

Global Climate Change

Why does an increase in CO₂ in the atmosphere lead to global warming?

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Global Climate Change

1. Heat balance on earth – greenhouse effect
2. Climate: A complicated dynamical system – positive and negative feedback loops
3. Climate models

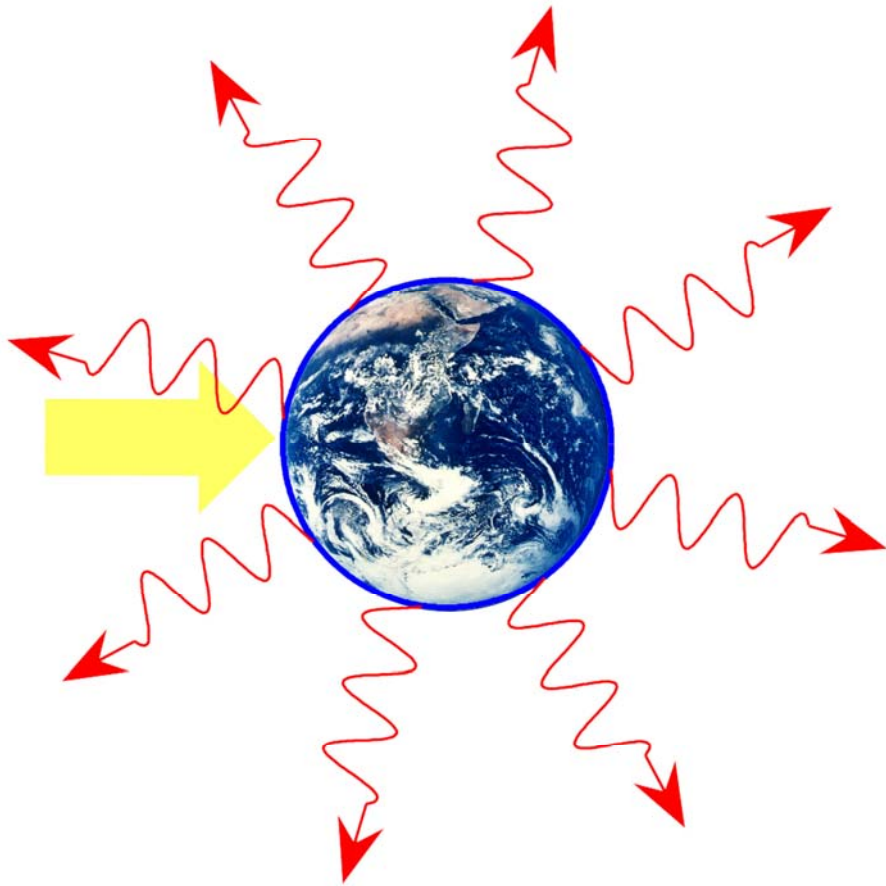
1. Heat Balance on Earth

Sunlight



- Earth absorbs light from the sun
- Sunlight
 - Mostly visible light
 - Some ultraviolet and infrared (IR) light

Heat Balance on Earth



- Earth radiates infrared light (IR) into space
- Amount of IR emitted depends on the temperature
- Energy Balance:
 - Heat absorbed = Heat radiated into space
 - $P_{in} = P_{out}$

Greenhouse Effect

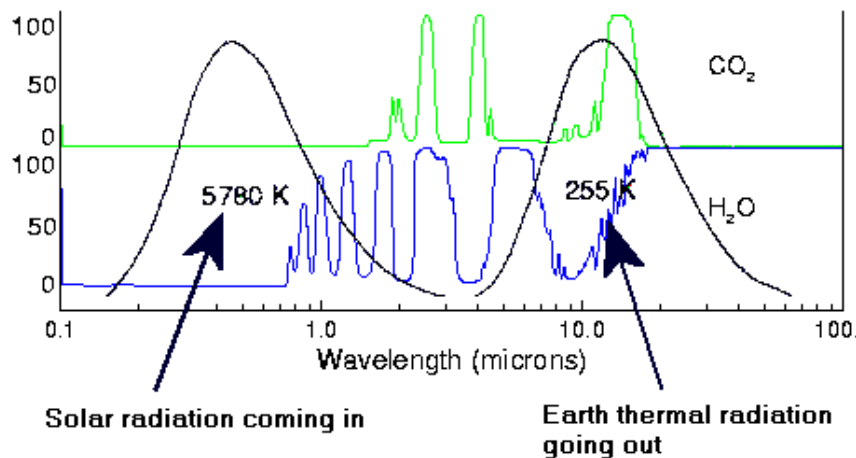


Greenhouse gases = H_2O , CO_2 , methane, CFCs, nitrous oxides, ozone (= GHGs)

- Certain gases in the atmosphere absorb IR but are transparent to visible
 - Visible transmitted
 - IR absorbed by molecules of the GHGs
- Molecules that absorb IR immediately re-emit IR
 - Emitted in random direction
 - Half the IR is emitted towards earth's surface
- Without the greenhouse effect the average temperature of earth would be ~ 60 °F lower

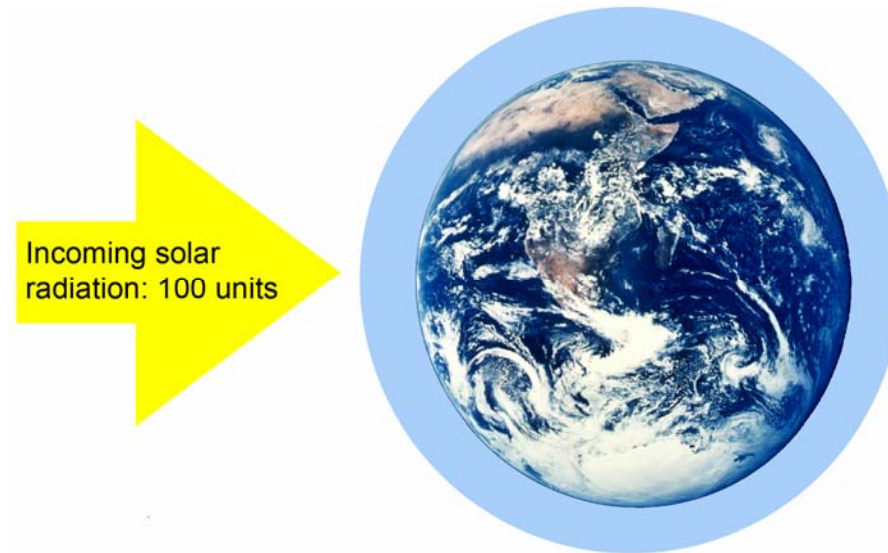
Absorption and Emission Bands

- Solar radiation in
- IR radiation out



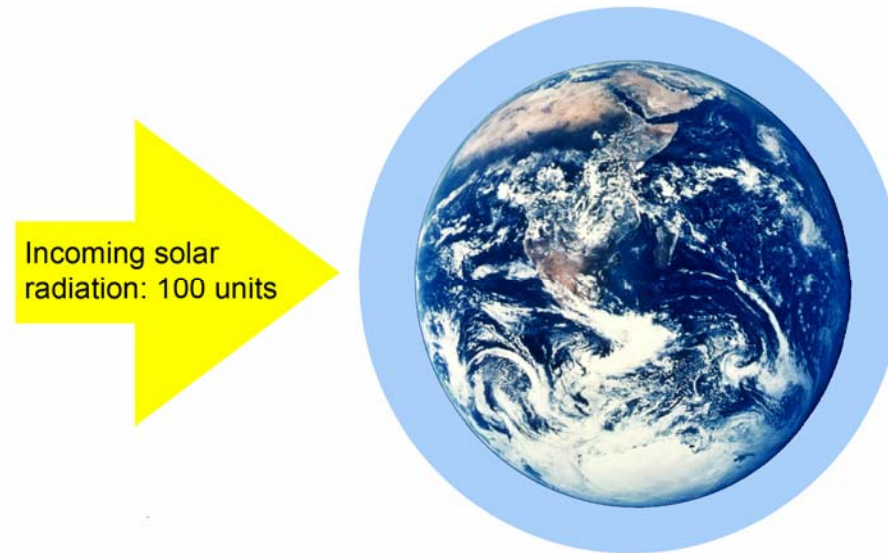
- Absorption by H₂O
- Absorption by CO₂
- CO₂ fills windows in the H₂O absorption band

Energy balance with greenhouse effect



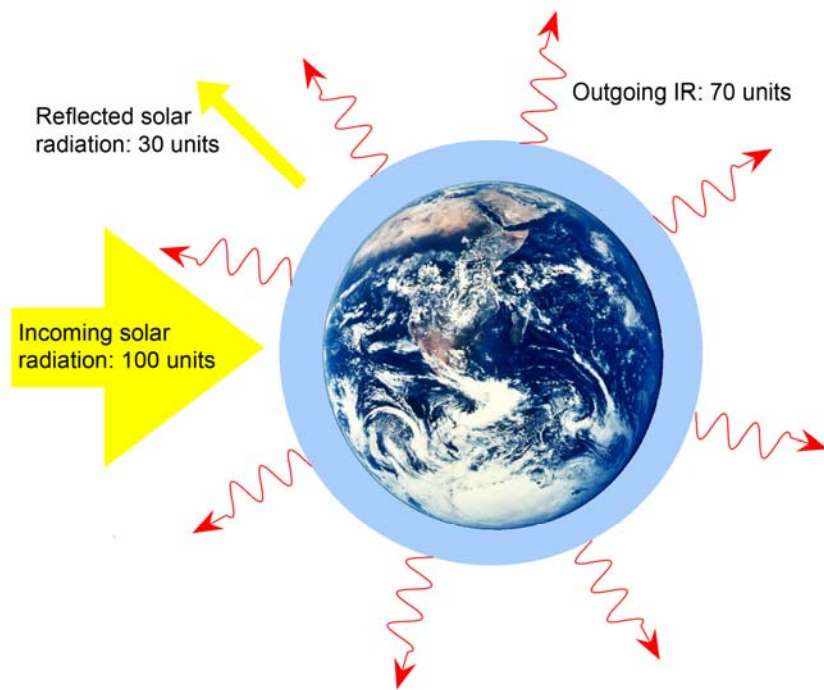
- Incoming solar radiation = 100 units
- Total absorbed by surface = 133 units
 - 45 from solar radiation
 - 88 from the greenhouse effect (IR)
- Total emitted by surface = 133 units
 - 104 IR
 - 29 non-radiative (evaporation & thermals)

Energy balance with greenhouse effect



- Total IR leaving upper atmosphere to space = 70 units
 - 66 emitted by atmosphere
 - 4 emitted by surface
- Reflected solar radiation = 30 units
 - 25 reflected by atmosphere
 - 5 reflected by surface
- Energy balance: 100 units in and 100 units out: $P_{in} = P_{out}$

Radiation of IR into Space



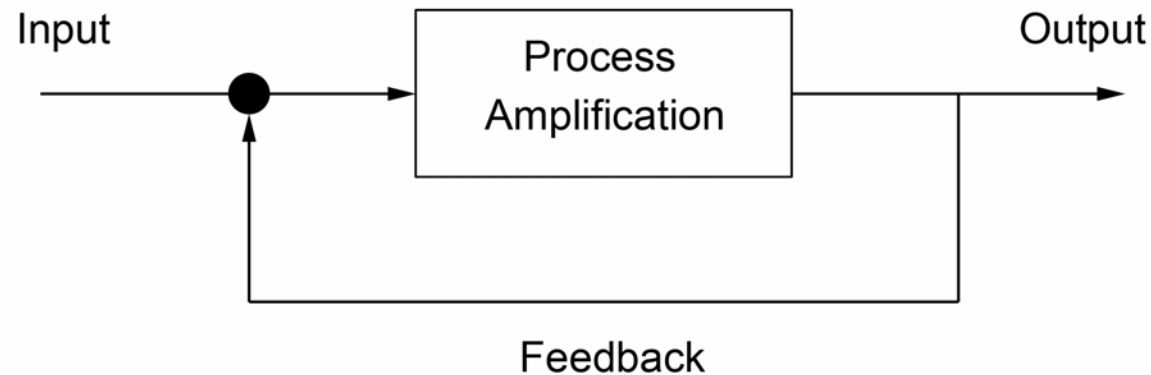
- Most of the IR earth radiates into space is radiated by the upper atmosphere (95%)
- Heat diffuses to upper atmosphere by IR scattering (absorption and emission)
- More GHGs, slower rate of diffusion

Enhanced Greenhouse Effect



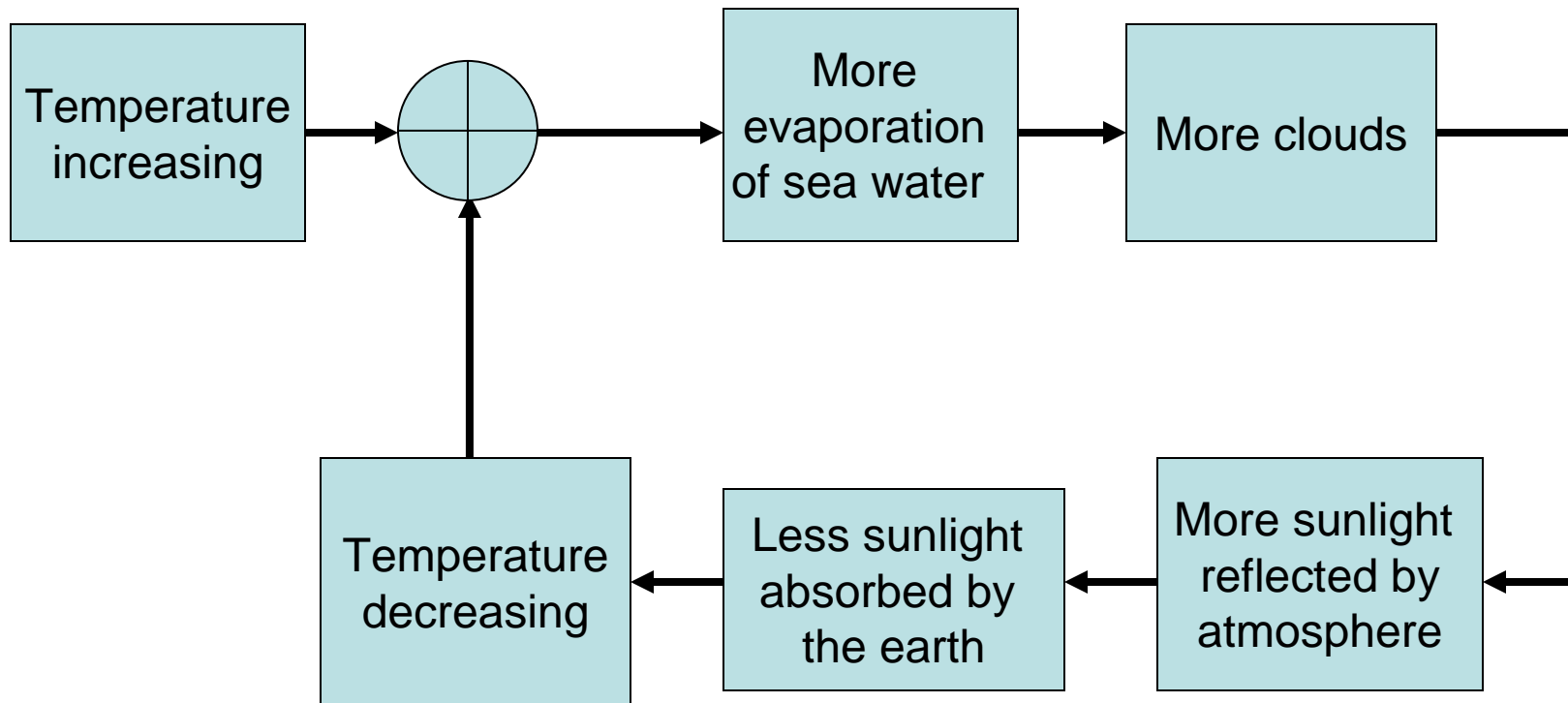
- The concentration of GHGs (CO_2) in the atmosphere has been increasing
- Slows the flow of heat from the earth's surface to upper atmosphere
- $P_{\text{out}} < P_{\text{in}}$: temperature increases
- Radiative forcing
- Global warming

2. Global Warming – Feedback Loops



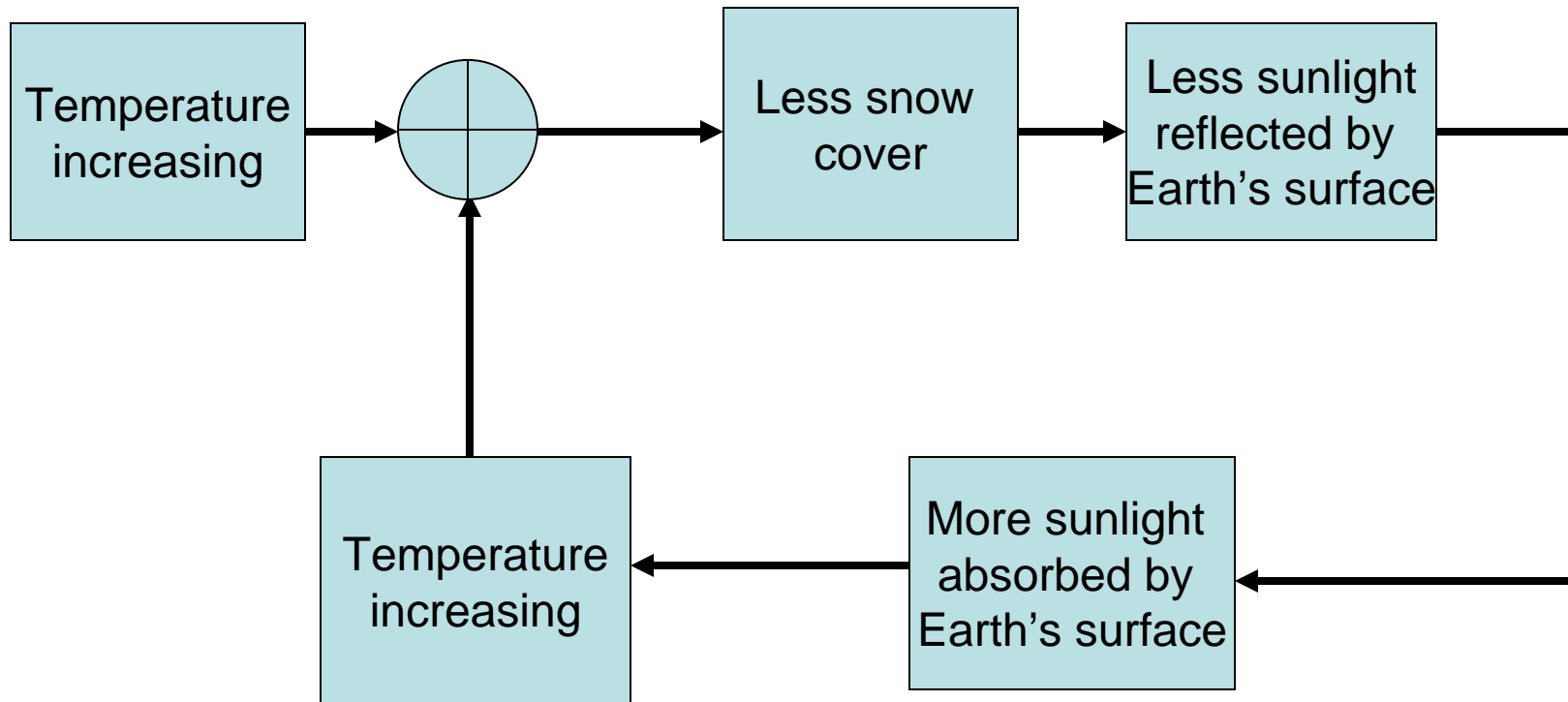
- Output modifies the input
- Positive feedback: increases input – runaway process
- Negative feedback: decreases input – controlled process
- The climate involves many positive and negative feedback loops

Negative Feedback Loop



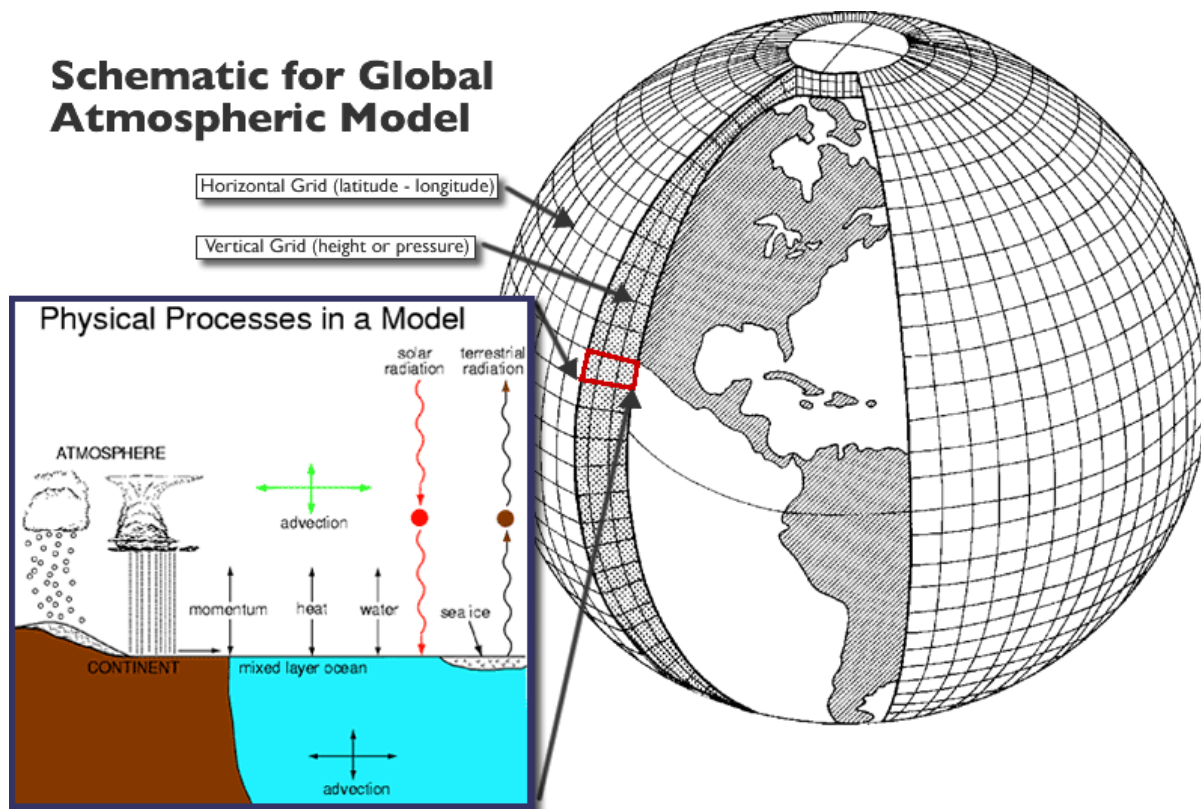
This effect of increasing temperature mitigates temperature rise.

Positive Feedback Loop



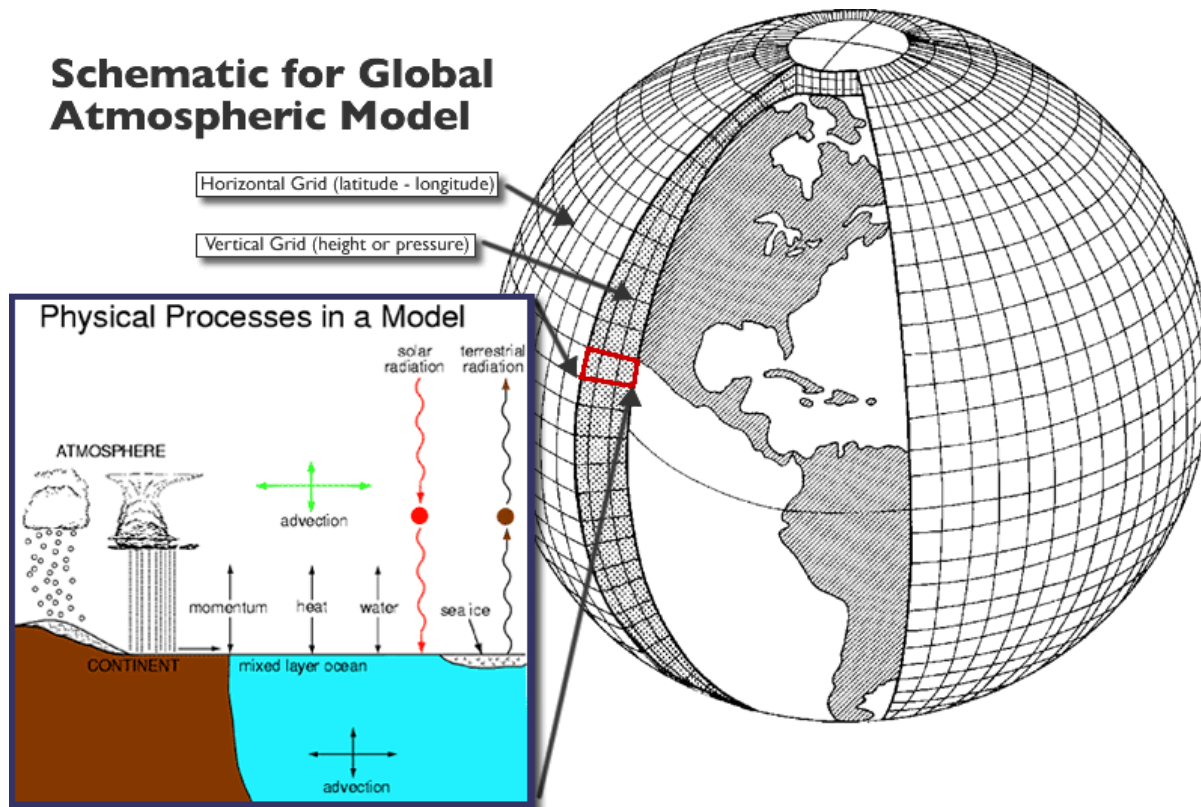
This effect of increasing temperature enhances temperature rise.

3. Climate Models



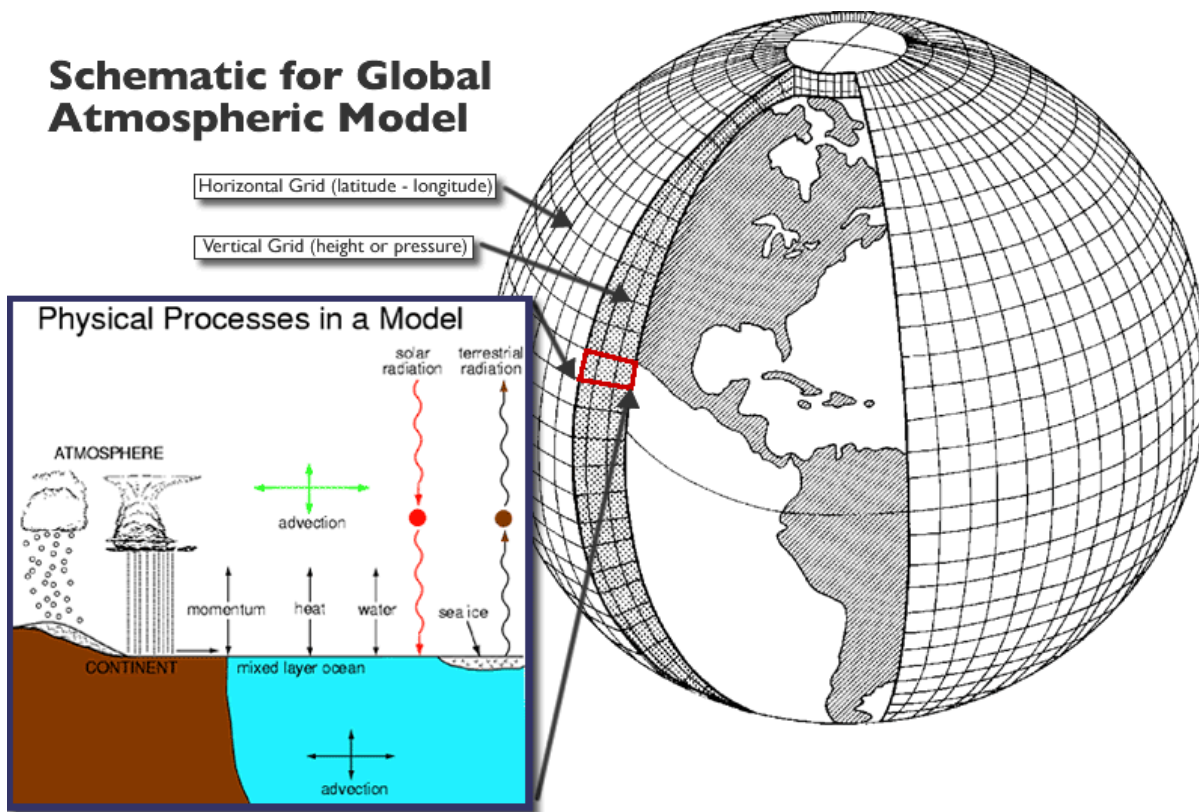
- Atmosphere / oceans divided into a 3-d grid
- At each grid point laws of physics applied
- Interactions with neighboring grid points
- Computers

Physical Processes



- Motion of air / water
- Heat transfer
- Radiation
- Moisture content
- Surface hydrology
- Chemistry
- Droplet nucleation

Accuracy



- Number of grid points
- Include all relevant processes
- How well processes are modeled

Summary

- Climate is a very complicated dynamical system.
- Increased concentration of greenhouse gases slows diffusion of heat from surface to upper atmosphere, warming the atmosphere, reduces P_{out} .
- Feedback loops can enhance or mitigate global warming.
- Climate models use laws of physics at a basic level.