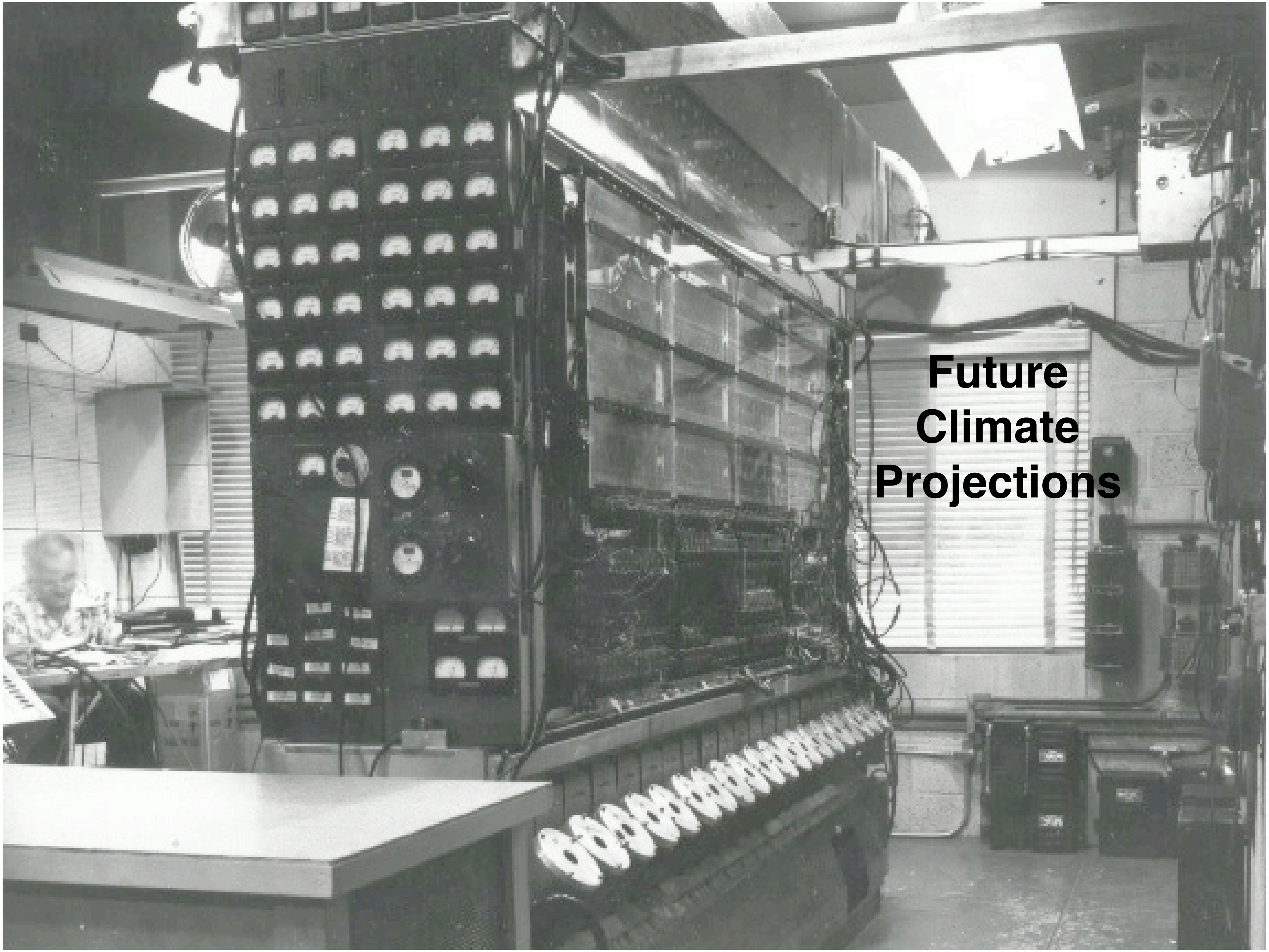

Future
Climate
Projections

CLIMATE FEEDBACKS

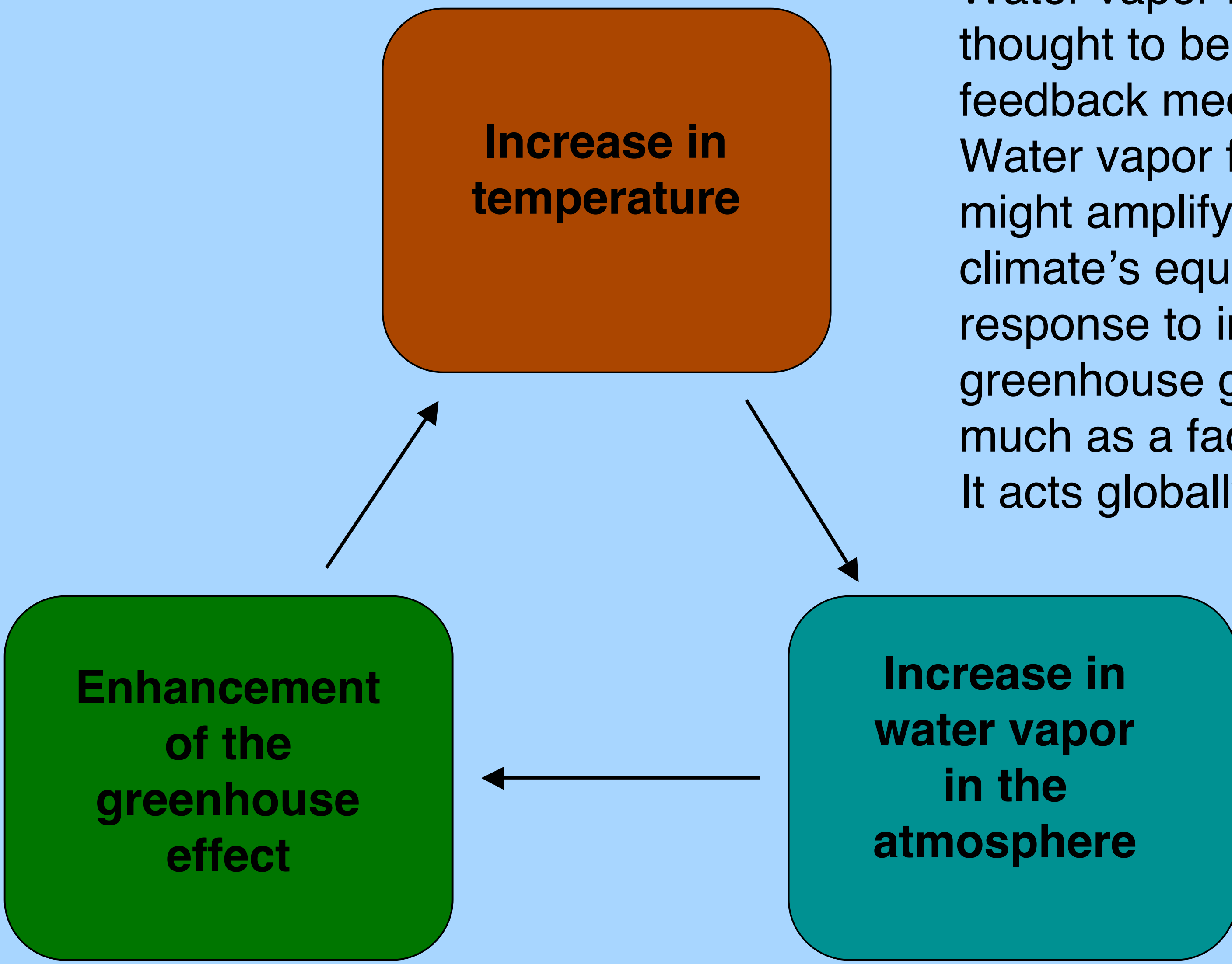
If the climate's response to an increase in greenhouse gases were simply to increase its temperature to compensate for the increase in greenhouse trapping of infrared radiation, the climate change problem would be quite simple. Unfortunately, there are climate feedbacks that come into play, influencing the climate's response. The main climate feedbacks are:

(1) Water vapor feedback

(2) Surface albedo feedback

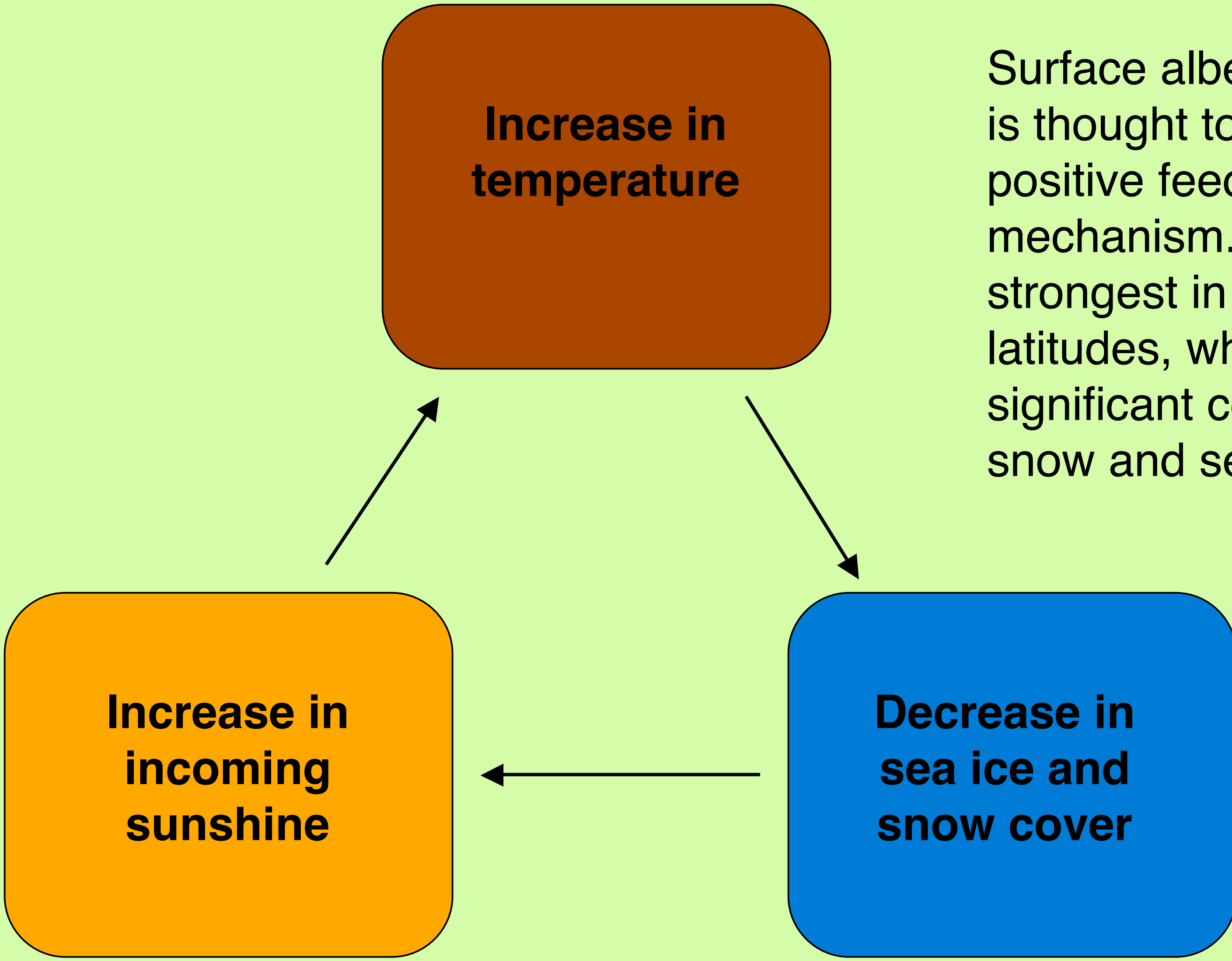
(3) Cloud feedback

WATER VAPOR FEEDBACK



Water vapor feedback is thought to be a positive feedback mechanism. Water vapor feedback might amplify the climate's equilibrium response to increasing greenhouse gases by as much as a factor of two. It acts globally.

SURFACE ALBEDO FEEDBACK



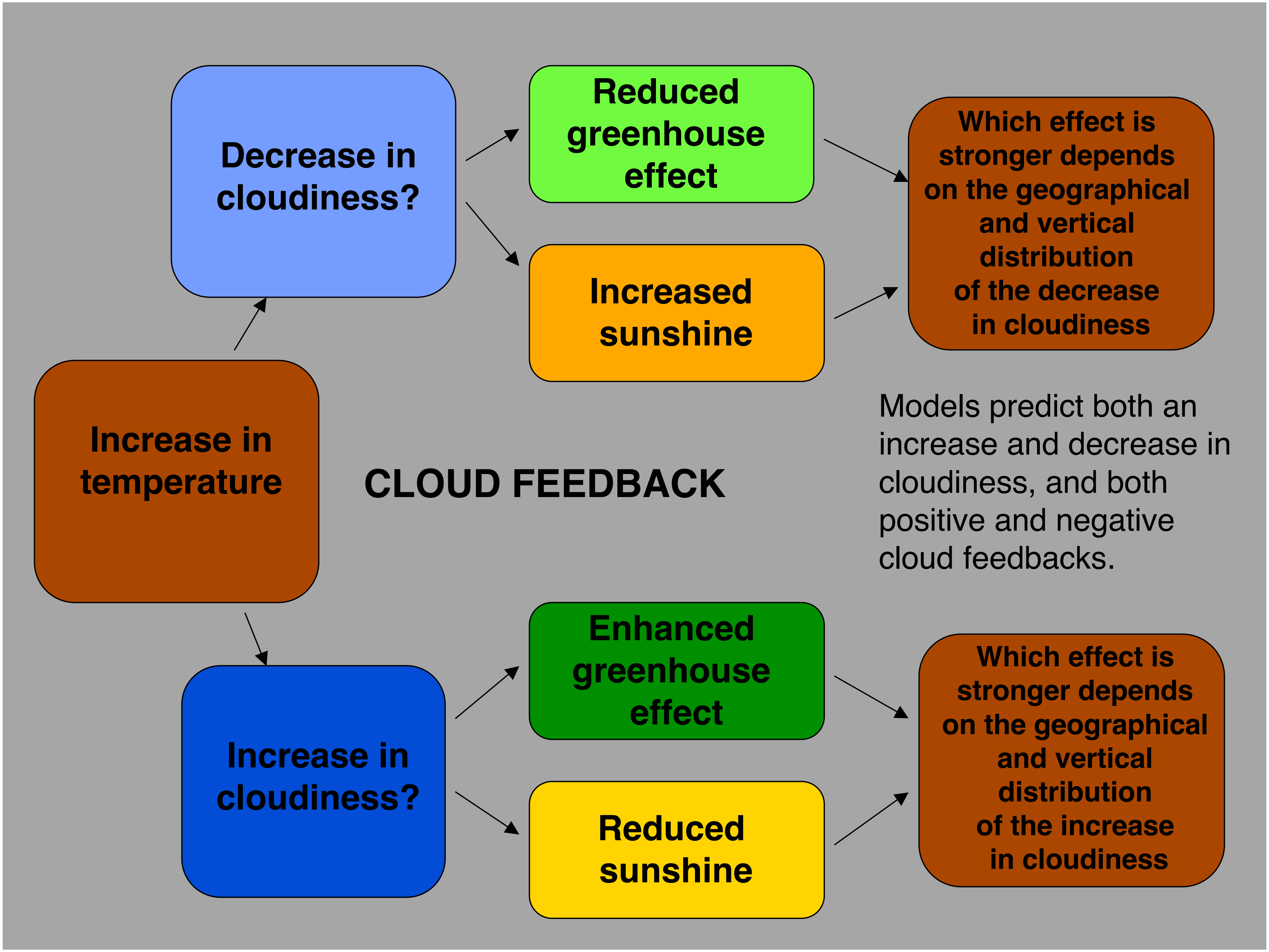
Surface albedo feedback is thought to be a positive feedback mechanism. Its effect is strongest in mid to high latitudes, where there is significant coverage of snow and sea ice.

To understand how cloud feedback might work, you have to understand some facts about clouds:

(1) Clouds absorb radiation in the infrared, and therefore have a greenhouse effect on the climate. If you put a cloud high in the atmosphere, it will have a stronger greenhouse effect than if you put it low in the atmosphere.

(2) Clouds reflect sunshine back to space. So more clouds means less sunshine for earth. If you put a cloud high in the atmosphere, it will reflect about the same amount of sunshine as if you put a cloud low in the atmosphere.

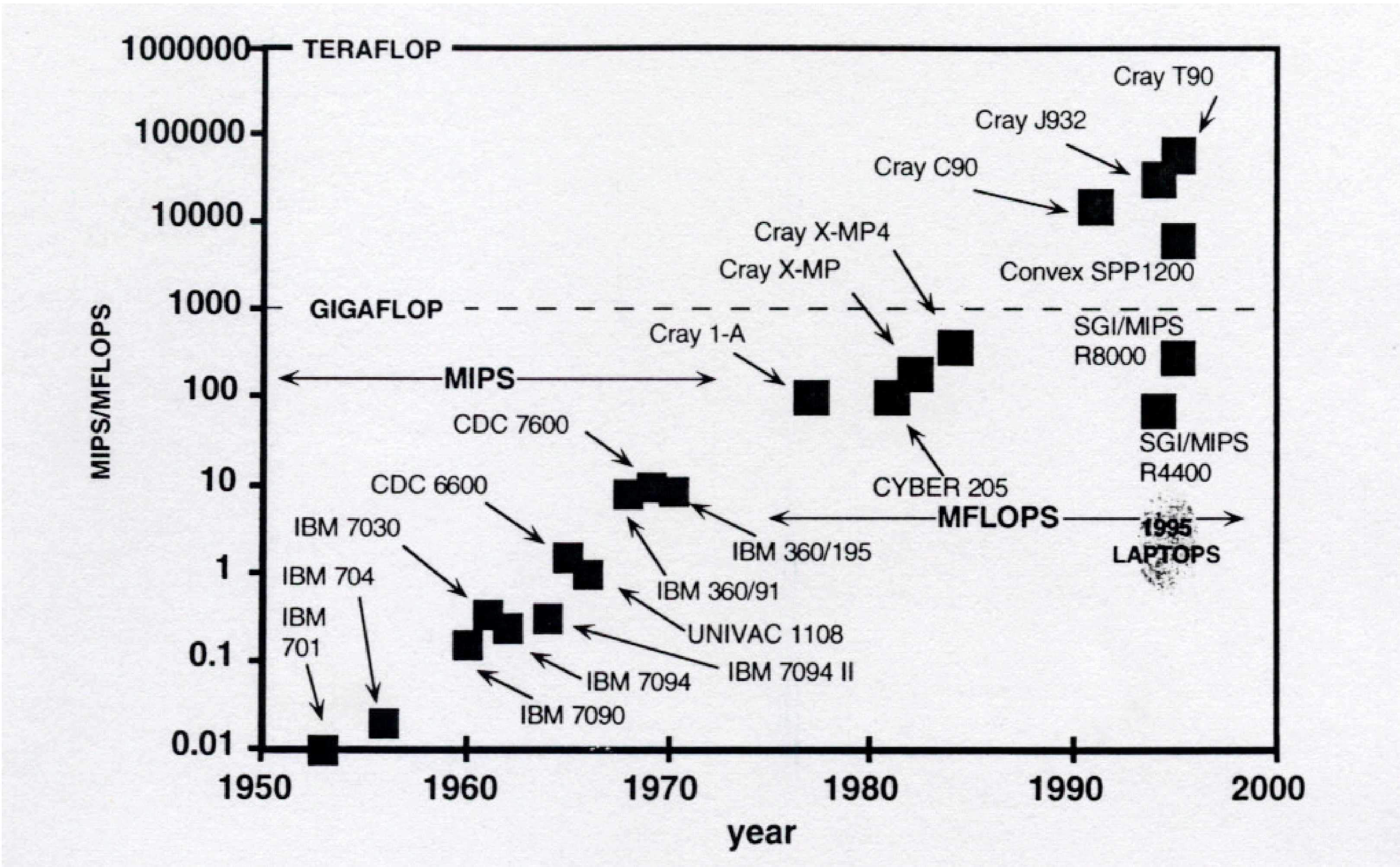

Photo taken in Los Angeles
August 2003


Decrease in cloudiness?
Reduced greenhouse effect
Increased sunshine
Which effect is stronger depends on the geographical and vertical distribution of the decrease in cloudiness
Increase in temperature
CLOUD FEEDBACK
Models predict both an increase and decrease in cloudiness, and both positive and negative cloud feedbacks.
Enhanced greenhouse effect
Increase in cloudiness?
Reduced sunshine
Which effect is stronger depends on the geographical and vertical distribution of the increase in cloudiness

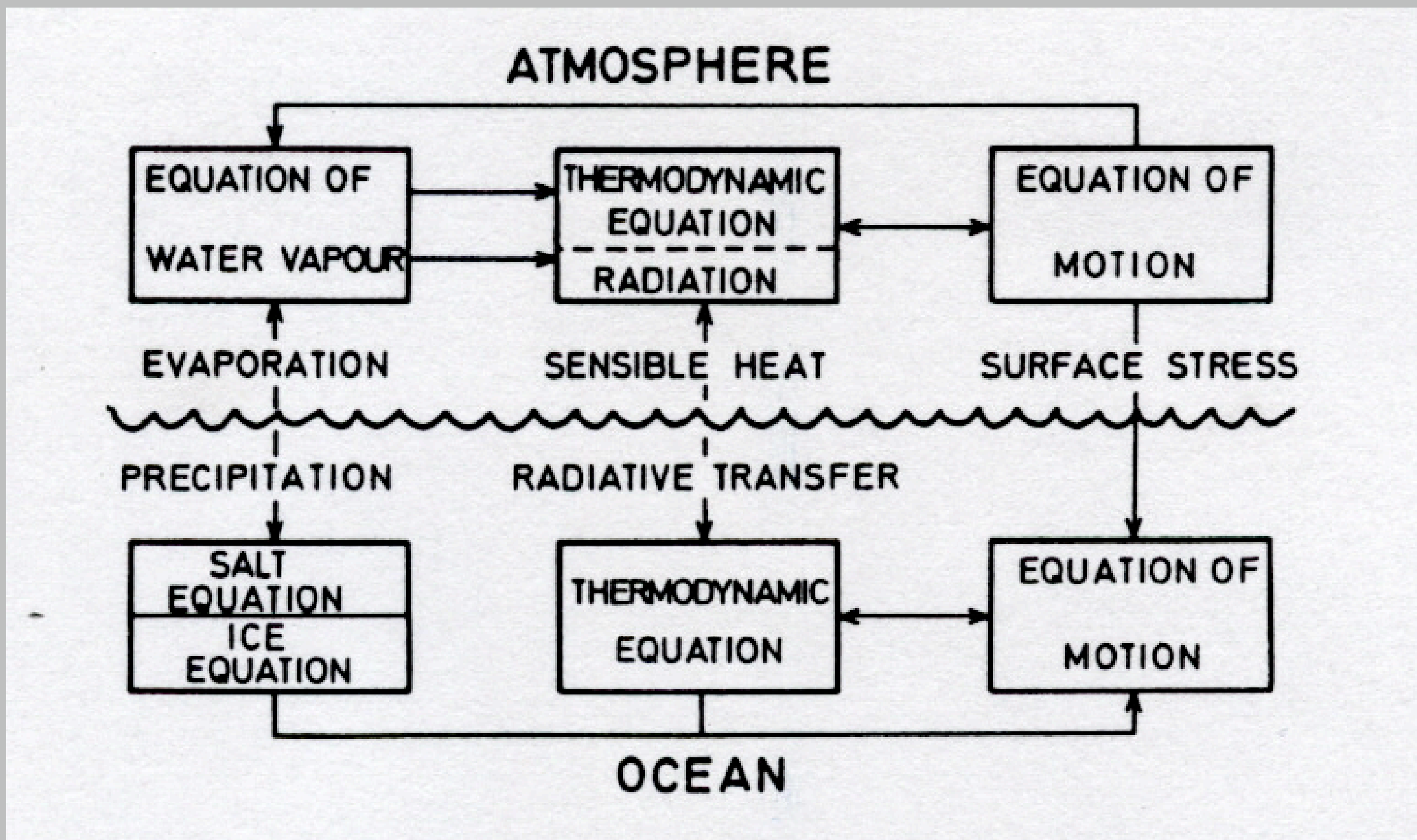
Lewis Richardson (1881-1953)

In the 1920s, he proposed solving the weather prediction equations using numerical methods. Worked for six weeks to do a six-hour "hindcast" by hand. Proposed a wild scheme to predict the weather in real time. His scheme was totally impractical because of the lack of computing power.

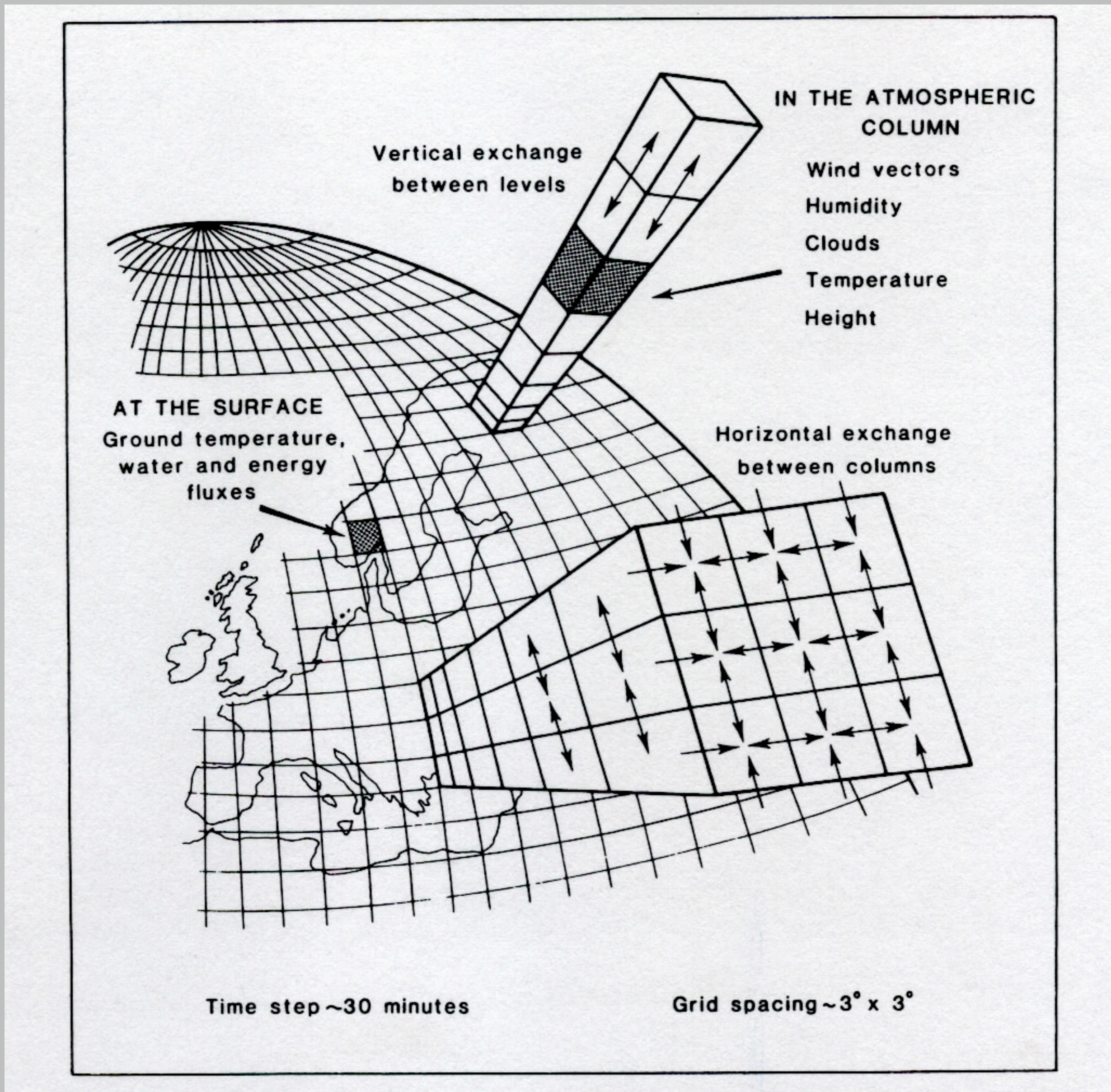
Over the past 50 years, there has been a remarkable increase in computing power, which has facilitated the development of numerical models to study weather and climate. We call these general circulation models (GCMs).



structure of a general circulation model



Computational grid of a general circulation model

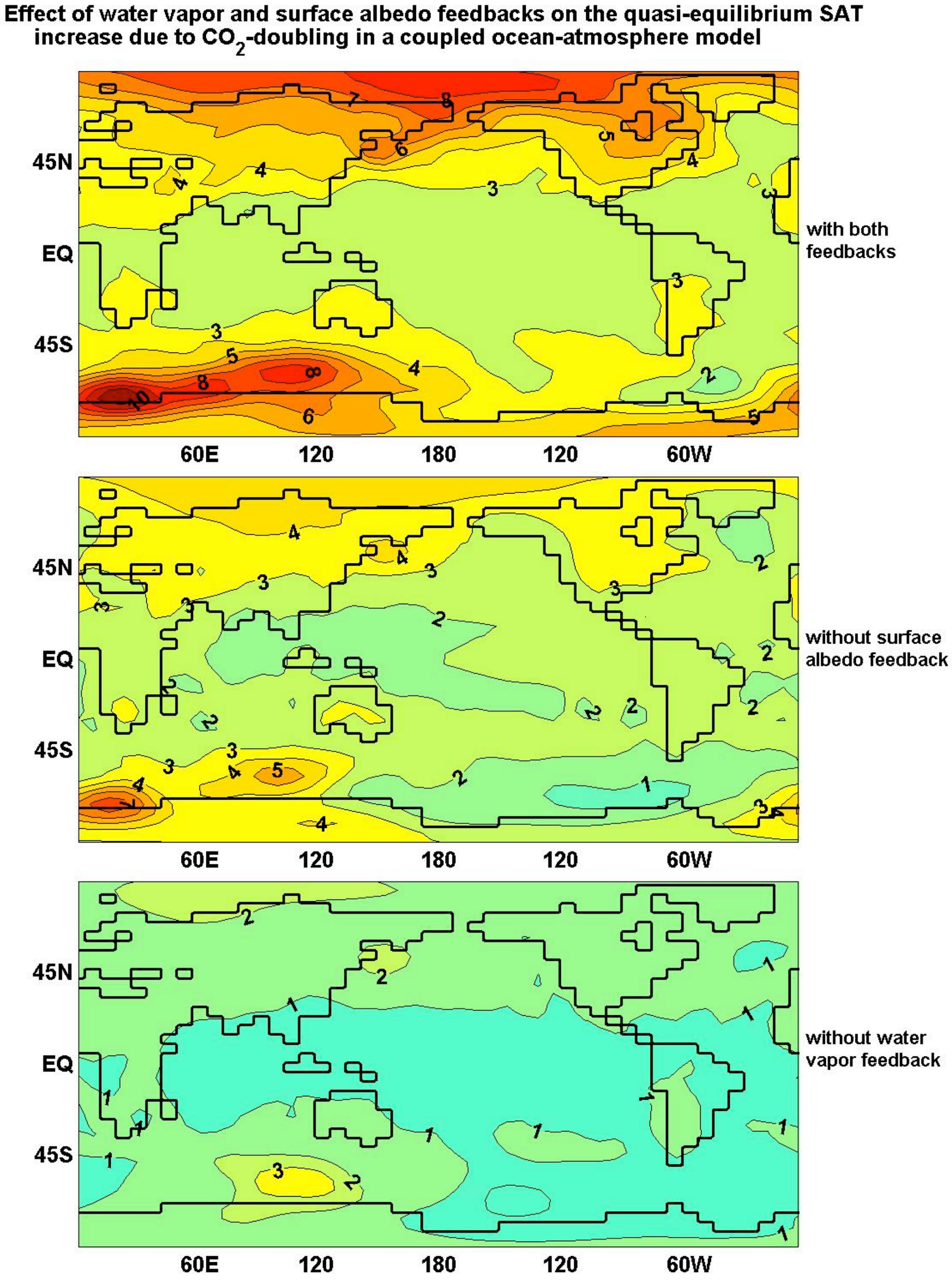


This is the typical resolution of a climate model. Note that there are many important processes for climate (such as cloud feedback), that cannot be resolved explicitly on such a coarse grid.

Transient vs Equilibrium climate response

Transient response refers to the evolution of the climate system as it responds to external forcing, such as an increase in greenhouse gases.

Equilibrium response refers to the final state of the climate system after it has adjusted to the external forcing. The magnitude of the equilibrium response compared to the magnitude of the forcing is referred to as the **climate sensitivity**.



Equilibrium response of a climate model when feedbacks are removed.

If the forcing associated with a doubling of CO_2 is approximately 4 W/m^2, what is the approximate sensitivity of each model on a global-mean basis?

To calculate the climate sensitivity, we divide the response by the forcing.

Key Concepts

Transient response

Equilibrium response

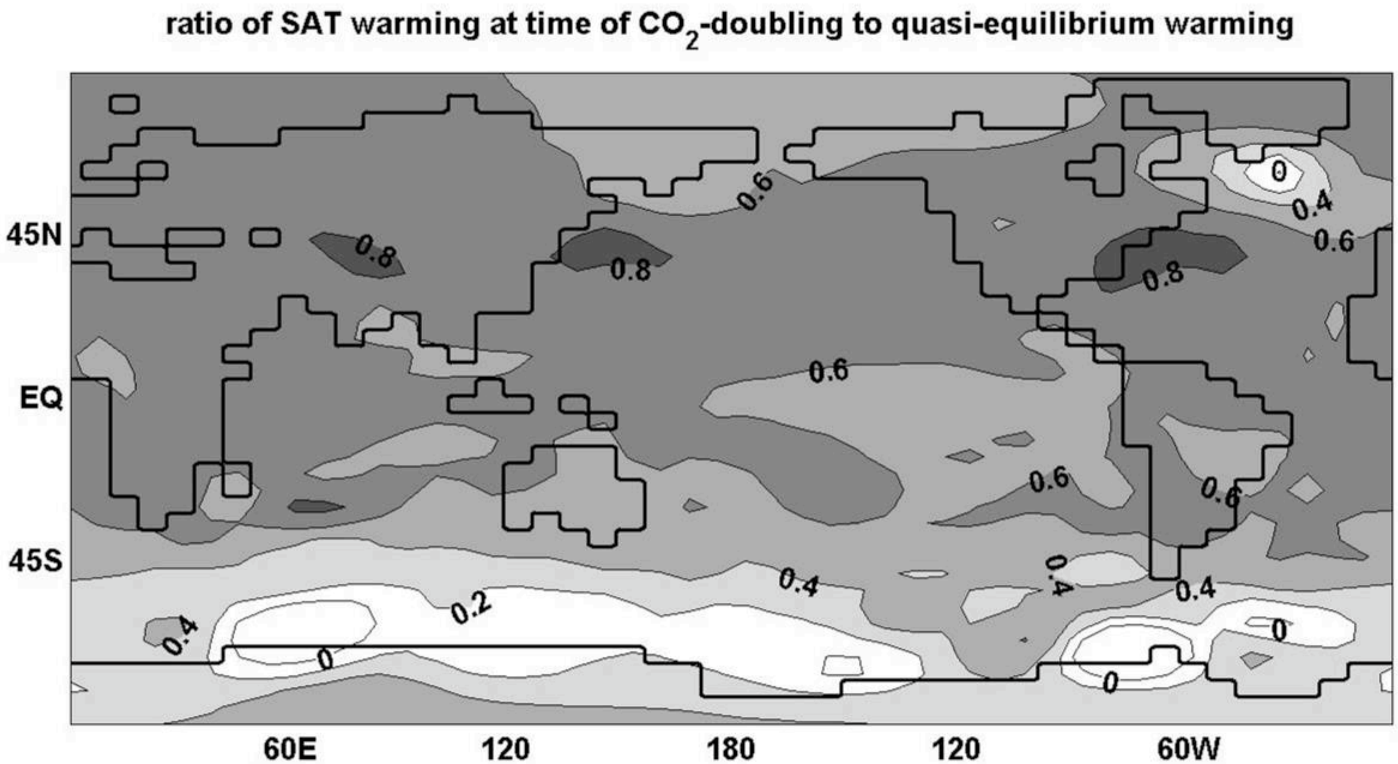
Climate sensitivity

Water vapor feedback

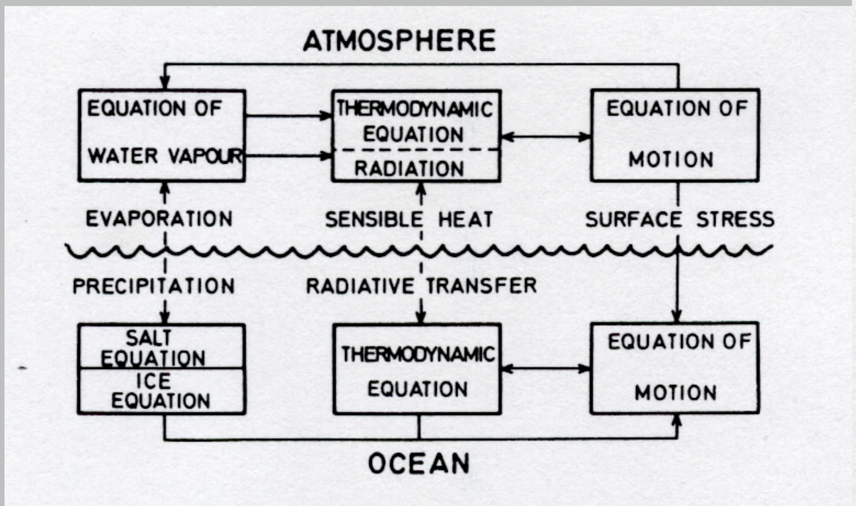
Surface albedo feedback

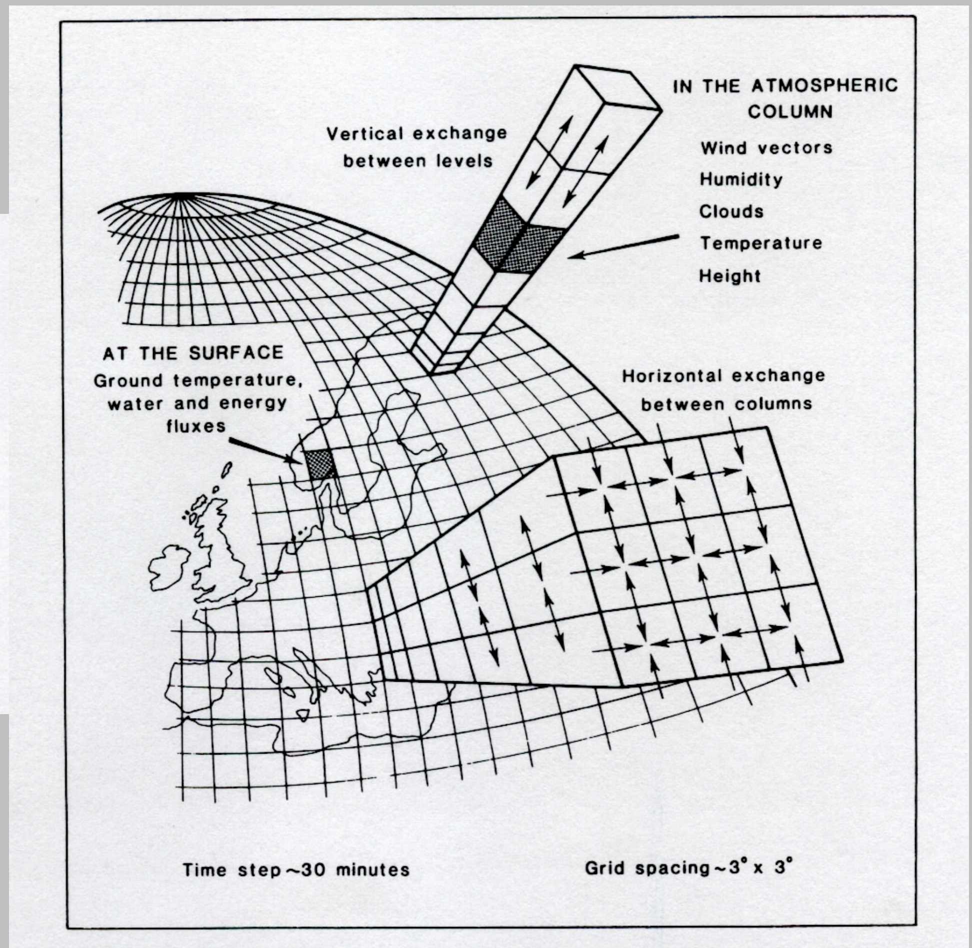
Cloud feedback

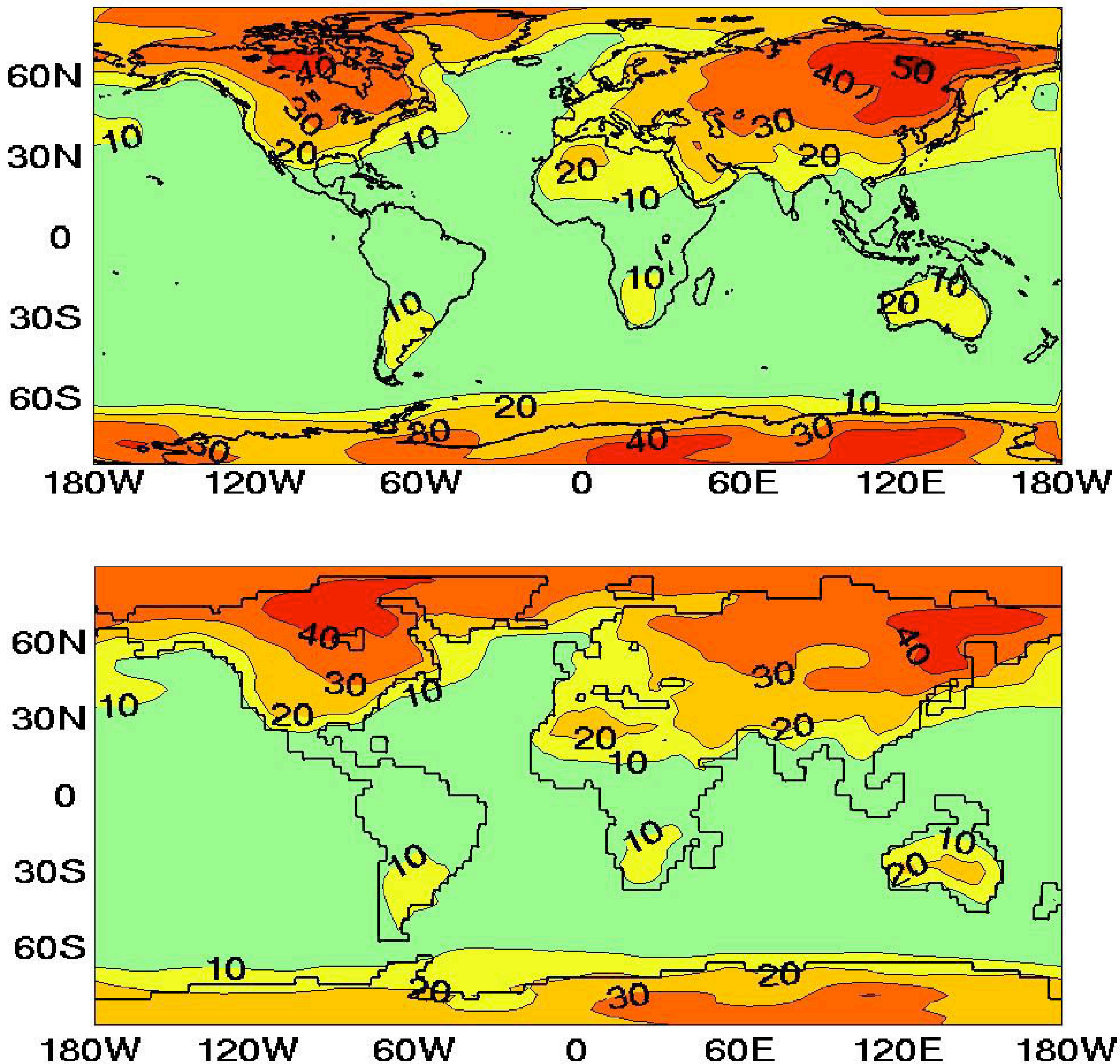
A climate model's transient response to increasing greenhouse gases.



Atmosphere and Ocean General Circulation Model Structure: What are climate models good for?

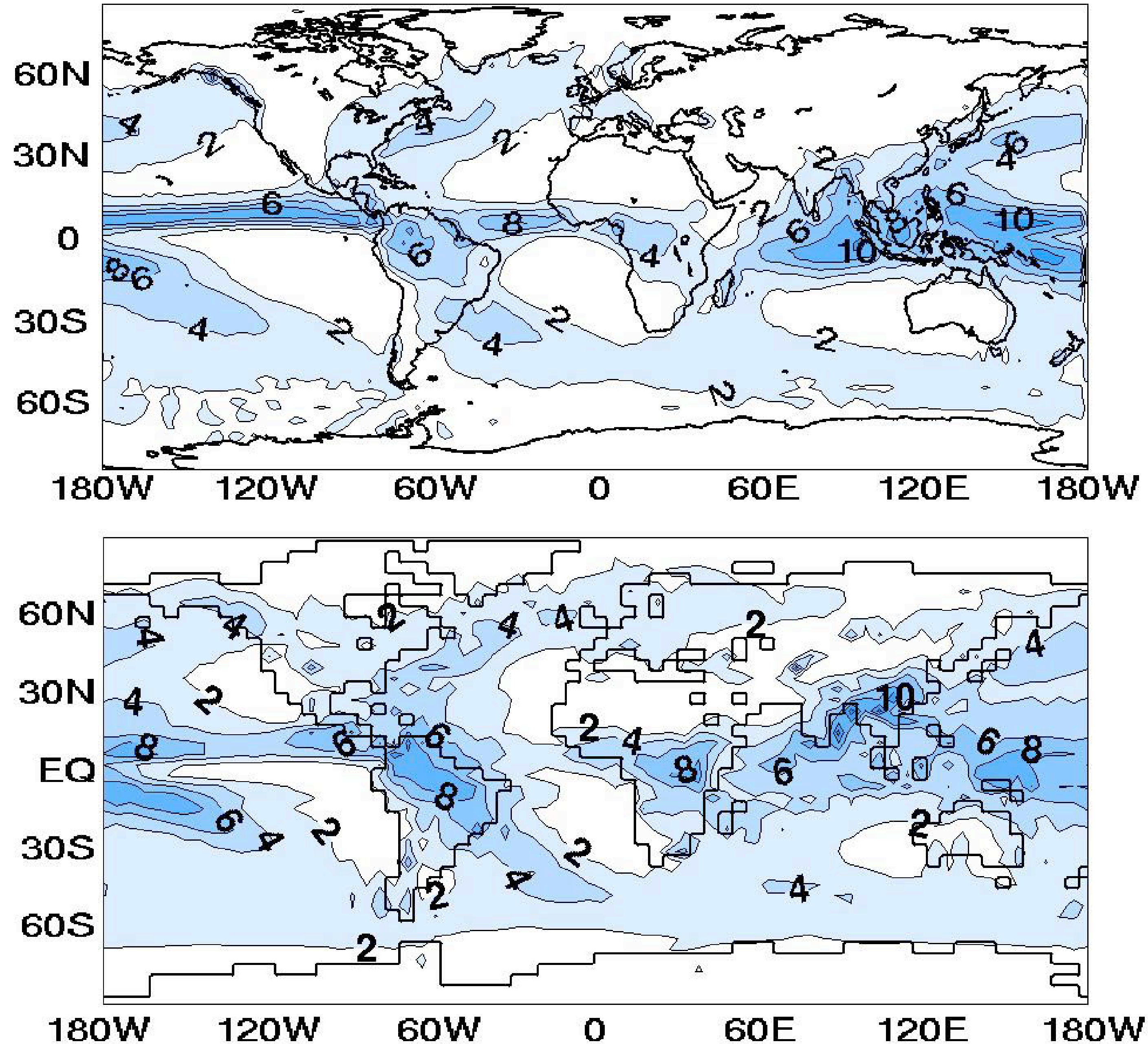






observed (top) and simulated (bottom) amplitude of the seasonal cycle. Simulation was done at National Center for Atmospheric Research in Boulder, Colorado.

Observed (top) and simulated (bottom) annual mean precipitation rates

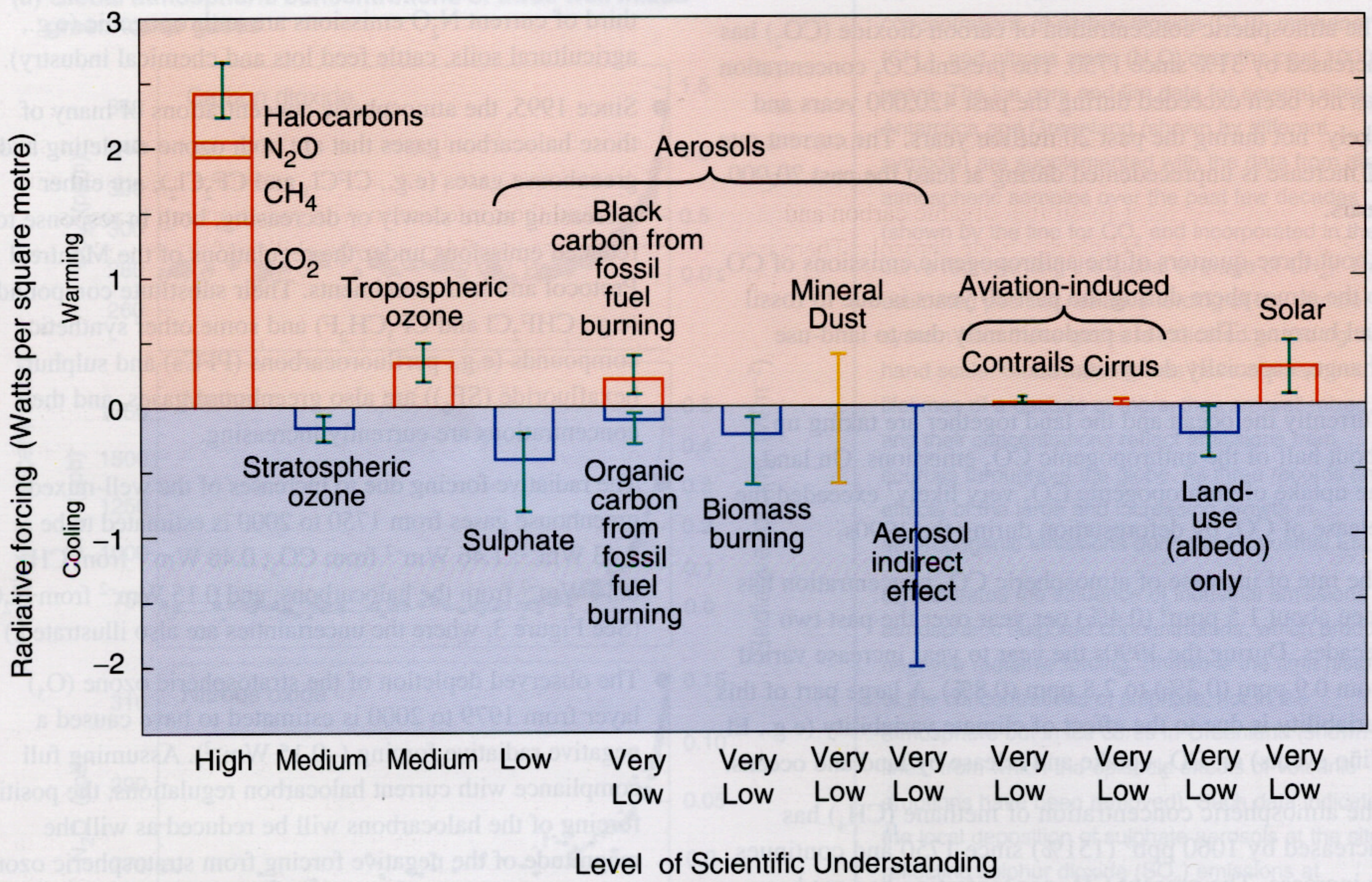


A key idea in climate change research is the concept of

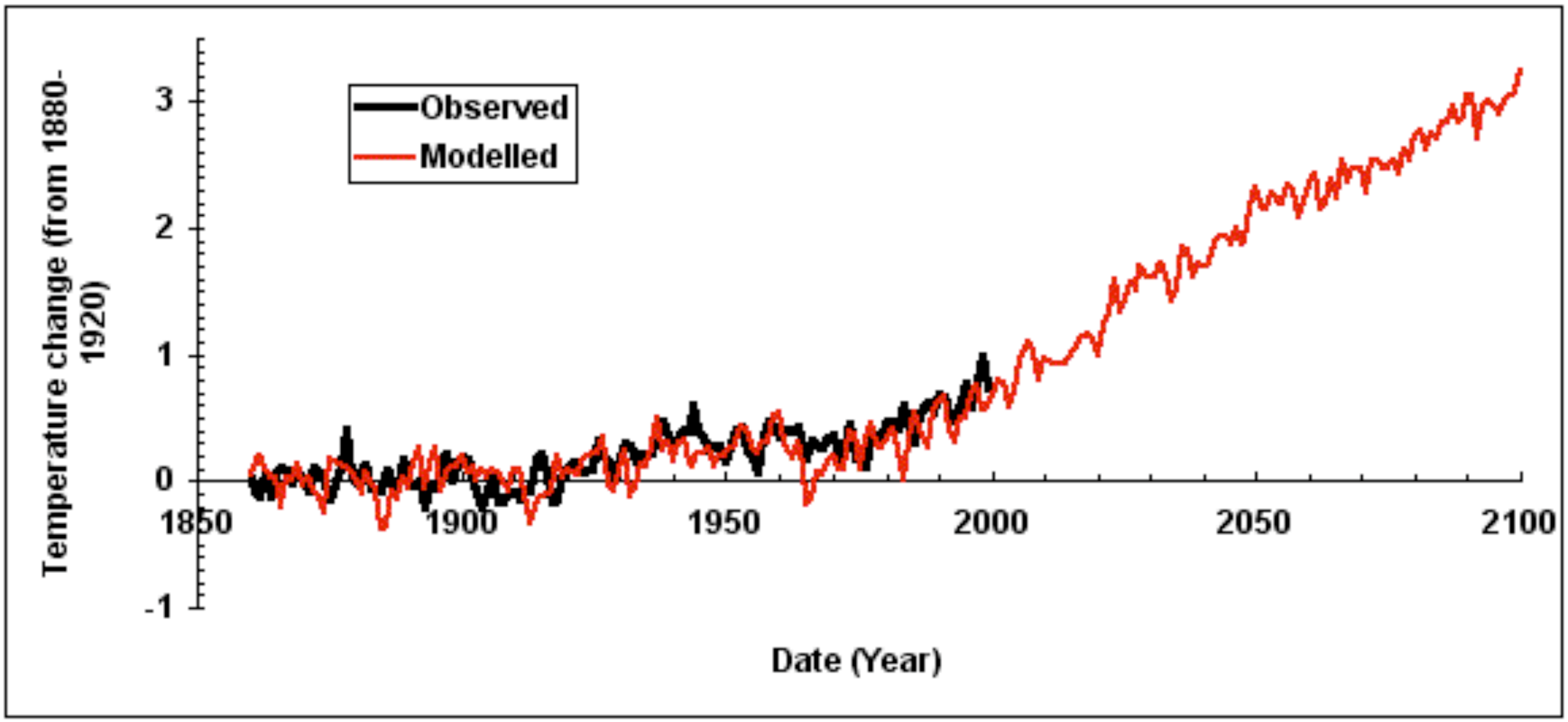
RADIATIVE FORCING

This allows us to quantify the importance of the various factors that have potential to change climate. It is defined as the radiation change in W/m^2 at the tropopause due to the forcing agent (e.g. increase in greenhouse gases)

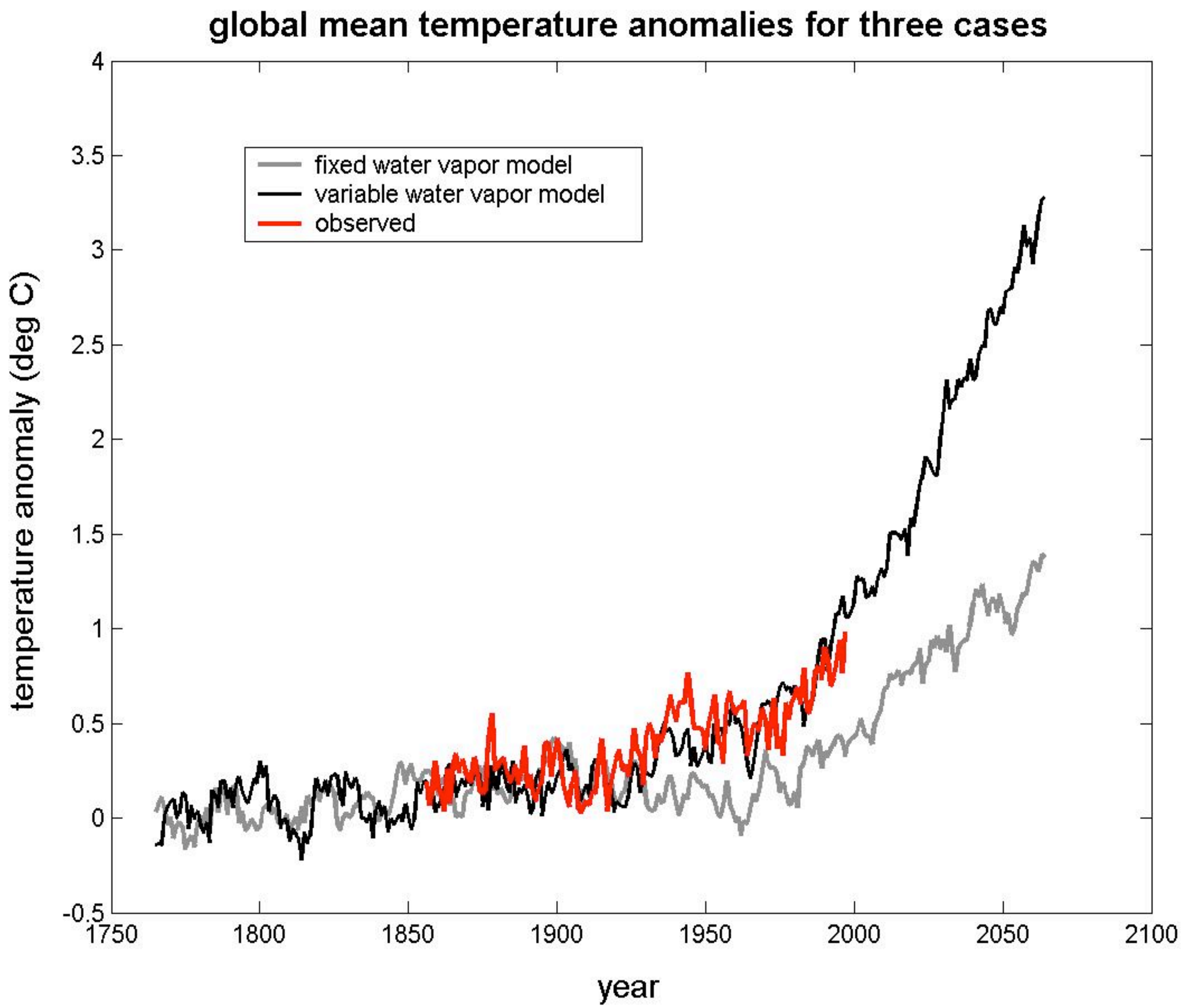
The global mean radiative forcing of the climate system for the year 2000, relative to 1750



When our best guess of the observed increase in greenhouse gases and sulfate aerosols is imposed on a general circulation model, the model simulates the warming trend over the past century quite well. Note that the warming trend over the next century is projected to dwarf that of the past century. This particular model was developed at the Hadley Centre in the U.K.

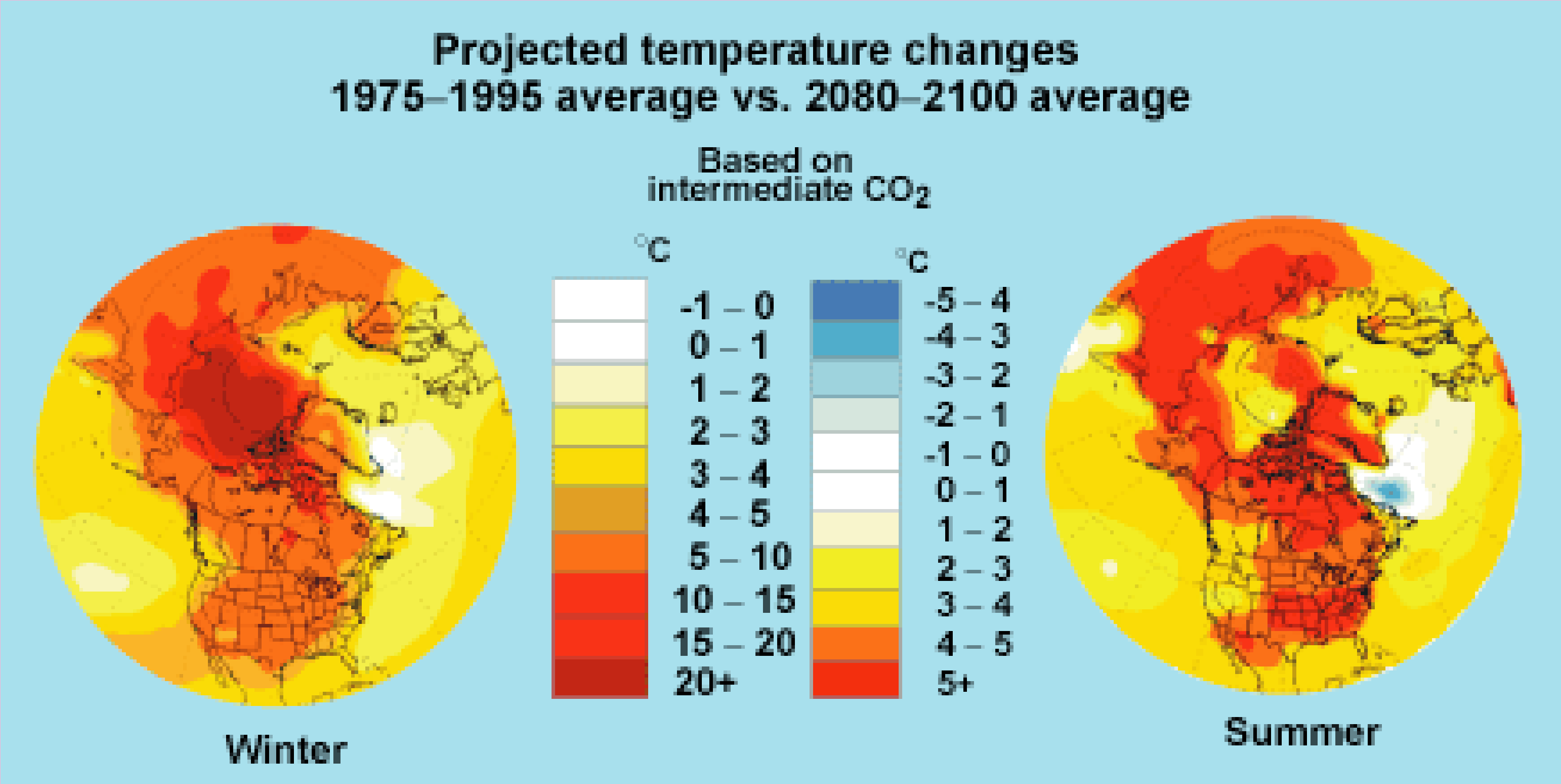


An example of how transient climate change experiments can help us learn about the climate system.

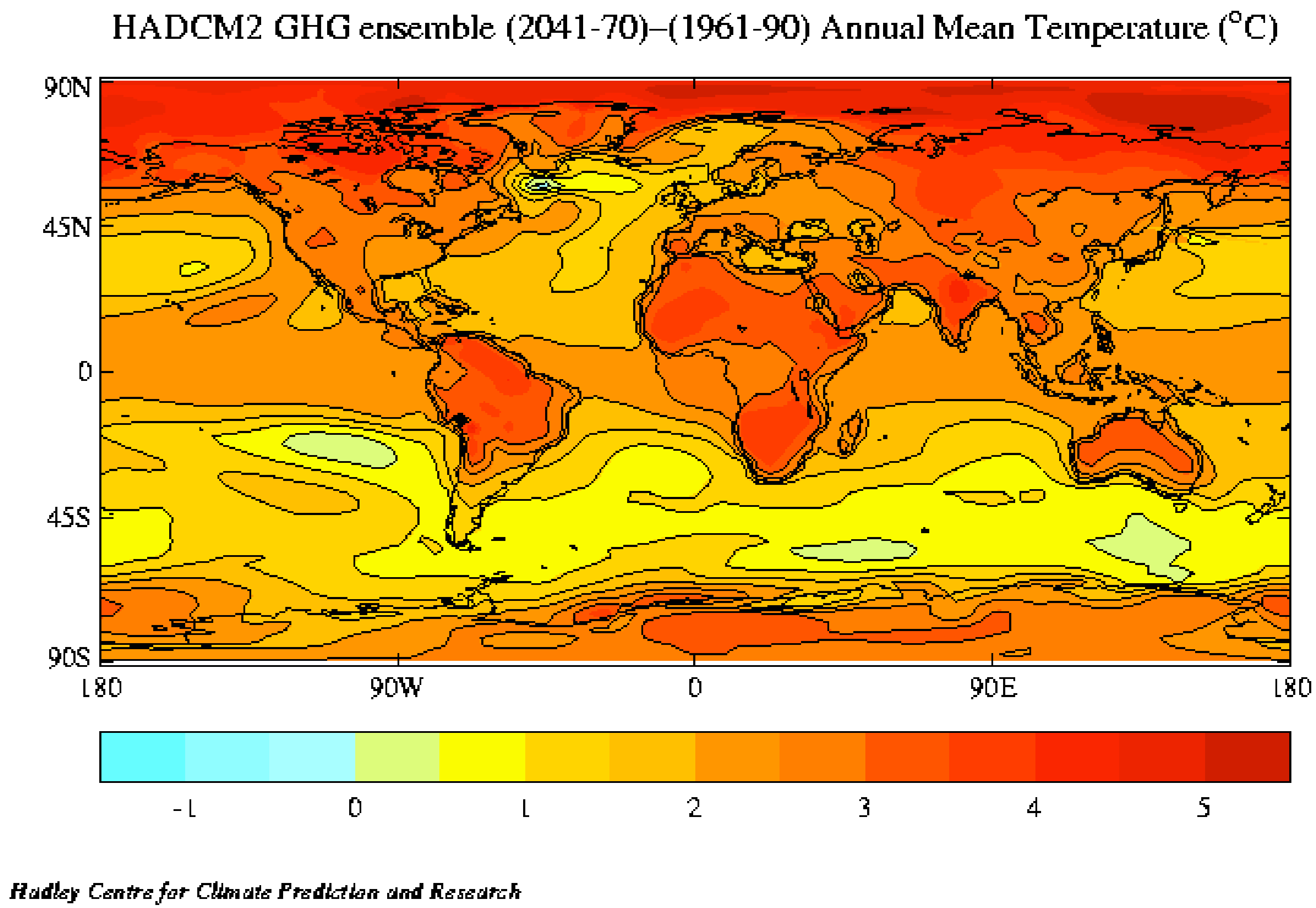


Princeton -GFDL model

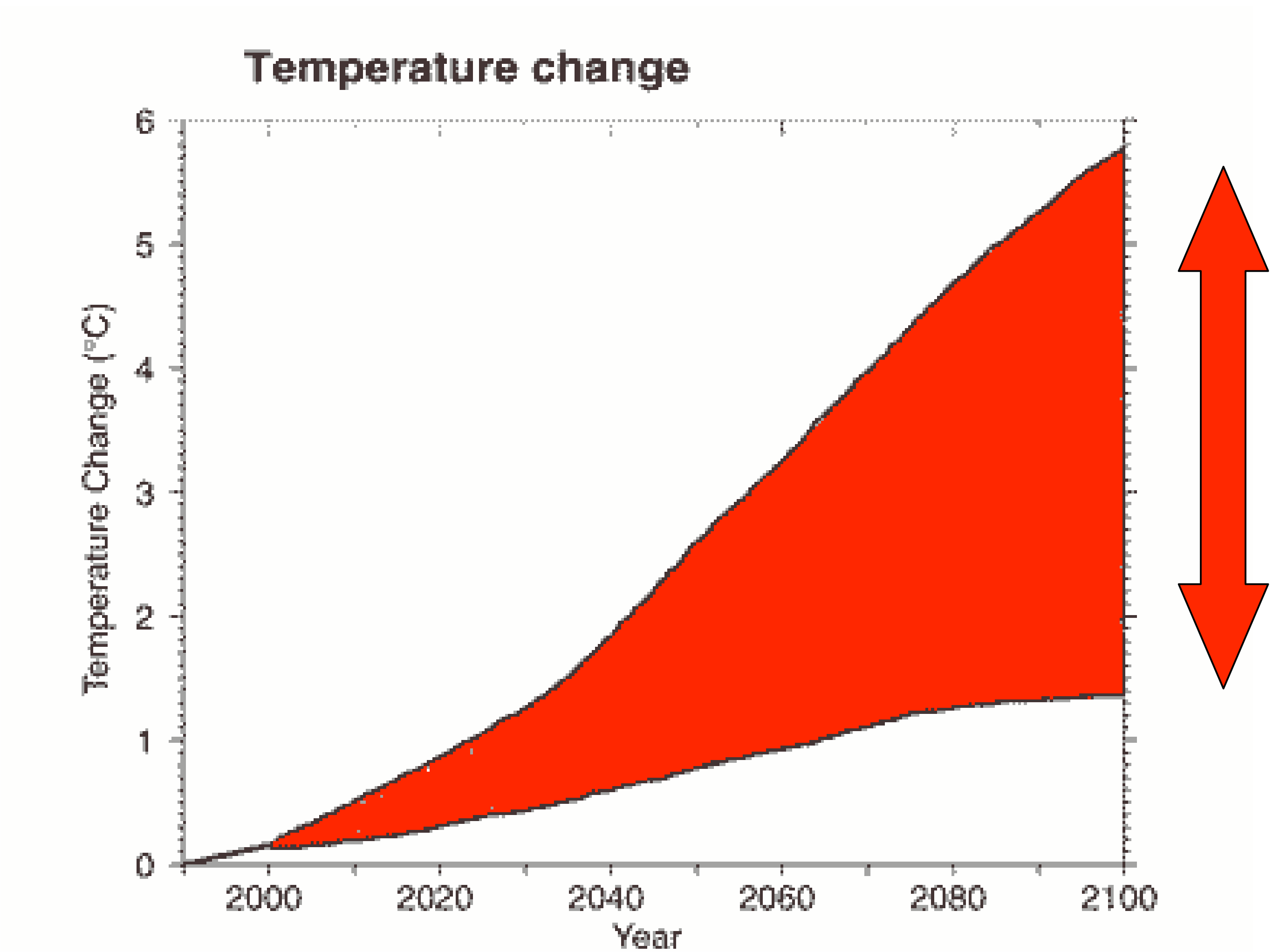
In transient climate change experiments, we can examine not only global mean temperature, but also the simulated geographical distribution of the climate change. This is an example from a simulation done with the Canadian Climate Model.



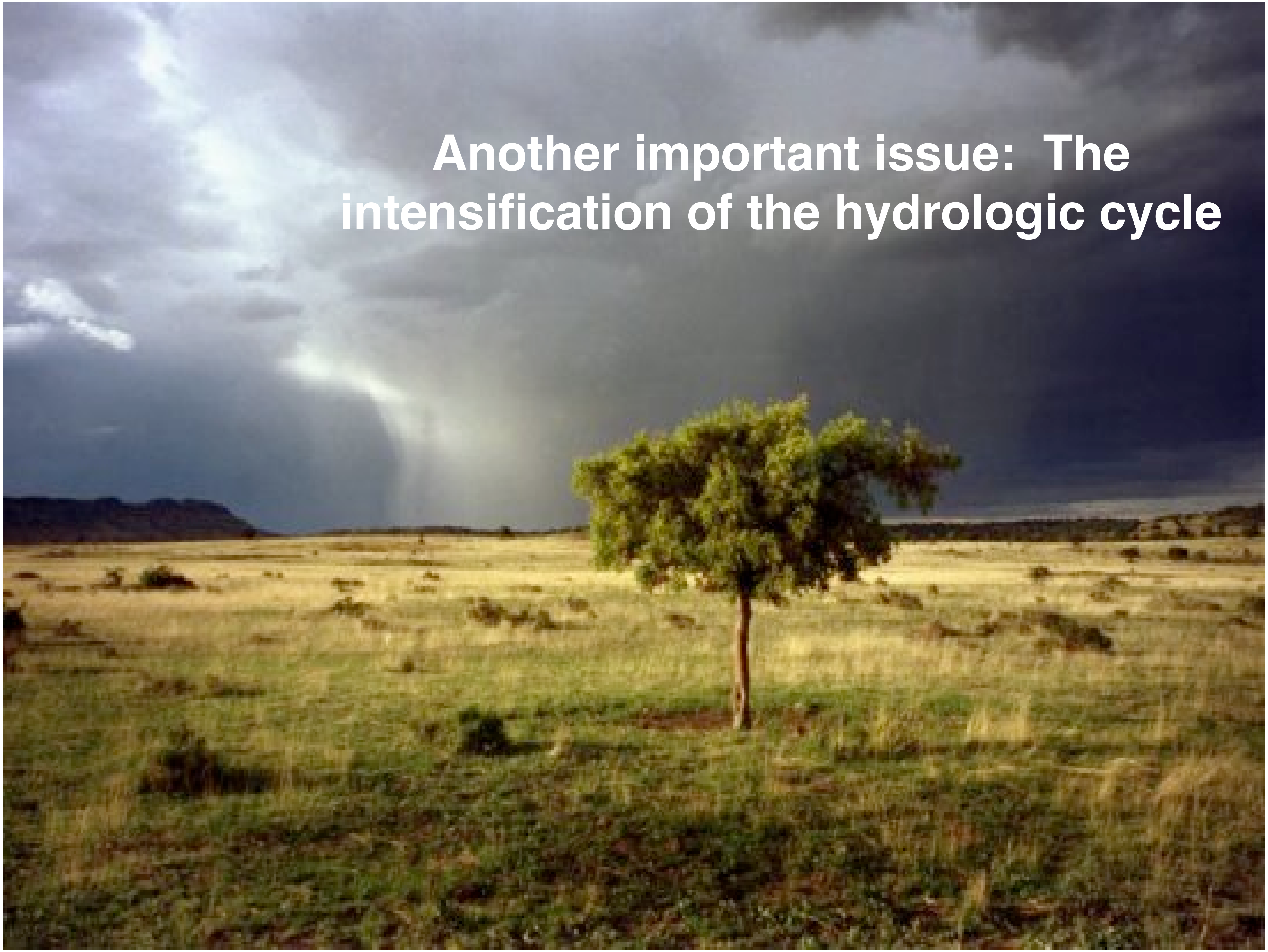
Here is an example of the temperature increase projected by the Hadley Centre model. On the regional scale, climate models tend to differ significantly.



Uncertainty about the future: **This plot shows the upper and lower limits of the warming over the coming century predicted by current GCM simulations.**



This range is due to two factors: (1) uncertainty in emissions scenarios and (2) different model sensitivities (i.e. different simulations of climate feedbacks).


Another important issue: The
intensification of the hydrologic cycle