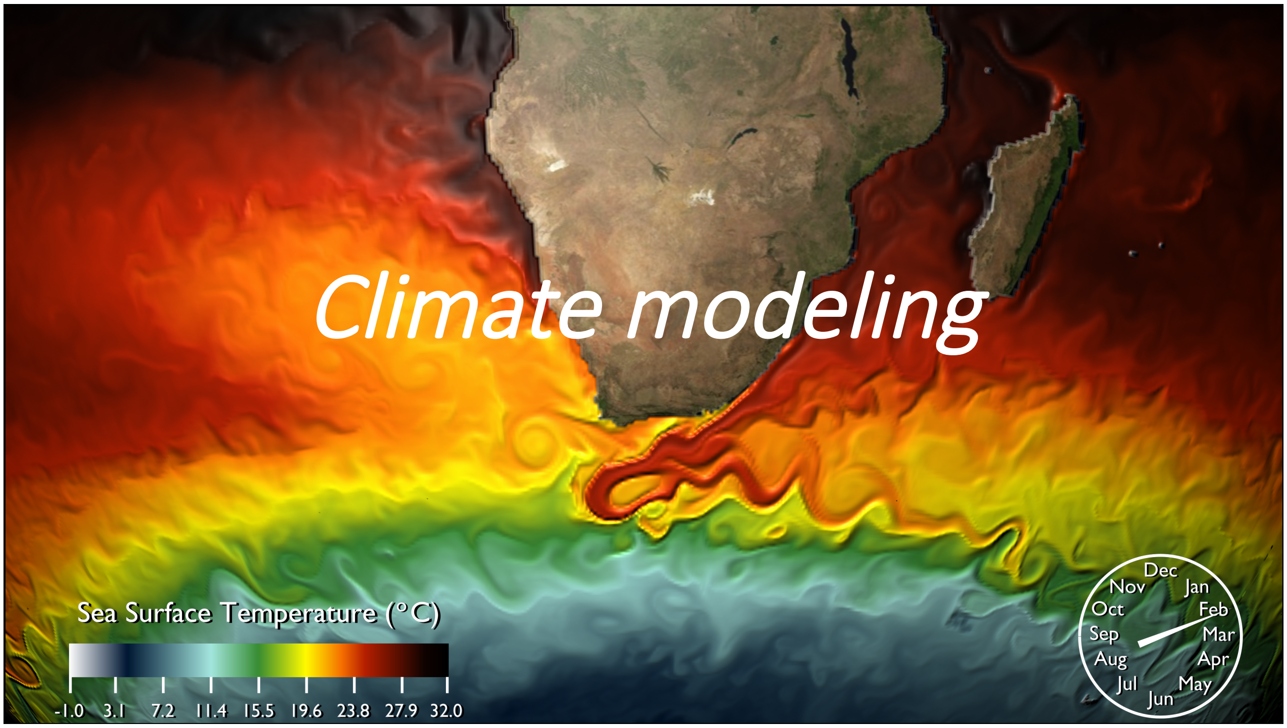
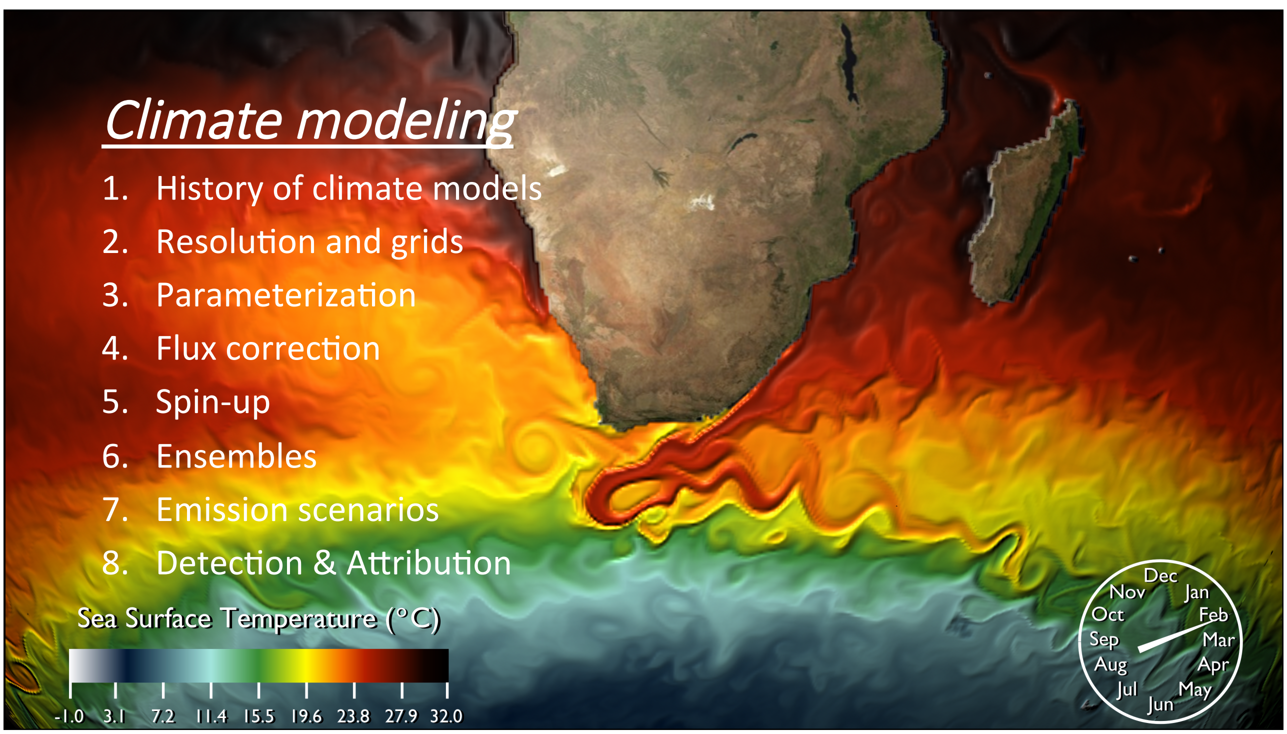

Climate modeling
Sea Surface Temperature (°C)
-1.0 3.1 7.2 11.4 15.5 19.6 23.8 27.9 32.0
Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov


Climate modeling
1. History of climate models
2. Resolution and grids
3. Parameterization
4. Flux correction
5. Spin-up
6. Ensembles
7. Emission scenarios
8. Detection & Attribution
Sea Surface Temperature (°C)
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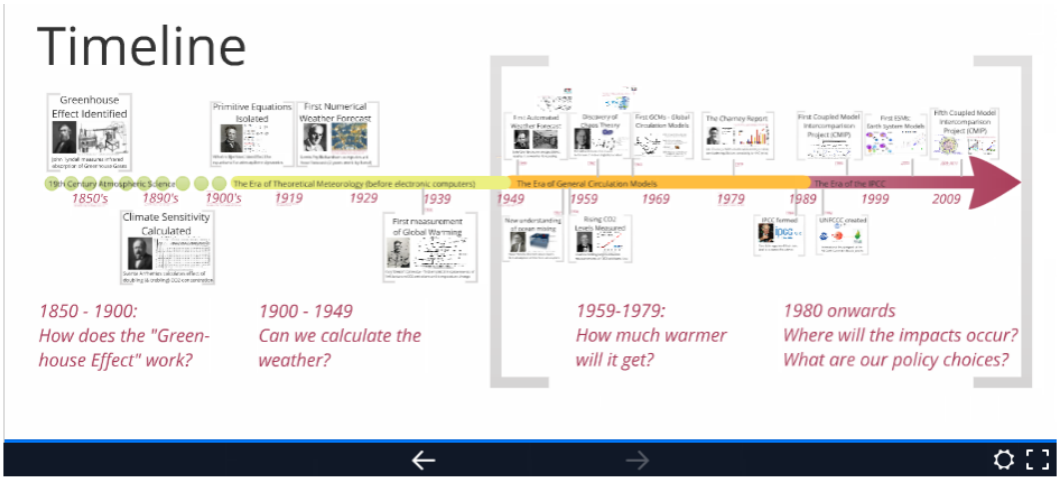
1. History of climate models

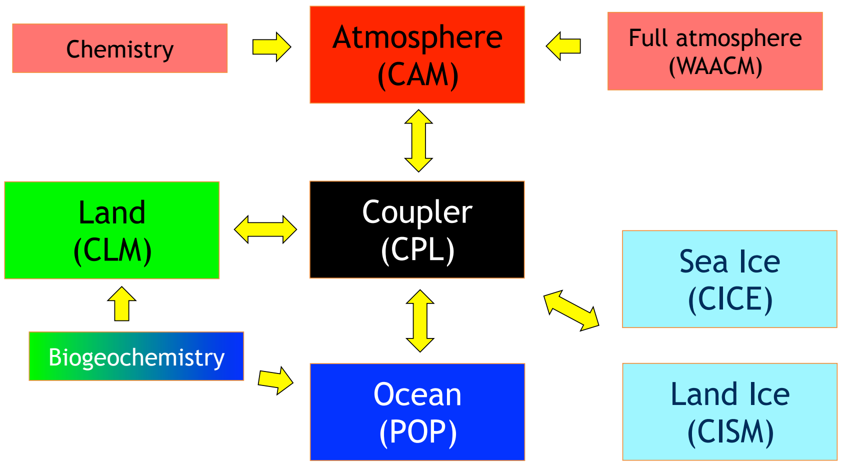


https://prezi.com/pakaaiek3nol/timeline-of-climate-modeling/

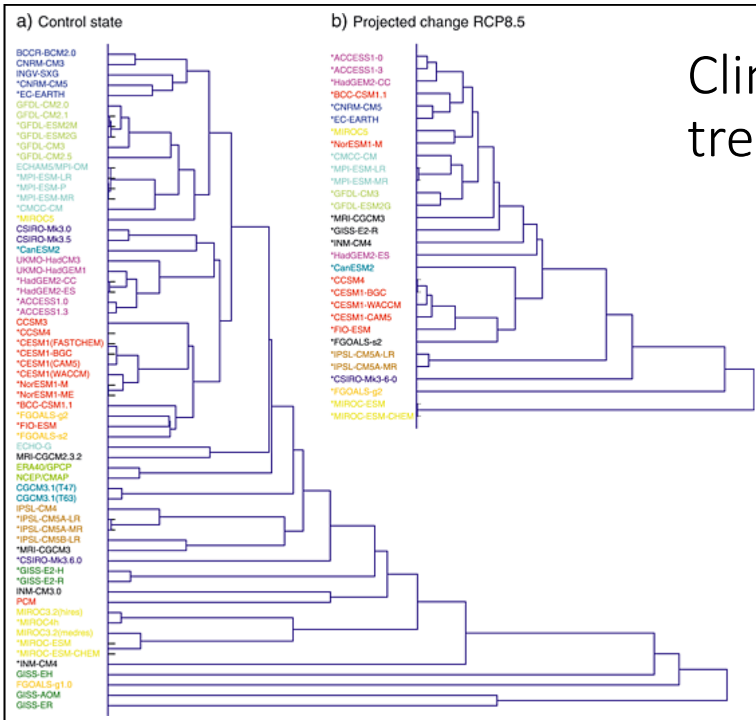
1. History of climate models

- ***Early 1900s:*** Bjerknes identifies the equations for atmospheric dynamics
- ***1917-19:*** Richardson attempted a 6-hour weather forecast (BY HAND!) using these equations
- ***1949:*** first digital computers applied to computing atmospheric dynamics. First automated weather forecast by John Von Neumann (24 hours to compute a 24 hour forecast over NA on a 15 x 13 grid!)
  - [***2008:*** Peter Lynch re-implemented this forecast on a Nokia cellphone in less than 1 sec!]
- ***1965:*** First "GCMs" Global Circulation Models (GFDL, UCLA, LLNL, NCAR)
- ***1979:*** Charney report (National Academy review) warns of climate change. Equilibrium sensitivity is +/- 3C
- ***1988***: United Nationals assembled the IPCC, an international body to assess the science for the benefit of policy makers
- ***1995:*** 16 modeling centers around the world compared their model projections for future climate change (the first "CMIP"= Coupled Model Intercomparison Project)
- ***2005:*** First Earth System Models (beyond the just the atm and ocean)
- ***2013:*** CMIP5 finished!

Community Earth System Model (CESM) components



Slide courtesy C. Zarzycki, NCAR

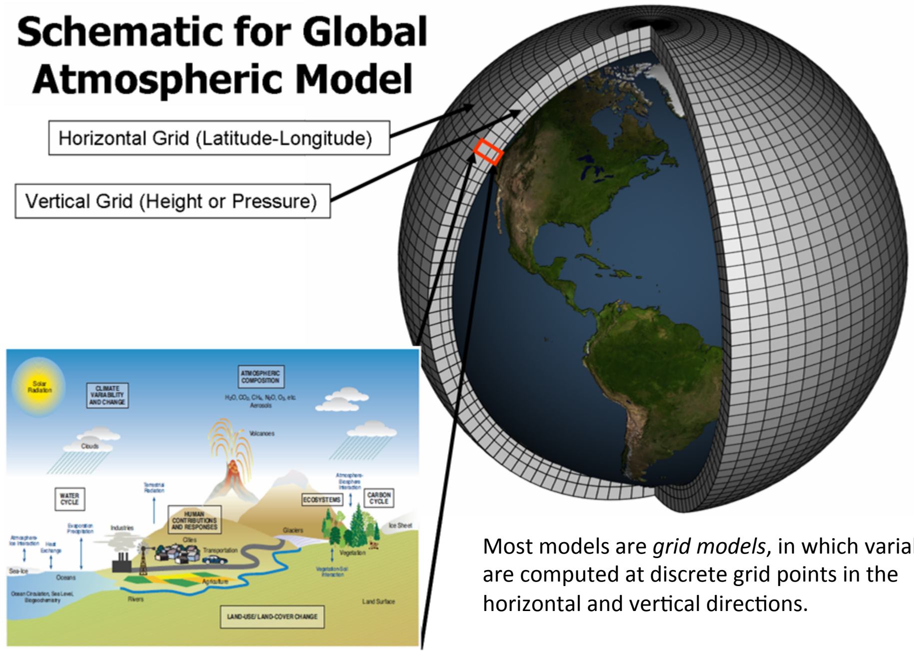


Climate Model "family tree"

- models are strongly tied to their predecessors
- Some exchange ideas and code with other models
- models in the new ensemble are neither independent of each other nor independent of the earlier generation.
- (left) statistical methods can identify similarities between model versions
- interdependence of models complicates the interpretation of multimodel ensembles but largely goes unnoticed

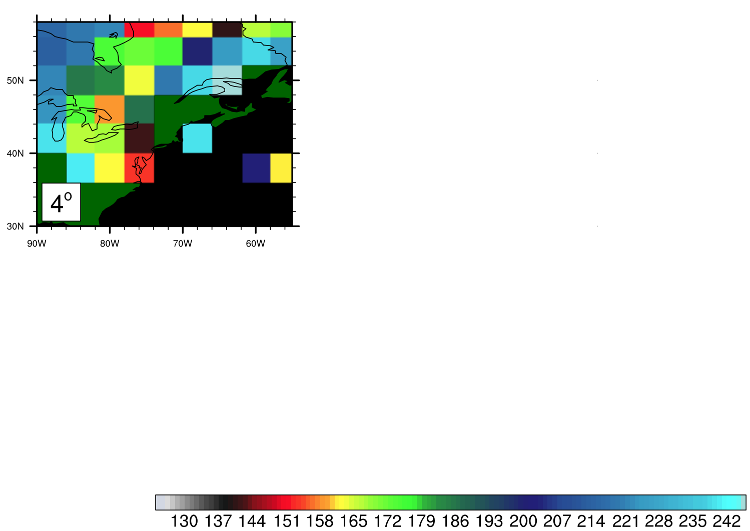
Knutti et al. (2013)

2. Resolution and grids



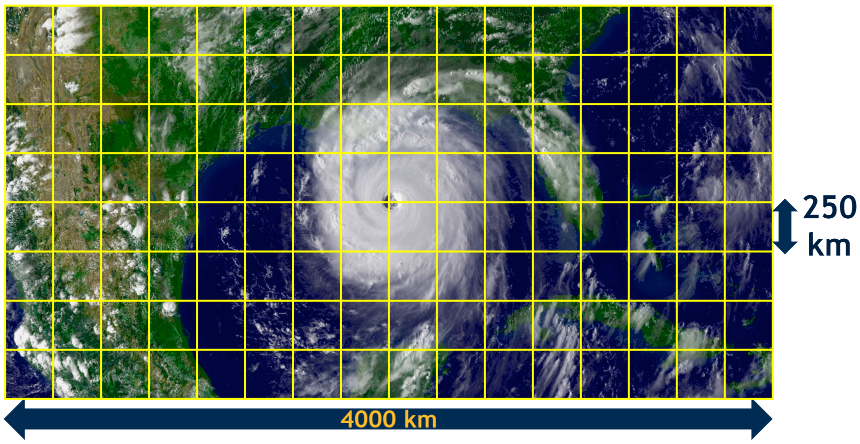
Most models are *grid models*, in which variables are computed at discrete grid points in the horizontal and vertical directions.

2. Resolution and grids
What are we looking at?



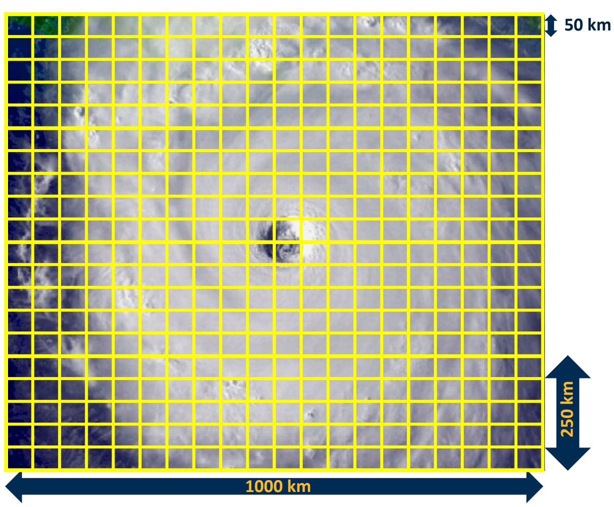
Slide courtesy C. Zarzycki, NCAR

2. Resolution
Why do we need resolution?

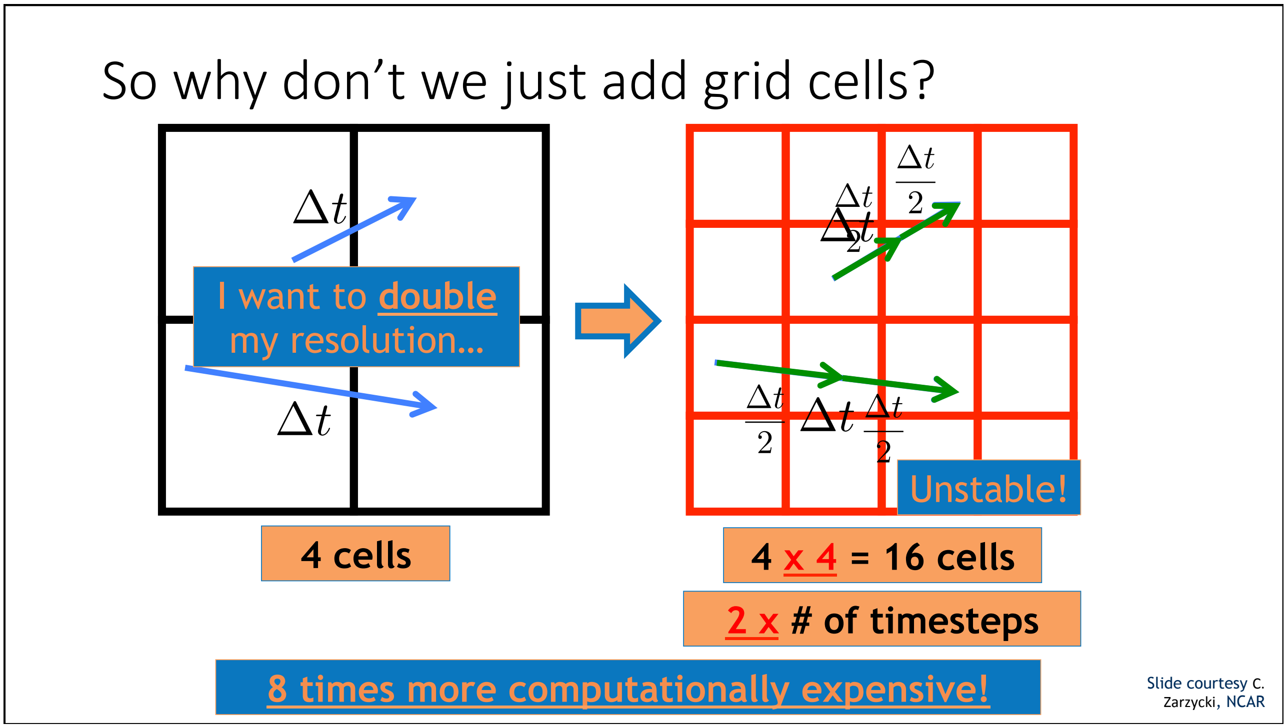


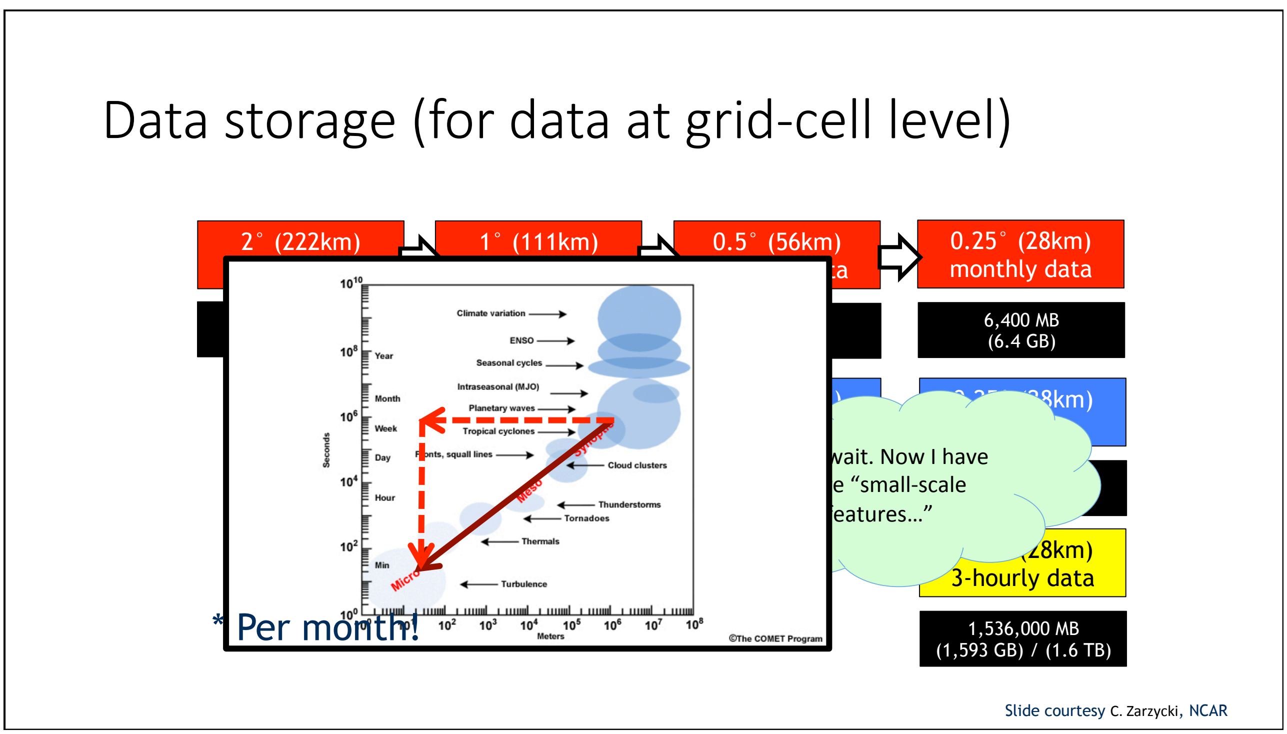
Slide courtesy C. Zarzycki, NCAR

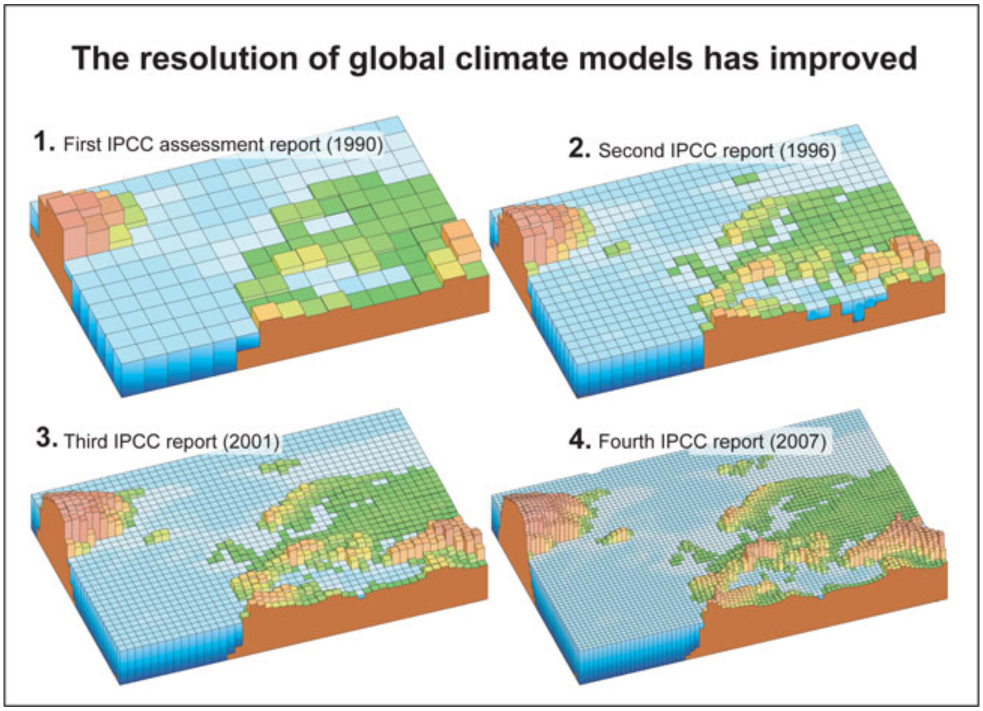
Why do we need resolution?



Slide courtesy C. Zarzycki, NCAR


So why don't we just add grid cells?
Δt
I want to double my resolution…
Δt
$\frac{\Delta t}{2}$
Unstable!
4 cells
4 x 4 = 16 cells
2 x # of timesteps
8 times more computationally expensive!
Slide courtesy C. Zarzycki, NCAR


Data storage (for data at grid-cell level)
2° (222km)
1° (111km)
0.5° (56km)
0.25° (28km) monthly data
6,400 MB (6.4 GB)
wait. Now I have
e "small-scale
eatures…"
(28km) 3-hourly data
1,536,000 MB (1,593 GB) / (1.6 TB)
* Per month!
Climate variation
ENSO
Seasonal cycles
Intraseasonal (MJO)
Planetary waves
Tropical cyclones
Cloud clusters
Thunderstorms
Tornadoes
Thermals
Turbulence
Year
Month
Week
Day
Hour
Min
Seconds
Meters
©The COMET Program
Slide courtesy C. Zarzycki, NCAR

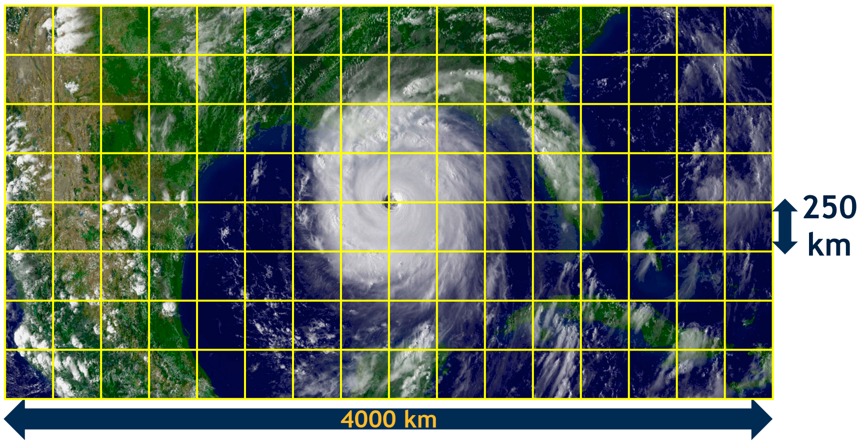


What is "high" resolution?

- True definition of "high resolution" somewhat ambiguous and moving target
- Current IPCC models (FAR/5AR): ~50-100 km
- Global numerical weather prediction: 15-40 km
- Most people call their simulations "high resolution" if…
  - They are running < 50 km for climate applications
  - <15 km for weather forecasting

Slide courtesy C. Zarzycki, NCAR

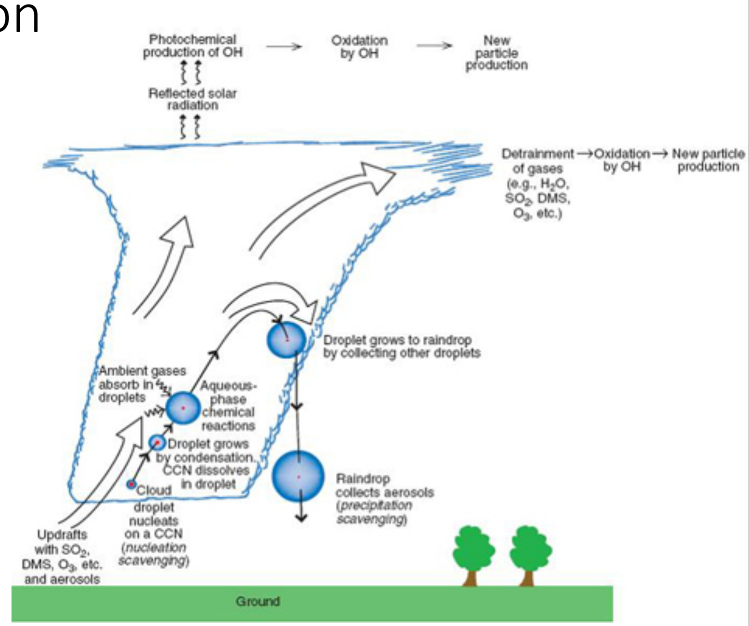
3. Parameterization



Slide courtesy C. Zarzycki, NCAR

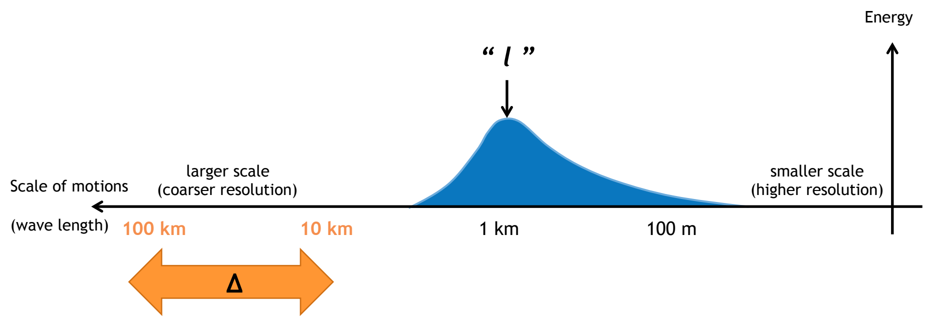
3. Parameterization

- Cloud microphysics occur at spatial scales that are too small to model explicitly
- Parameterization makes the problem solvable
- BUT can introduce errors and requires additional constants (sometimes not well constrained)



3. Parameterization

"model grid size (Δ) >> characteristic scale (*l*)"

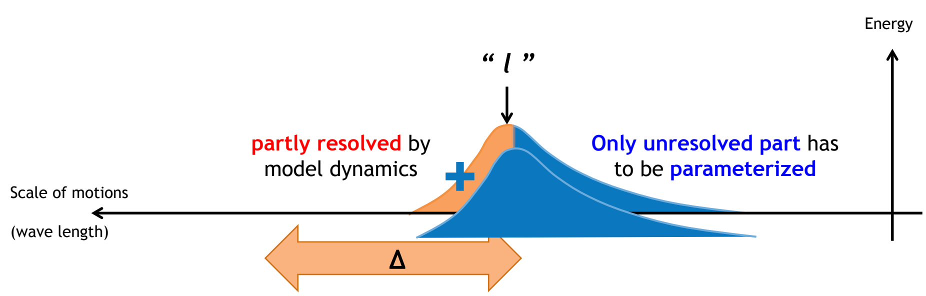


Small-scale processes are **not resolved at all** and **entirely parameterized**.
The assumption is valid at traditional resolution: Δ ~ *O*(10-100 km).

Slide courtesy C. Zarzycki, NCAR

Parameterization

At higher model resolution: Δ ~ *l*



Slide courtesy C. Zarzycki, NCAR

4. Flux correction

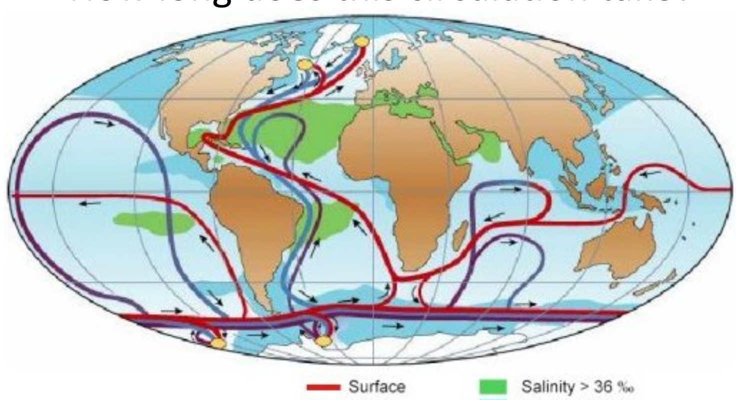
What is it?

Why was it employed?

5. Spin up

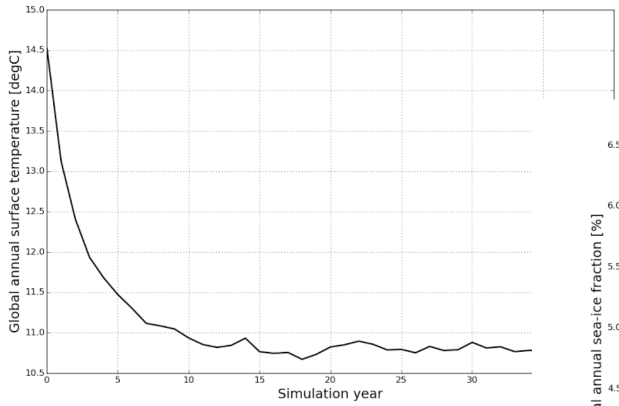
- Time required for the ocean model to reach a state of equilibrium
- Ocean model is initialized with present ocean state and integrated forward until circulation is consistent with prescribed water mass structure

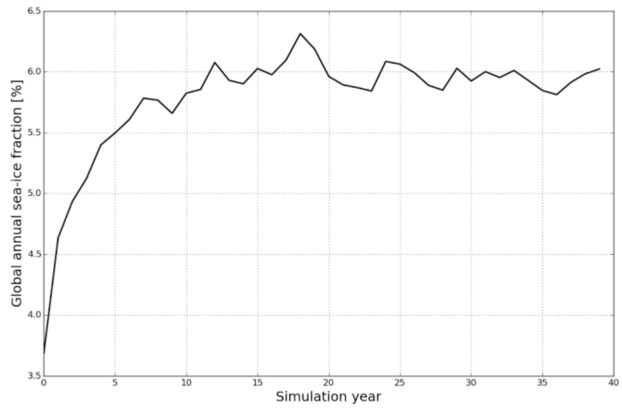
How long does this circulation take?



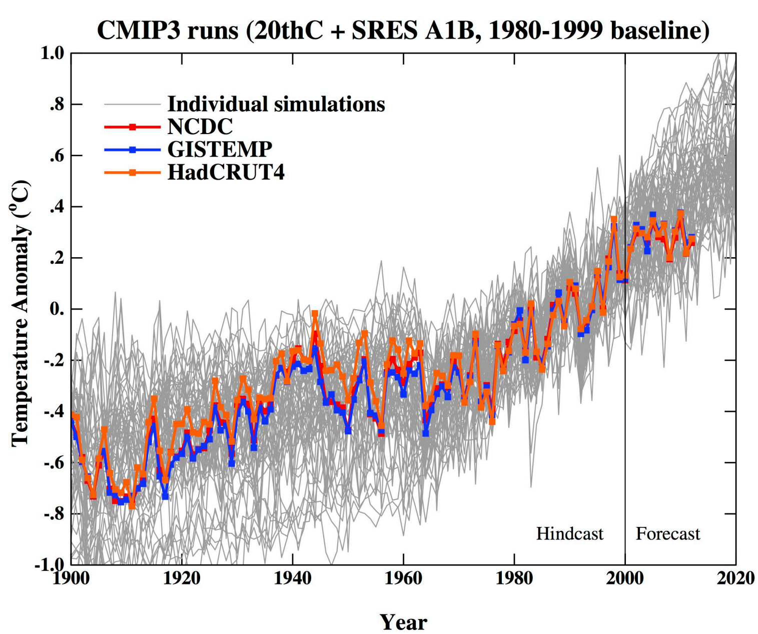
(Rahmstorf, Nature 2002)

Model spin up example

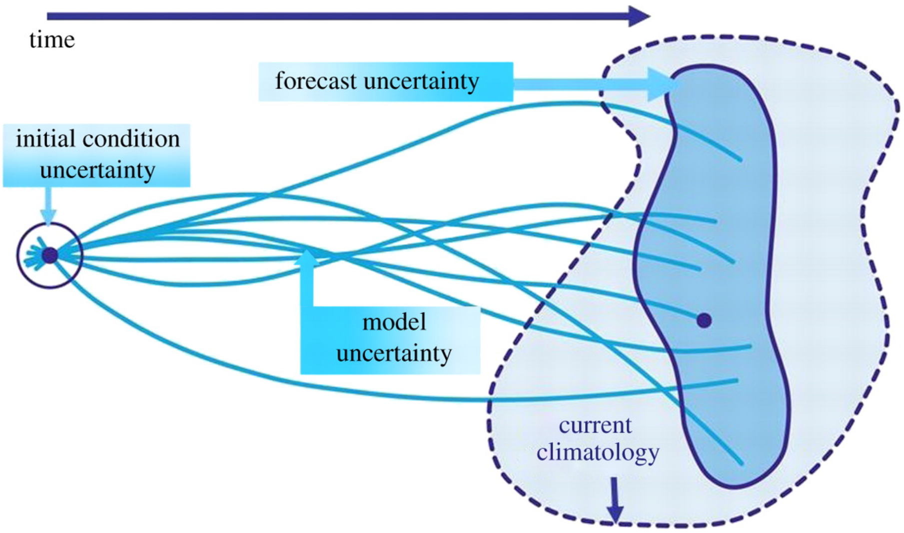




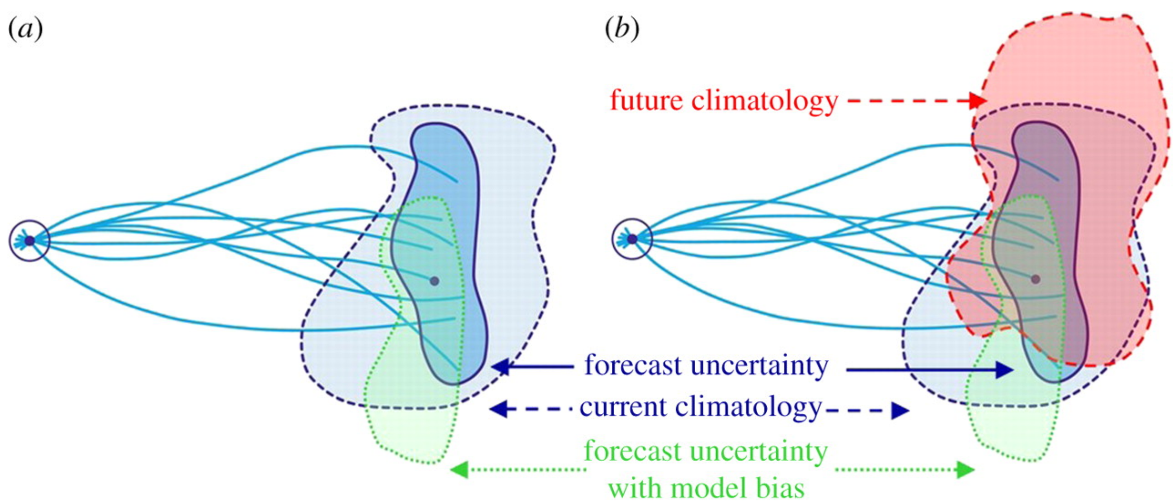
6. Ensembles



6. Ensembles

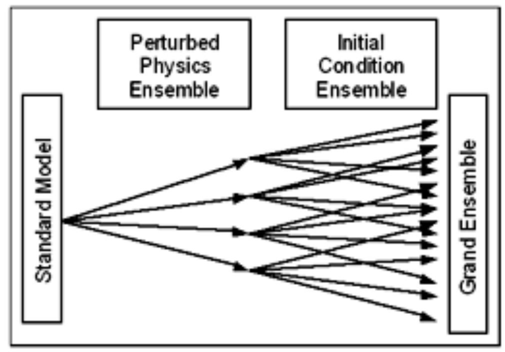


6. Ensembles



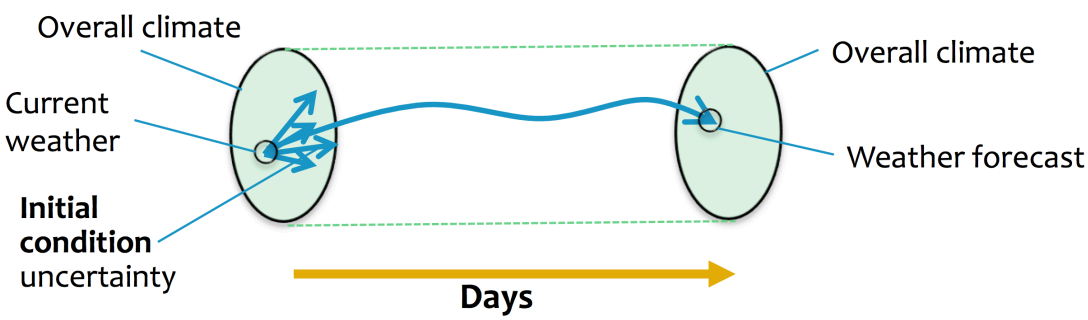
Types of ensembles

1. Initial condition ensemble (e.g., CESM large ensemble)
2. Perturbed physics ensembles (PPEs)
3. Multimodel ensembles (MME) (e.g., CMIP3/5)



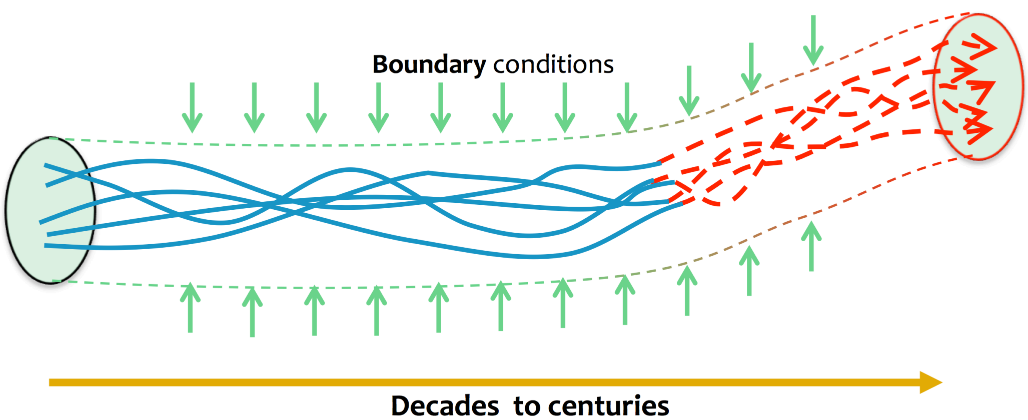
How can we model the climate at the end of the century, when we cannot predict the weather 2 weeks from now??

Prediction vs Projection



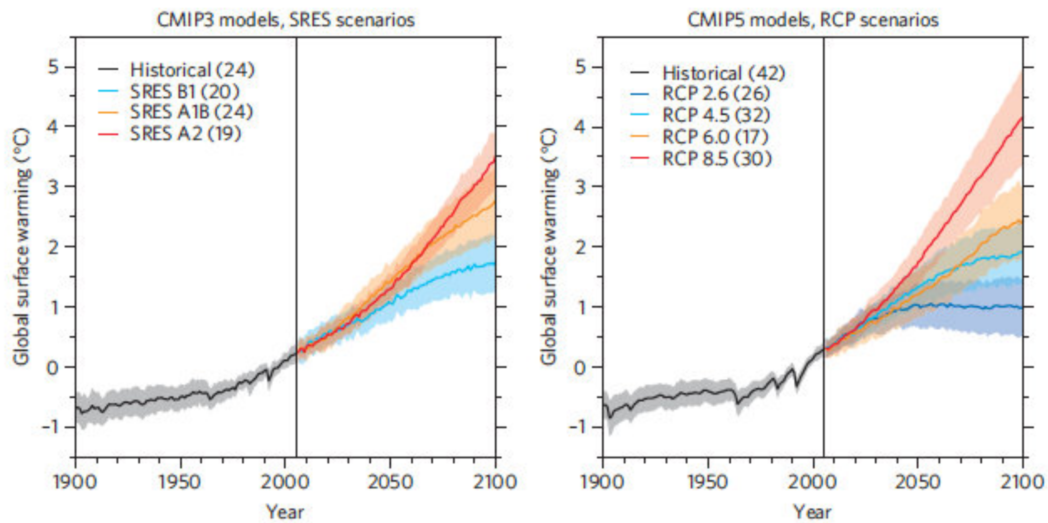
Weather ***predictions*** are a ***initial value problem***

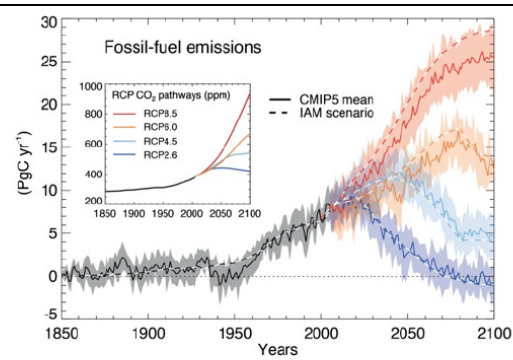
Prediction vs Projection

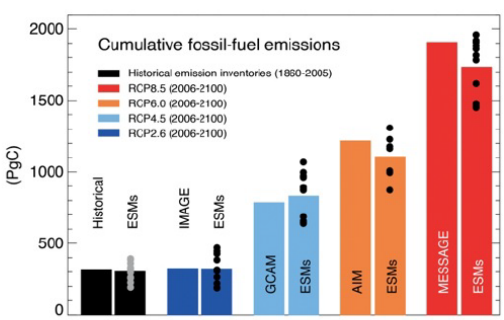


Climate ***projections*** are a ***boundary value problem***

7. Emission scenarios







No mitigation

Some mitigation

Serious mitigation

Insane mitigation

Representative Concentration Pathways

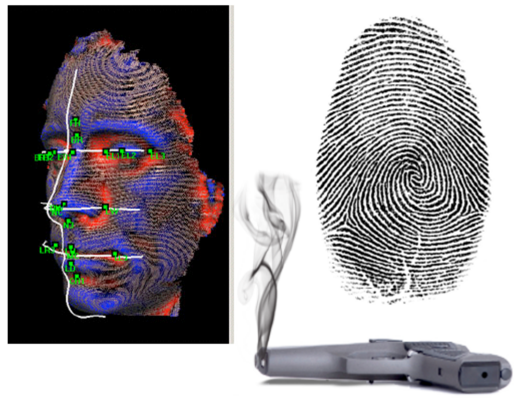
These scenarios describe plausible emissions trajectories based on different economic & technological assumptions

8. Detection & Attribution

Detection

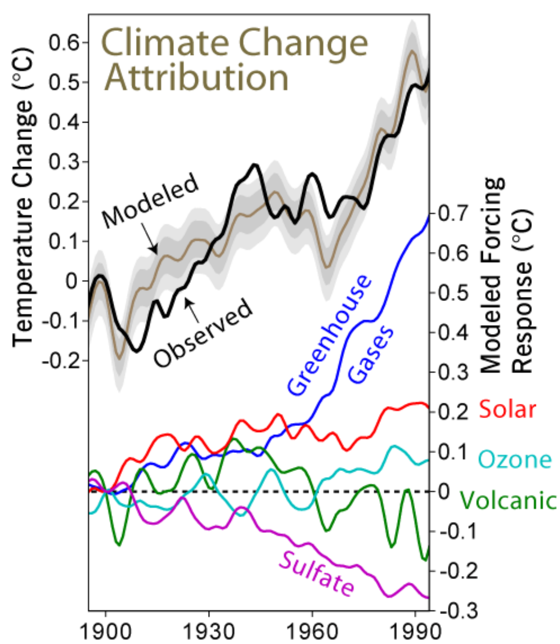
"What happened?"

Attribution

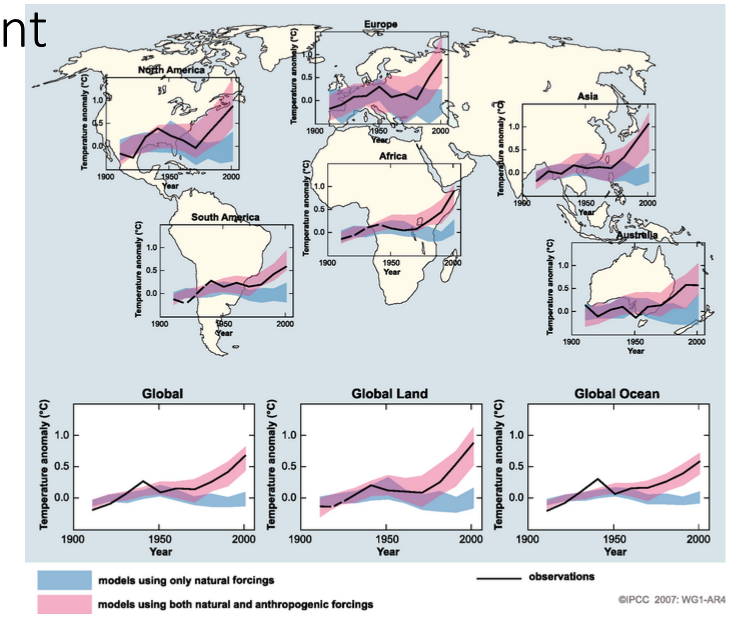


"Who did it?"

Attribution of recent climate change



Attribution of recent climate change



Last millennium example