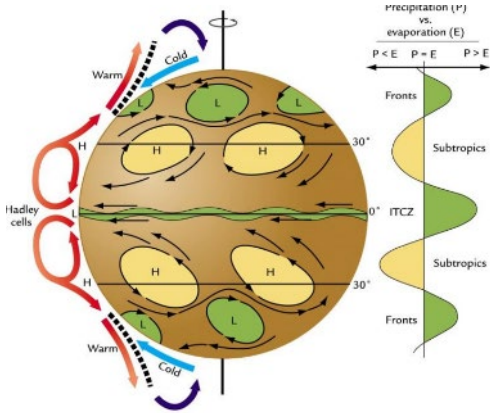
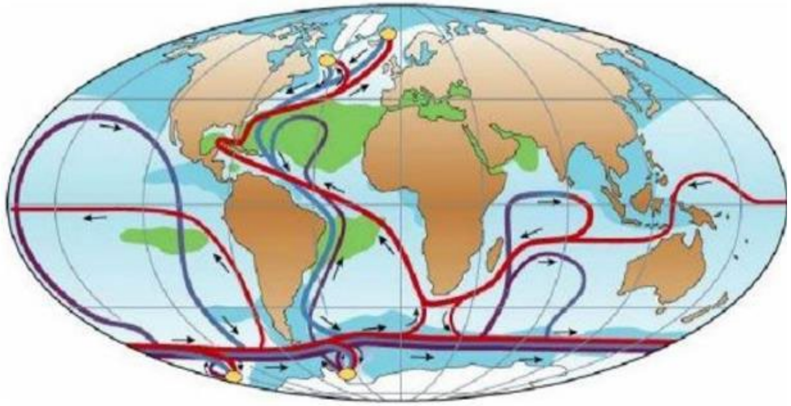
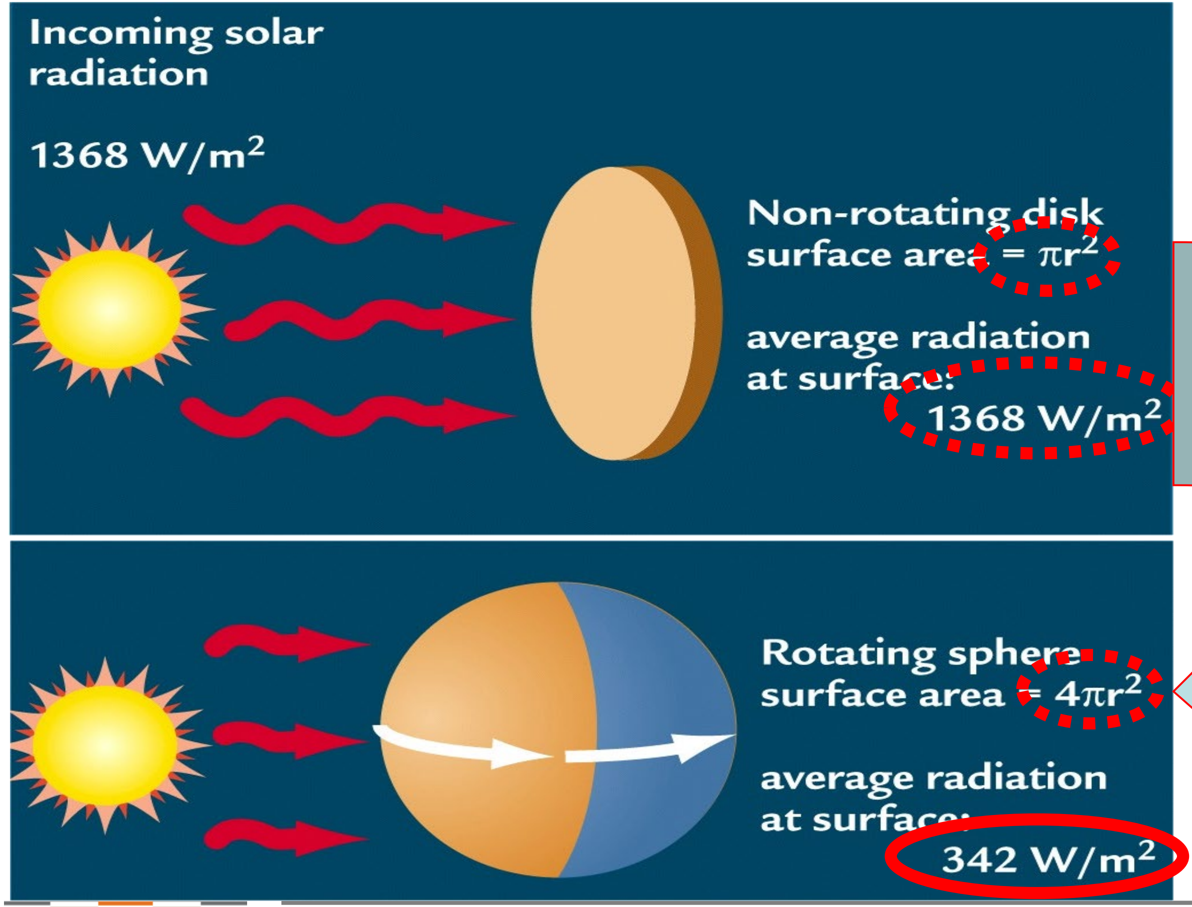
II - Energy Flow in the Climate System



1. Circulation cells and precipitation
2. The Ocean Land Exchange
3. Where do the Seasons come from?
4. Seasonal Land-Ocean variability
5. Wind effects on Ocean flows
6. Energy transport in the Oceans
   by conveyer belts



Energy Input and Energy Distribution on Earth

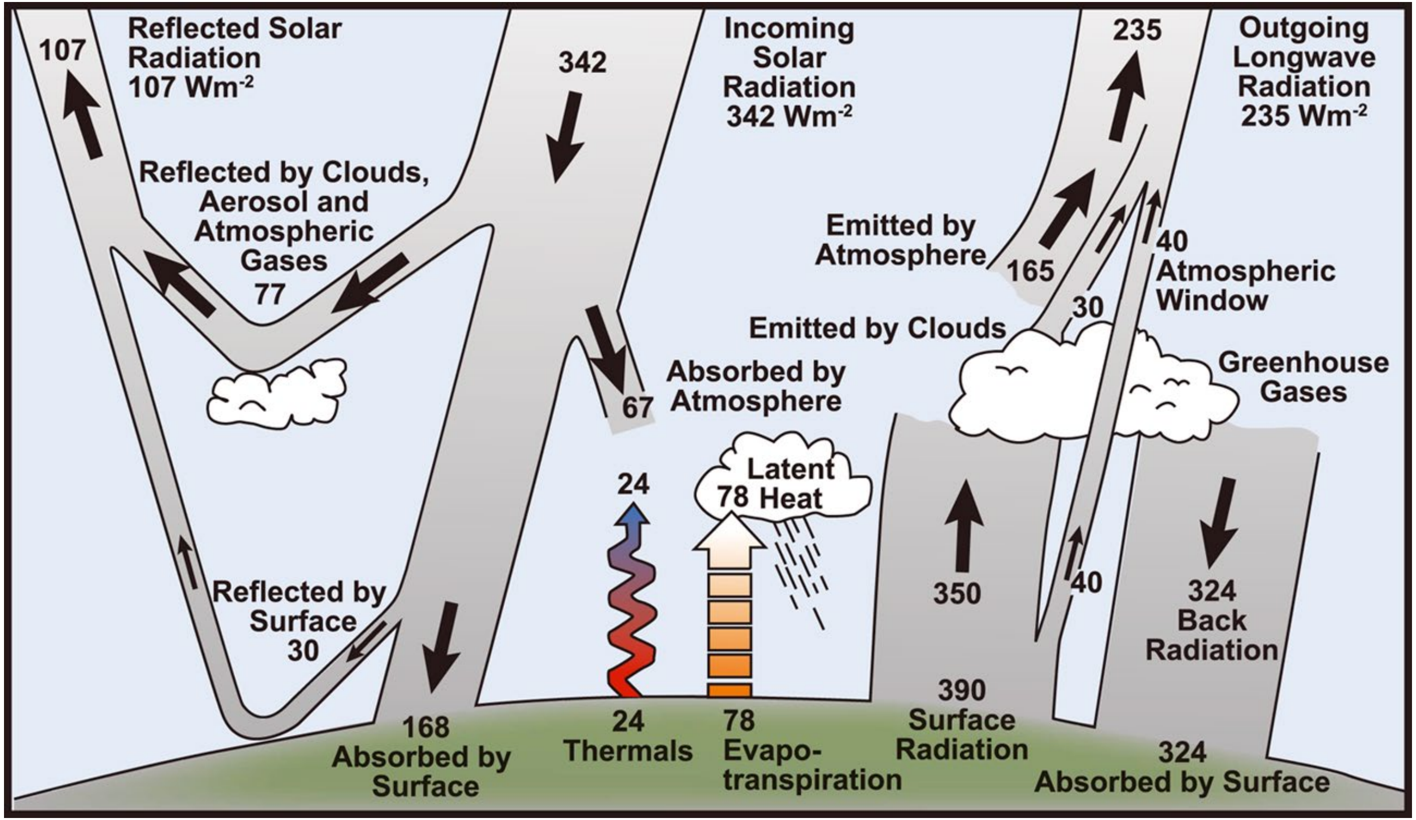


The total energy input per second at top of the atmosphere is
1368 W/m²

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)



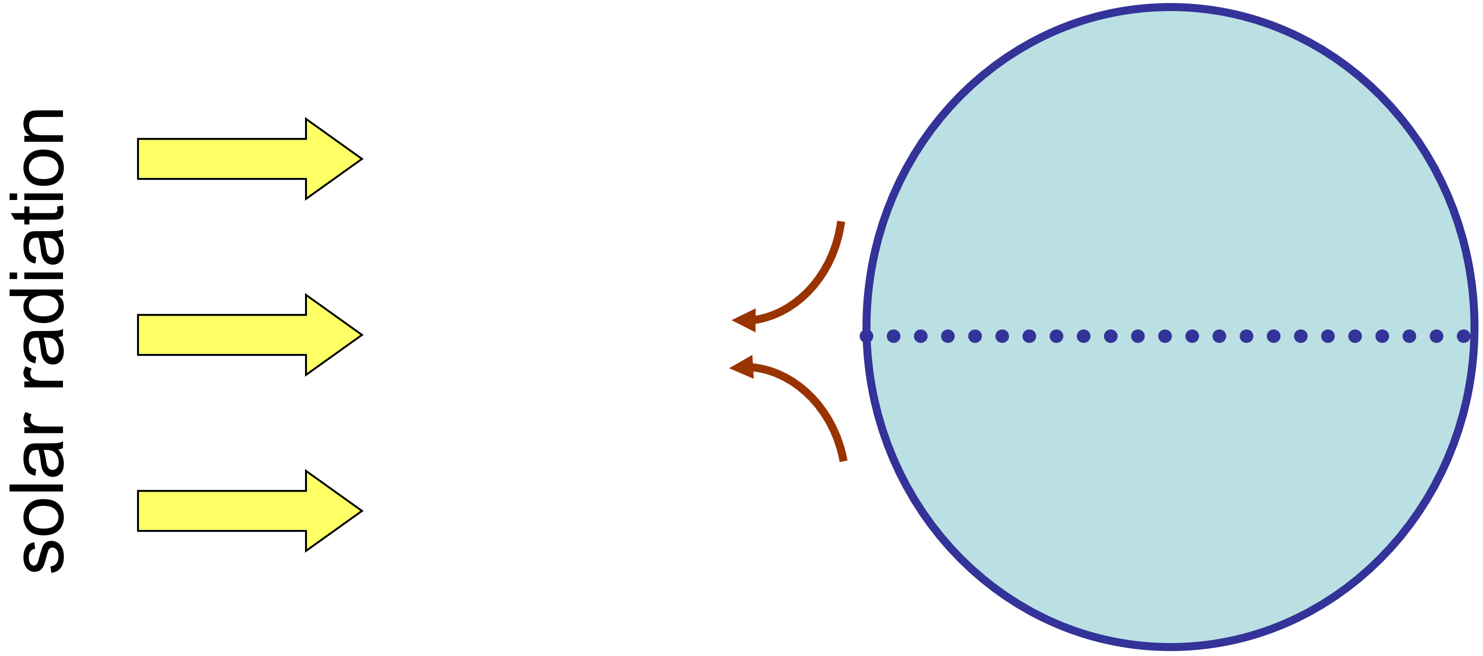
First law of thermodynamics: conservation of energy

Quelle: Kiehl and Trenberth, 1997

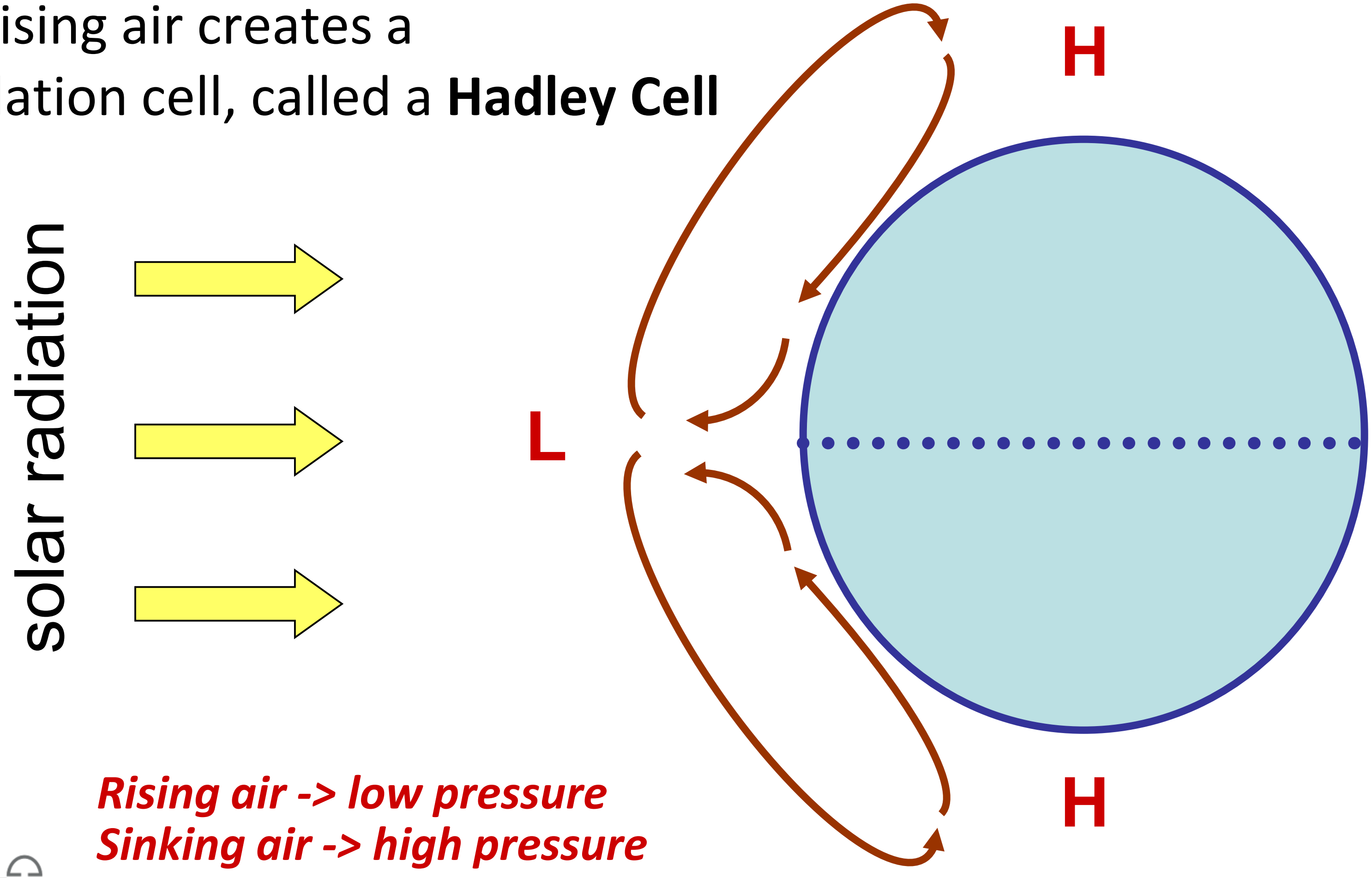
Example: 168 + 324 = 492 = 24 + 78 +390 and 342 = 107 + 235 and 165 + 30 + 40 = 235

Air circulation in the atmosphere

Air near the equator is warmed, and rises

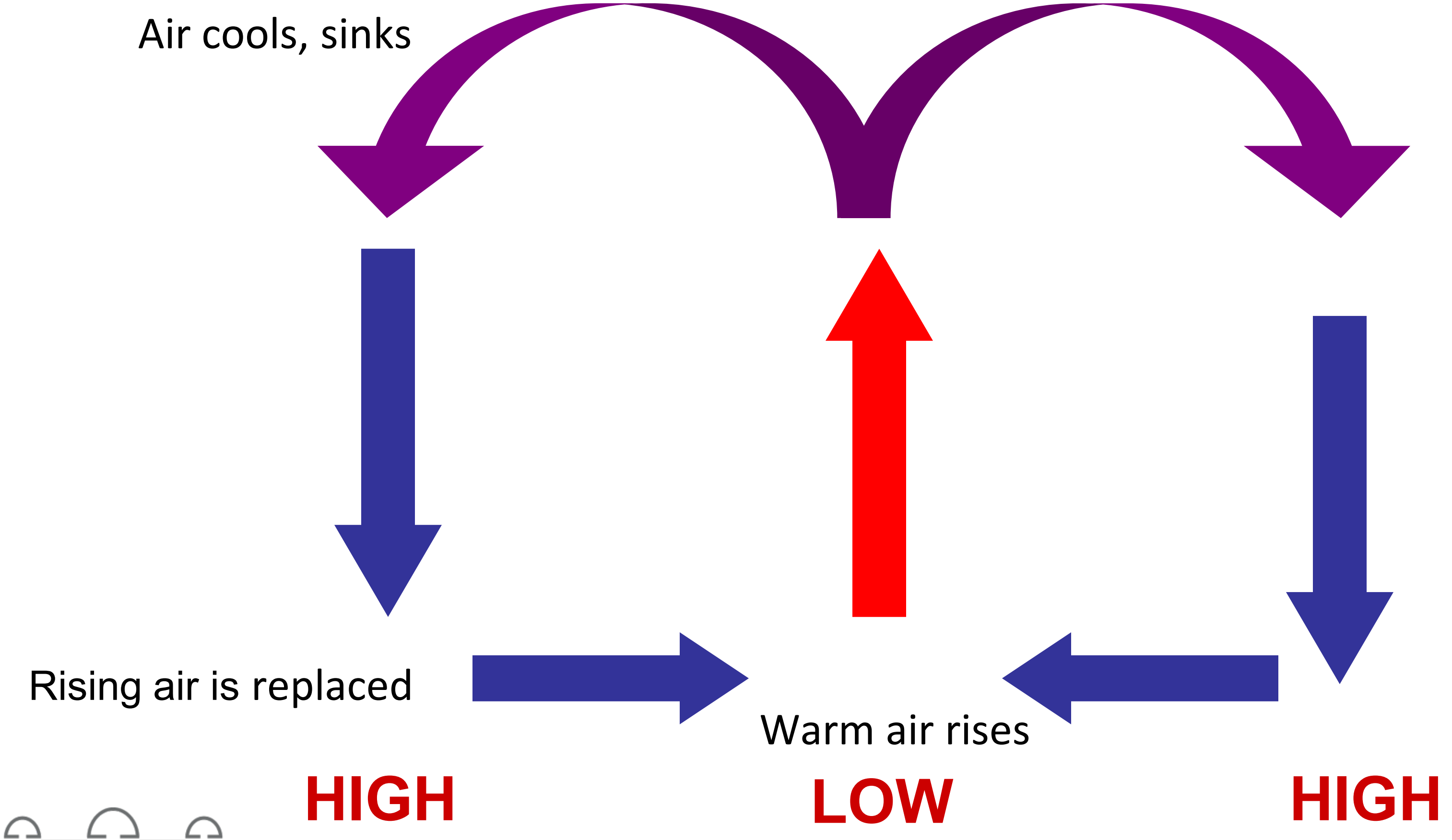


The rising air creates a circulation cell, called a **Hadley Cell**



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

Hadley Circulation Cell



Air cools, sinks

Rising air is replaced

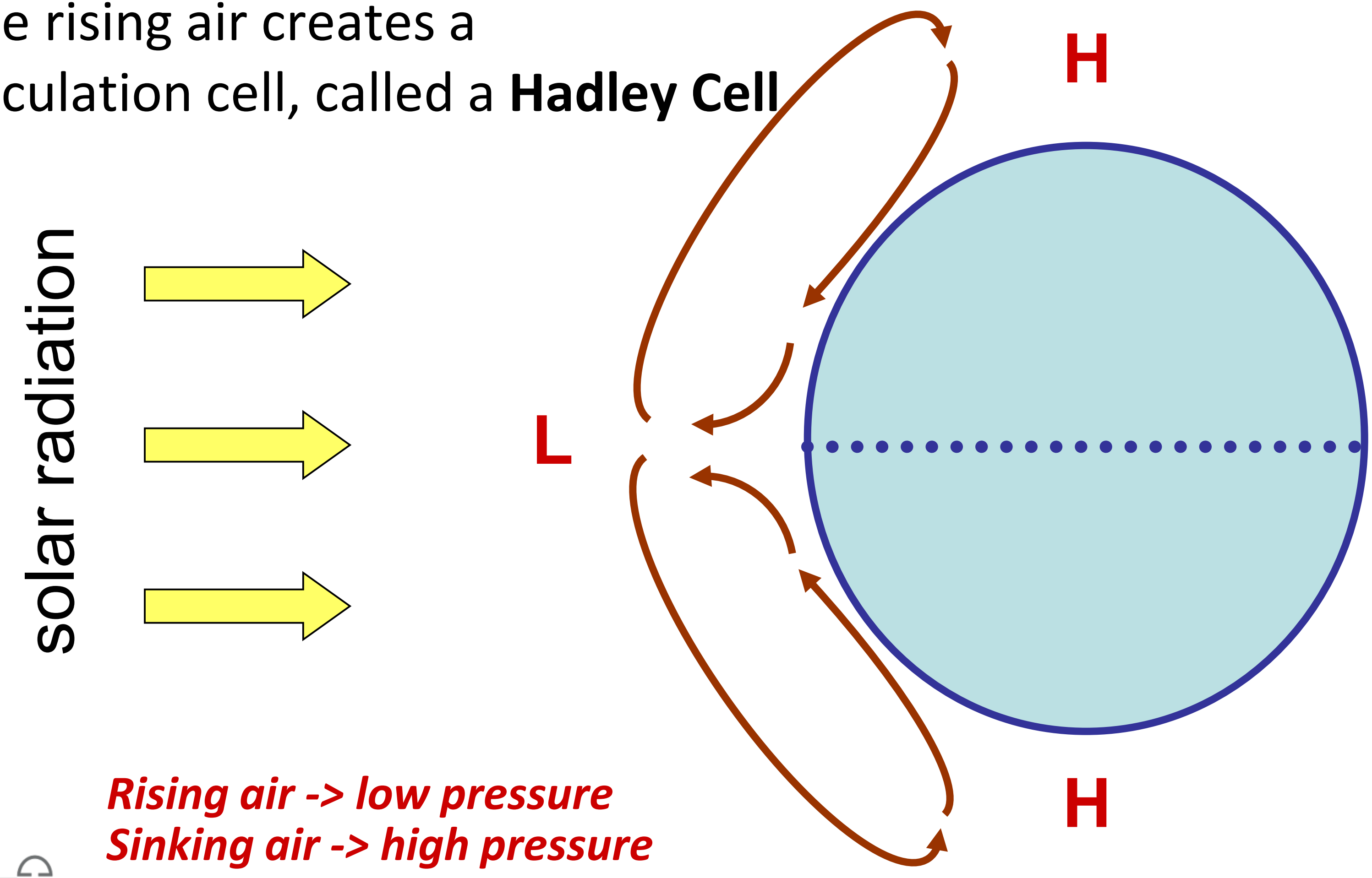
Warm air rises

HIGH

LOW

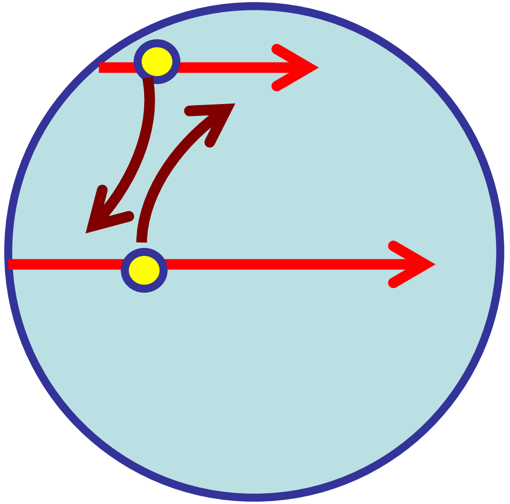
HIGH

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



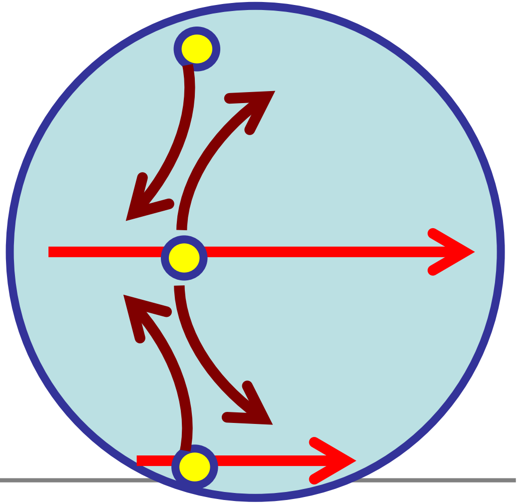
Rising air -> low pressure
Sinking air -> high pressure

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.



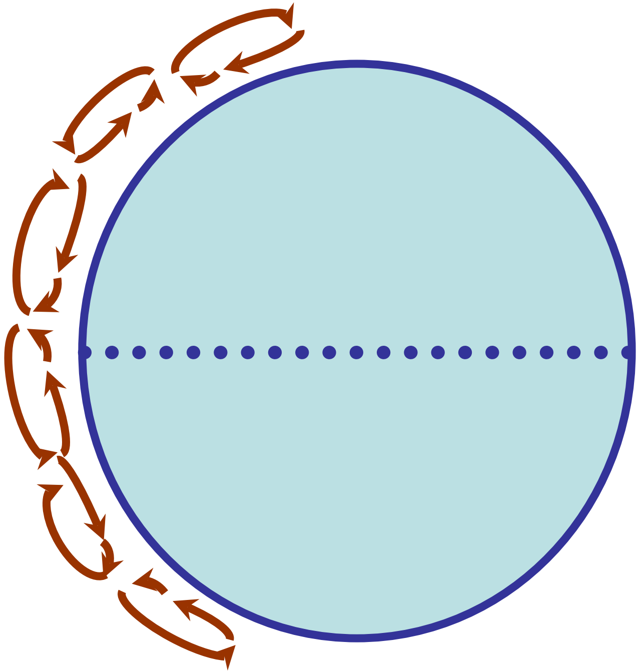
When objects move north or south, their angular momentum causes them to appear to go slower or faster.

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

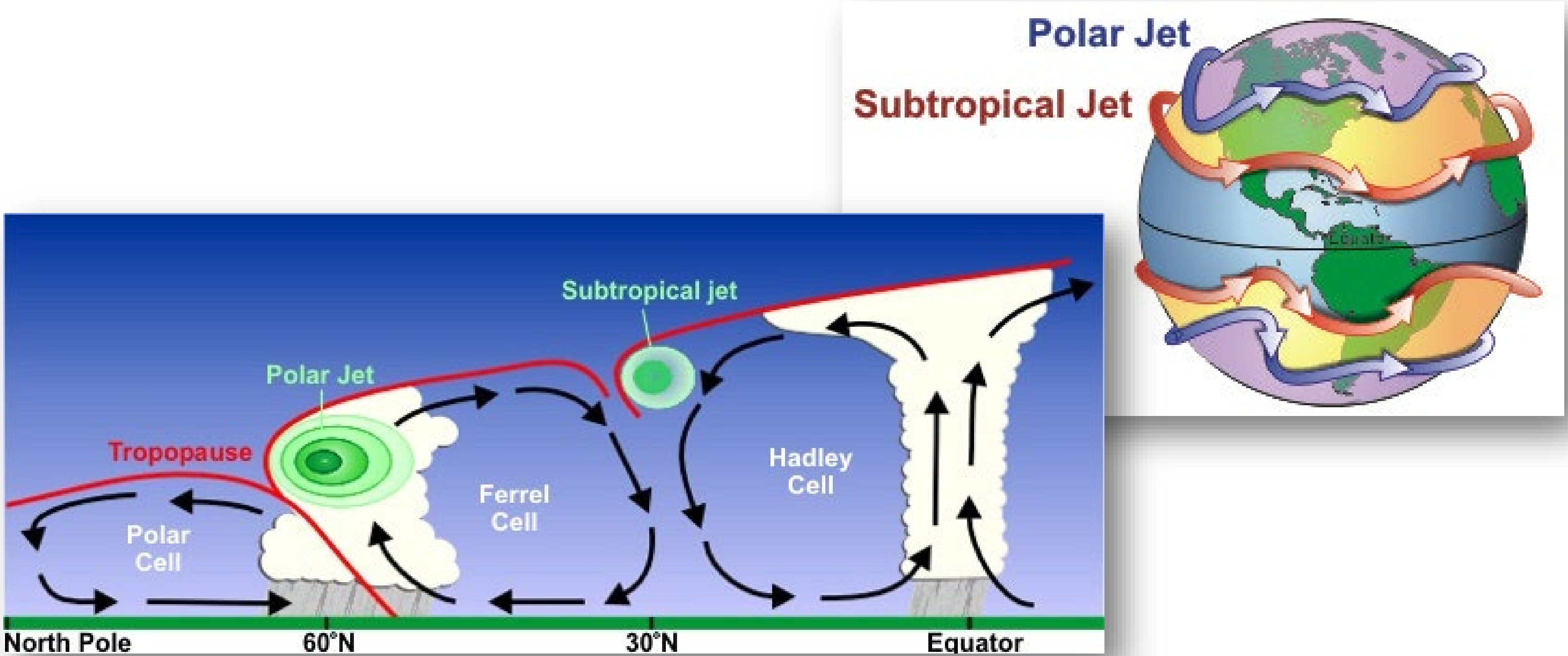
Global Atmospheric Flux Processes

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.

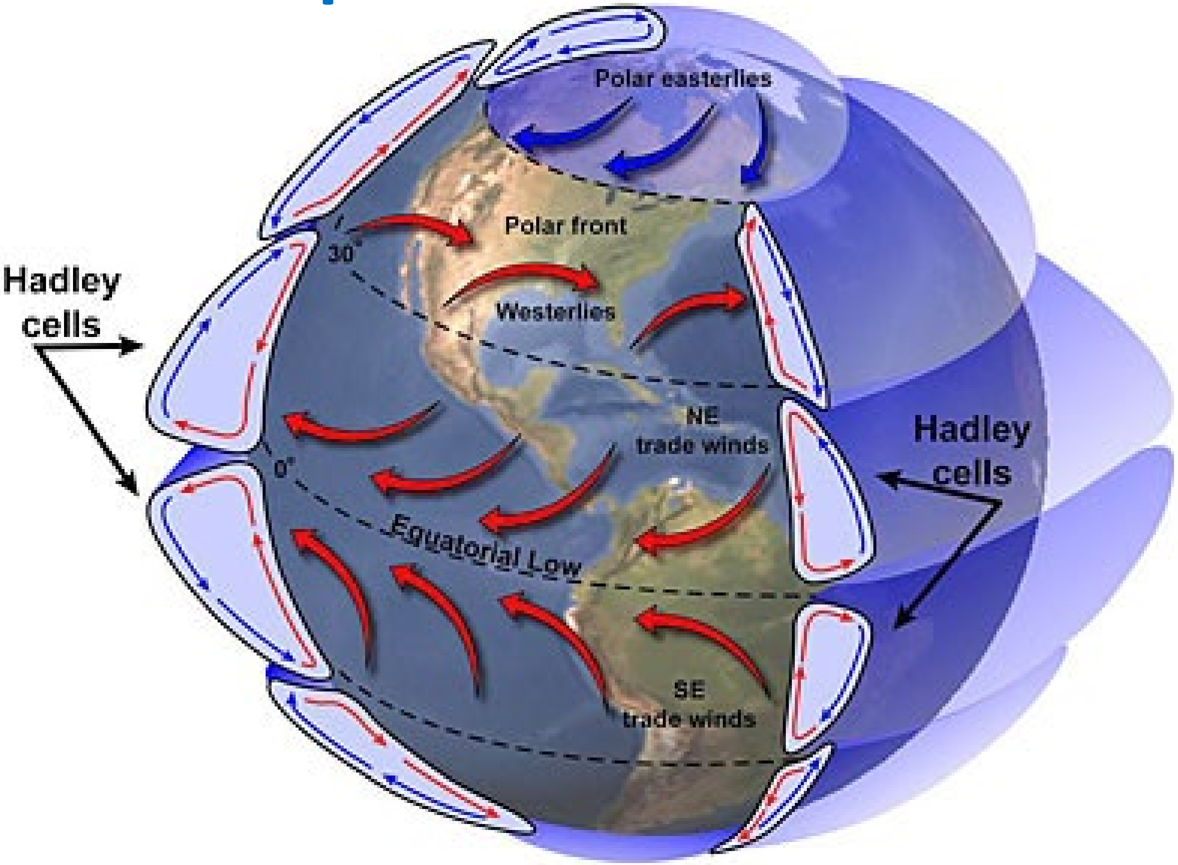


Circulation cells and the Jet Streams



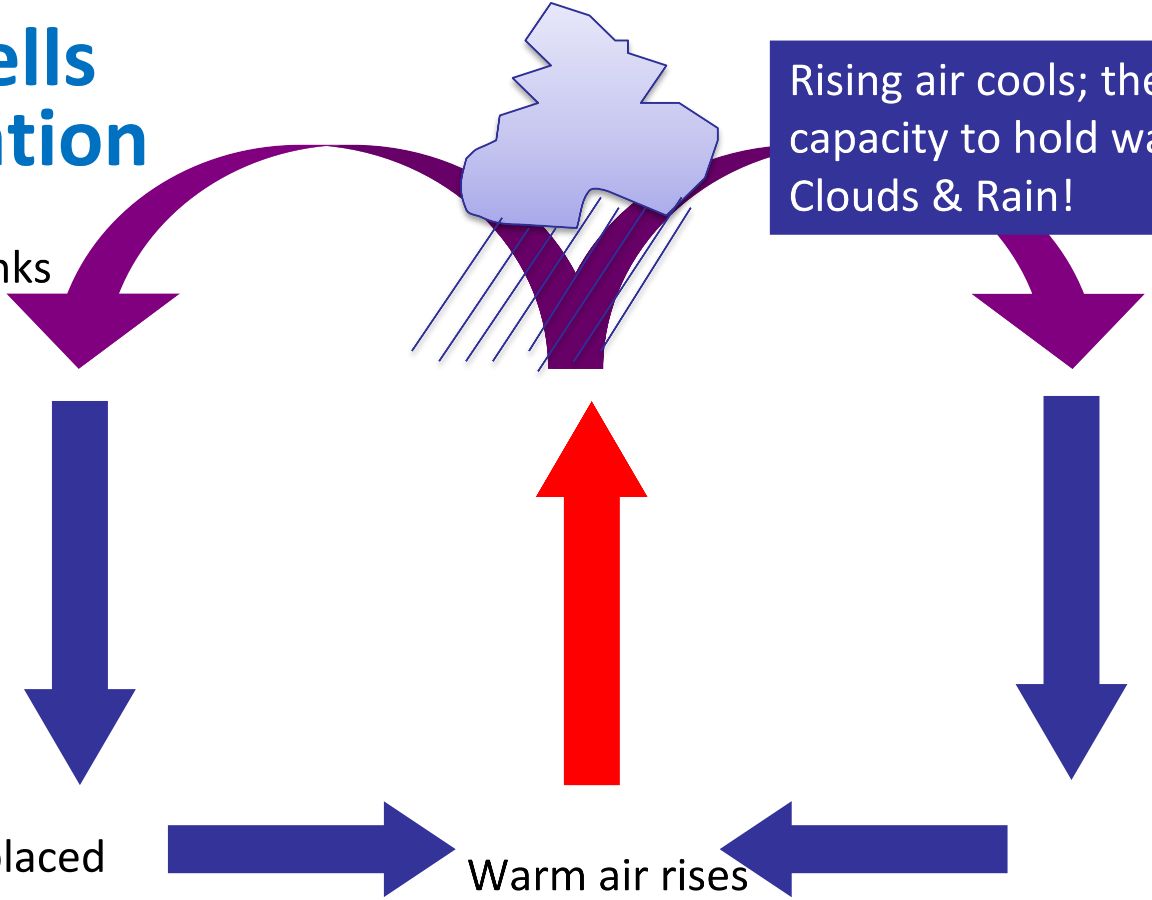
Source: https://wiki.bildungsserver.de

Global Atmospheric Flux and Ciculation Cells



Credit: NASA

Circulation cells and precipitation



Rising air cools; the air's capacity to hold water drops: Clouds & Rain!

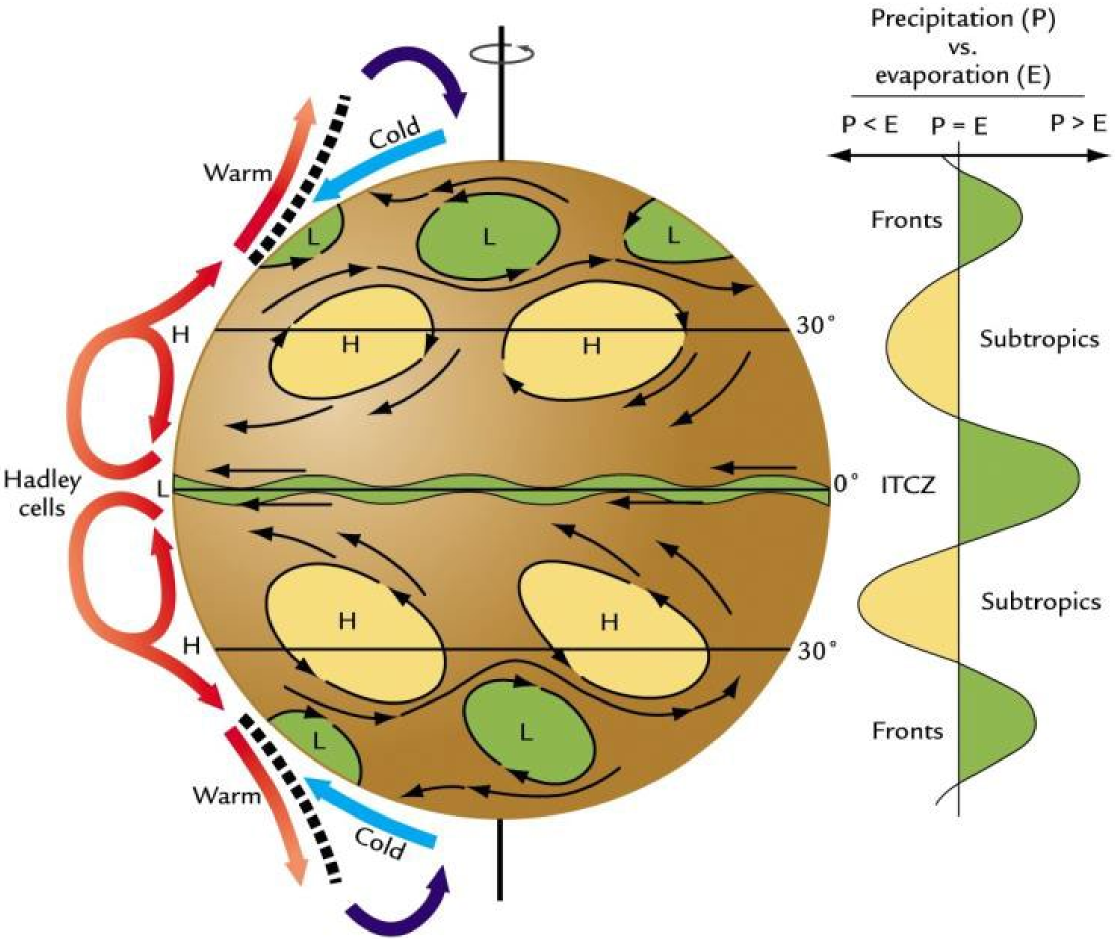
Air cools, sinks

No rain in regions where air is descending

Rising air is replaced

Warm air rises

HIGH **LOW** **HIGH**


Precipitation (P)
vs.
evaporation (E)
P < E
P = E
P > E
Fronts
Subtropics
ITCZ
Subtropics
Fronts
Cold
Warm
Hadley
cells
H
L
H
L
L
L
H
H
30°
0°
H
H
30°
L
L
Warm
Cold

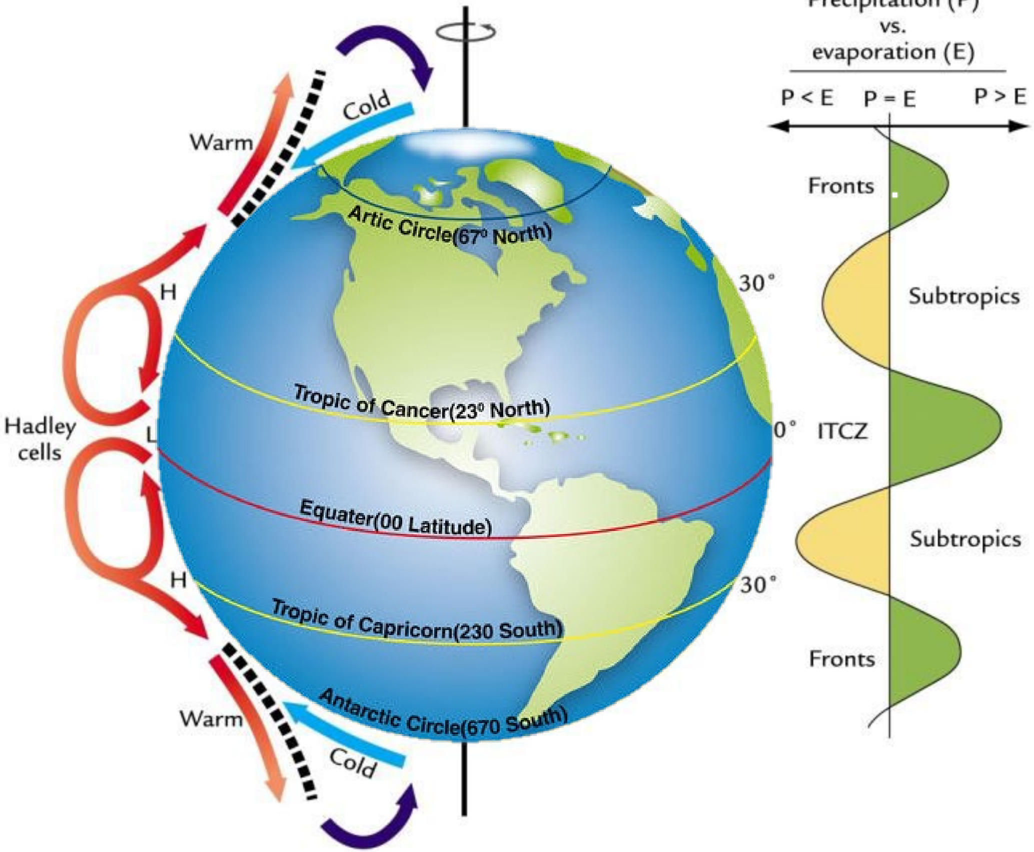
The Ocean Land Exchange in the Climate System

Caution:
Zonal weather pattern is not completely true.
The pattern is disrupted by land-sea contrasts

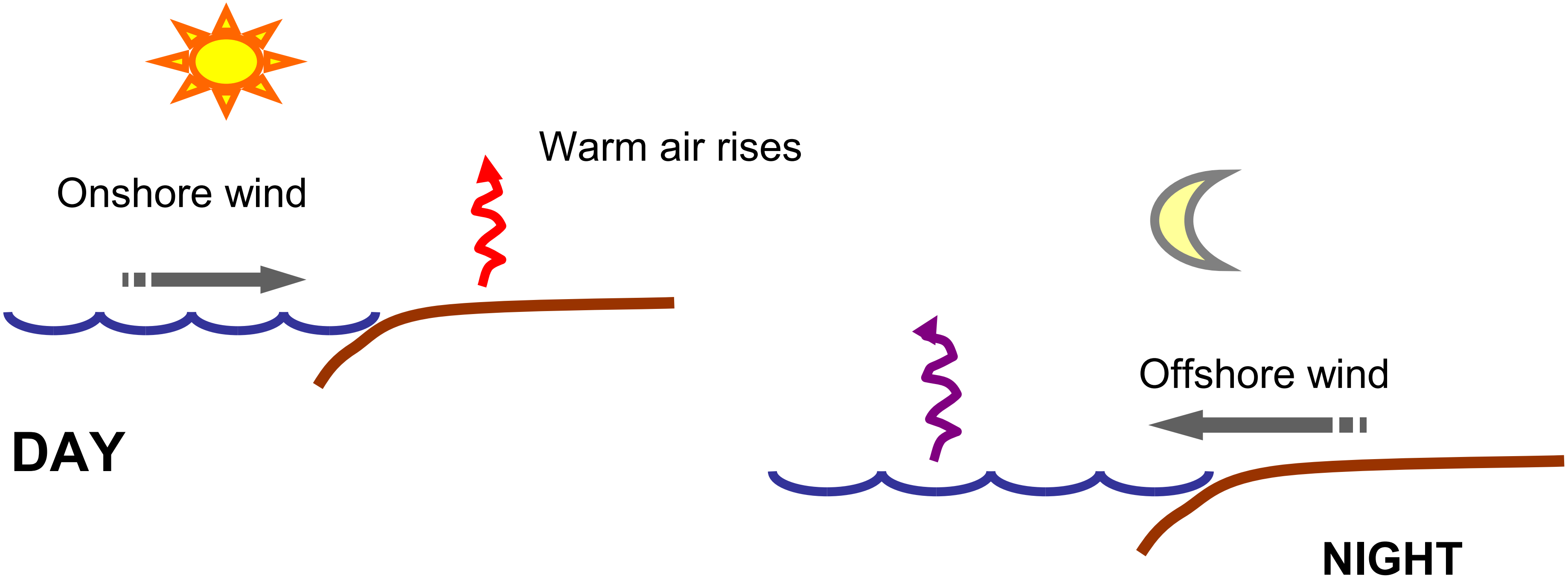
Land heats and cools rapidly

Water heats and cools slowly

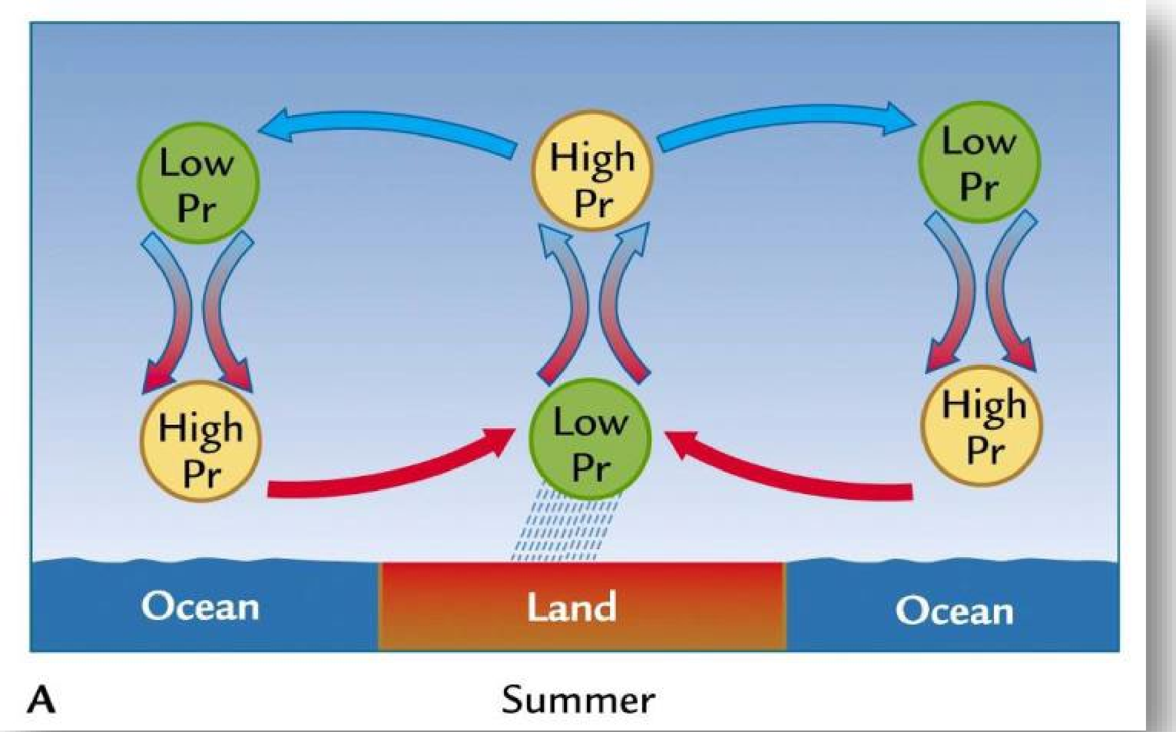
2/3 of Earth‘s surface is covered by Oceans



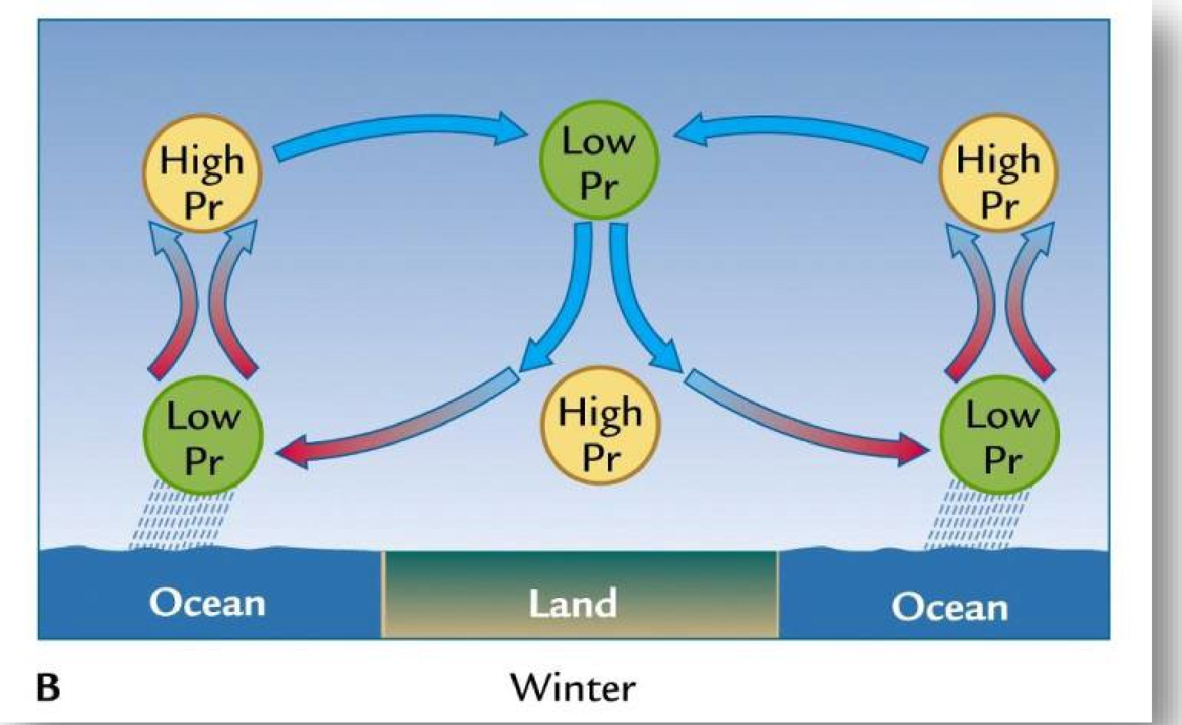
Day/Night Land Ocean Exchange by Sea Breeze



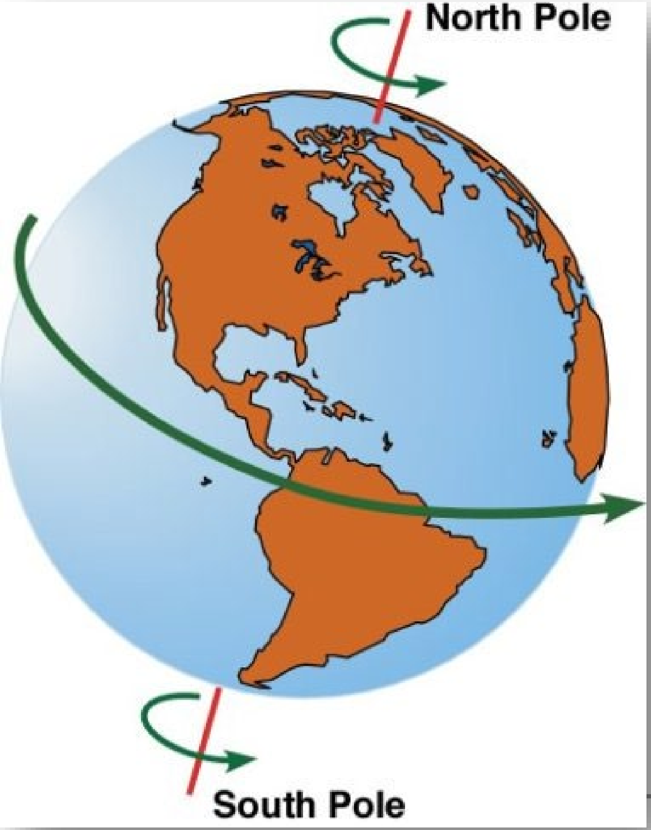
A: Seasonal Land-Ocean Variability in Summer



B: Seasonal Land-Ocean Variability in Winter

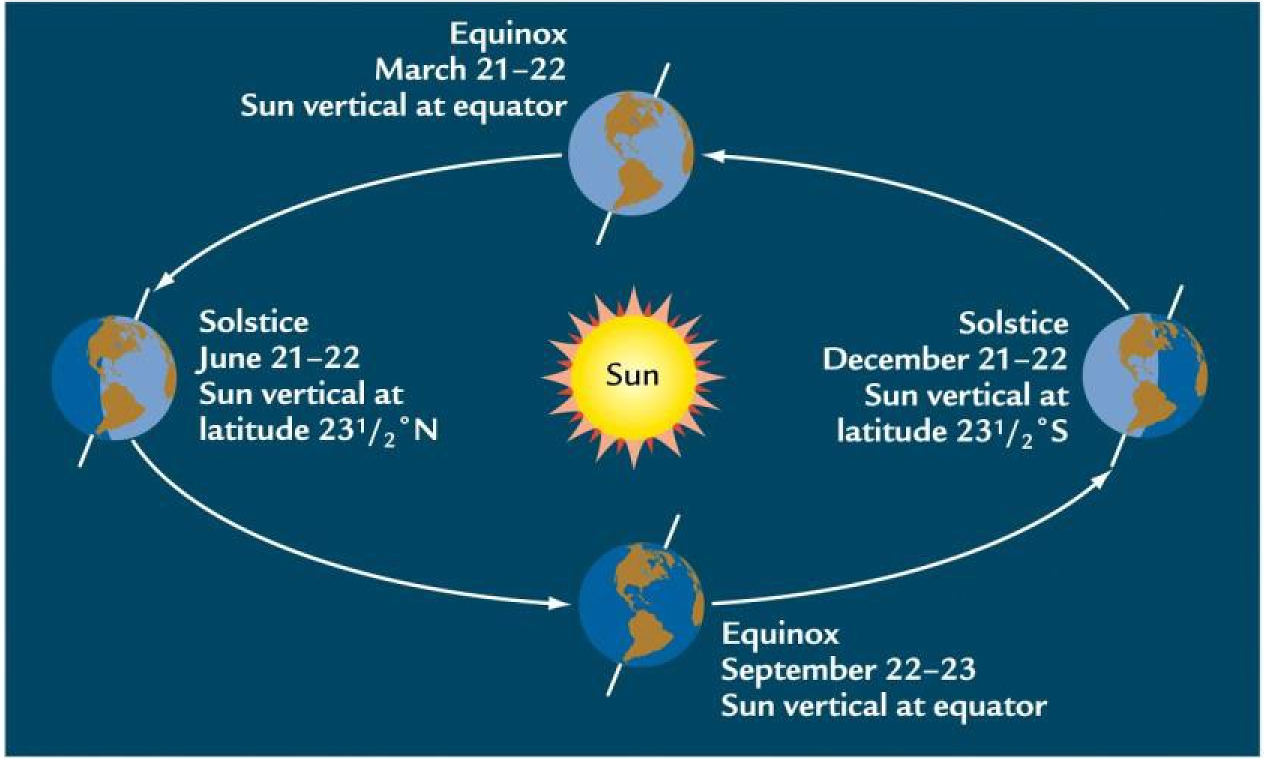


Where do the Seasons come from?



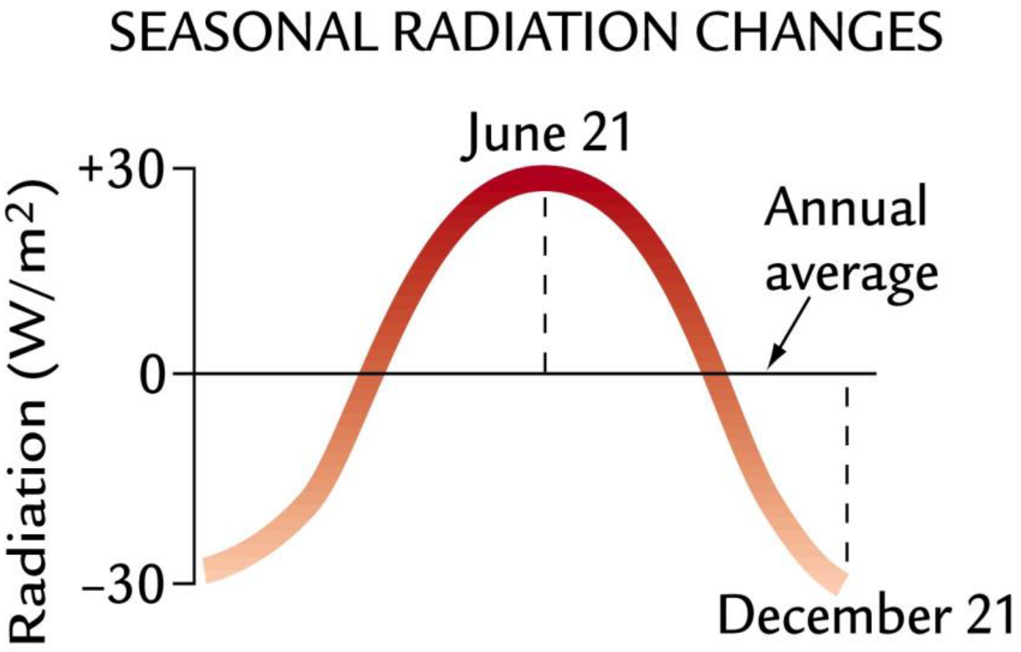
Earth’s rotational plane is tilted with respect to its orbit by 23.5 °

Where do the Seasons come from?



A Earth's orbit

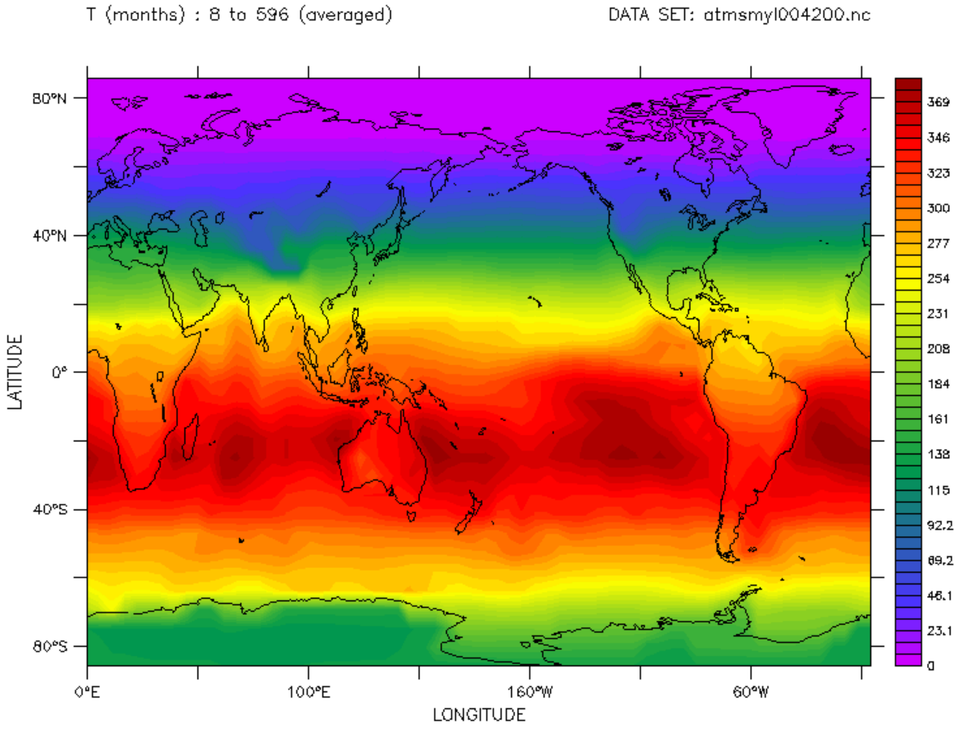
Seasonal Radiation (Northern Hemisphere)



Top Solar Radiation in the Northern Winter

North Winter:
[Dec/Jan/Feb]

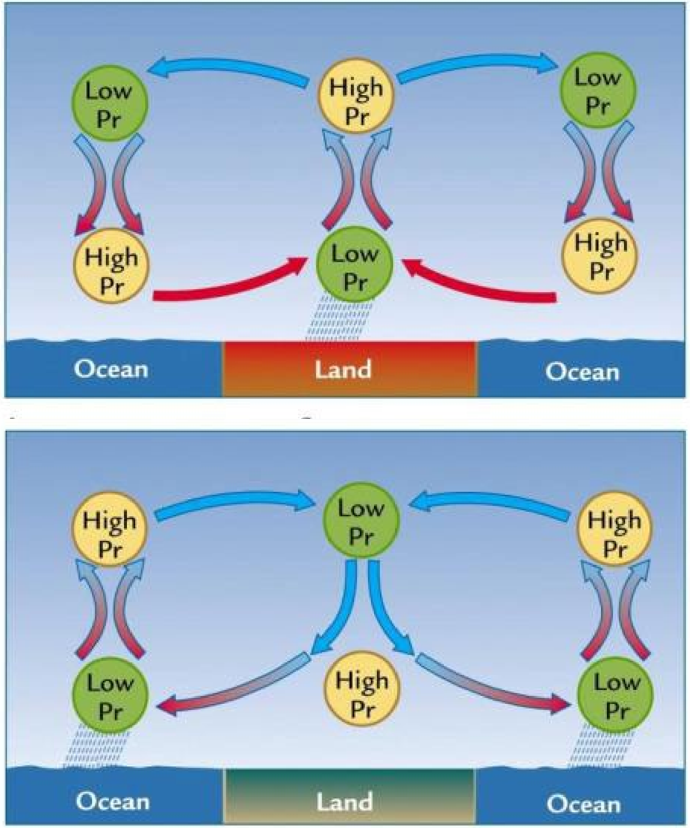
Solar energy is concentrated near the equator



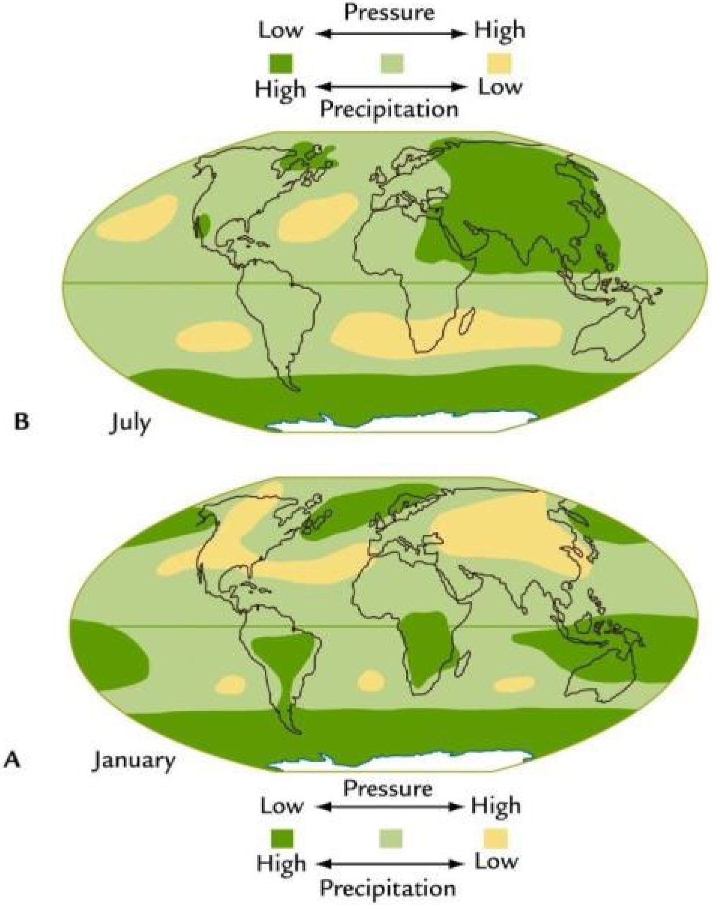
Top Solar Radiation in DJF (W/m~2)

Image: Netherlands Center for Climate Research

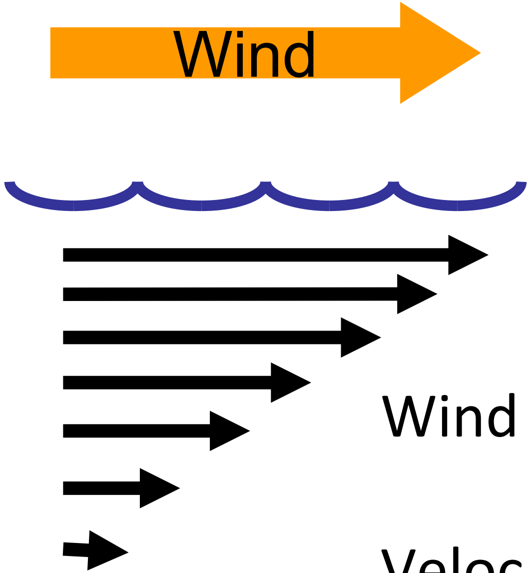
Seasonal Land-Ocean Variability and Precipitation



B Winter



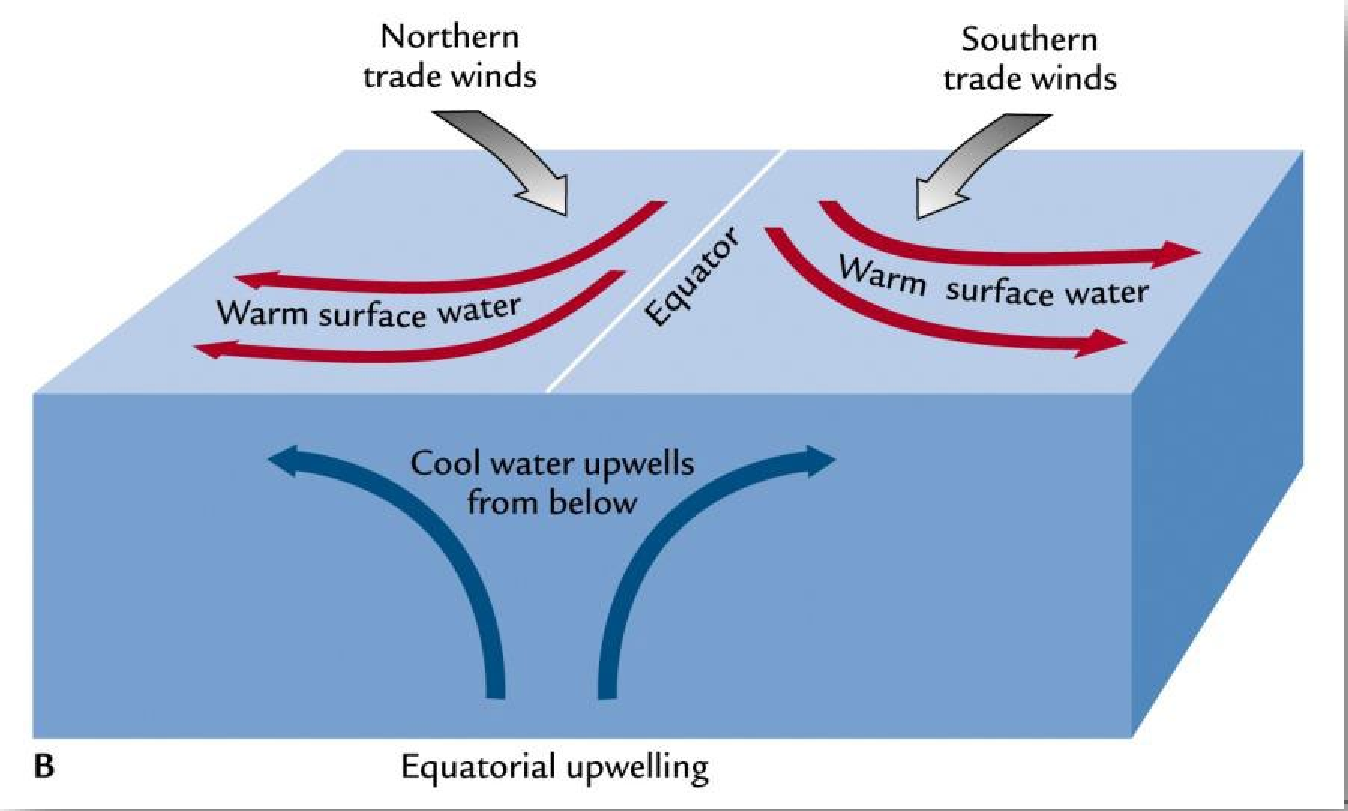
Wind Effects on Oceans



Wind moves surface water

Velocity of water decreases with depth

Coupling between Wind and Ocean Flow

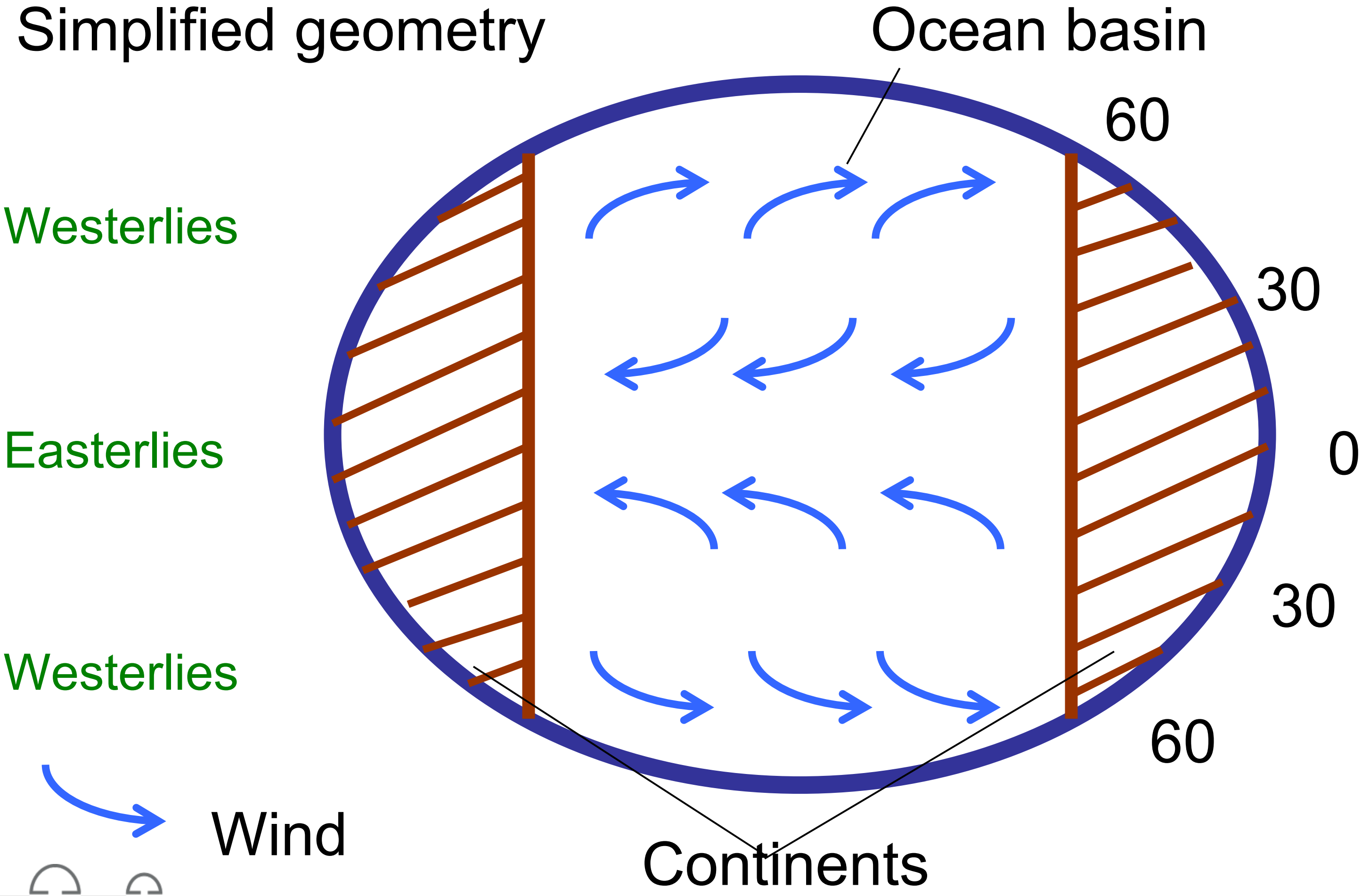


Equatorial upwelling

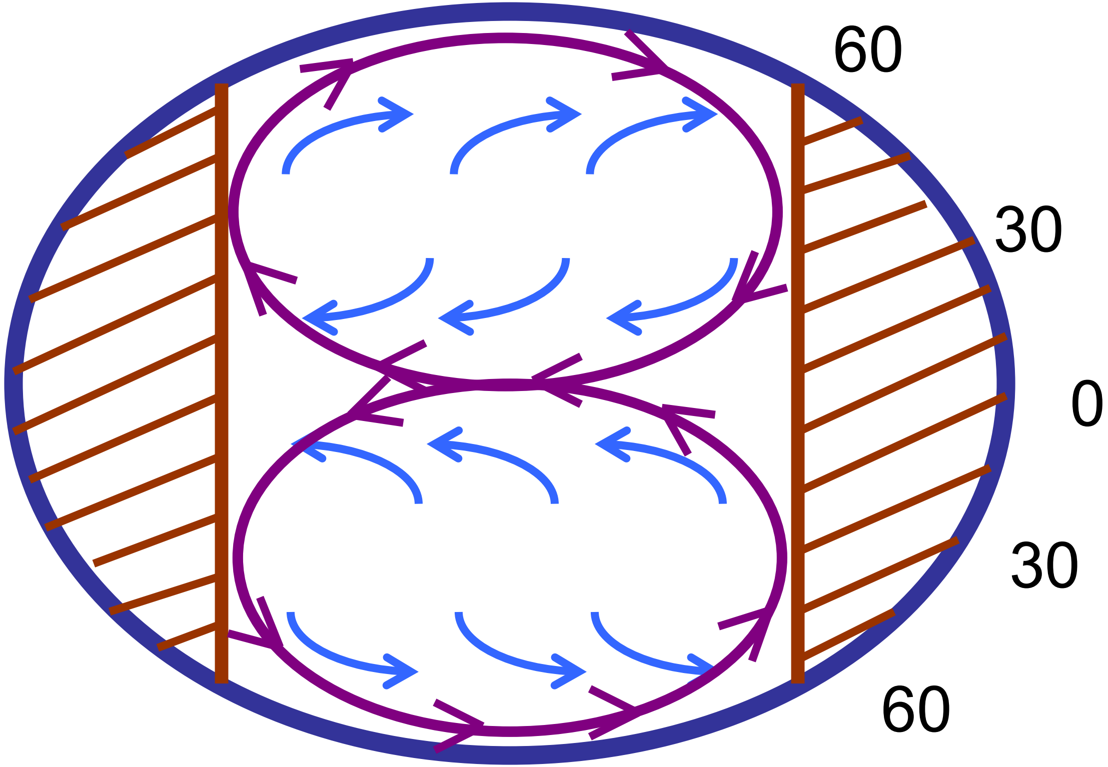
Consequences of upwelling

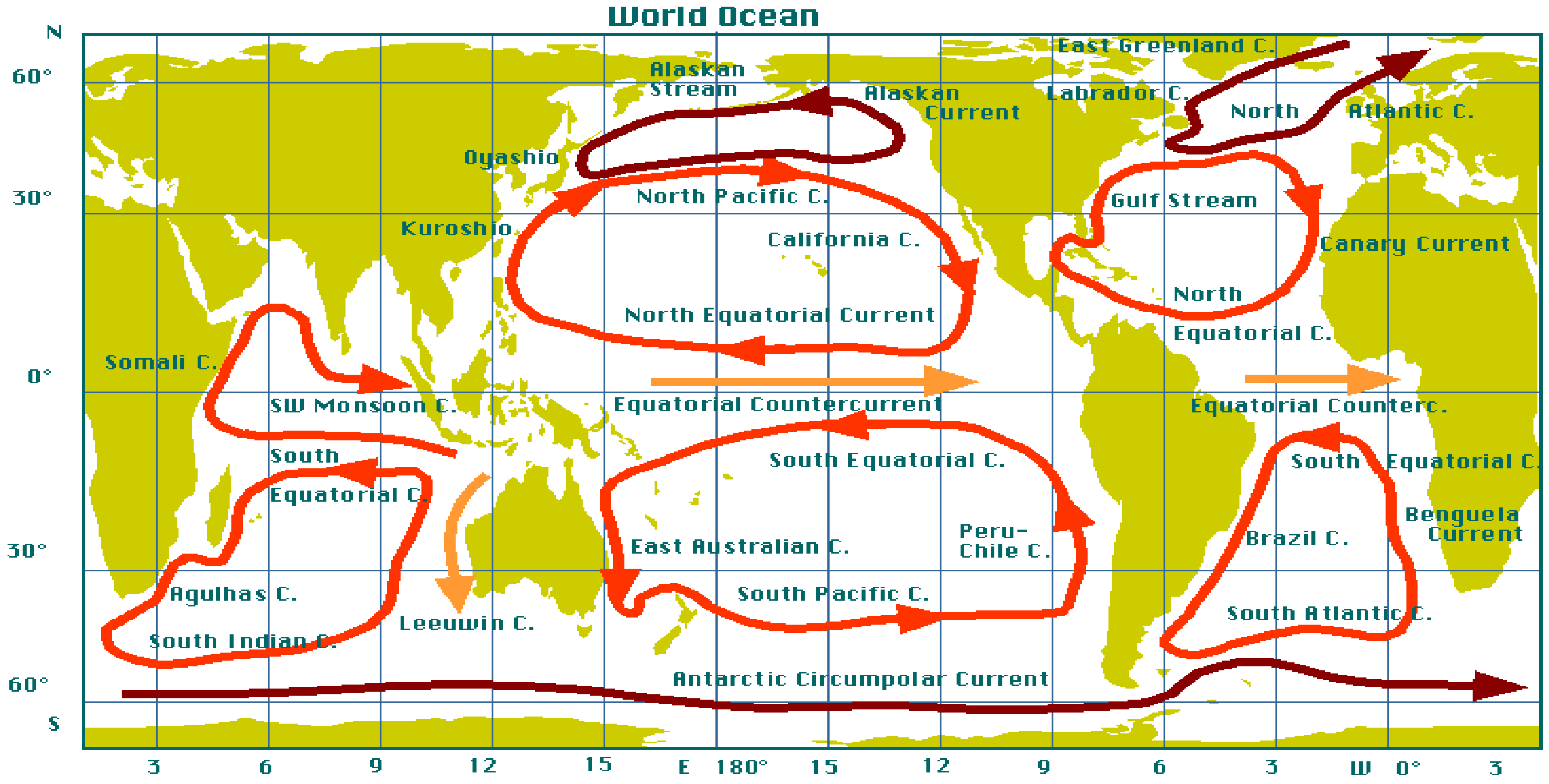
- Deep water is rich in nutrients (P, N, Fe)
- Upwelling brings nutrient-rich water to the surface ocean, fueling biological productivity (phytoplankton)
- Zooplankton eat the phytoplankton
- Fish eat both of these -> good fisheries in upwelling zones

Simplified geometry



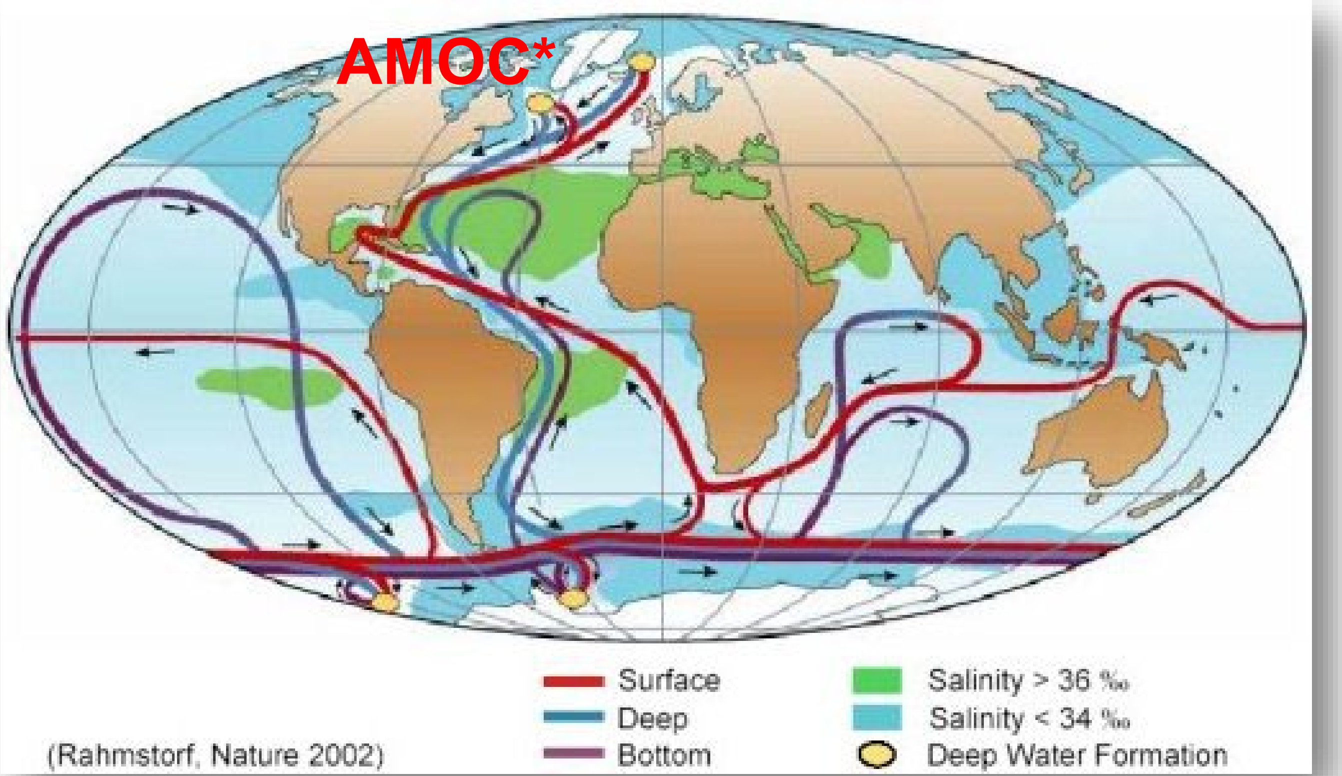
Ocean currents form large GYRES





http://www.es.flinders.edu.au/~mattom/IntroOc/notes/figures/fig2a2.html

Energy Transport by Conveyer Belt in the Oceans



(Rahmstorf, Nature 2002)

***Atlantic meridional overturning circulation (AMOC)**

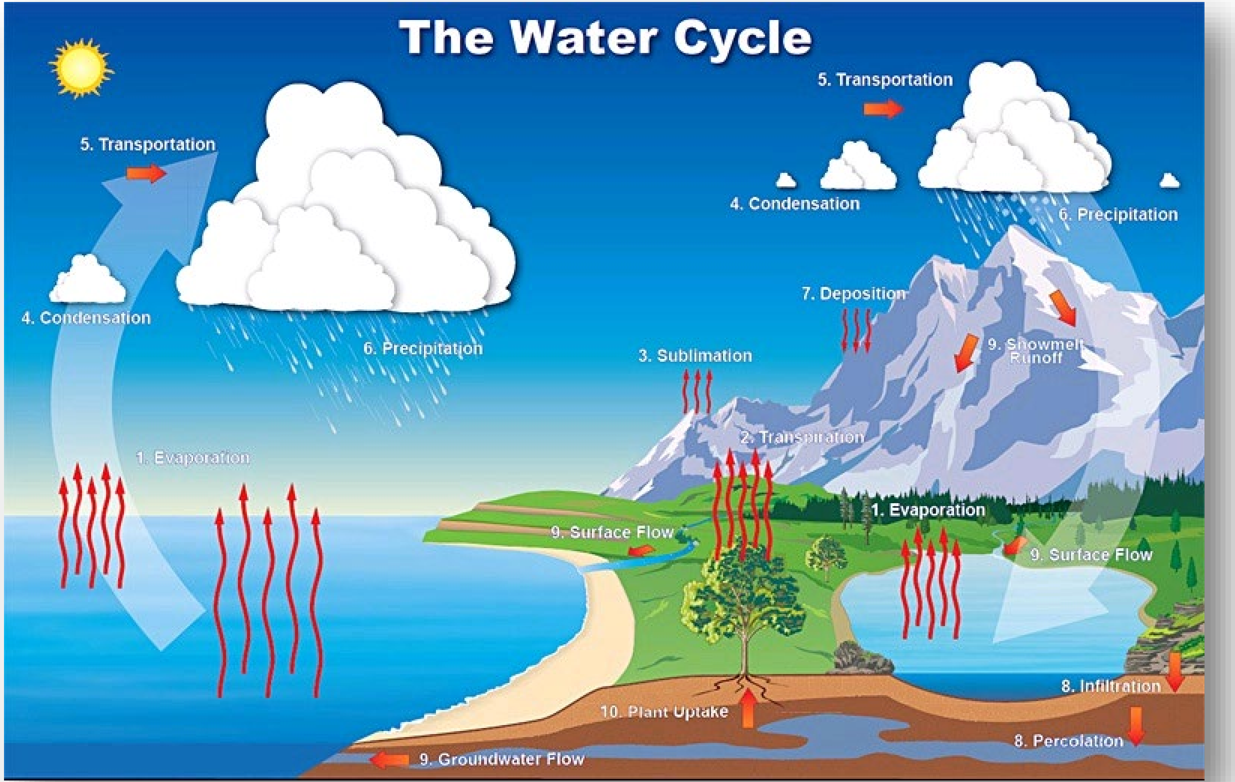
Result: Energy Transport in the Earth System

Solar energy received is greatest near the equator.

Energy is moved from the equator to the poles.

Energy is transferred by wind and ocean currents

Climate and the Water Cycle



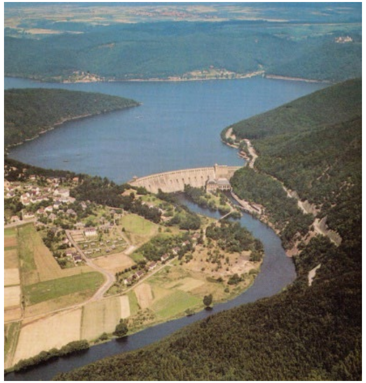
The basic water balance

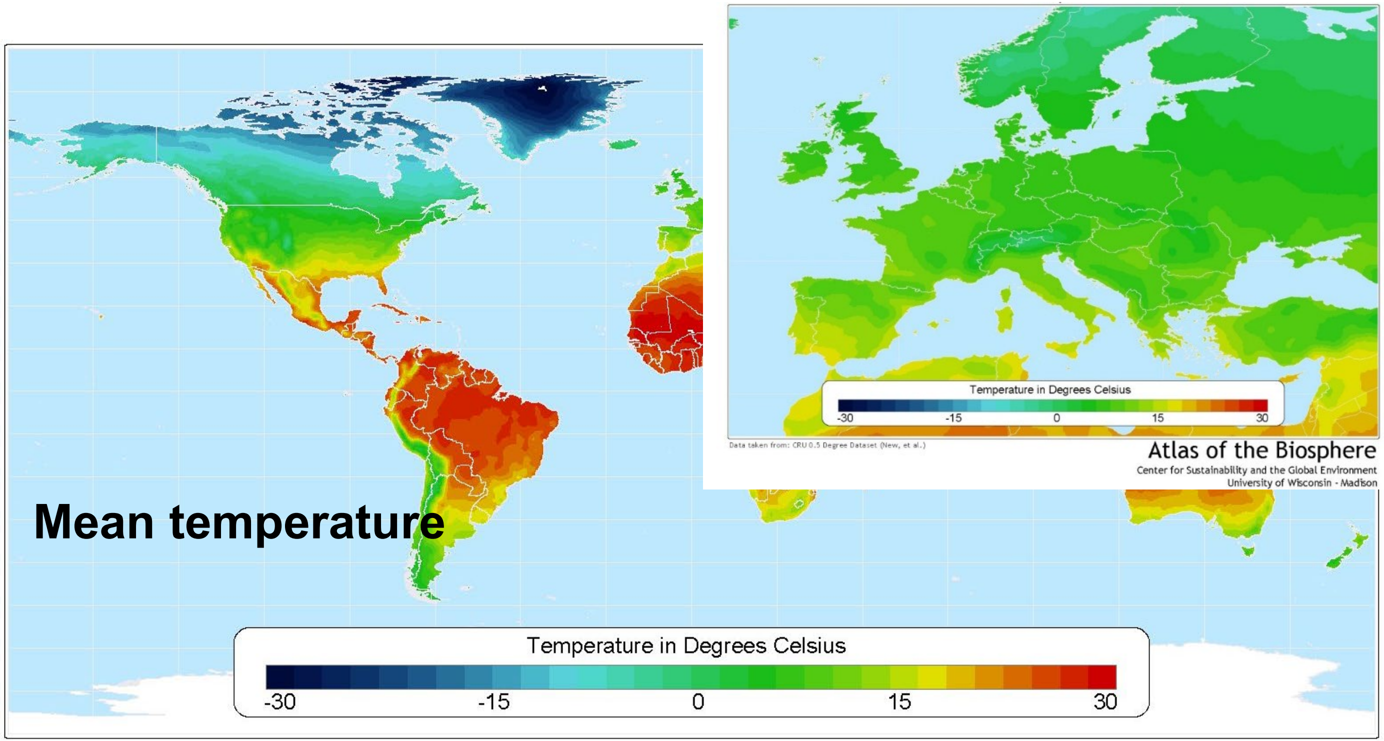
=

+

+

+/- Storage





Mean temperature

Data taken from: CRU 0.5 Degree Dataset (New, et al.)

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Data taken from: CRU 0.5 Degree Dataset (New, et al.)

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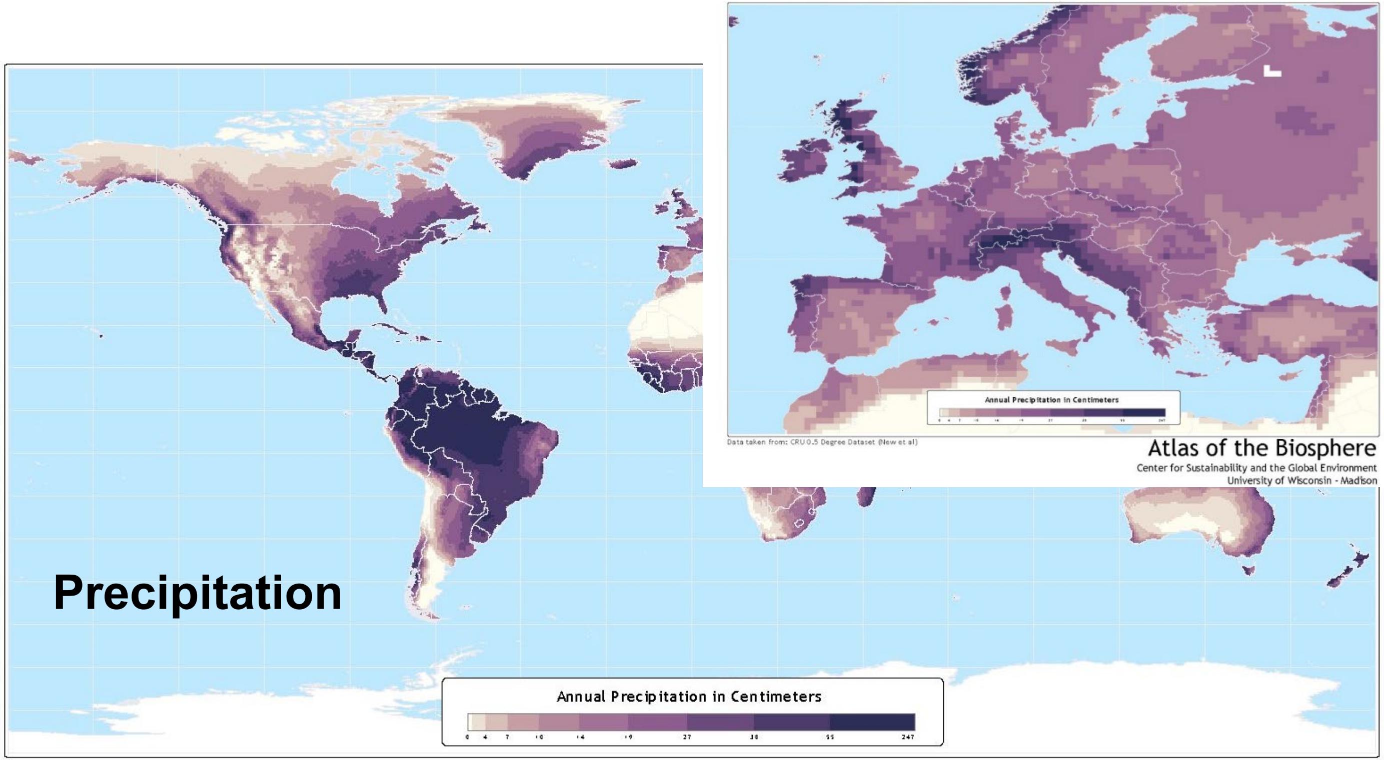
Precipitation



Data taken from: CRU 0.5 Degree Dataset (New et al)

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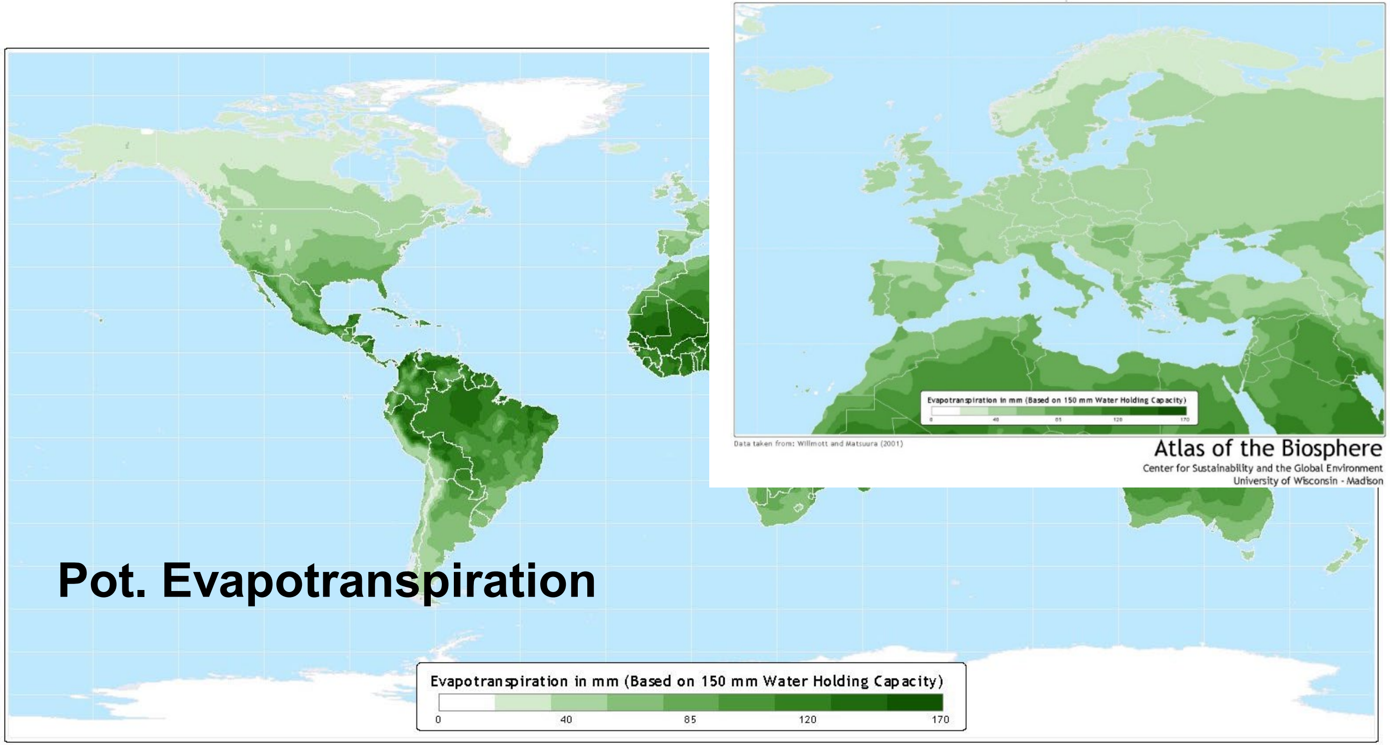
Pot. Evapotranspiration



Data taken from: Willmott and Matsuura (2001)

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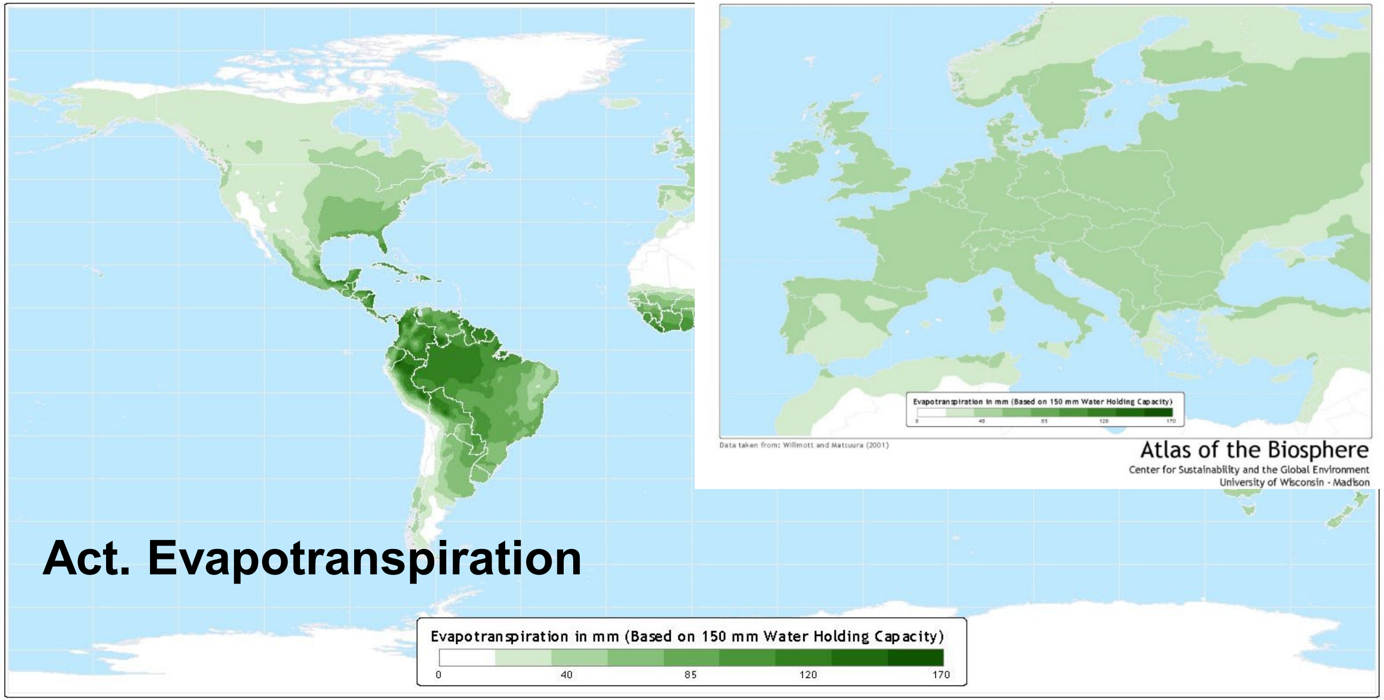
Act. Evapotranspiration



Data taken from: Willmott and Matsuura (2001)

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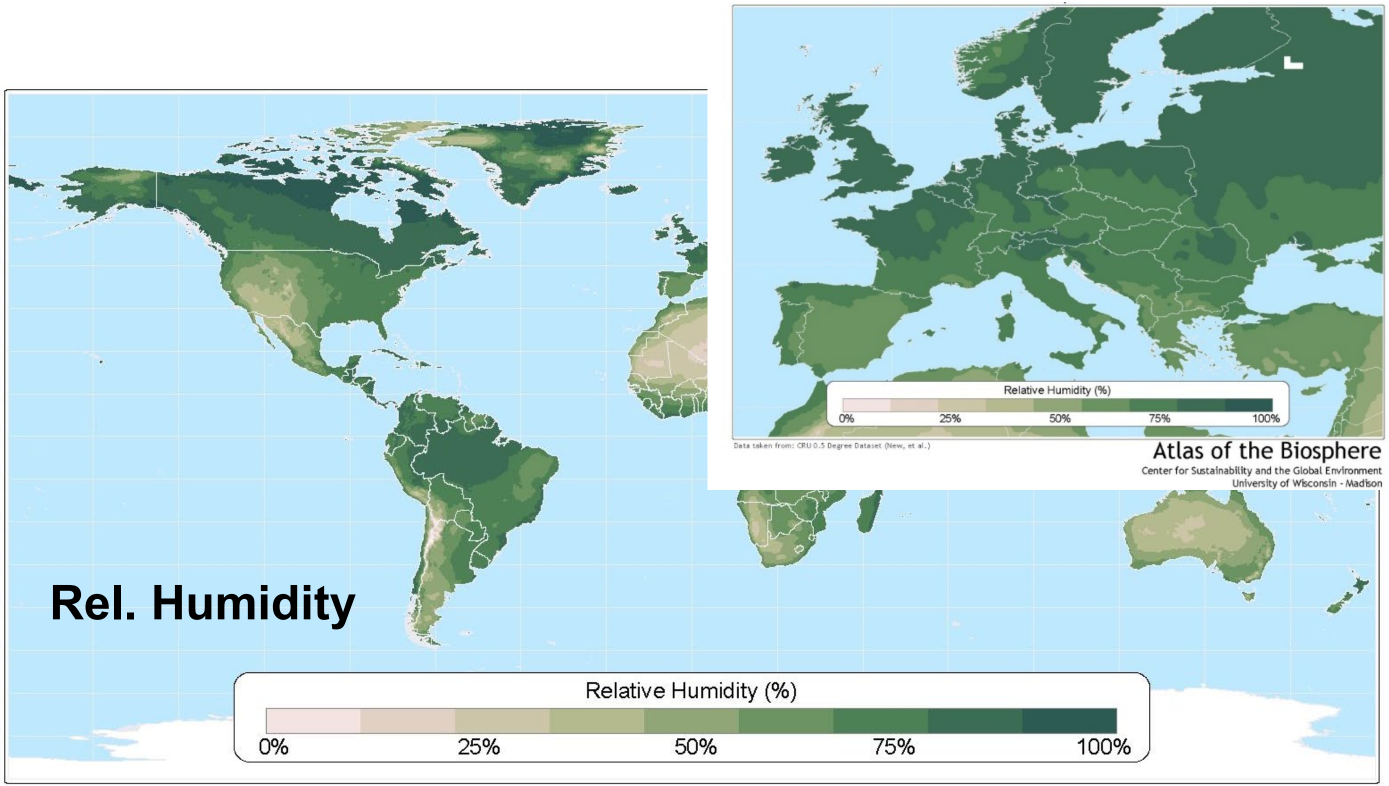
Rel. Humidity



Data taken from: CRU 0.5 Degree Dataset (New, et al.)

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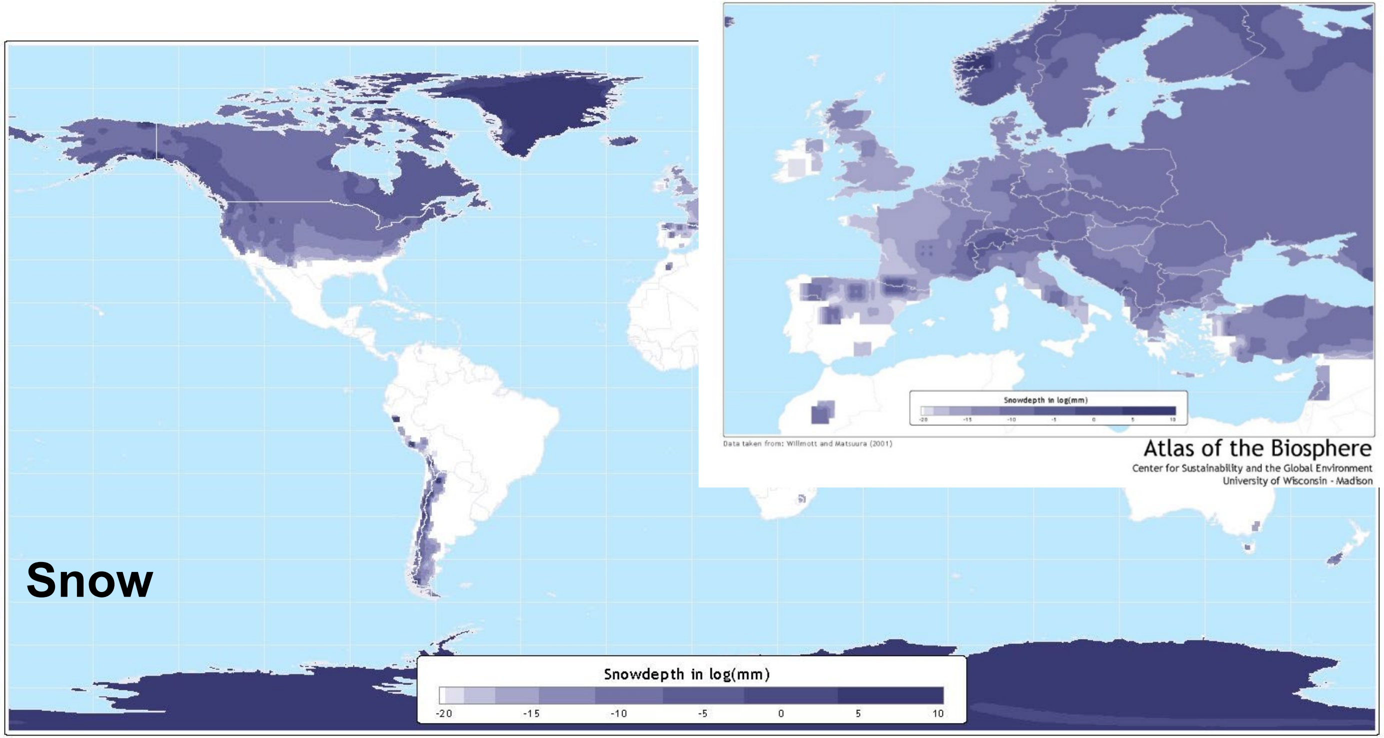

Snow

Data taken from: Willmott and Matsuura (2001)

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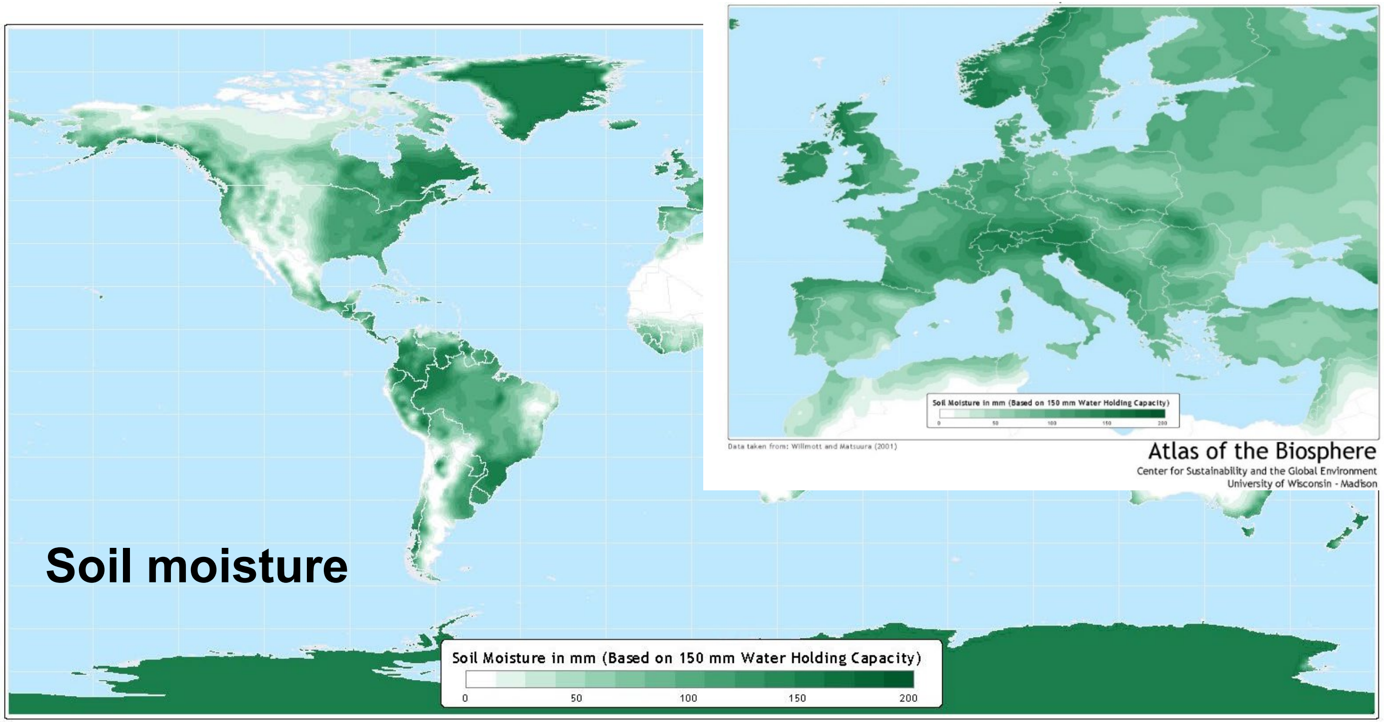
Soil moisture



Data taken from: Willmott and Matsuura (2001)

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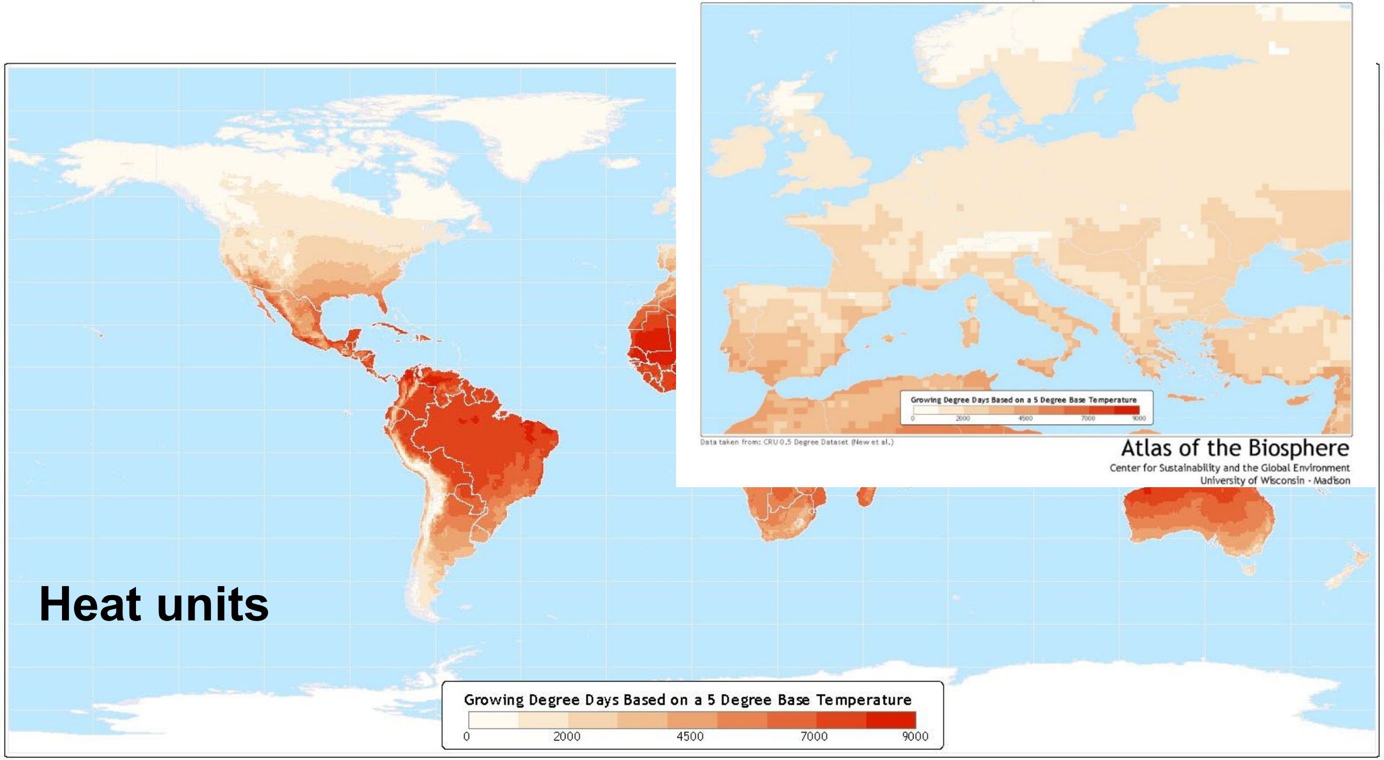
Heat units



Data taken from: CRU 0.5 Degree Dataset (New et al.)

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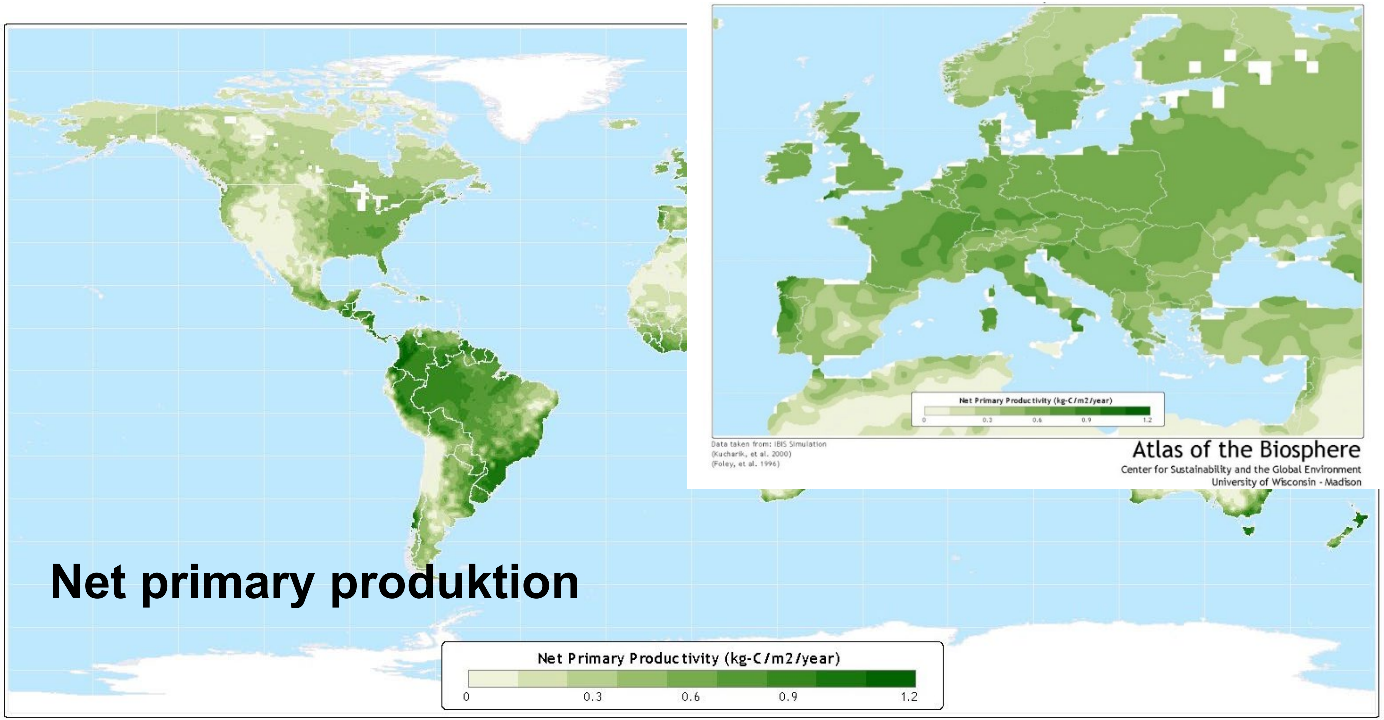
Net primary produktion



Data taken from: IBIS Simulation
(Kucharik, et al. 2000)
(Foley, et al. 1996)

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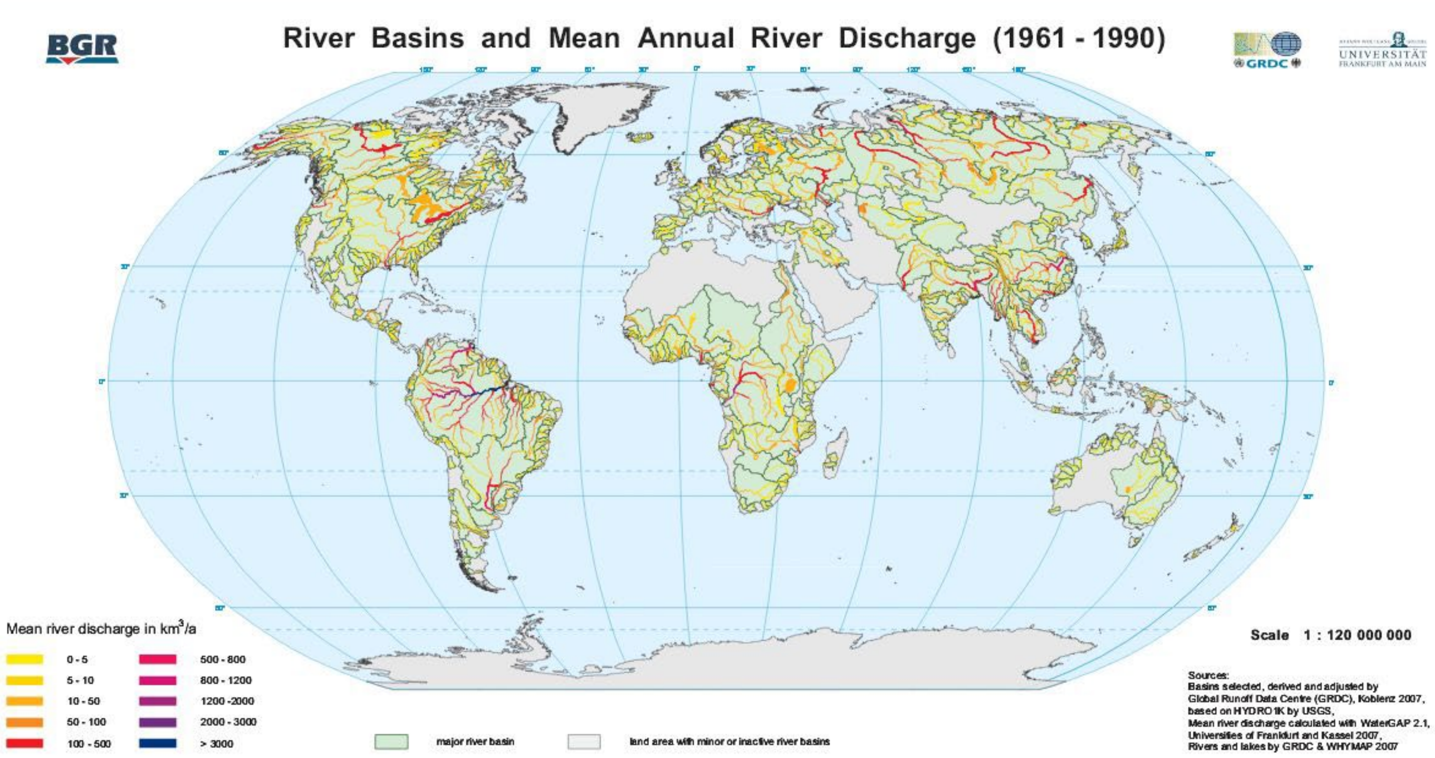
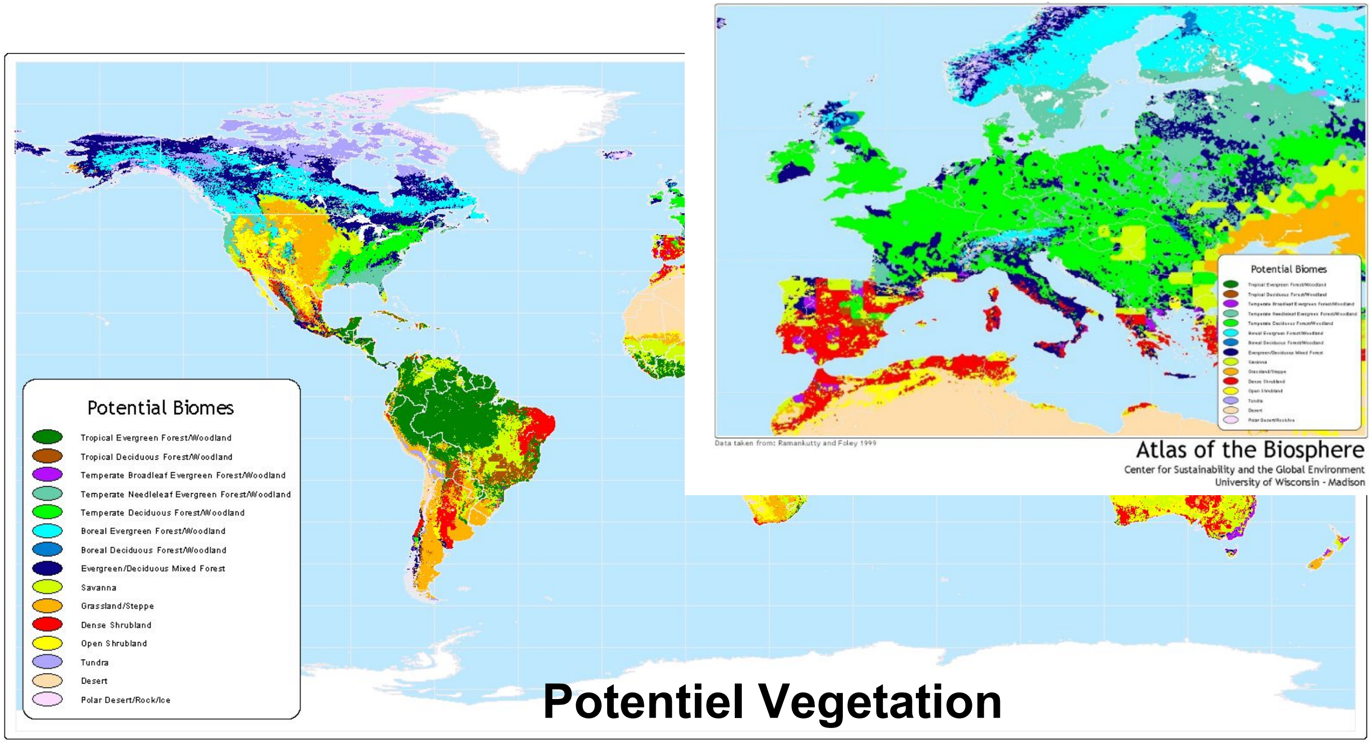


River Basins and Mean Annual River Discharge (1961 - 1990)

Sources:
Basins selected, derived and adjusted by
Global Runoff Data Centre (GRDC), Koblenz 2007,
based on HYDRO1K by USGS,
Mean river discharge calculated with WaterGAP 2.1,
Universities of Frankfurt and Kassel 2007,
Rivers and lakes by GRDC & WHYMAP 2007

Potentiel Vegetation



Data taken from: Ramankutty and Foley 1999

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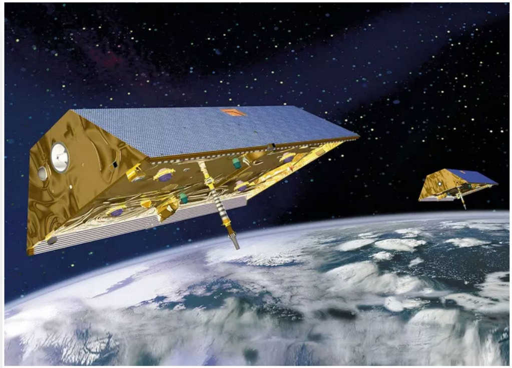
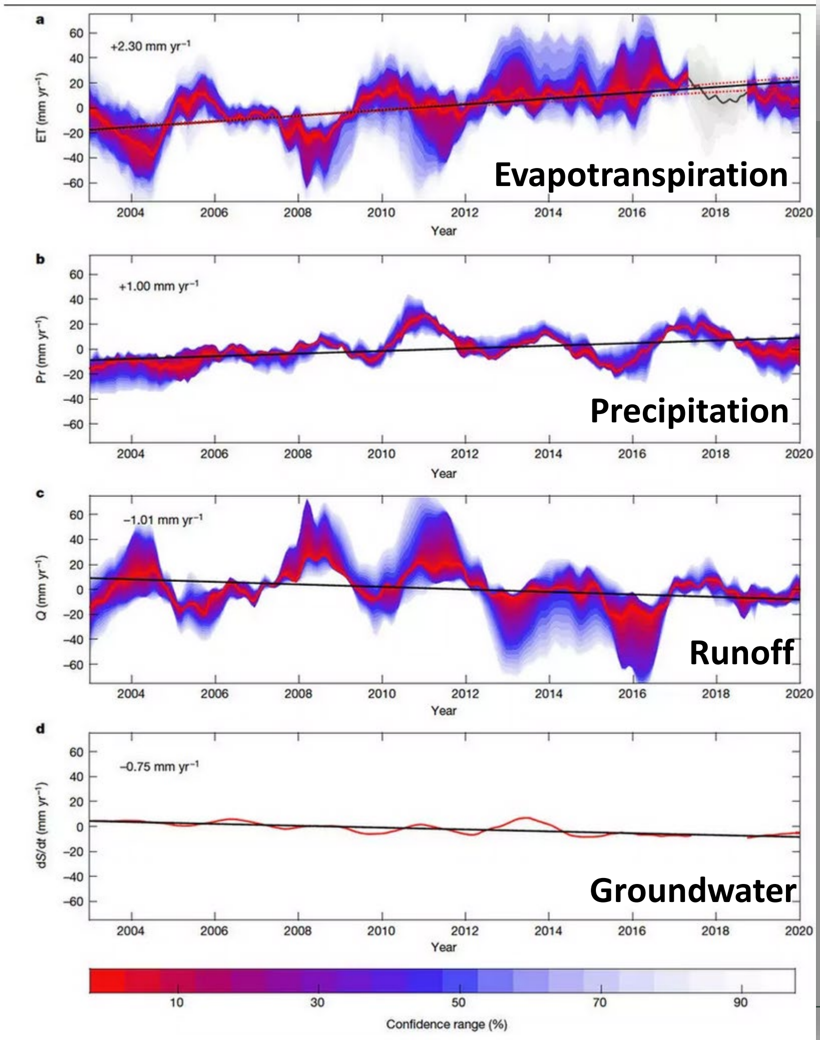
Global water trends



NASA Gravity Recovery and Climate Experiment (GRACE mission) Twin Satellites, concept art Image: NASA PO.DAAC.

Gravity Recovery and Climate Experiment (GRACE)



Pascolini-Campbell et al (2021)