



The Science of Global Warming

Global Warming can be understood qualitatively using the two concepts:

- Energy Balance
- Feedback Loops

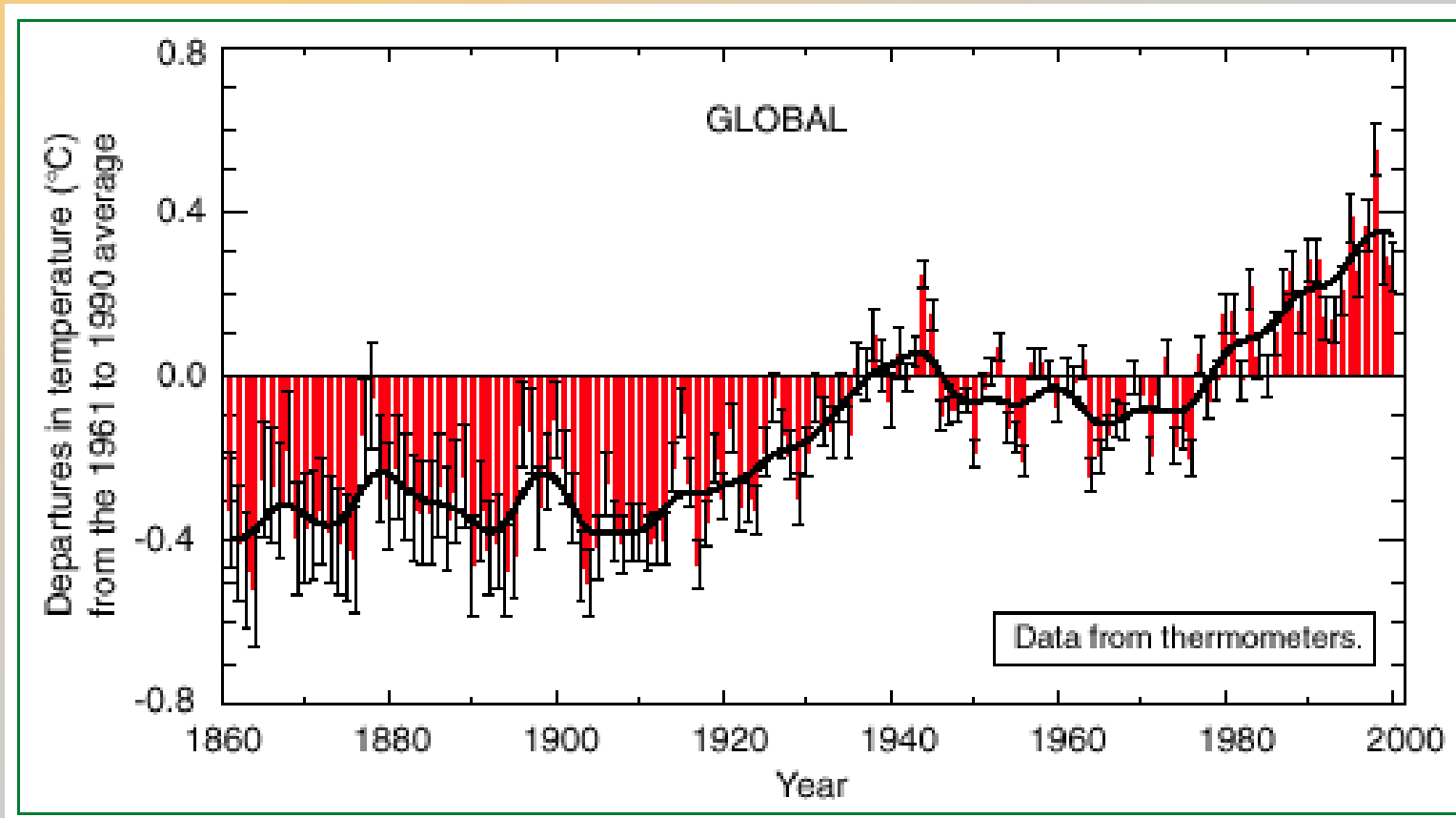
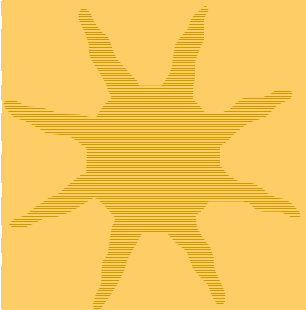
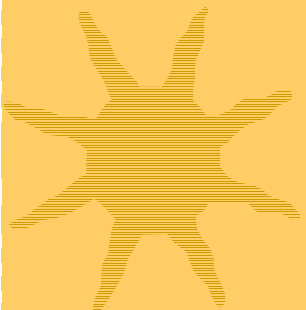
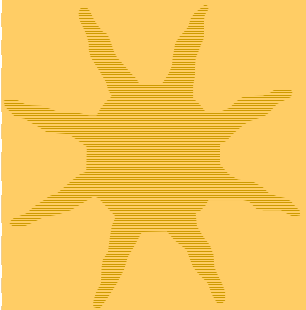
Two important Definitions

Greenhouse effect : natural, beneficial consequence of an atmosphere

Global warming : our (possible) enhancement of the greenhouse effect



Observed Temperature Changes

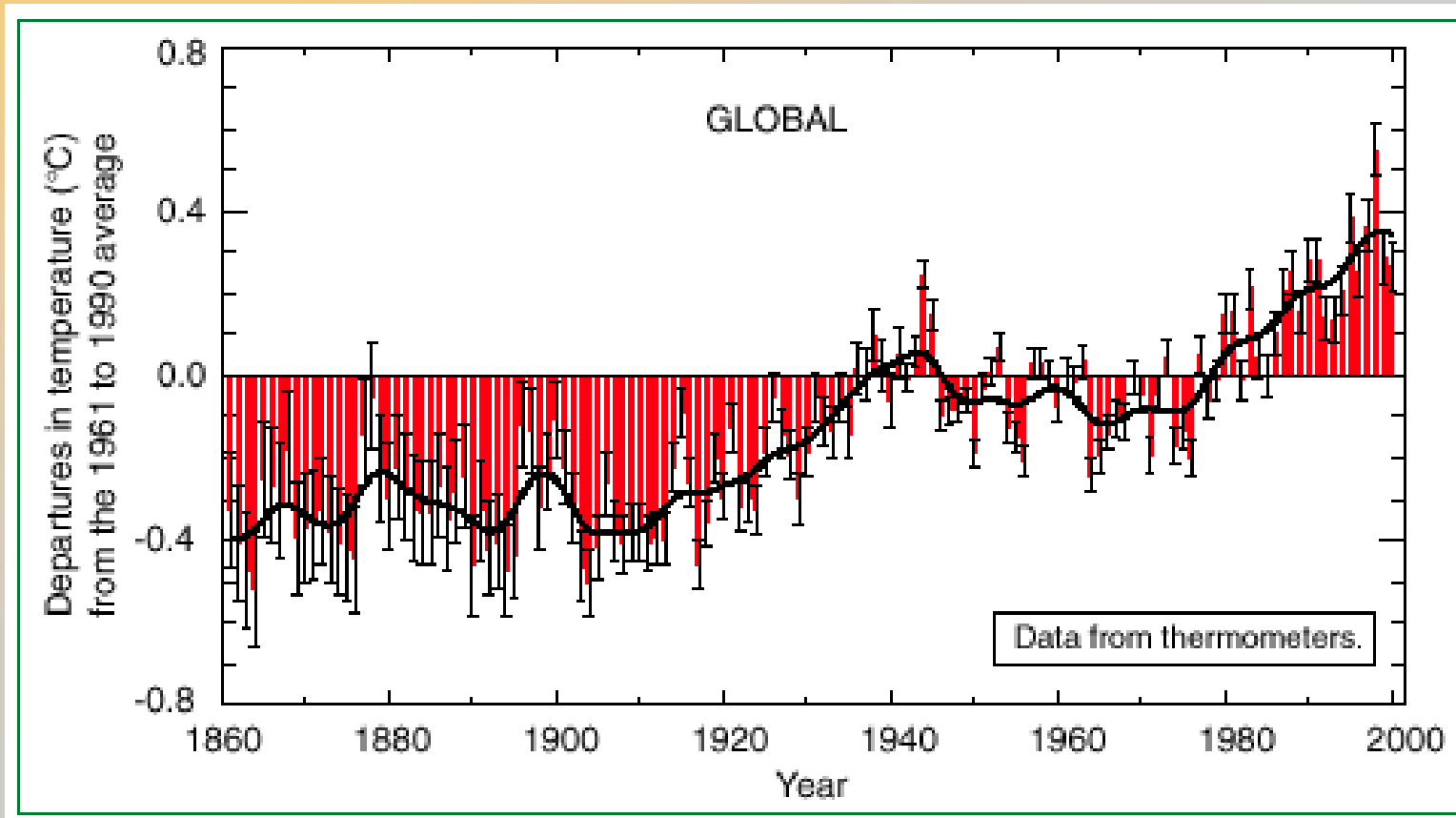


(IPCC, 2001)

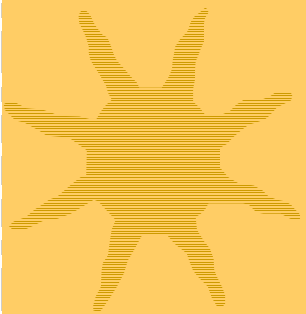
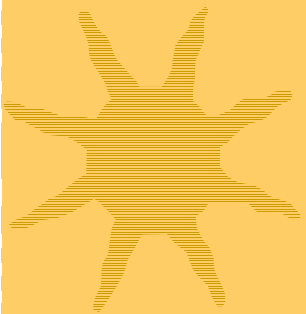
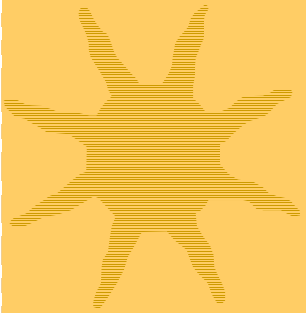


Observed Temperature Changes

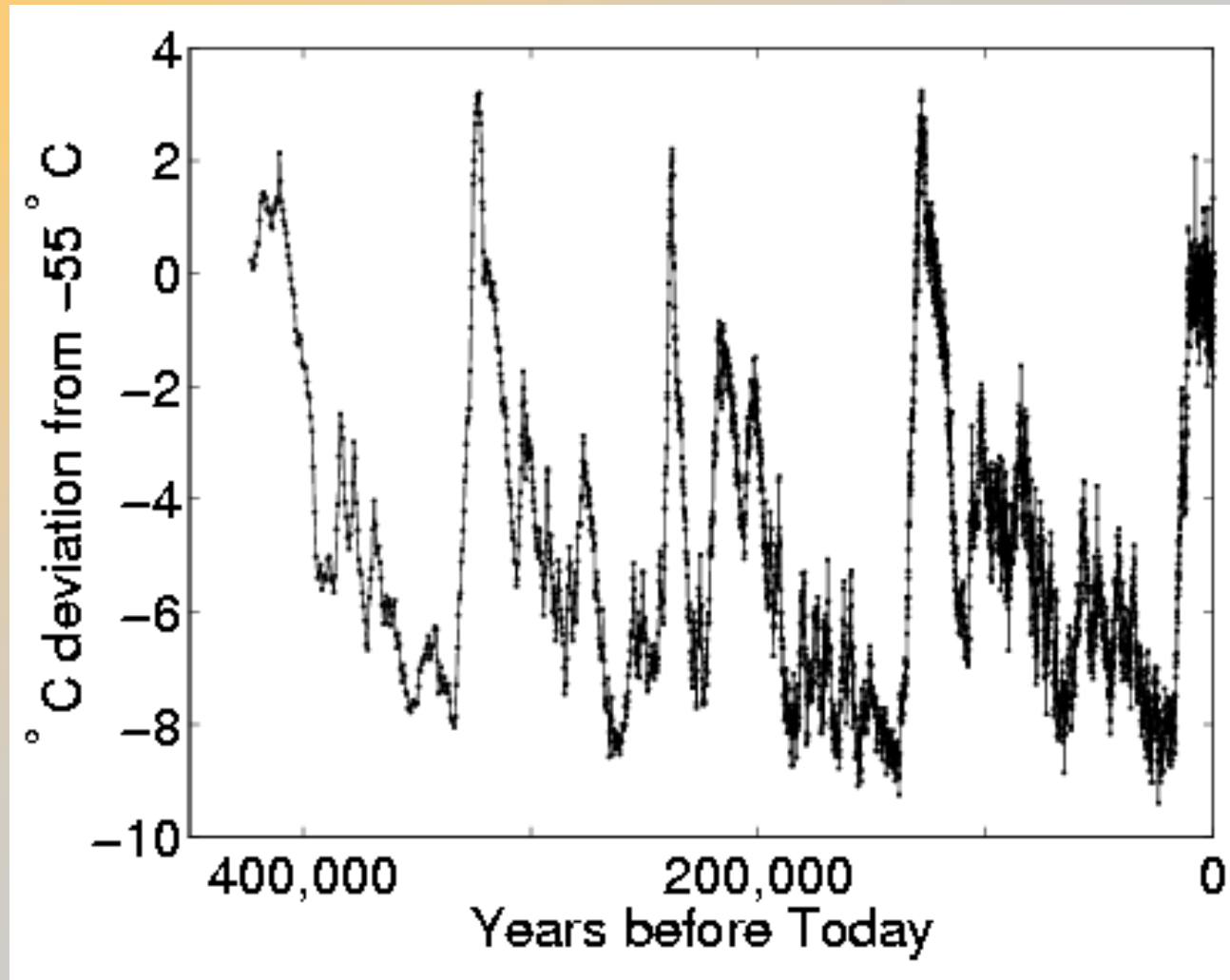
1 degree in 150 years. Is that a lot?



(IPCC, 2001)



Long-Term Observed Temperature Changes

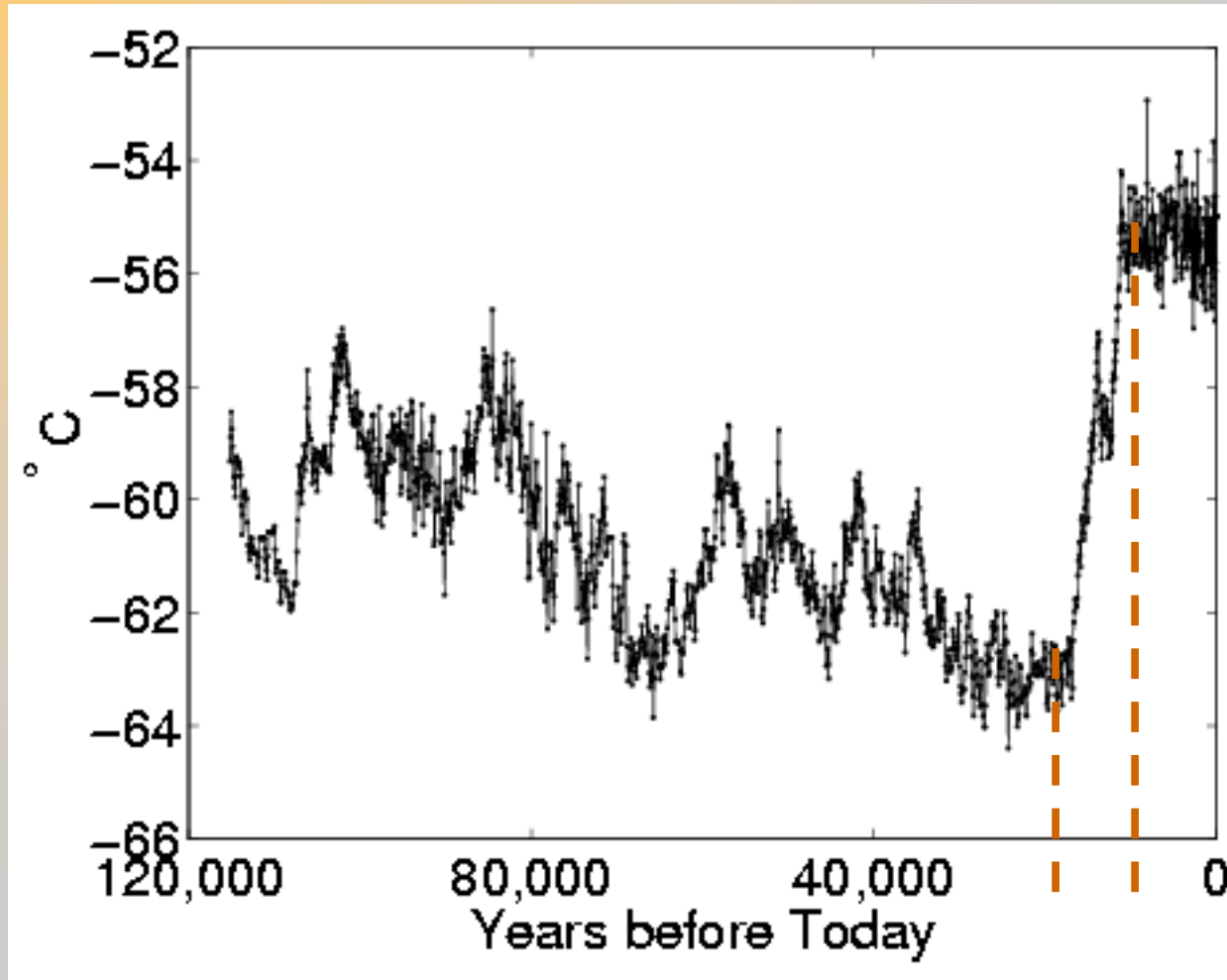


(Vostok IceCoreData, Petit et al. 1997)



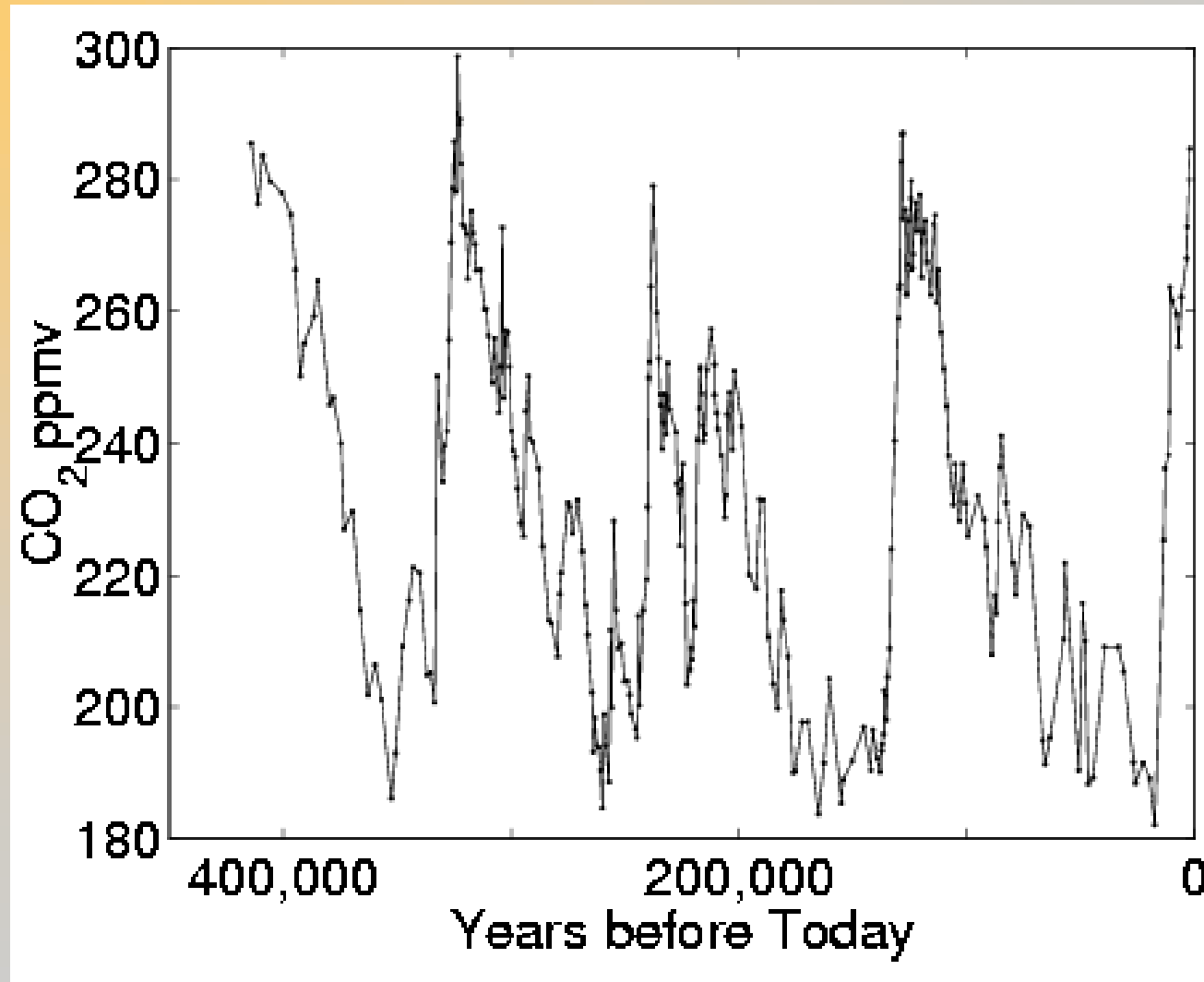
Rate of Temperature Change

- $7\text{ }^{\circ}\text{C}$ per 10,000 years = $0.1\text{ }^{\circ}\text{C}$ in 150 years
- About $7\text{ }^{\circ}\text{C}$ difference between now and an ice age



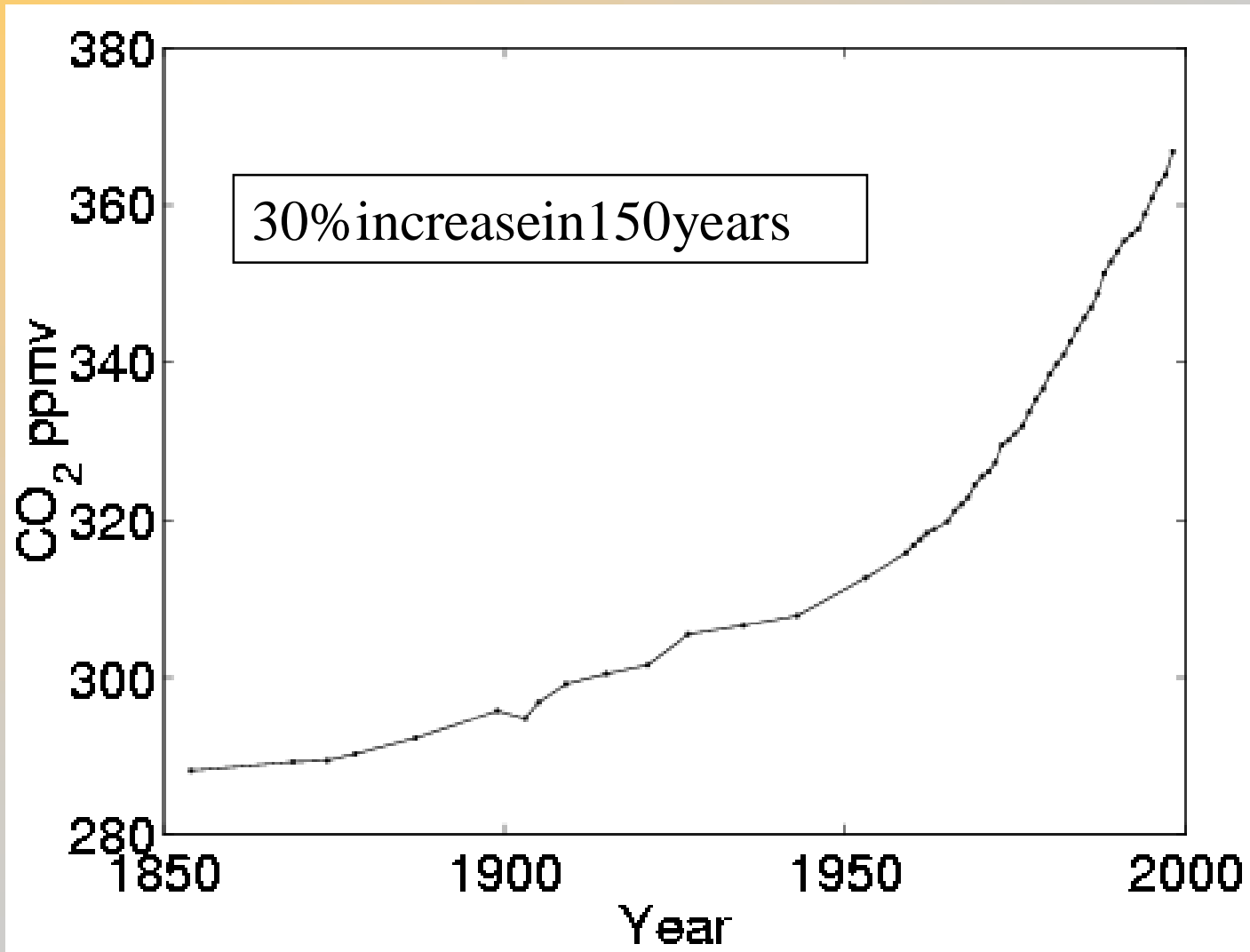


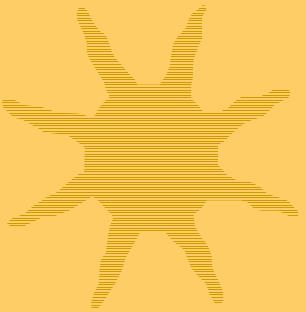
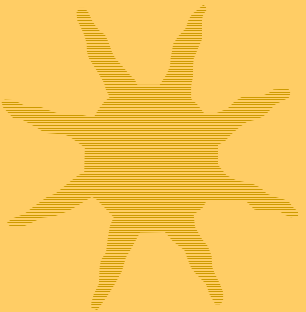
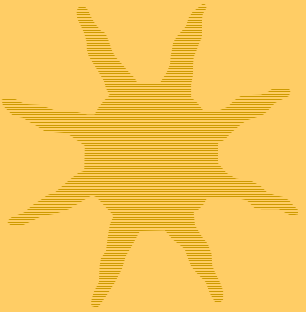
Long-term Levels of CO₂ 2





Long-term Levels of CO₂ ₂





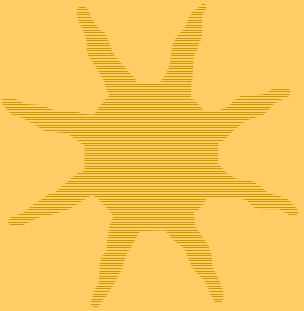
Models

- A Model is a Representation of Reality
 - Simple enough to gain understanding
 - Include the necessary complexities

- Introduce a Simple Model of Energy Balance
- Understand the Vocabulary
- Point out some of the Challenges and Accomplishments
- Possible Consequences

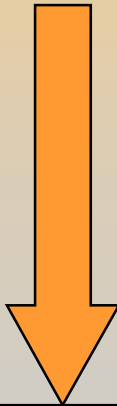


Greenhouse Effect 101: Energy from the Sun

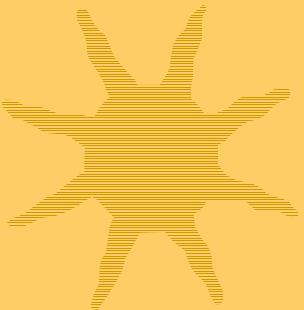


100 units of energy
input from the Sun

(arbitrary energy units)

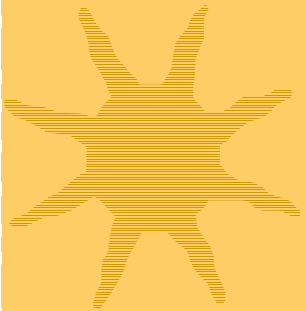
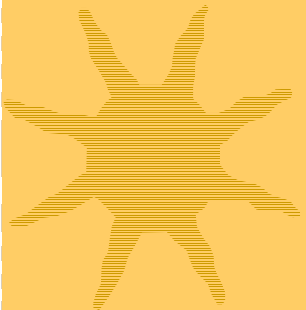
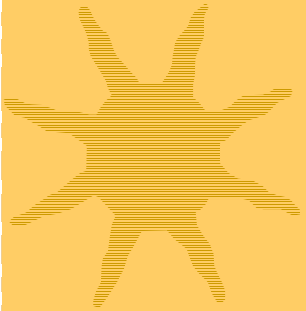


Temperature increases

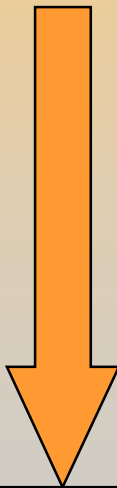




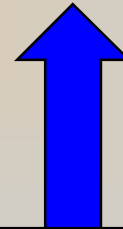
Greenhouse Effect 101: The Surface Warms



100 units of energy
input from the Sun



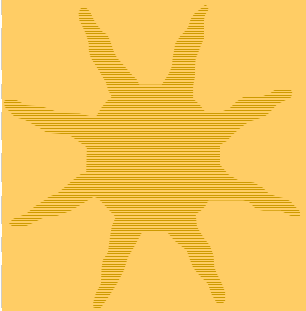
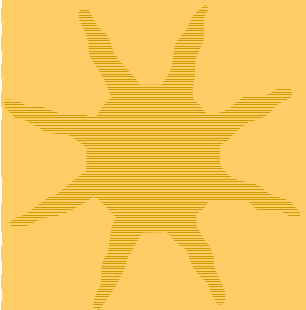
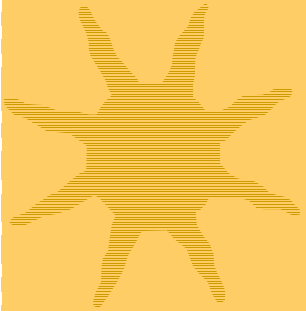
30 units of energy
output from the Earth



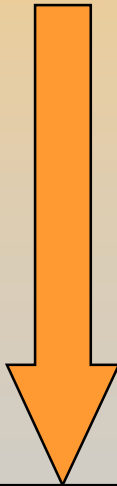
Temperature: -67°C



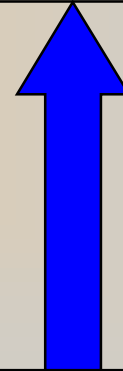
Greenhouse Effect 101: The Surface Warms



100 units of energy
input from the Sun



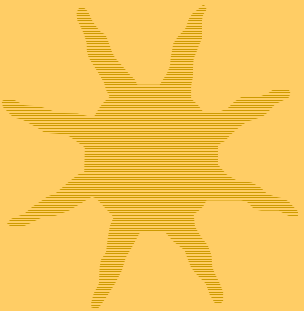
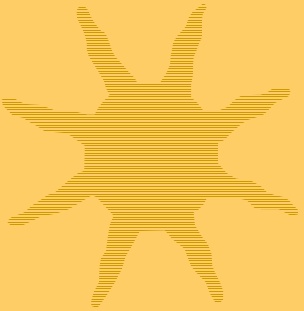
70 units of energy
output from the Earth



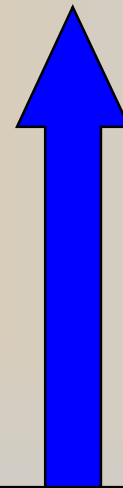
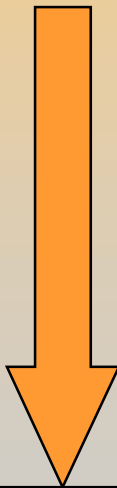
Temperature: $-19\text{ }^{\circ}\text{C}$



Greenhouse Effect 101: A Balance is Achieved



100 units of energy input from the Sun = 100 units of energy output from the Earth



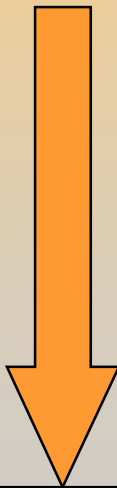
Temperature: 5.3 °C



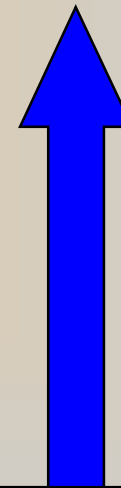
Greenhouse Effect 101: A Balance is Achieved

- Temperature increases until a balance is achieved

100



100

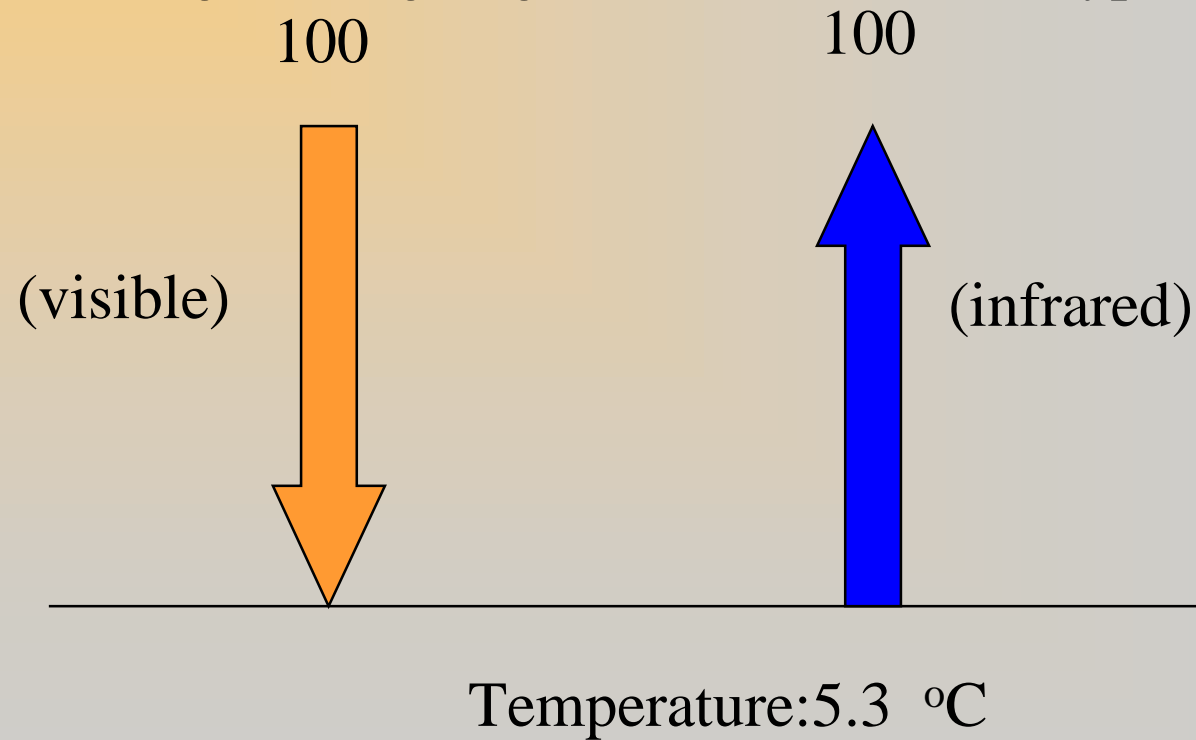


Temperature: 5.3 °C



Greenhouse Effect 101: Types of Radiation

- Temperature increases until a balance is achieved
- Incoming and outgoing radiation not the same type

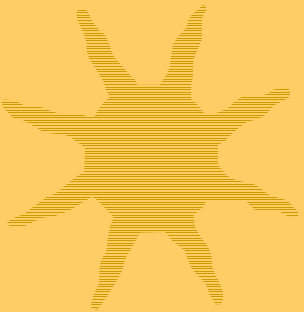
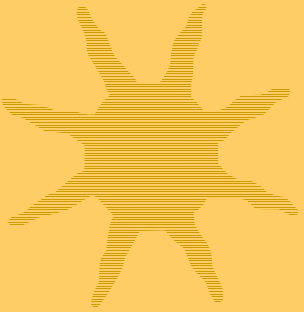




Greenhouse Effect 101: Effect of an Atmosphere

The atmosphere has a number of effects:

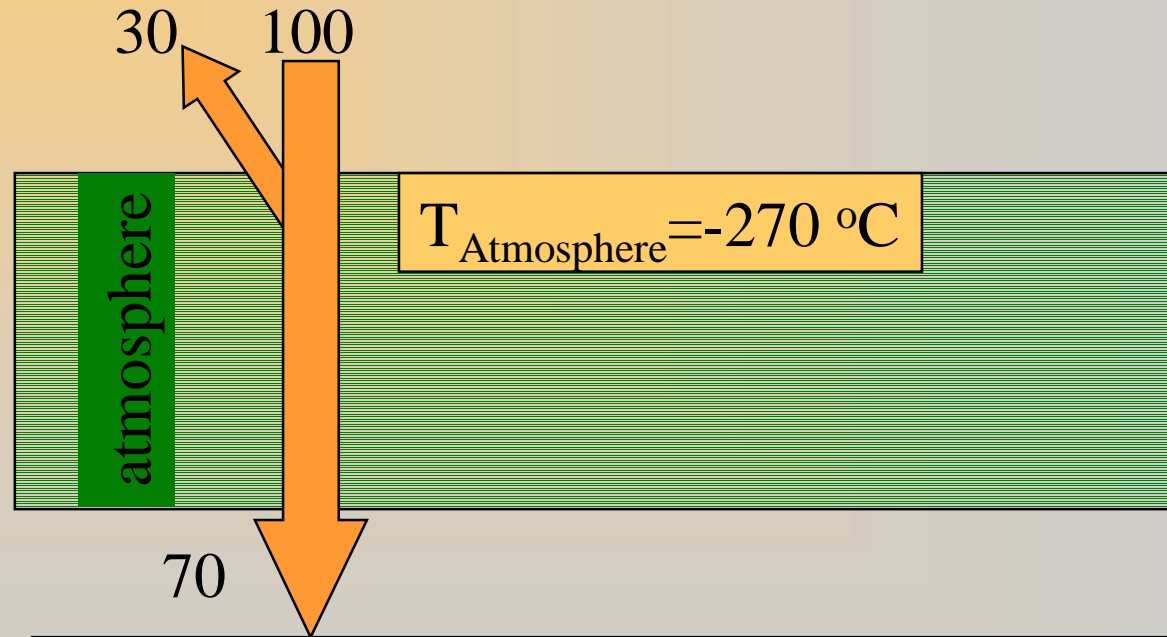
- 30 percent reflection of incoming radiation
- Nearly transparent to visible
- “Greenhouse gases” absorb infrared light which warms the atmosphere
 - Carbon dioxide (CO_2)
 - Water vapor (H_2O)
 - Methane (CH_4)





Greenhouse Effect 101: Reflection

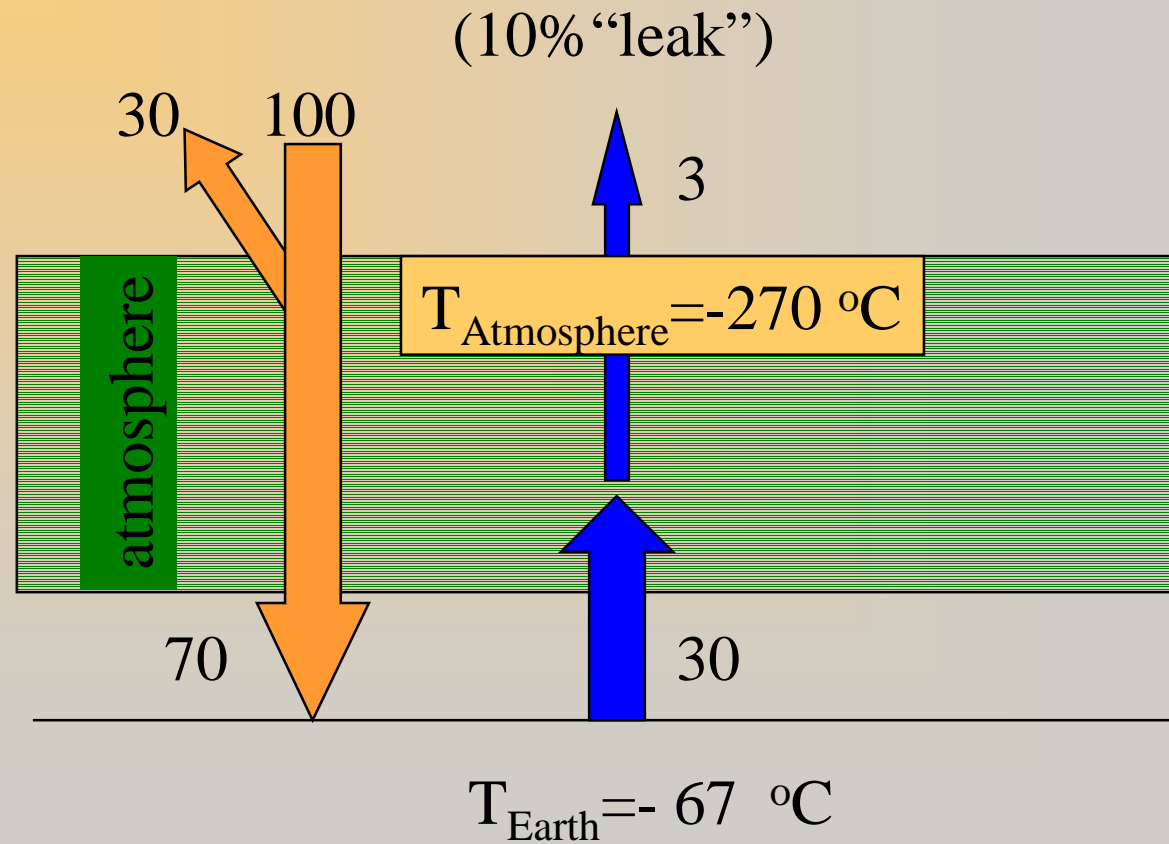
(30% reflection)



$T_{\text{Earth}} = -270\text{ }^{\circ}\text{C}$

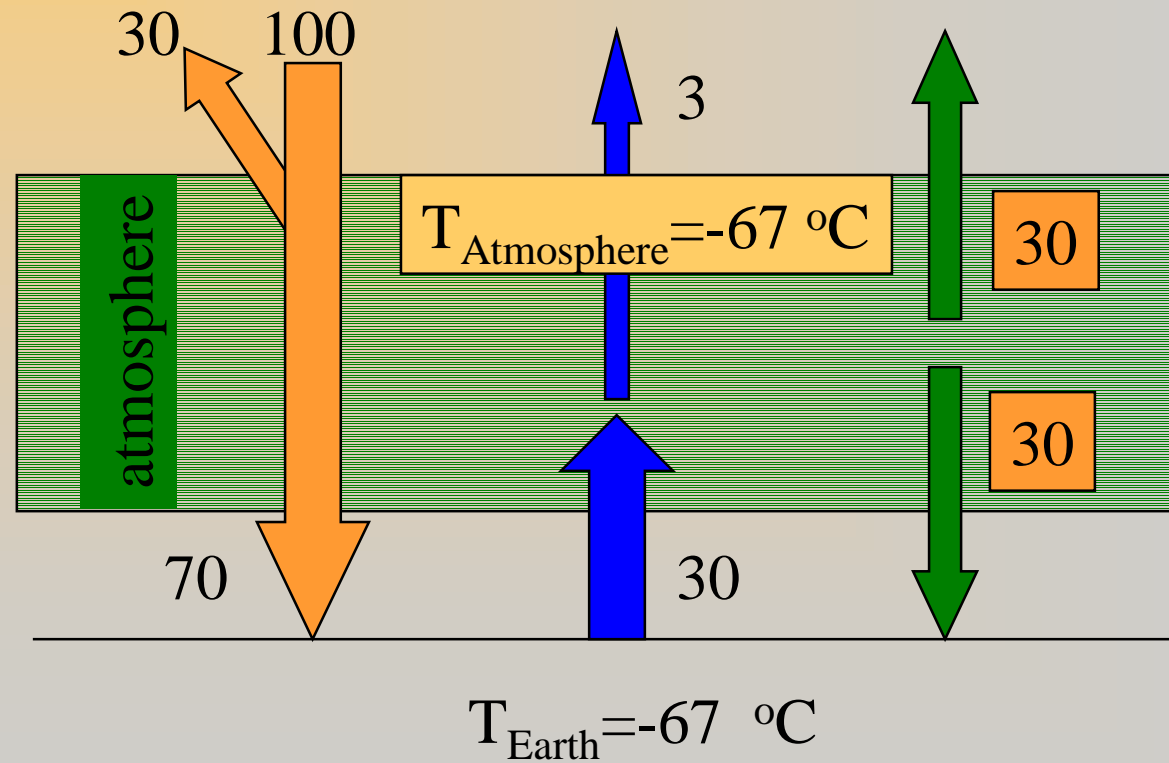


Greenhouse Effect 101: Partial Absorption



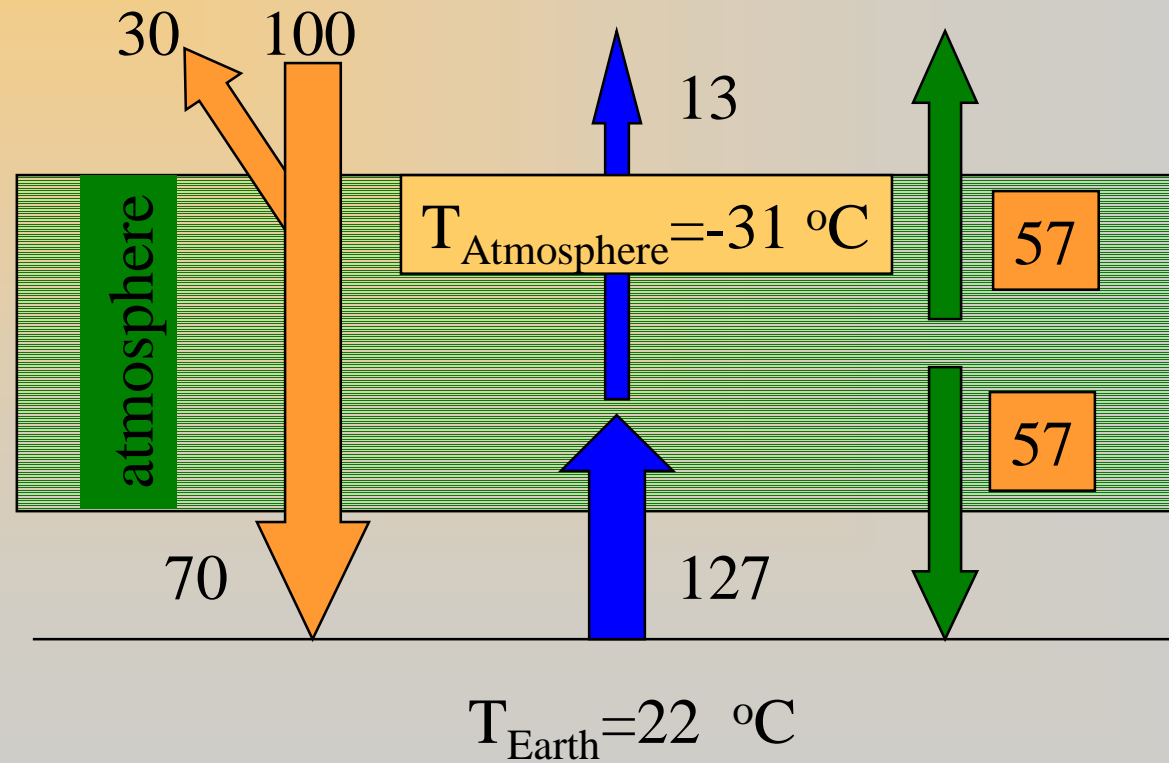


Greenhouse Effect 101: Energy Re-radiated Up & Down



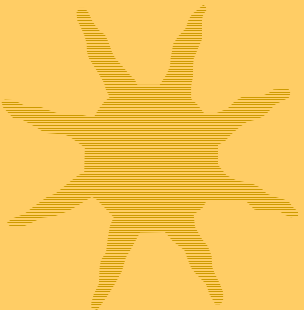
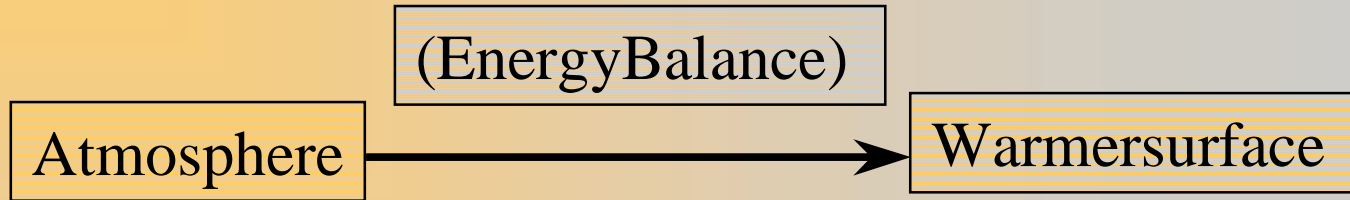


Greenhouse Effect 101: A Balance is Achieved

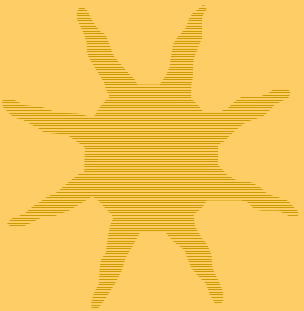




Greenhouse Effect 101: Energy Balance

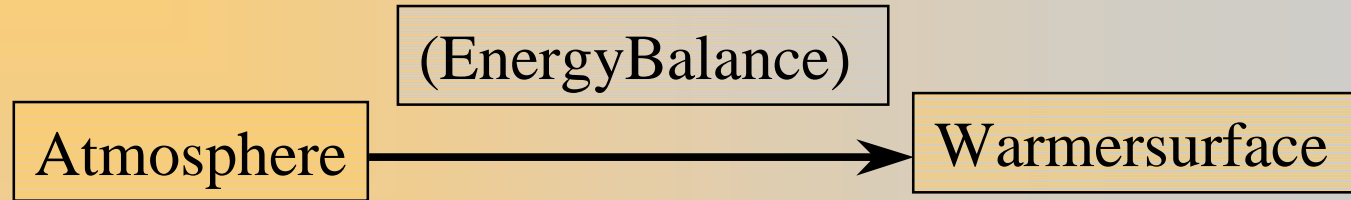


- What can affect this balance?





Greenhouse Effect 101: Energy Balance



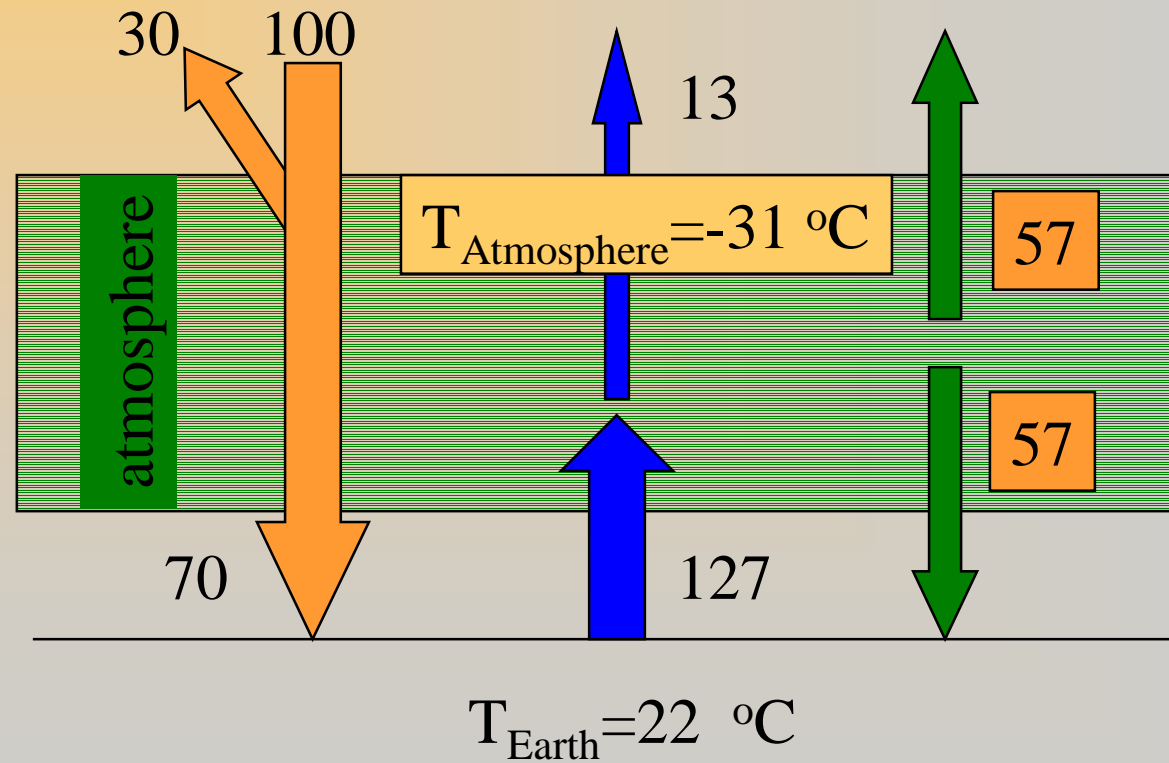
• What can affect this balance?

Input from the Sun (luminosity)
Reflectivity (ice, clouds, etc.)
Infrared absorption (CO_2 , H_2O , etc.)
Ocean heating and evaporation

⋮

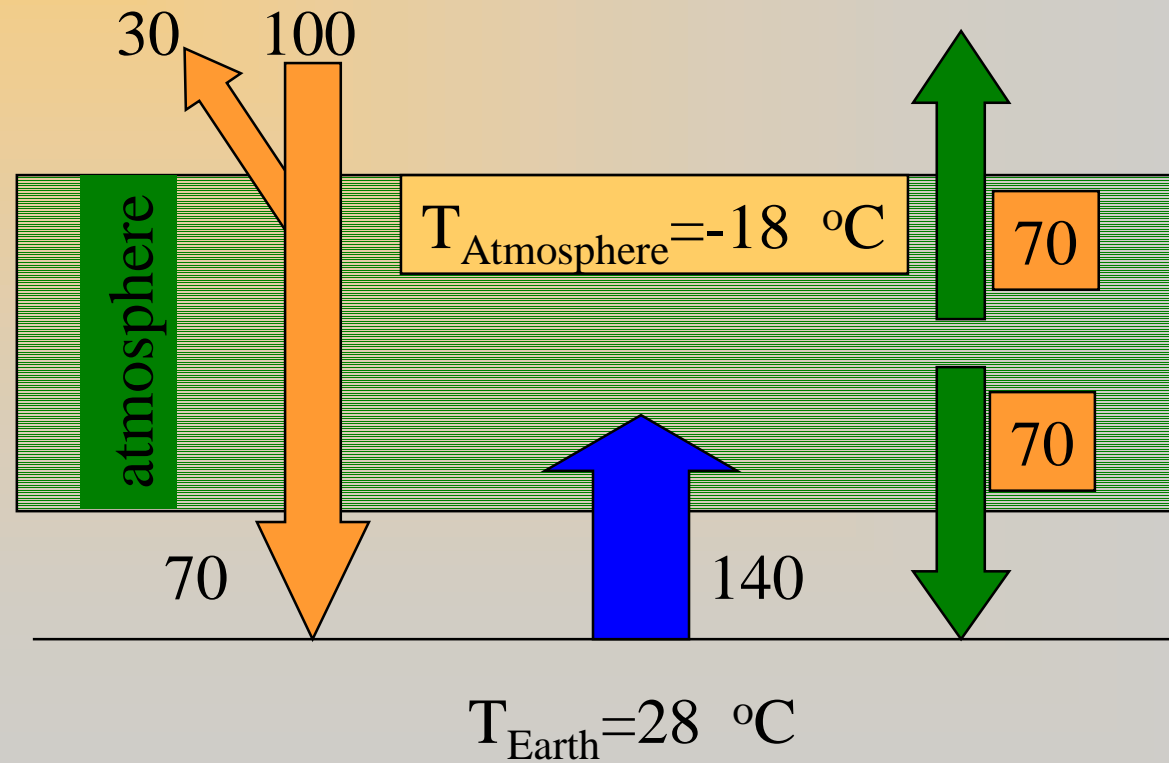


Greenhouse Effect 101: A Balance is Achieved



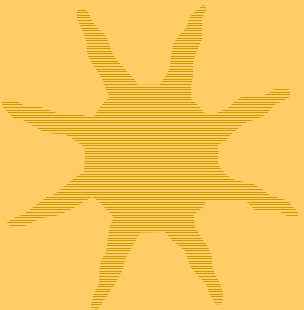
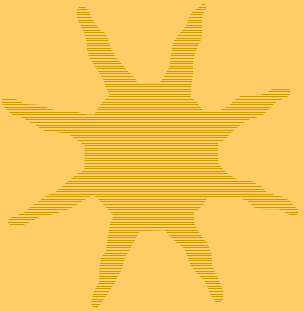


Greenhouse Effect 101: Closing the CO₂ “hole”





Negative Feedback: Balance



Increasingthermostat → increasesbodytemperature
Increasingbodytemperature → decreases thermostat



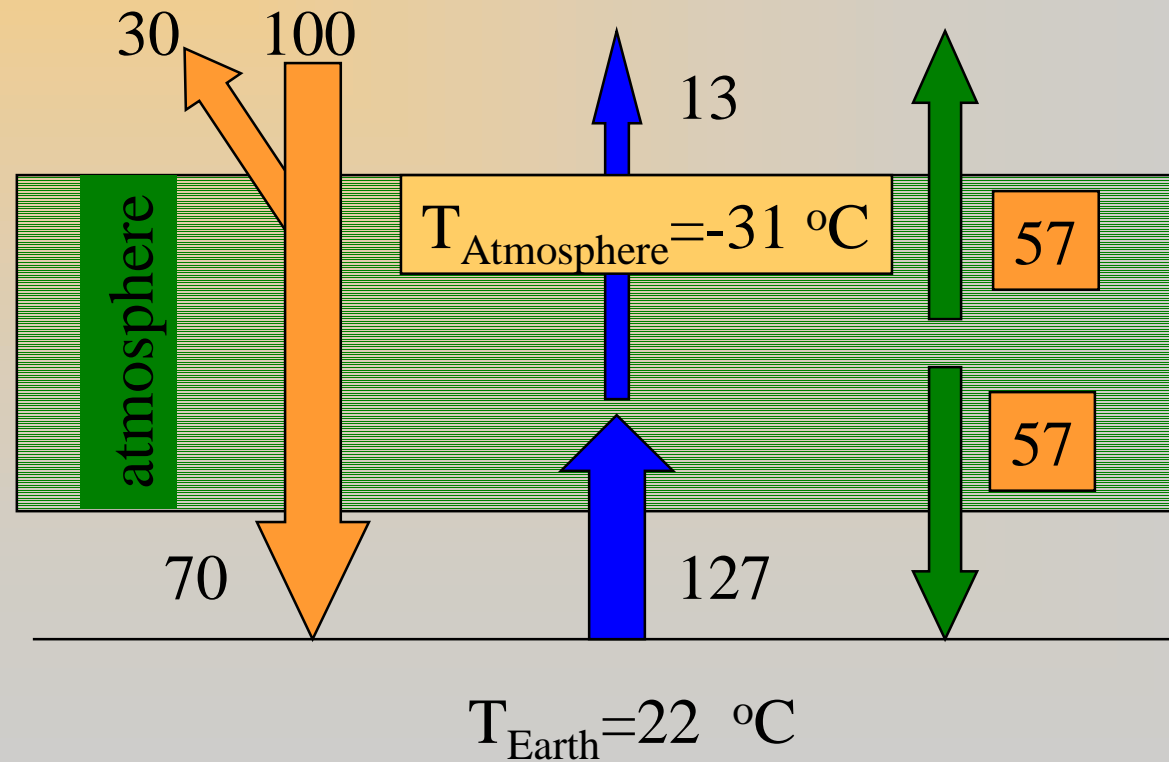
A balance is achieved



Negative Feedback: Balance

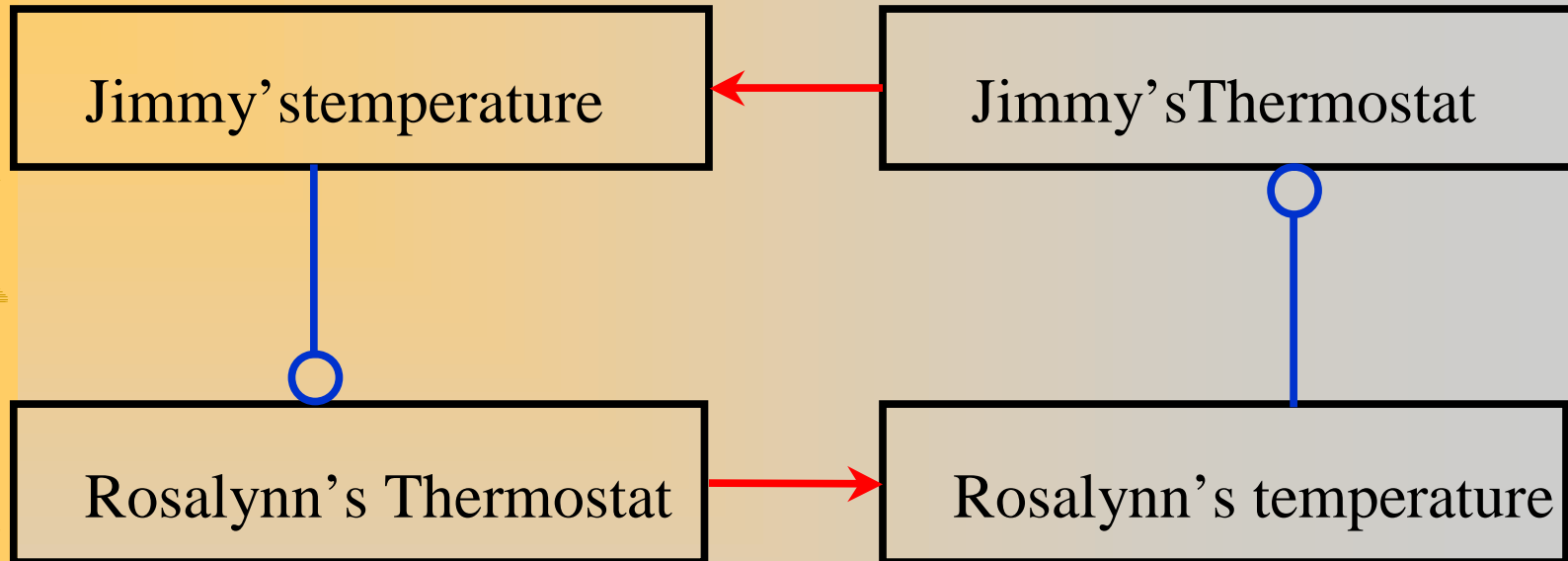


A balance is achieved





Positive Feedback: No Balance



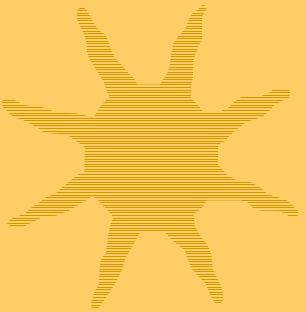
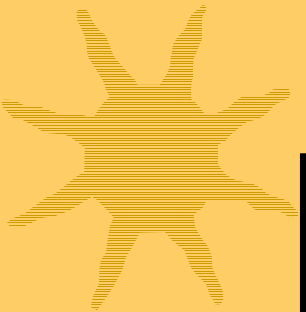
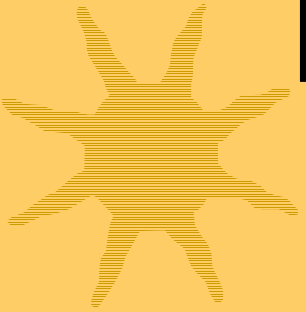
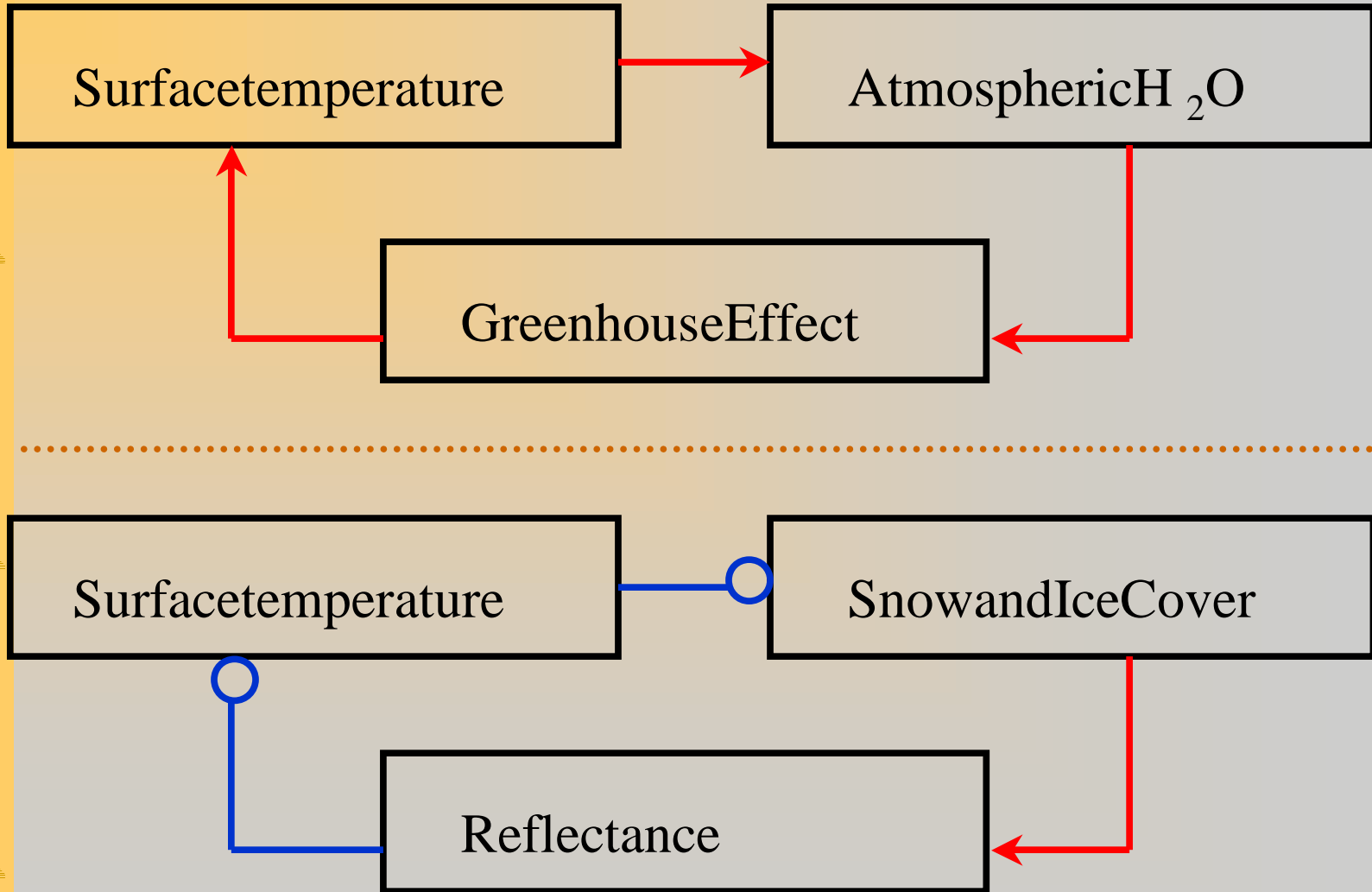
Jimmy gets warm → turns down Rosalynn's thermostat

Rosalynn gets cold → turns up Jimmy's thermostat

A balance is *not* achieved

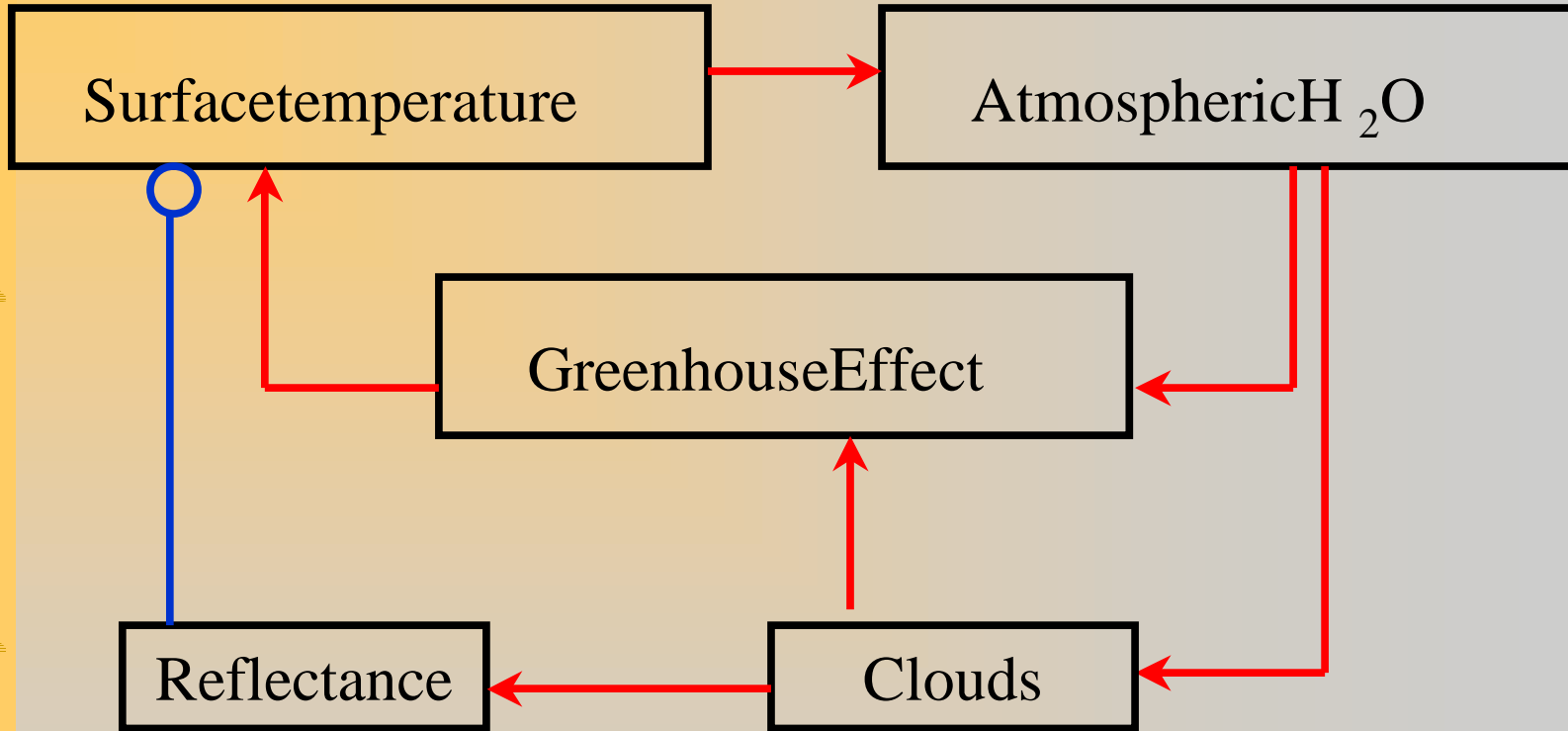


Some Feedback Loops





FeedbackwithClouds



Cloudshavebothapositiveanda
negativeeffectontemperature



IPCC2001

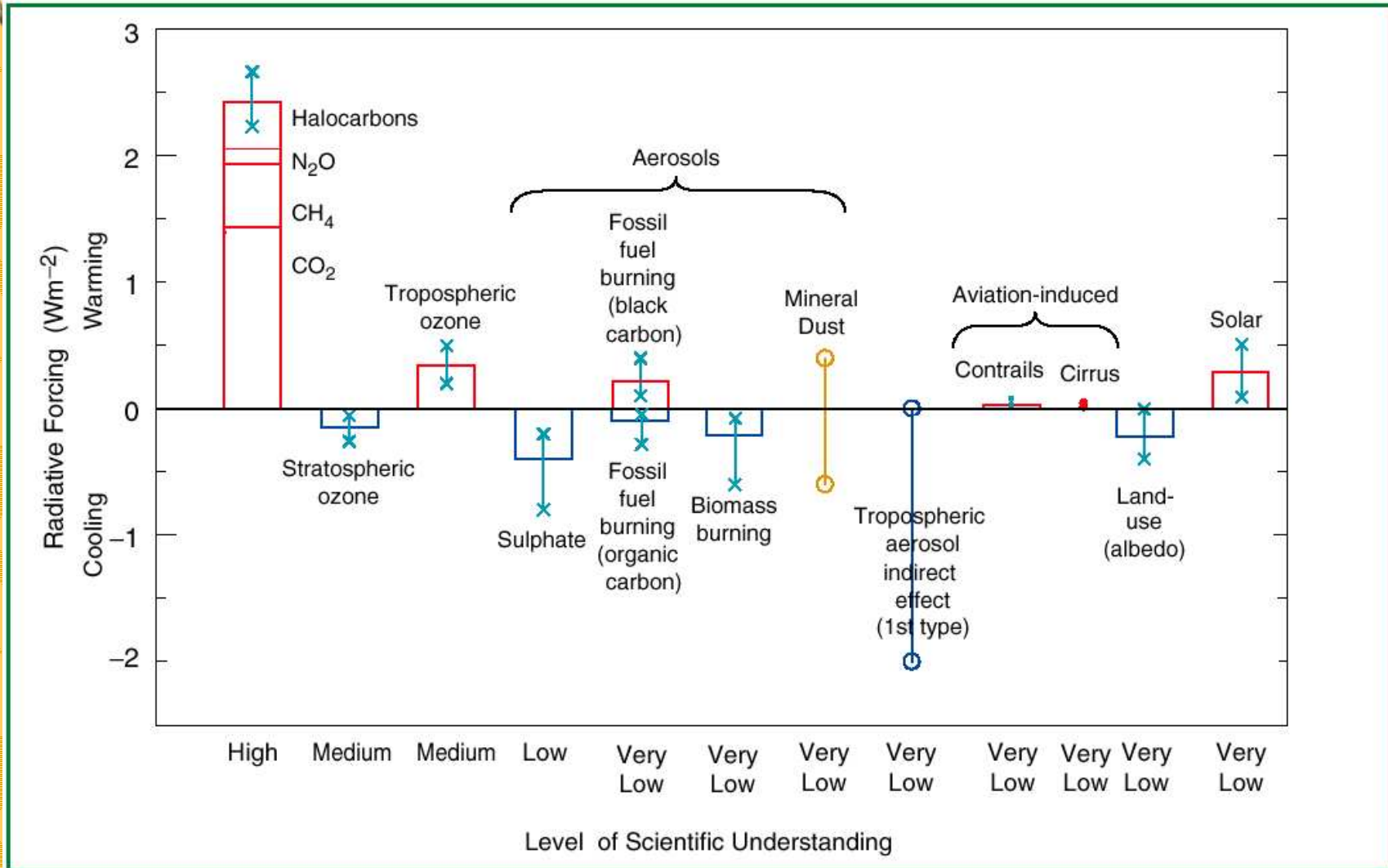
• The complexity of the processes in the climate system prevents the use of extrapolation of past trends or statistical and other purely empirical techniques for projections.

• **Detection** is the process of demonstrating that an observed change is significantly different (in a statistical sense) than can be explained by natural variability.

• **Attribution** is the process of establishing cause and effect with some defined level of confidence, including the assessment of competing hypotheses.



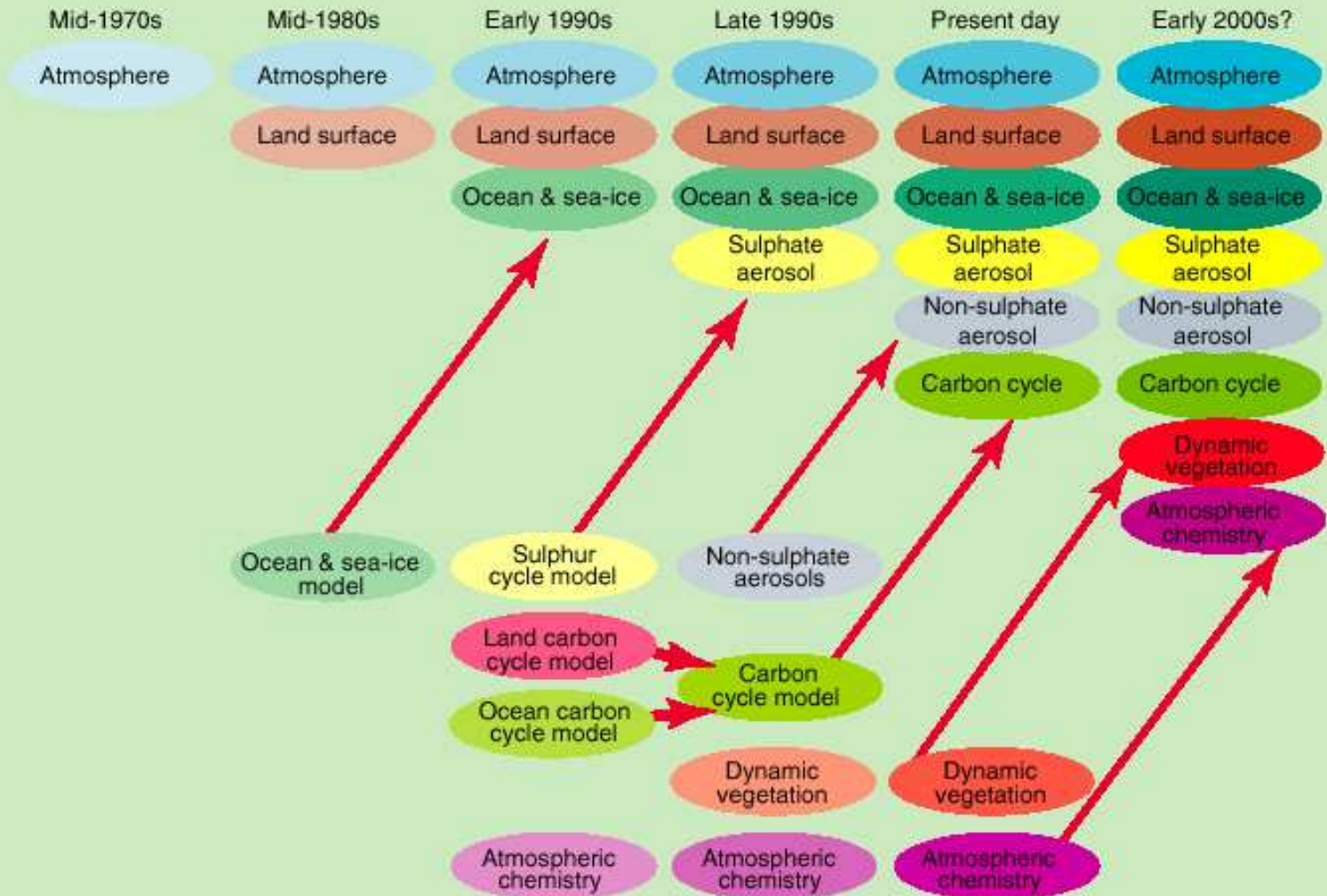
EffectsonTemperature





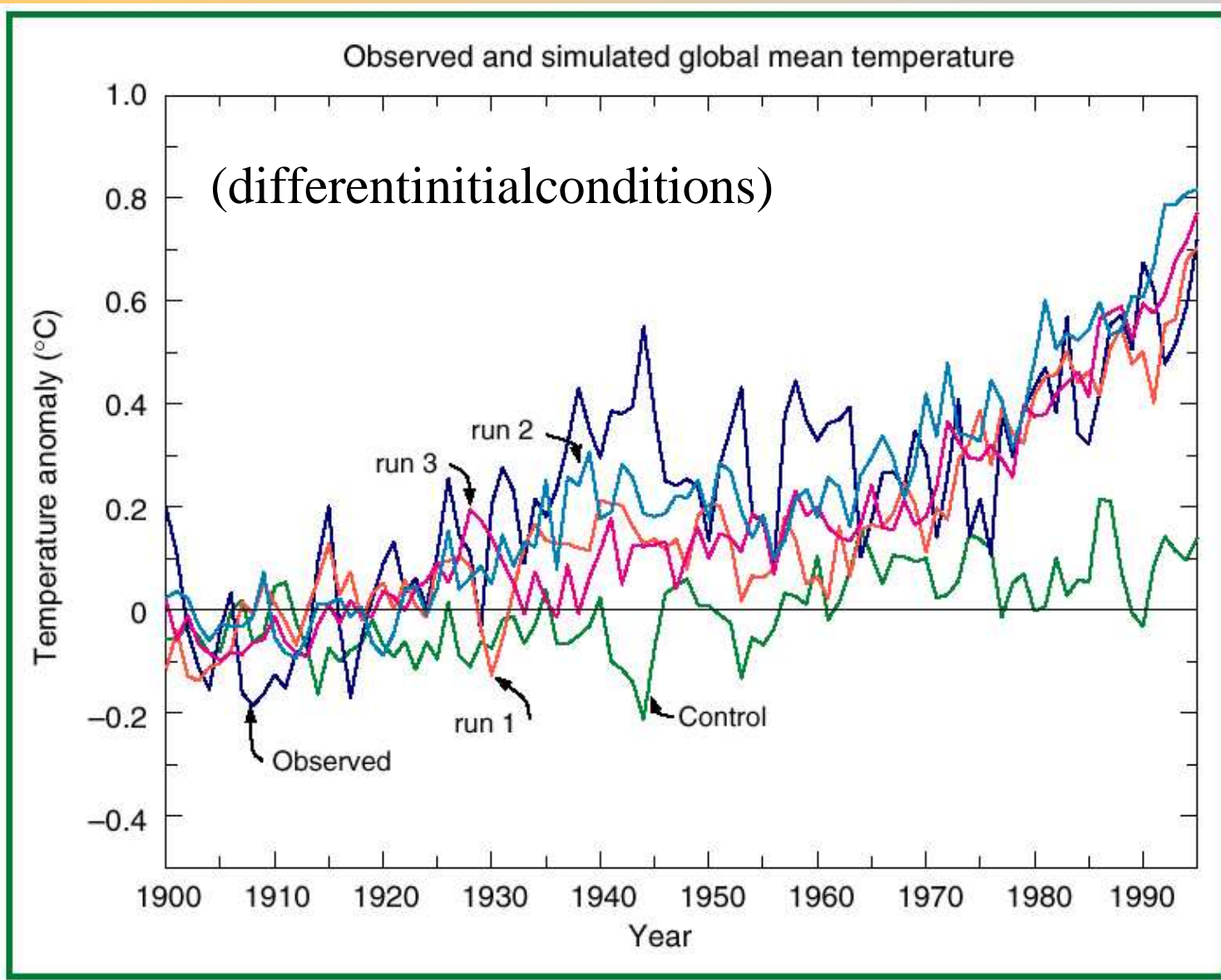
Improvements of the Models

The Development of Climate models, Past, Present and Future



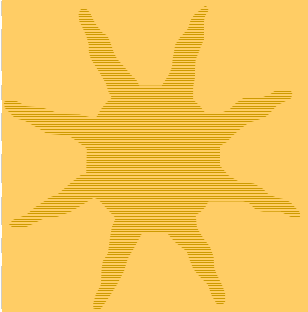
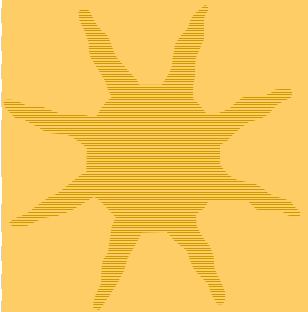
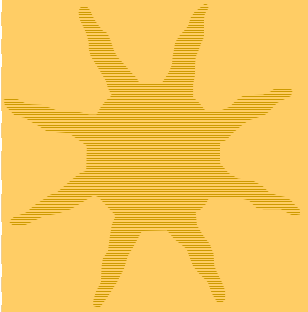


Temperature: Models and Reality



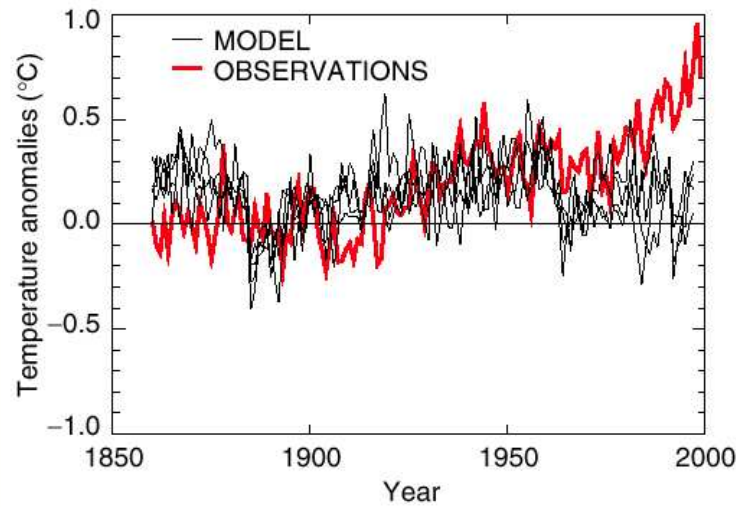


Natural versus Artificial



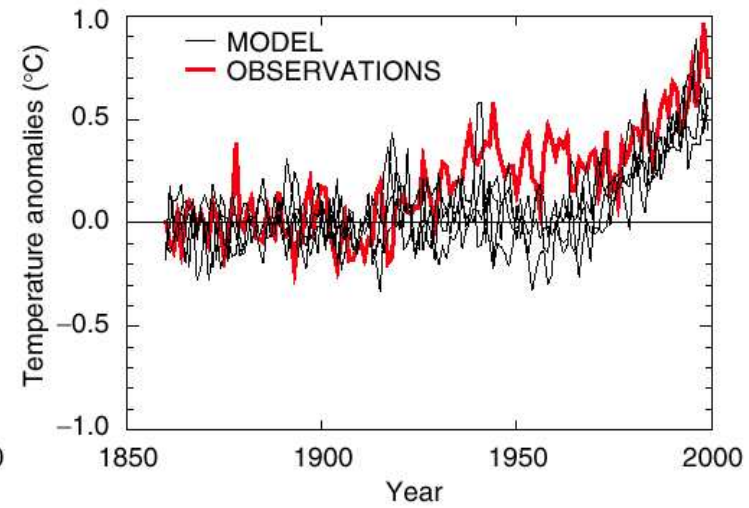
(a)

NATURAL : Annual global mean temperatures



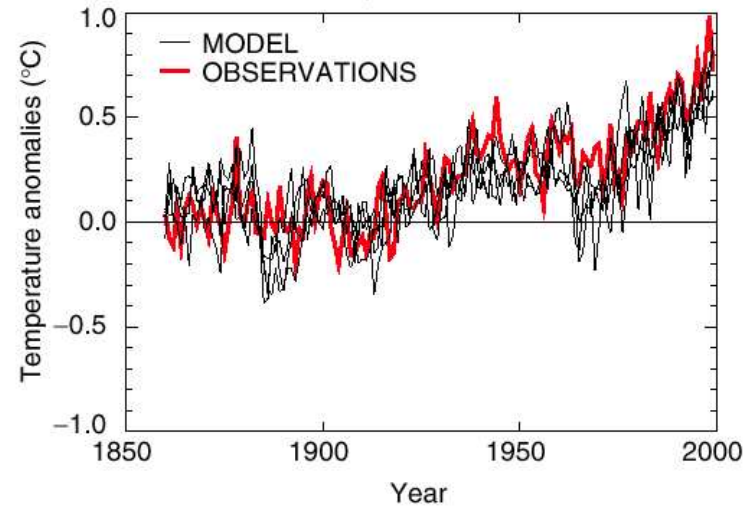
(b)

ANTHROPOGENIC : Annual global mean temperatures



(c)

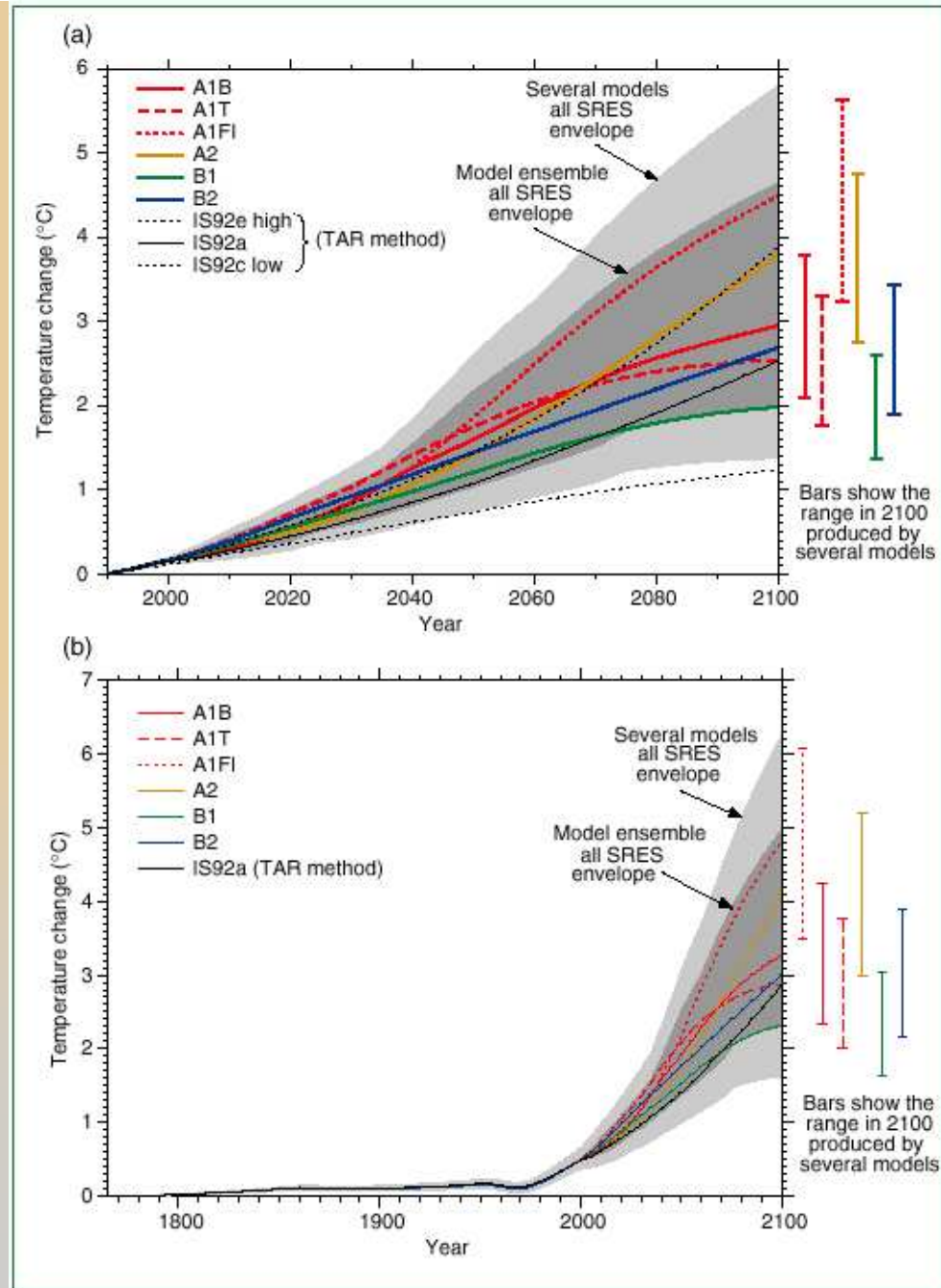
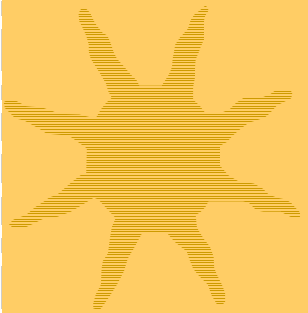
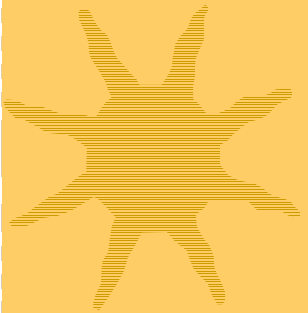
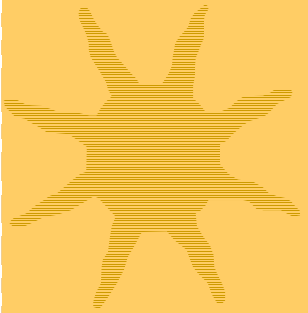
ALL FORCINGS : Annual global mean temperatures





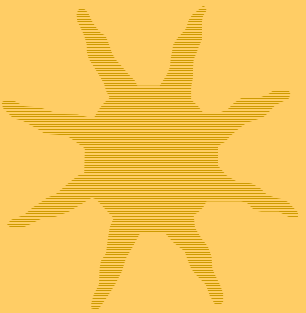
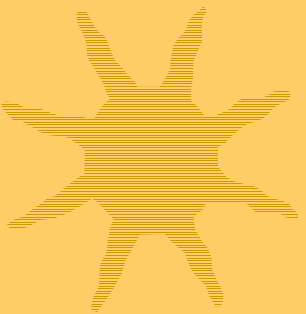
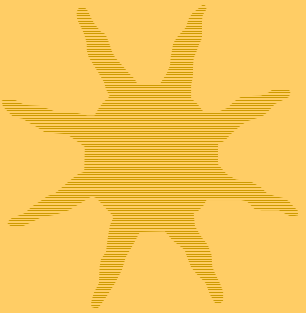
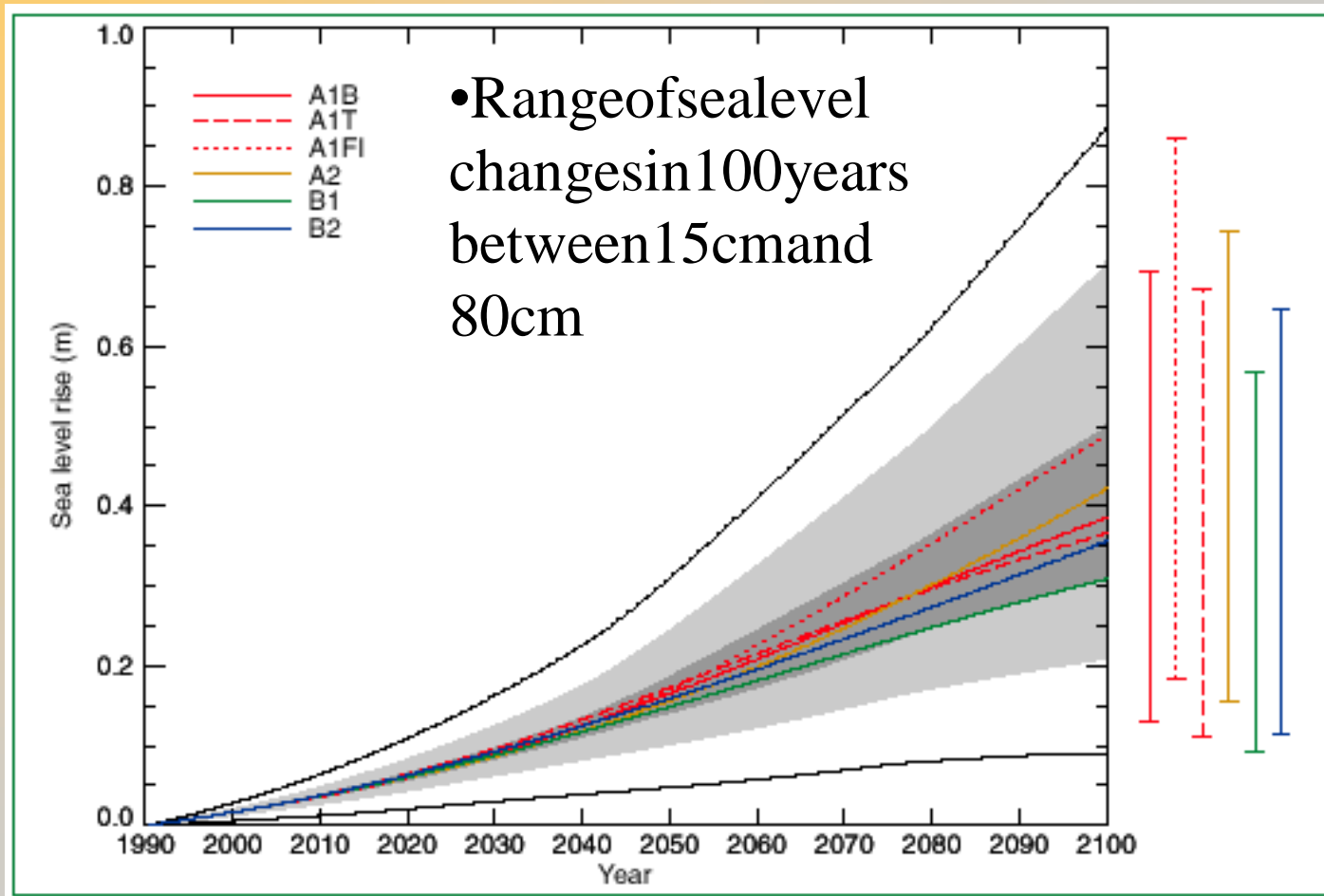
Model Scenarios: Temperature

- Range of temperature changes in 100 years between 1.5 °C and 6 °C





Model Scenarios: Sea Level





Conclusions

- Global Warming can be understood qualitatively using the concepts of Energy Balance and Feedback
 - Observed warming of 1 degree C in 100 years
 - Computer models estimate further warming
 - Modeling energy balance
 - Feedback
 - Very good knowledge of effect of greenhouse gases
 - Uncertainty about cloud feedback loop
 - Uncertainty about future technology
- All of the stabilization profiles studied require CO₂ emissions to eventually drop well below current levels.*

