Agronomy 406
World Climates
January 16, 2018

Variations in the global energy balance.

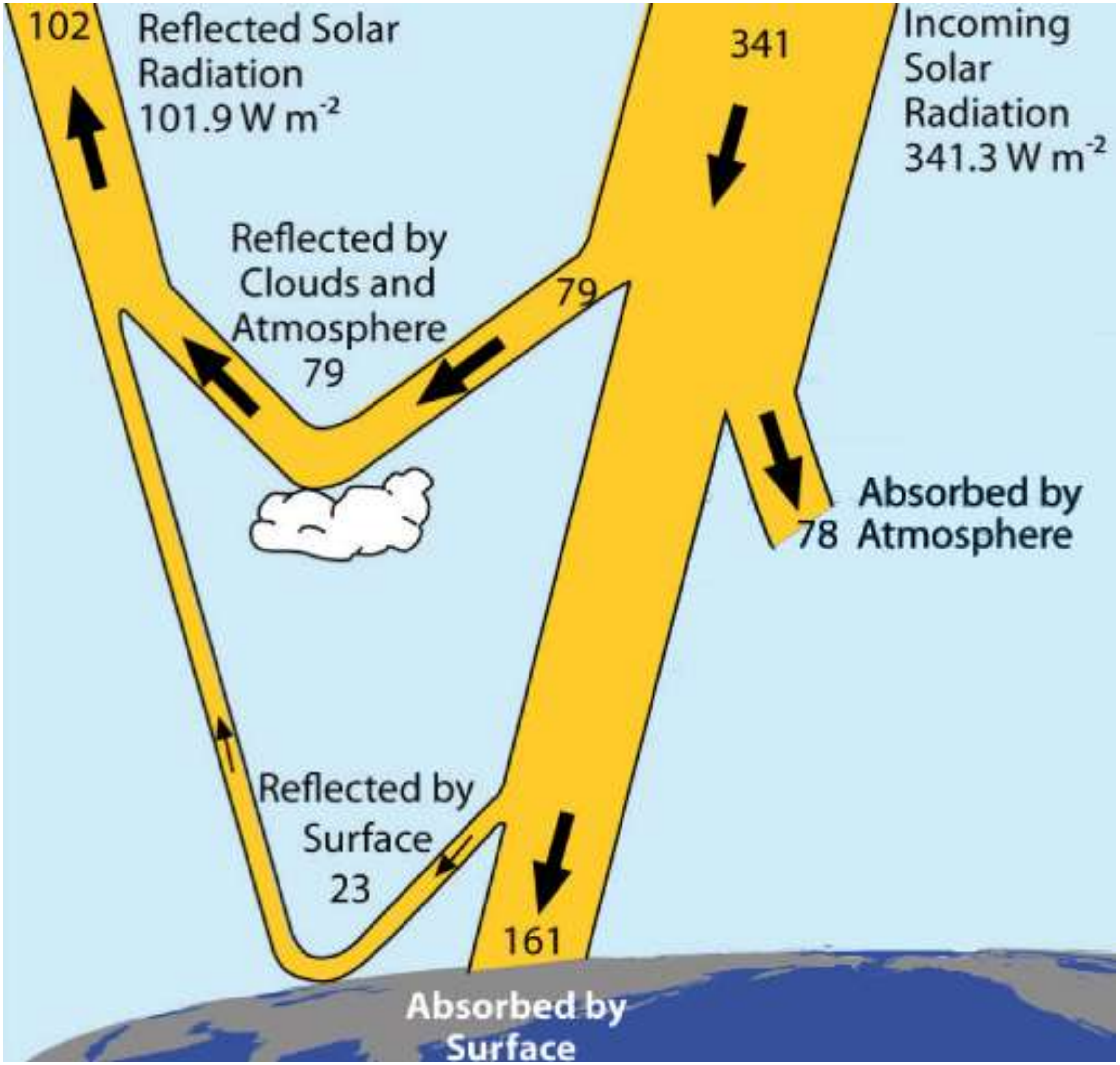
Review for today:

Online textbook: 2.1.4 The heat balance at the top of the atmosphere: geographical distribution

For Thursday:

Online textbook: 2.1.6 Heat balance at the surface

Short-wave radiation budget



planetary albedo =

reflected / incoming

= (102 W m^{-2})/(341 W m^{-2})

= 0.30

gain to atmosphere

= 78 W m^{-2}

gain to surface

= 161 W m^{-2}

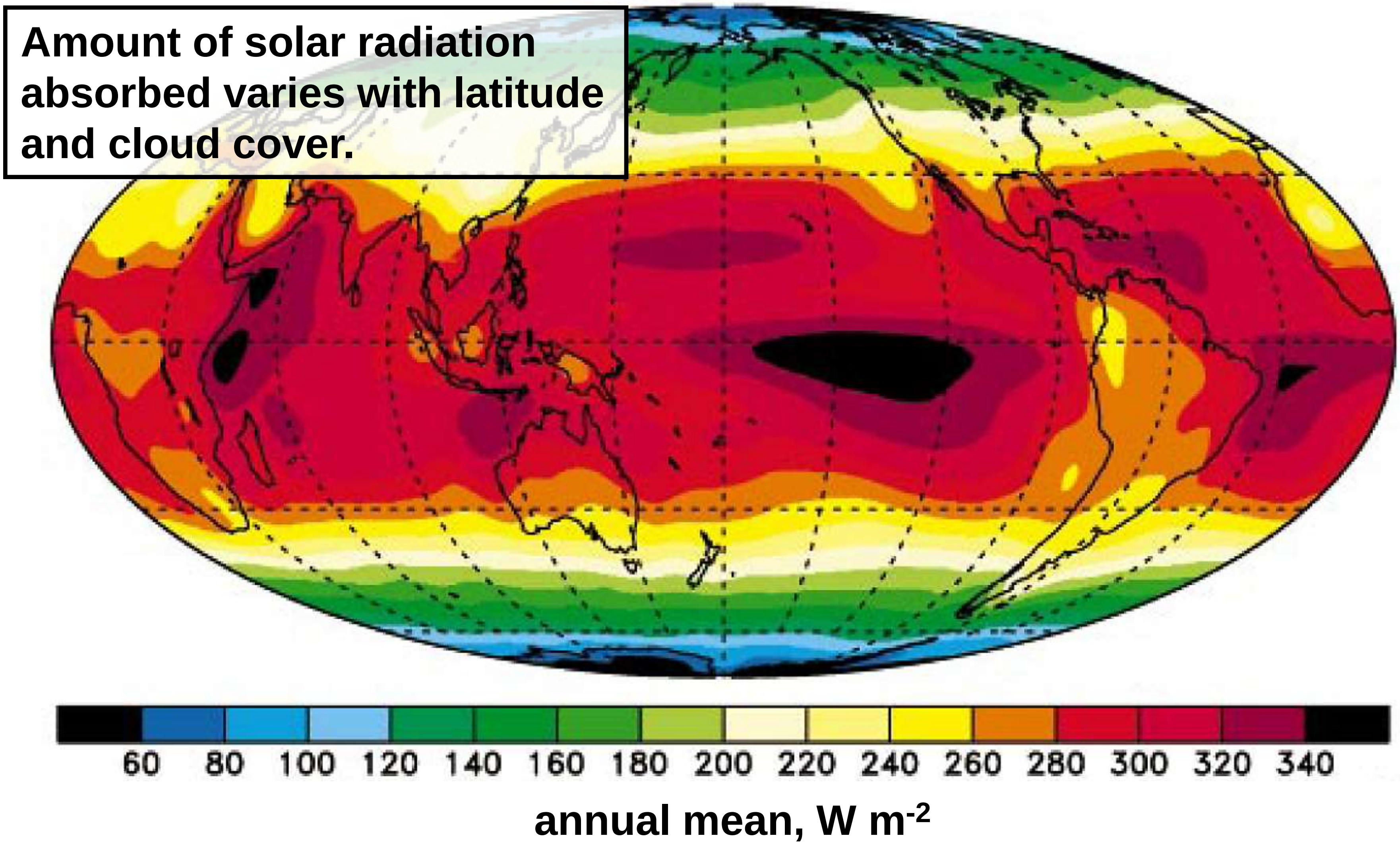
total gain to system

= (incoming - reflected)

= (341 - 102) W m^{-2}

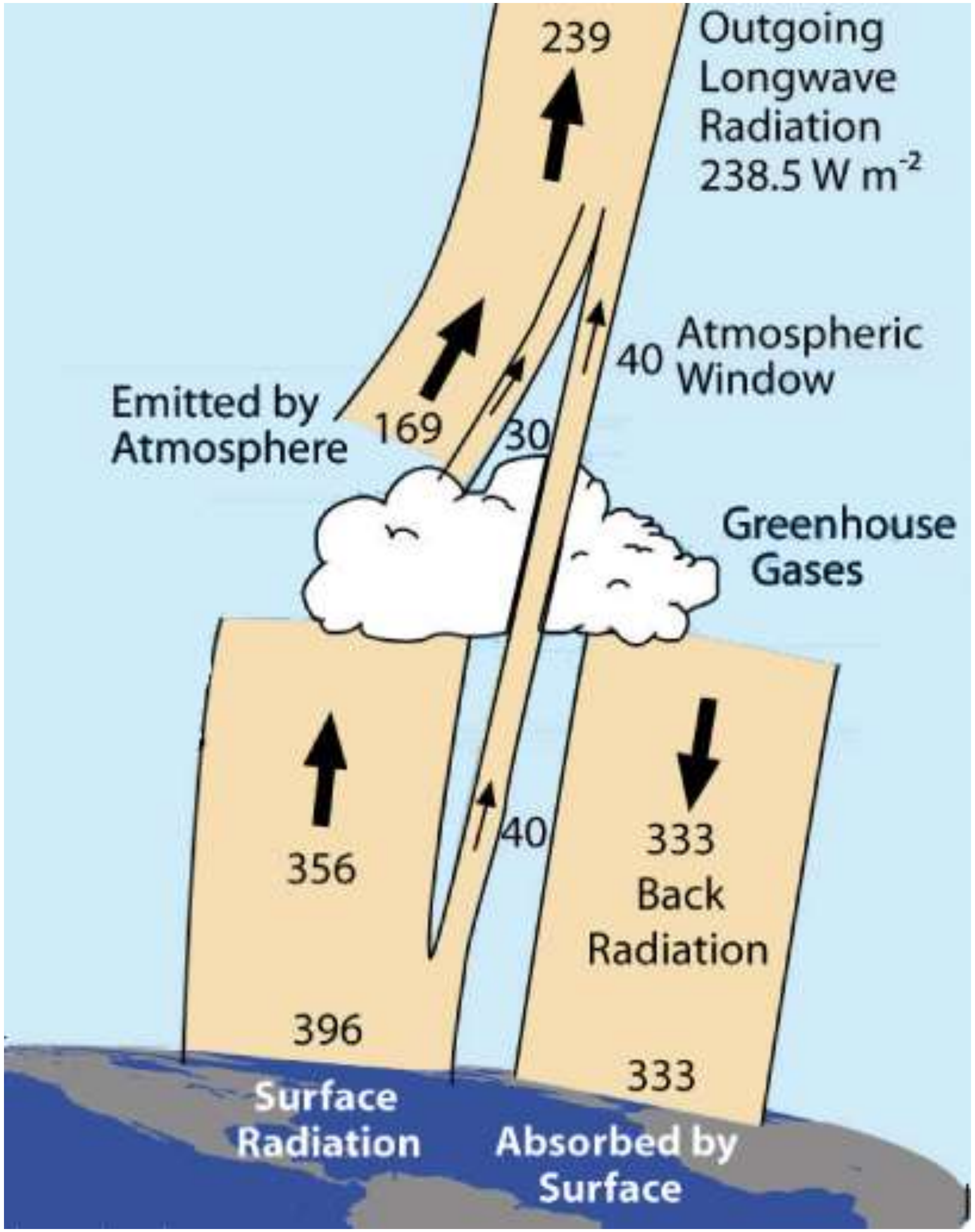
= **239 W m^{-2}**

Solar radiation absorbed by Earth (measured at top of the atmosphere)



Trenberth and Stepaniak (2003)

Long-wave radiation budget



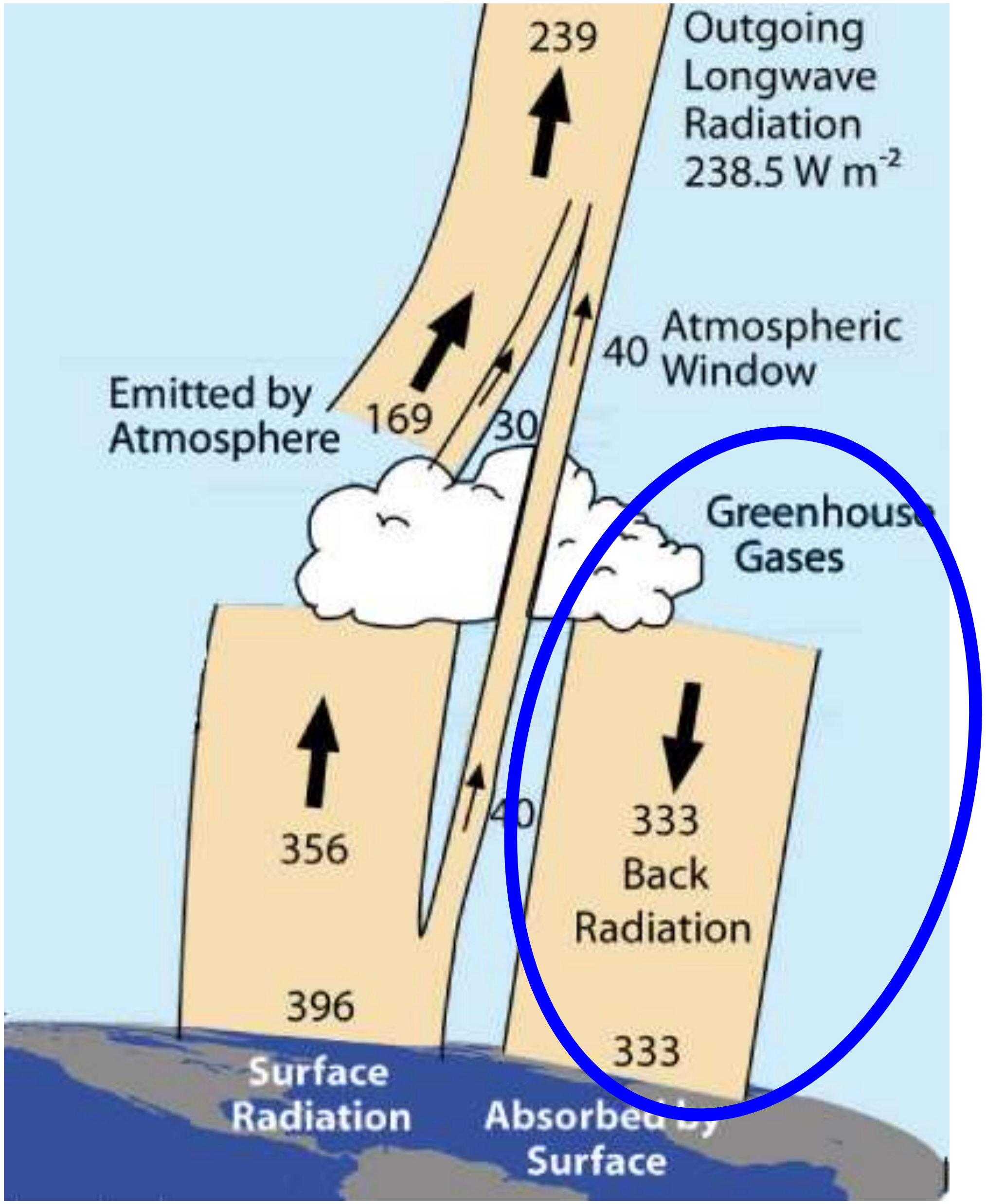
Net long-wave gain to system:

= (incoming - outgoing)

= 0 - 239 W m^{-2}

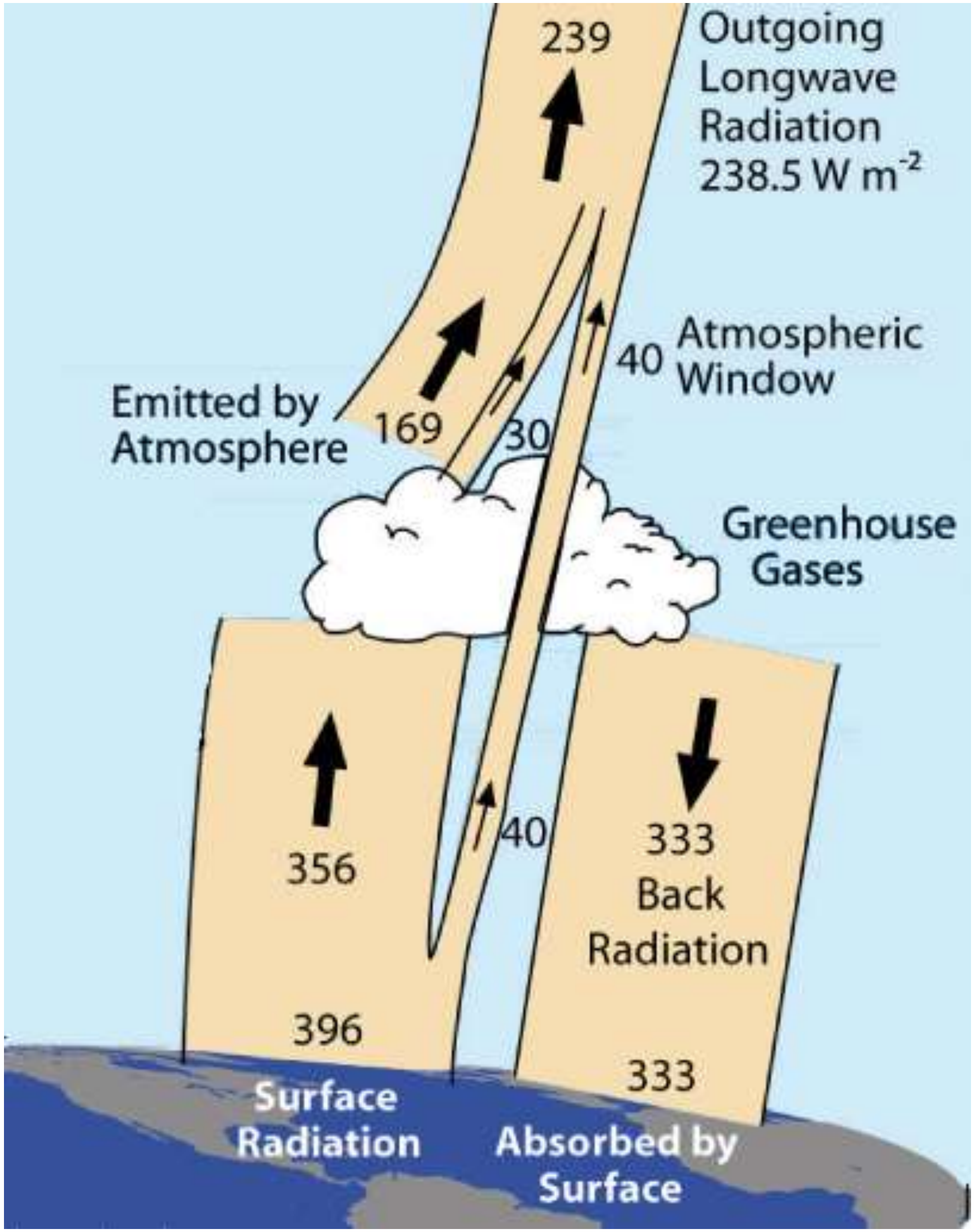
(i.e., a **loss** of 239 W m^{-2})

Long-wave radiation budget



This is the greenhouse effect.

Long-wave radiation budget



Net long-wave gain to system:

= (incoming - outgoing)

= 0 - 239 W m^{-2}

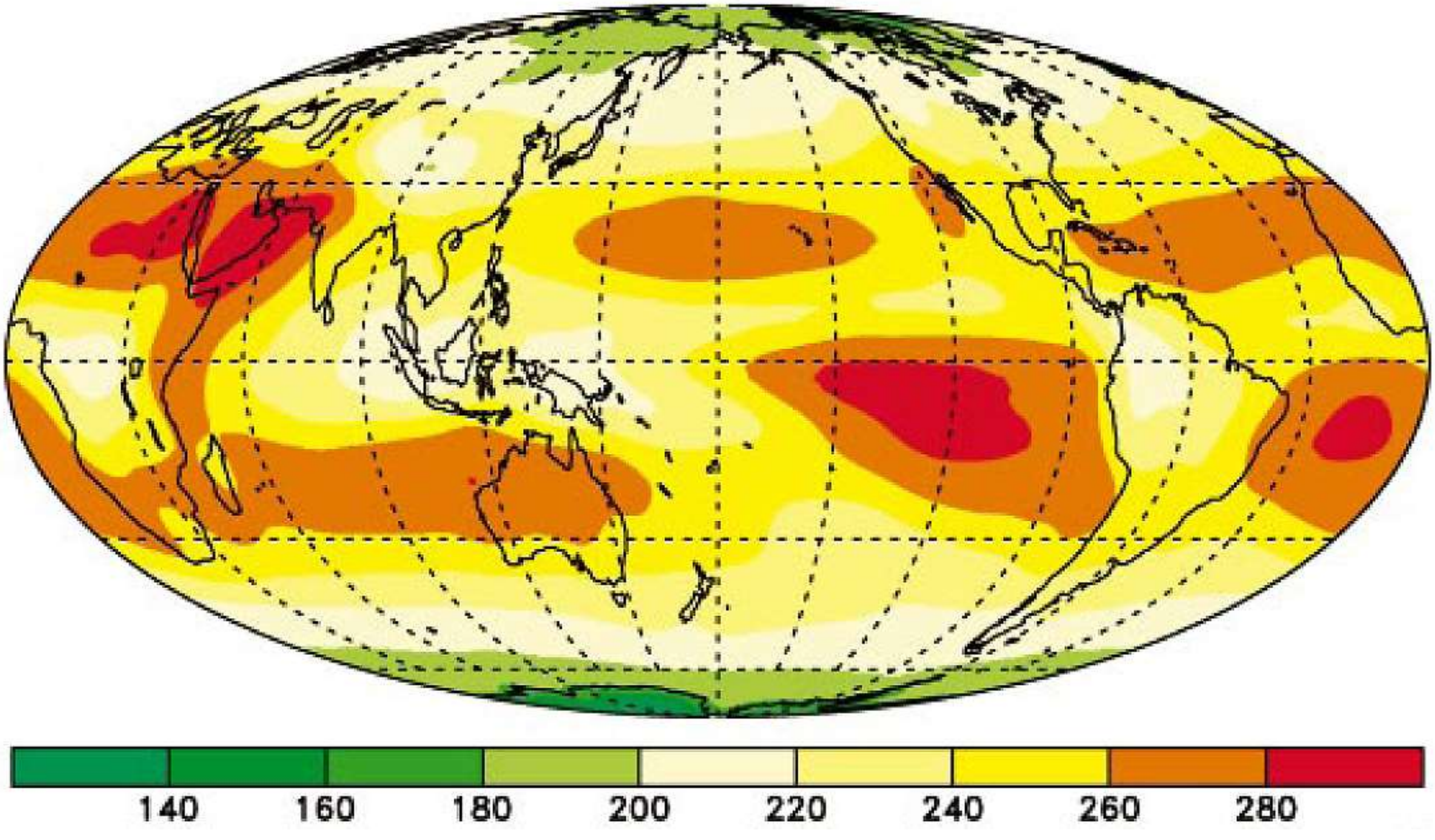
(i.e., a **loss** of 239 W m^{-2})

What is the net LW gain or loss for the surface?

What is the net LW gain or loss for the atmosphere?

Work out these values in your teams.

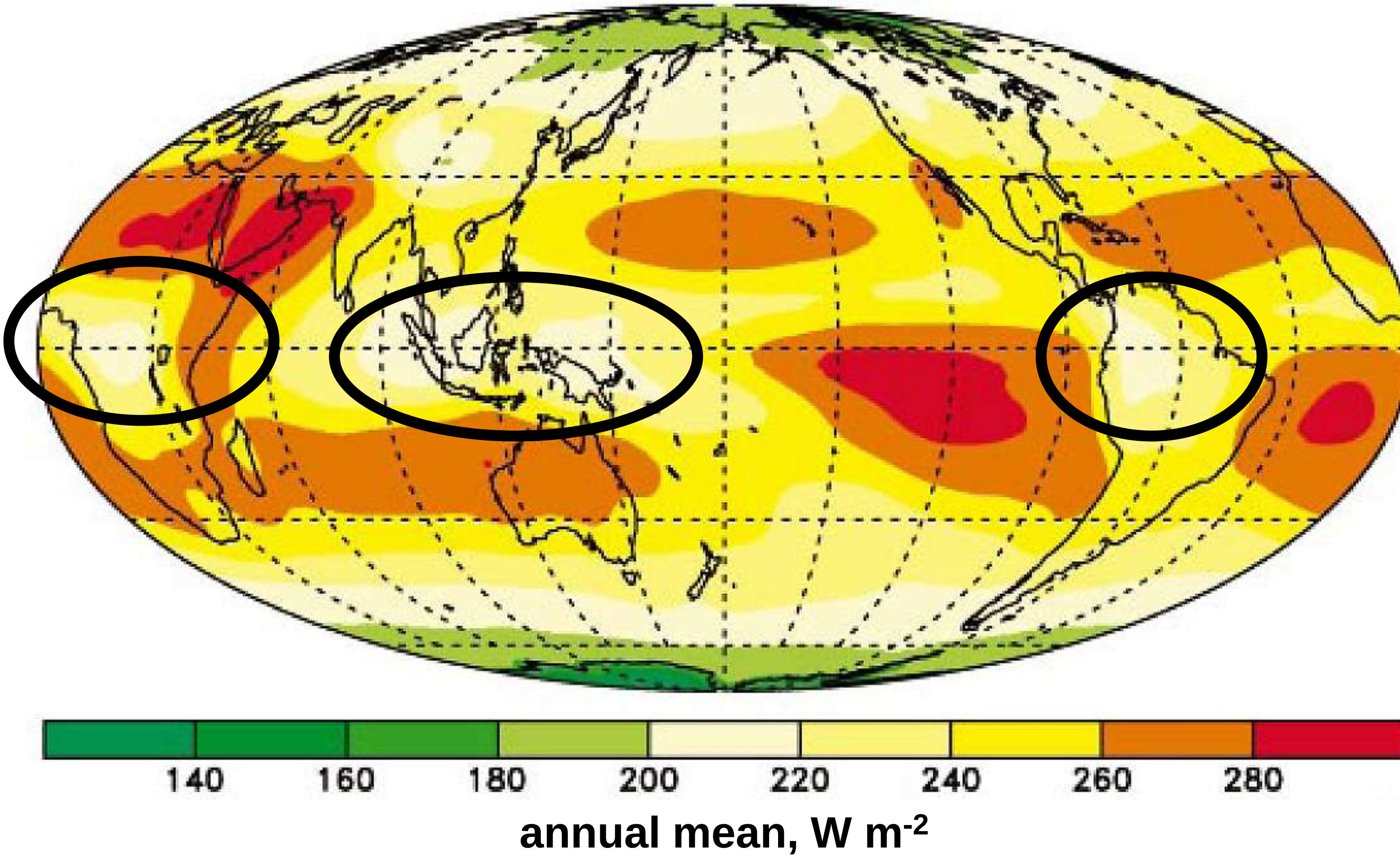
Long-wave radiation emitted by Earth (measured at top of the atmosphere)



annual mean, W m^{-2}

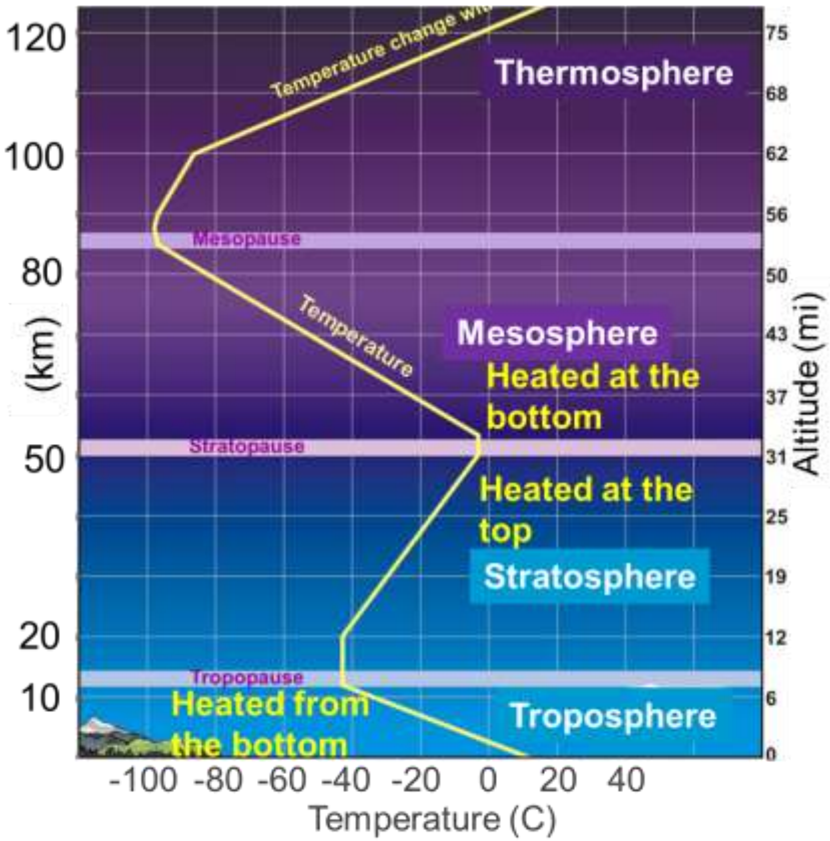
Trenberth and Stepaniak (2003)

High clouds over the Indonesian "warm pool" and tropical rainforests reduce outgoing longwave radiation



Trenberth and Stepaniak (2003)

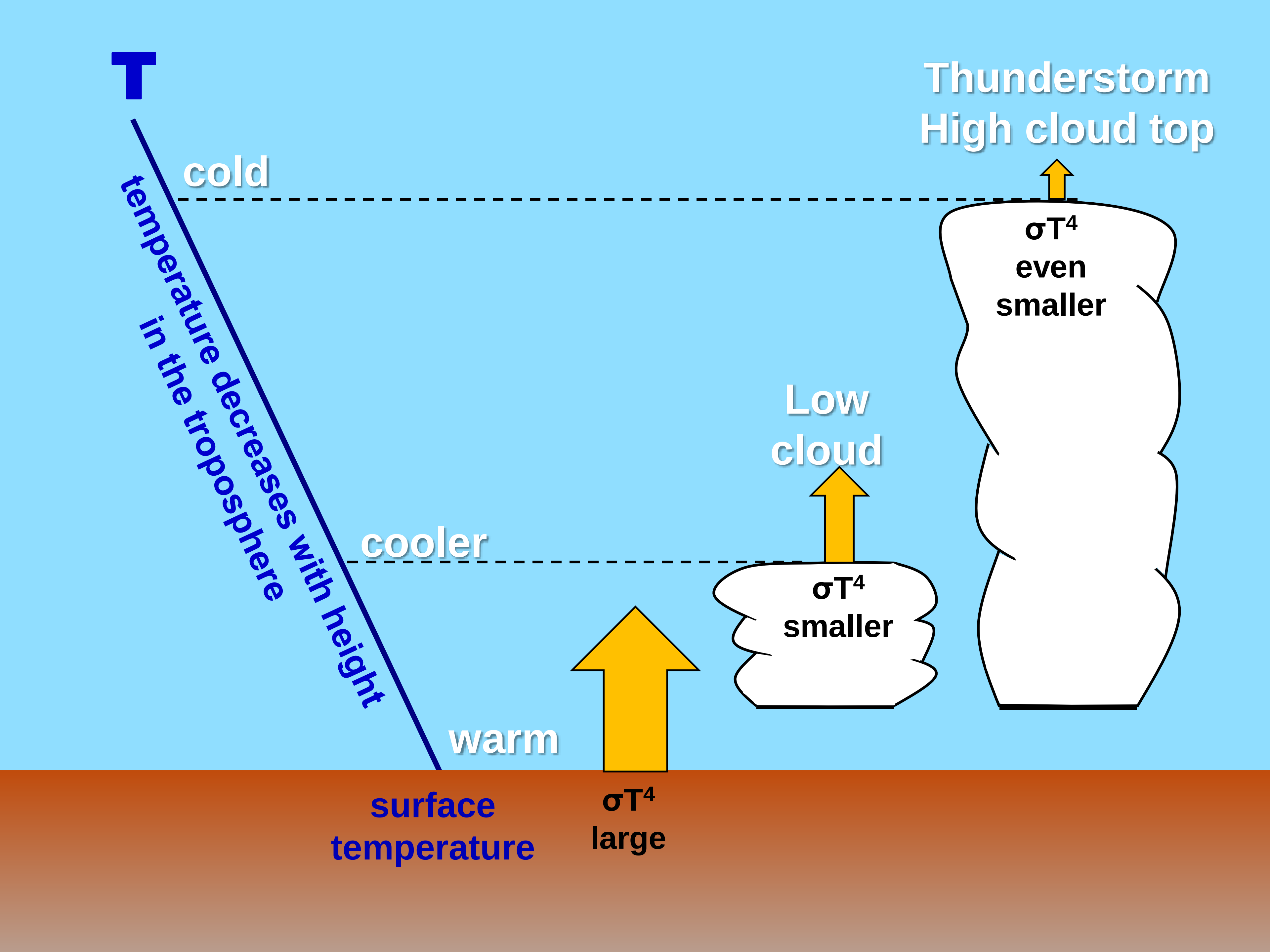
Why do clouds affect emission of long-wave radiation from Earth to space?



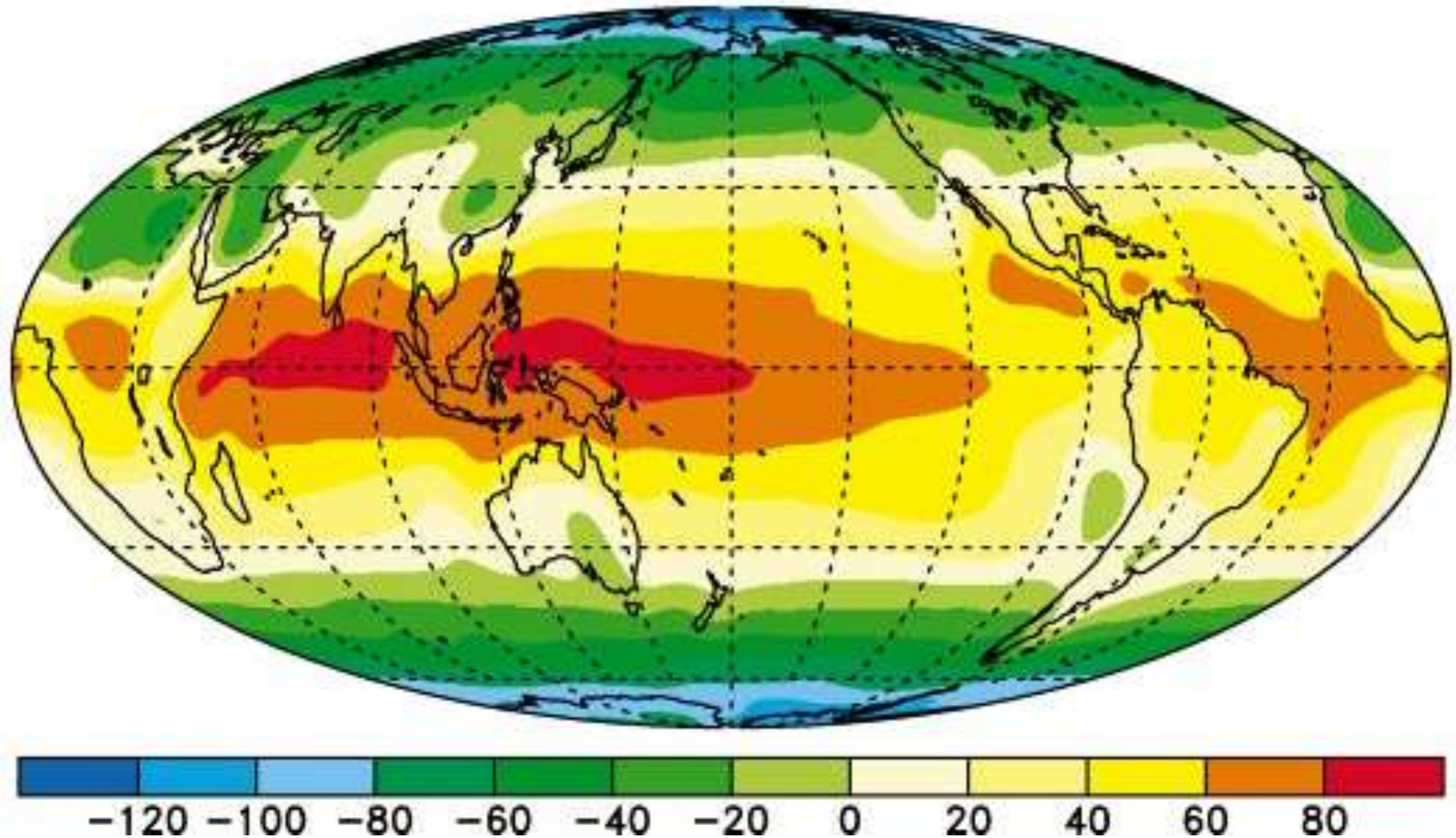
Two key points:

1. Clouds radiate energy to space from their **tops**.

2. In the troposphere **temperature decreases with height.** Almost all clouds and rain are contained within the troposphere.


T
Thunderstorm
High cloud top
cold
temperature decreases with height
in the troposphere
σT4
even
smaller
Low
cloud
cooler
σT4
smaller
warm
surface
temperature
σT4
large

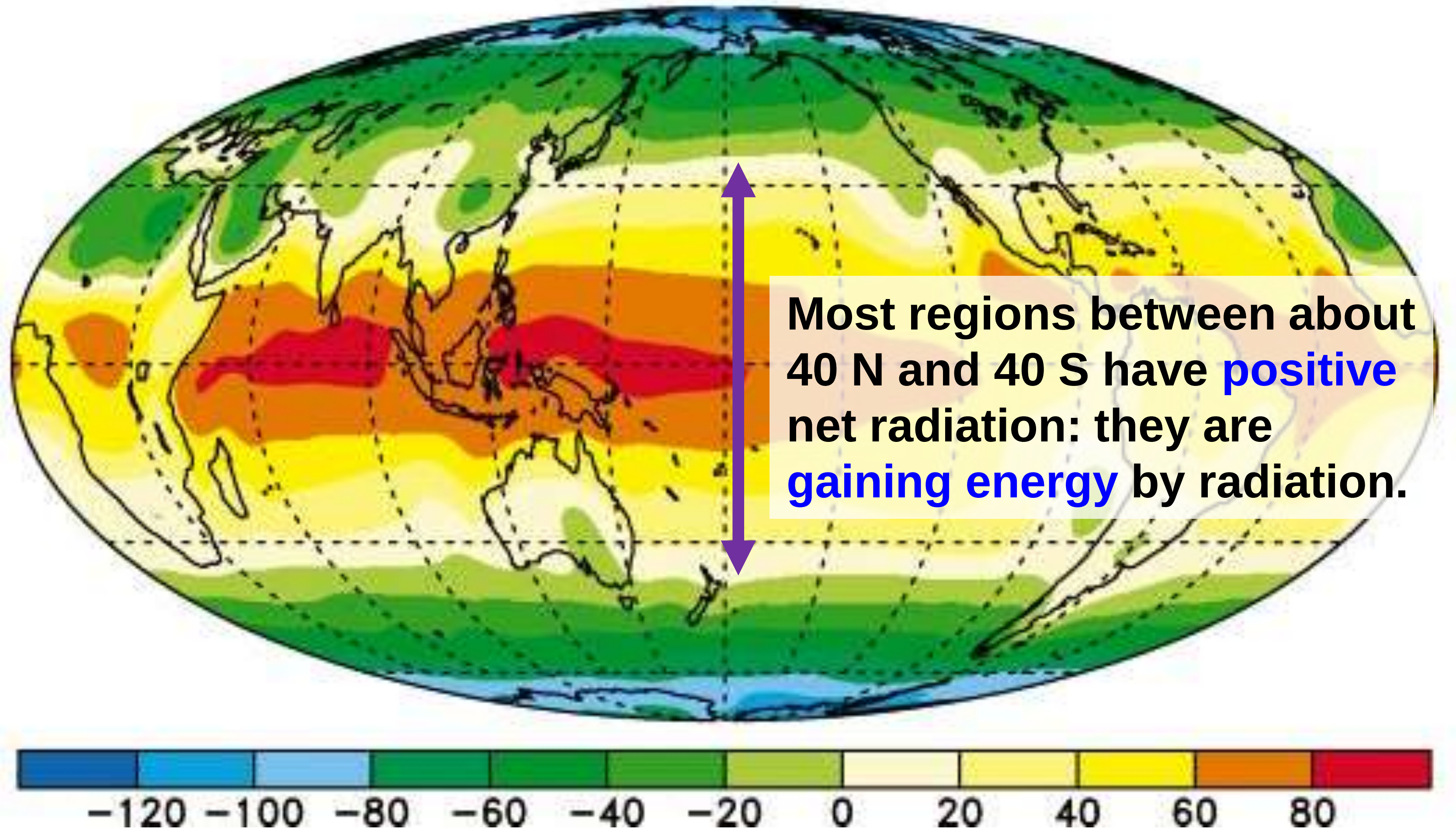
Net radiation: absorbed minus emitted (measured at top of the atmosphere)



annual mean, W m^{-2}

Trenberth and Stepaniak (2003)

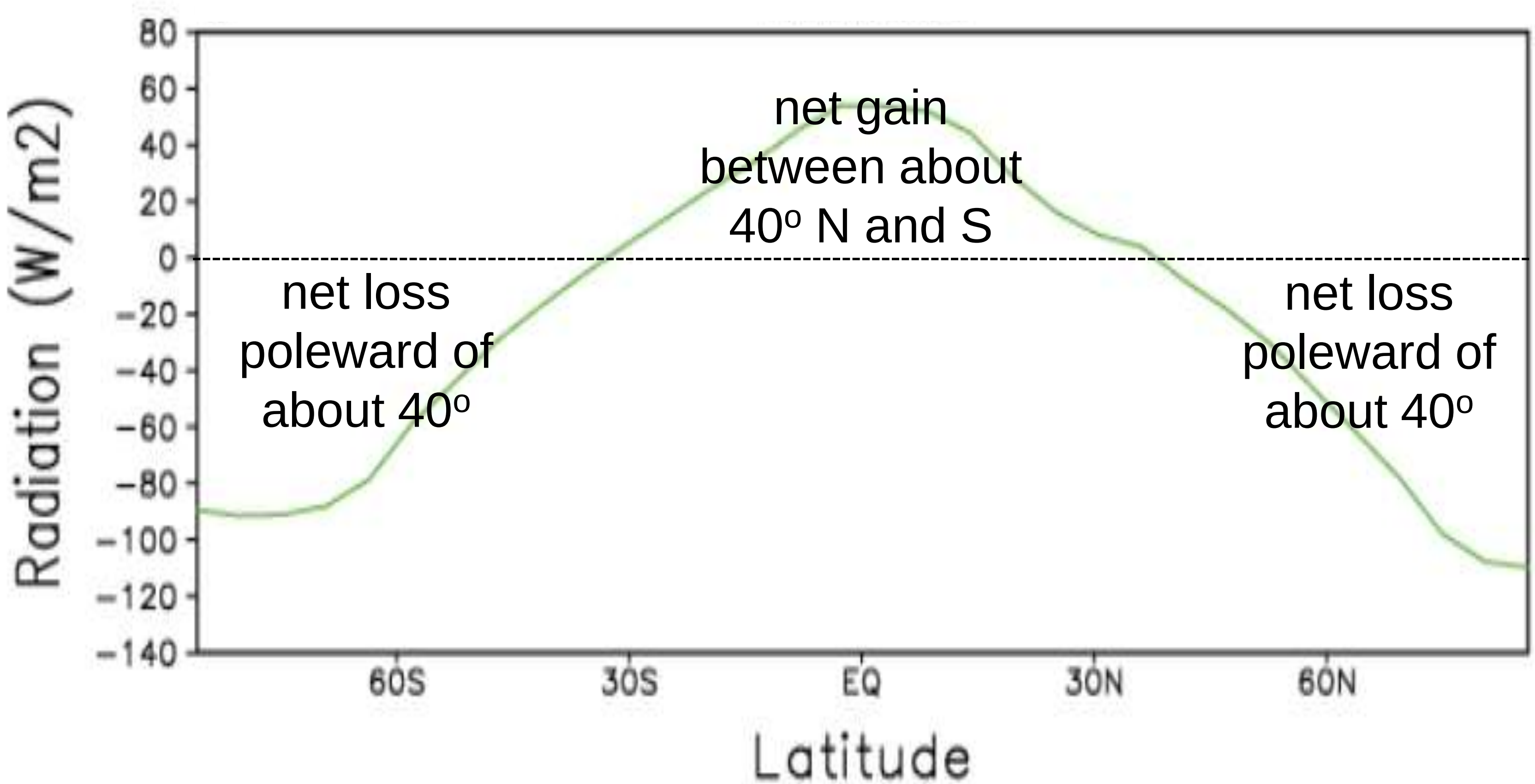
Net radiation: absorbed minus emitted (measured at top of the atmosphere)



annual mean, W m^{-2}

Trenberth and Stepaniak (2003)

Net radiation as a function of latitude



What will happen in each latitude band if it continues gaining/losing energy like this?

Goosse et al., http://www.climate.be/textbook

Summary of global short and long wave radiation fluxes

Net gain to atmosphere:

= 78 (SW gain) – 176 (LW loss)

= - 98 W m^{-2}

Net gain to surface:

= 161 (SW gain) – 63 (LW loss)

= 98 W m^{-2}

So: we need an energy flux of 98 W m^{-2} from the surface to the atmosphere in order to balance.

Transferring energy between the surface and atmosphere

Radiation is not the only way for the surface to gain or lose energy.

Sensible heat flux (F_{SH}) transfers energy between the surface and atmosphere by vertical movement of air that has **warmer or colder temperature** than the surface.

Latent heat flux (F_{LE}) transfers energy by vertical movement of **water vapor** to or from the surface.

- Energy is used to evaporate water or sublimate ice.
- When the vapor condenses or freezes, **the energy that was used to evaporate the water is released.**

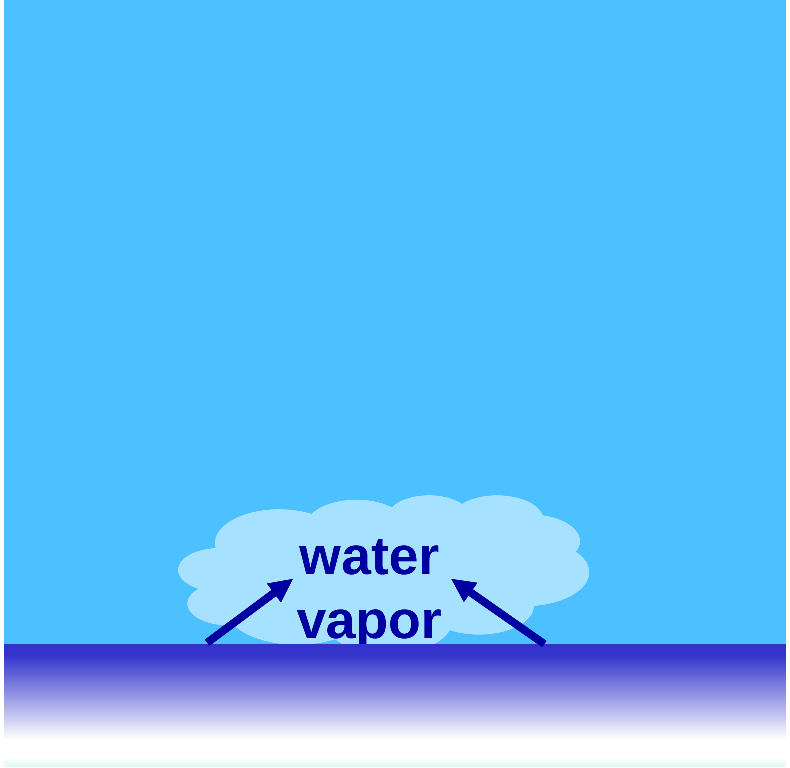
Both sensible heat flux and latent heat flux involve **convection**, i.e., the bulk movement of a fluid (air).

Sensible heat flux (F_{SH})

Latent heat flux (F_{LE})

Water is evaporated from the surface into the air above.

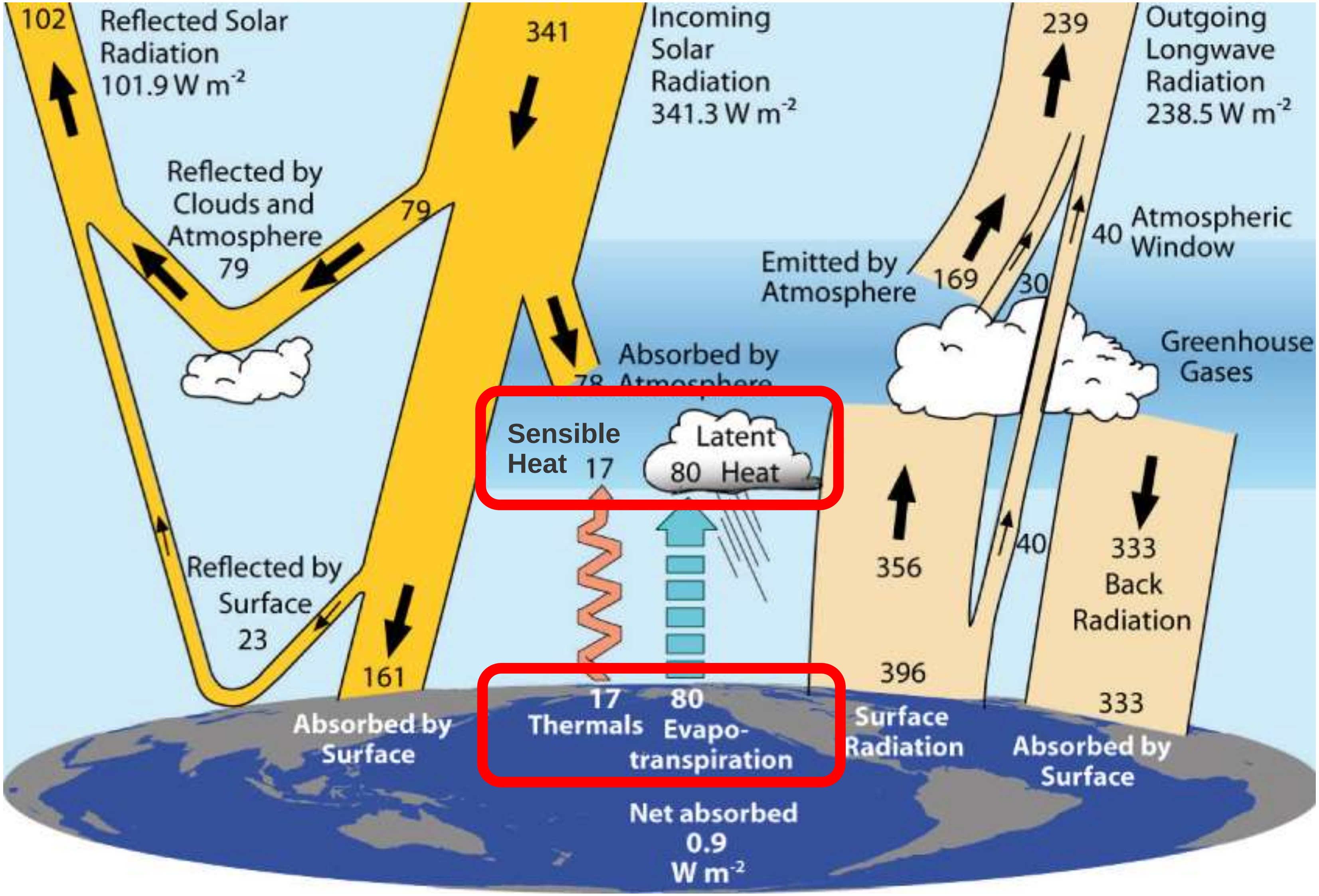
Evaporation consumes heat.



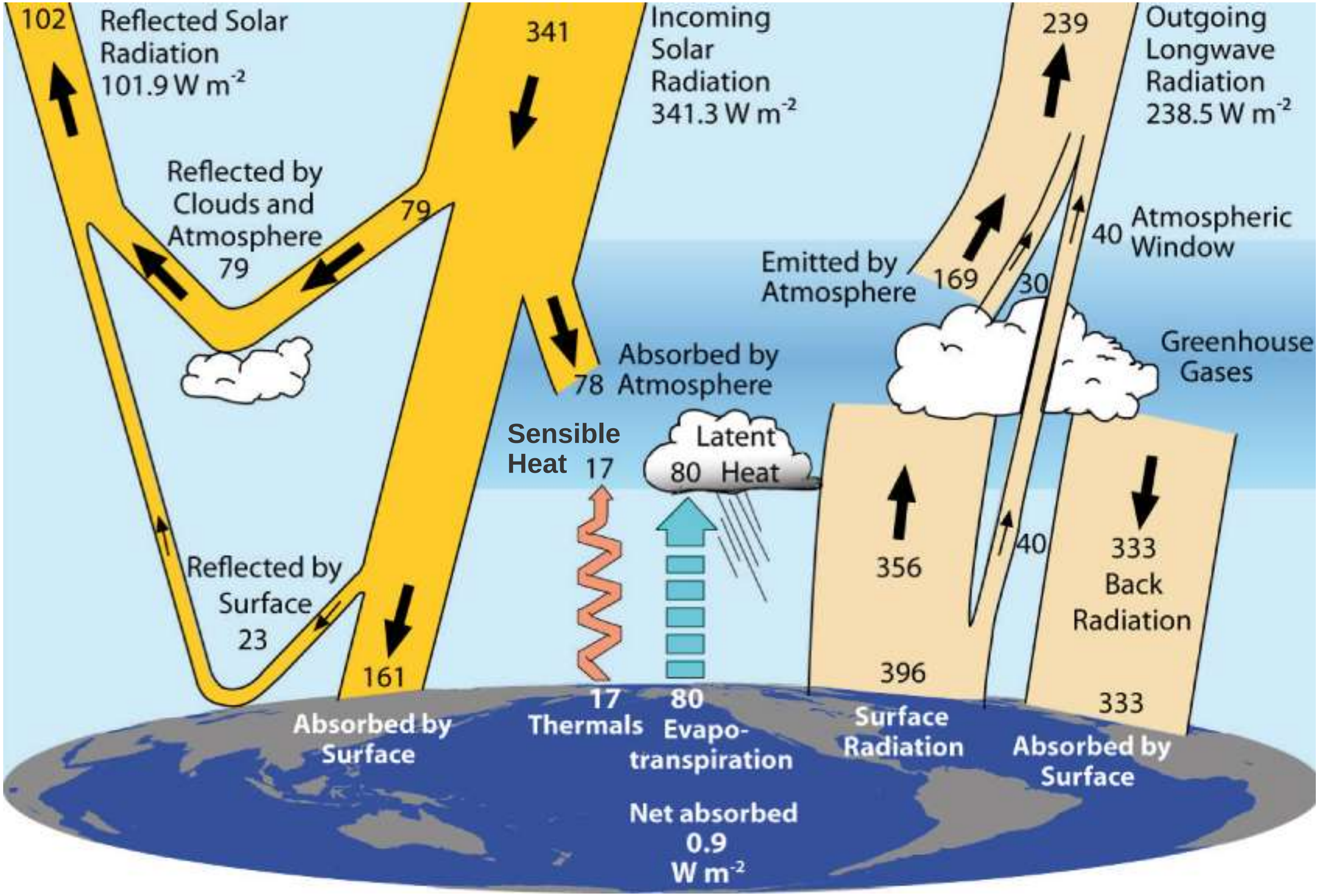
Rising air carries water vapor from the surface.

When vapor condenses and rain falls, the heat that had been used to evaporate it is released.

Sensible and latent heat fluxes transfer energy from the surface to the atmosphere



Look at the net effect of all the energy transfers



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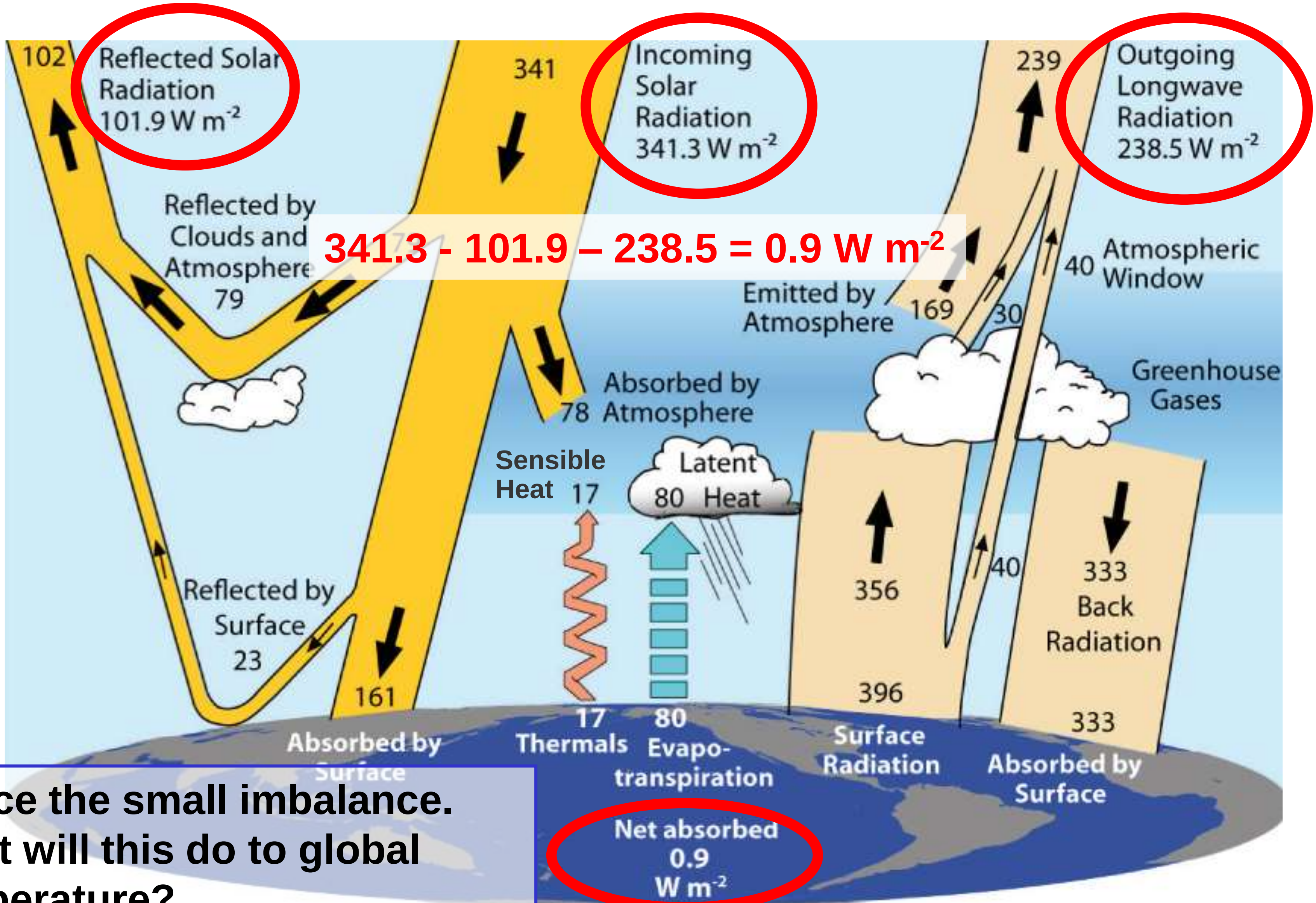

Notice the small imbalance. What will this do to global temperature?

Where does the excess 0.9 W m^{-2} go?

Start by thinking about **heat capacity.**

The heat capacity of air is about 1200 joules m^{-3} K^{-1}.

The joule (J) is a unit of energy. (One watt is an energy flow of one joule per second.) Heat is one form of energy.

In words, what does "heat capacity" mean? How would you explain this to someone with a limited knowledge of science? (Hint: Think about the units "joules m^{-3} K^{-1}".)

Where does the excess 0.9 W m^{-2} go?

Heat capacity of air is about 1200 joules m^{-3} K^{-1}

Heat capacity of water is about 4,000,000 J m^{-3} K^{-1}

Then one cubic meter of water holds about (4,000,000 / 1200) = **3300 times** as much heat as one cubic meter of air.

The **density scale height** of the atmosphere is about 8000 meters. This is how thick the atmosphere would be if its density was constant.

So: the **whole atmosphere** can hold as much heat as only (8000 m / 3300) = **2.4 m** depth of ocean.

The ability of the atmosphere to store heat is a tiny fraction compared to the oceans. So most of the excess heat will go into the oceans.

Net radiation at the surface

Some of the sun's radiation reaches the surface:

This is F_{sol}

Subtract the amount reflected from the surface:

This is αF_{sol} where α is albedo

The surface emits infrared (long wave) radiation, because it has a temperature above absolute zero:

Call this $F_{IR}\uparrow$

The atmosphere emits radiation toward the surface, because it has a temperature above absolute zero:

Call this $F_{IR}\downarrow$

Putting it all together, **net radiation Q*** is:

$$Q^* = F_{sol}(1-\alpha) + (F_{IR}\downarrow - F_{IR}\uparrow)$$