Last Time…

What factors (other than human) influence climate?

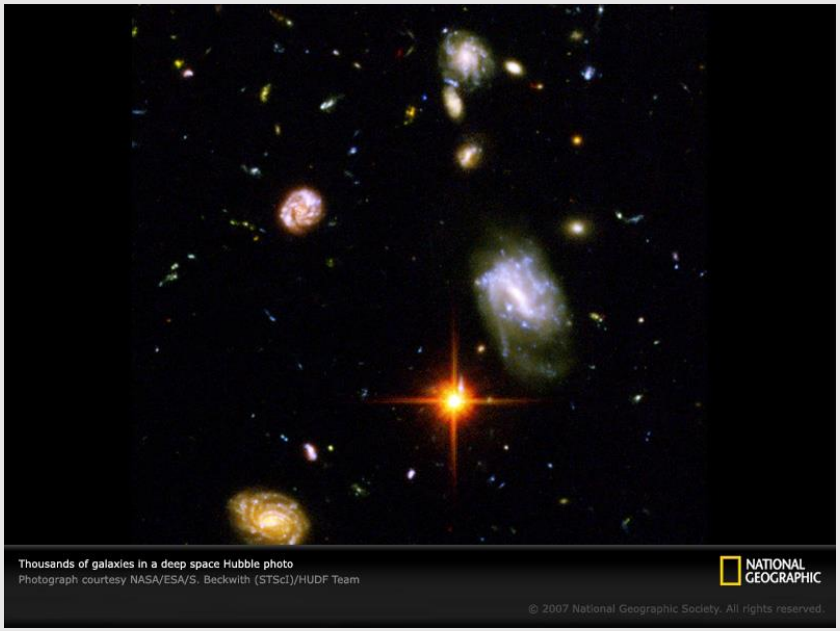
Climate Forcing Mechanisms

External

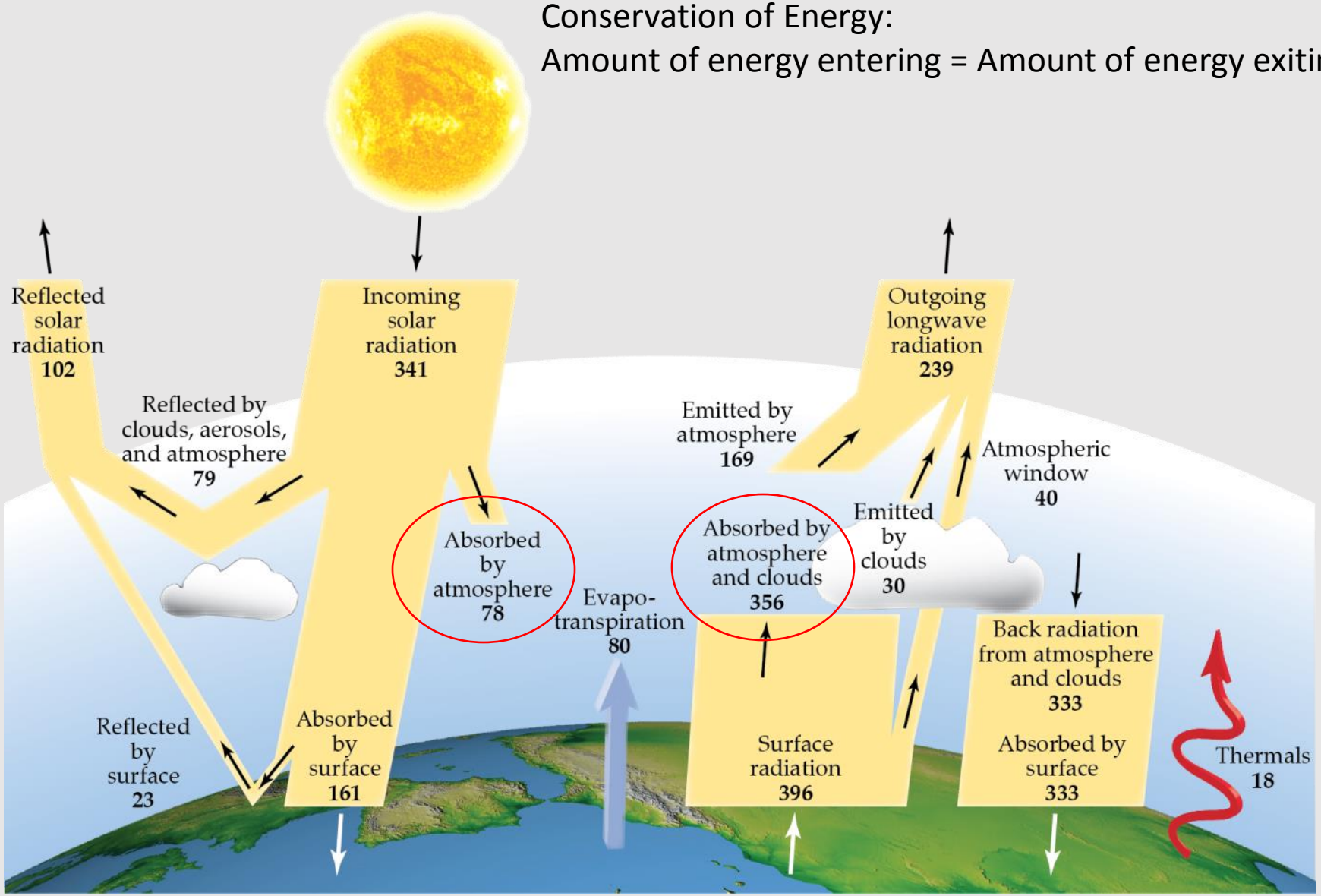
- Galactic variations
- Orbital variations
- Solar variations

Internal

- Albedo
- Orogeny
- Epeirogeny
- Volcanic activity
- Atmospheric composition



Conservation of Energy:
Amount of energy entering = Amount of energy exiting



Greenhouse Effect

The amount of energy entering = amount of energy exiting

It just changes form

When absorbed, generates heat (molecular motion) and changes to longer wavelength

Clouds

Reflect incoming solar radiation (high albedo)

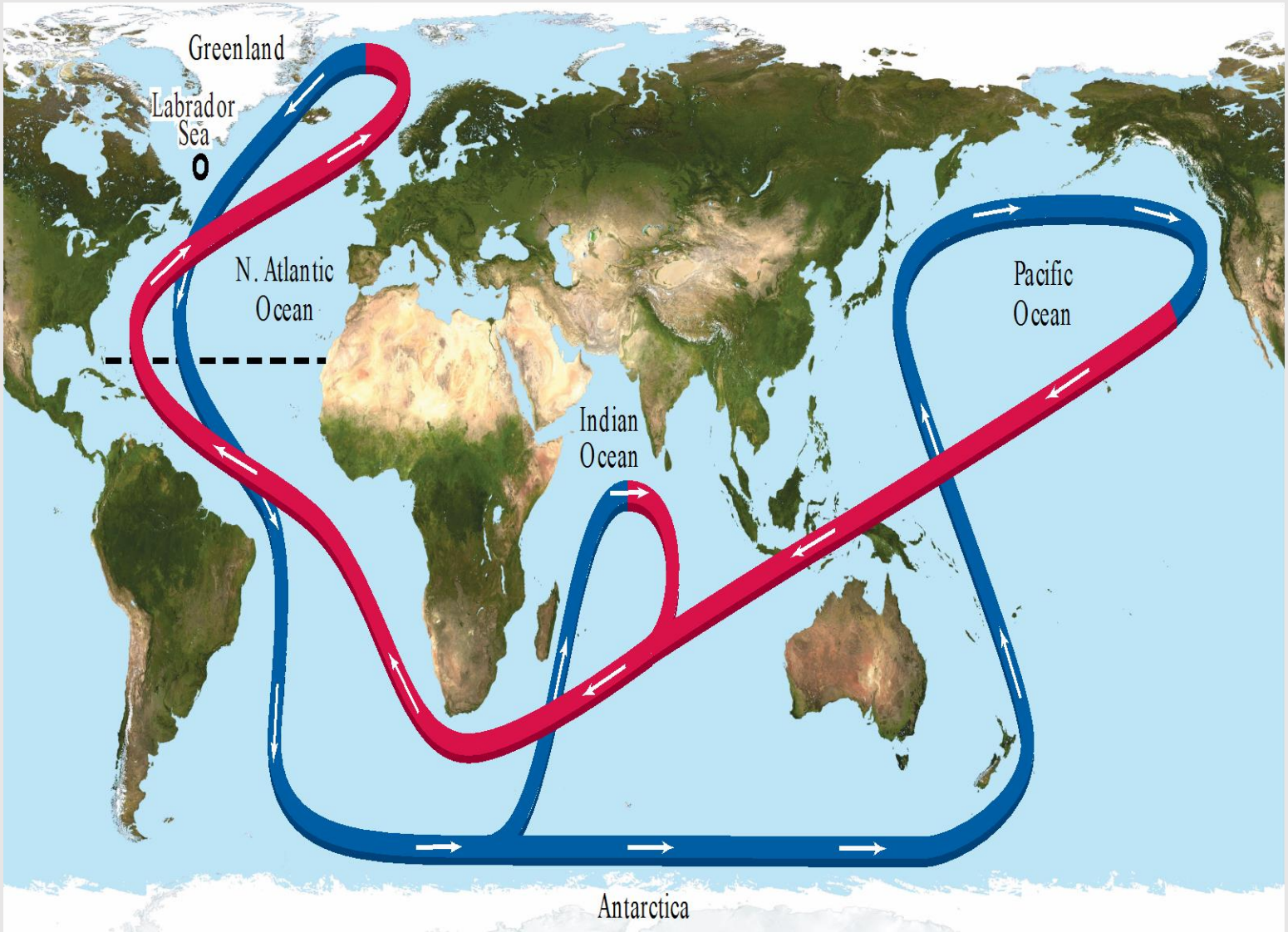
- Cools the planet

Absorb radiation from Earth's surface and re-radiate (like a GHG)

- Warms the planet

NET EFFECT = COOLING

Ocean Conveyer Belt



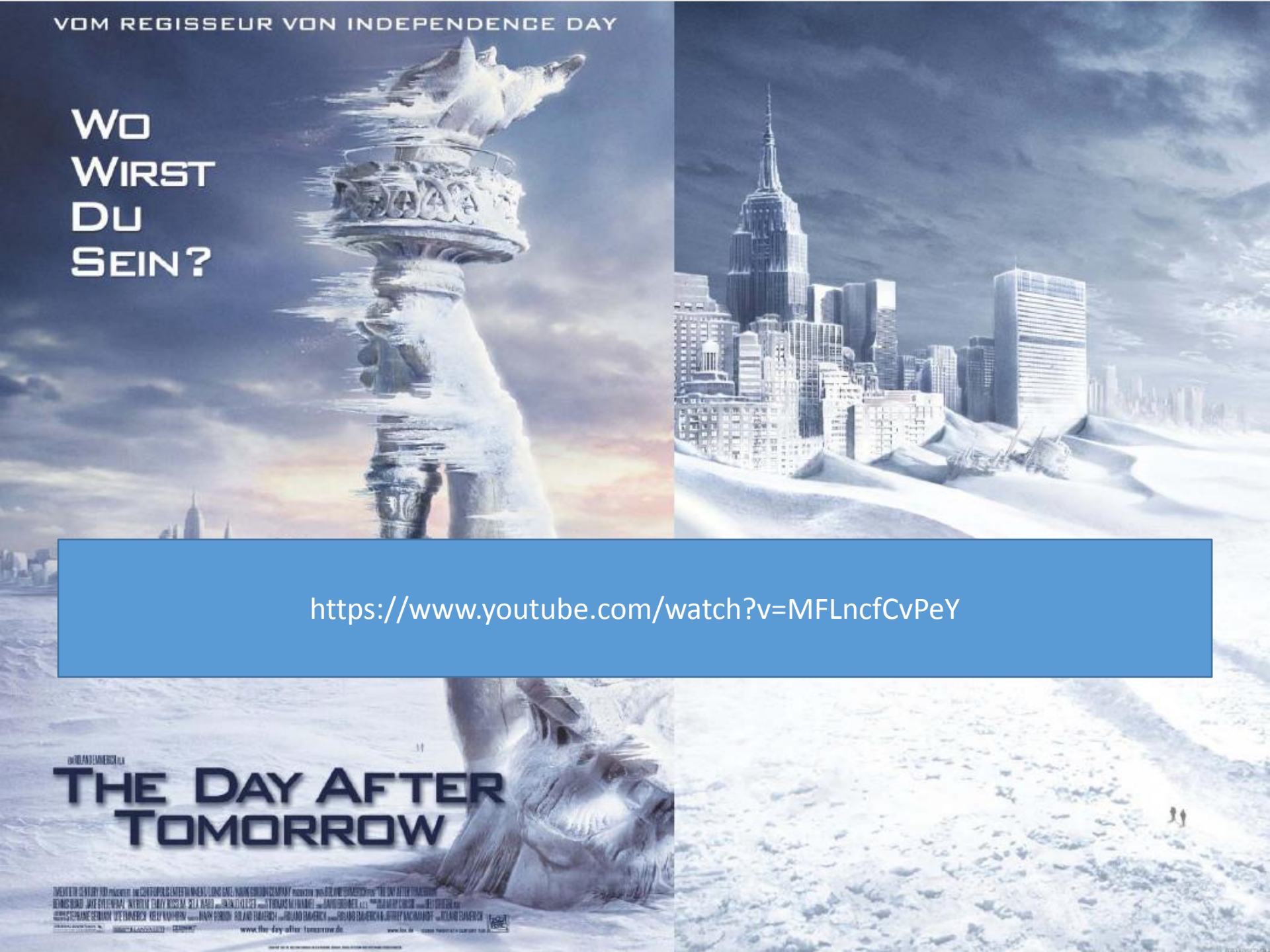
Cold, dense water sinks at the poles

Warm water rises at the equator

Warming at poles

- Decreases albedo (more warming)
- Increased ice melt
- Decreases salinity (more fresh water melting into ocean)

Critical desalinization point???



https://www.youtube.com/watch?v=MFLncfCvPeY

Could It Happen?

The Global Conveyor Belt in the Northern Atlantic has slowed in recent years

- Labrador Current has declined (measured by satellites)
- Deep, cold, southward currents slower (measured by ocean transects 5 times since 1957)

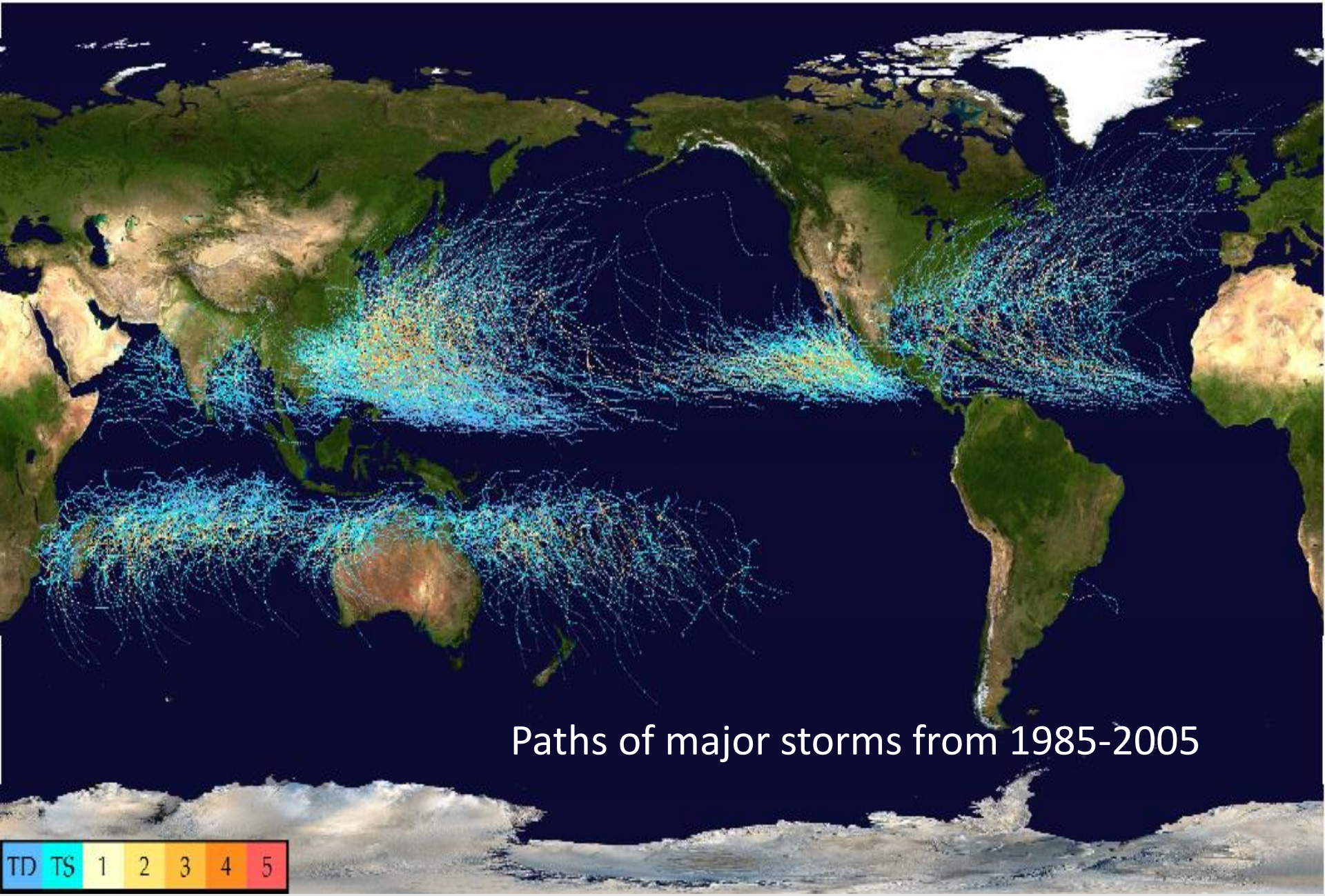
Could It Happen?

- Some currents have slowed
- Large variations are normal

More, long-term measurements needed

Temperatures in the North Atlantic coastal regions are warming, rather than cooling

Tropical Storms



Storms

- Number and severity of storms vary widely from year to year and by location
- Most major storms originate in the tropics
  - Warm water evaporates from the sea, rises in atmosphere, condenses at cooler higher altitudes
  - Storms grow until they pass over land and are cut off from warm surface waters

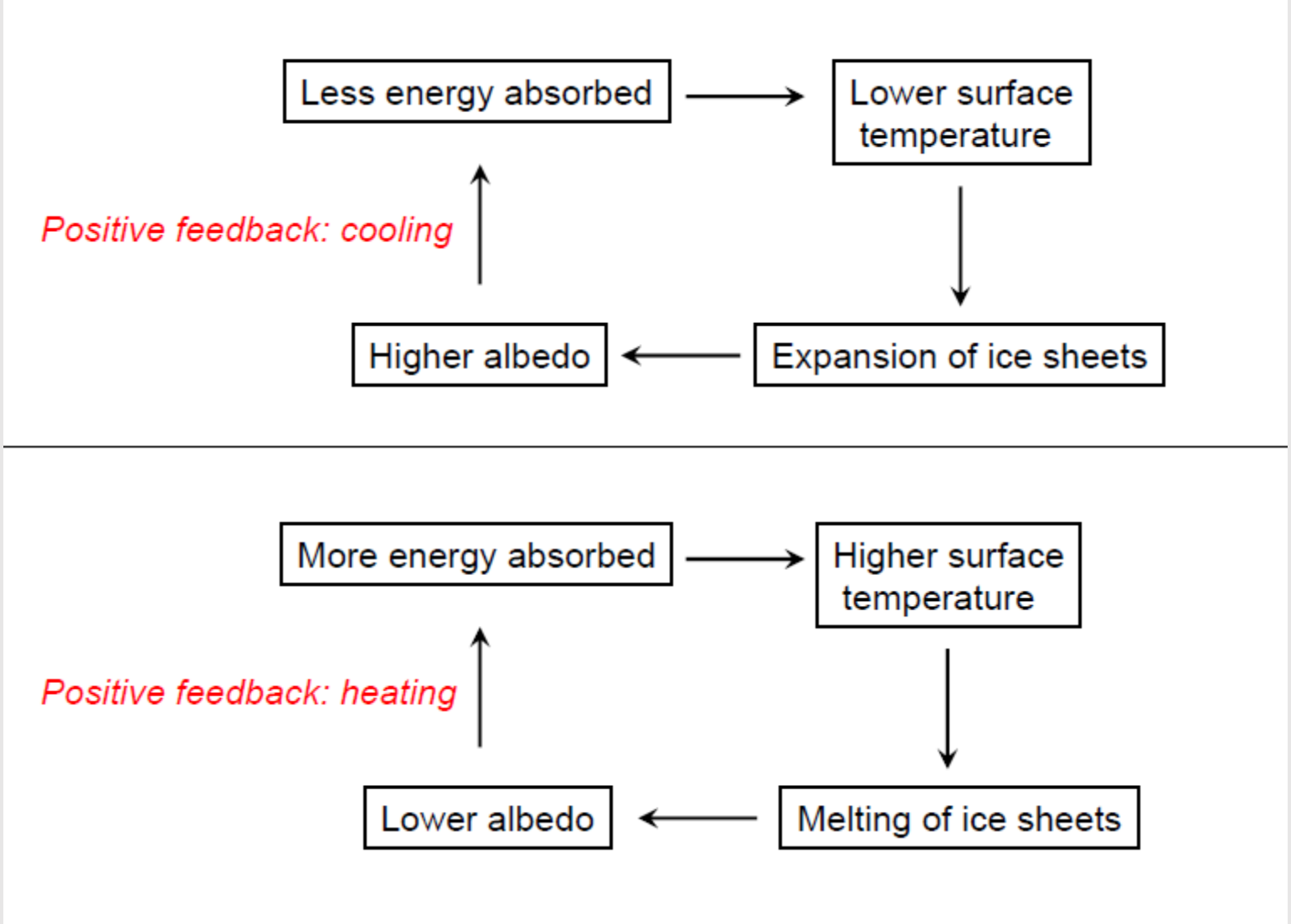
Storms

Global climate change, through warming of sea surface, should increase severity of storms

Difficulties in Understanding Climate

- Nonlinearity
- Complex interactions
  - Many factors
  - **Positive feedback**
    - Snowball earth

Snowball Earth



Runaway Greenhouse Effect?

Positive Feedback

Self-reinforcing effect; effect causes more of itself

The system is unstable; will spiral out of control as the effect amplifies it

Difficult to Make Predictions

Climate forcing mechanisms (internal and external) prohibit direct experimental manipulation

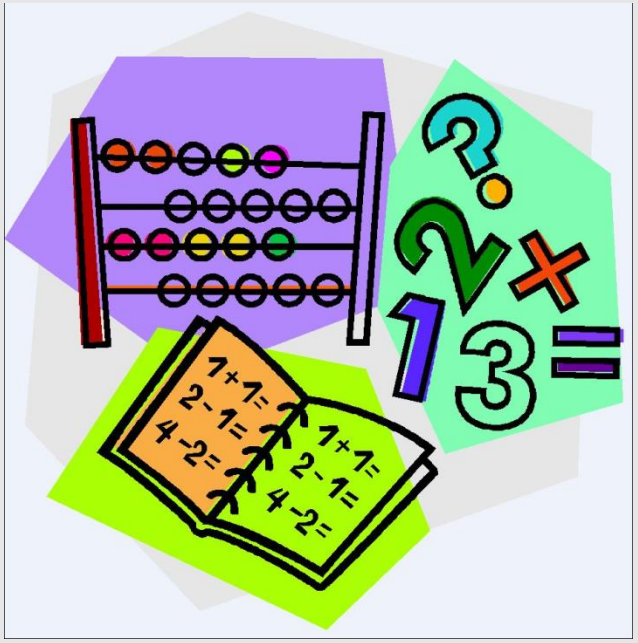
- –Slow
- –Large
- –Unapproachable
- –Costly

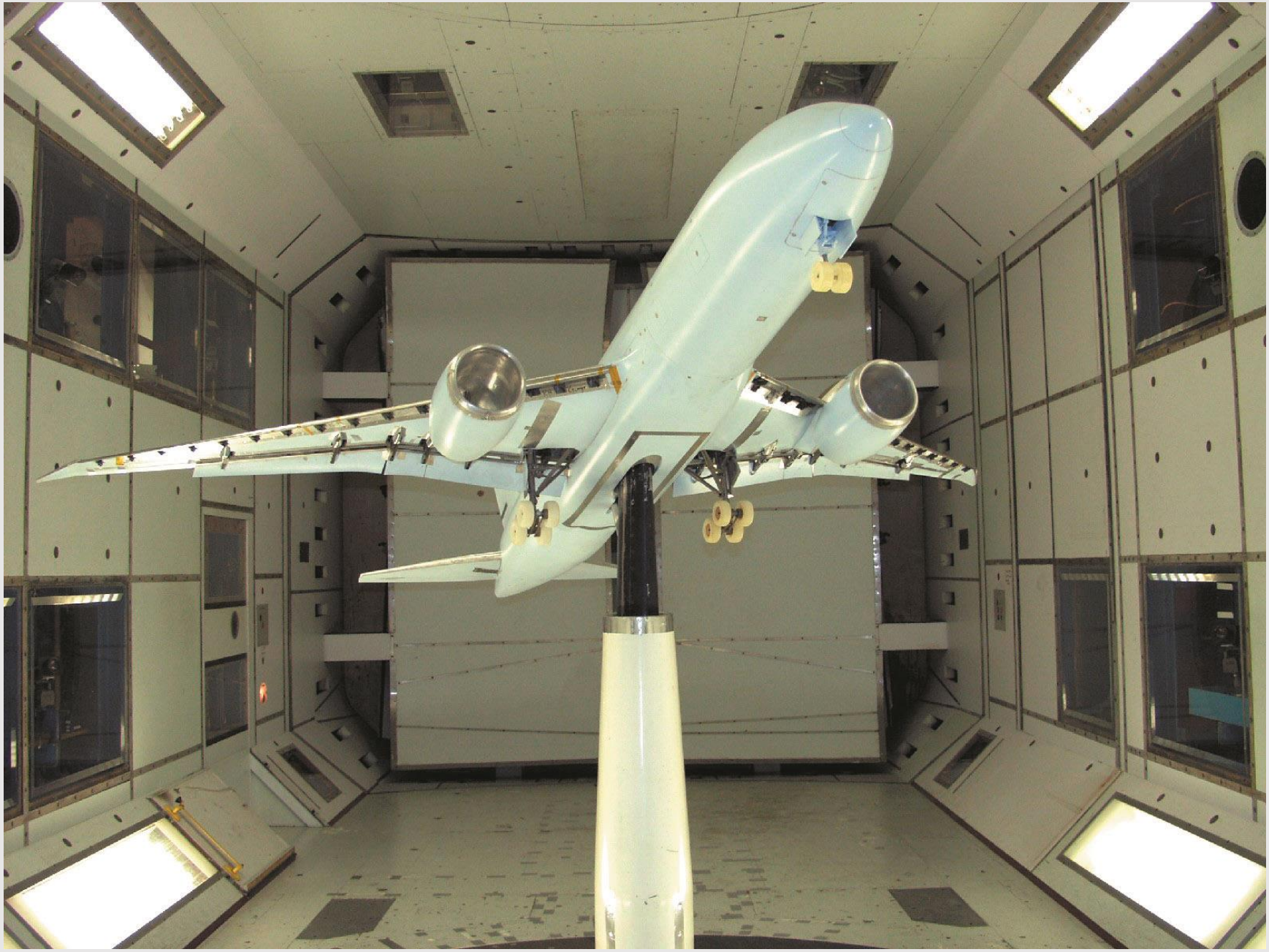
Models of Climate

- Shorter in duration
- Smaller in size
- More accessible
- Less expensive

Models of Climate

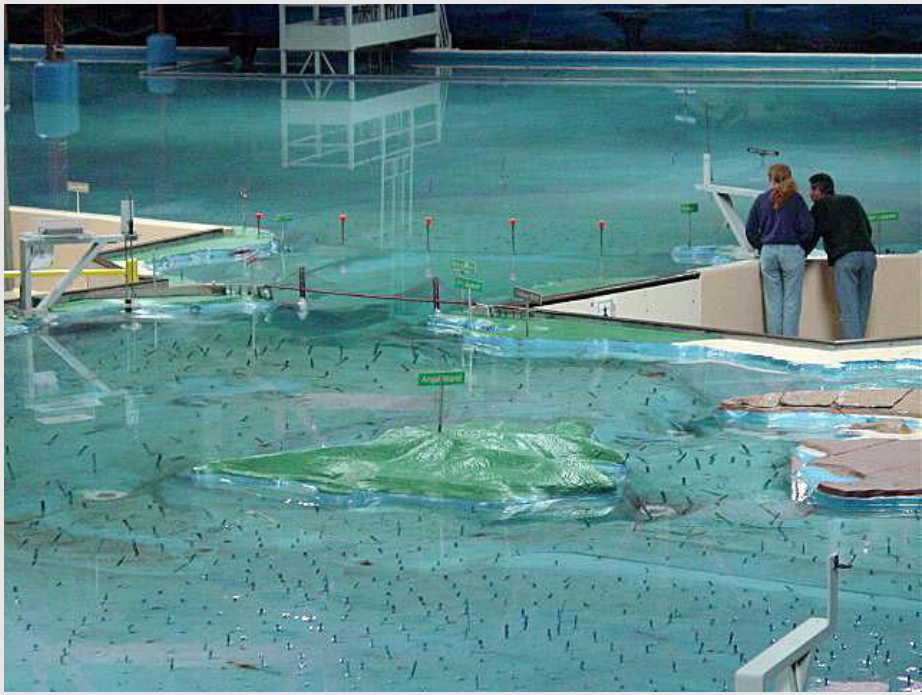
Physical models or mathematical abstractions.





Physical Models

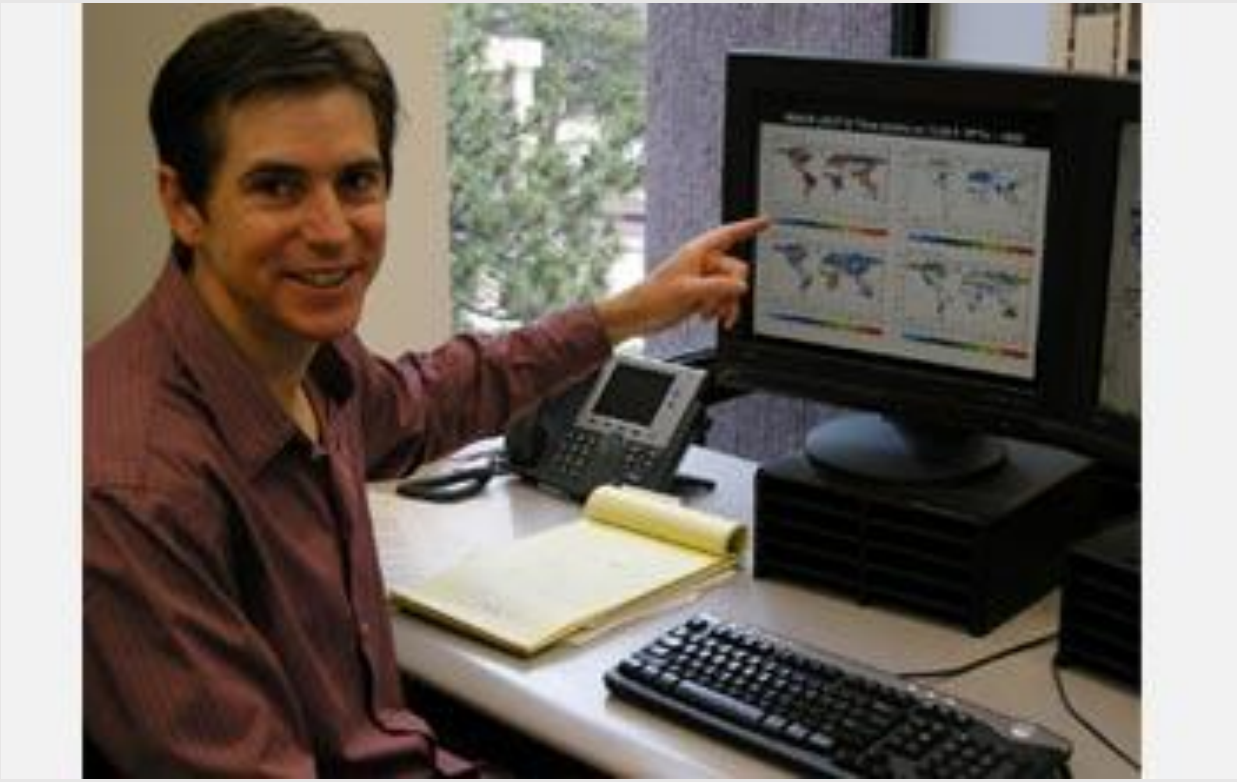
Mimic the functions of their full-size counterparts



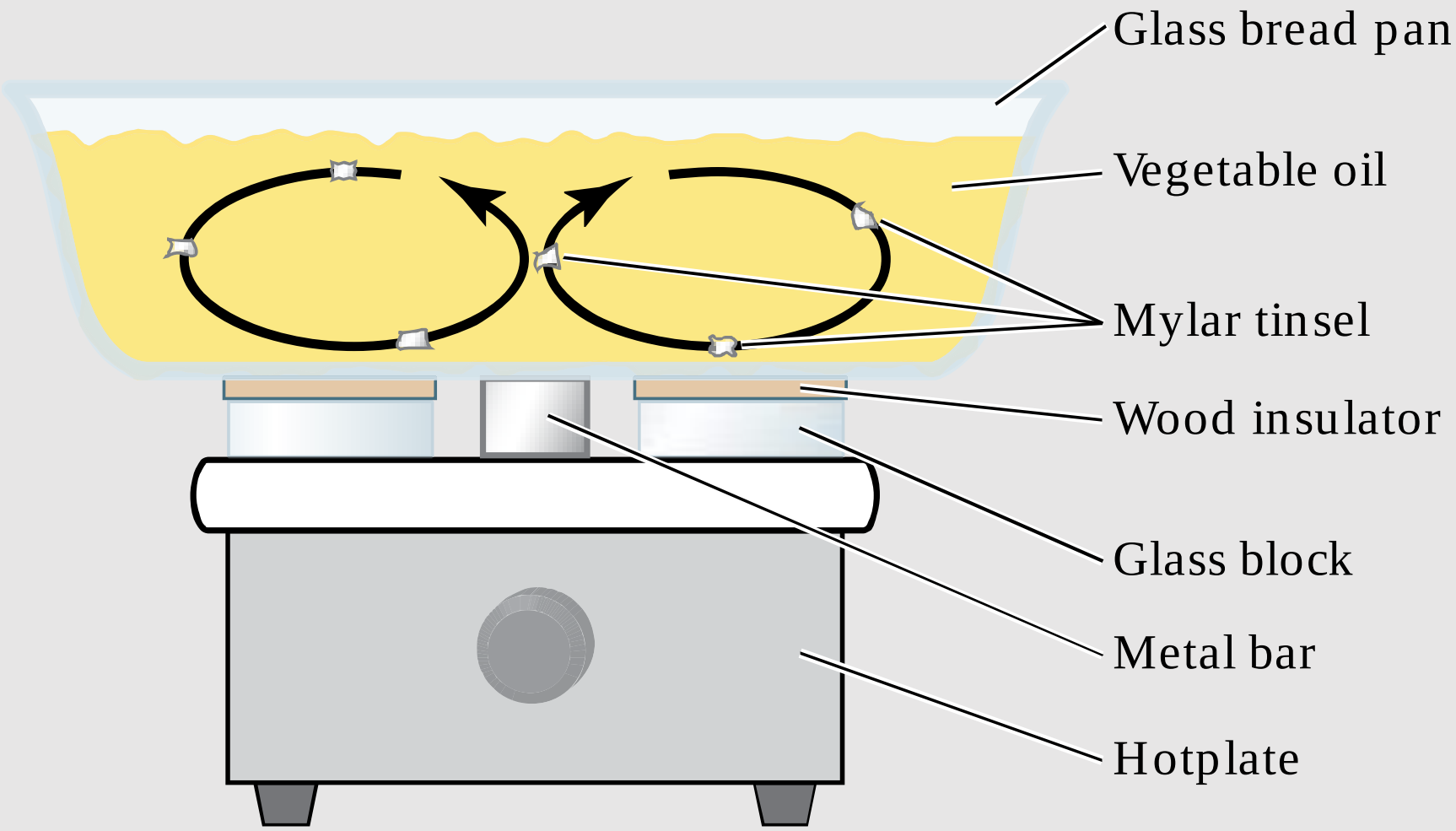
Model of SF Bay to determine how diverting water might influence water quality

Computer Simulation Models

Supplement or replace physical models



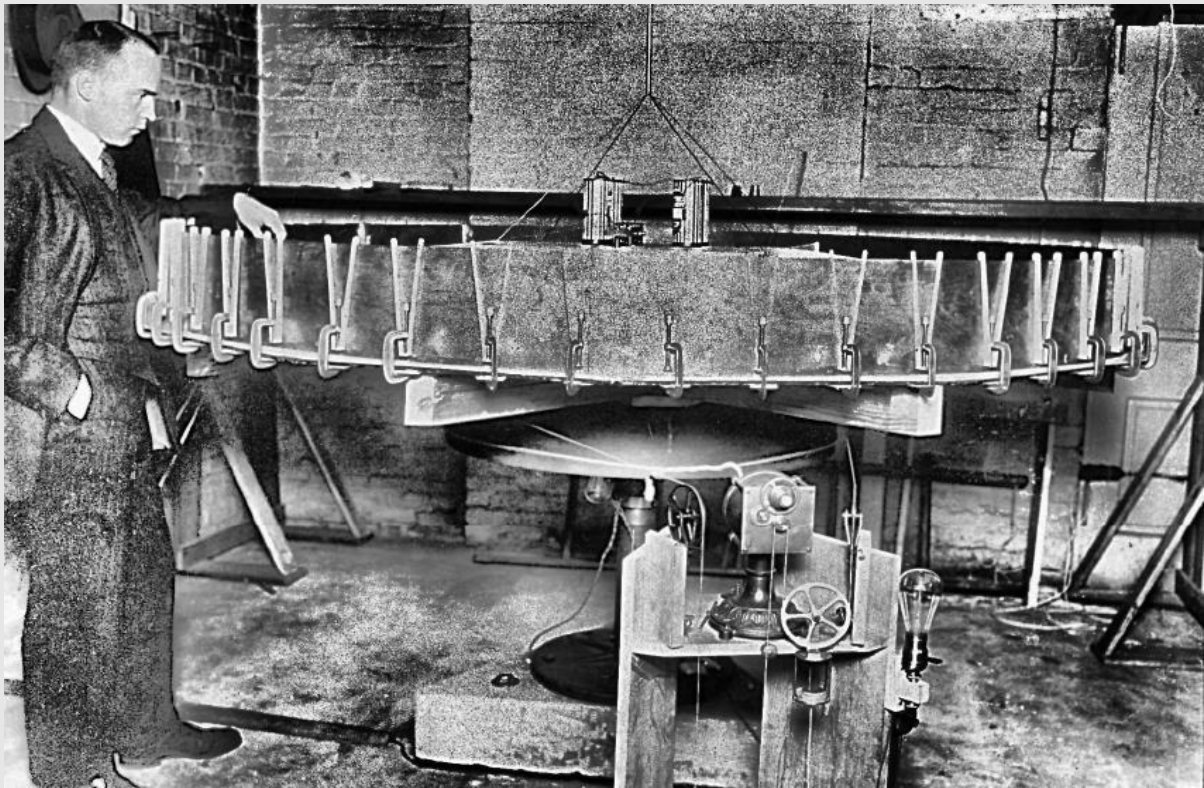
Early climate models were physical



General Circulation Models

GCM stands for General Circulation Model and **Global Climate Model**

1926: explanation of large-scale motions of the atmosphere in terms of fluid mechanics. A heated tank on a turn table.

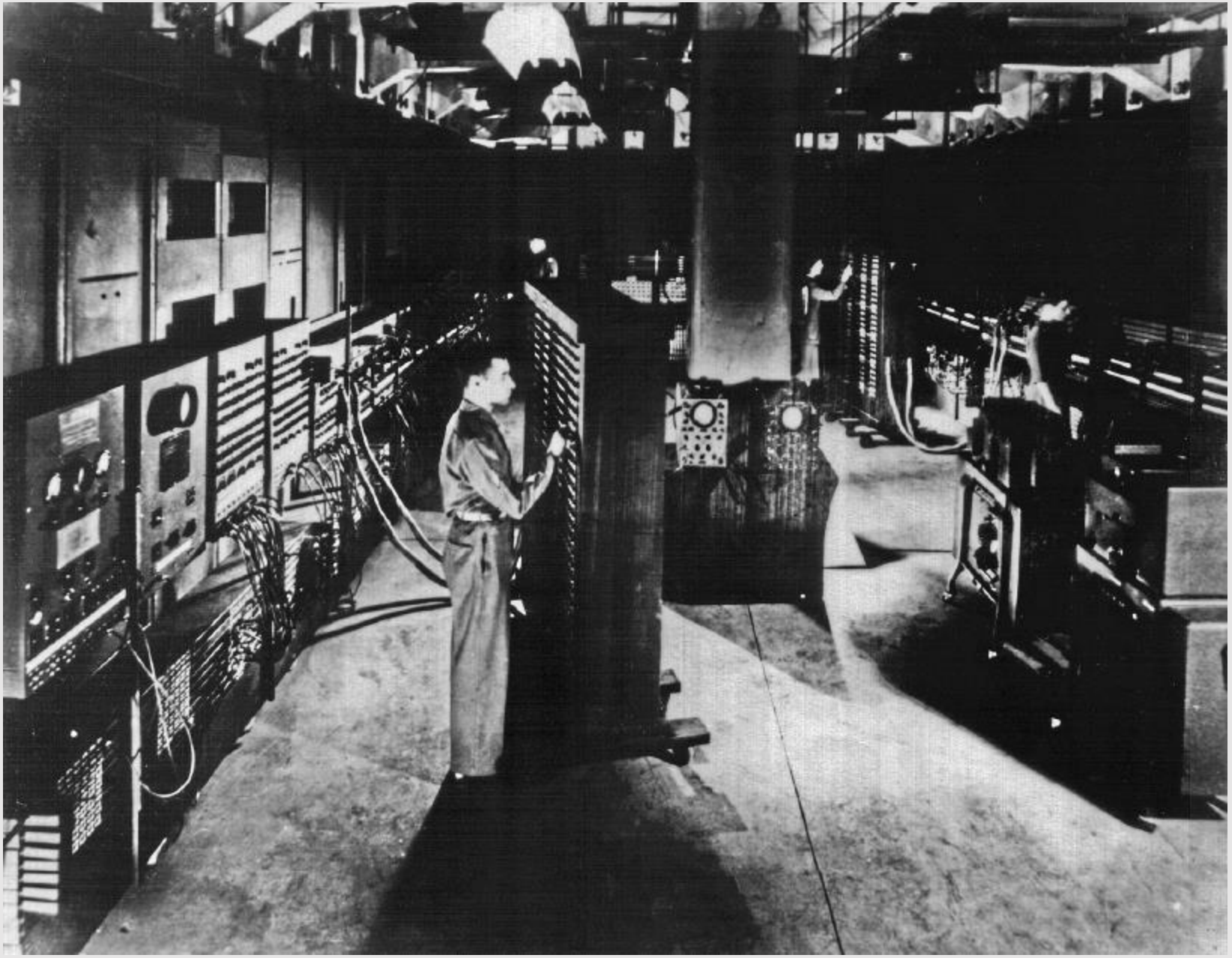


GCMs

Digital computers developed near end of WWII

First digital computer used to calculate trajectories of artillery shells and design hydrogen bomb

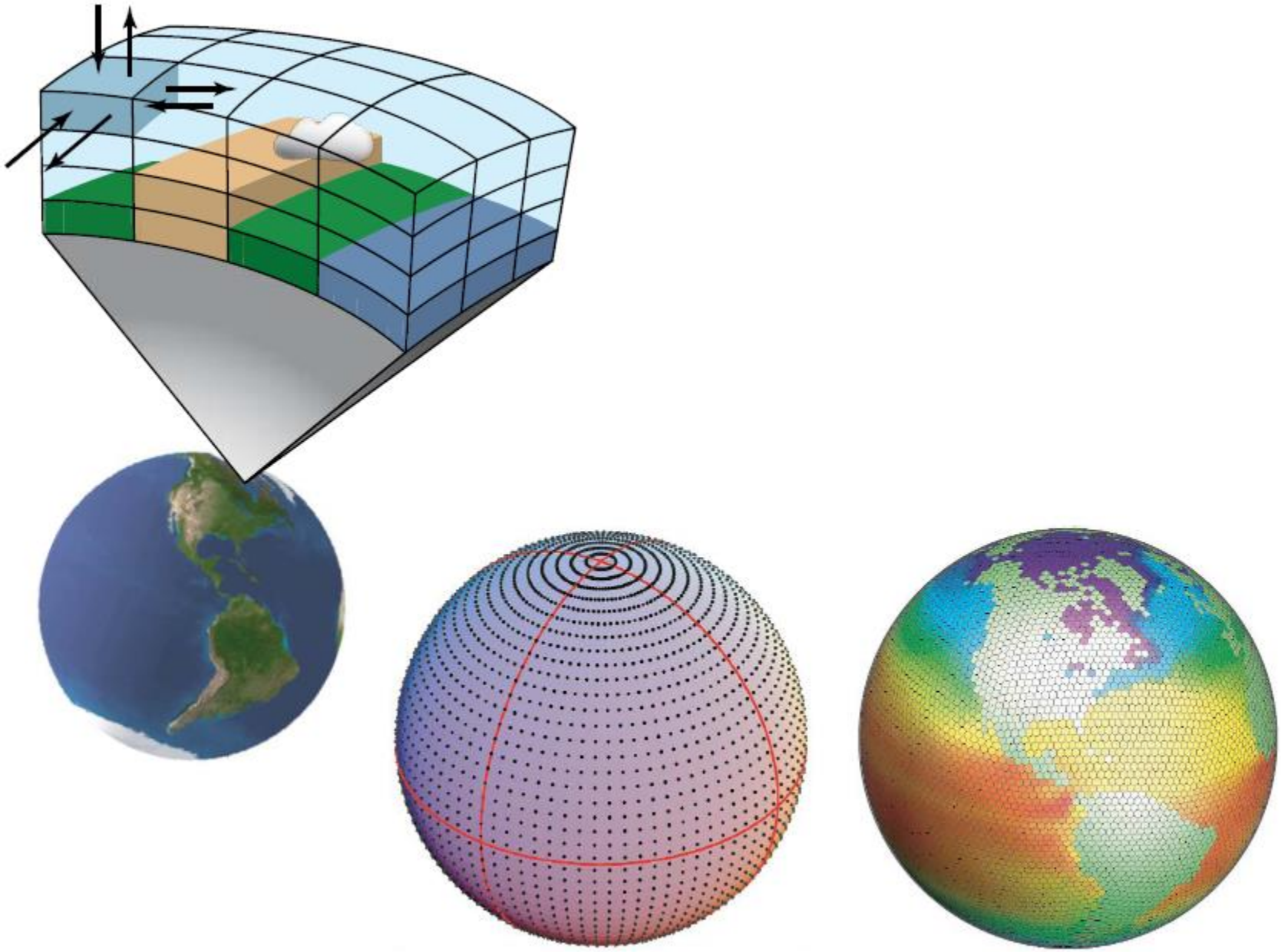
Used for climate models in 1950




NEC
SX-9

How Do They Work?

- Divide the world into boxes
  - The breadth and width of the boxes varies by model
- Passage of time is calculated in steps
  - Calculations made for discrete moments separated by certain time intervals (vary by model)
- Accuracy of models increases with smaller grid size and shorter time steps, but this requires longer computation time



Time Required to Calculate 300 Years of Climate

Year	Computing Time	Resolution
1975	50 days	Low
1994	760 days 352 computer cluster	High
2004	37 years 2,560 computer cluster	Very High

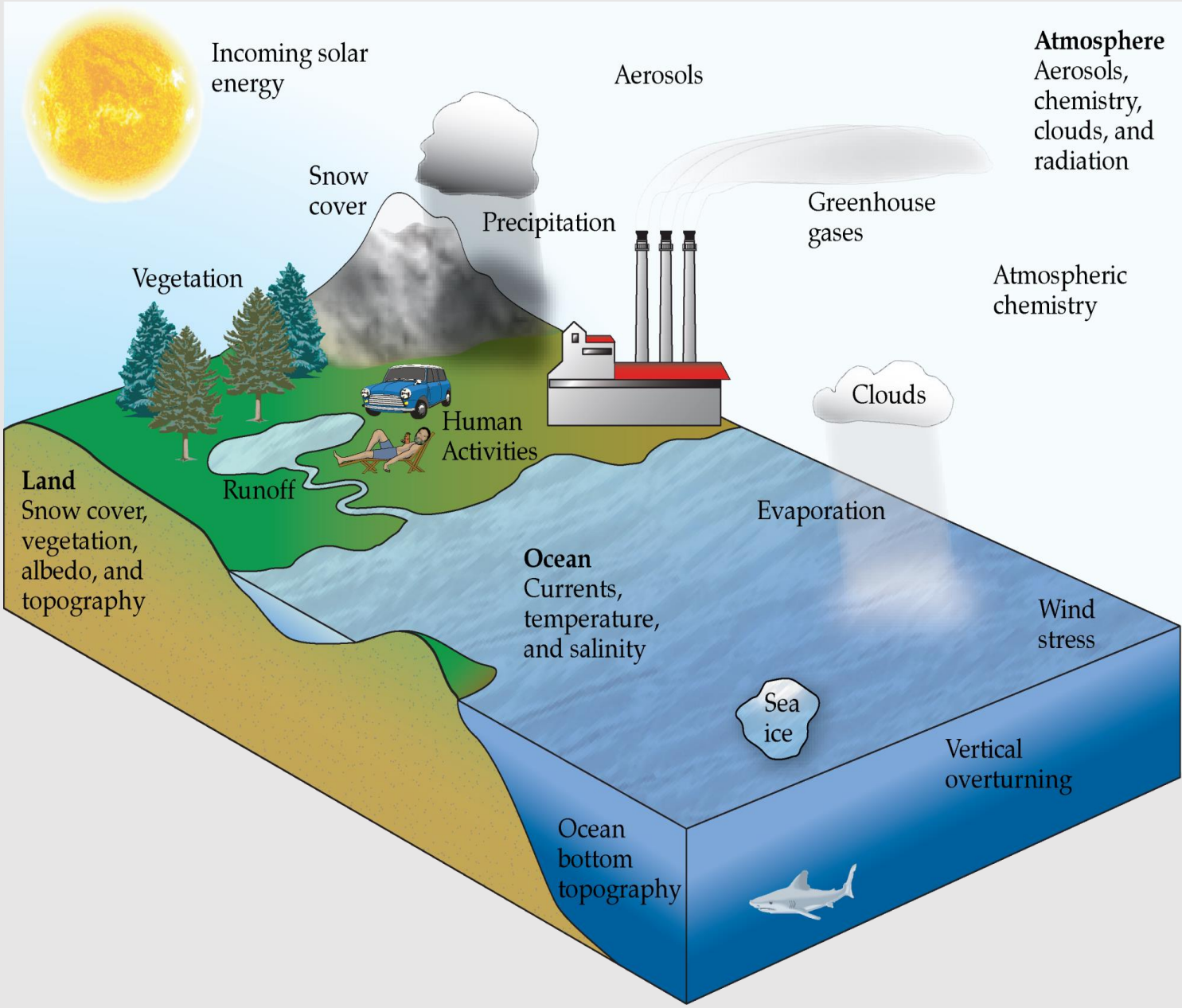
GCMs

- To cut down on computer time:
  - Run different parts of a model simultaneously on separate, linked computers
  - Use results of a low resolution model to run a high resolution model. Ex: use results of a model that covers N. America to run a model that only covers California

Combined models cut down on computation time, can calculate long term climate reconstructions

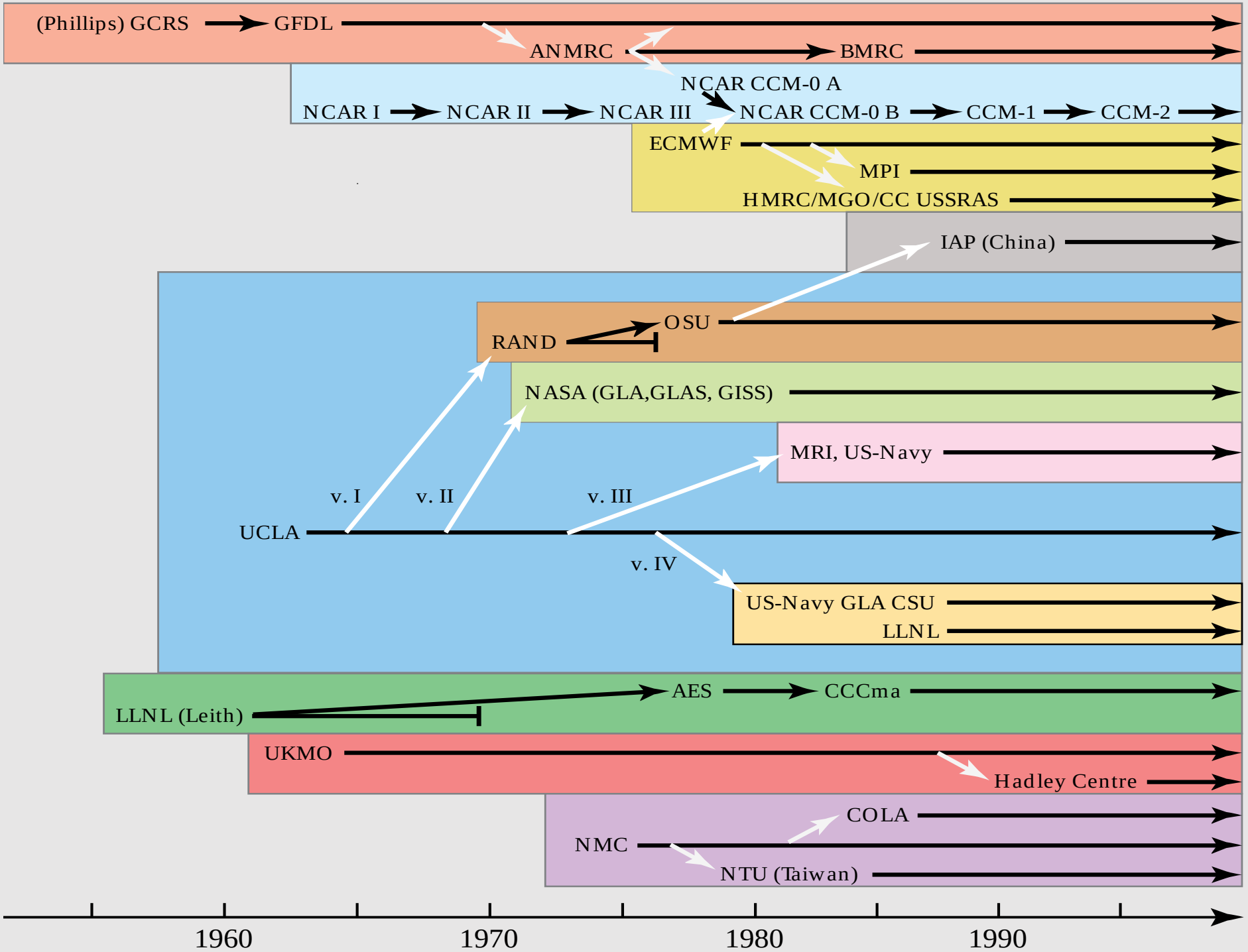
GCMs divide the planet into separate processes

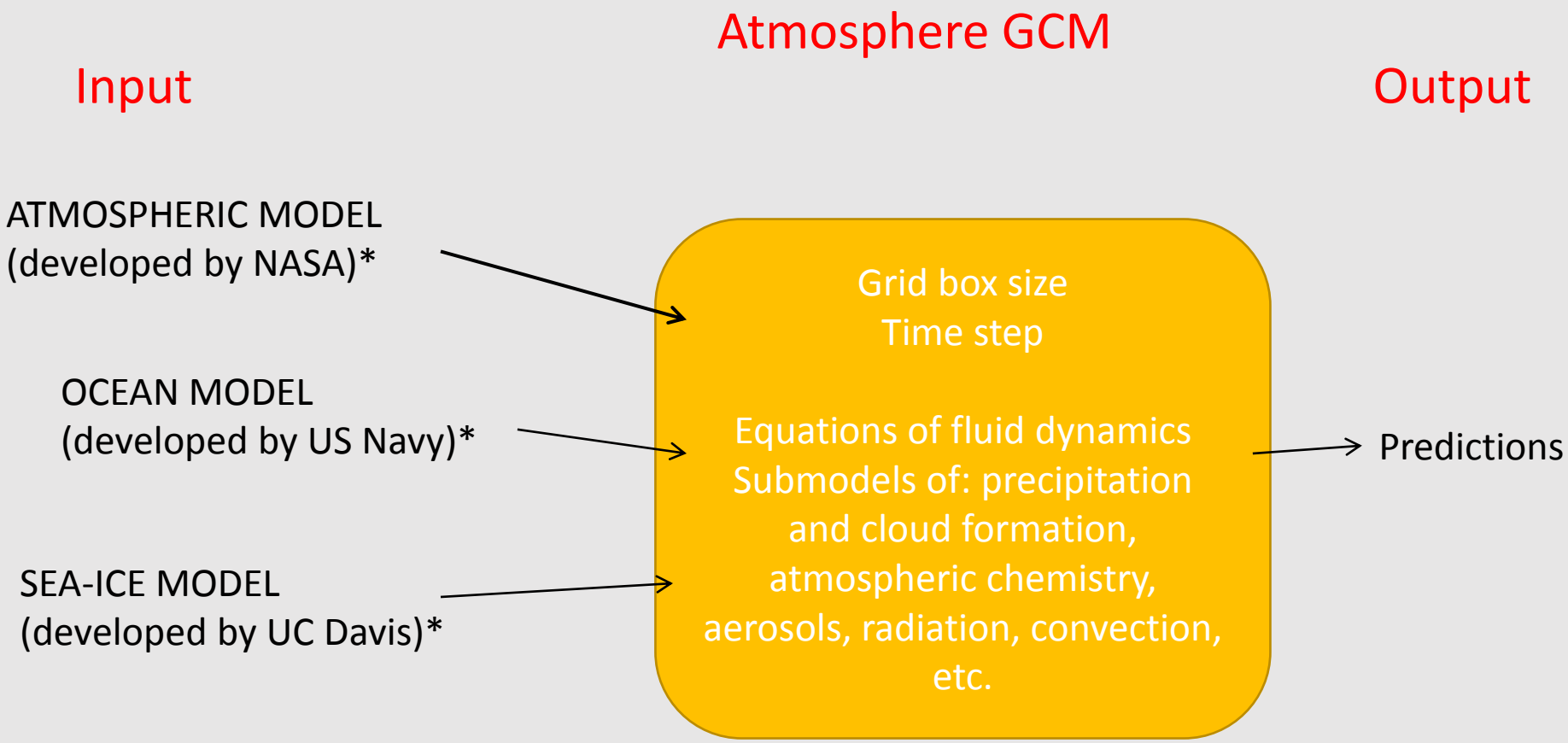
Each process has a separate model



GCMs: Input

- These separate models are independently developed by various researchers/institutions
- Independent models are incorporated into a large computer program
  - Coordinates timing and format of data exchange among atmosphere, ocean, sea ice and land models


(Phillips) GCRS
GFDL
ANMRC
BMRC
NCAR CCM-0 A
NCAR I
NCAR II
NCAR III
NCAR CCM-0 B
CCM-1
CCM-2
ECMWF
MPI
HMRC/MGO/CC USSRAS
IAP (China)
OSU
RAND
NASA (GLA,GLAS, GISS)
MRI, US-Navy
v. I
v. II
v. III
UCLA
v. IV
US-Navy GLA CSU
LLNL
AES
CCCma
LLNL (Leith)
UKMO
Hadley Centre
COLA
NMC
NTU (Taiwan)
1960
1970
1980
1990



*These are examples. Each model has many independent developers.

ATMOSPHERE

Grid box size

Time step

Equations of fluid dynamics

Submodels of: precipitation and cloud formation, atmospheric chemistry, aerosols, radiation, convection, etc.

OCEAN

Grid box size

Time step

Equations of fluid dynamics

Submodels of: ocean fluid motions, wind stress on surface mixing layers, freshwater inputs, etc.

LAND

Grid box size

Time step

Equations of fluid dynamics

Submodels of: carbon cycling, vegetation, albedo, etc.

- GCMs vary:
  - In the information they use as an input
  - In the equations used in the GCM

- Different GCMs give different output (predictions)
  - These give us different scenarios

Testing a GCM

- To verify a GCM, use it to simulate the climate for some time in the past and compare the model's output with what actually occurred.
- Discrepancies indicate problems with the model.

Solar Job Boom Continues As Prices Spur Demand
-Thanks Anna Gomes!

http://www.livescience.com/53387-solar-job-boom-amid-strong-demand.html

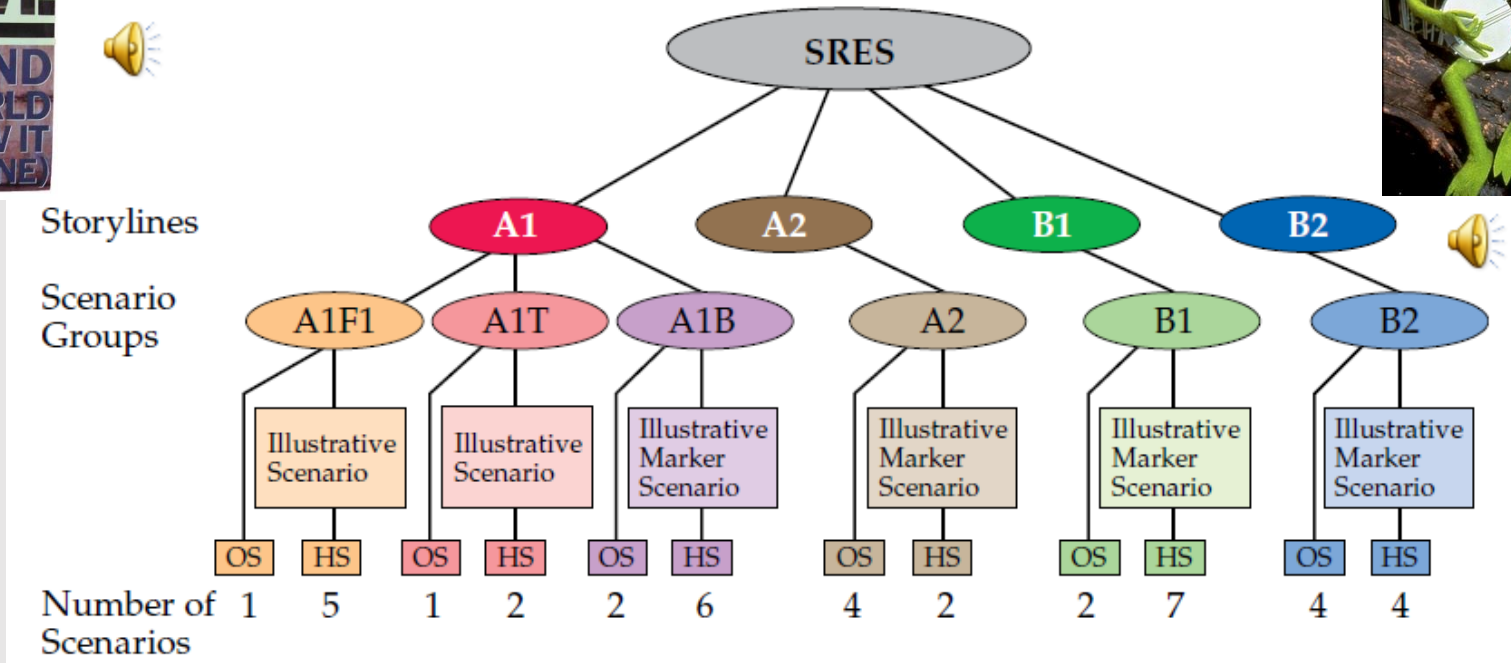
"The U.S. solar power industry continued its hiring spree in 2015, growing nearly 12 times faster than overall U.S. employment. The solar industry has seen 123 percent growth in employment since 2010."

"Solar is seen as one of the primary low-carbon alternatives to coal-fired power plants, the globe's largest source of greenhouse gas emissions driving climate change. About 25 percent of all the nation's solar power capacity has been installed in just the last year, according to the census."

Now realizing how interconnected everything is and how climate change is not only affecting our environment, but also the industries.

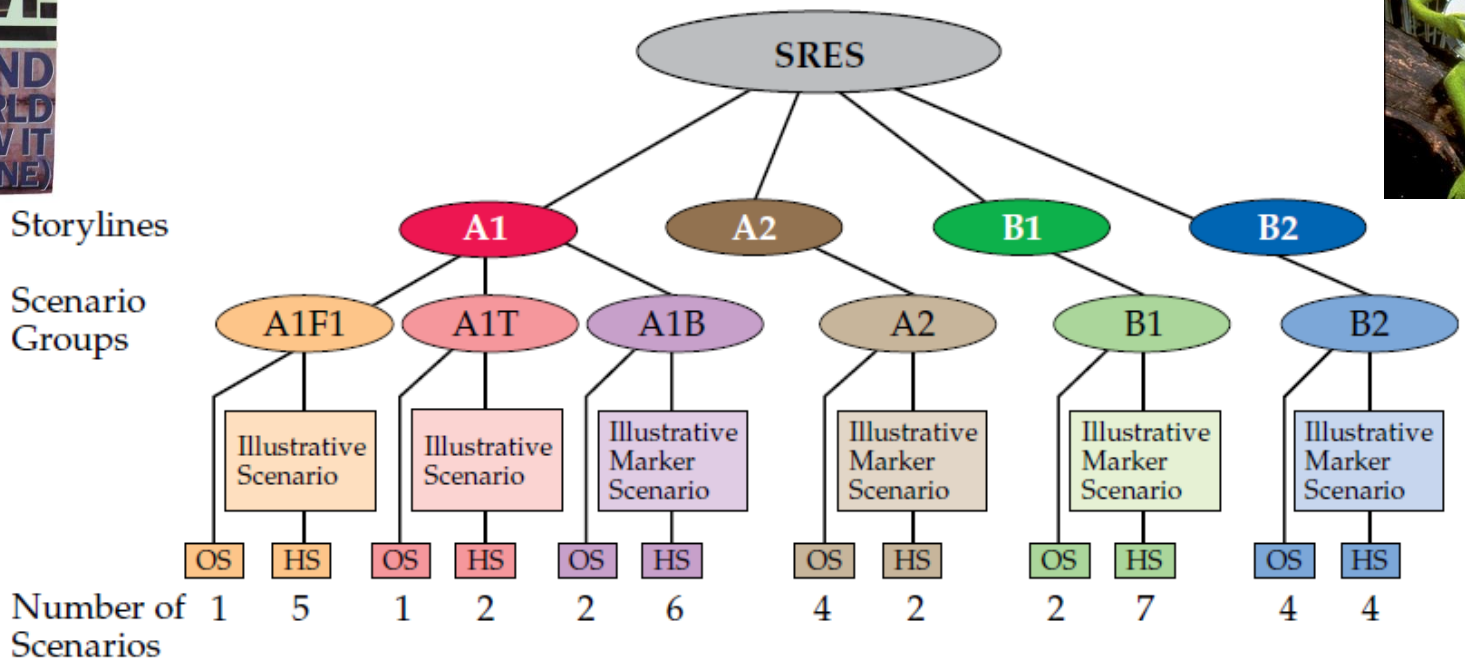
Prediction Scenarios

- A1: assumes slowing human population growth but rapid economic development based on fossil fuels (A1F1), alternative fuels (A1T) or a mix of both (A1B)



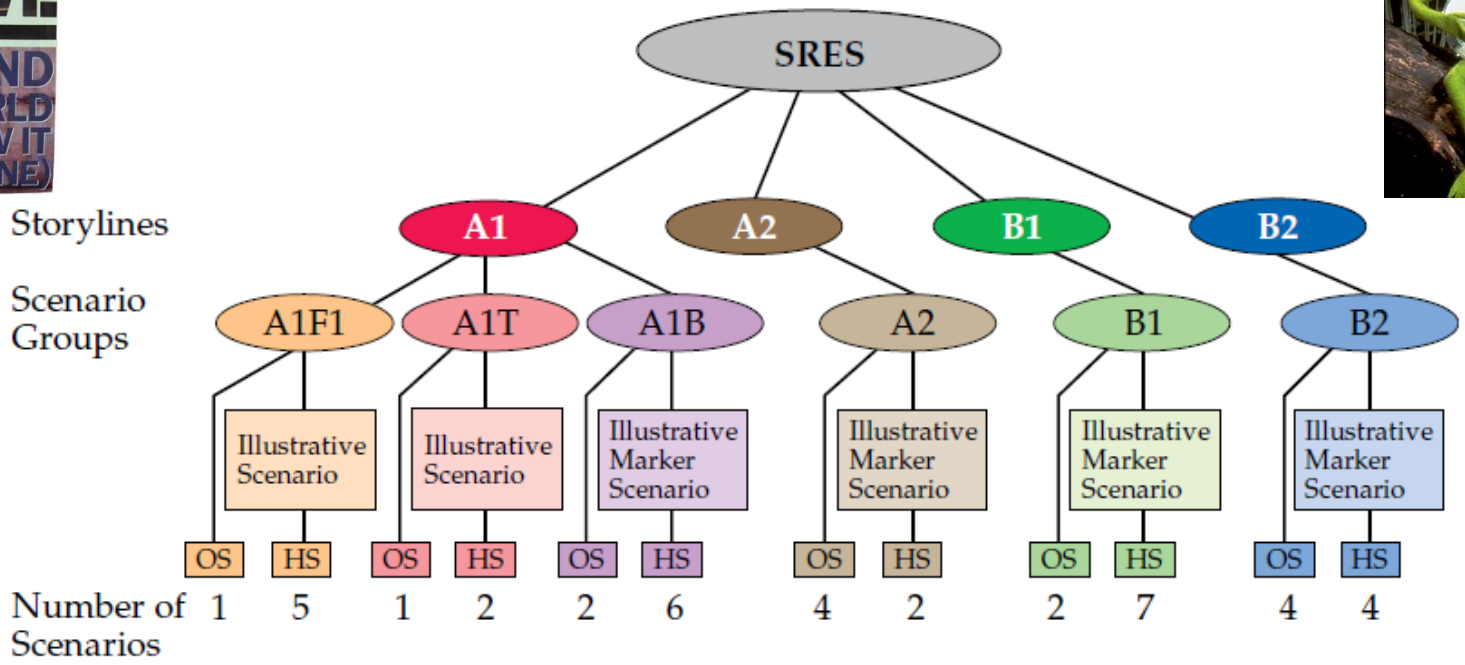
Prediction Scenarios

- A2: regional autonomy (rather than international cooperation), sustained human pop growth, fragmented economic development, slow technological adoption



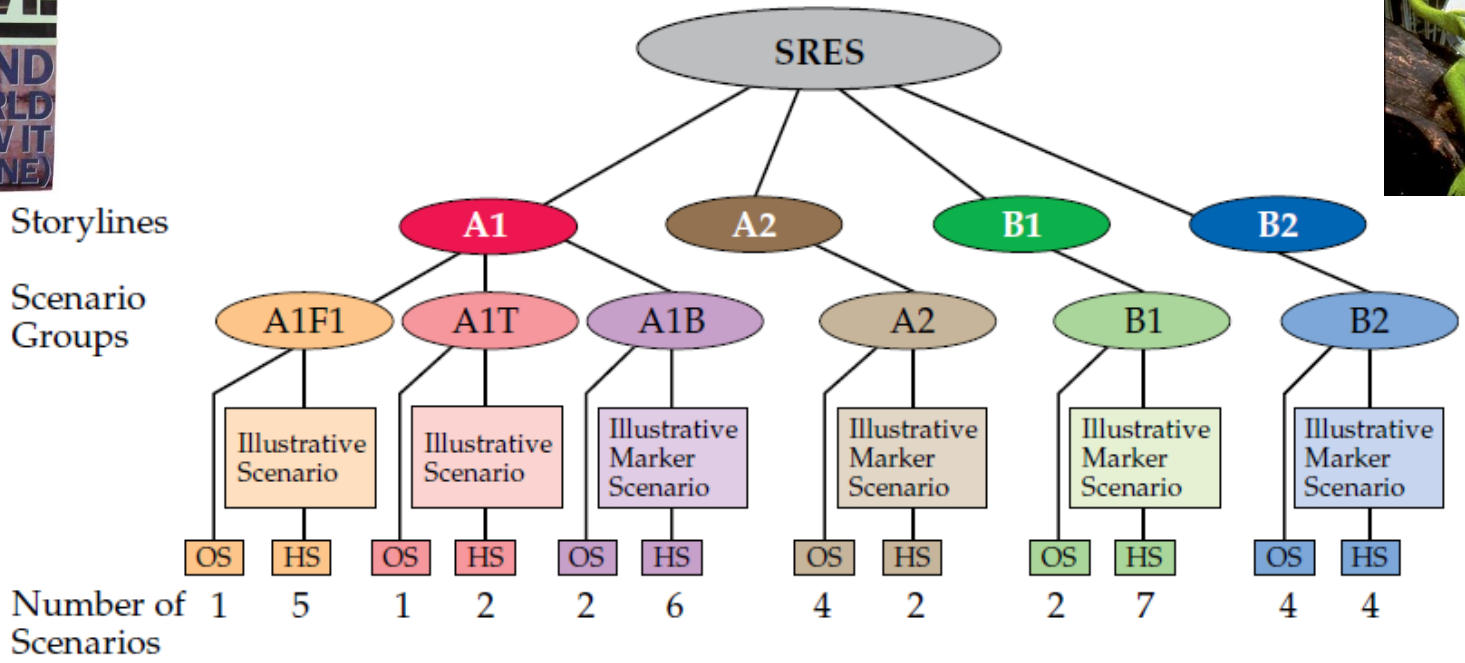
Prediction Scenarios

- B1: worldwide shift to international agreements that promote adoption of clean and resource-efficient technologies



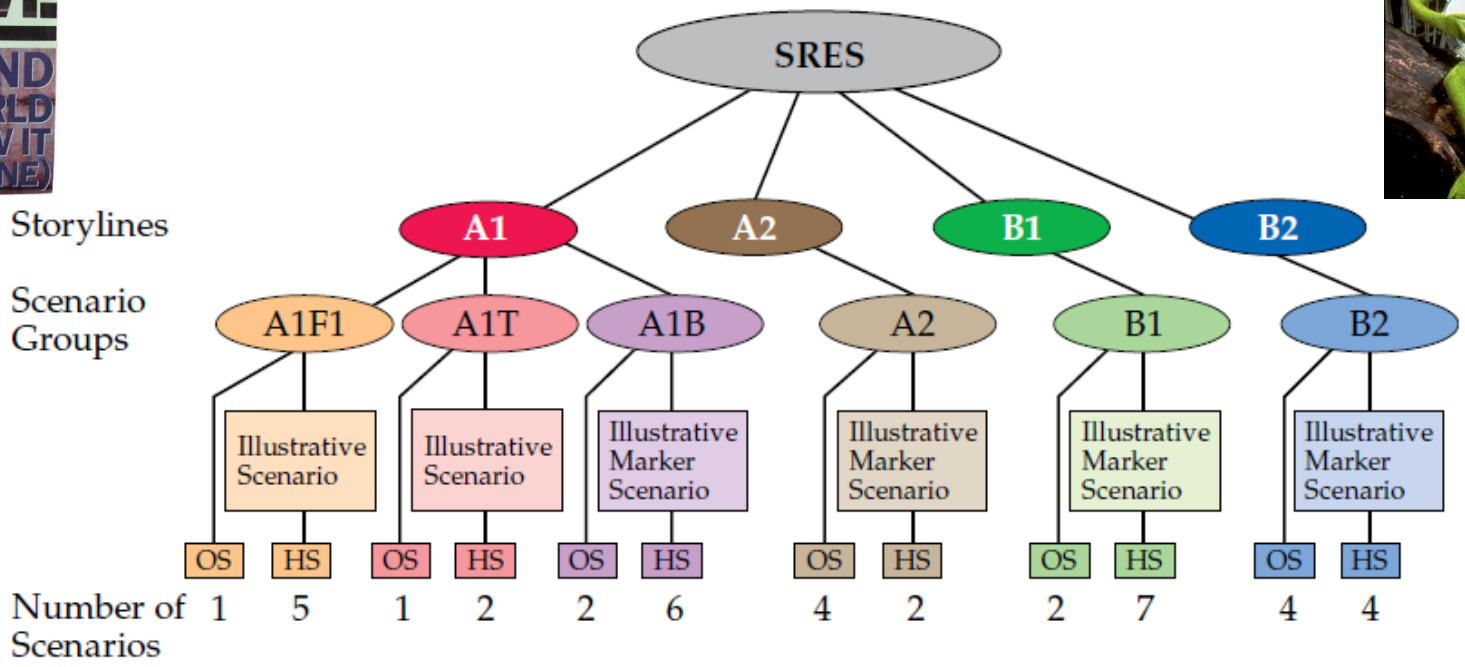
Prediction Scenarios

- B2: local solutions to sustainability with intermediate economic growth and diverse technological change

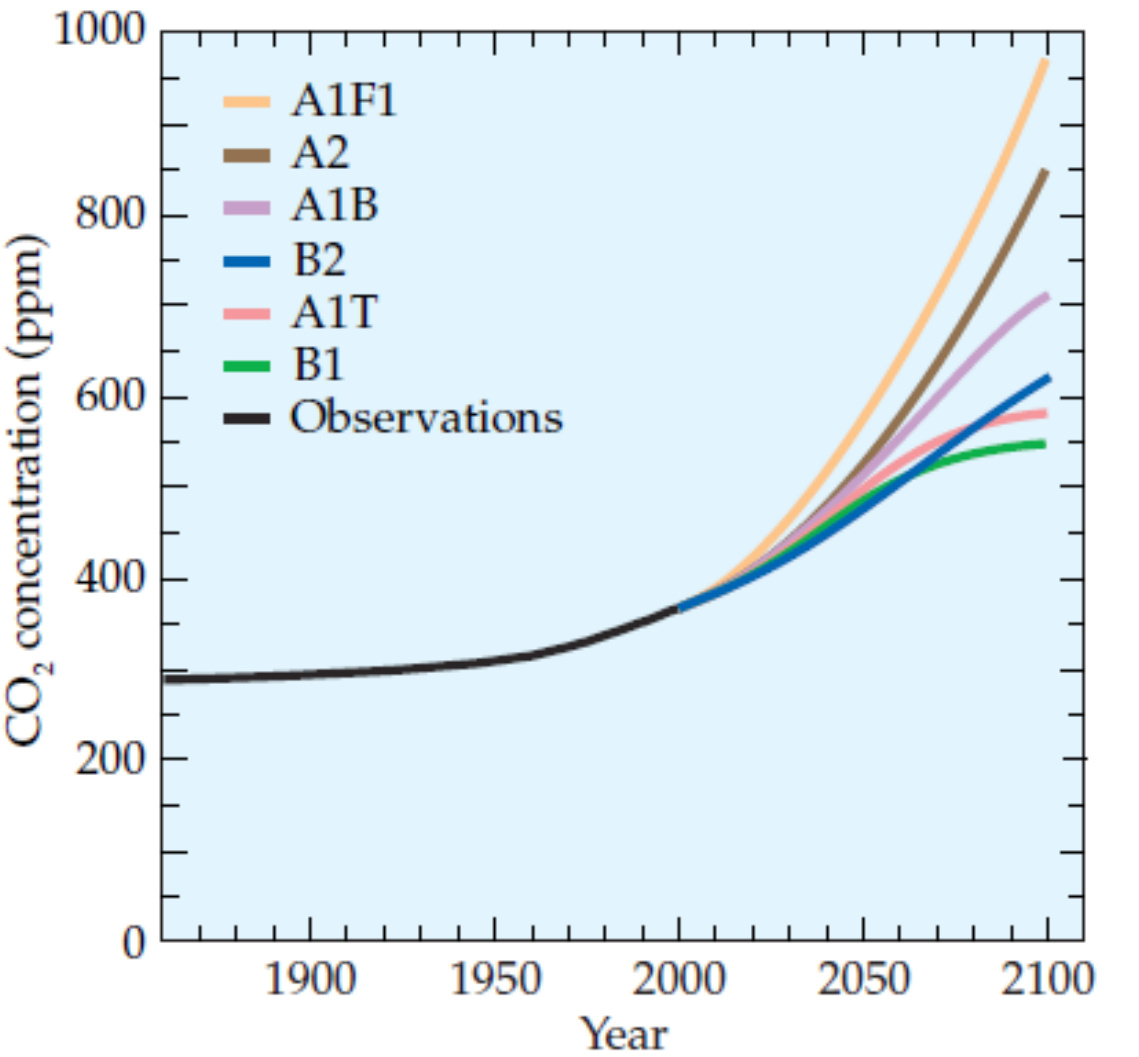


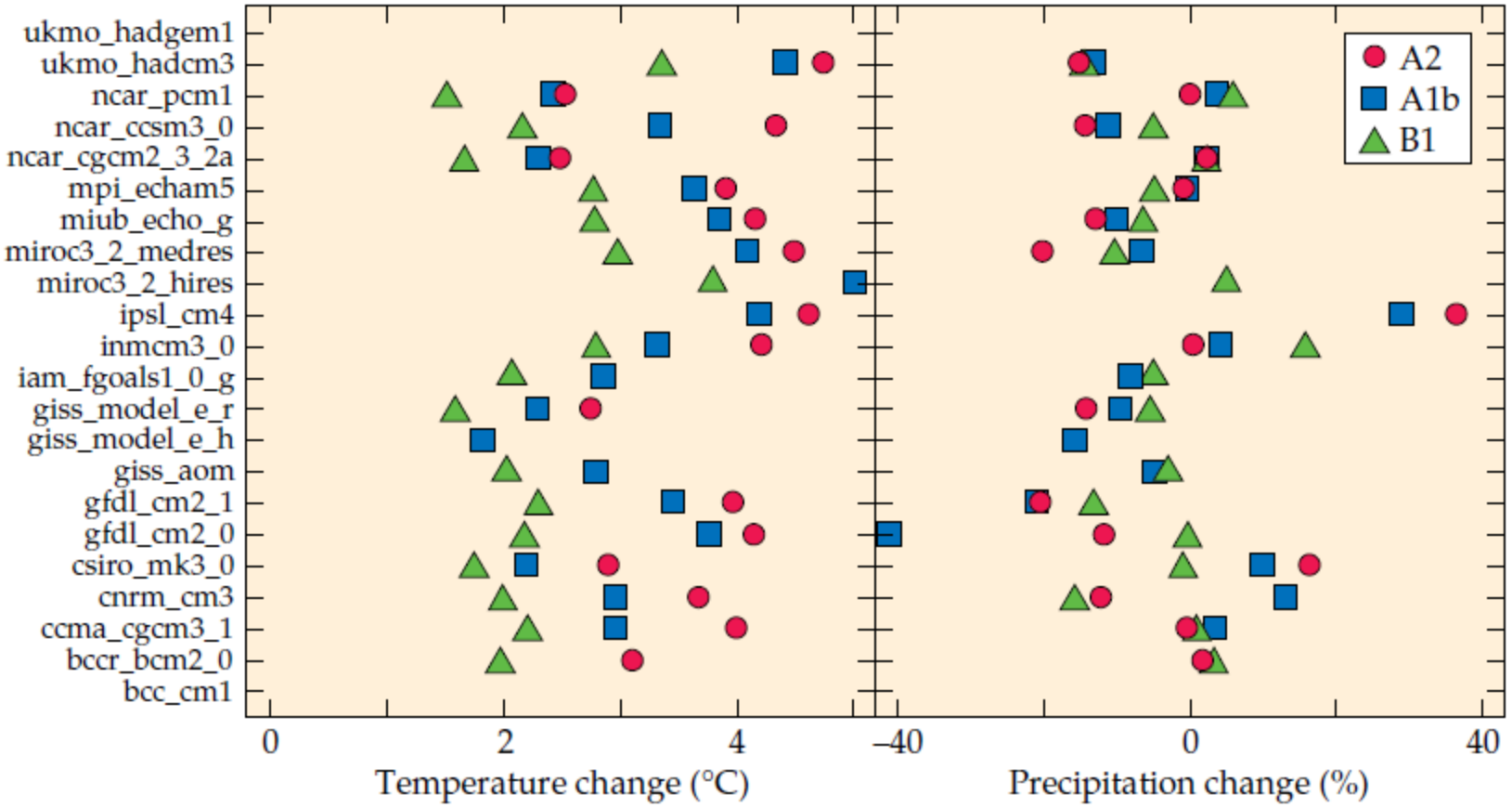
Prediction Scenarios

- Remember: “A”s are the worst case scenario and “B”s are the best case scenarios



We use GCMs to create scenario predictions for the future





Variation among models created by different institutions, using the same scenarios

Lobell *et al.* (2006) *Ag. For. Met.* 141:208-218.

Storylines/Scenarios Have Been Replaced by Representative Concentration Pathways (RPCs)

4 different GHG concentration trajectories

4 possible climate futures, depending on how much GHGs are emitted in years to come

Each named after range of radiative forcing values in the year 2100 relative to pre-industrial values:

+2.6

+4.5

+6.0

+8.5

RPC 2.6

GHG emissions peak between 2010-2020

Emission decline substantially thereafter

RPC 4.5

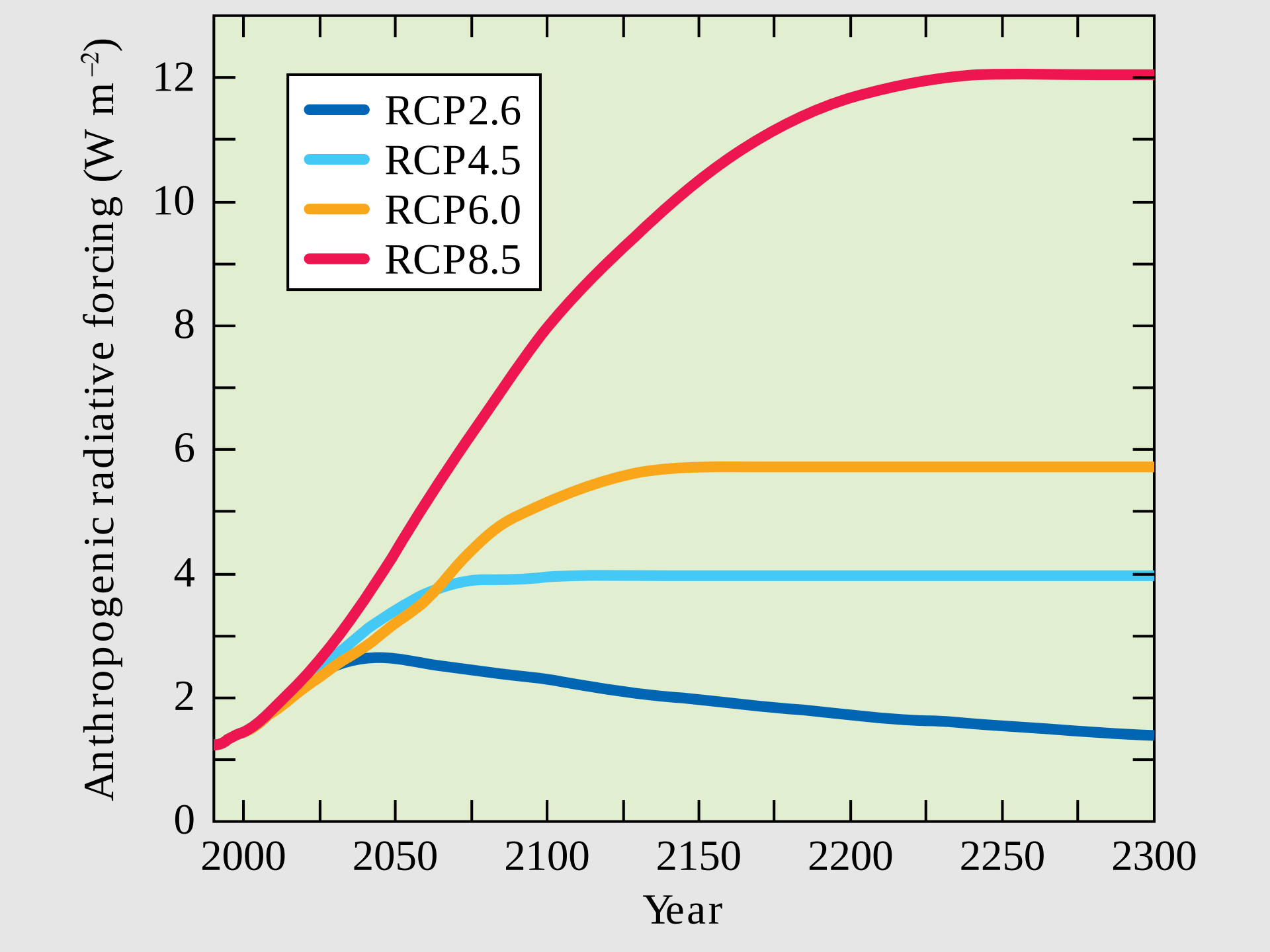
GHG emissions peak around 2040, then decline

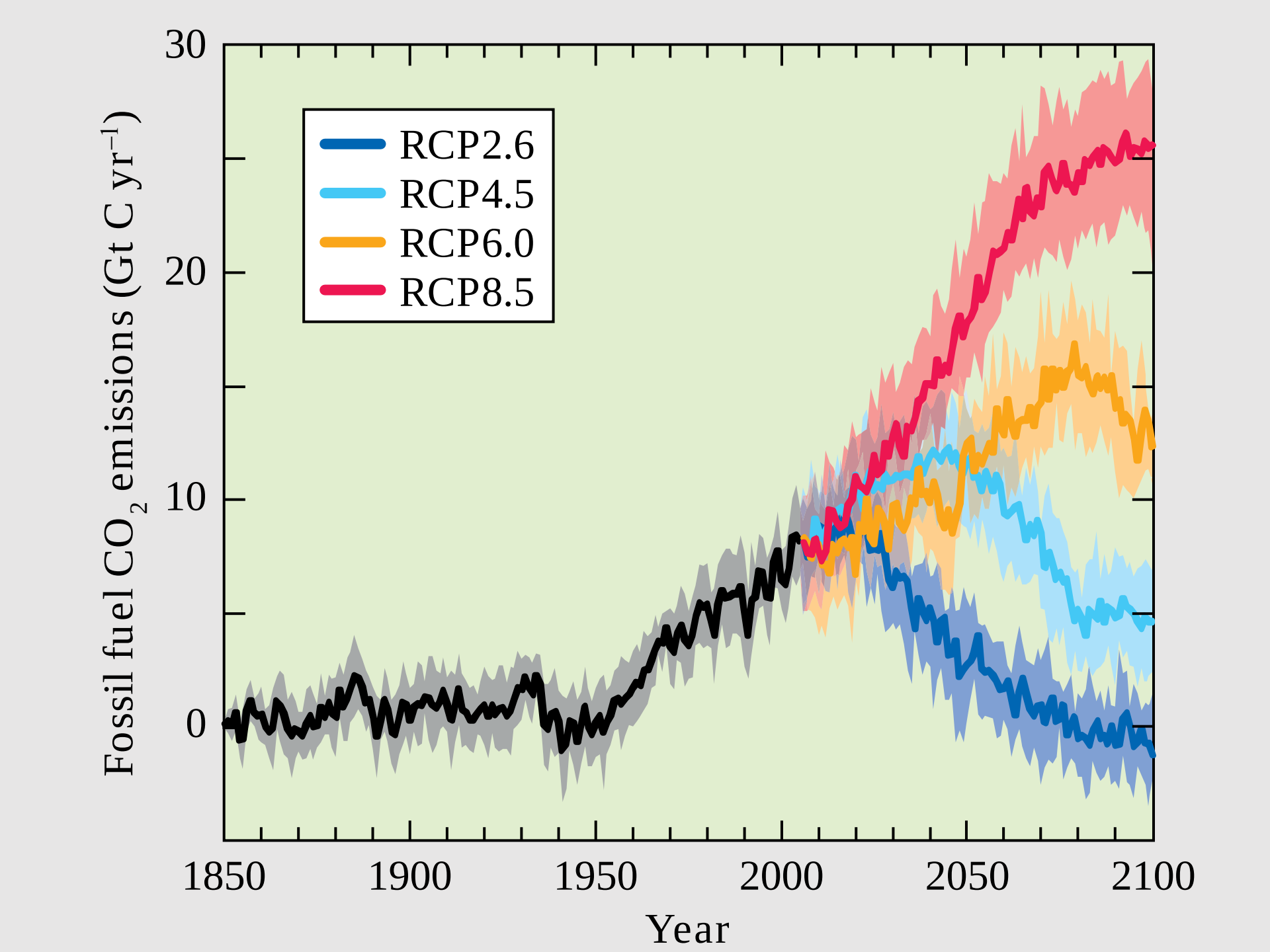
RPC 6.0

GHG emissions peak around 2080, then decline

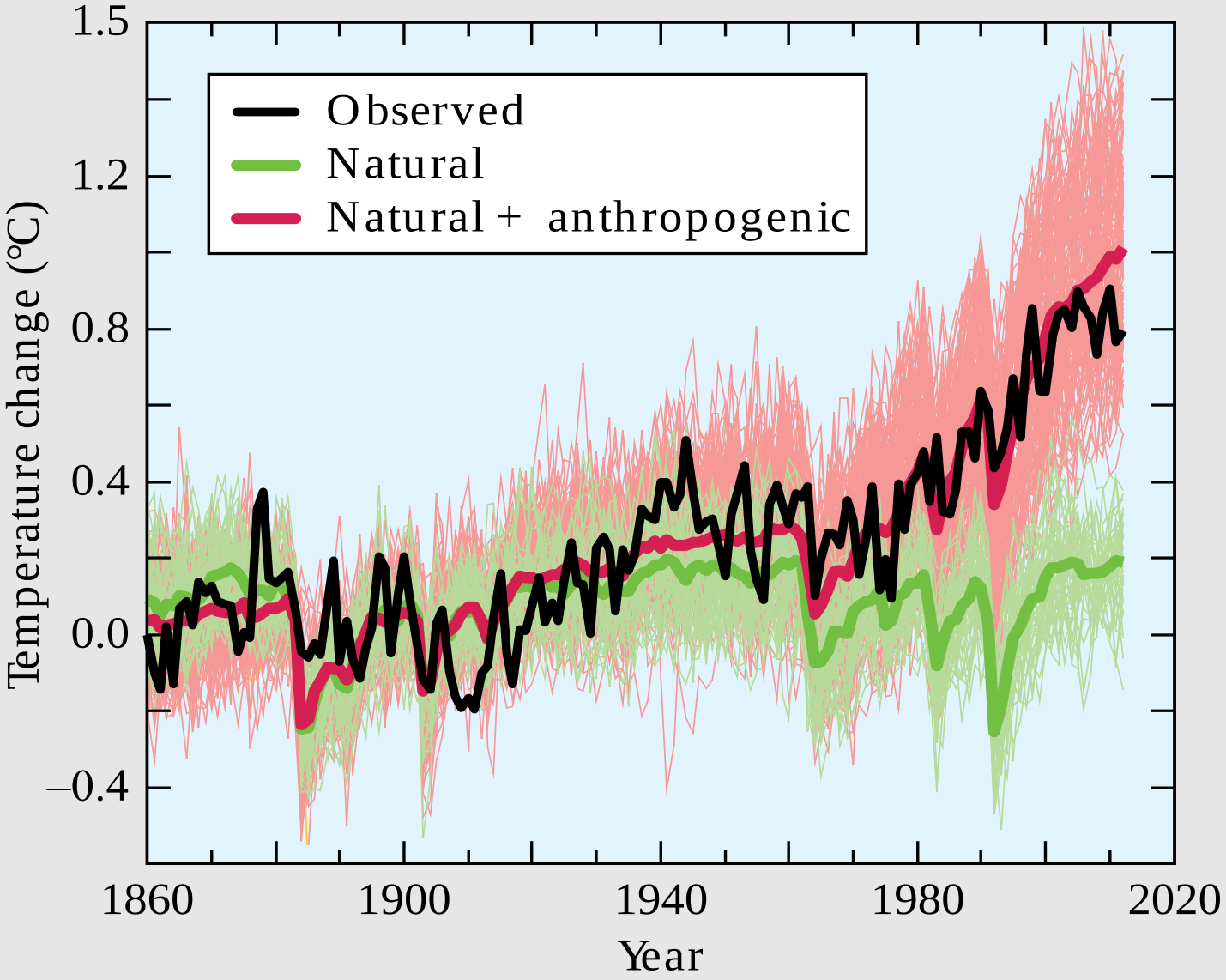
RPC 8.5

GHG emissions continue to rise throughout the 21st century


RCP2.6
RCP4.5
RCP6.0
RCP8.5
Anthropogenic radiative forcing (W m⁻²)
0
2
4
6
8
10
12
2000
2050
2100
2150
2200
2250
2300
Year


RCP2.6
RCP4.5
RCP6.0
RCP8.5
Fossil fuel CO_2 emissions (Gt C yr^{-1})
30
20
10
0
1850
1900
1950
2000
2050
2100
Year

Is the observed global temperature changes over the past 125 years natural or caused by humans?



Based on 16+ GCMs
Models run 3 times
0 is the mean temp
for the time period