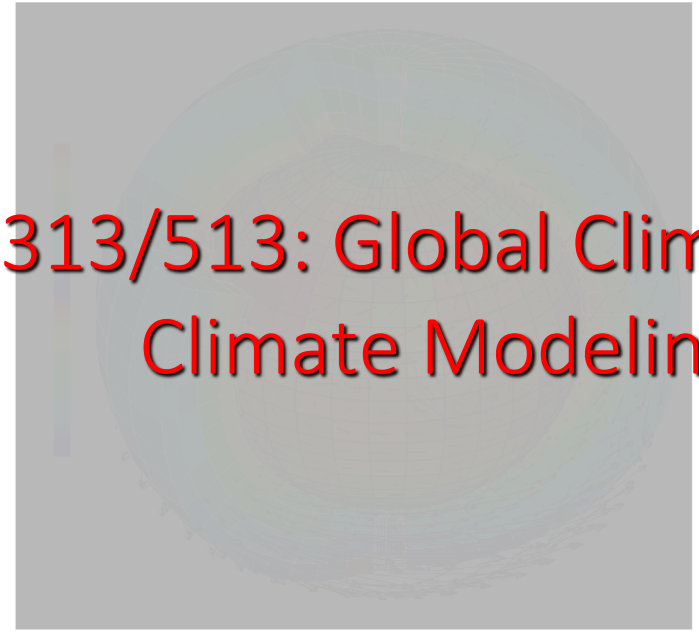
GEOG 313/513: Global Climate Change
Climate Modeling



Scientific Models: What and Why

- **What:** representations of real-world phenomena or objects.

- **Why:**

- Models are tools, not answers
- Model output can be ugly if not based on solid understanding

Global Climate Models

Theoretical Usage:

- Provide a platform to conduct experiments on the Earth.
- Scientific method: prediction, evaluation and understanding

Applied Usage:

- Climate Information and Impact Assessment
- Decision Making (tomorrow, next month, 30-years from now)

Numerical Weather Prediction

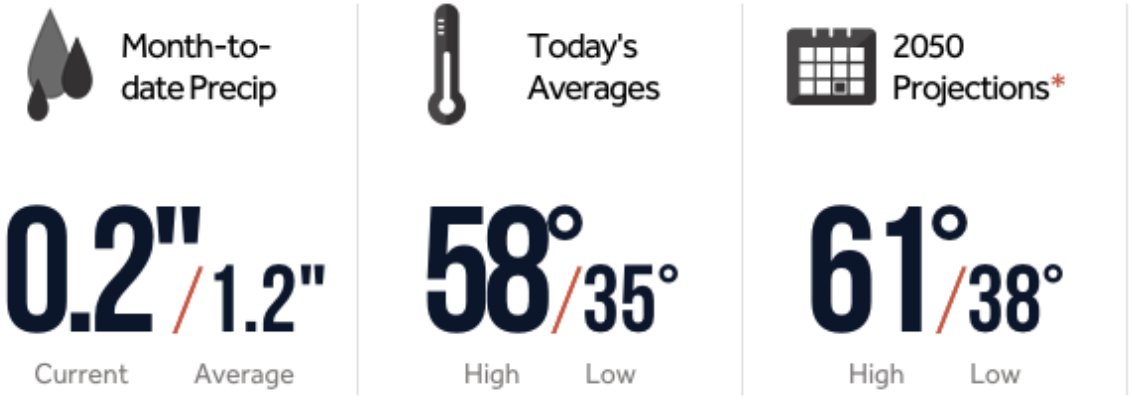
Motivation: To produce an accurate forecast.

Methods: Numerical solutions to atmospheric fluid motion that describe the time evolution of the atmosphere

$$X^{forecast} = X^{initial} + F(X)\partial t$$

1. Make them programmable into a powerful computer.
2. Solve prognostic equations at each time step…repeat…repeat
3. Forecasting is mean to be DETERMINISTIC (exact, certain place/time)

Your Local Forecast



- Climate models can't tell you what the weather will be like on November 10, 2060
- But they can tell you a range of what climatological statistics of a November 10, 2060 day would look like

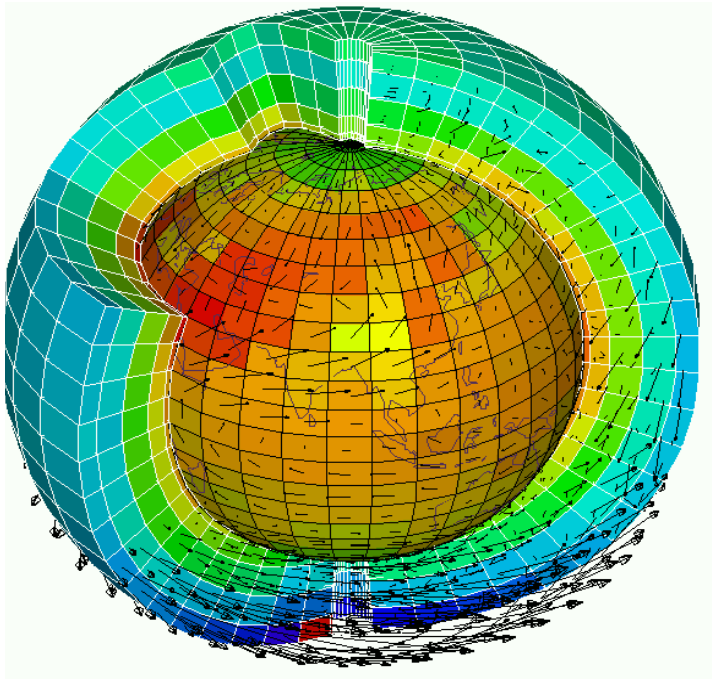
wxshift.com

Global Climate Models

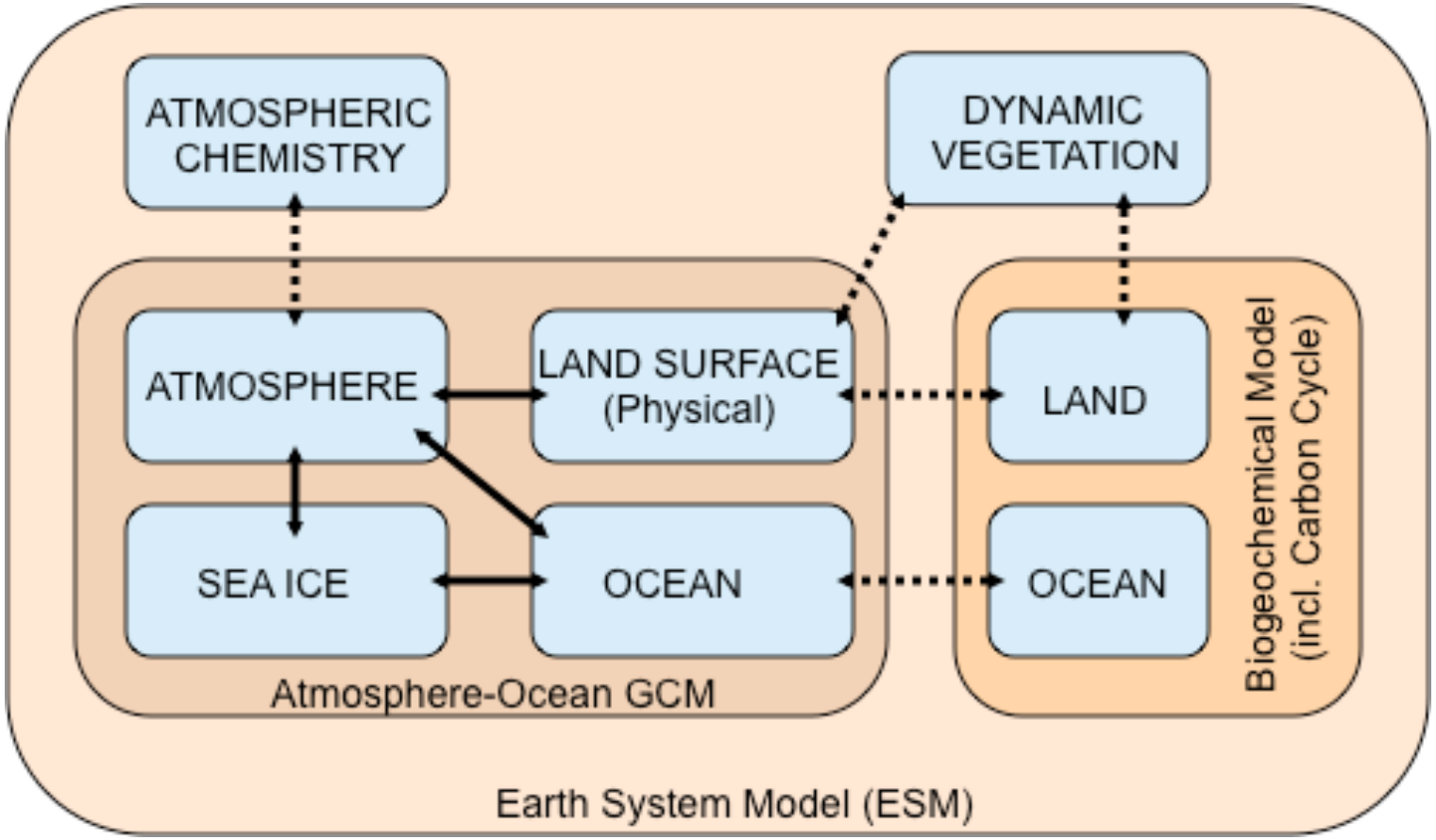
defined: numerical representations of the interactive climate system based on laws of physics and physical parameterizations.

Atmosphere	Biogeochemistry	Temperature
Ocean	Surface Hydrology	Precipitation
Land surface	Carbon Cycle	Winds
Cryosphere	Ecology	Snowpack

Divide the Earth up into little blocks

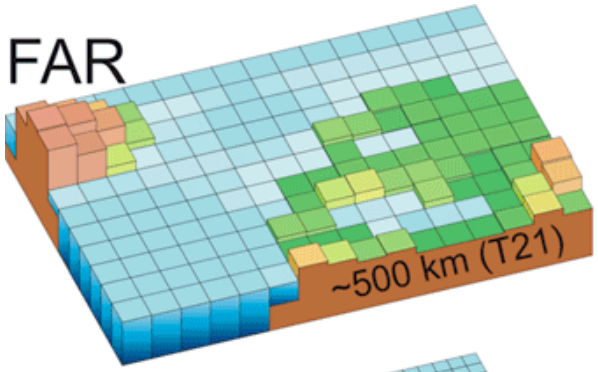


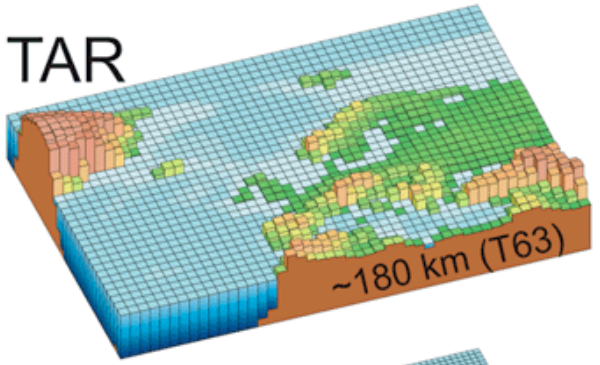
Two-way interaction/coupling and FEEDBACKS



Modeling Advances

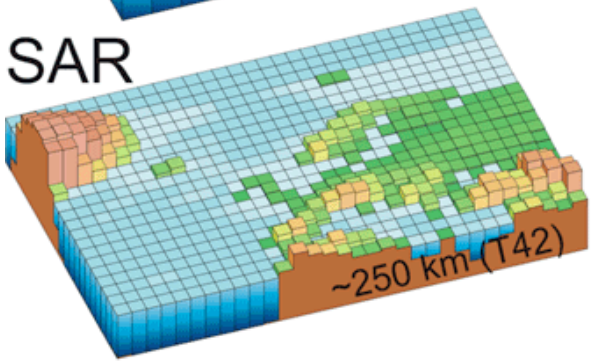
1990

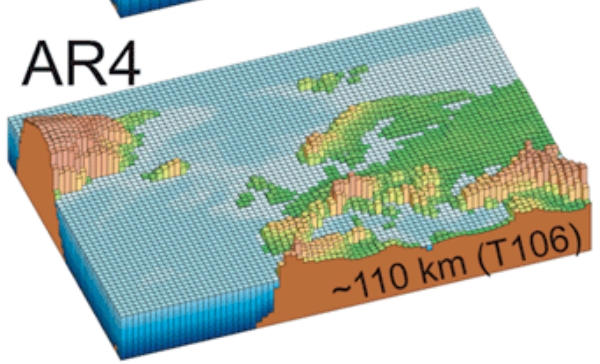




1995

2000





2005

Computation limits to running models

Today we are down to ~50km for best models

Parameterizations and Model Physics

- Represent processes within a grid cell using equations with physically or empirically derived parameters.
- How to make rain???

Models and more models

Model	Country	Model	Country
ACCESS1-0	Australia	CCSM4	U.S.A.
CSIRO-Mk3-6-0	Australia	CESM1-BGC	U.S.A.
CanESM2	Canada	CESM1-CAM5	U.S.A.
bcc-csm1-1	China	GFDL-CM3	U.S.A.
BNU-ESM	China	GFDL-ESM2G	U.S.A.
FGOALS-g2	China	GFDL-ESM2M	U.S.A.
FIO-ESM	China	GISS-E2-R	U.S.A.
CNRM-CM5	France	MIROC5	Japan
IPSL-CM5A-LR	France	MIROC-ESM	Japan
IPSL-CM5A-MR	France	MIROC-ESM-CHEM	Japan
MPI-ESM-LR	Germany	MRI-CGCM3	Japan
CMCC-CM	Italy	HadGEM2-CC	U.K.
NorESM1-M	Norway	HadGEM2-ES	U.K.
inmcm4	Russia	HadGEM2-AO	Korea

Why are there 40+ models?

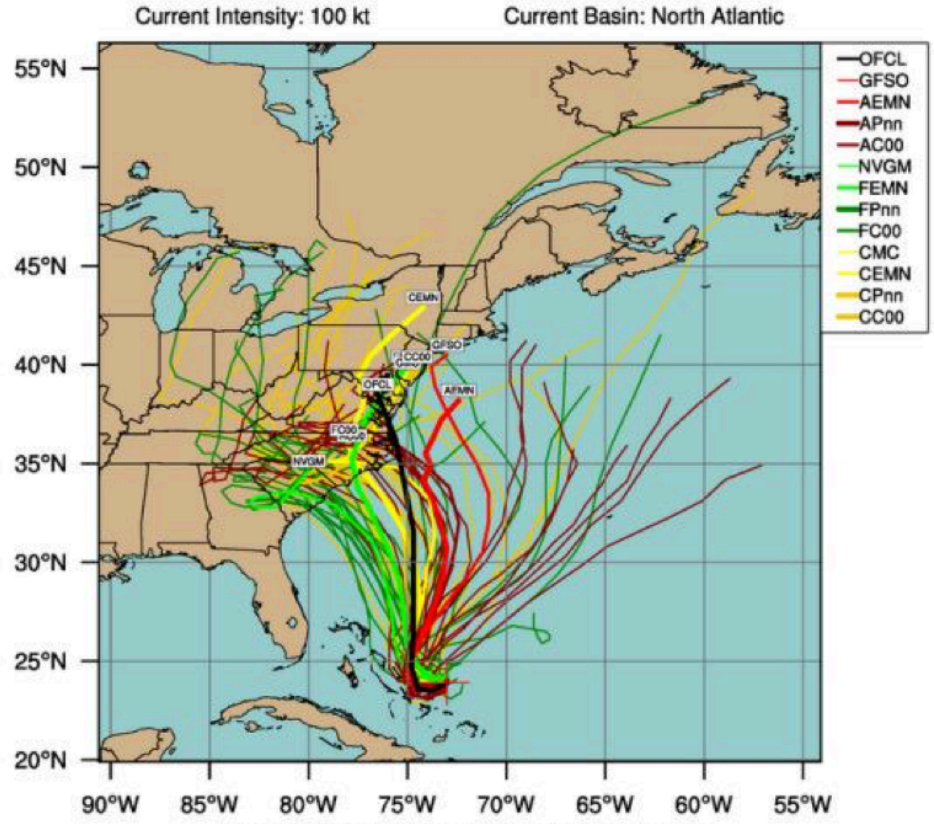
Different

- resolutions
- Ocean, biosphere, cryosphere models
- Parameterizations
- Feedback strengths
- Levels of complexity

Climate Sensitivity

MAJOR HURRICANE JOAQUIN (AL11)

EPS track guidance initialized at 0000 UTC, 01 October 2015

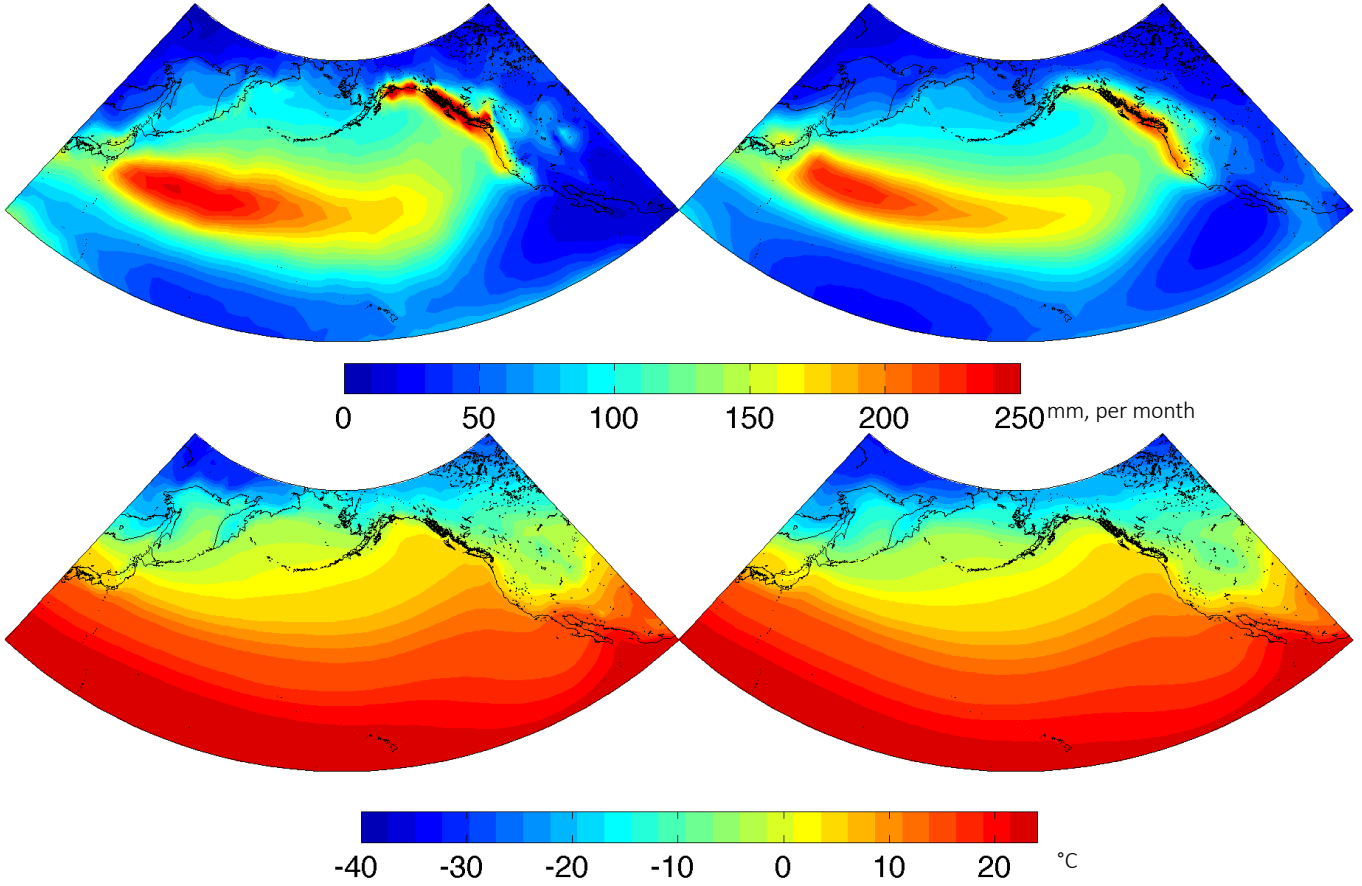


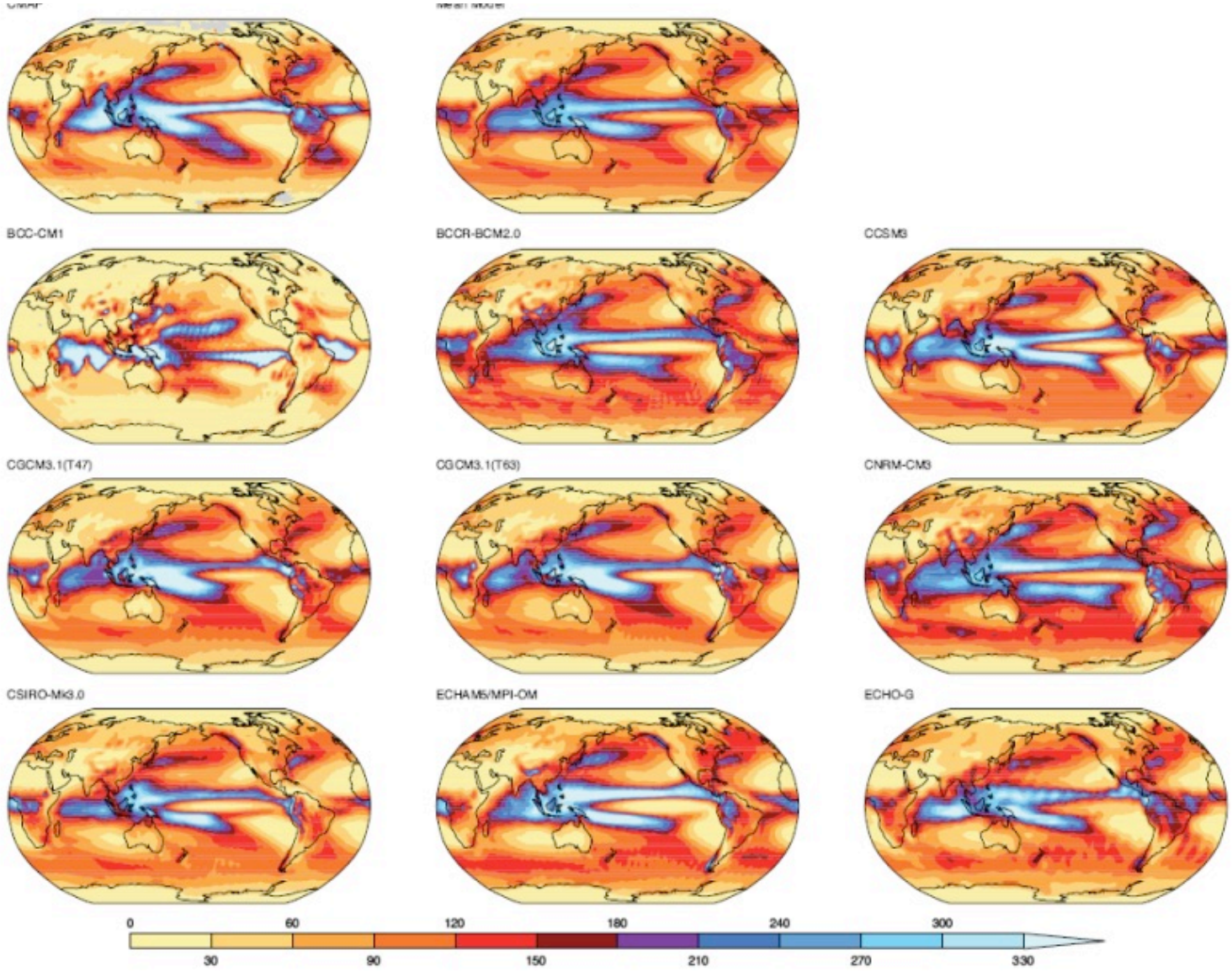
Which model is right?

- Models will respond differently to the same radiative forcing experiment, e.g., a doubling of CO_2
- Solution: Use a range of models to determine the range of possible future scenarios. A mean of models is often superior to any single model (error cancelation).
- This approach is used in weather forecasting (e.g., hurricane tracks)

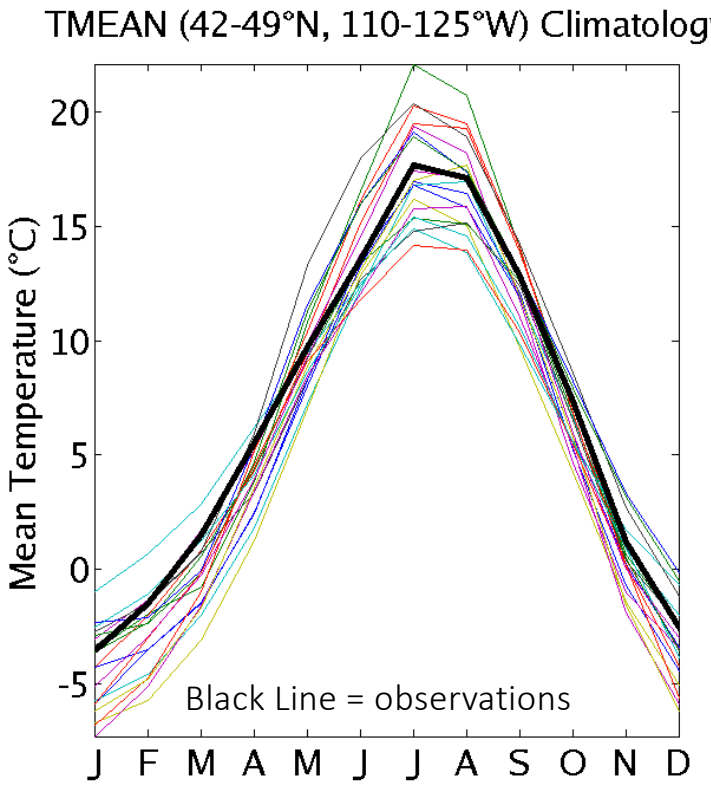

abc 2 TOMORROW
2 DEGREE GUARANTEE
775°
Mostly Cloudy
Isolated Shower

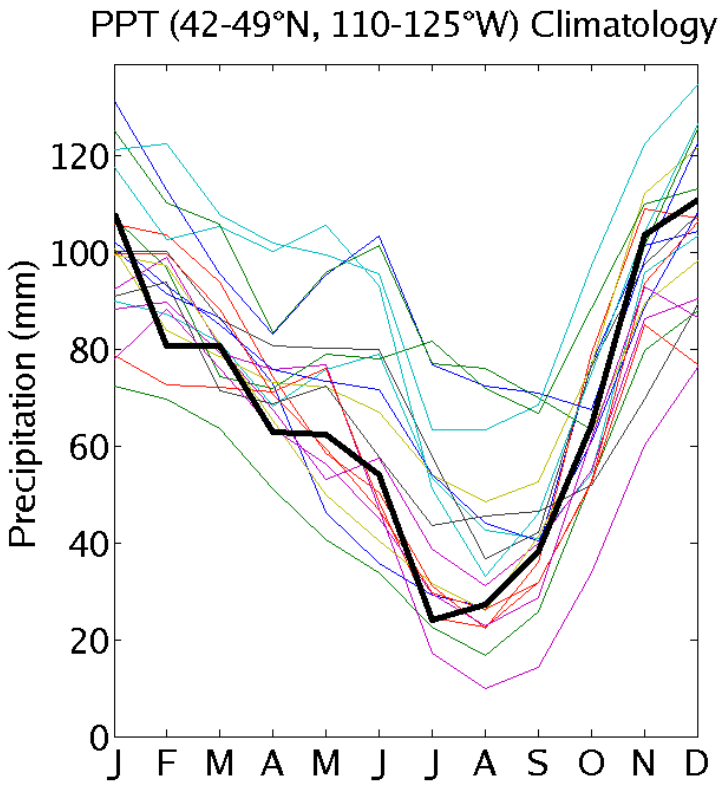
Can models reproduce observed climate?



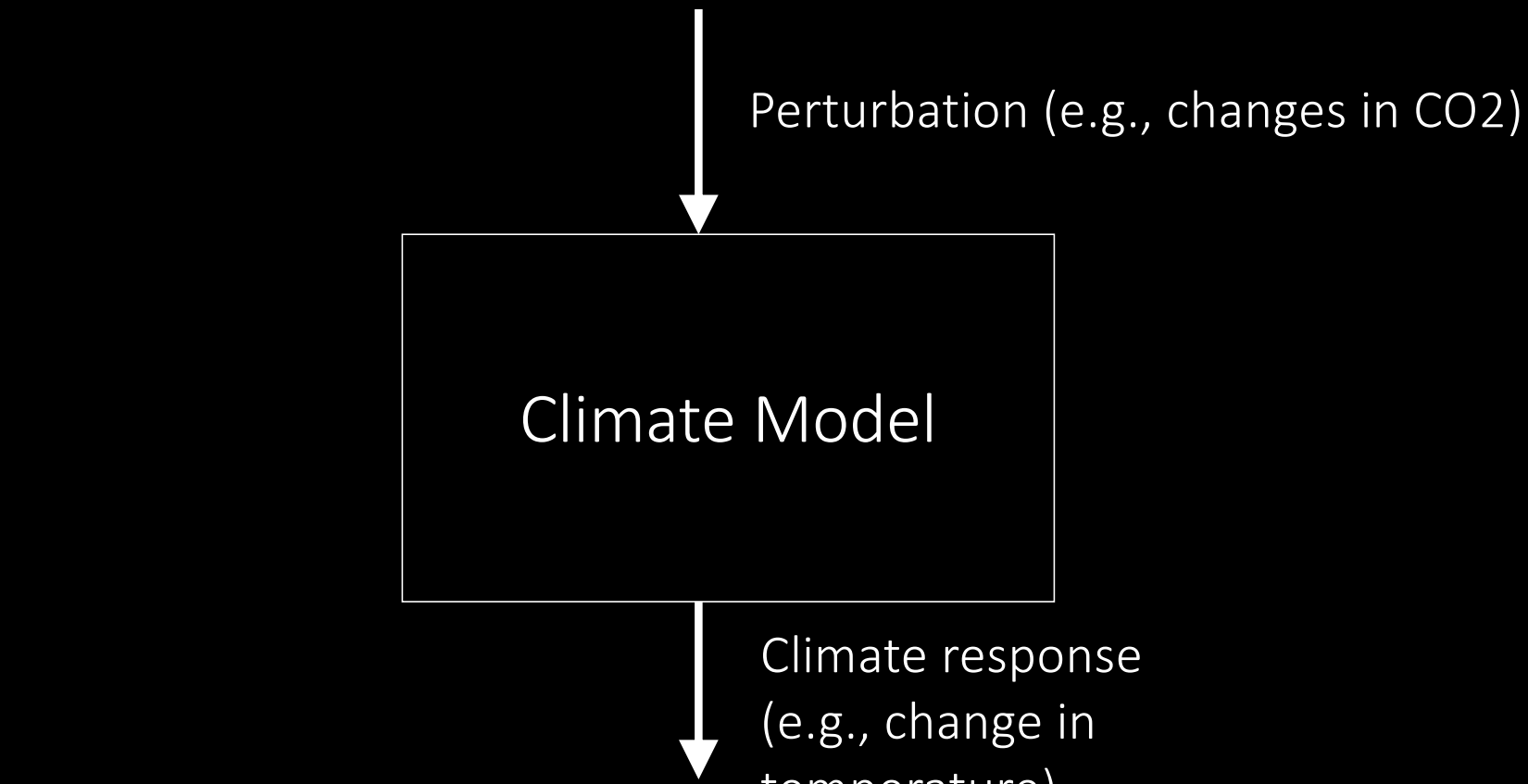

BCC-CM1
BCCR-BCM2.0
CCSM3
CGCM3.1(T47)
CGCM3.1(T63)
CNRM-CM3
CSIRO-Mk3.0
ECHAM5/MPI-OM
ECHO-G
0
30
60
90
120
150
180
210
240
270
300
330

How about over the NW United States?

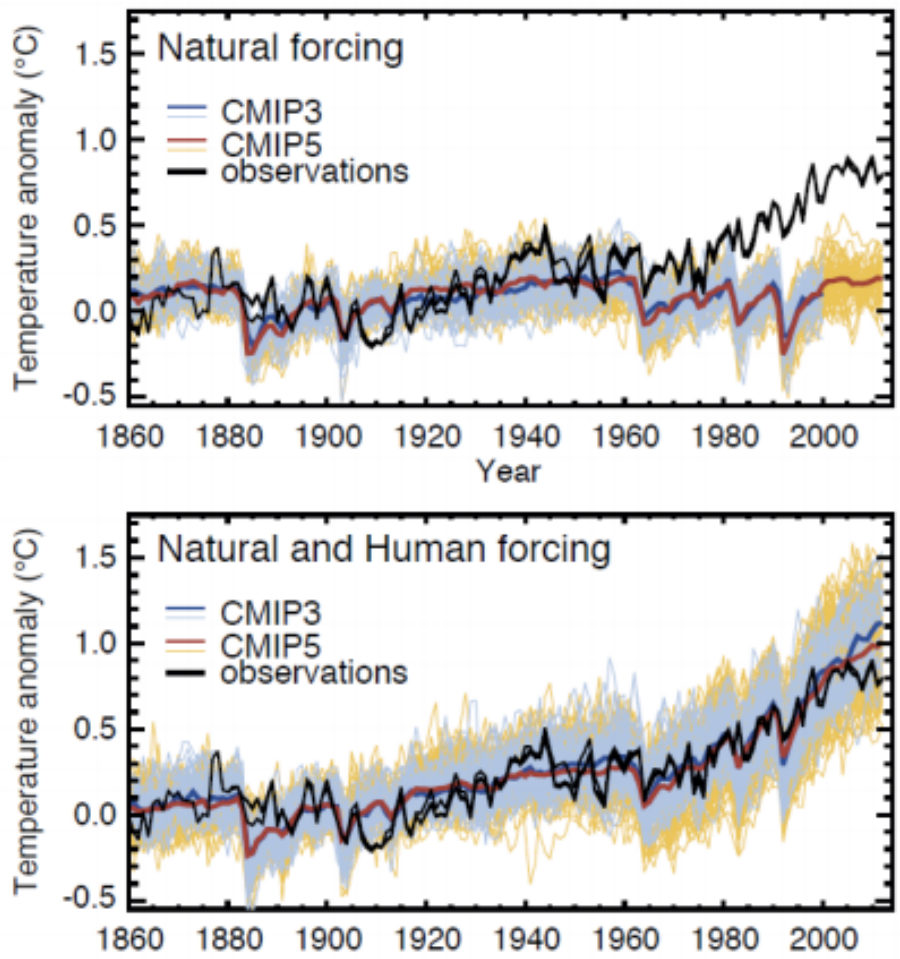




Model Schematic



20th Century Climate: Model Simulations



Experiment 1:

Solar + Volcanic Only

Experiment 2:

Solar + Volcanic

+ Anthropogenic GHG

+ Anthro Aerosols

+ Land Use Changes

G

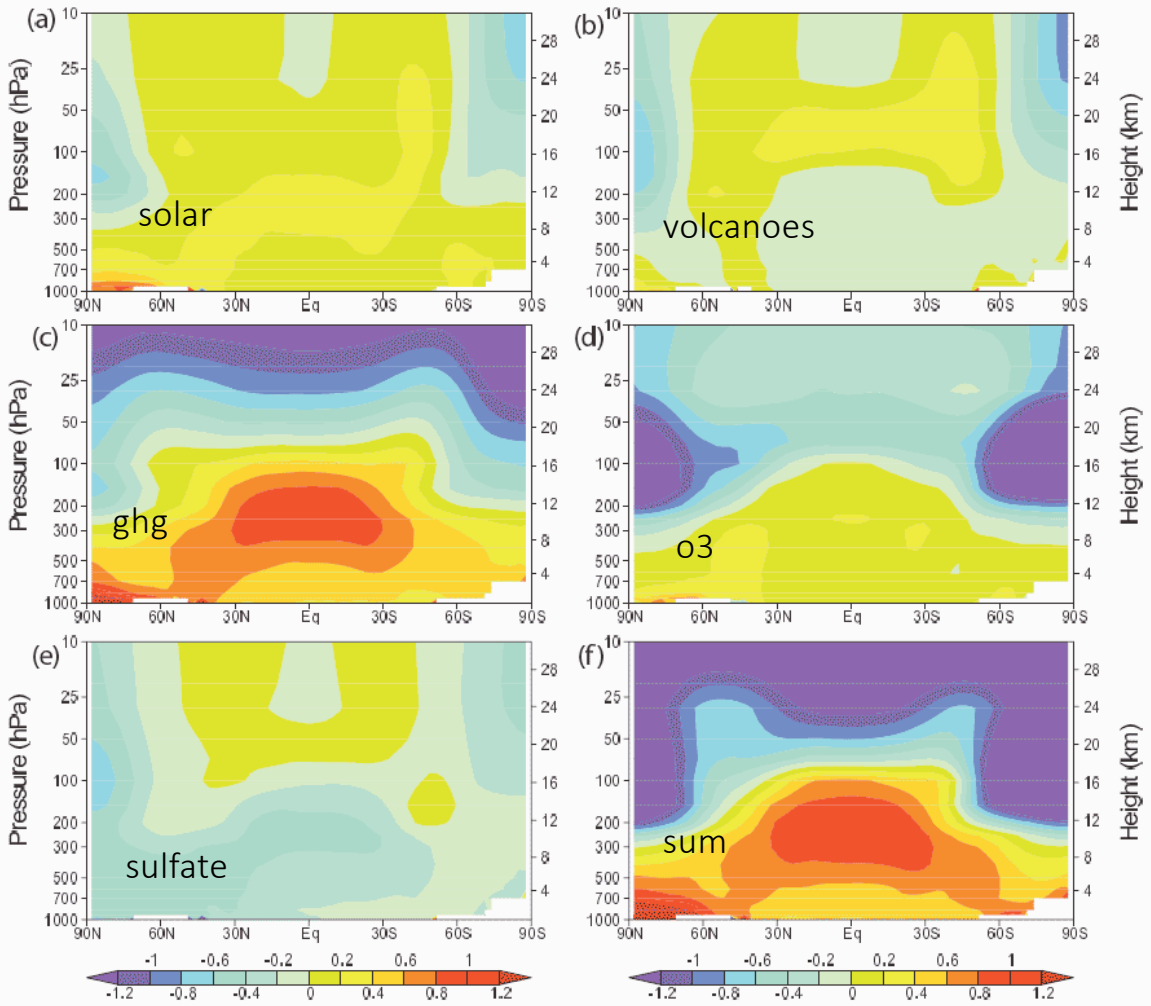


Figure 9.1. *Zonal mean atmospheric temperature change from 1890 to 1999 (°C per century) as simulated by the PCM model from (a) solar forcing, (b) volcanoes, (c) well-mixed greenhouse gases, (d) tropospheric and stratospheric ozone changes, (e) direct sulphate aerosol forcing and (f) the sum of all forcings. Plot is from 1,000 hPa to 10 hPa (shown on left scale) and from 0 km to 30 km (shown on right). See Appendix 9.C for additional information. Based on Santer et al. (2003a).*

Predicting Future Climate

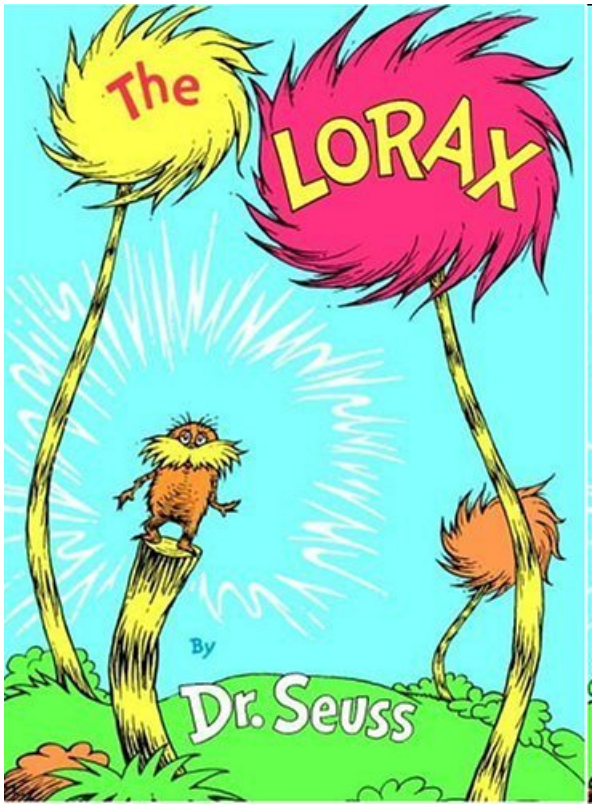
Solar irradiance and volcanic aerosols

- Have not played dominant role in long term climate changes in past 150 years
- *Hence changes in these are not explicitly considered in climate change experiments*

Greenhouse gas and aerosol emissions

- Future socioeconomic and energy policies provide us with idea of future emissions
- Since changes have been *attributed* to increases in atmospheric concentrations, then future climate change hinges on predicting their concentrations

The Future Storylines



What factors affect future CO_2 levels?

1. Global Population (Demographics)
2. Type of energy generation
3. Growth Rate of Economy
4. Type of Economy (material vs. service/info based)
5. Cooperation among countries (Globalization)
6. Sequestration efforts

Representative Concentration Pathways (RCP)

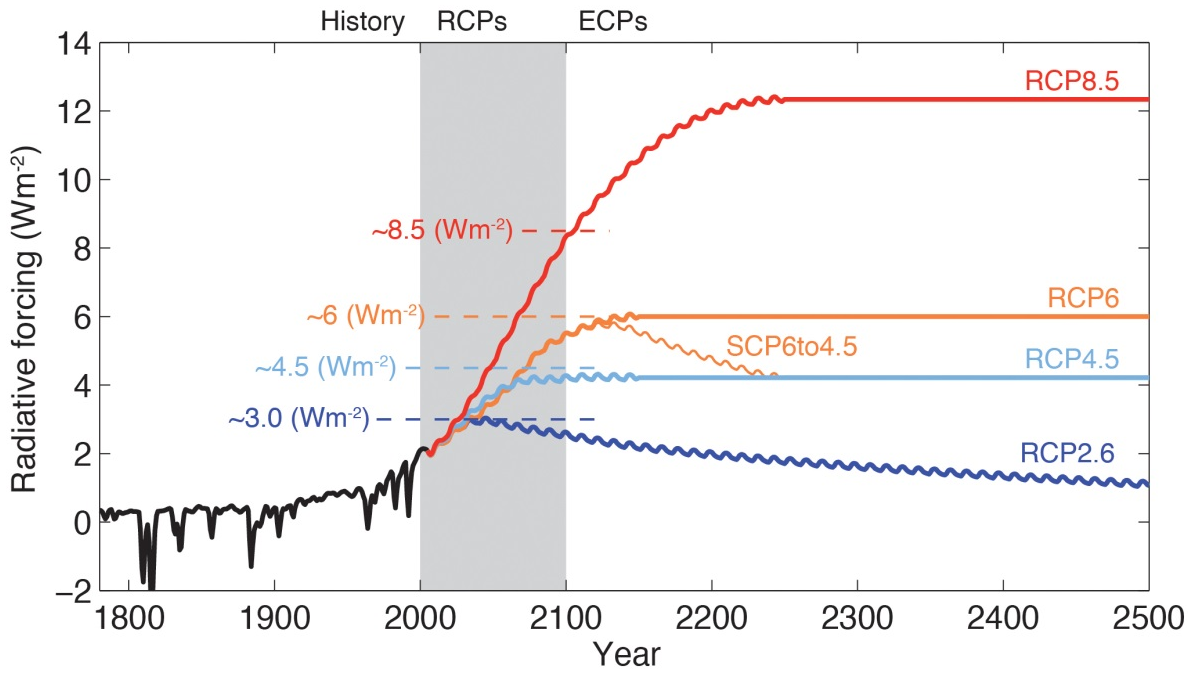
Specify watts/m2 of radiative forcing and reflect concentrations and corresponding emissions, but NOT socio-economic storylines.

RCP8.5: No climate policy future. Business as usual.

RCP6.0: Adapt to Risk

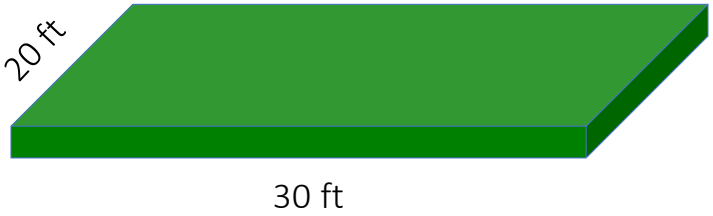
RCP4.5: Moderate Mitigation and Climate Policy

RCP2.6: Aggressive Climate Policy and Carbon Sequester and Capture Technology



Anthropogenic Forcing
To-date

+ 1.6 W/m^2



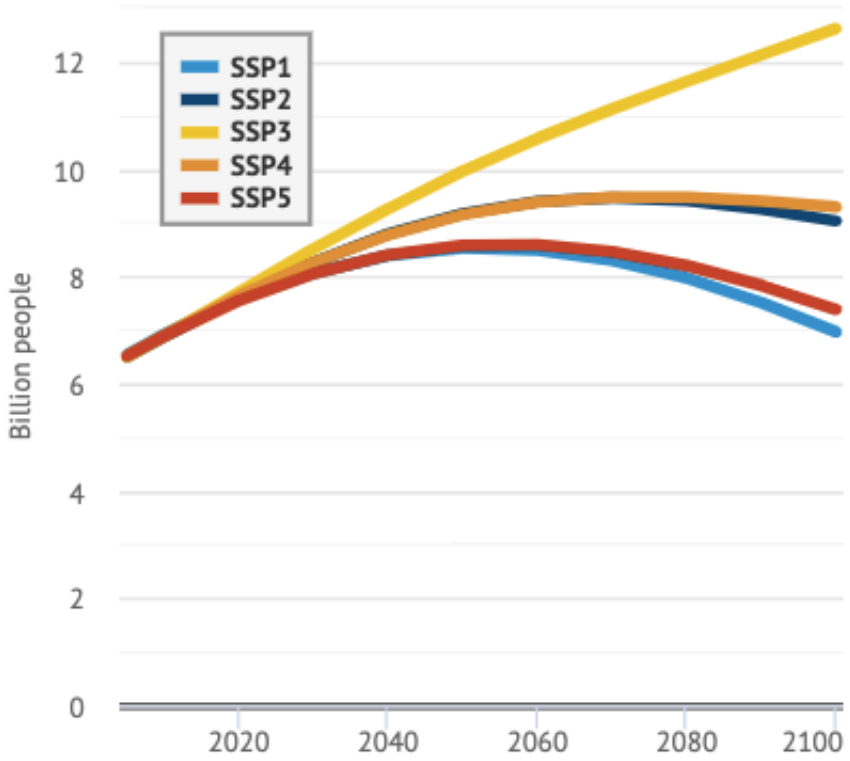
Anthropogenic Forcing
By 2100

Shared Socioeconomic Pathways (SSP)

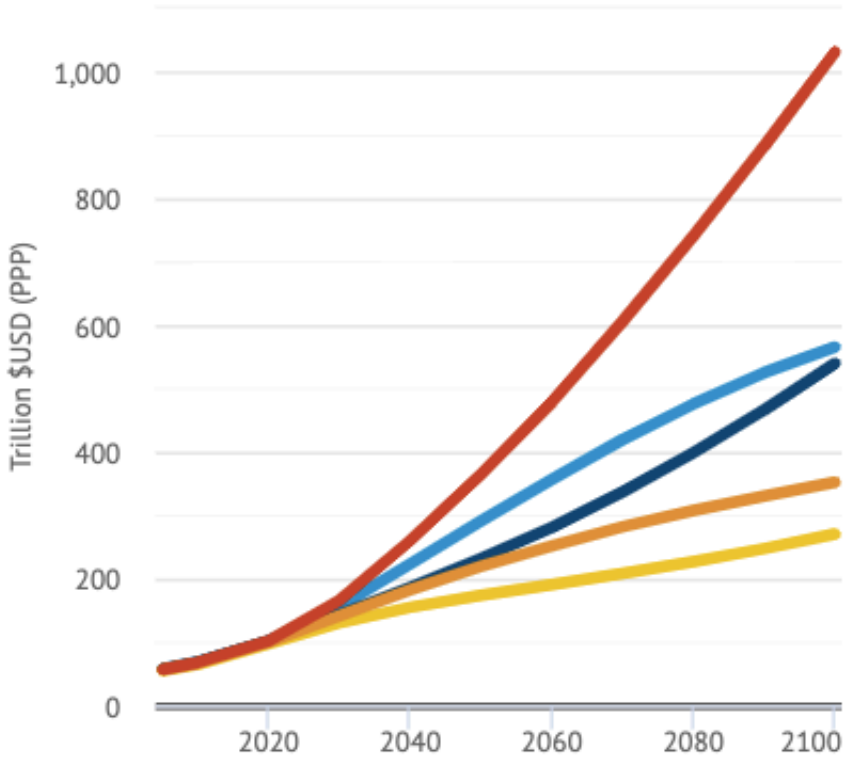
Story lines that describe future changes in:

- population growth
- governance efficiency
- inequality across and within countries
- technology change
- environmental conditions

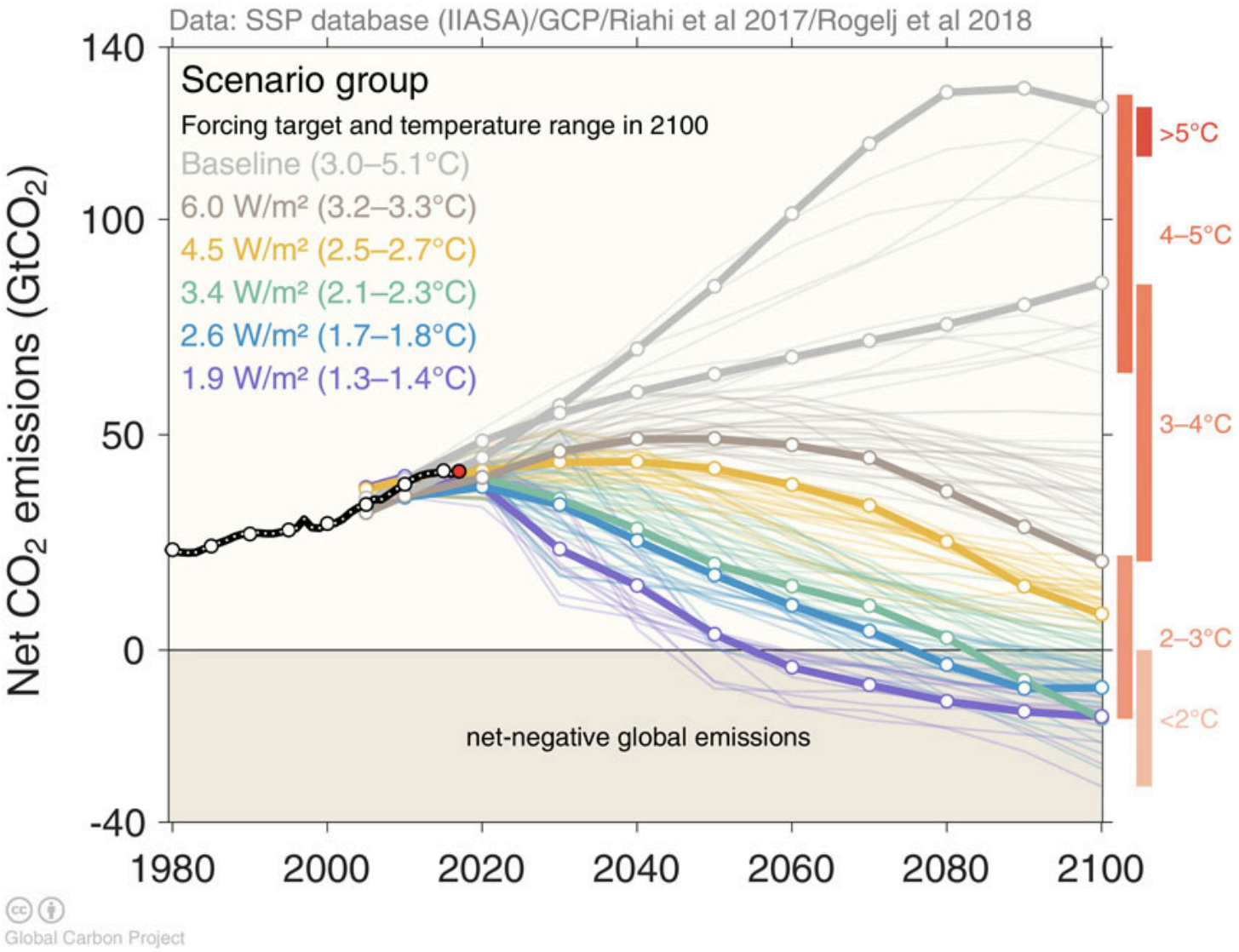
Global population

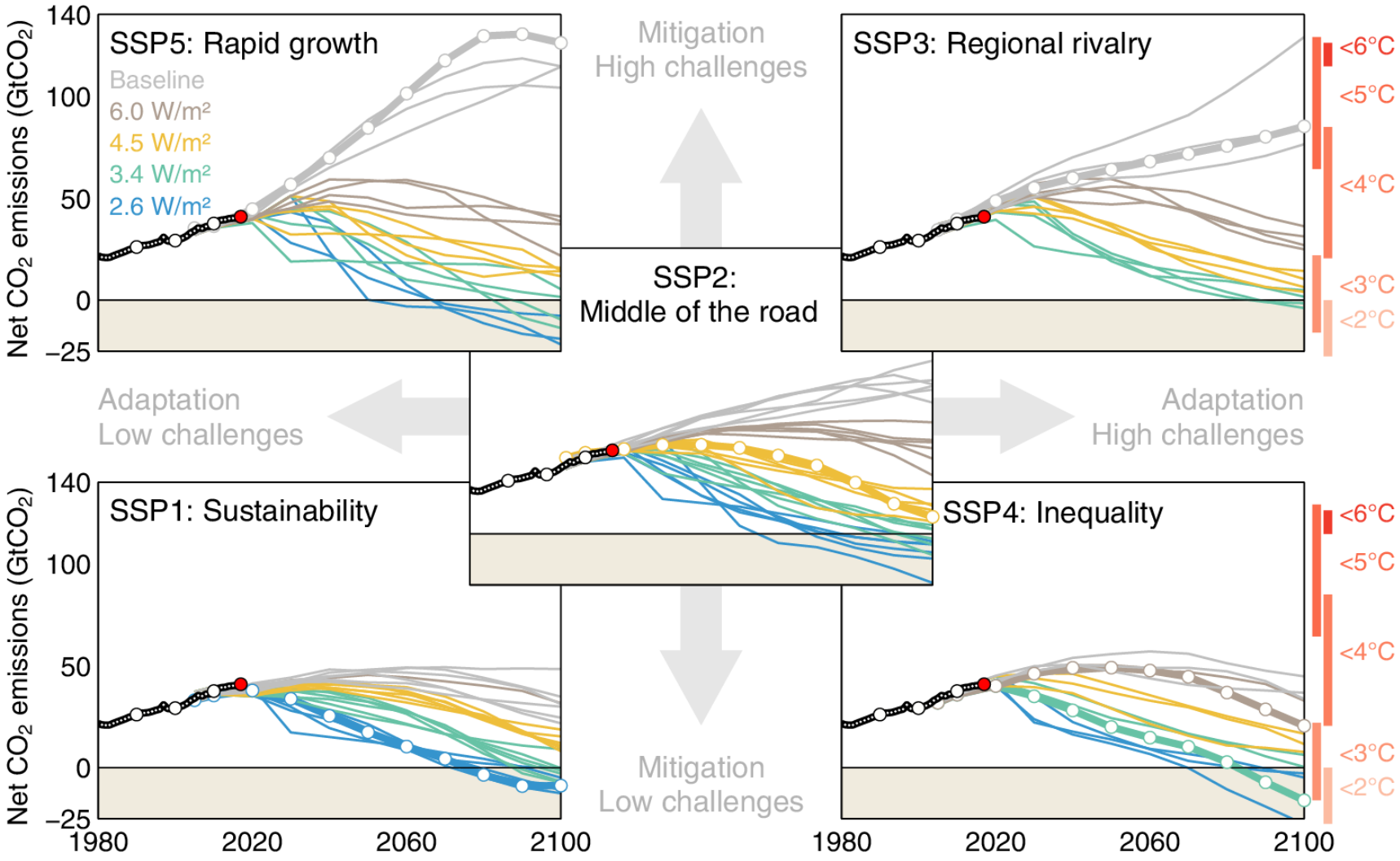


Global GDP

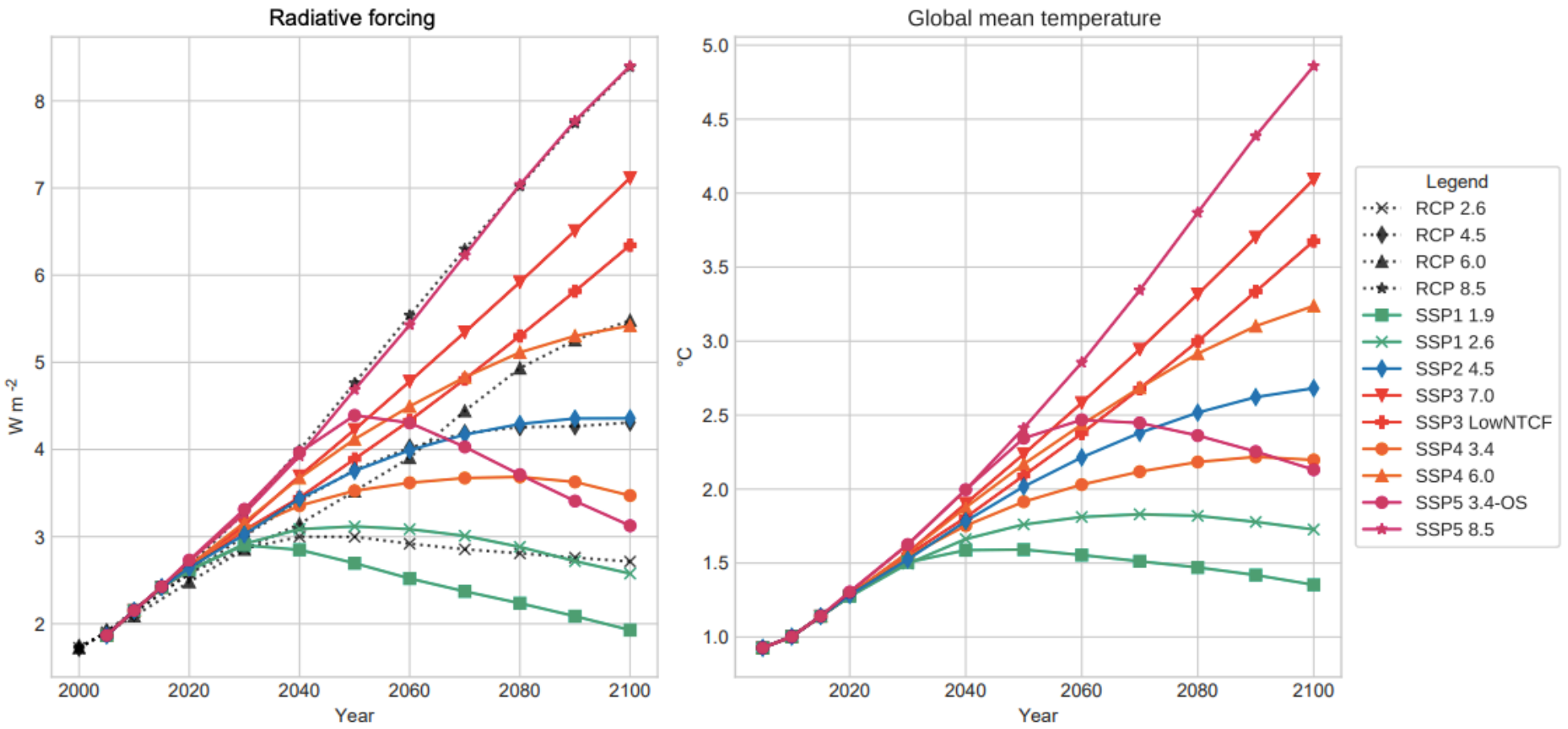


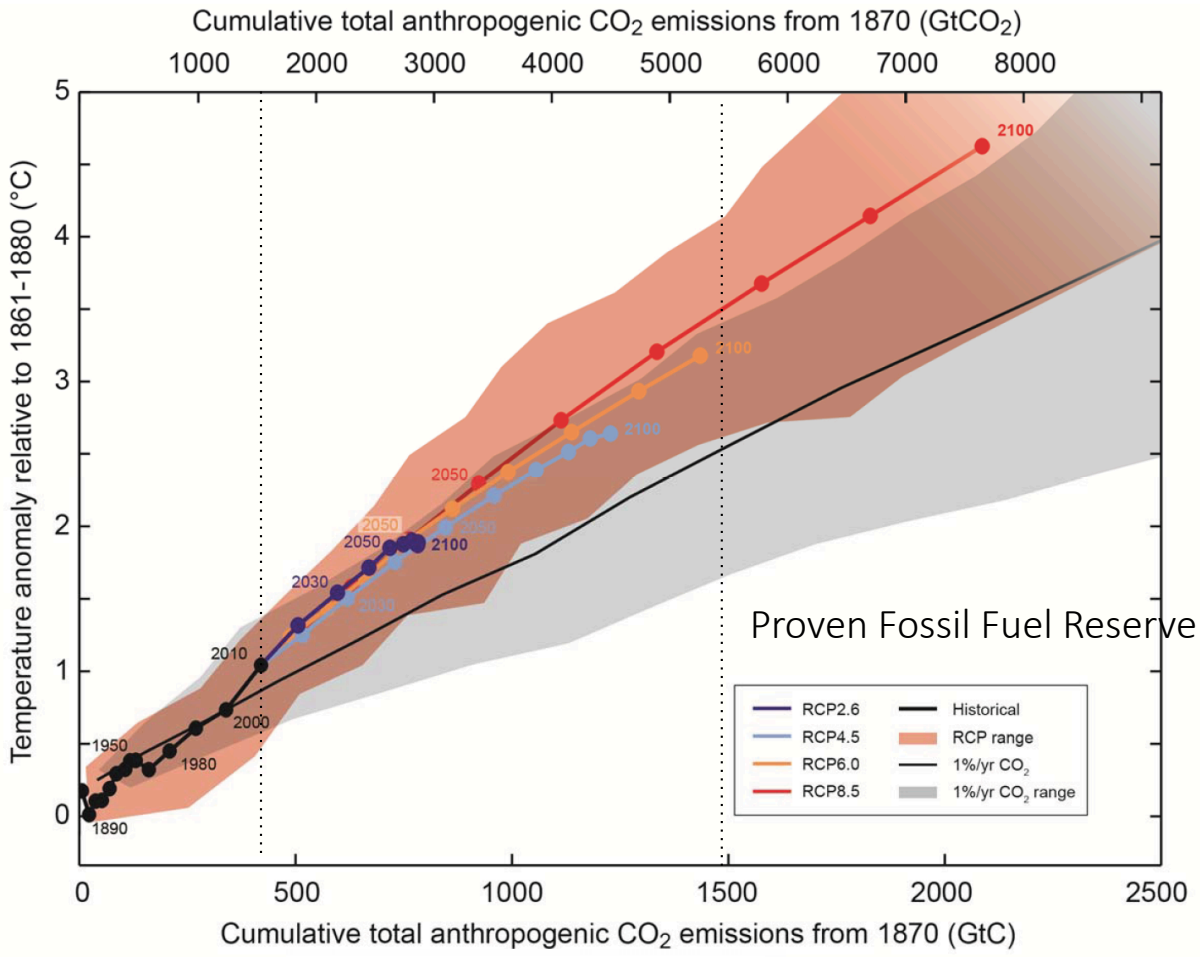
CB





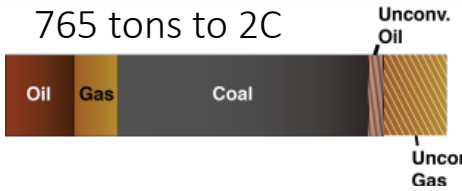
Projected CO_2 Emissions



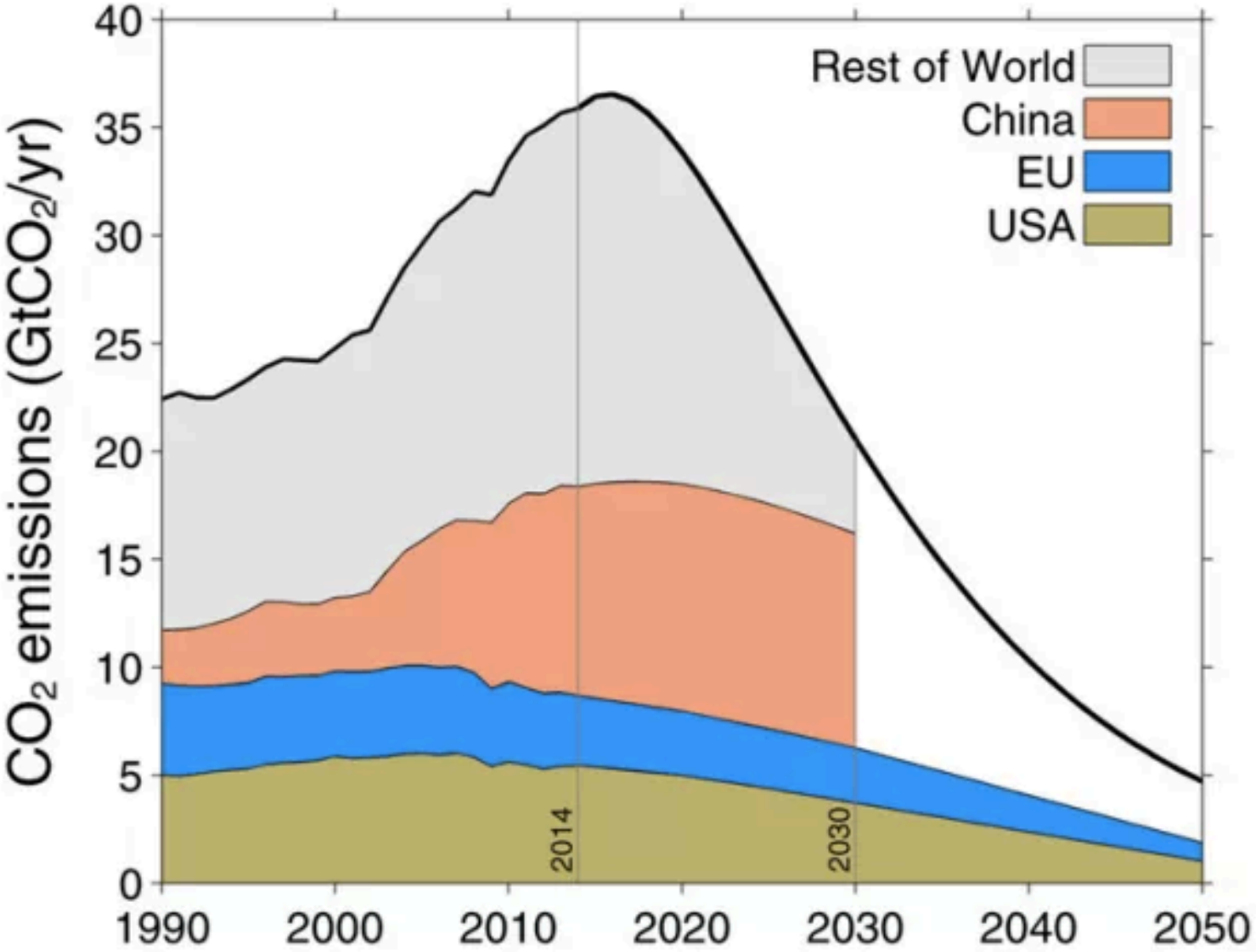


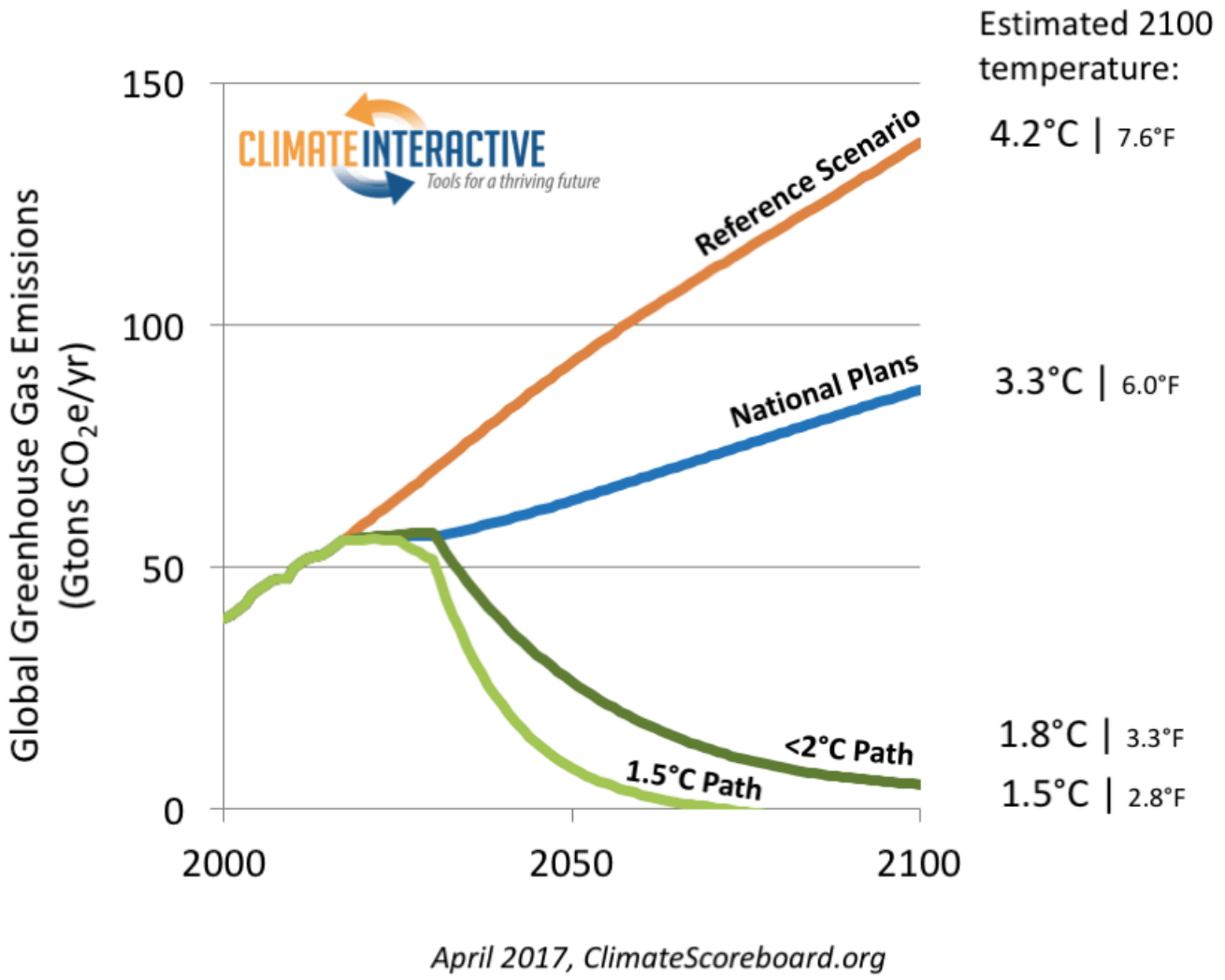
Proven Fossil Fuel Reserve

765 tons to 2C



Fuels Available


Rest of World
China
EU
USA
CO_2 emissions ($GtCO_2$/yr)
0
5
10
15
20
25
30
35
40
1990
2000
2010
2020
2030
2040
2050
2014
2030


Estimated 2100 temperature:
CLIMATE INTERACTIVE
Tools for a thriving future
Reference Scenario
National Plans
<2°C Path
1.5°C Path
4.2°C | 7.6°F
3.3°C | 6.0°F
1.8°C | 3.3°F
1.5°C | 2.8°F
Global Greenhouse Gas Emissions (Gtons CO_2e/yr)
150
100
50
0
2000
2050
2100
April 2017, ClimateScoreboard.org