Global Warming and the Hydrological Cycle

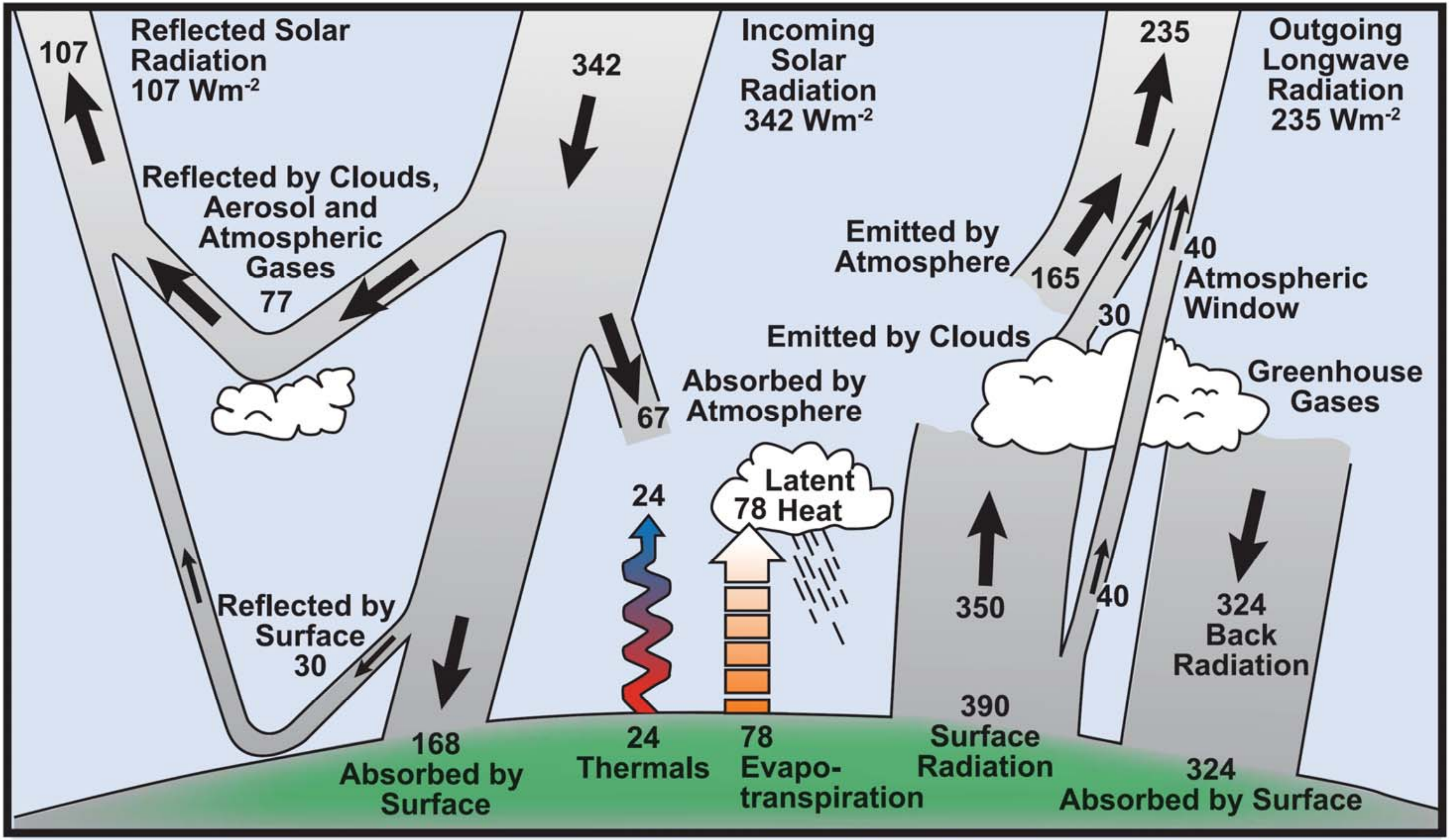
Climate Change Projections

- Wet regions will become wetter
- Dry regions will become drier
- Precipitation will occur less frequently
- Precipitation will be more intense

Why?

Concepts

- Surface energy budget
- Saturation and temperature
- Adiabatic expansion and compression
- The hydrological and energy cycle
- Effects of global warming



FAQ 1.1, Figure 1. *Estimate of the Earth's annual and global mean energy balance. Over the long term, the amount of incoming solar radiation absorbed by the Earth and atmosphere is balanced by the Earth and atmosphere releasing the same amount of outgoing longwave radiation. About half of the incoming solar radiation is absorbed by the Earth's surface. This energy is transferred to the atmosphere by warming the air in contact with the surface (thermals), by evapotranspiration and by longwave radiation that is absorbed by clouds and greenhouse gases. The atmosphere in turn radiates longwave energy back to Earth as well as out to space. Source: Kiehl and Trenberth (1997).*

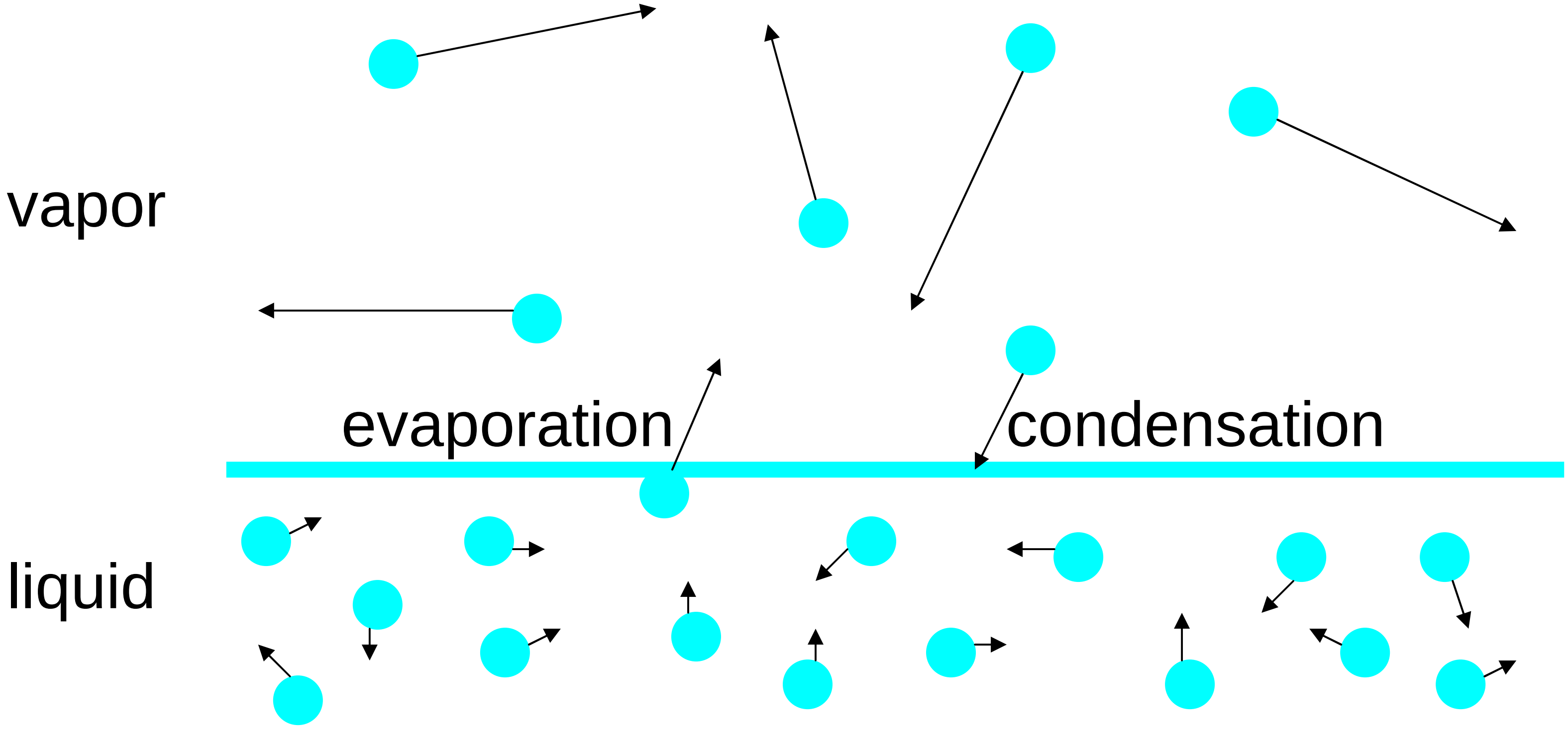
Surface Energy Budget

- Energy transfer between the surface and the atmosphere is not purely radiative
- Net (up – down) IR flux is 66 W m^{-2}
- Evaporative heat flux is 78 W m^{-2}
- A major component of energy transport in the atmosphere is via water (latent heat)
- The hydrological cycle is closely tied to the energy cycle

Latent Energy Transport

- Energy is required to convert liquid water to vapor
- When liquid water evaporates, the surface is cooled
- Water vapor rises in the atmosphere
- When water vapor condenses, the atmosphere is heated
- Precipitation falls back to the surface

Evaporation and Condensation

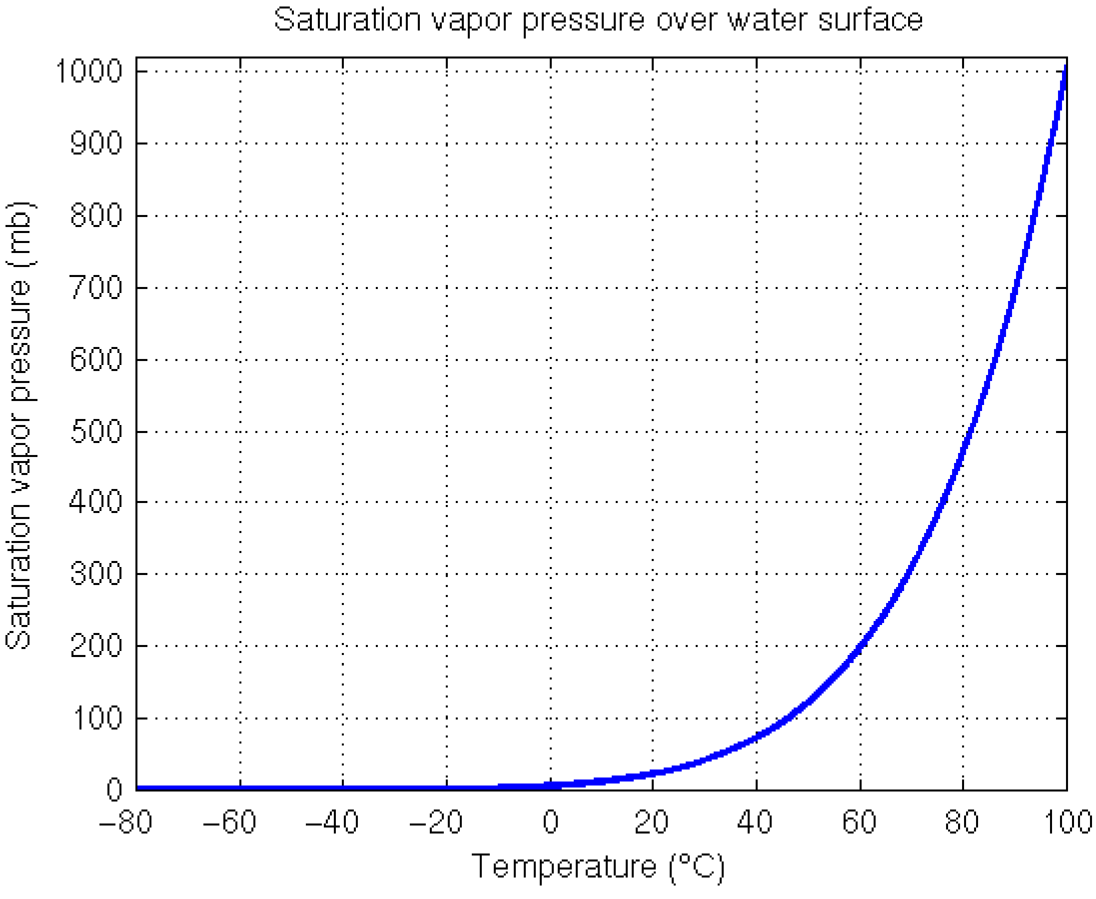


Saturation occurs when evaporation and condensation are in equilibrium

Saturation

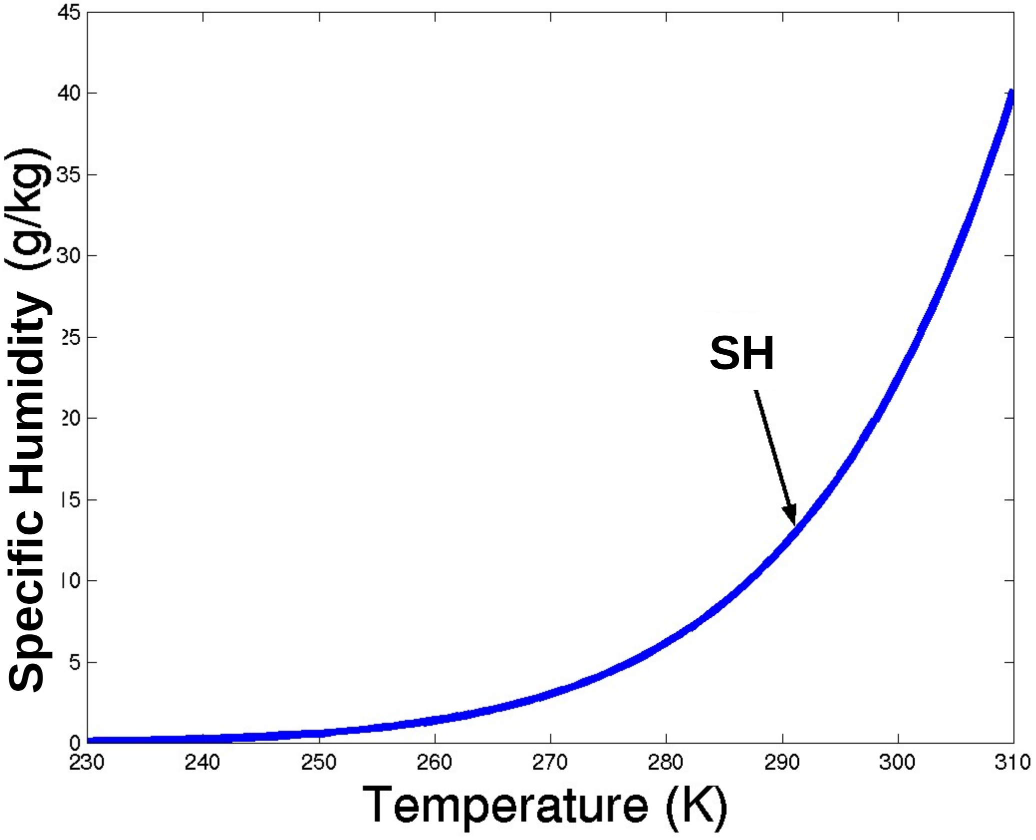
- Saturation units are vapor pressure or specific humidity (SH) (g water per kg air)
- Relative humidity (RH) is the amount of water vapor as a percentage of saturation
- RH < 100% → water evaporates
- RH > 100% → water condenses
- RH = 100% → equilibrium at saturation

Saturation and Temperature



From http://www.atmos.washington.edu/2003Q3/101/webnotes.html

Saturation and Temperature



From http://www.atmos.washington.edu/2002Q4/211/notes_water.html

Humidity and Temperature

RH = 100%, SH = 3 g/kg

RH = 15%, SH = 6 g/kg

From http://commons.wikimedia.org/wiki/Category:Snow
and http://commons.wikimedia.org/wiki/Saguaro

Adiabatic Expansion

Why does temperature usually decrease with height?

- When an air parcel rises, it goes to a level with less atmospheric pressure
- Since pressure is less, the air parcel expands
- In order to expand, it must work to push the surrounding air out of the way

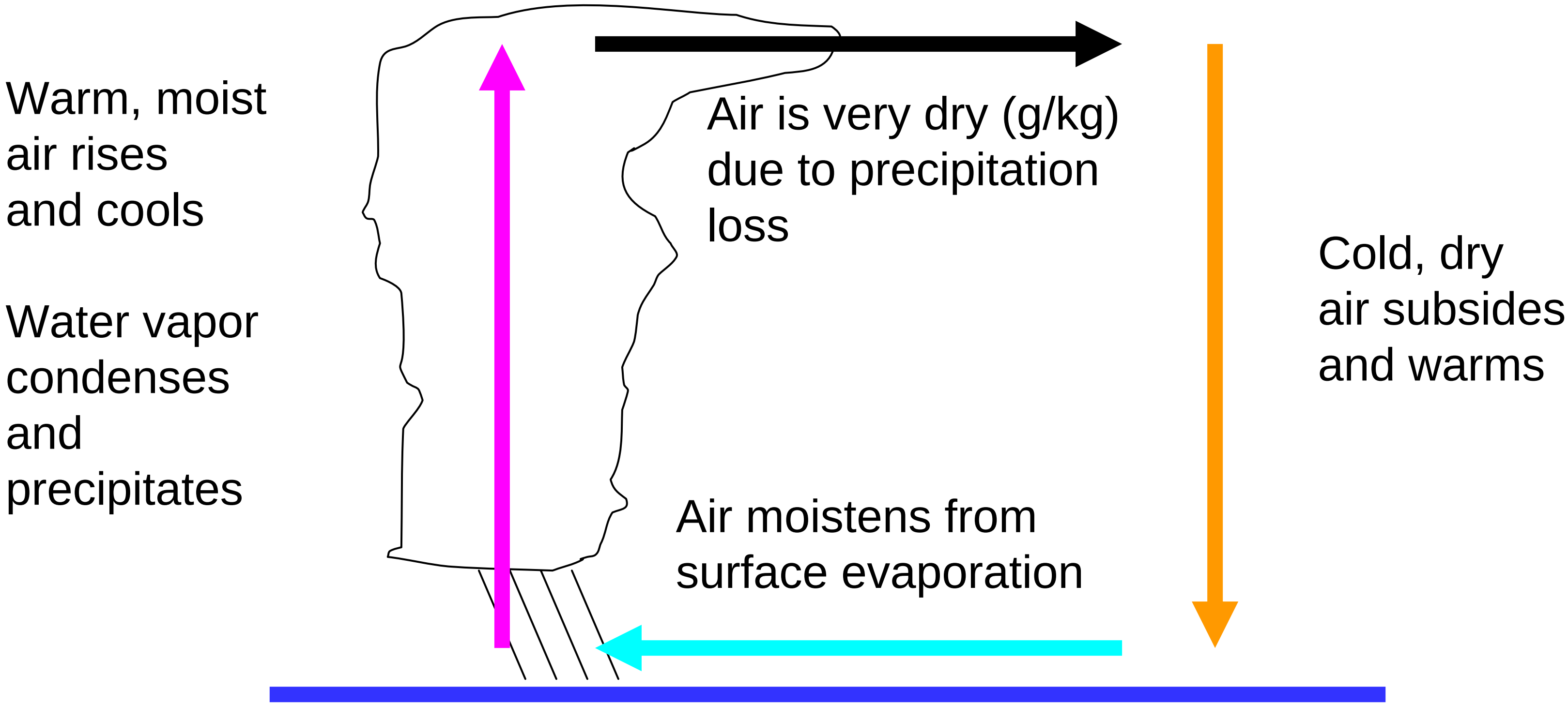
Adiabatic Expansion

- If there is no energy input into the system (adiabatic), then the energy for the work of expansion must come from internal energy
- Internal energy is energy from the motion of molecules (temperature)
- Less internal energy means the air parcel cools down

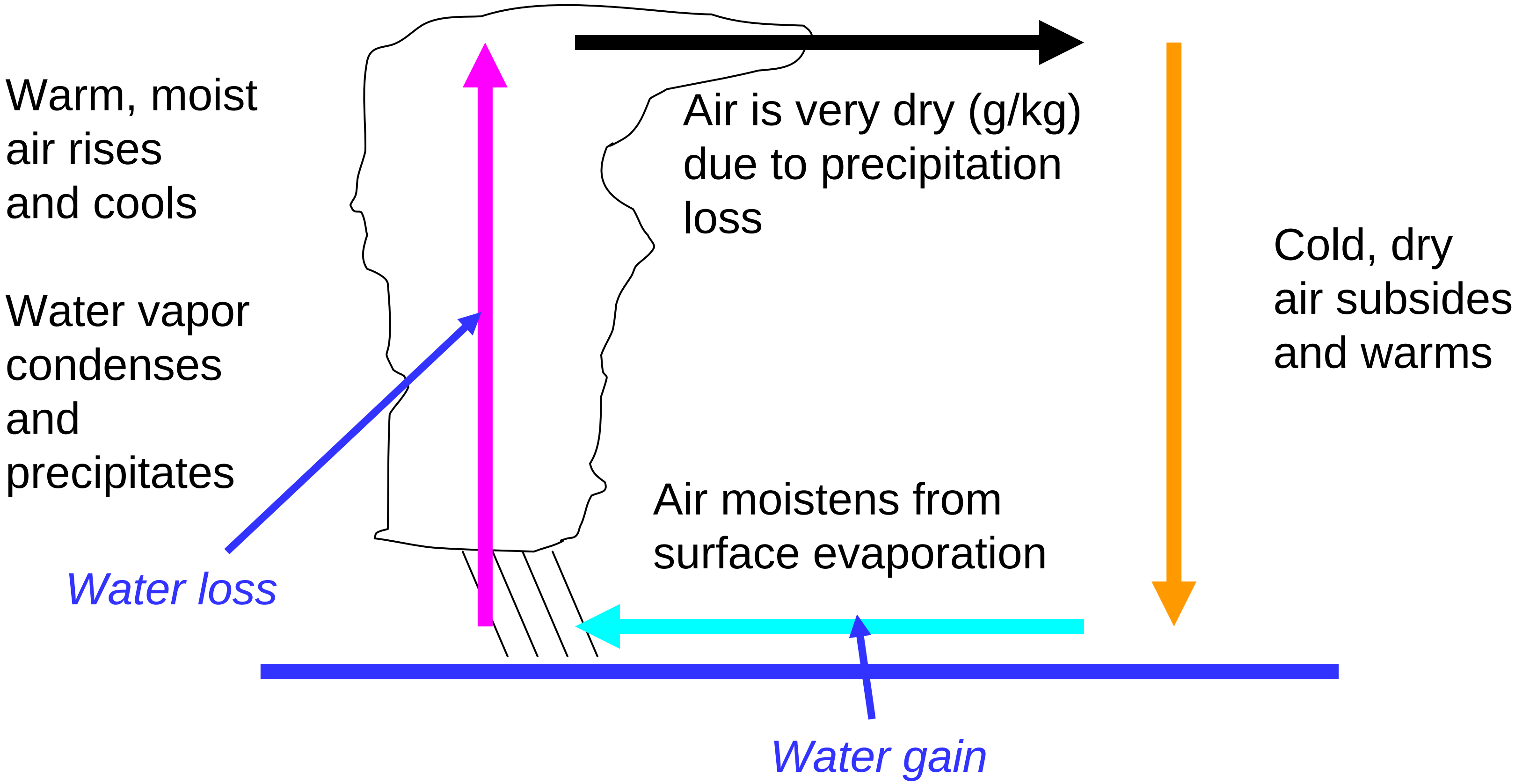
Adiabatic Compression

- When an air parcel subsides, it goes to a level with more atmospheric pressure
- Since pressure is greater, the air parcel is compressed
- Compression increases the internal energy of the air parcel
- The air parcel warms up

The Hydrological Cycle



The Hydrological Cycle



The Energy Cycle

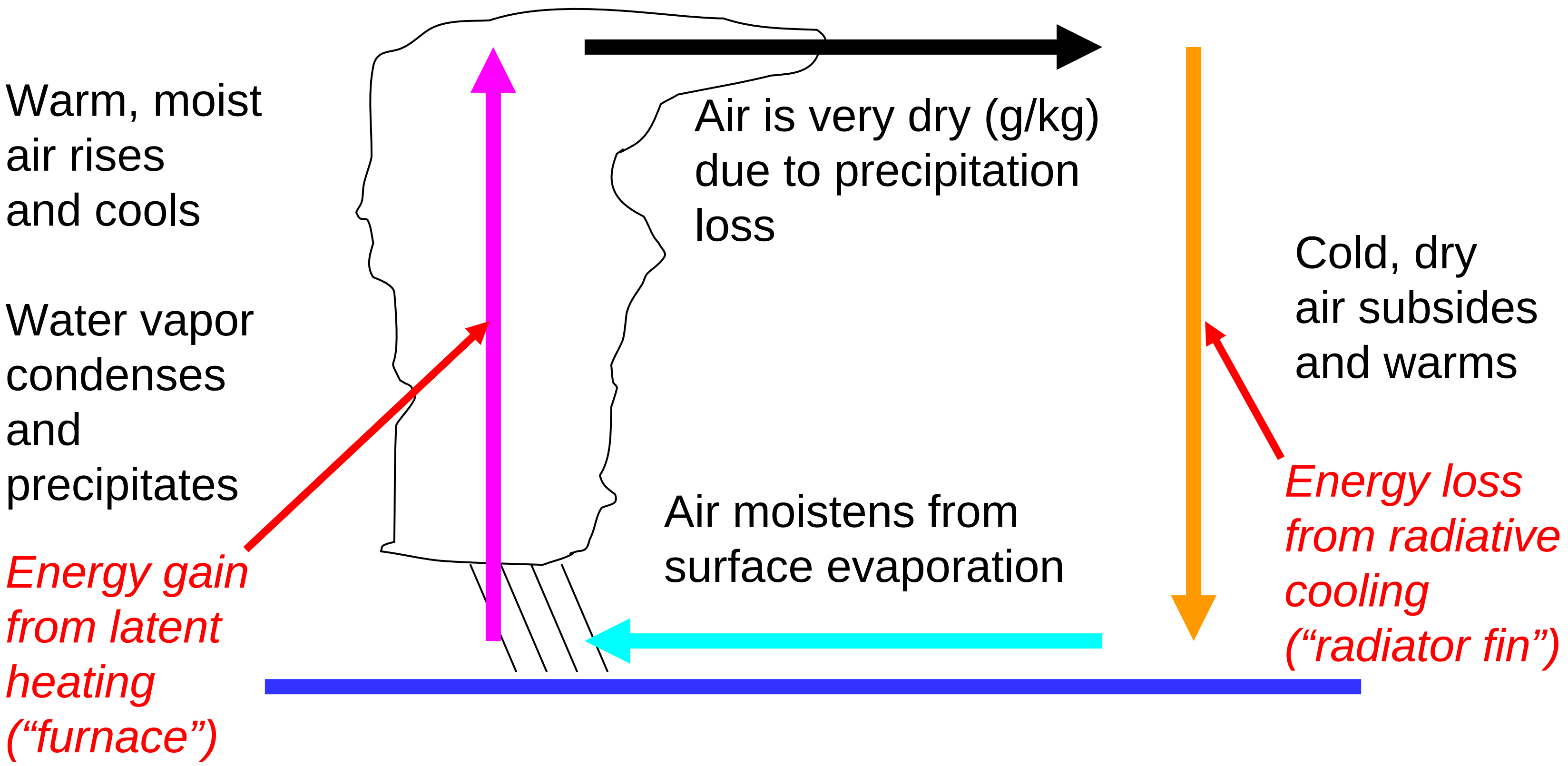
How does the rising air maintain positive buoyancy so it can continue rising?

→ latent heat from condensation

How does the subsiding air maintain negative buoyancy so it can continue sinking?

→ net radiative cooling (more emitted than absorbed)

The Hydrological Cycle



Water and Energy Balance

Approximately…

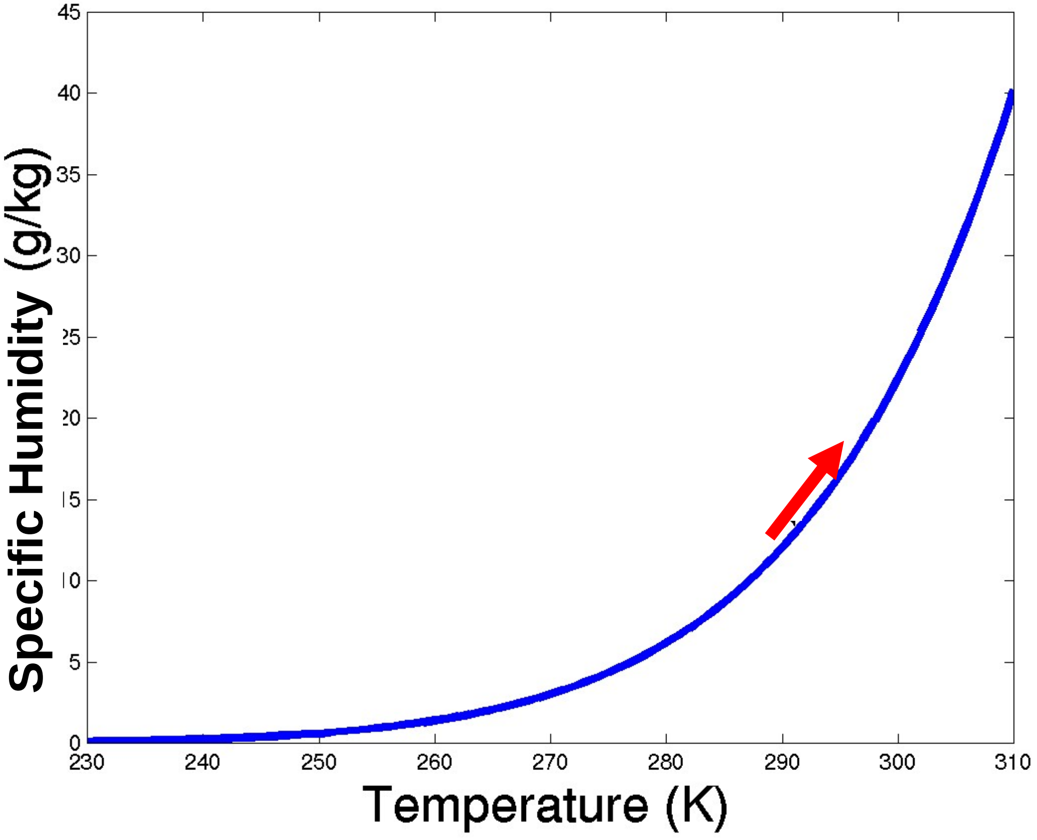
precipitation = surface evaporation

latent heating = atmos. radiative cooling

Implication…

the magnitude of radiative cooling controls the magnitude of precipitation

Global Warming and Saturation



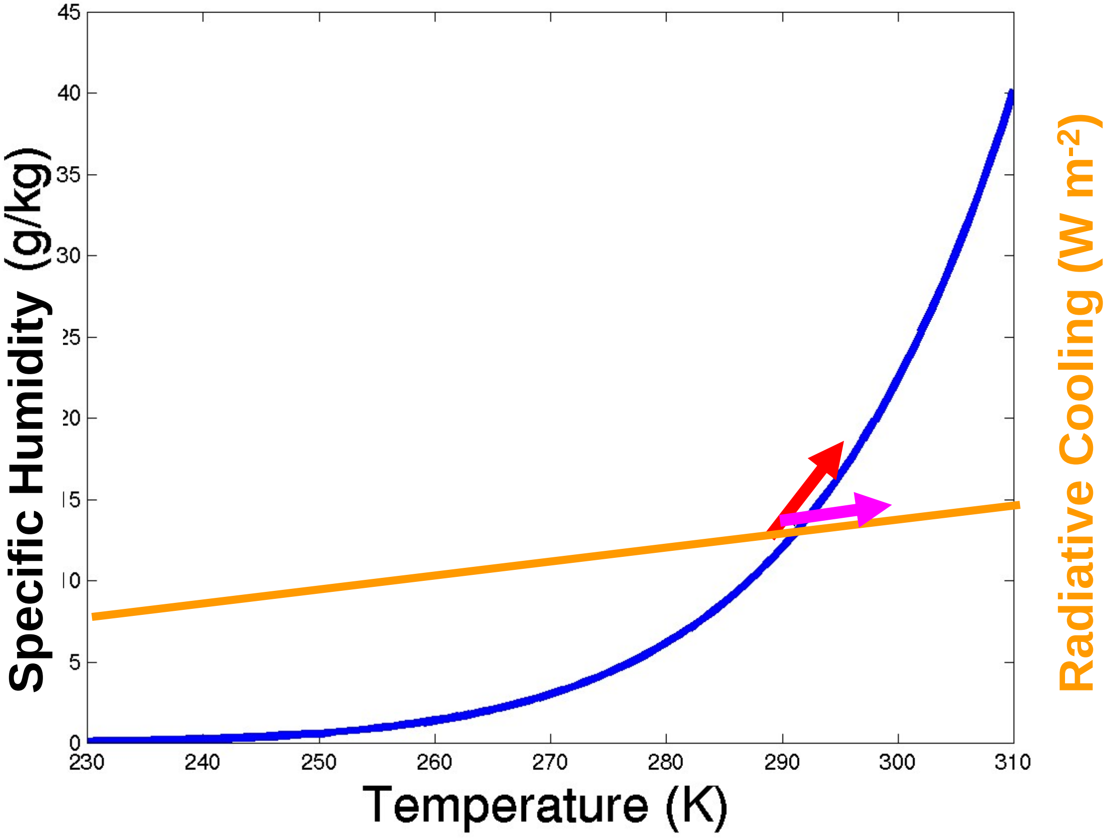
As temperature warms, saturation specific humidity *strongly* increases

More water can evaporate into the atmosphere

Global Warming and Saturation

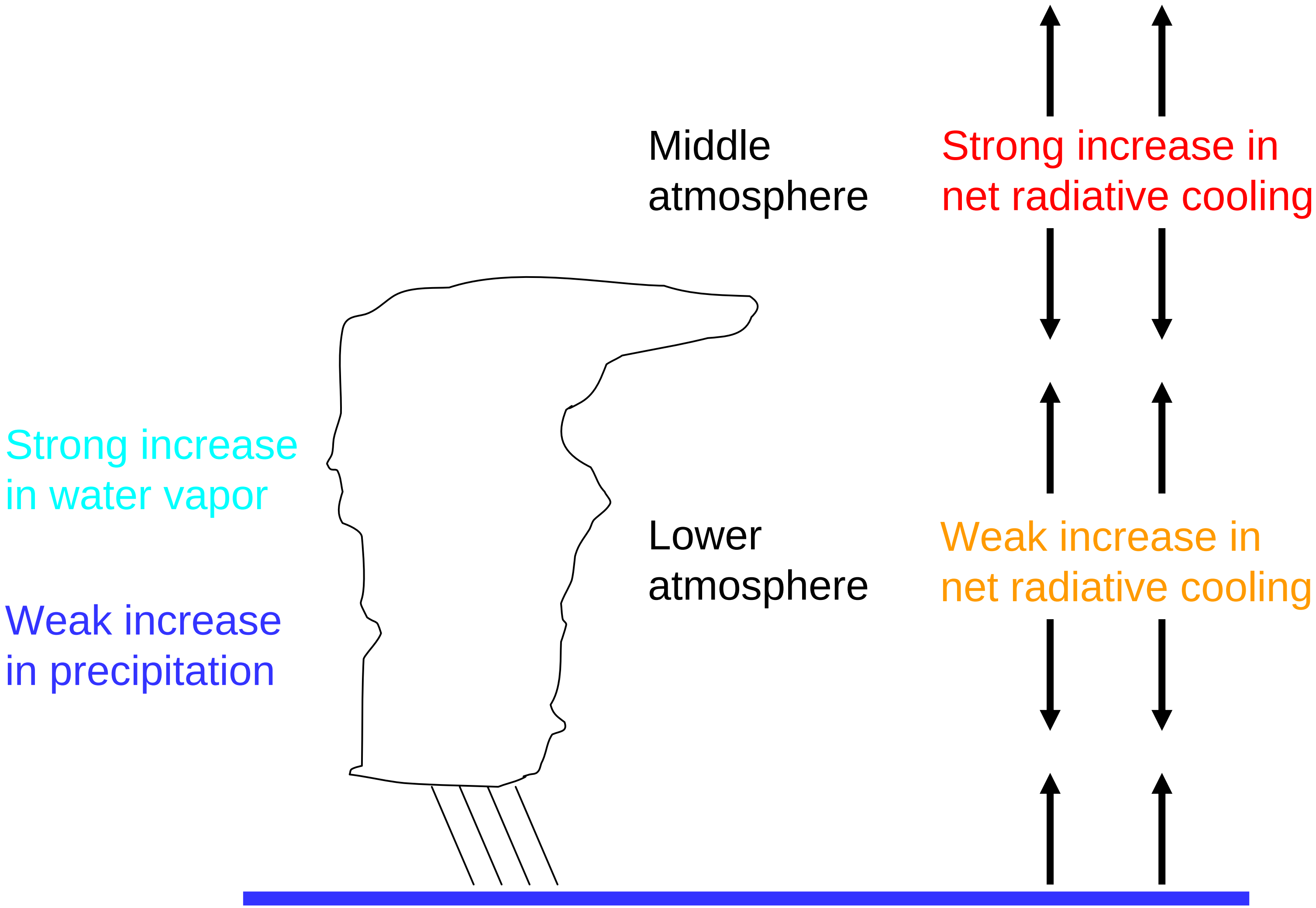
- More evaporation from dry regions means dry regions get drier
- More water vapor in the atmosphere means more condensation and precipitation in wet regions

Saturation & Radiative Cooling



As temperature warms, net radiative cooling of the lower atmosphere *weakly* increases

Global Warming Effects



Water and Energy Balance

Approximately…

latent heating = atmos. radiative cooling

Implication…

a small increase in radiative cooling means there can only be a small increase in precipitation

Global Warming & Precipitation

- Weak increase in global average precipitation
- Strong increase in water vapor available to be rained out

Implication…

Precipitation events become stronger but less frequent