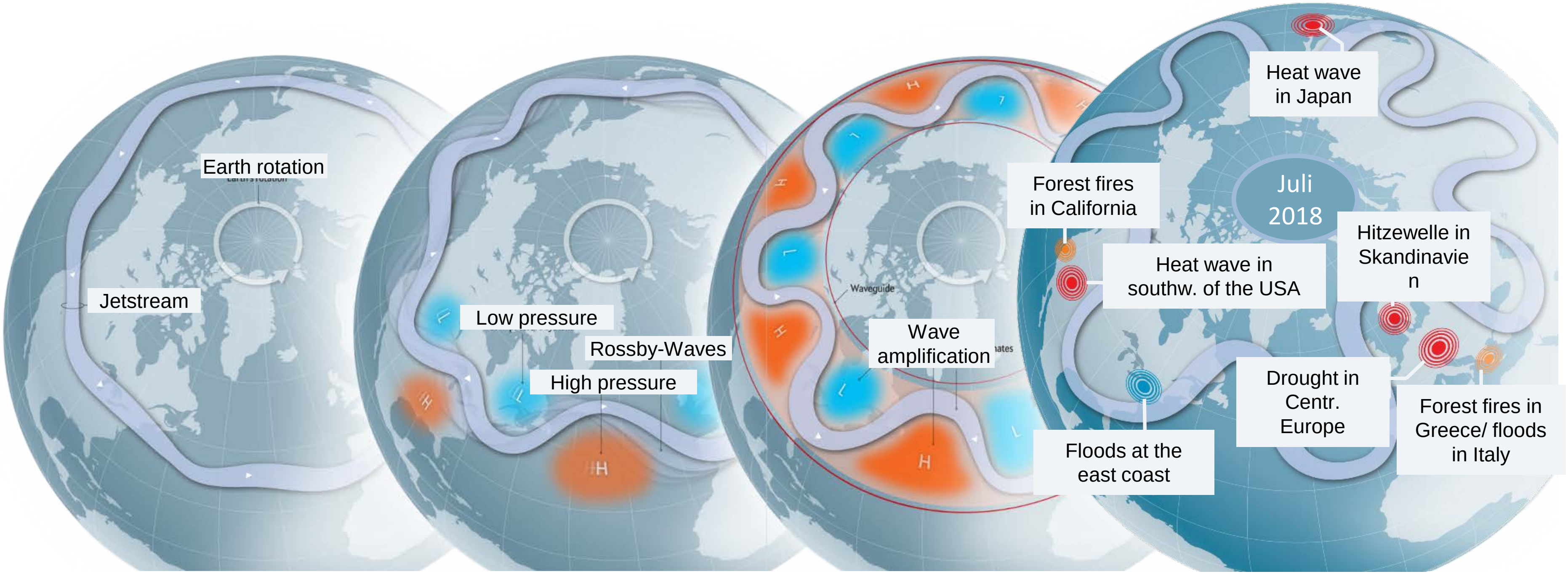
Source: https://www.abc.net.au

Dynamical development of highs and lows, NH



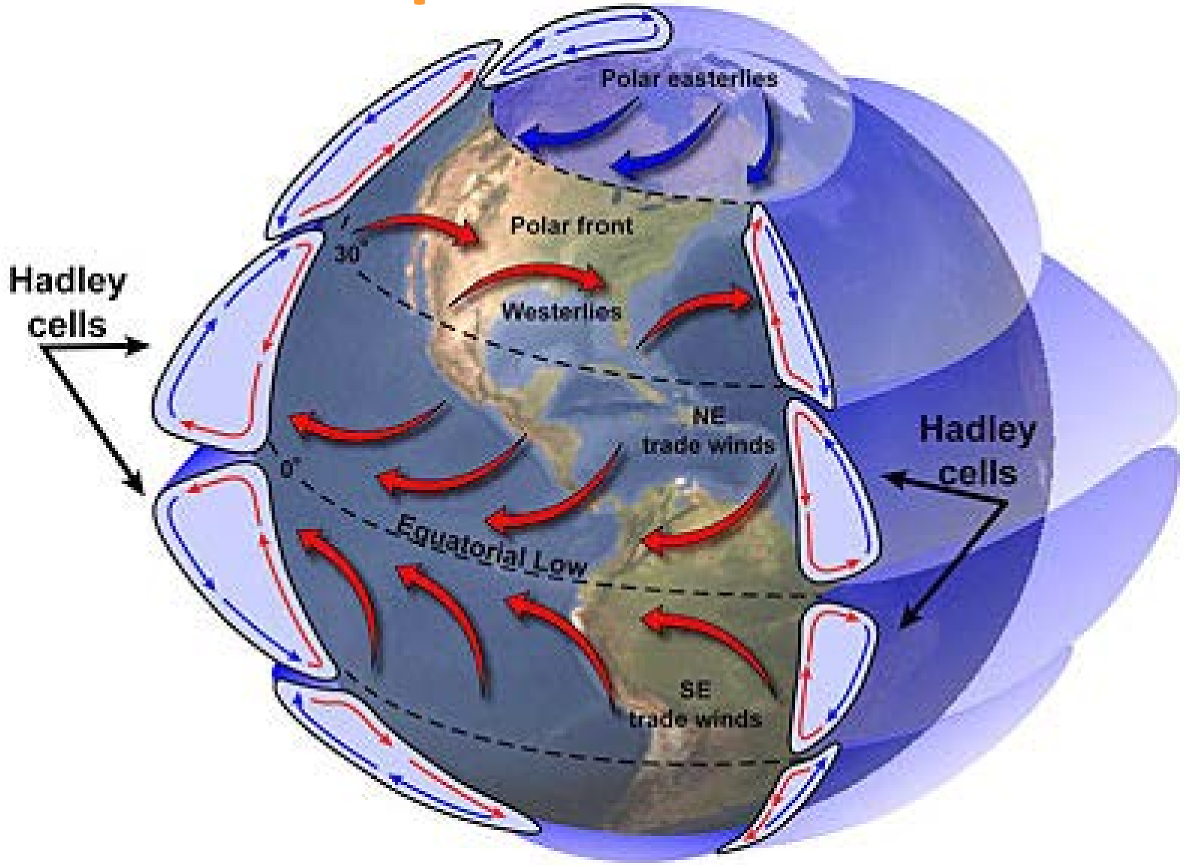
Schematic 2-D projection of Rossby wave, upper level jet stream, and breaking way to produce an atmospheric blocking event

Circulation pattern change because of the change in energy input



Scientific American, March 1, 2019 by Michael E. Mann

6. Global Atmospheric Flux and Ciculation Cells



Credit: NASA