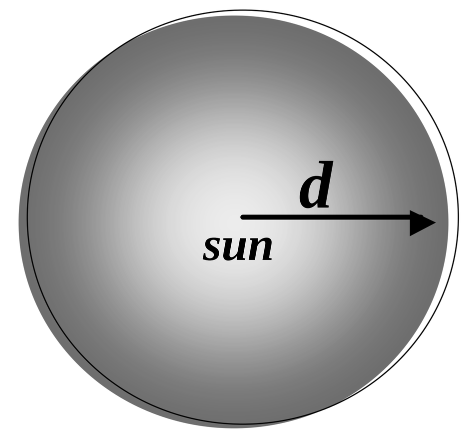
# Solar Flux and Flux Density

- Solar Luminosity (***L***)
  the constant flux of energy put out by the sun

**$L = 3.9 \times 10^{26}$ W**

- Solar Flux Density (***$S_d$***)
  the amount of solar energy per unit area on a sphere centered at the Sun with a distance ***d***




**$S_d = L / (4 \pi d^2)$ W/m²**



# Solar Flux Density Reaching Earth

- Solar Constant (***S***)
  The solar energy density at the mean distance of Earth from the sun ($1.5 \times 10^{11}$ m)

**$S = L / (4 \pi d^2)$**
**$= (3.9 \times 10^{26}\ \text{W}) / [4 \times 3.14 \times (1.5 \times 10^{11}\ \text{m})^2]$**
**$= 1370\ \text{W/m}^2$**



# Solar Energy Incident On the Earth

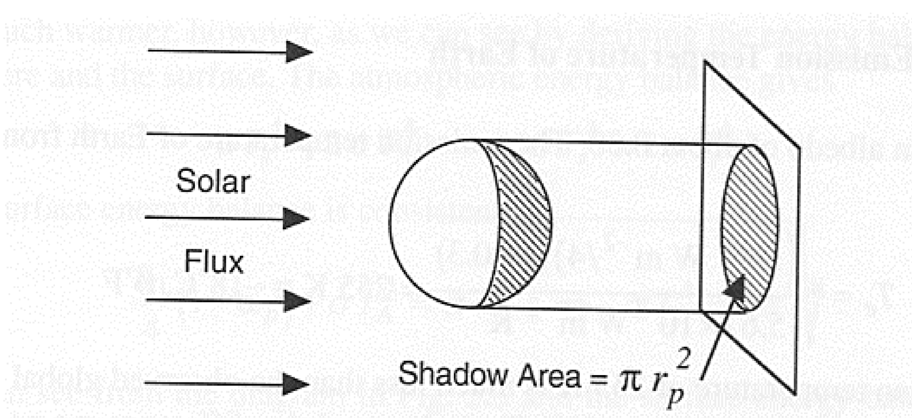
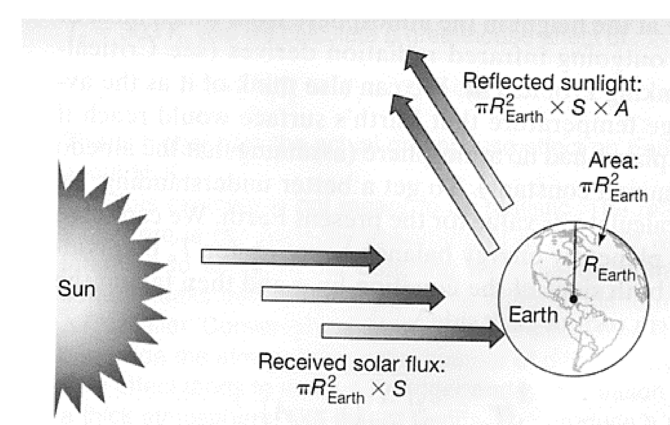



Fig. 2.2 Diagram showing the shadow area of a spherical planet.

- Solar energy incident on the Earth
  = total amount of solar energy **can be** absorbed by Earth
  = (Solar constant) x (Shadow Area)
  = $S \times \pi R^2_{Earth}$



# Solar Energy Absorbed by Earth




BOX FIGURE 3-1
The amount of sunlight received by and reflected by Earth.

(from *The Earth System*)

- **Solar Constant (S)**
  = solar flux density reaching the Earth
  = 1370 W/m²
- **Solar energy incident on the Earth**
  = S x the "flat" area of the Earth
  = $S \times \pi R^2_{Earth}$
- **Solar energy absorbed by the Earth**
  = (received solar flux) – (reflected solar flux)
  = $S \pi R^2_{Earth} - S \pi R^2_{Earth} \times A$
  **= $S \pi R^2_{Earth} \times (1-A)$**

**A** is the *planetary albedo* of the Earth, which is about 0.3.

# What Happens After the Earth Absorbs Solar Energy?

- ❑ The Earth warms up and has to emit radiative energy back to the space to reach a equilibrium condition.
- ❑ The radiation emitted by the Earth is called “terrestrial radiation” which is assumed to be like blackbody radiation.

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# Blackbody Radiation

- ❑ Blackbody

  A blackbody is something that emits (or absorbs) electromagnetic radiation with 100% efficiency at all wavelength.

- ❑ Blackbody Radiation

  The amount of the radiation emitted by a blackbody depends on the absolute temperature of the blackbody.

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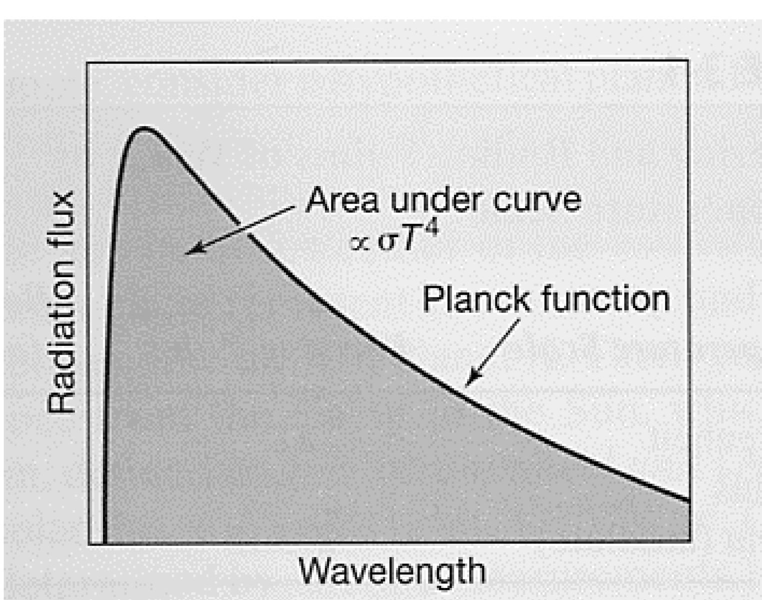
# Energy Emitted from Earth



(from *The Earth System*)

- **The Stefan-Boltzmann Law**

  The energy flux emitted by a blackbody is related to the fourth power of the body’s absolute temperature

  **F =** s**T⁴**   where σ is $5.67 \times 10^{-8}$ W/m²/K

- **Energy emitted from the Earth**

  = (blackbody emission) x (total area of Earth)

  = $(\sigma T_e^4)$ x $(4\pi R^2_{Earth})$

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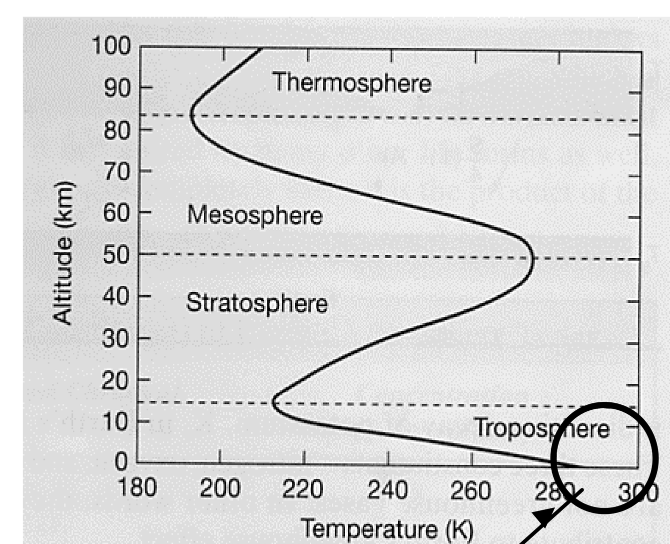
# Planetary Energy Balance



(from *Global Physical Climatology*)

- **Energy emitted by Earth = Energy absorbed by Earth**

$$\sigma T_e^4 \times (4\pi R^2_{Earth}) = S \pi R^2_{Earth} \times (1-A)$$

$$\sigma T_e^4 = S/4 * (1-A)$$

$$= 1370/4 \text{ W/m}^2 * (1-A)$$

$$= 342.5 \text{ W/m}^2 * (1-A)$$

$$= 240 \text{ W/m}^2$$

- **Earth’s *blackbody* temperature**

  **$T_e$ = 255 K (-18C)**

**Earth’s *surface* temperature**

**$T_S$ = 288 K (15C)**

***greenhouse effect (33C) !!***

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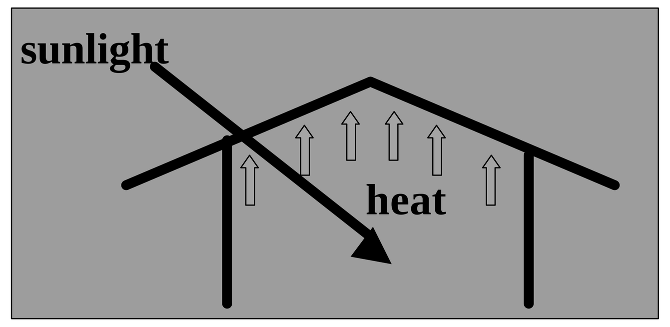
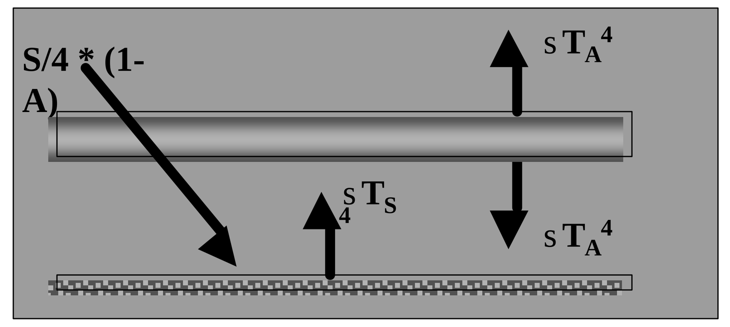
# Greenhouse Effect

## Greenhouse




- allow sunlight to come in
- trap heat inside the house

## Atmosphere




At the top of the atmosphere:

$S/4*(1-A) = \sigma T_A^4$ ➔ $\mathbf{T_A}=T_e =$ **255K**

For Earth's surface:

$S/4*(1-A) + \sigma T_A^4 = \sigma T_S^4$

➔ $\mathbf{T_S} = 1.19 T_A =$ **303K**

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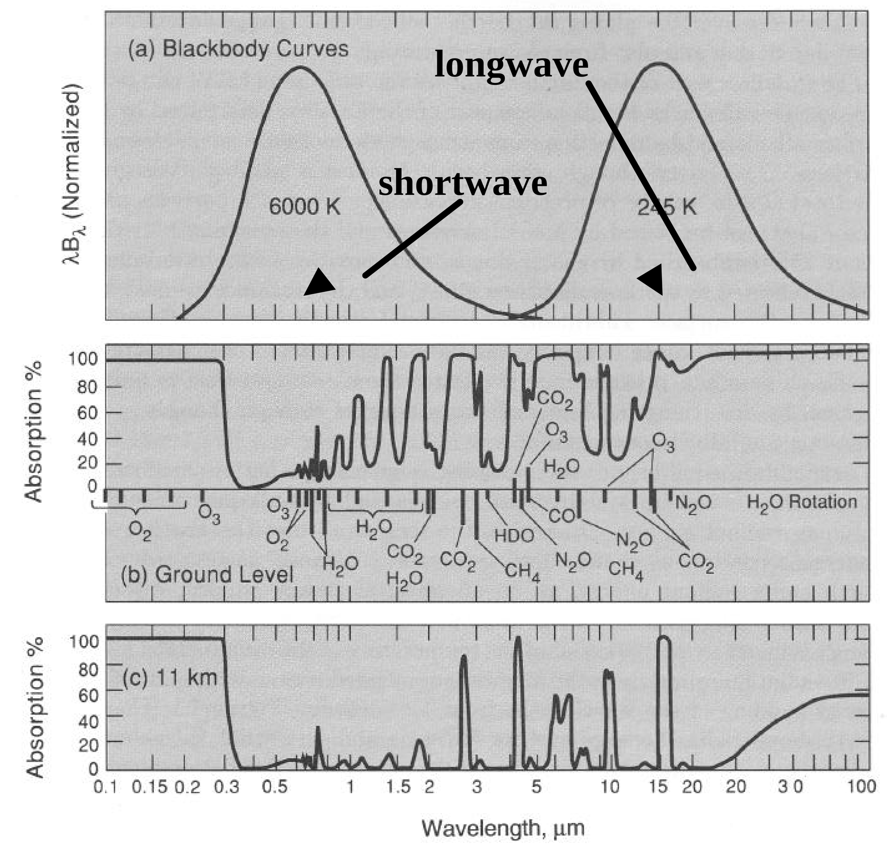
# Different Wavelengths of Solar and Earth's Radiation

## Normalized Planck Function




(from *Climate System Modeling*)

## Planck Function

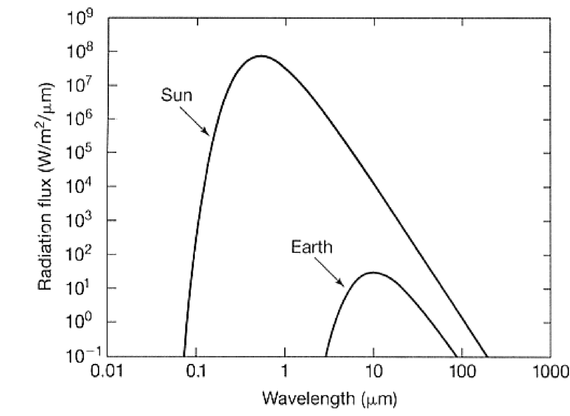



FIGURE 3-8
Blackbody emission curves for the Sun and Earth. The Sun emits more energy at all wavelengths.

(from *The Earth System*)

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# Greenhouse Gases

| **Important Atmospheric Greenhouse Gases** | |
|---|---|
| ***Name and Chemical Symbol*** | ***Concentration (ppm by volume)*** |
| Water vapor, $H_2O$ | 0.1 (South Pole)–40,000 (tropics) |
| Carbon dioxide, $CO_2$ | 360 |
| Methane, $CH_4$ | 1.7 |
| Nitrous oxide, $N_2O$ | 0.3 |
| Ozone, $O_3$ | 0.01 (at the surface) |
| Freon-11, $CCl_3F$ | 0.00026 |
| Freon-12, $CCl_2F_2$ | 0.00047 |

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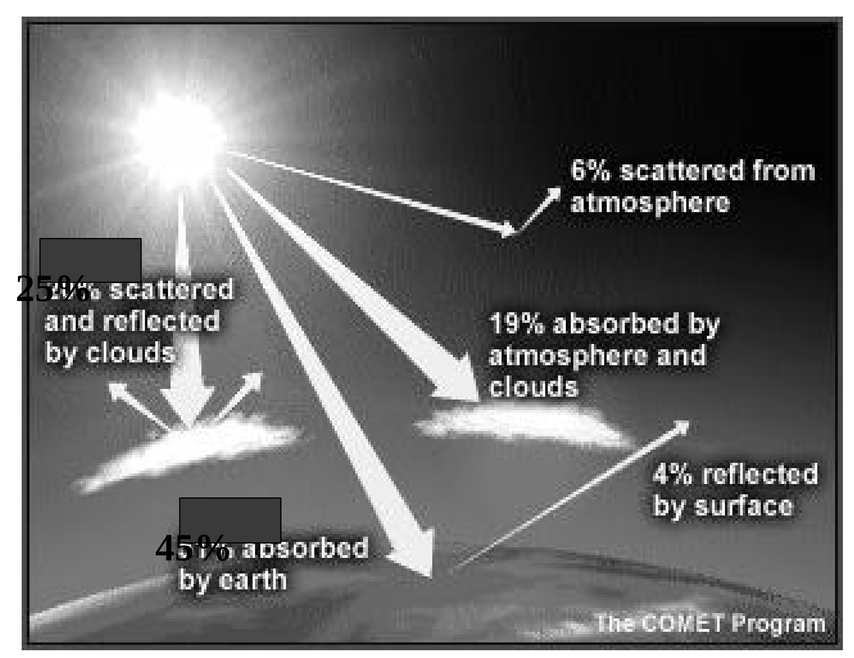
# Where Does the Solar Energy Go?




**(from NCAR/COMET website)**

Incoming solar energy (100)

- 70% absorbed
  - 45% by Earth's surface (ocean + land)
  - 25% by the atmosphere and clouds
- 30% reflected and scattered back
  - 20% by clouds
  - 6% by the atmosphere
  - 4% by surface

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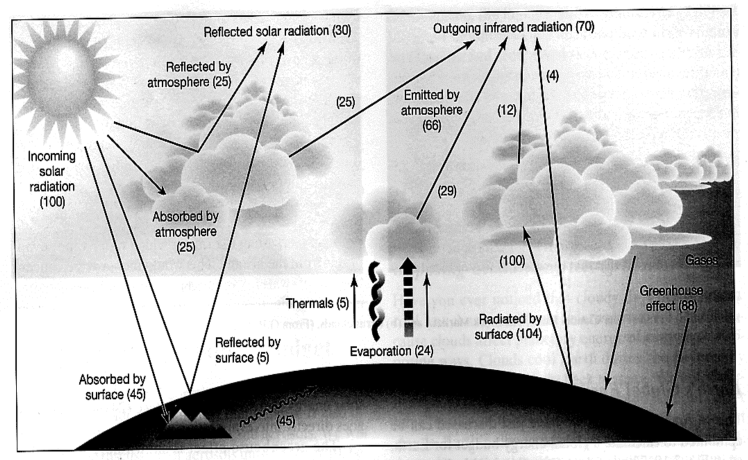
## Where Is Earth's Radiation Emitted From?



(from *The Earth System*)

Radiation back to Space (70 Units)

- 70 (units) radiation back to space
  - 66% by the atmosphere
  - 4% by surface (through clear sky)
- Greenhouse emission (back to surface)
  - 88% (of solar radiation)

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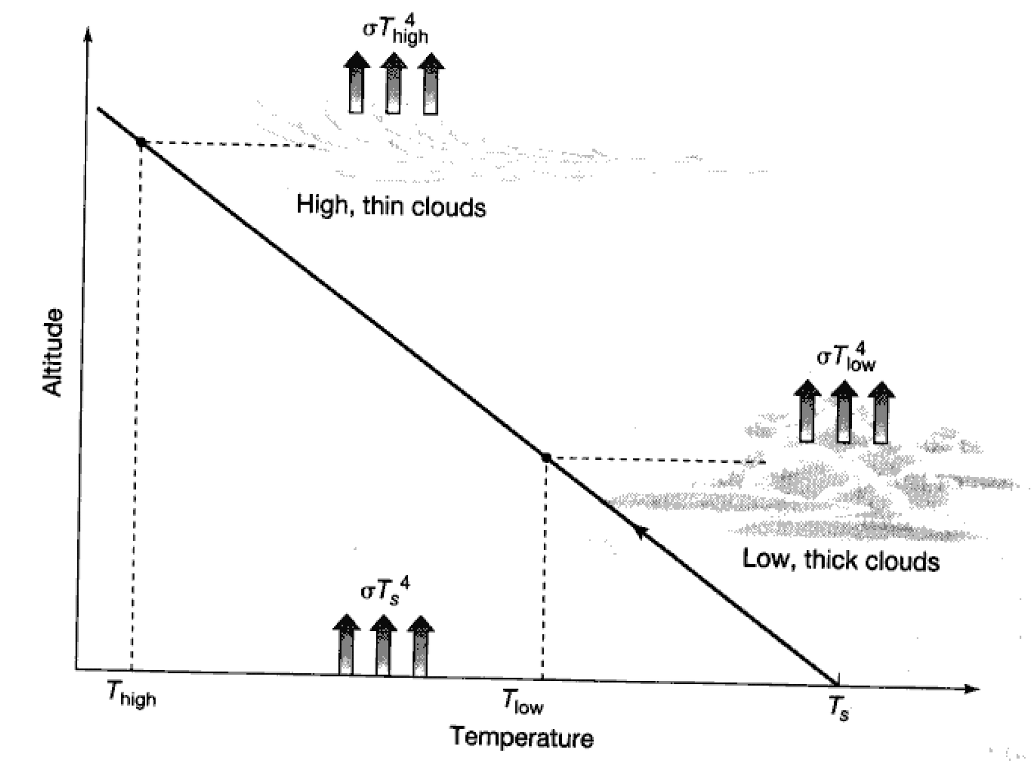
## Important Roles of Clouds In Global Climate




(from The Earth System)

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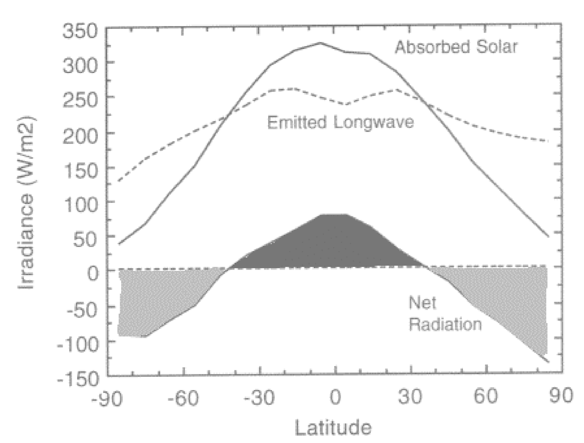
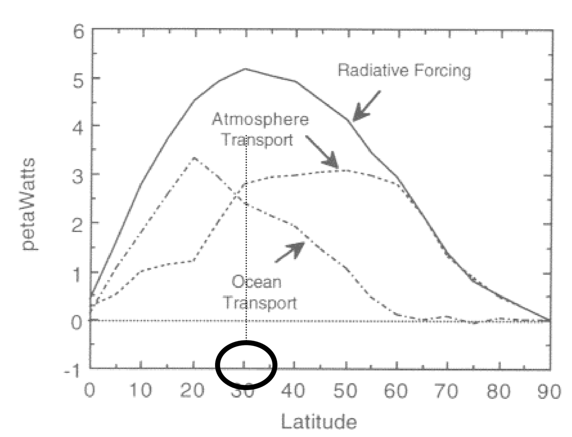
## Polarward Energy Transport

**Annual-Mean Radiative Energy**




Polarward heat flux is needed to transport radiative energy from the tropics to higher latitudes

**Polarward Heat Flux**




The atmosphere dominates the polarward heat transport at middle and high latitudes. The ocean dominates the transport at lower latitudes.

**(1 petaWatts = $10^{15}$ W)**

(figures from *Global Physical Climatology*)

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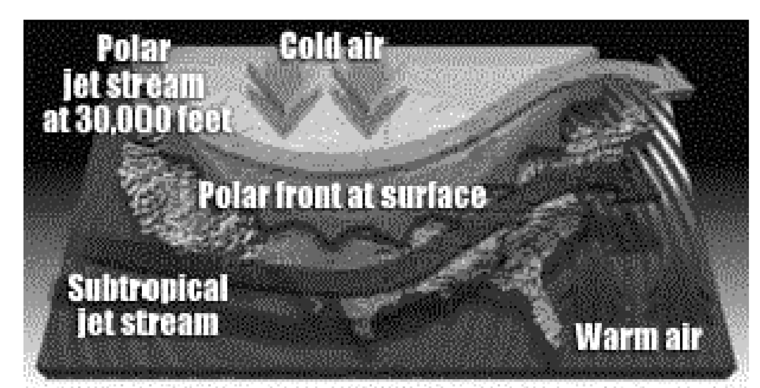
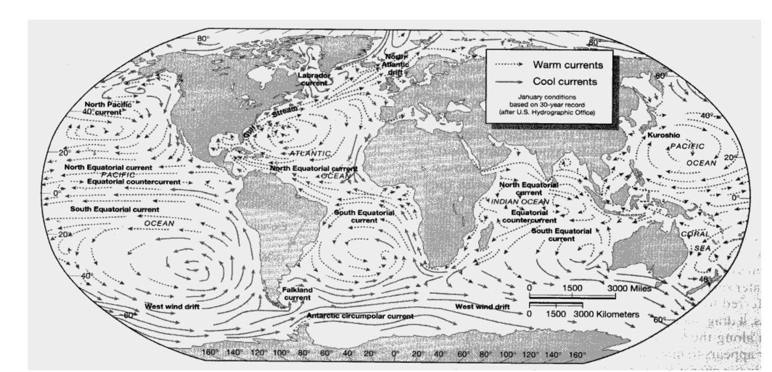
## How Do Atmosphere and Ocean Transport Heat?

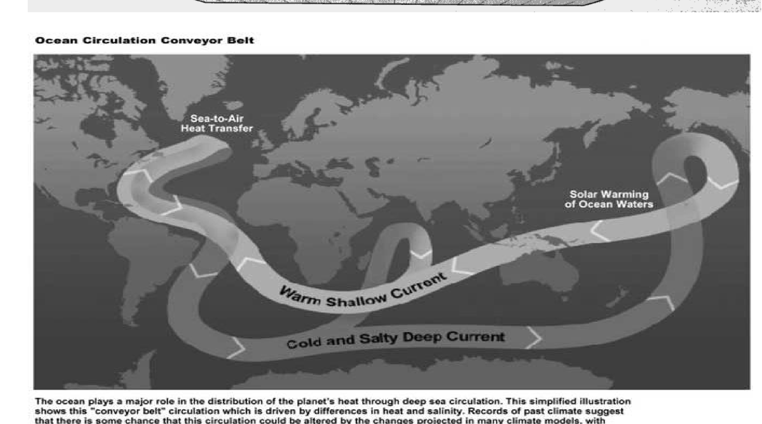
Atmospheric Circulation




(from USA Today)

Ocean Circulation






(top from *The Earth System*)
(bottom from USGCRP)

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