Project presentation

- Topic has to be chosen before 31 May
- Start early → topics need refinement
- Presentation of 15 mins total
  - 12 mins talk + 3 mins Q&A
- Presentations in English
- Evaluation criteria:
  - Clarity, creativity, integrity
  - Results not important
- **Two people pair up for a project**
  - **Joint report with author contribution statement**
  - **Joint presentation**

WORKLOAD

- 3 ECTS Course
- 90 h in total for the entire semester
  - 90 h = 30 h lecture + 60 h self study
- 6 h per week for 15 weeks
  - 6 h = 2 h lecture + 4 h self study
- **Division of self study workload (60h)**
  - **Per person:**
    - **Lecture comprehension: 15 h**
    - **Project work: 30 h**
    - **Project presentation & report: 15 h**
  - **Per project team (of two members):**
    - **Project work: 60 h**
    - **Project presentation & report: 30 h**

LECTURE 2:
Introduction to the earth's climate

ML-4430: Machine learning approaches in climate science

28 Apr 2021

Bedartha Goswami

What is Climate

1

- Weather, on average?
- The climate system

Components of the climate system

2

- Atmosphere
- Ocean
- Land
- Cryosphere
- ~~Biosphere~~
- ~~Anthroposphere~~

The Atmosphere

3

- Vertical structure
- Meridional Structure

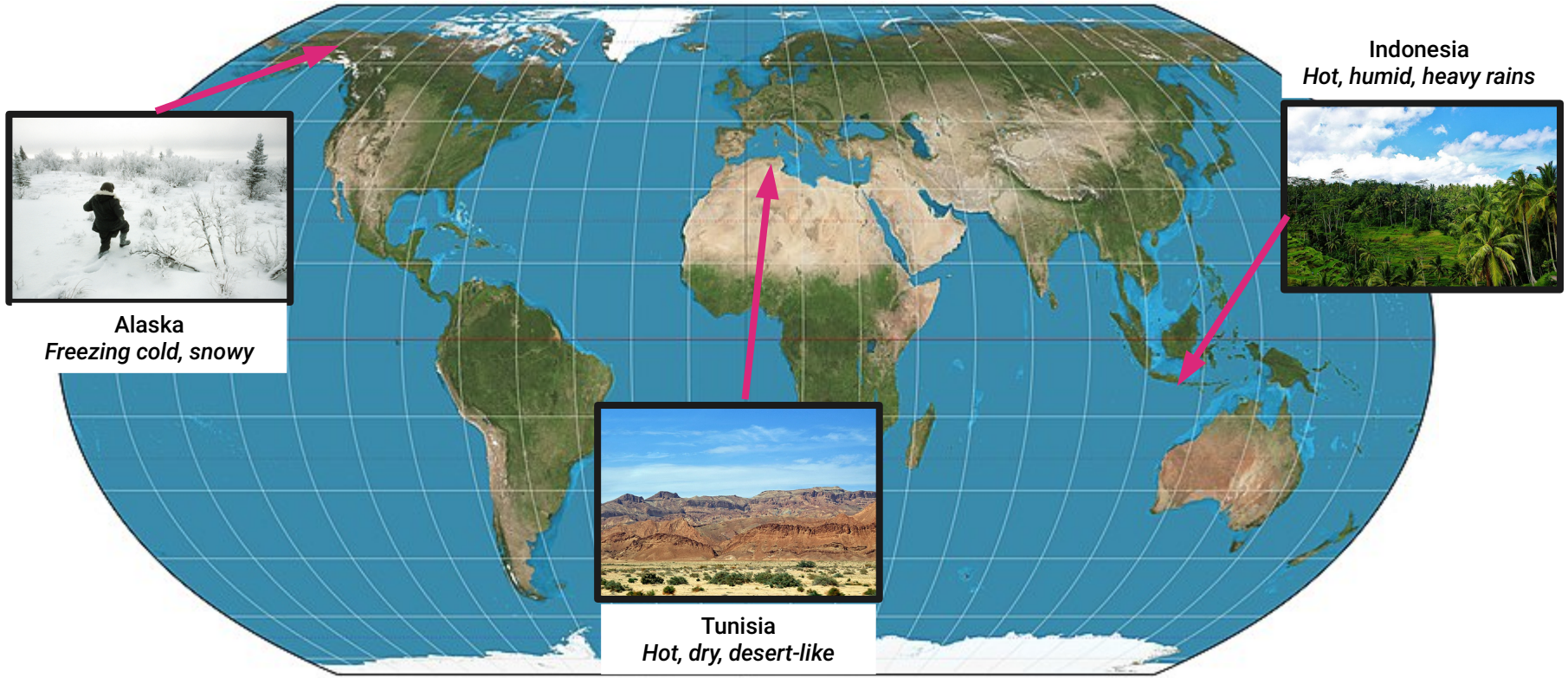
Additional topics

4

- Climate Forcings
- ~~Climate Feedbacks~~
- Climate Sensitivity

Outline

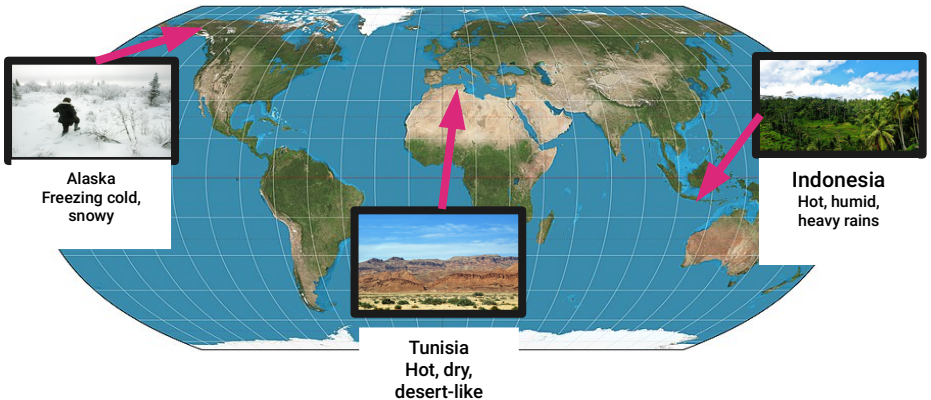
Image source: Wikipedia

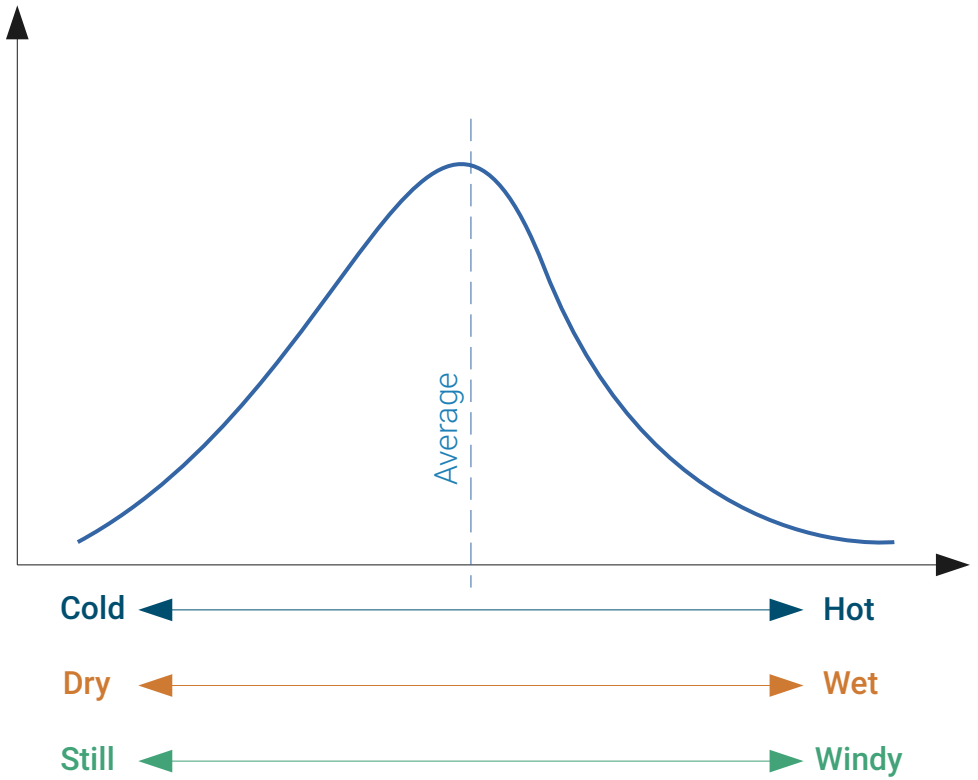


1. What is climate → Weather, on average?

Several questions arise:

- Is the weather the same all year around?
- Does it differ depending on time of day?
- Do certain weather events (droughts, floods, blizzards, etc.) repeat at longer intervals such as decades or centuries?
- What about longer time scales?

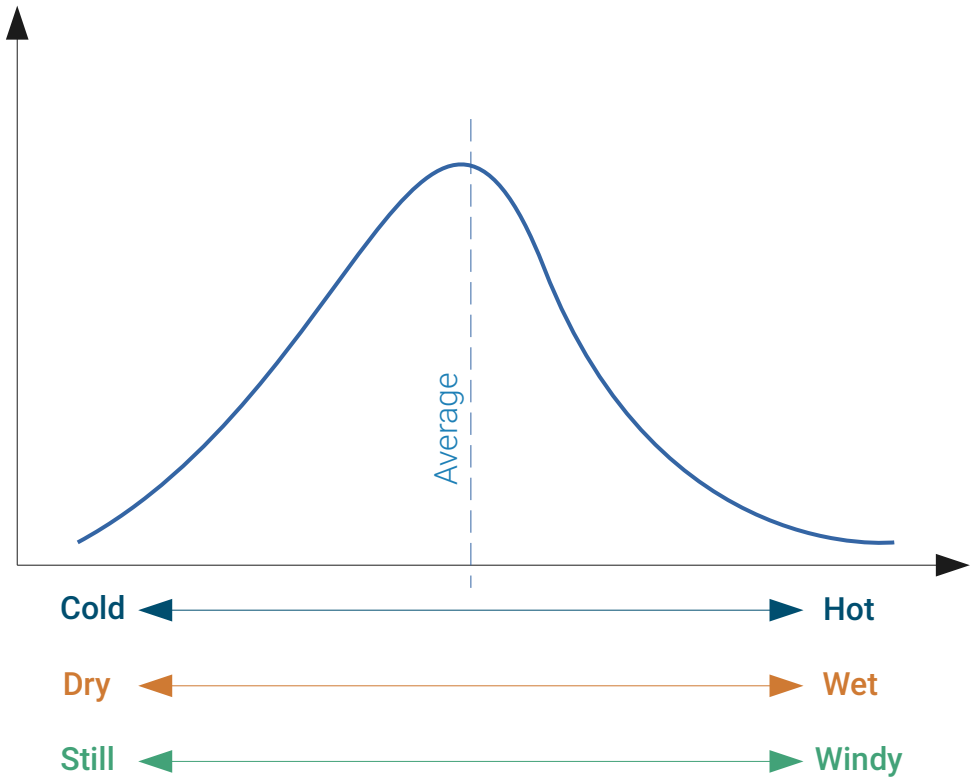




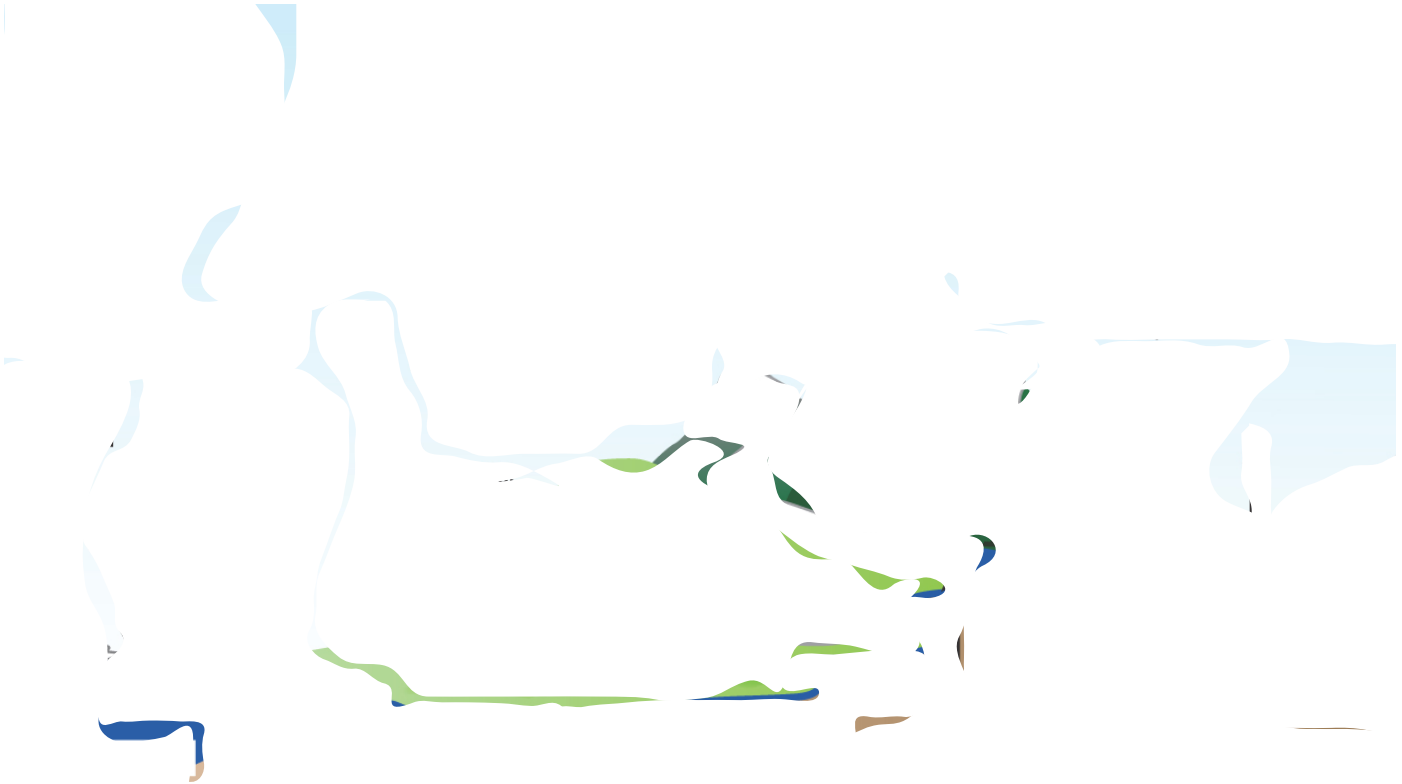
1. What is climate → Weather, on average?

Climate is a distribution of (weather) states

- Given a particular location or region
- Given a particular temporal scale (daily, weekly, annual, decadal, etc.)
- Climate change is thus *a change in the distribution* of weather states
- A change in the mean is only one (of many) indicator of climate change



IPCC, AR4, The Physical Science Basis, 2007



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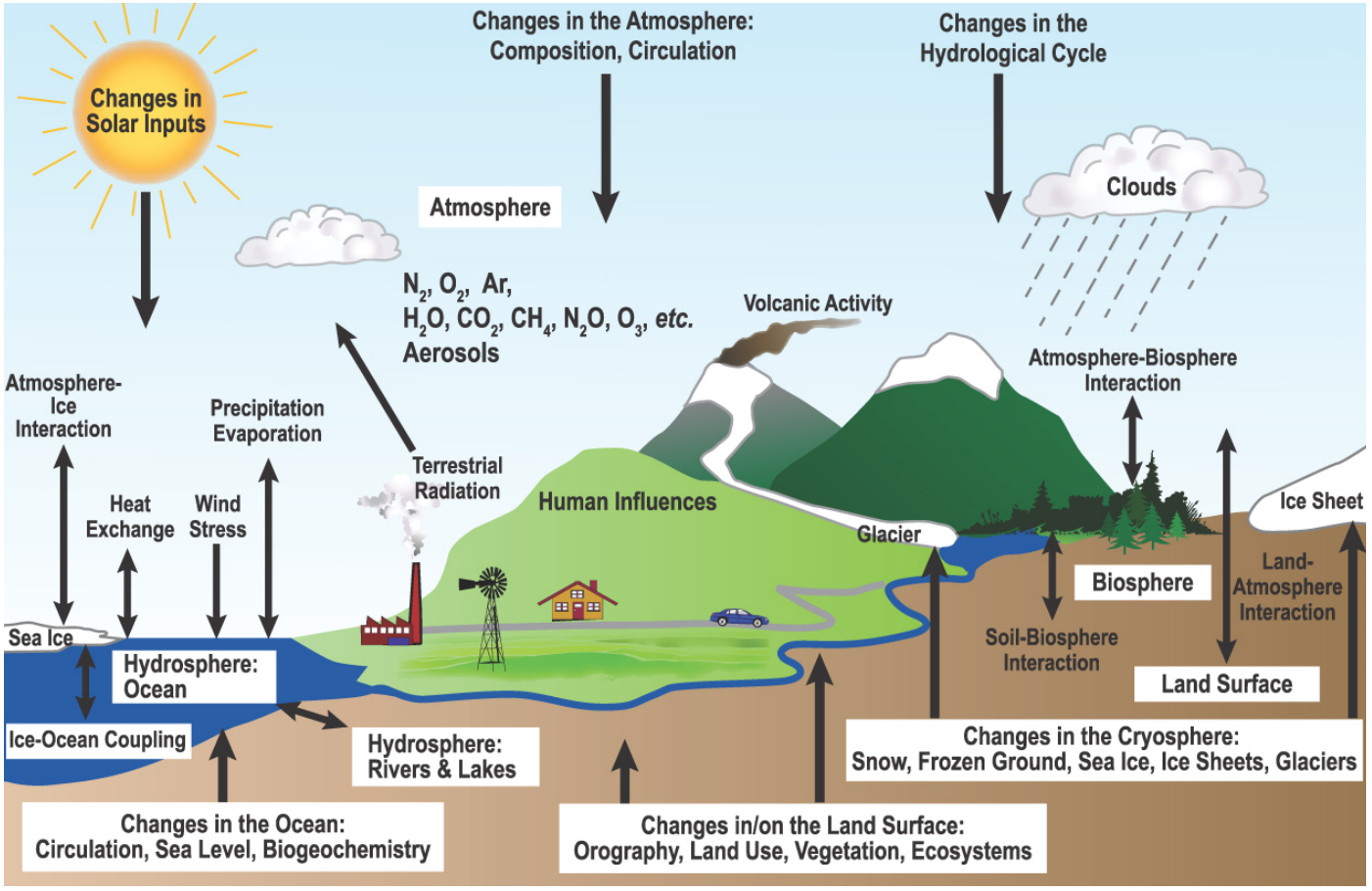

What is Climate

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- Weather, on average?
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The Atmosphere

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- Vertical structure
- Meridional Structure

Components of the climate system

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- Land
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- ~~Biosphere~~
- ~~Anthroposphere~~

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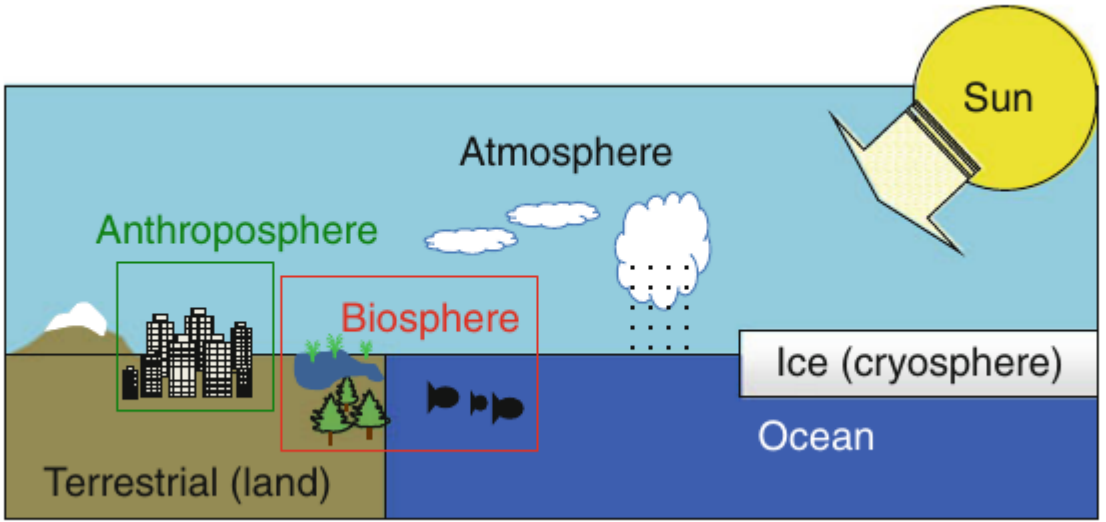
- ~~Climate Feedbacks~~
- Climate Sensitivity

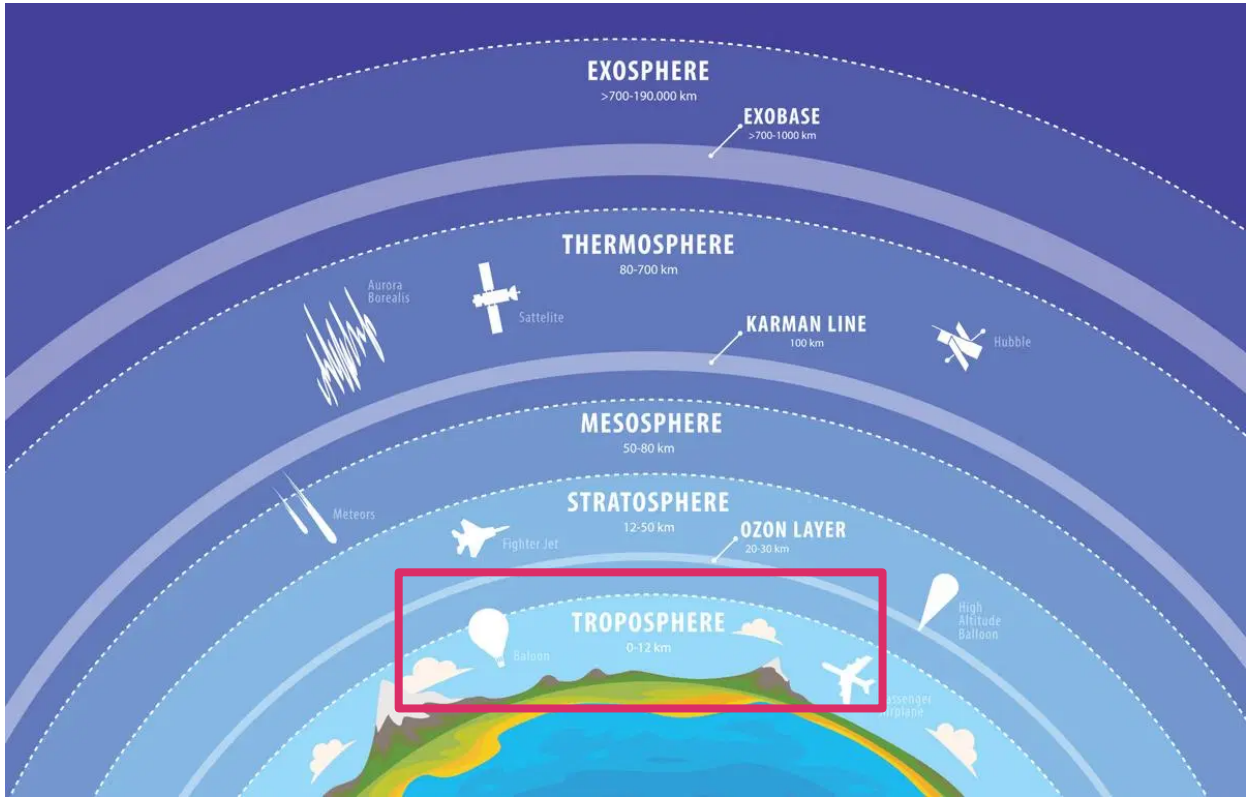
Outline

Gettelman & Rood, 2016



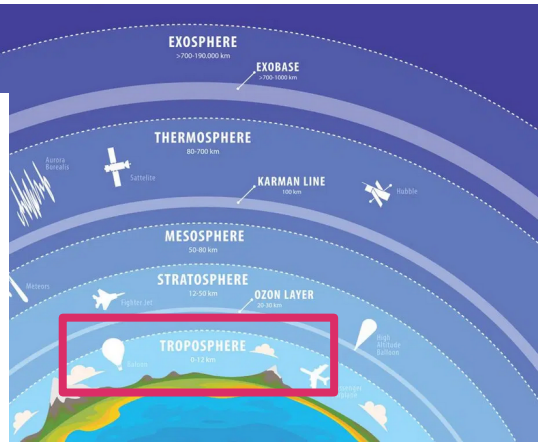
2. Components of the climate system

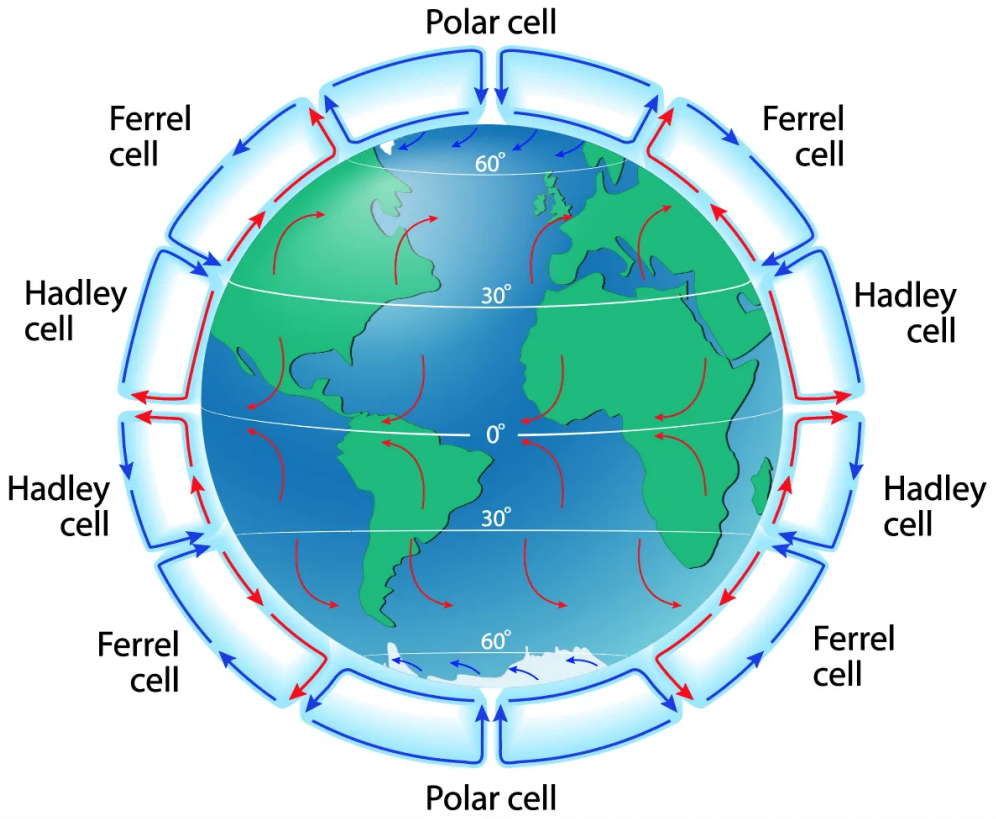
Image source: https://tropicsu.org/



2. Components of the climate system → Atmosphere

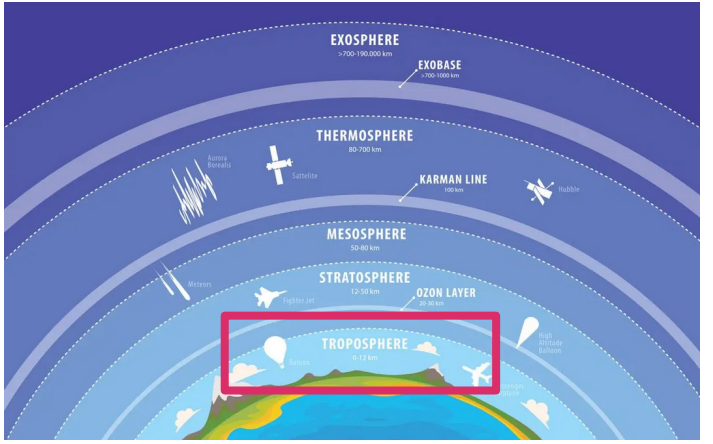
Image source: https://www.internetgeography.net/





Atmosphere

- Most relevant climate dynamics in the troposphere
- Exchange of heat and energy with land, ocean, cryosphere, and the sun
- Marked by dominant and stable patterns of wind circulation
- Greenhouse gases: Water and CO2 → both are cycled through the atmosphere



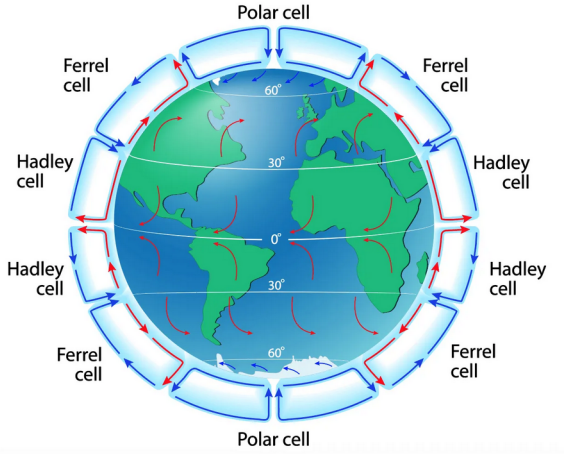


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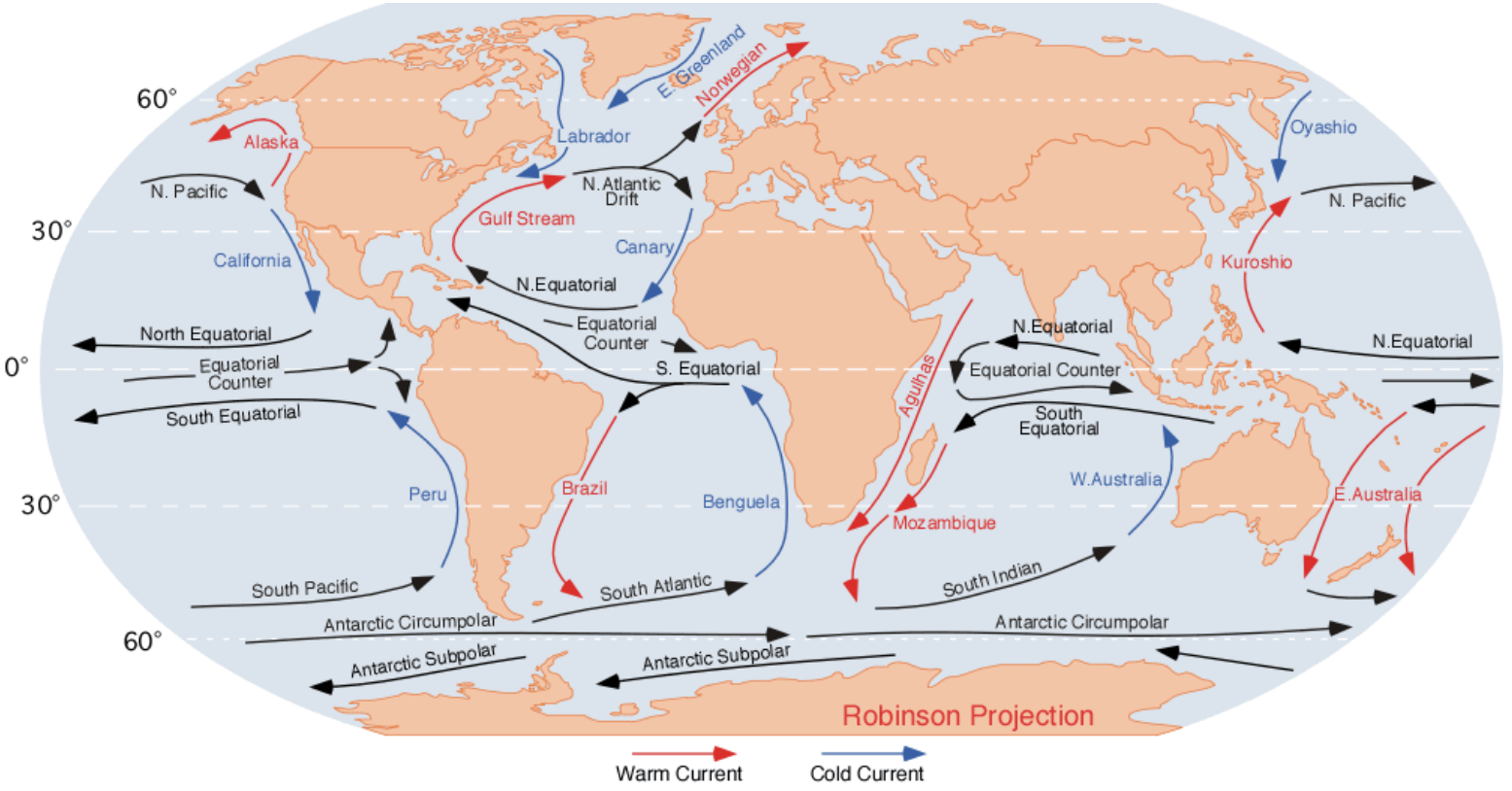
Image source: Wikipedia



2. Components of the climate system → Ocean

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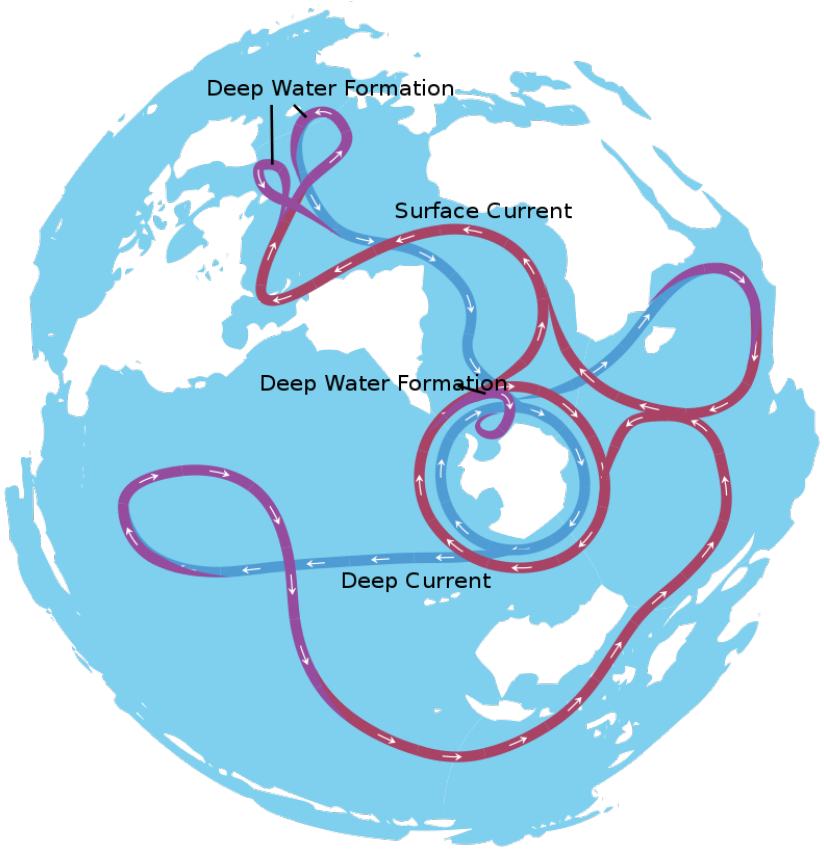
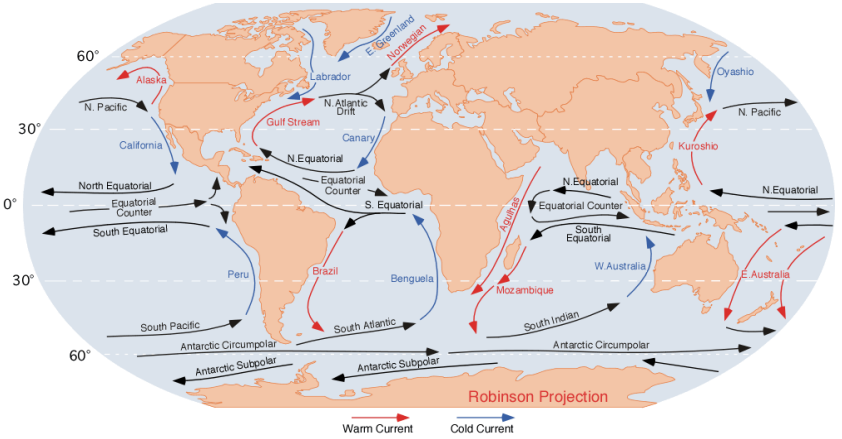
Image source: Wikipedia





2. Components of the climate system → Ocean

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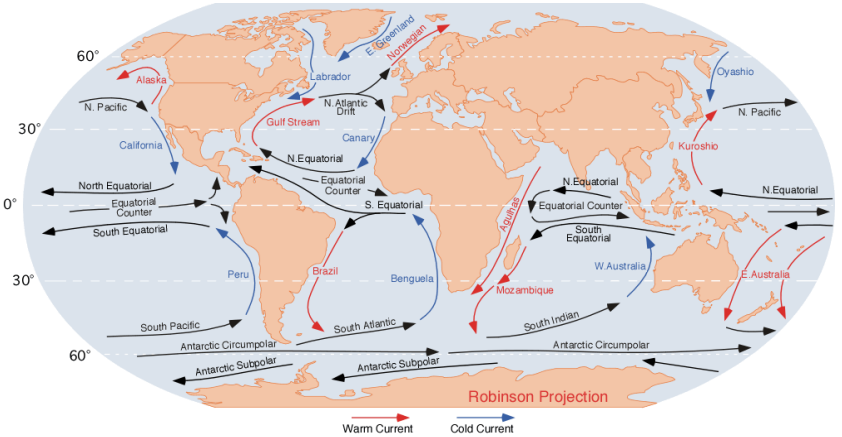
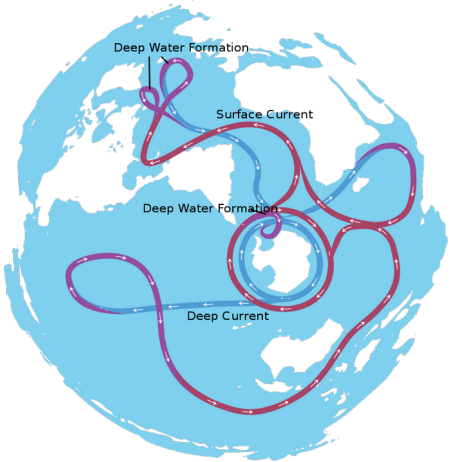
Ocean

- Dynamics composed of surface currents and deep water (thermohaline) currents
- Surface currents forced by earth's rotation and surface winds
- Thermohaline circulation forced by density (and thus salinity) and temperature differences
- Dominant mode of northward transport of heat in the Atlantic





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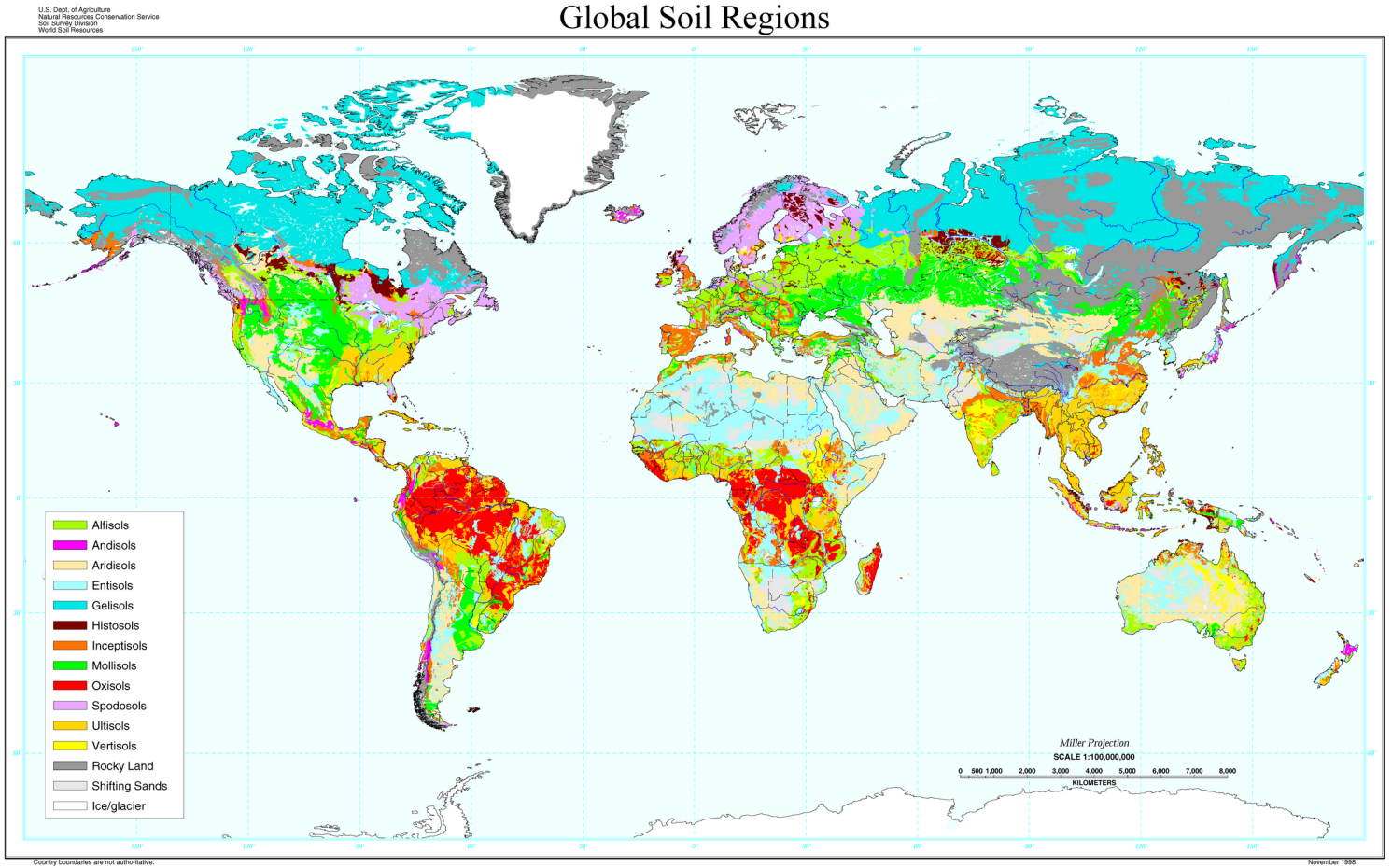

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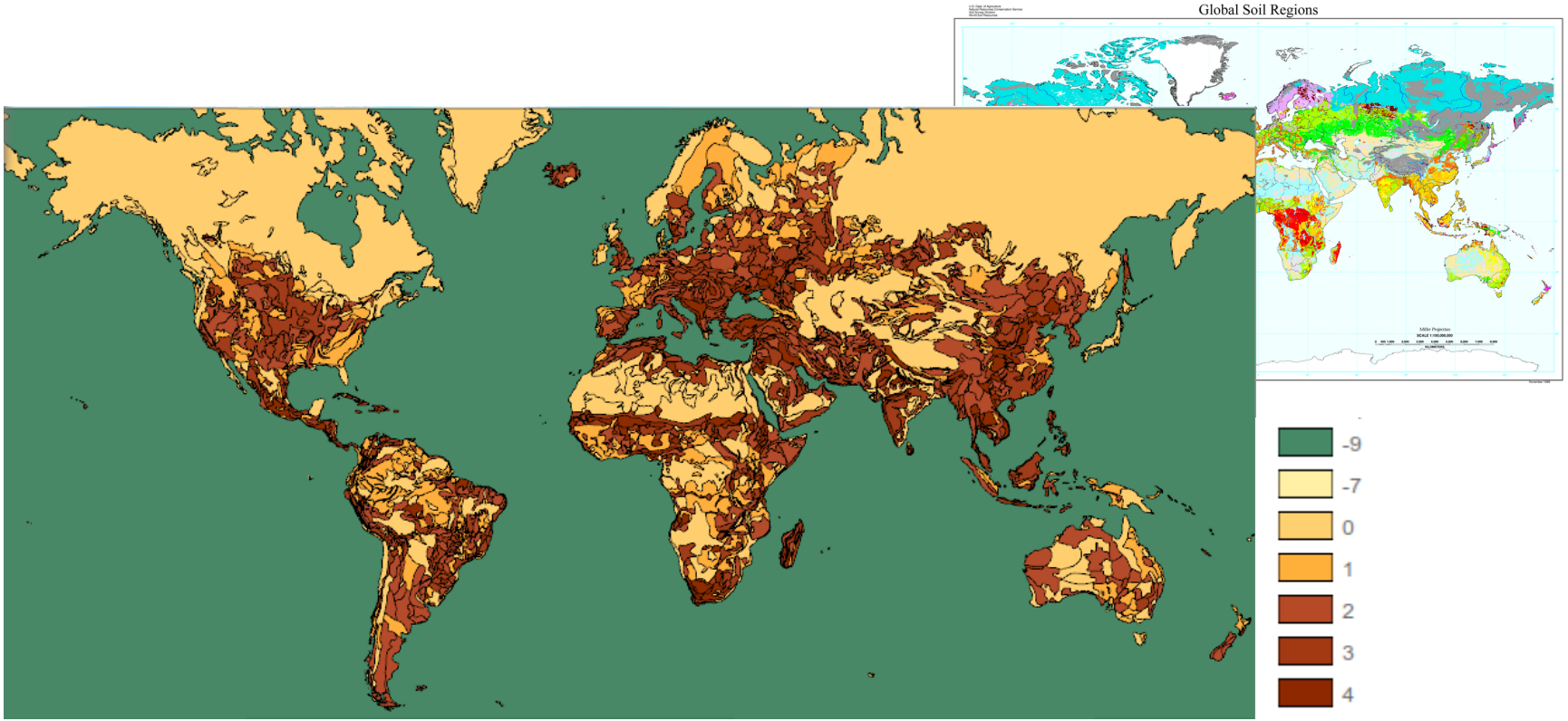

2. Components of the climate system → Land

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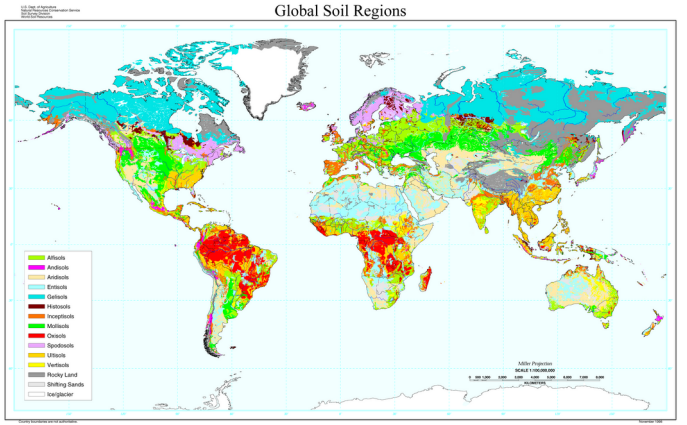
Land

- Soil plays the most important role
- Modulates water, CO2, and other important cycles
- Crucial determinant in climatological conditions
- Interface of atmosphere, cryosphere, ocean, and biosphere



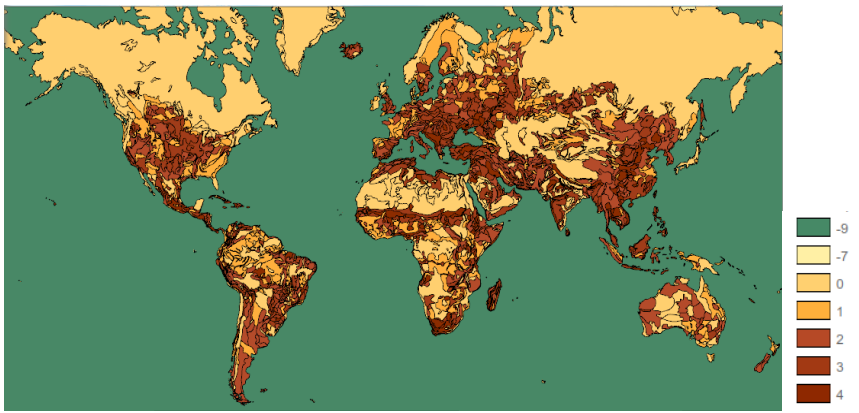
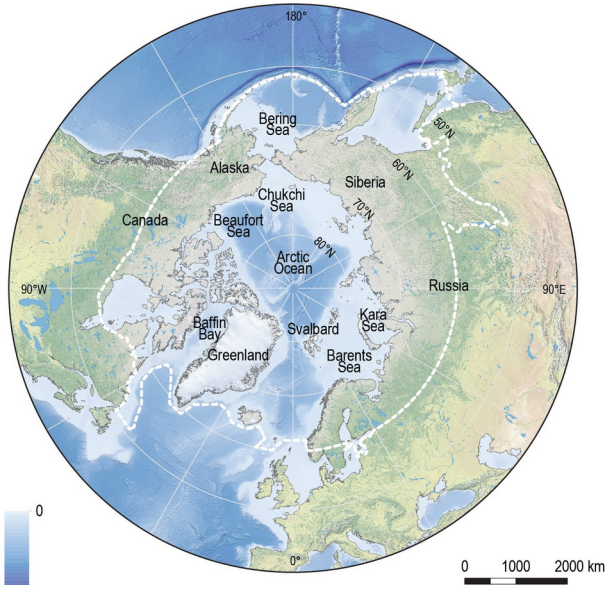
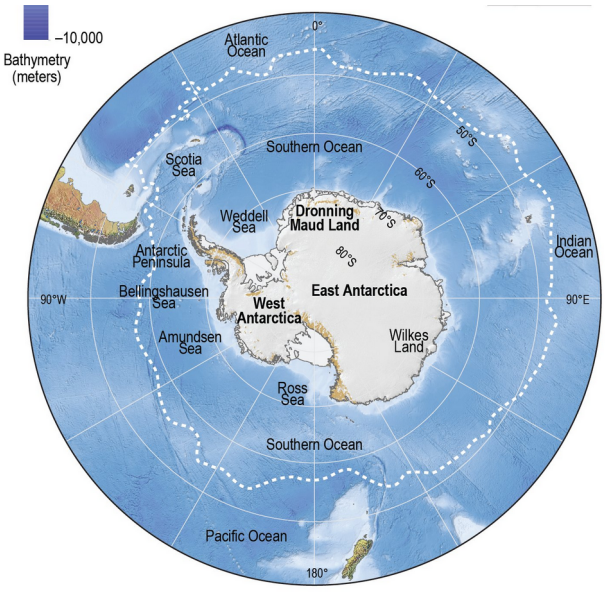


Image source: IPCC Special Report Ocean and the Cryosphere (2019)





2. Components of the climate system → Cryosphere

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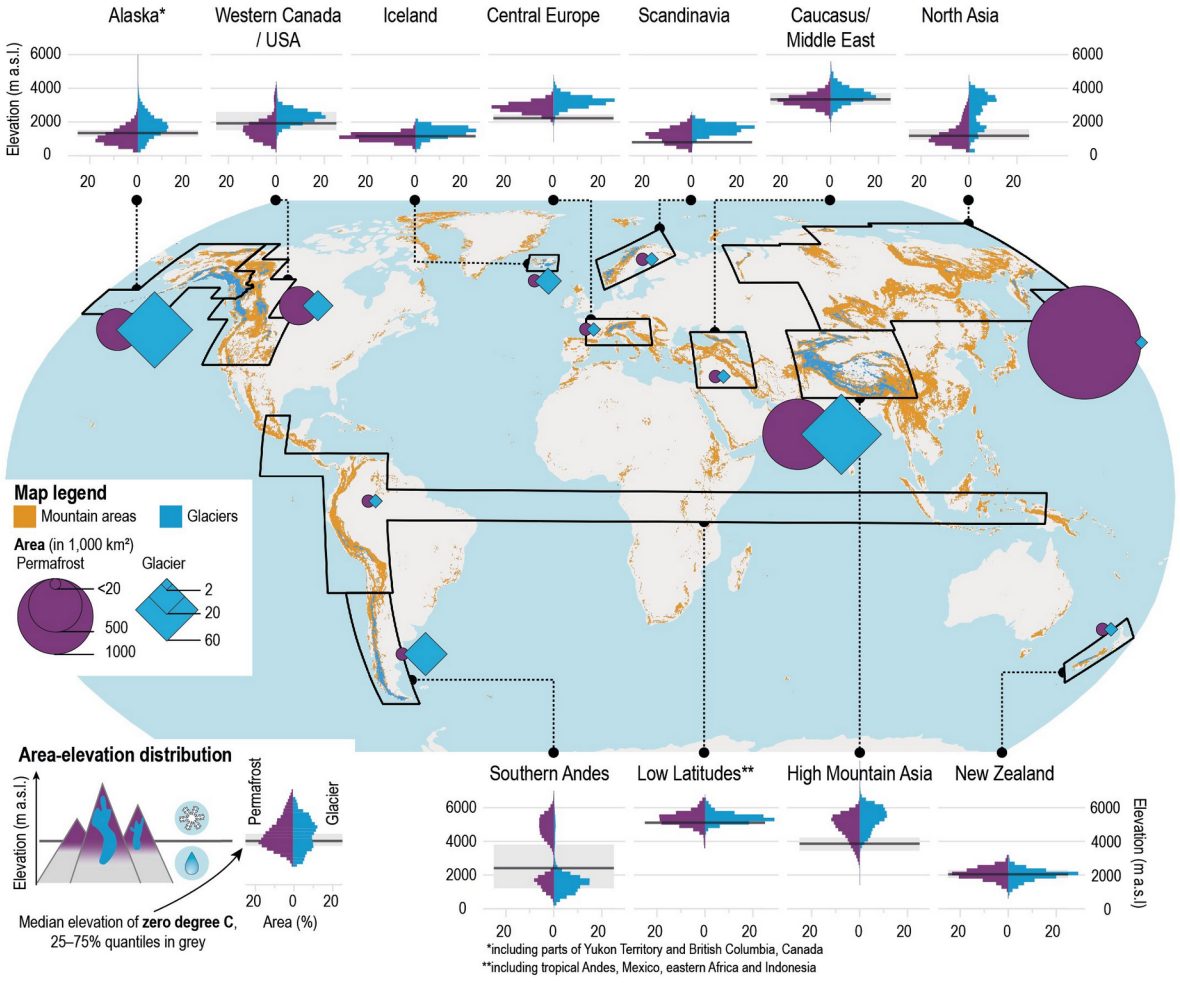
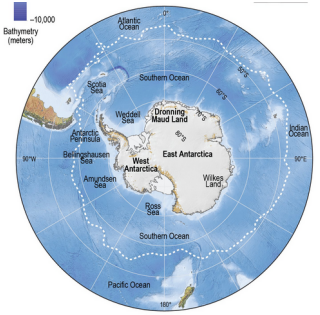
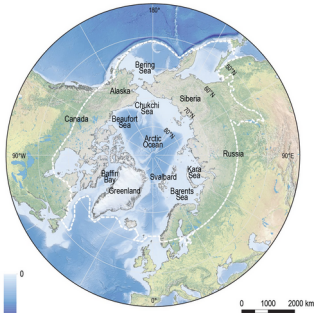
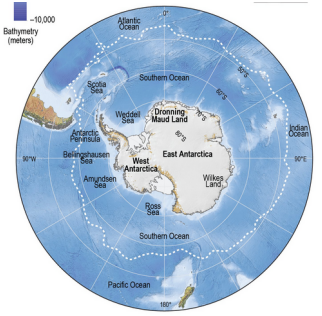


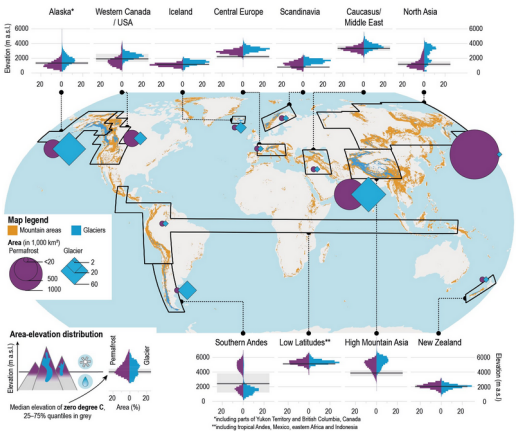


Cryosphere

- Polar regions and high mountain areas
- Important source of freshwater
- Global ice extent modulates global climate
- Arctic and Antarctic ice extent crucial to maintaining polar fronts which influence extratropical climate
- Glaciers influence regional and hemispherical climate systems







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- ~~Anthroposphere~~

The Atmosphere

3

- Vertical structure
- Meridional Structure

Additional topics

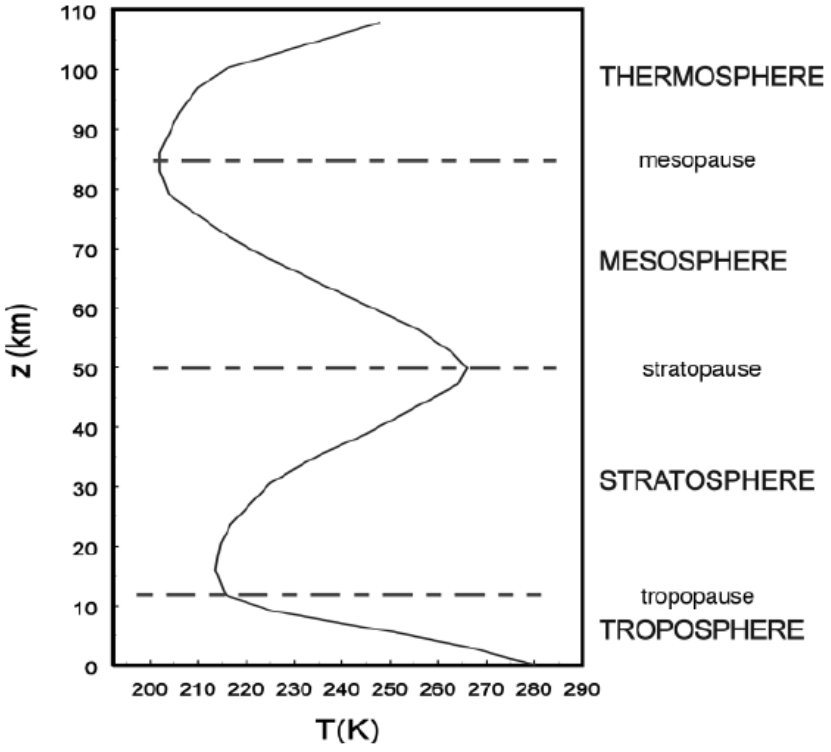
4

- Climate Forcings
- ~~Climate Feedbacks~~
- Climate Sensitivity

Marshall and Plumb (2008)

Vertical temperature profile

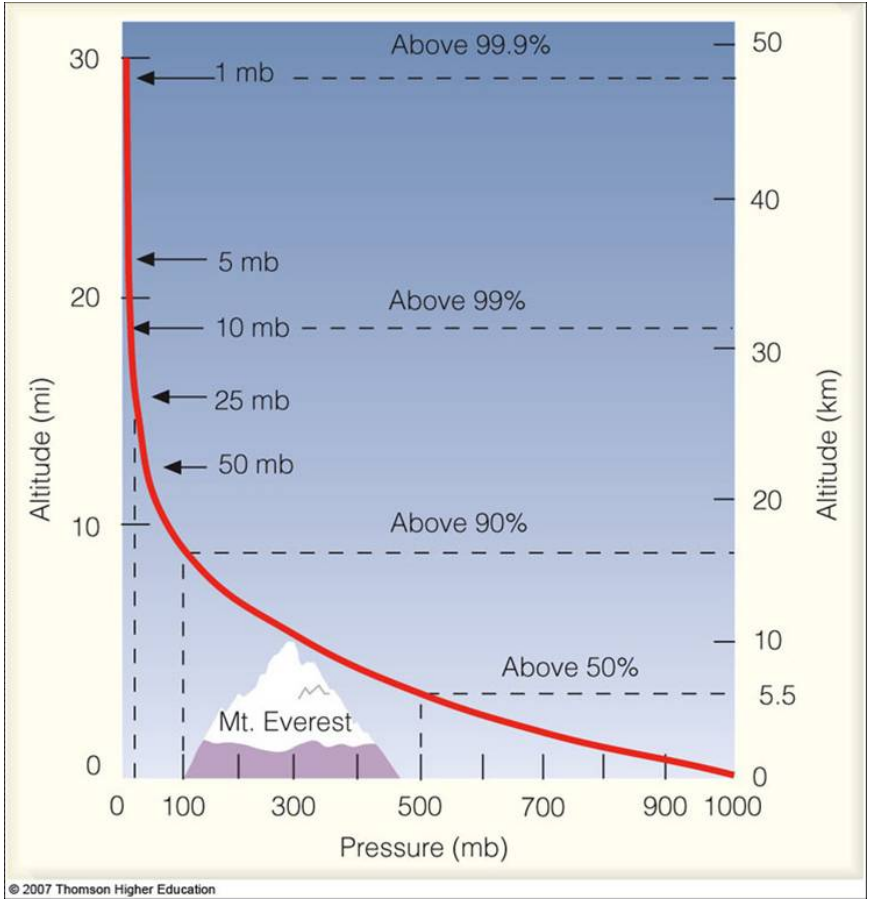
- 3 regions of warm temperature: surface, stratopause, and thermosphere
- Short wavelength UV absorbed in thermosphere (can get really hot)
- Medium wavelength UV absorbed in stratopause (by ozone)
- Stratosphere is stratified; little to no mixing
- Troposphere has all the water vapour; 85% mass of the entire atmosphere



https://apollo.nvu.vsc.edu/classes/met130/notes/chapter1/vert_pres3.html

Vertical pressure profile

- Decreases monotonically with altitude
- Pressure at surface is at 1000 mb (=hPa) by convention
- Tropopause (approx 10-16 km) is at around 100 – 200 mb pressure
- Allows a stratification of the atmosphere according to pressure levels (850 mb height, 250 mb height, and so on)
- Possible due to **hydrostatic balance**



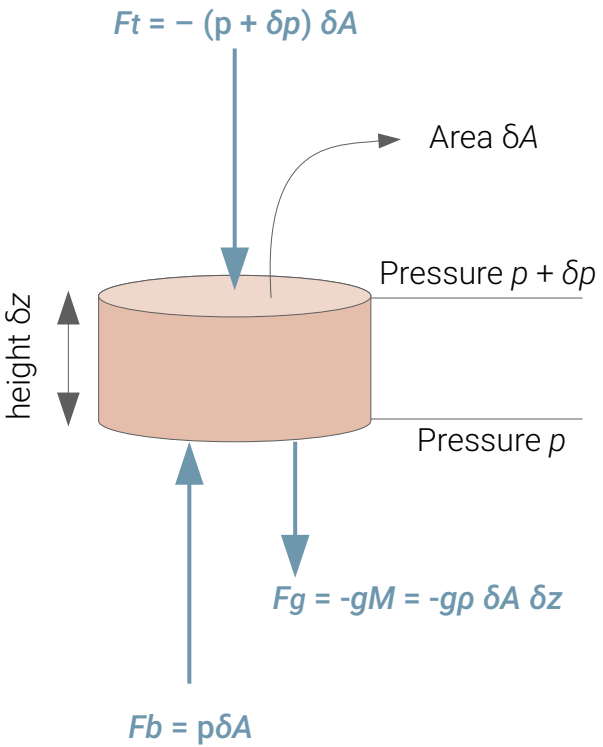
Hydrostatic balance

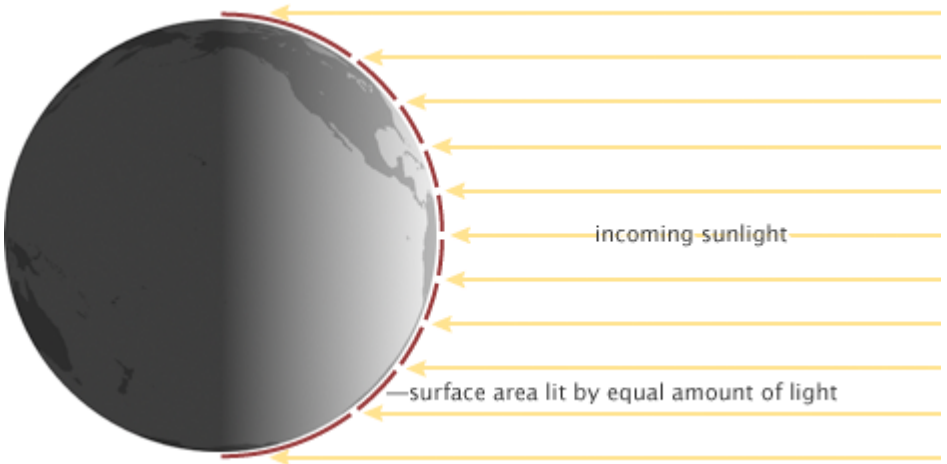
- Assume that there is no vertical acceleration, i.e. net force on the cylinder of air is zero

- $Ft + Fb + Fg = 0$
  $\Rightarrow -(p + \delta p)\,\delta A + p\delta A - g\rho\,\delta A\,\delta z = 0$
  $\Rightarrow \delta p / \delta z = -g\rho$

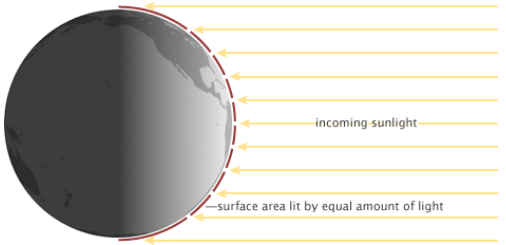
- Pressure decreases with height in proportion to the weight of the overlying atmosphere

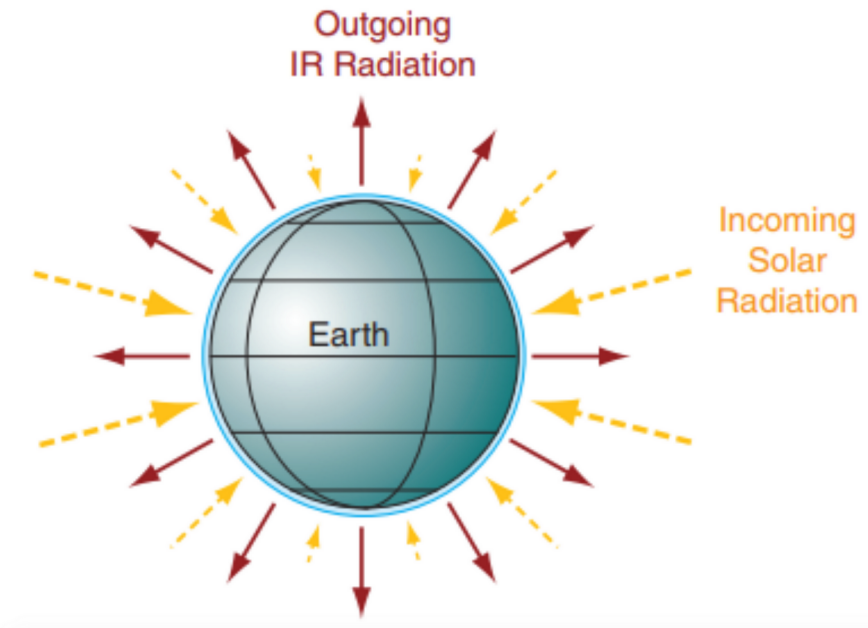
- The atmosphere fades away ...





3. The Atmosphere → Meridional Structure





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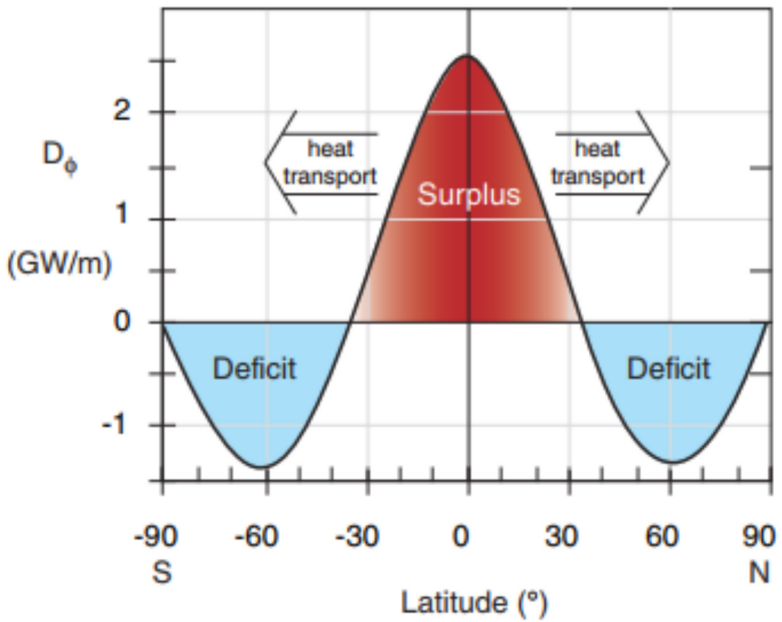

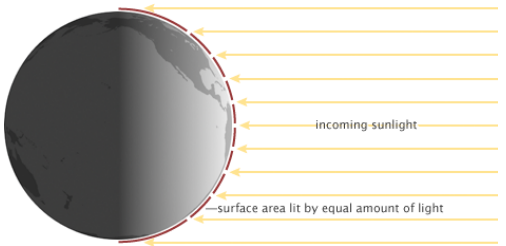

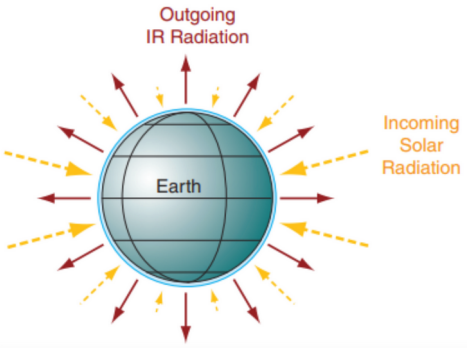

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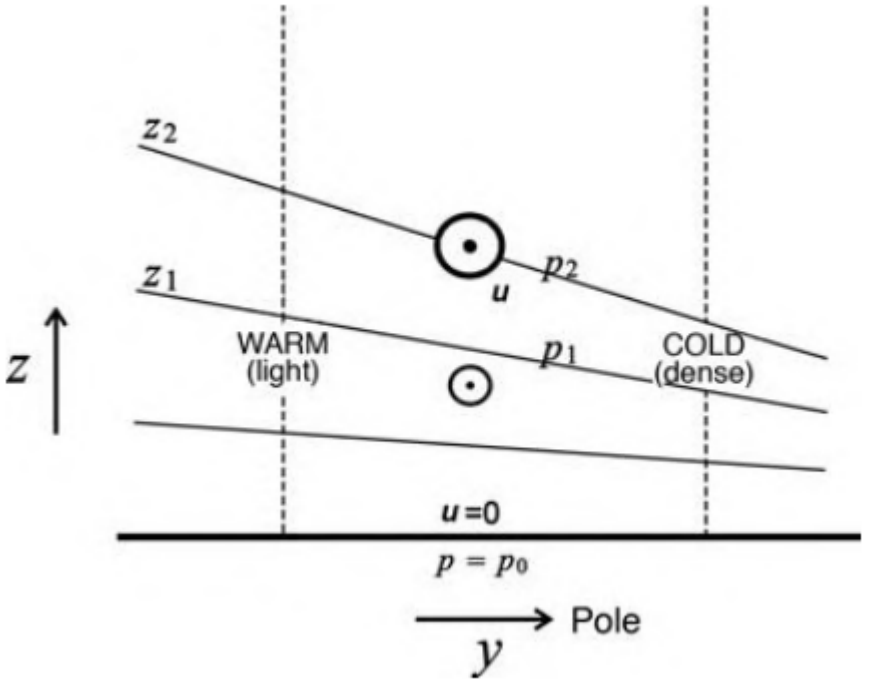
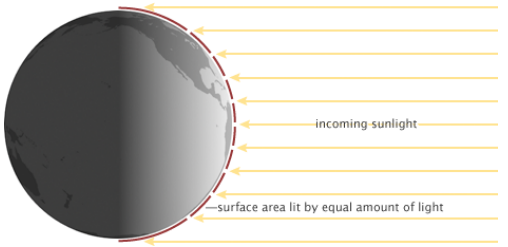
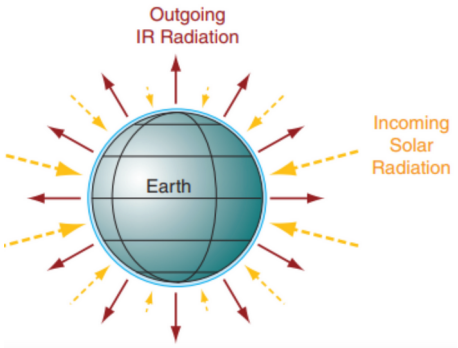
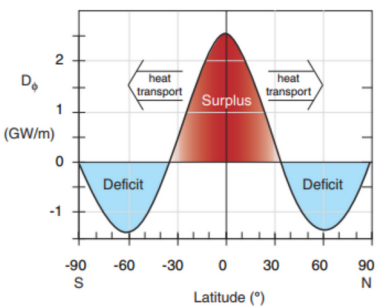
http://pressbooks-dev.oer.hawaii.edu/atmo/





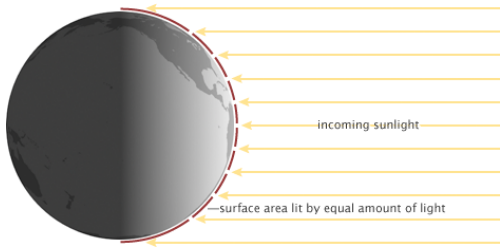


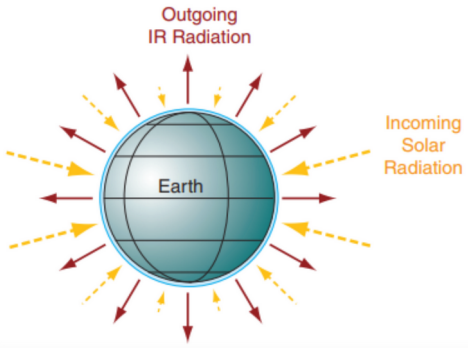


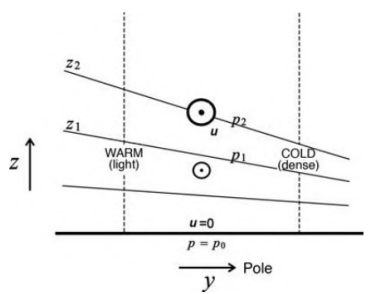
3. The Atmosphere → Meridional Structure

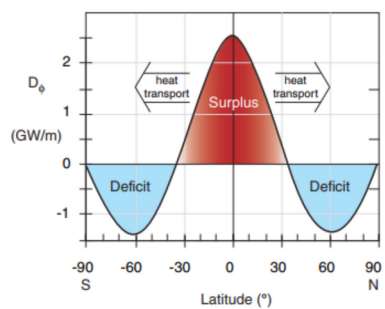
Meridional temperature and pressure gradient

- Sun heats up the equators more than the poles (due to the angle of inclination of sun rays)
- Outgoing IR radiation is more or less even
- Net radiation budget is such that there is a deficit at the poles and a surplus at equator
- Equator air is thus warmer, lighter and taller
- Polar air is thus colder, denser, and shorter
- Meridional pressure gradient is established









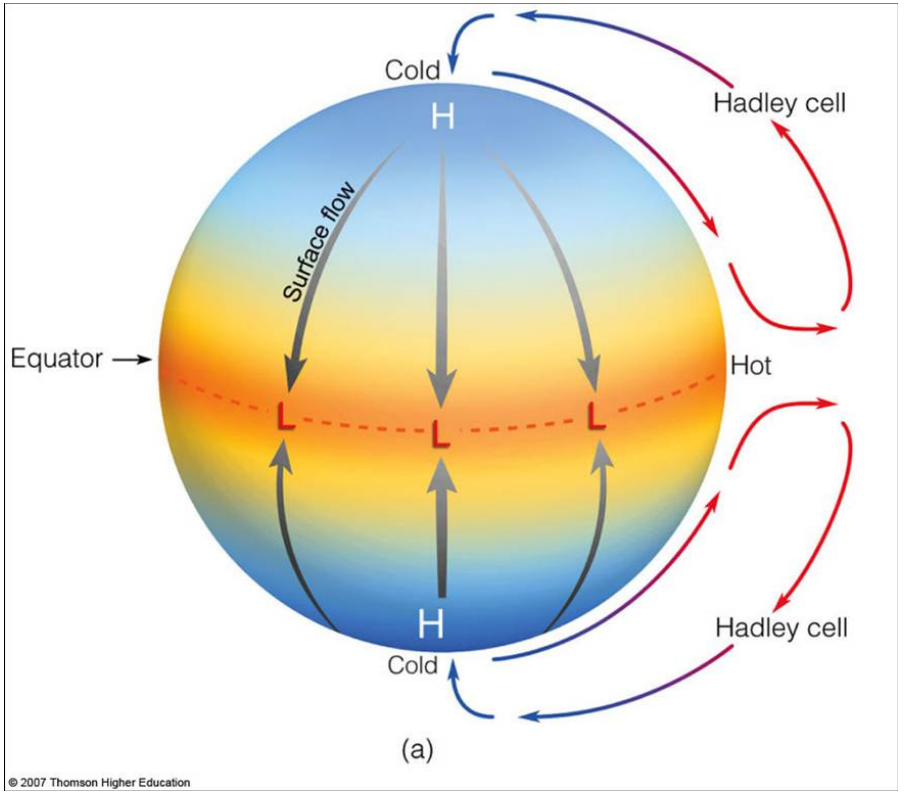
Single Cell Model

- Assumptions:
  - No land masses
  - No seasons
  - No rotation

- Thermally direct circulation: Hadley Cell
  - "thermally direct": warm air rises and cold air sinks

- In presence of rotation, air is deflected eastwards due to Corioli's Force

- Air masses from equator never make it to the poles!

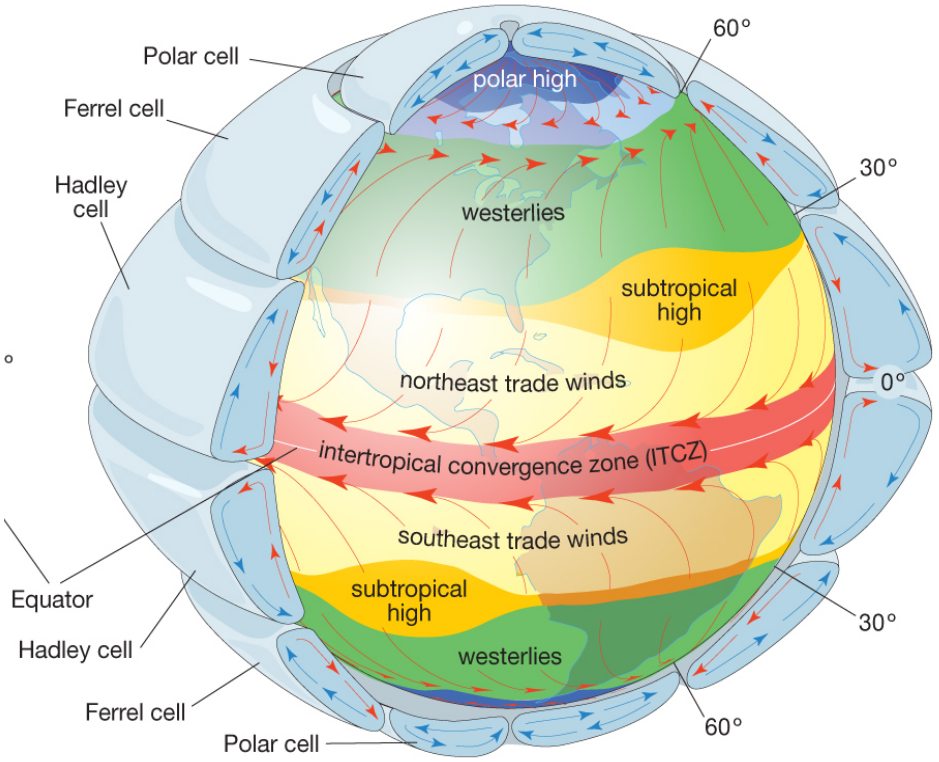


https://www.britannica.com/science/atmospheric-circulation

Three Cell Model

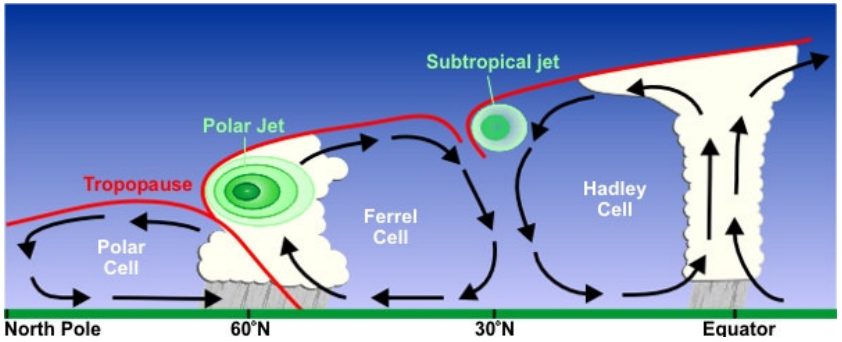
- Poleward moving air from the equator sinks at around 30N and 30S
  - This “subsidence” of dry air coincides with most deserts

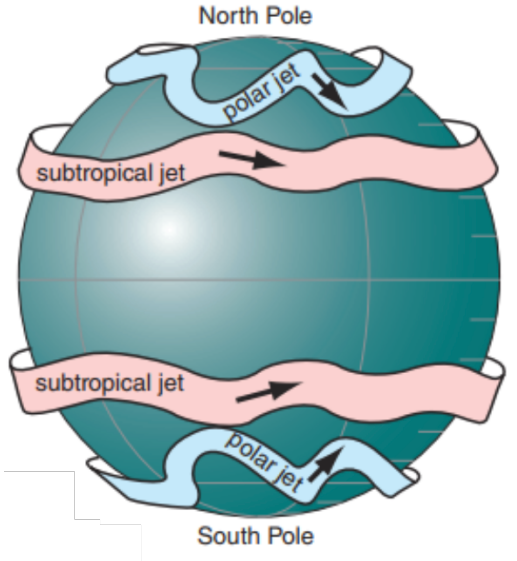
- The subsiding air is again sent equatorward and poleward
  - The northeasterly and southeasterly “trade winds” converge around the equator → intertropical convergence zone
  - Poleward westerlies converge at the polar front at 60N and 60S



Jet Streams

- Westerly jets in the upper troposphere (around 250 hPa – 150 hPa)
  - Subtropical jet: 30N and 30 S
  - Polar jet: 60N and 60S
- Due to energy imbalance on either side of polar and subtropical fronts respectively
- Strong pressure gradient across the fronts causes intense wind speeds
- The subtropical jets do not extend till the surface





What is Climate

1

- Weather, on average?
- The climate system

Components of the climate system

2

- Atmosphere
- Ocean
- Land
- Cryosphere
- ~~Biosphere~~
- ~~Anthroposphere~~

The Atmosphere

3

- Vertical structure
- Meridional Structure

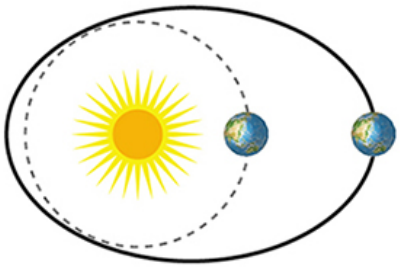
Additional topics

4

- Climate Forcings
- ~~Climate Feedbacks~~
- Climate Sensitivity

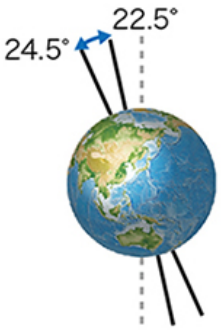
http://www.jamstec.go.jp/e/about/press_release/20141027/

100,000 years



Eccentricity

41,000 years

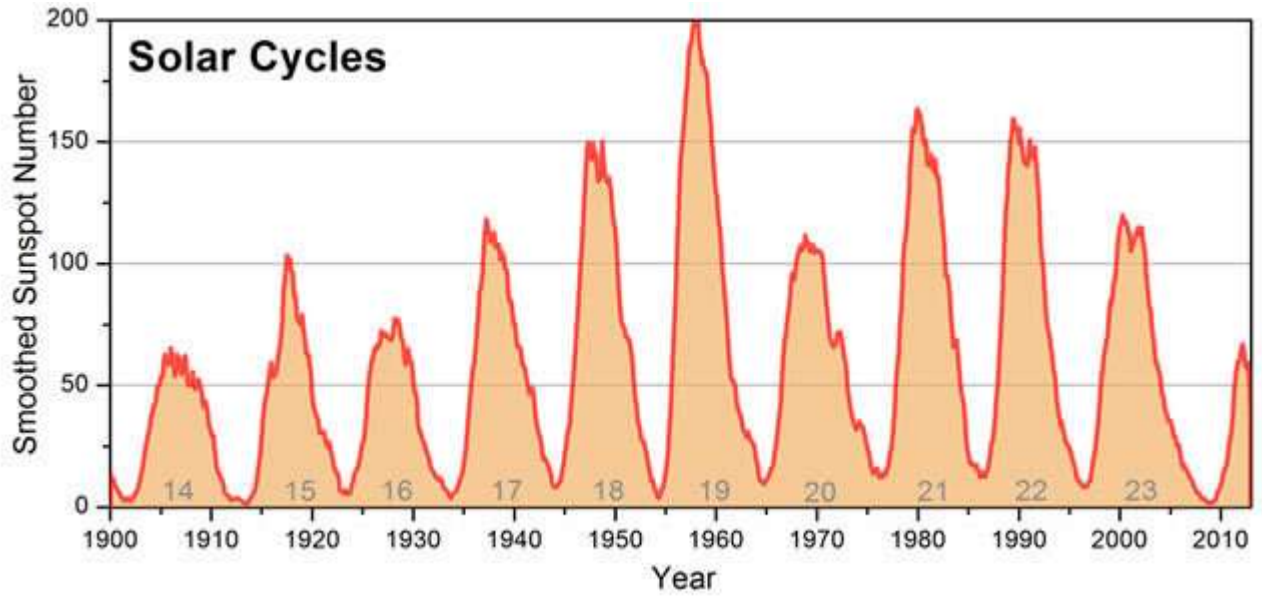


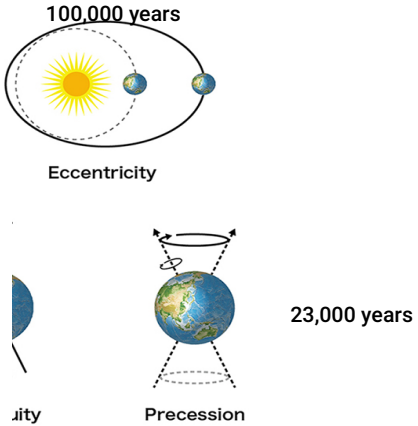
Obliquity

Precession

23,000 years

https://phys.org/news/2020-10-solar-sun.html



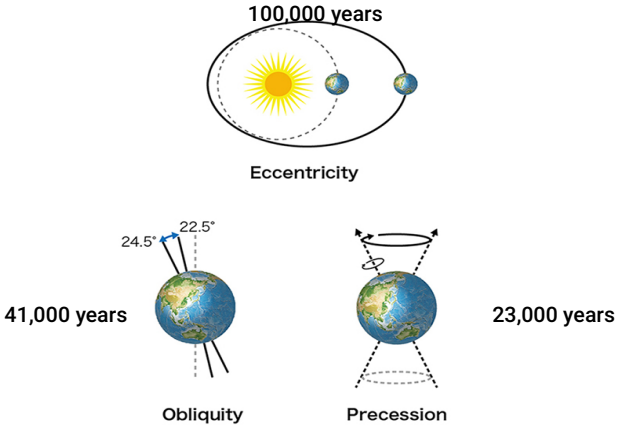


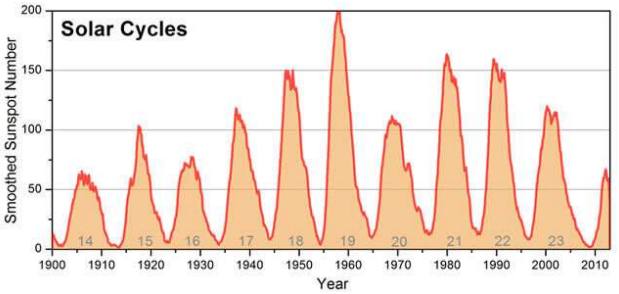
4. Additional topics → Climate Forcings

Climate forcings: External

- *Orbital forcings*, aka Milankovitch forcings
  - Changes in the earth's orbit changes the incoming solar radiation budget
  - Leads to changes in the climate

- *Solar cycles*, i.e., periodic ups and downs in the sun's activity leads to changes in incoming solar radiation, leading to changes in the climate





Climate Forcings: Internal

- *Anthropogenic*
  - Greenhouse gases
  - Stratospheric ozone
  - Tropospheric aerosols
  - Land surface change
- *Natural*
  - Volcanic aerosols
  - Thermohaline circulation

Climate sensitivity

- Change in a climate parameter for a given change in a climate forcing
  - Typical example: What is the climate sensitivity of temperature with respect to a doubling of atmospheric CO2?

- Two kinds of climate sensitivity:
  - Transient Climate Response
  - Equilibrium Climate Sensitivity

- Estimated from:
  - Historical climate records
  - Climate models
  - Paleoclimate records

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4. Miscellaneous → Q&A