A Short Introduction to Climate Basics

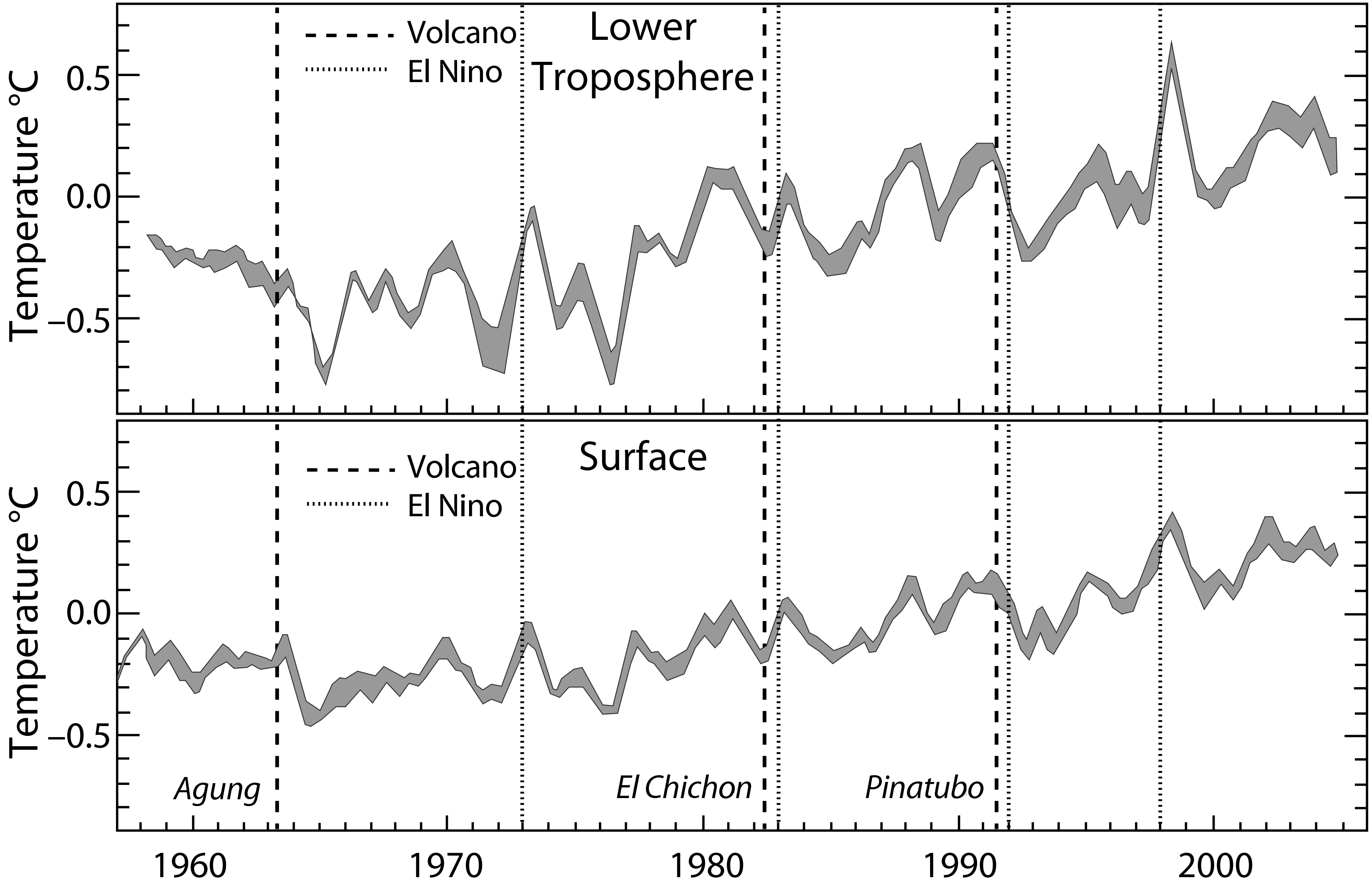
NorMER Climate Change Workshop

28. September 2014

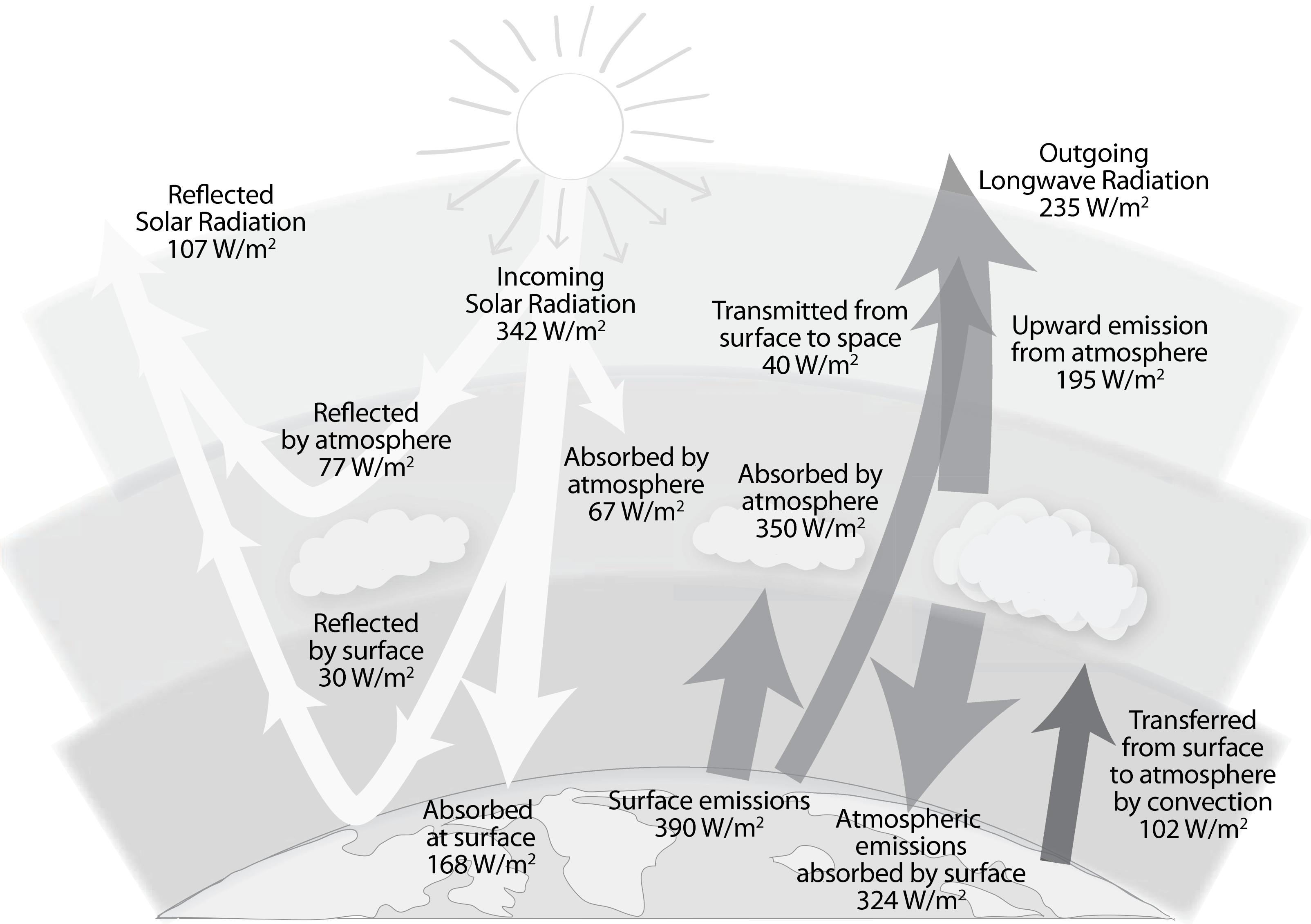
Overview

- Climate as the interaction of simple rules
  vs. Climate as the averaged weather
- Global energy budget $\longrightarrow$ our first climate model
- Greenhouse effect
- Important feedback loops
- Global circulation in atmosphere and ocean
- Modes of variability
- Global warming
- Literature list

Temperature change, Time-scales



Global energy budget



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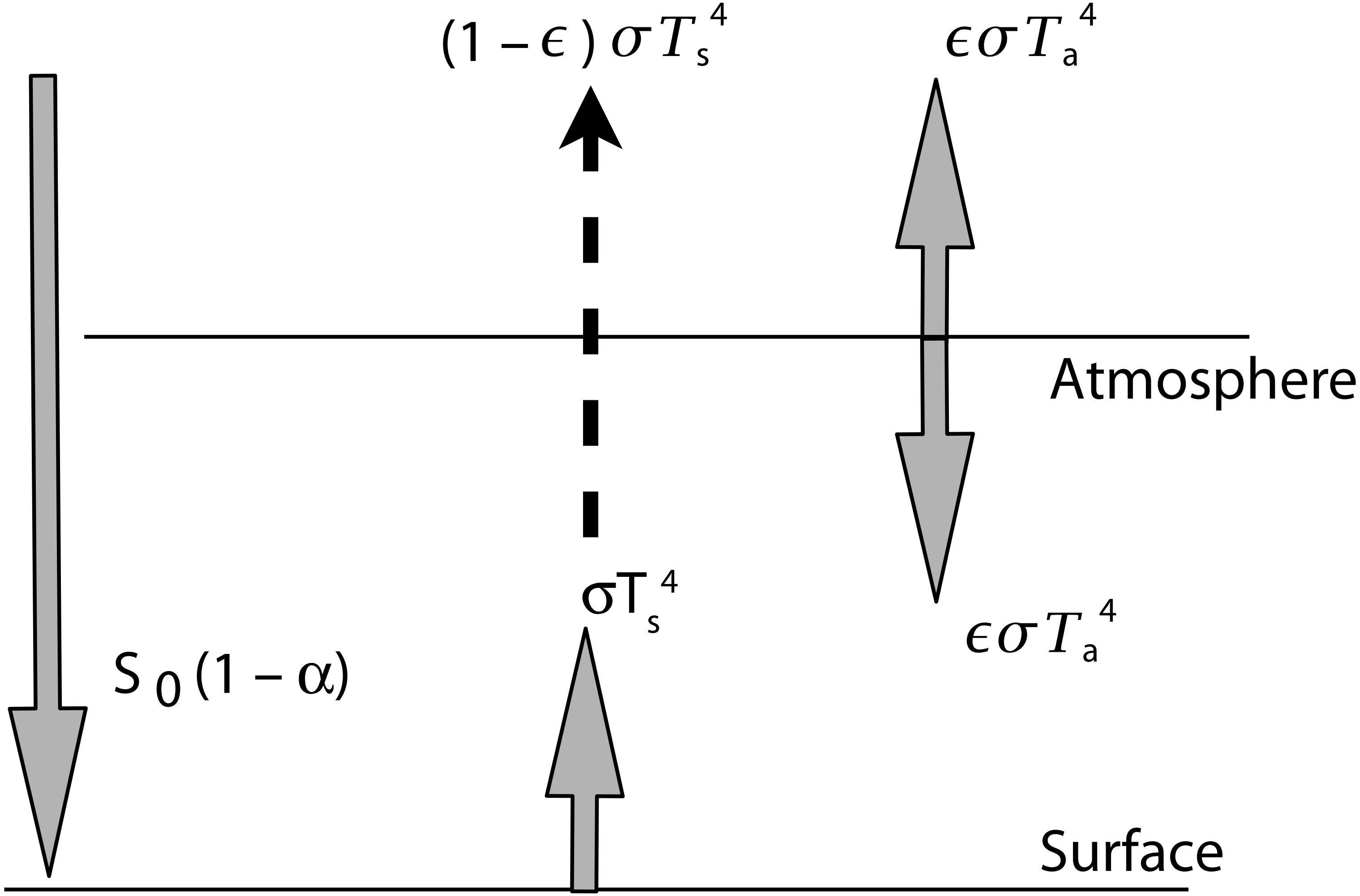
A simple energy balance model



A simple energy balance model

Atmosphere: $S_0(1-\alpha) = \sigma T_a^4$

Surface: $S_0(1-\alpha) + \sigma T_a^4 = \sigma T_s^4 \qquad \rightarrow 2S_0(1-\alpha) = \sigma T_s^4$

Atmosphere: $T_a^4 = \frac{S_0(1-\alpha)}{\sigma} \qquad \rightarrow T_a = \sqrt[4]{\frac{S_0(1-\alpha)}{\sigma}}$

Surface: $T_s^4 = \frac{2S_0(1-\alpha)}{\sigma} \qquad \rightarrow T_s = \sqrt[4]{\frac{2S_0(1-\alpha)}{\sigma}}$

Atmosphere: $T_a = \sqrt[4]{\frac{342 \cdot 0.7}{5.67 \cdot 10^{-8}} \frac{W/m^2}{W/(m^2K^4)}} \qquad \rightarrow T_a = 255K = -18°C$

Surface: $T_s = \sqrt[4]{\frac{2 \cdot 342 \cdot 0.7}{5.67 \cdot 10^{-8}} \frac{W/m^2}{W/(m^2K^4)}} \qquad \rightarrow T_s = 303K = +30°C$

emissivity: $\epsilon = 1$ for a black body

albedo: $\alpha = 0.3$ averaged over the earth

proportionality: $\sigma = 5.67 \cdot 10^{-8} \quad W/(m^2K^4)$ Stefan-Boltzmann constant

A simple energy balance model

Atmosphere: $S_0(1-\alpha) = \epsilon\sigma T_a^4 + (1-\epsilon)\sigma T_s^4$

Surface: $S_0(1-\alpha) + \epsilon\sigma T_a^4 = \sigma T_s^4 \qquad \rightarrow 2S_0(1-\alpha) = (2-\epsilon)\sigma T_s^4$

Surface: $T_s^4 = \frac{2S_0(1-\alpha)}{(2-\epsilon)\sigma} \qquad \rightarrow T_s = \sqrt[4]{\frac{2S_0(1-\alpha)}{(2-\epsilon)\sigma}}$

$\epsilon = 1$: $T_s = \sqrt[4]{\frac{2\cdot 342\cdot 0.7}{5.67\cdot 10^{-8}} \frac{W/m^2}{W/(m^2K^4)}} \qquad \rightarrow T_s = 303K = +30°C$

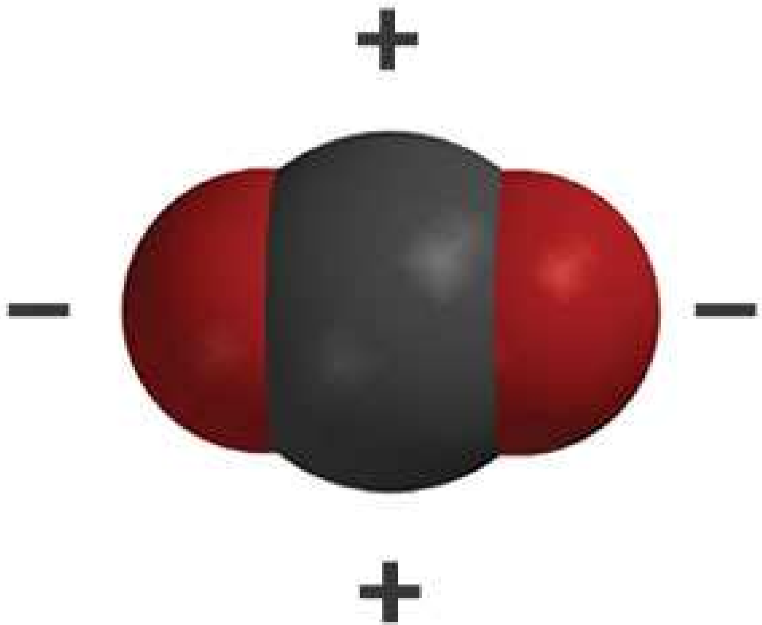
$\epsilon = 0$: $T_s = \sqrt[4]{\frac{2\cdot 342\cdot 0.7}{2\cdot 5.67\cdot 10^{-8}} \frac{W/m^2}{W/(m^2K^4)}} \qquad \rightarrow T_s = 255K = -18°C$

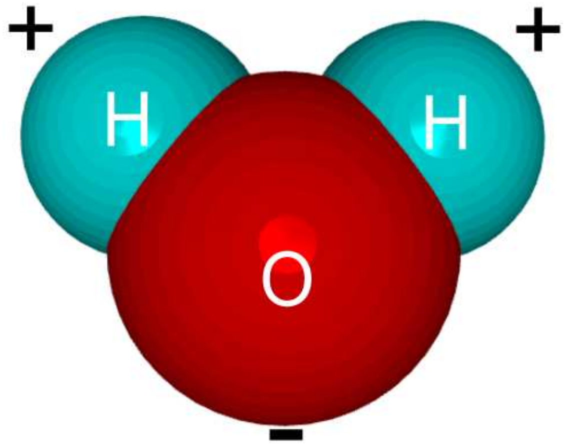
$\epsilon = 3/4$: $T_s = \sqrt[4]{\frac{2\cdot 342\cdot 0.7}{1.25\cdot 5.67\cdot 10^{-8}} \frac{W/m^2}{W/(m^2K^4)}} \qquad \rightarrow T_s = 287K = 14°C$

difference in ϵ: Greenhouse effect

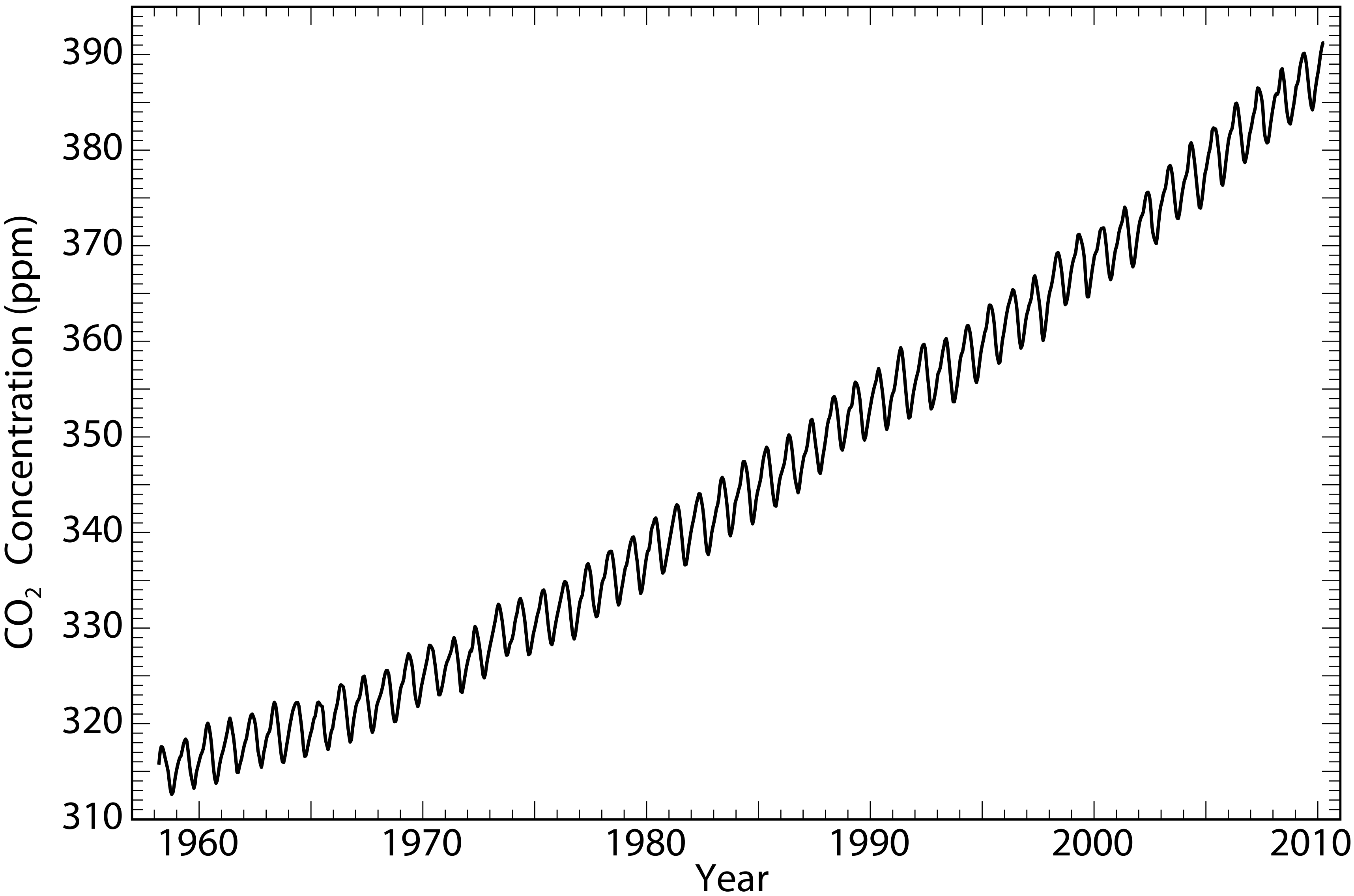
Greenhouse effect

- 1/2 of the greenhouse effect by water vapor
- 1/4 of the greenhouse effect by clouds
- 1/5 of the greenhouse effect by CO_2

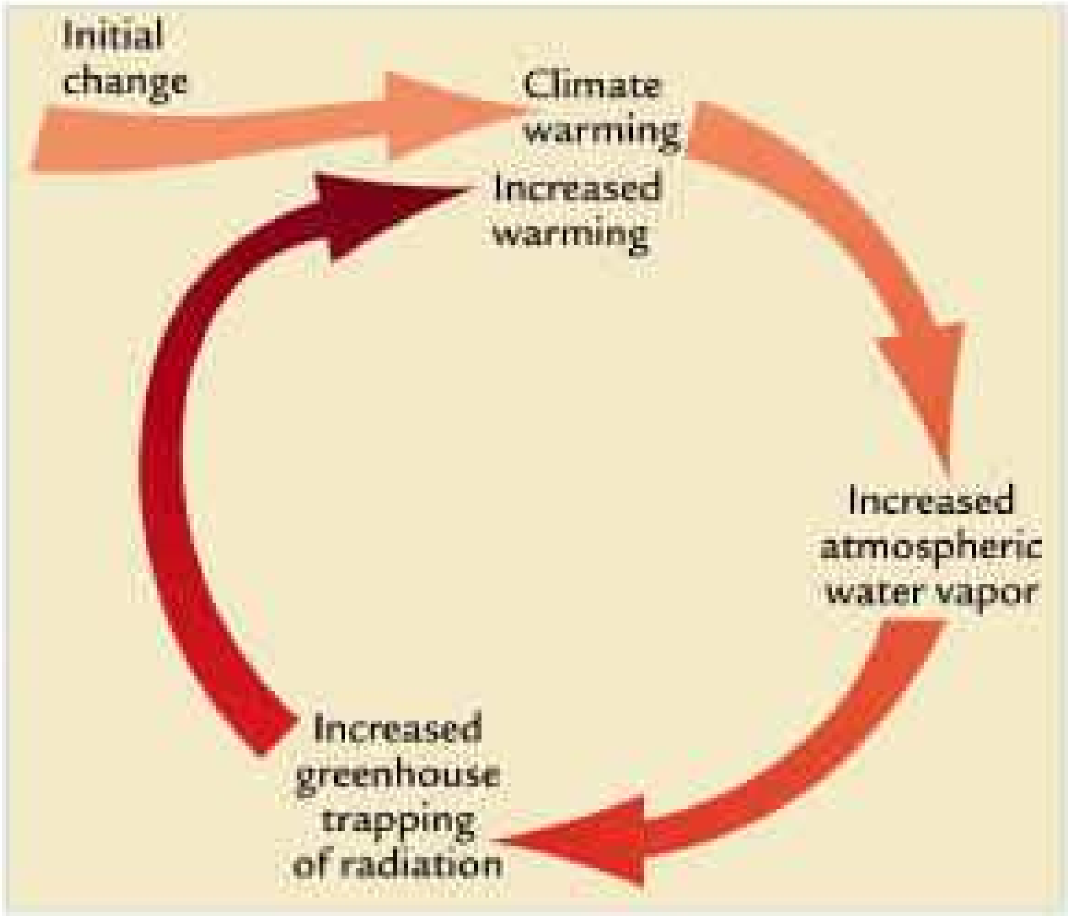




CO_2 at Mauna Loa

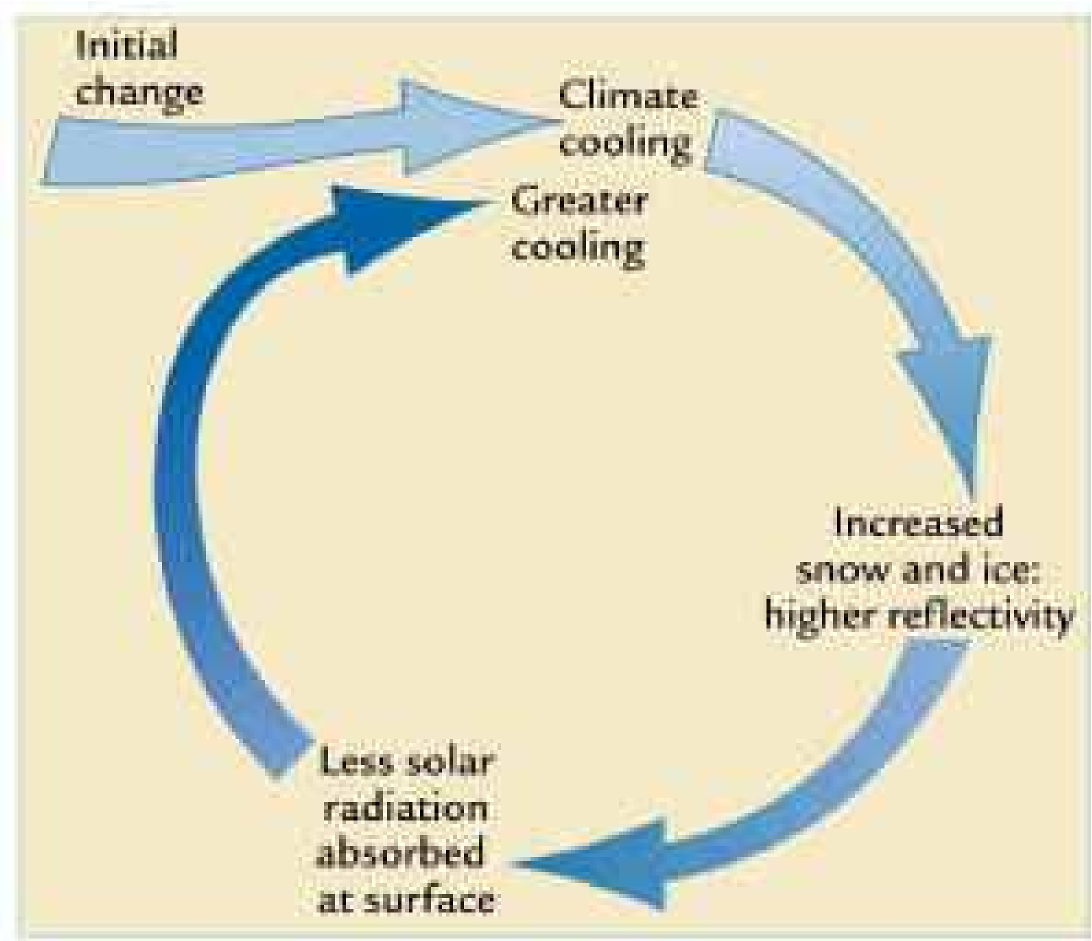


Water vapor feedback



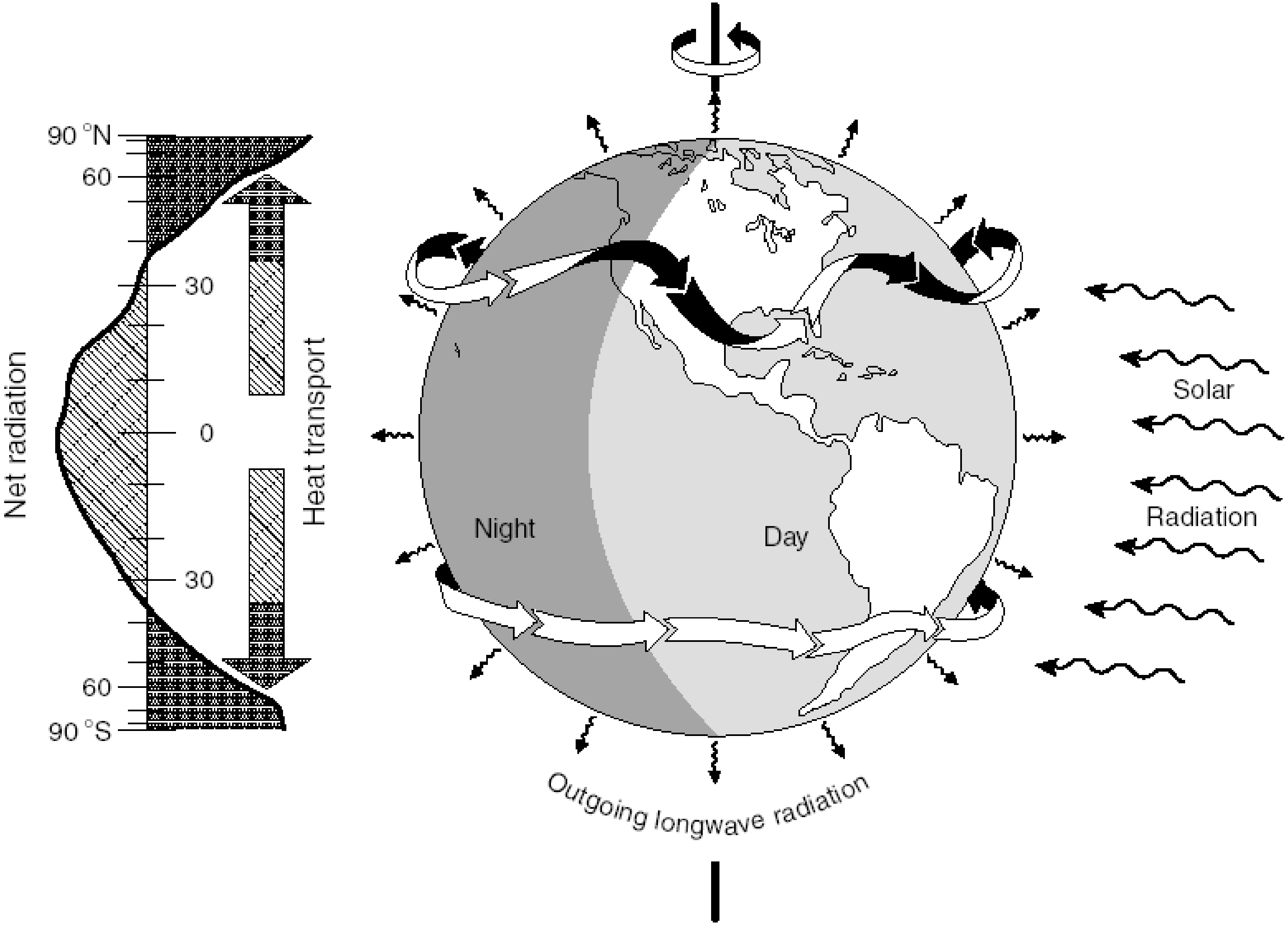
- Half of the greenhouse effect is due to water vapor.
- What happens when the temperature rises?
- Warmer air can hold more water vapor.
- More water vapor increases the greenhouse effect.
- Temperature rises even more.

Ice albedo feedback

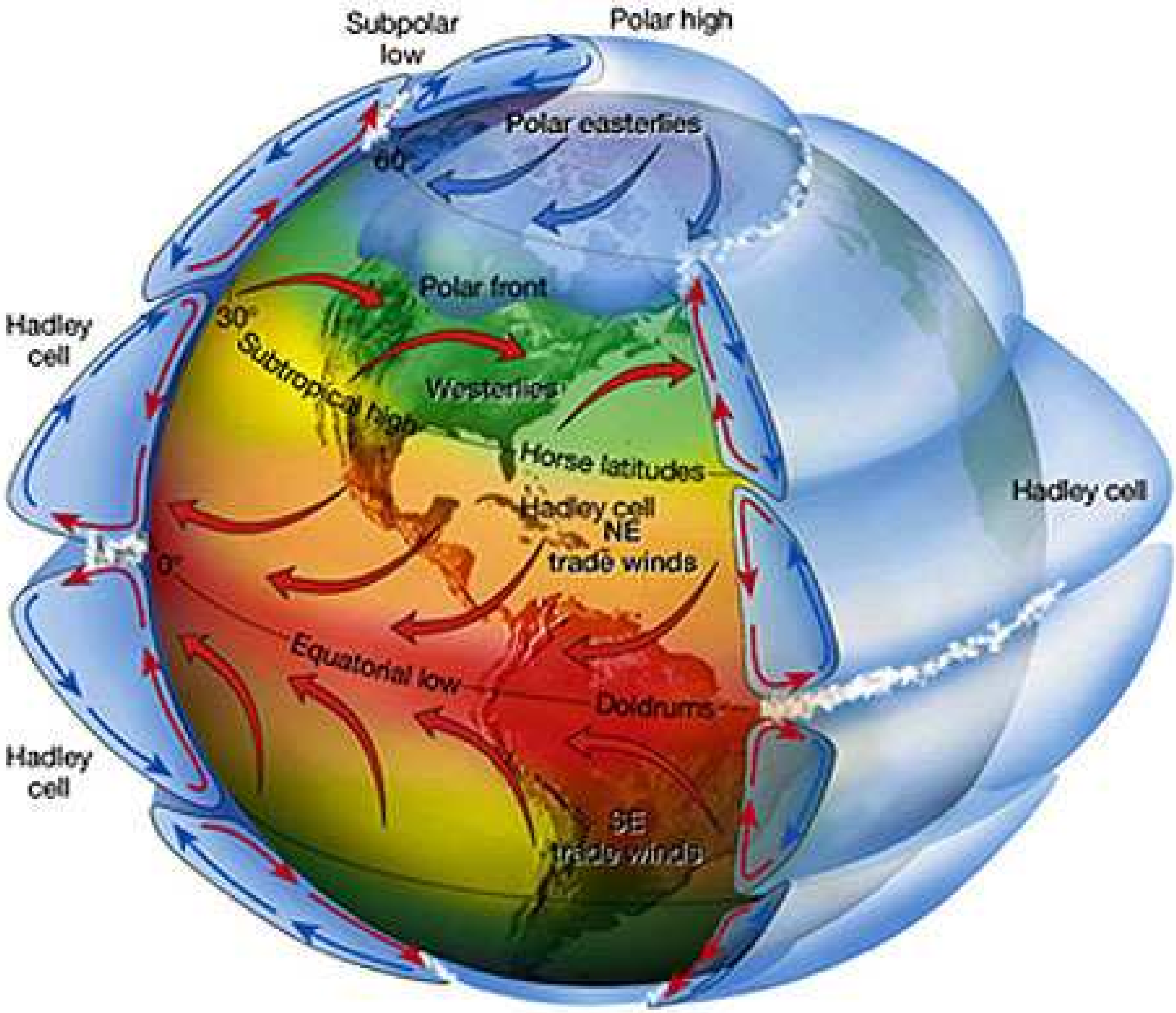


- Snow and ice have a high albedo reflecting 30 % - 80 % of sunlight.
- What happens when the temperature rises?
- Snow and ice cover and ice thickness is reduced exposing open water.
- Albedo is reduced and more sunlight is absorbed.
- Temperature rises even more.

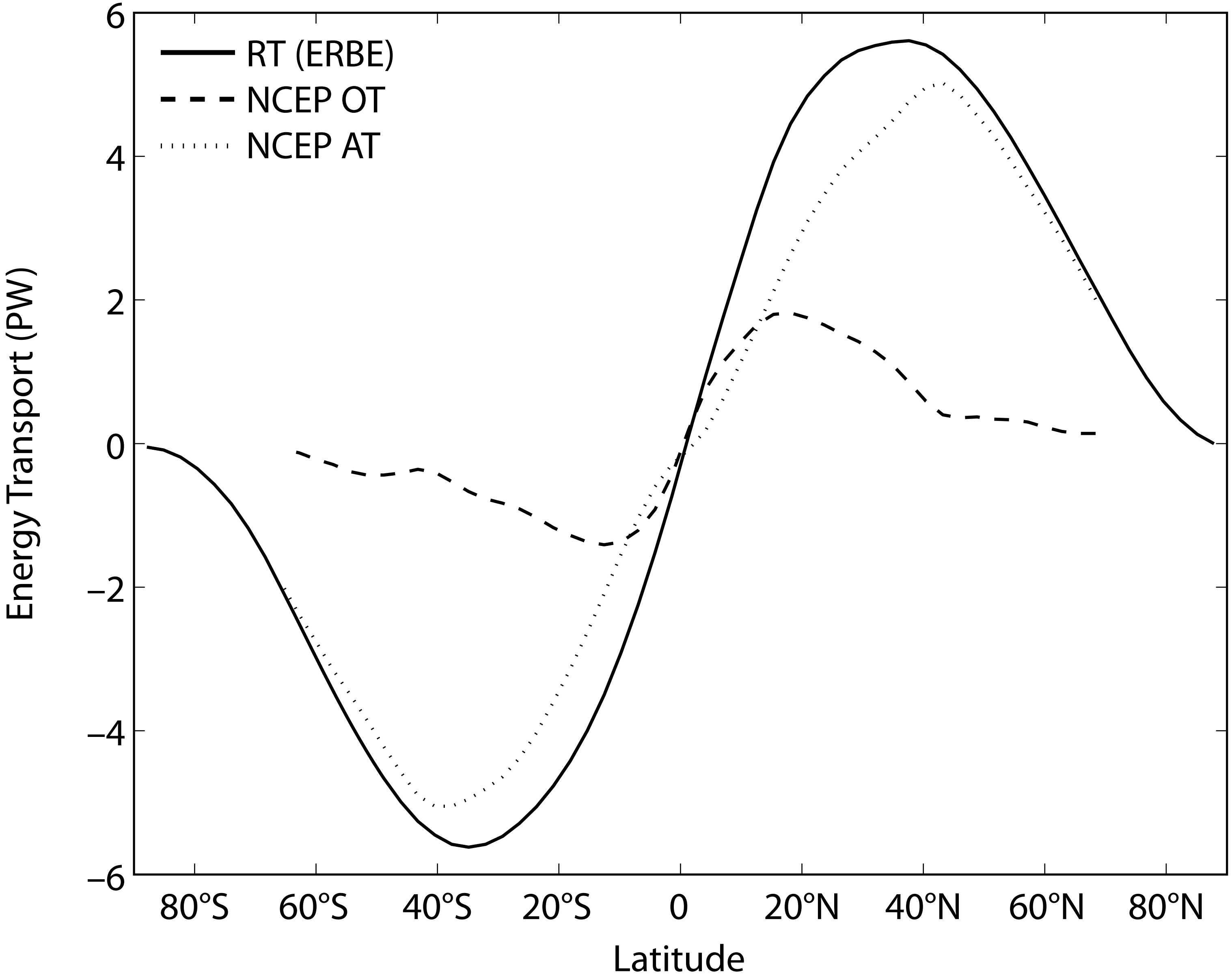
Differential heating



Atmospheric circulation systems



Meridional heat transport



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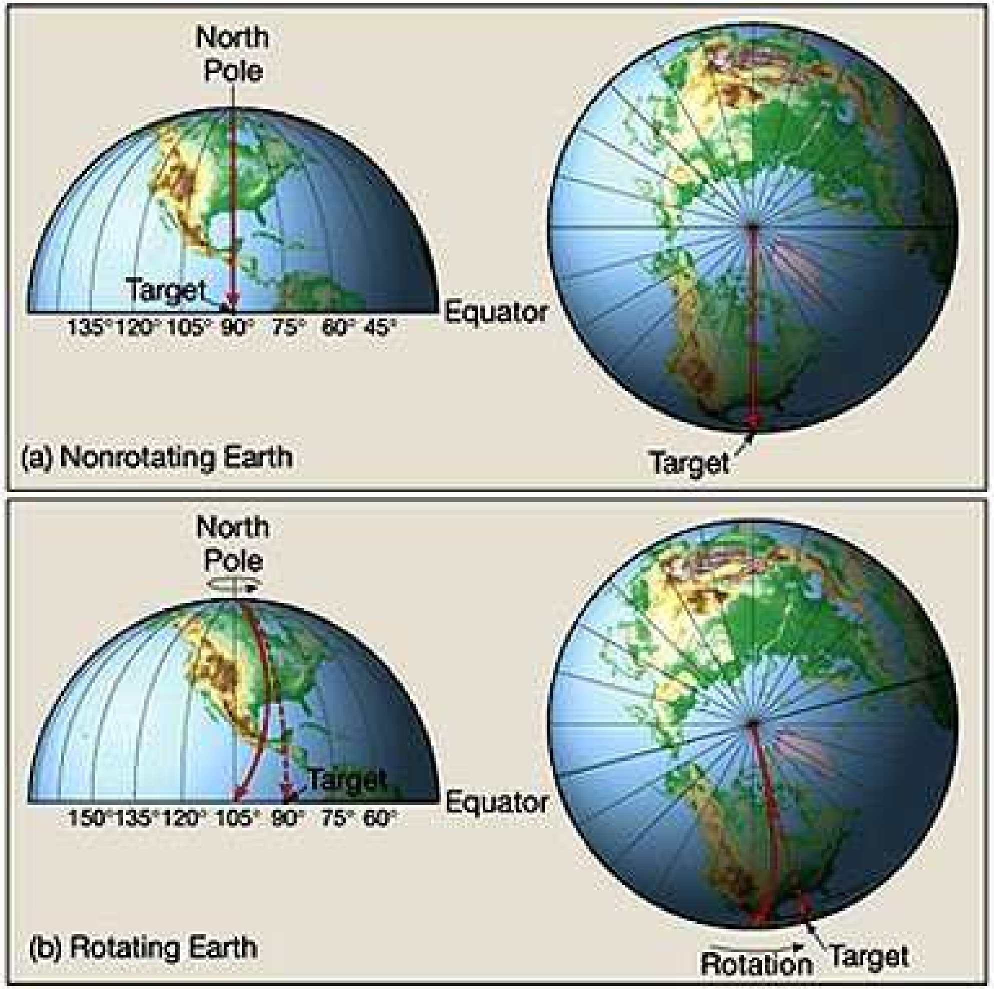
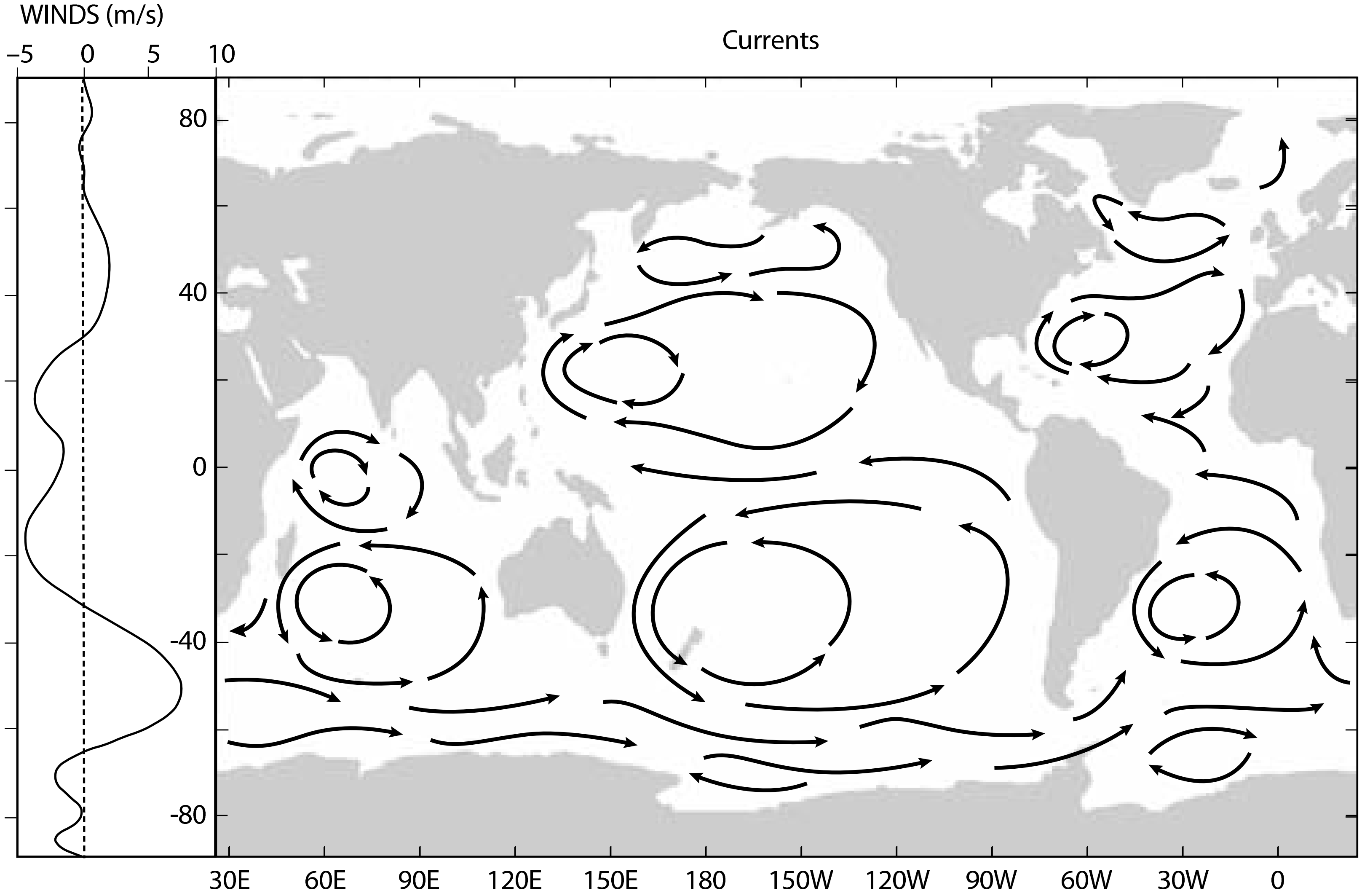
Coriolis Force

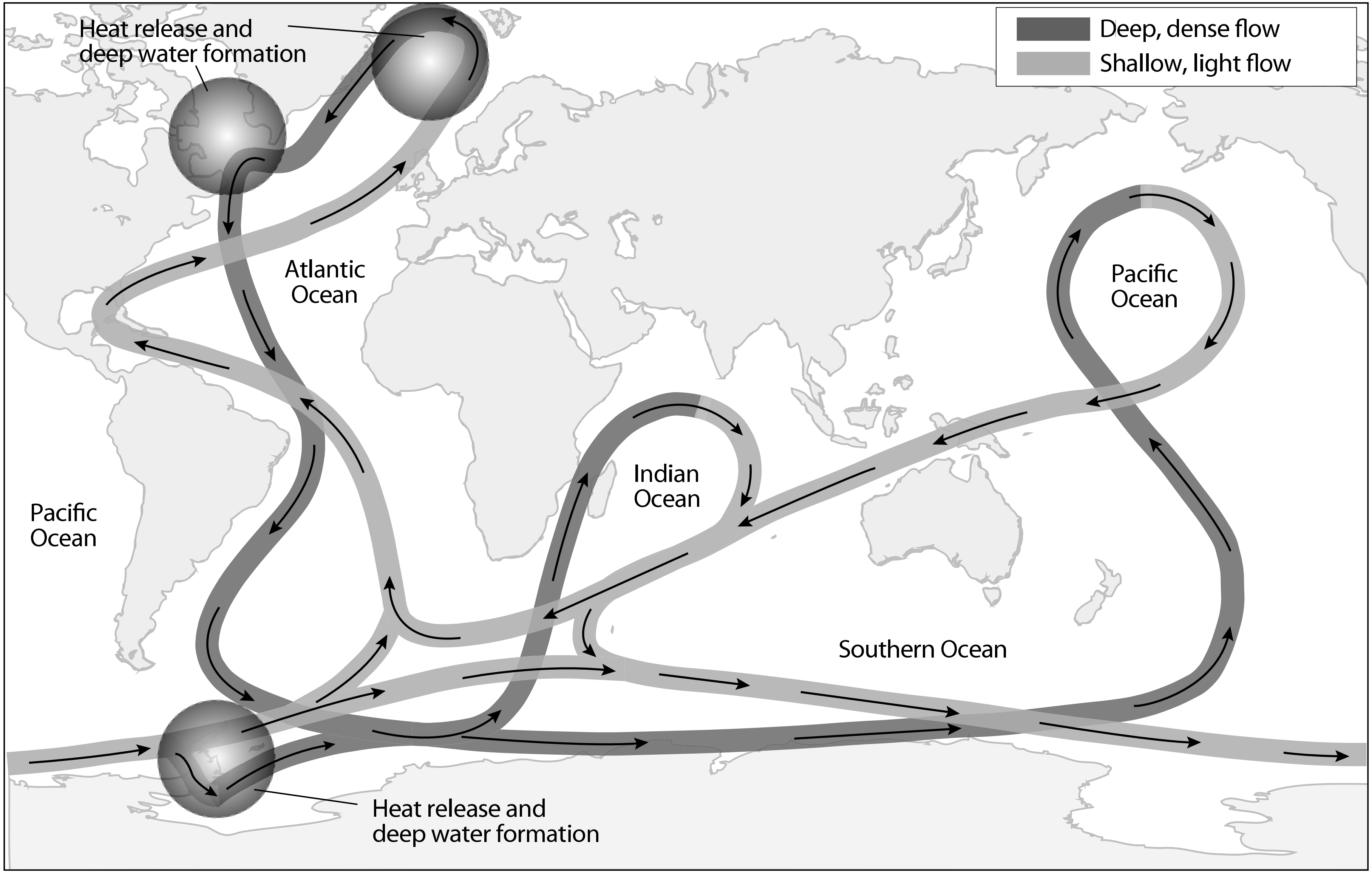


- Moving air or water parcels experience Coriolis force
- Parcels are deflected to the right on the Northern Hemisphere
- Balance between pressure gradient and Coriolis force: Geostrophic balance
- $-fv = -1/\rho \, \partial p/\partial x$
- $fu = -1/\rho \, \partial p/\partial y$

Wind-driven circulation



Conveyor belt



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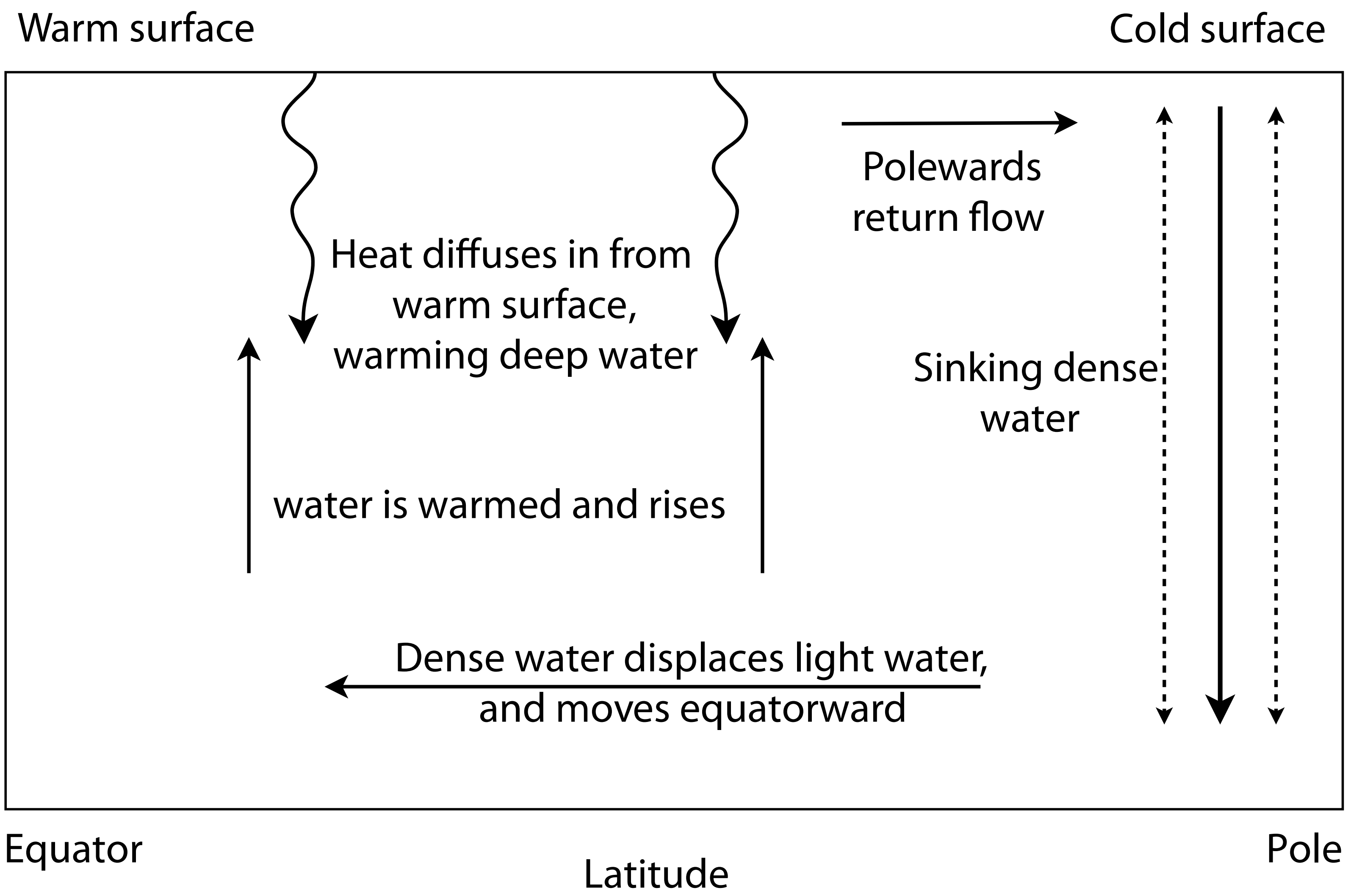
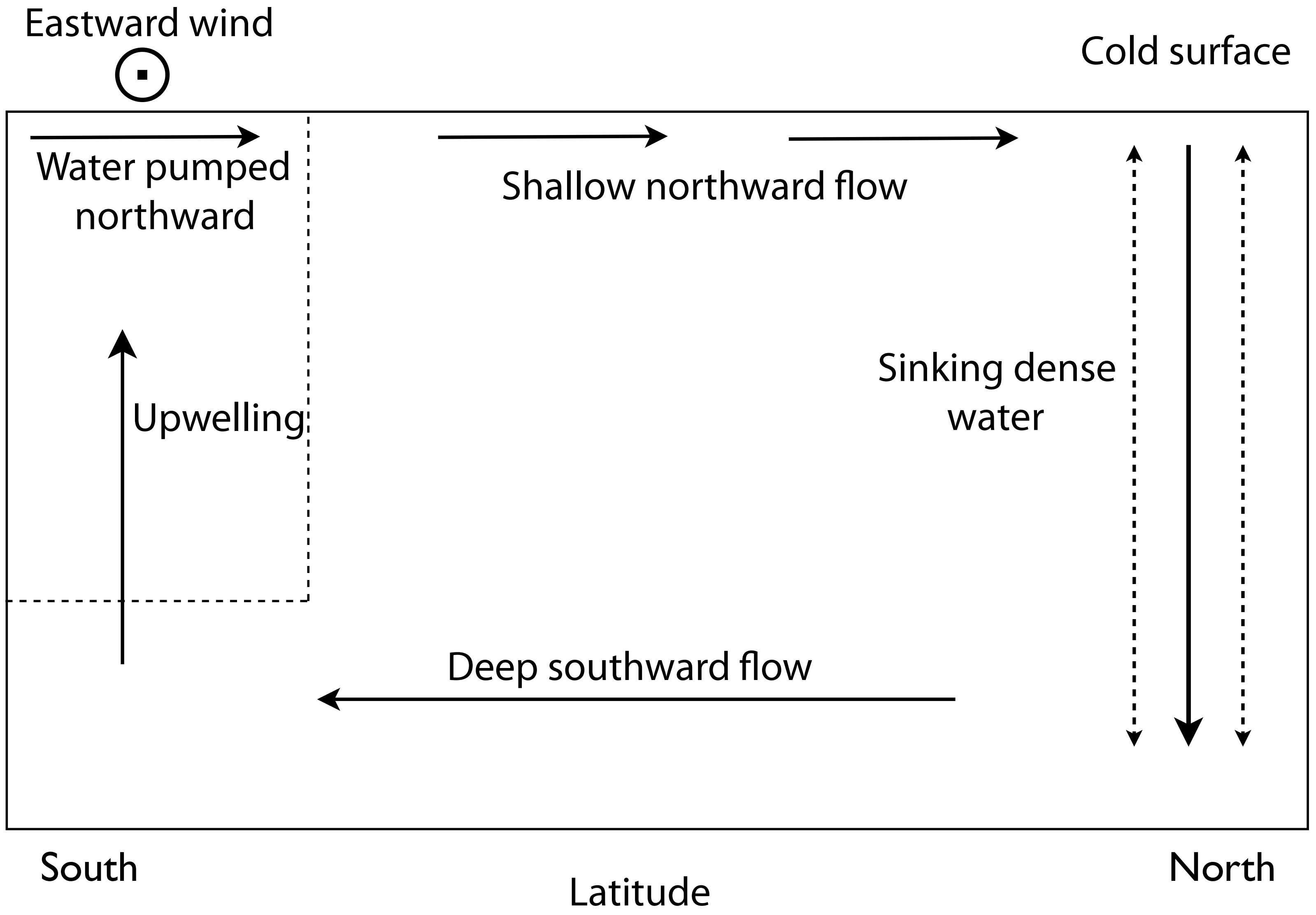
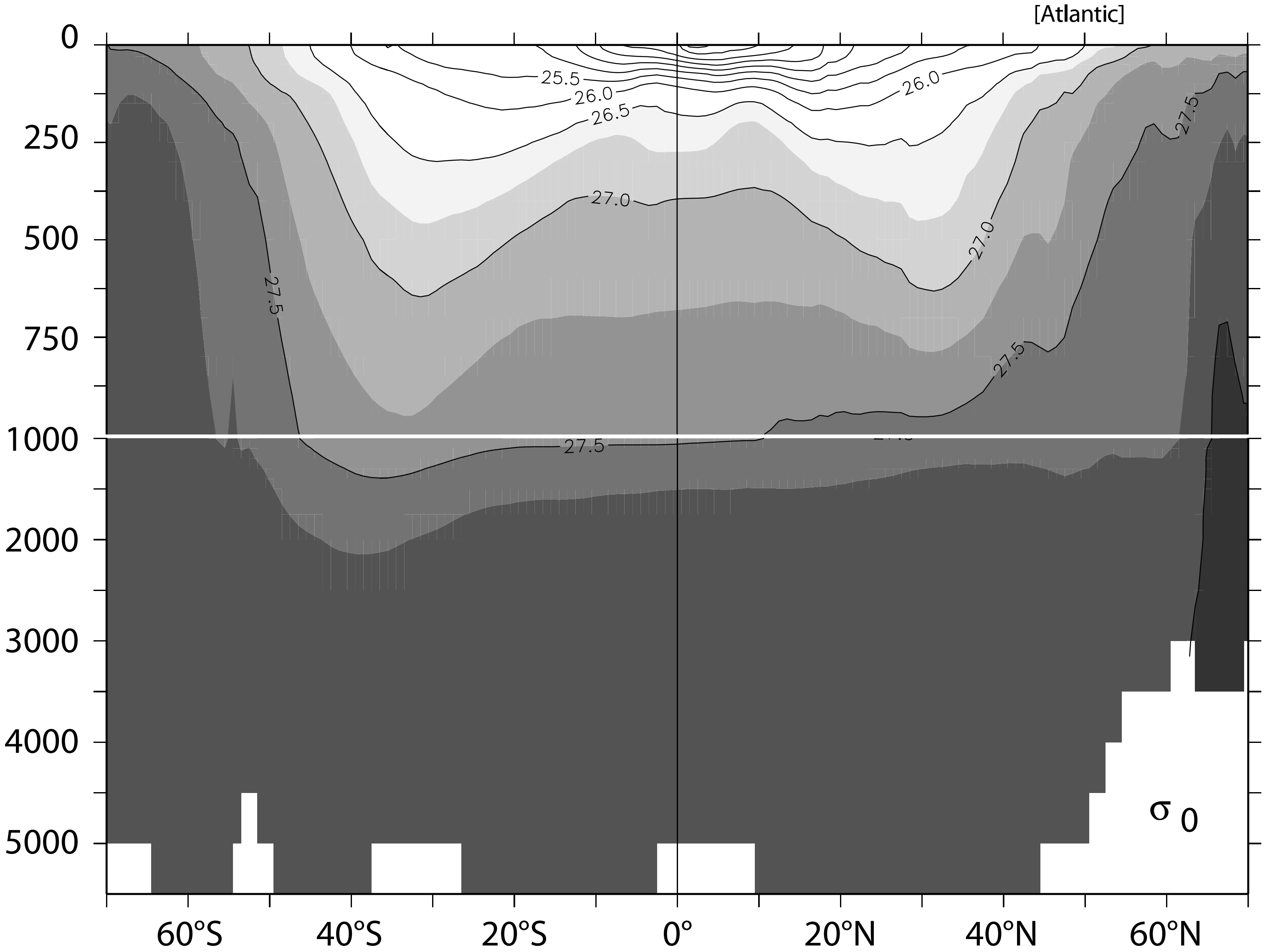
Meridional overturning circulation (MOC)



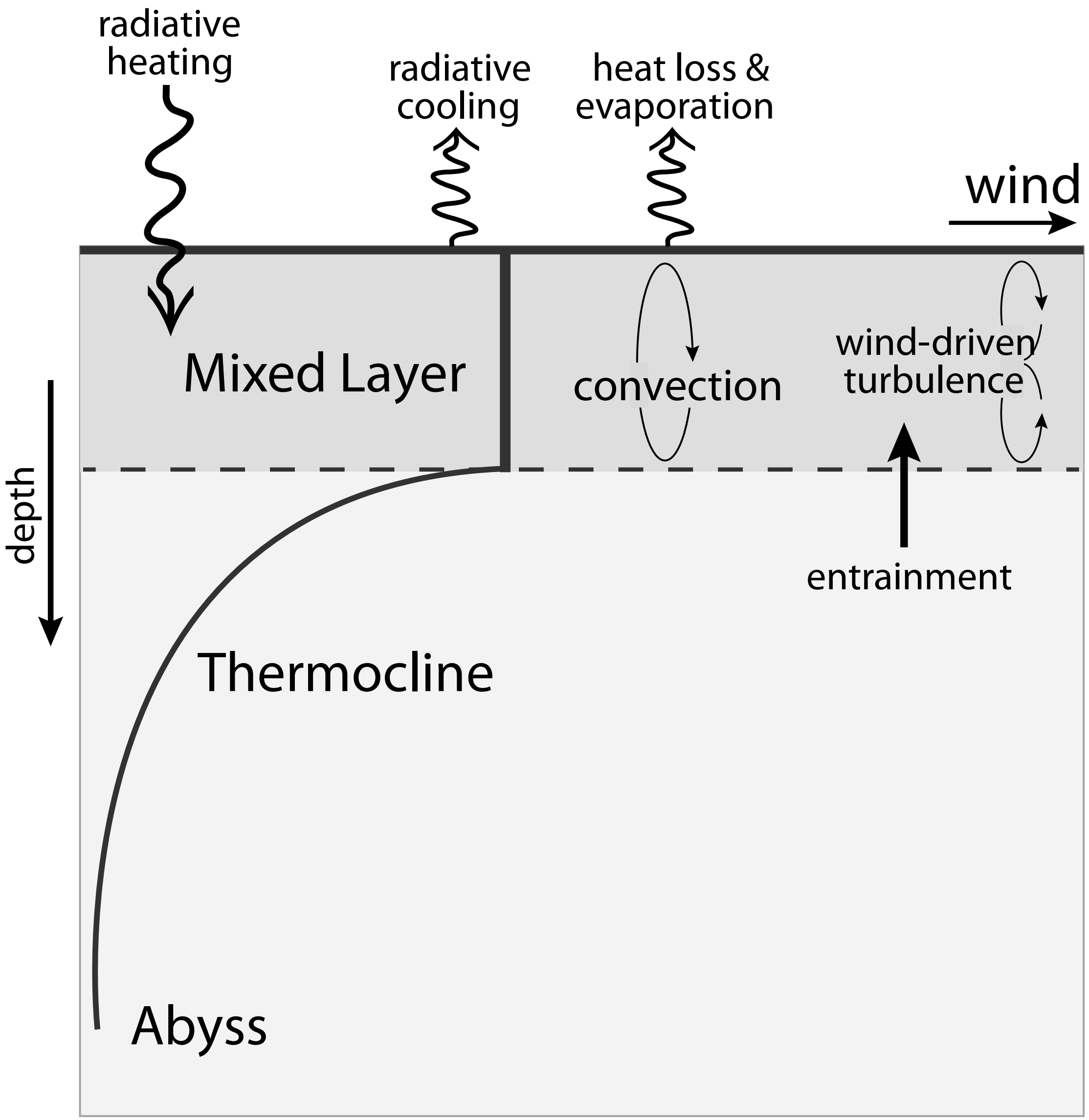
Meridional overturning circulation (MOC)



Averaged density in the Atlantic Ocean



Mixed Layer dynamics



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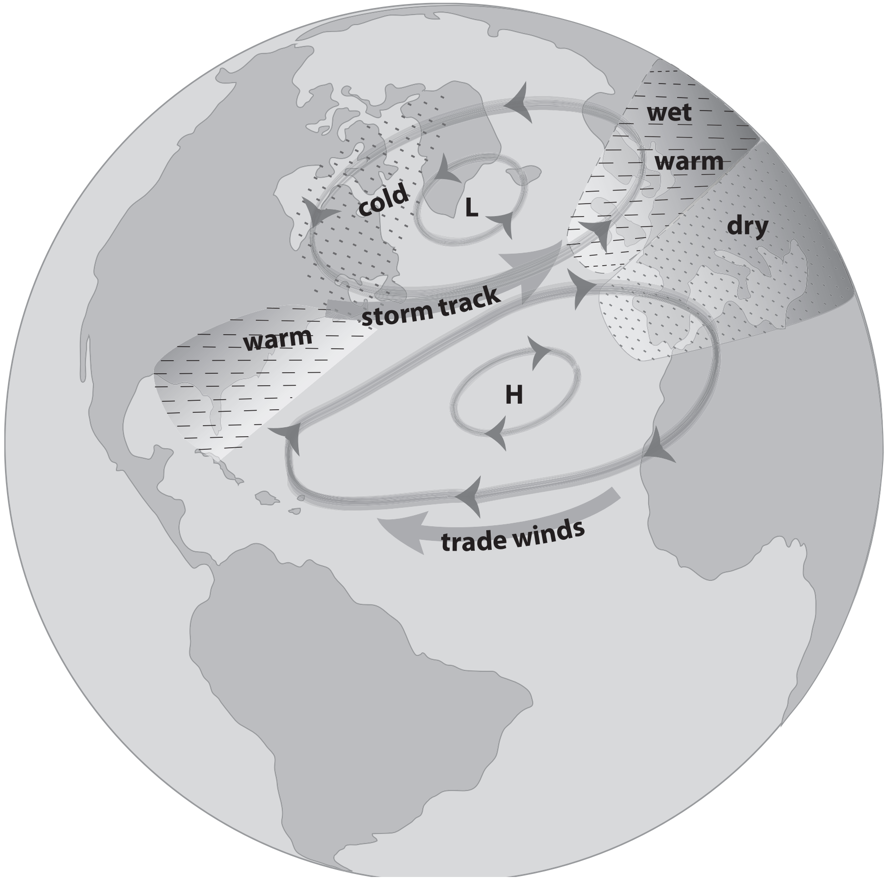
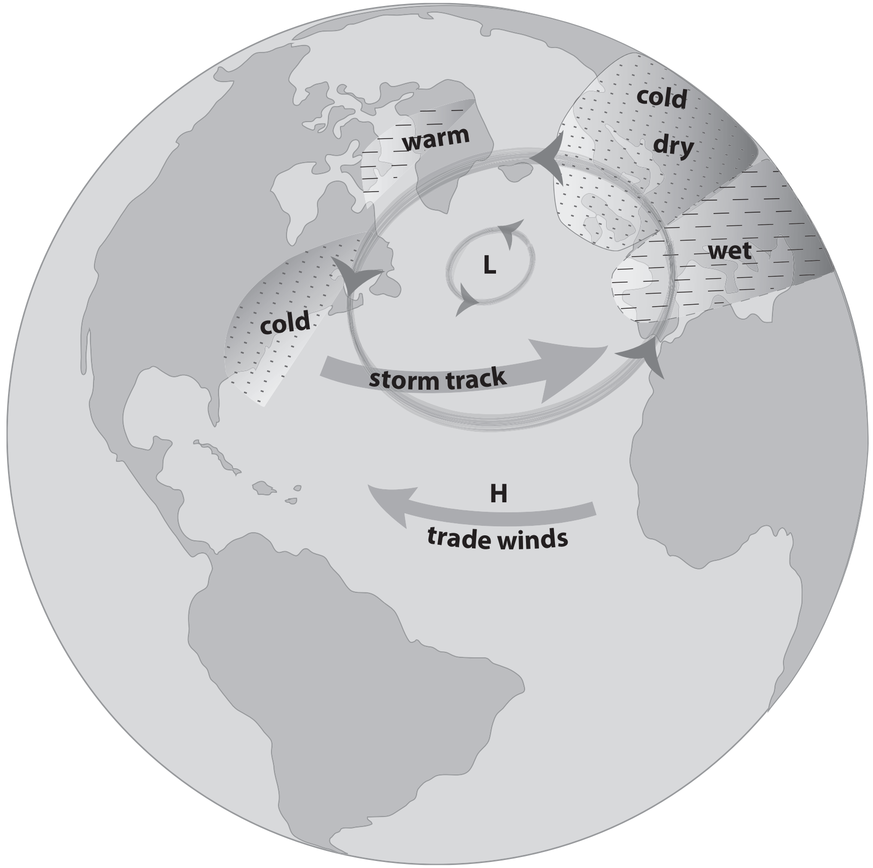
Natural modes of variability

- El Niño - Southern Oscillation (ENSO)
- Atlantic Multidecadal Oscillation (AMO)
- Atlantic Meridional Mode (AMM)
- North Atlantic Oscillation (NAO)
- Arctic Oscillation (AO)

North Atlantic Oscillation (NAO)





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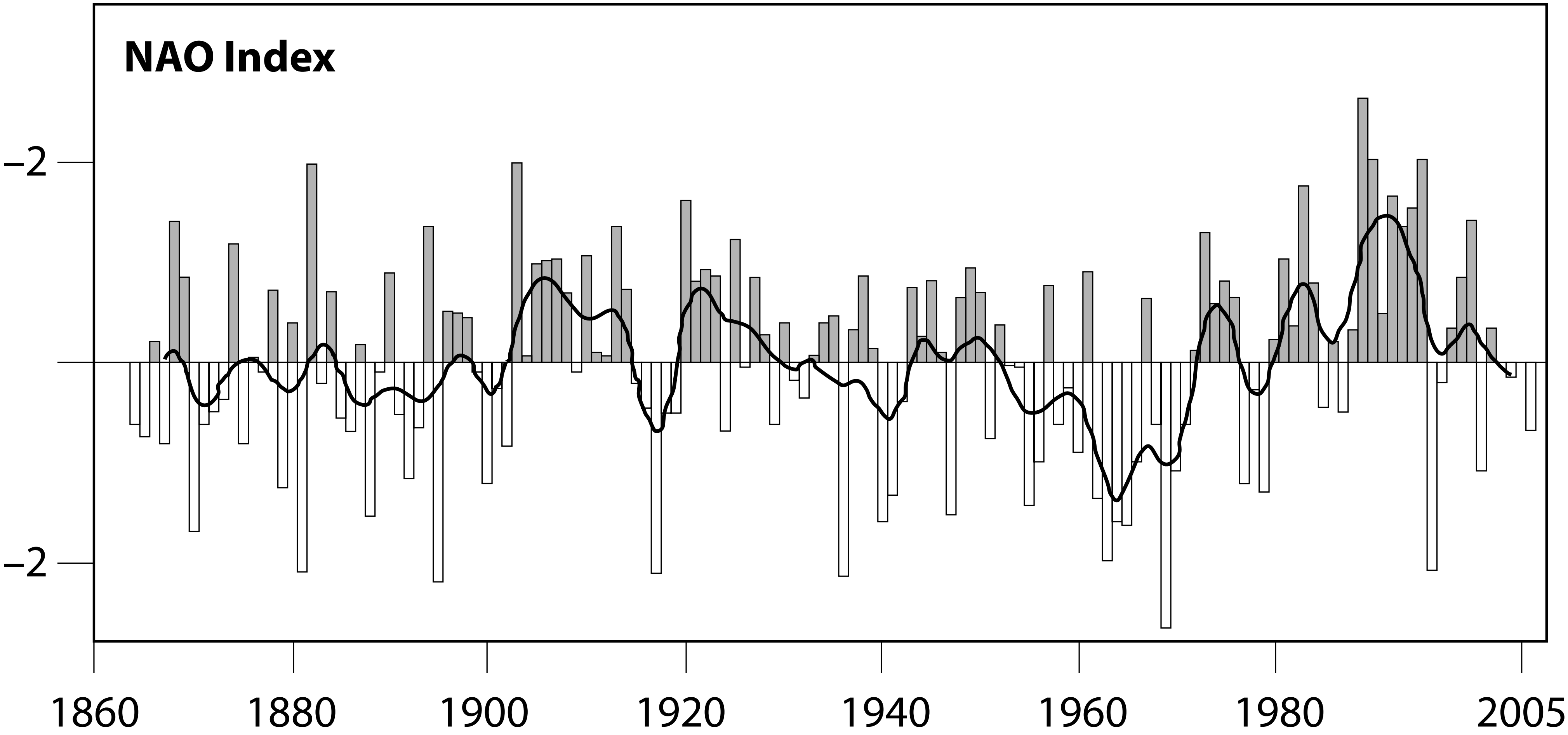
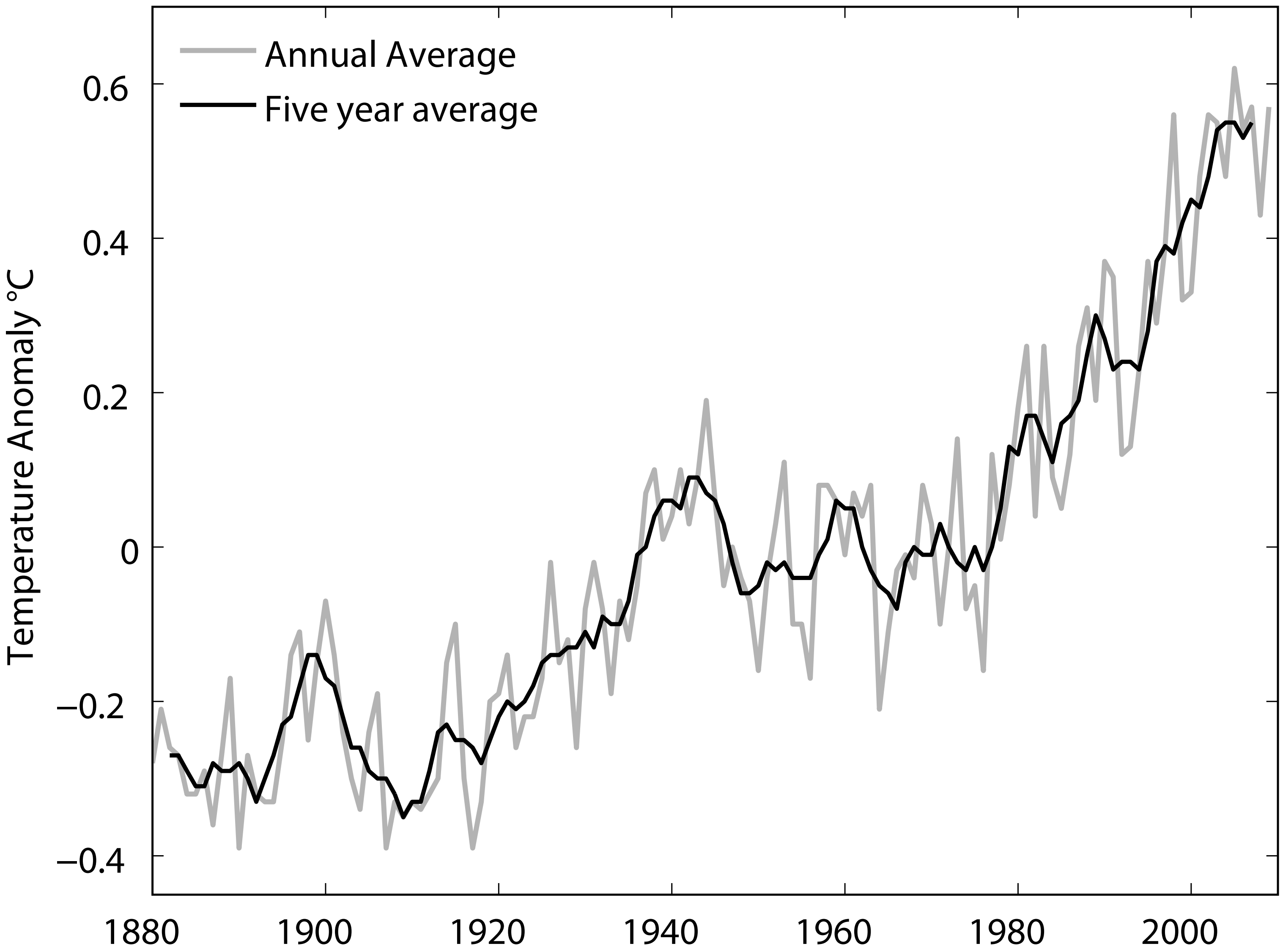
NAO index



Instrumental temperature record



Global mean surface temperature

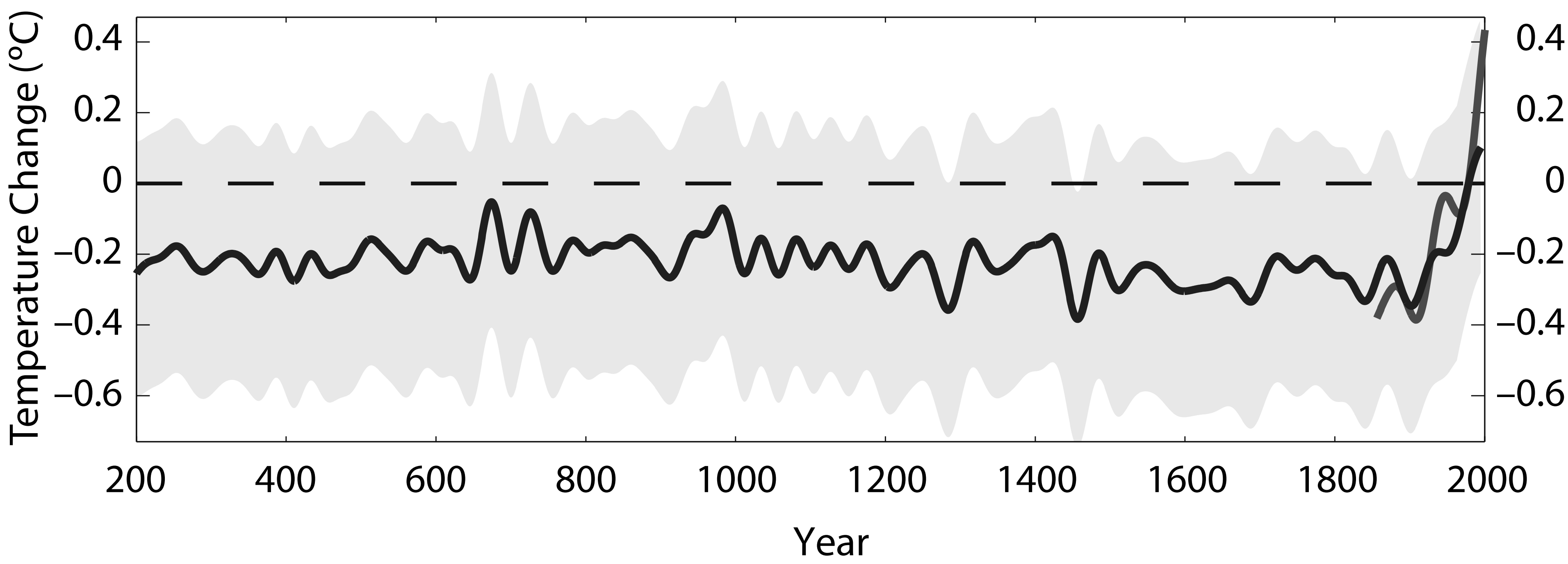


Figure 7.3. Global mean surface temperatures of the past 1,800 years.

Further reading

- Climate and the Oceans, G. Vallis
- Introduction to Geophysical Fluid Dynamics, B. Cushman-Roisin
- Atmosphere-ocean Dynamics, A. Gill
- An Introduction to Dynamic Meteorology, J. Holton
- Regional Oceanography: An Introduction, M. Tomczak and J. Godfrey
- The Atmosphere and Ocean: A Physical Introduction, N. Wells
- Principles of Planetary Climate, R. Pierrehumbert
- www.realclimate.org, blog with many different contributors
- University of Chicago lectures on youtube.com, D. Archer