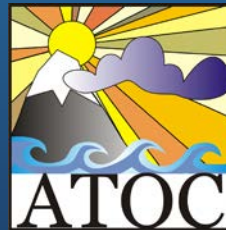


Introduction to climate modeling and sources of uncertainty

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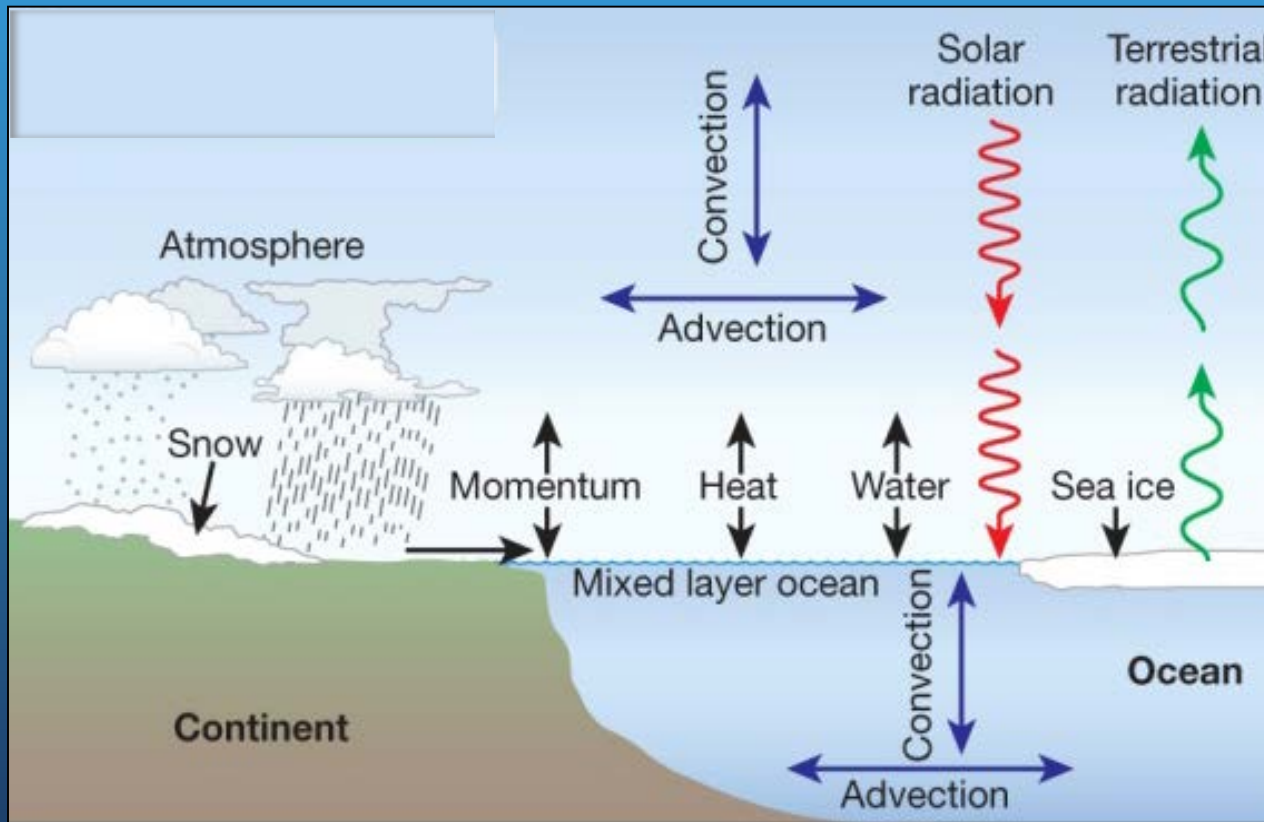
Outline

- What is a climate model?
- How do we use climate models?
- What are the sources of uncertainty in climate model simulations?
- What can we do and not do with climate models?
- Summary

What is a climate model?

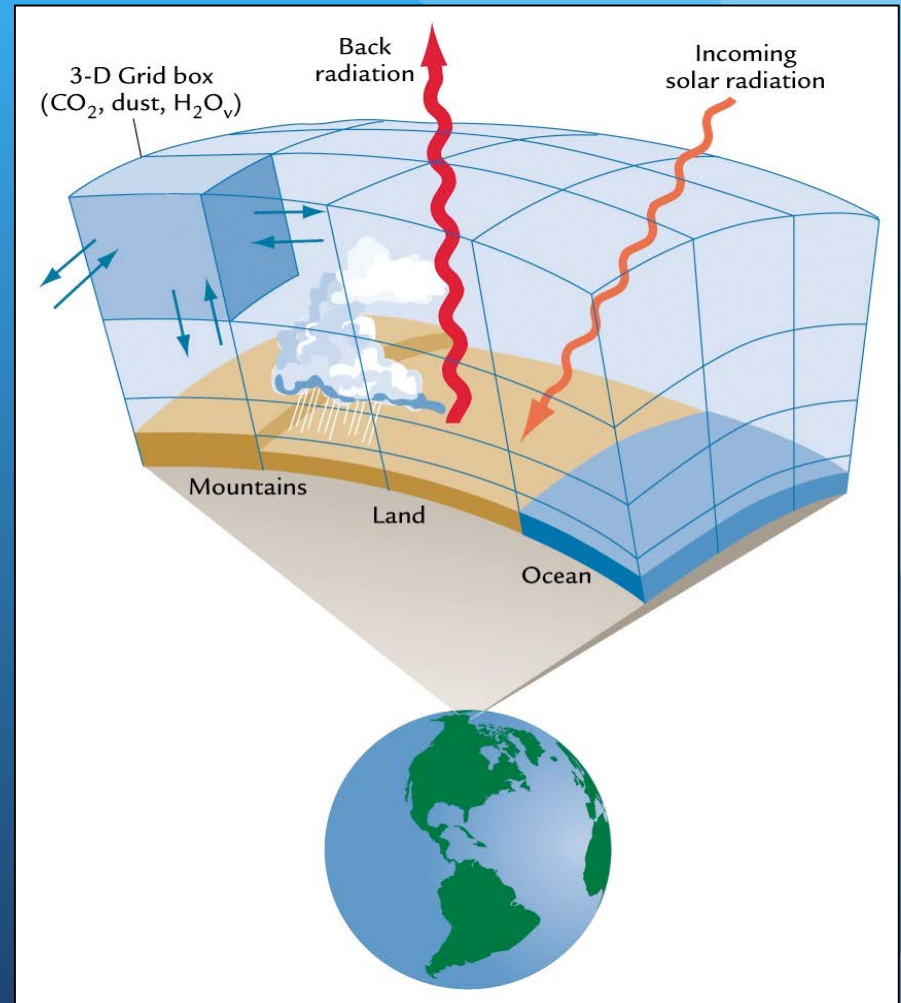
Climate models are systems of differential equations based on the basic laws of physics and chemistry. To “run” a model, scientists divide the planet into a 3-dimensional grid, apply the basic equations, and evaluate the results.

Wikipedia

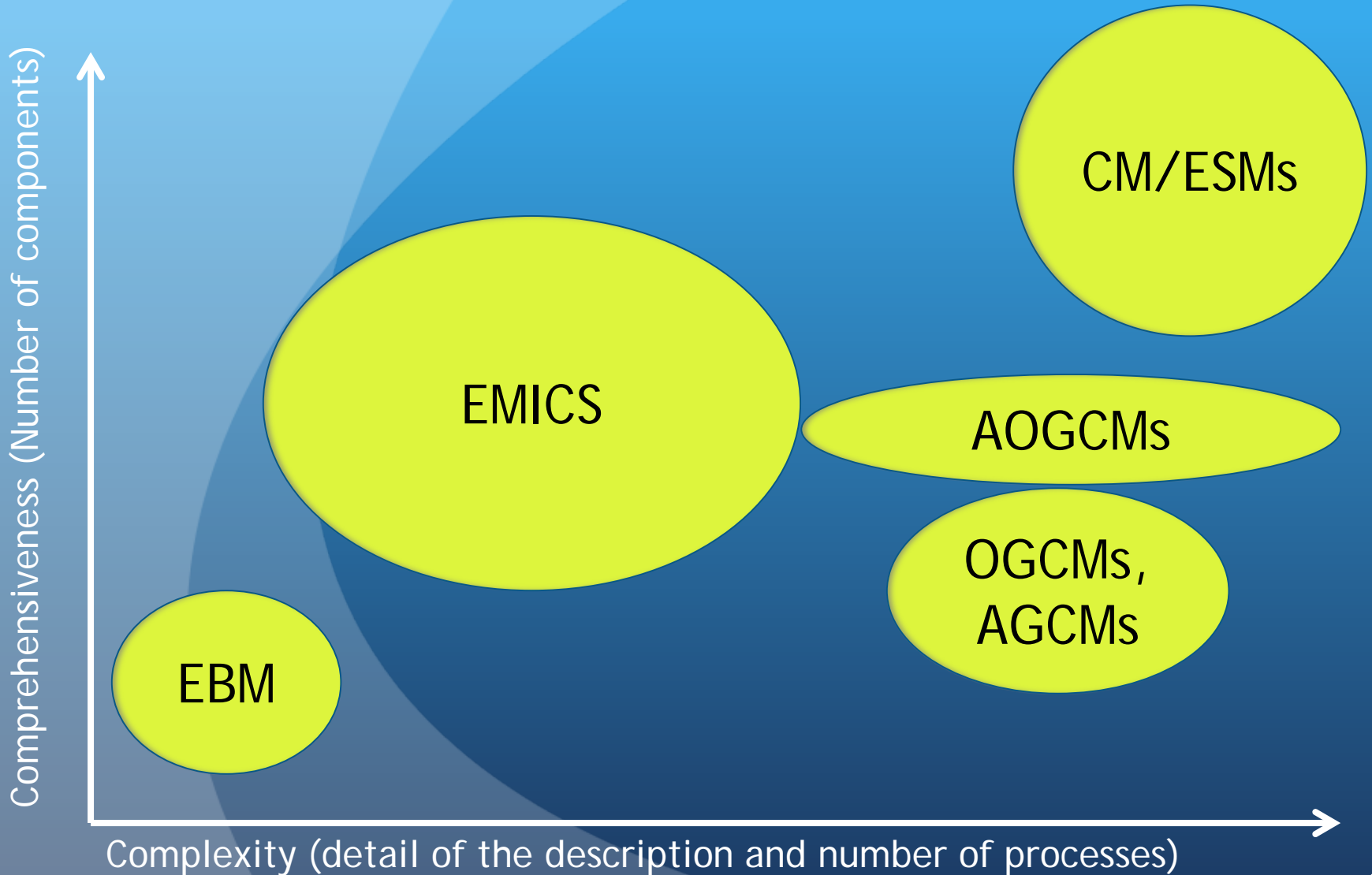


What is a climate model?

- Separate models for parts of the climate system:
 - Atmosphere, Ocean, sea ice, land ice, land surface, runoff, etc
- All solving equations for the balance of mass, momentum, energy, and more
- Coupled together to exchange fluxes between components



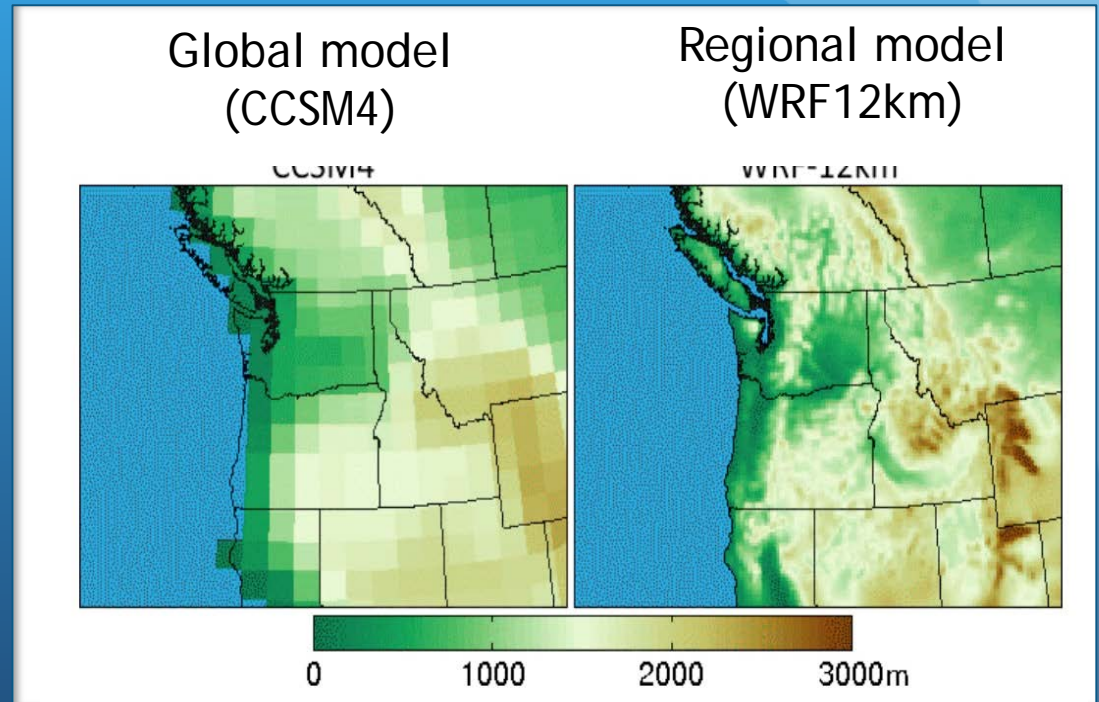
Different kinds of climate models



Regional versus global model resolution

Regional models:
Boundary problems,
missing
teleconnections

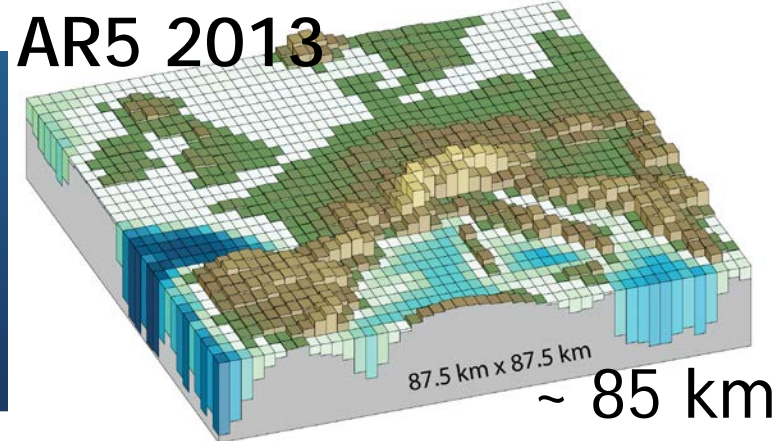
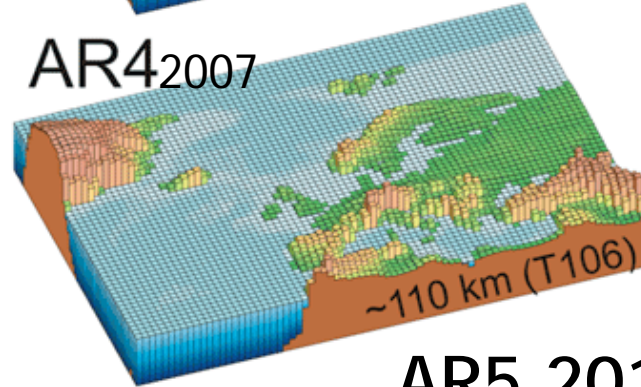
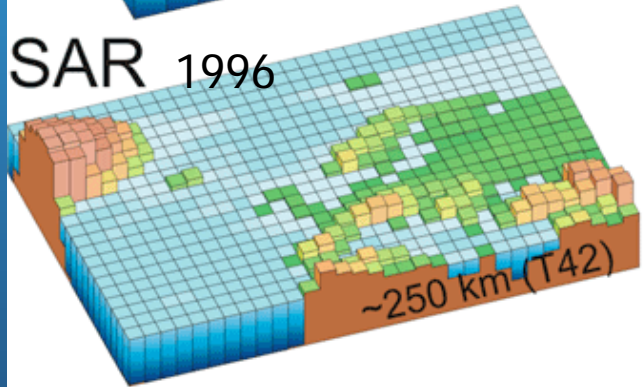
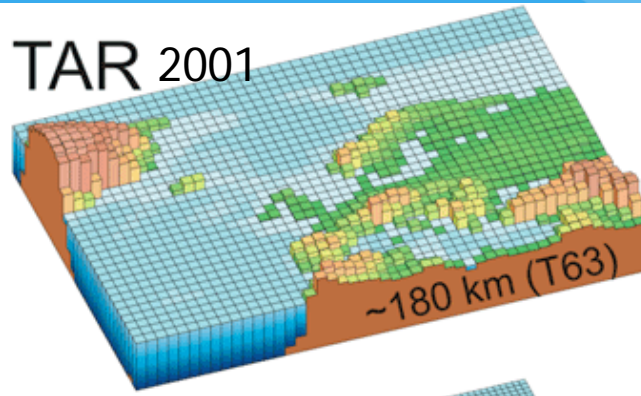
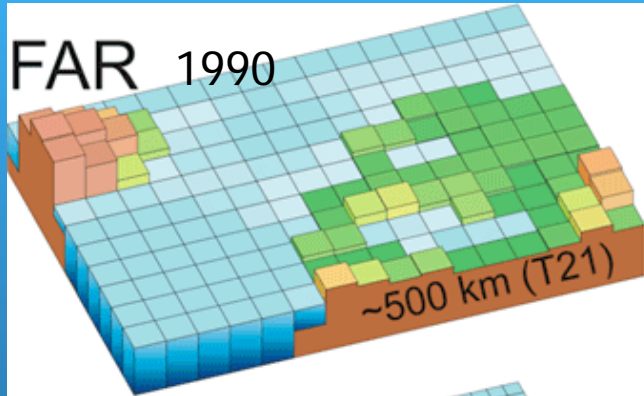
Global models:
coarser resolution,
missing processes,
more
parameterizations



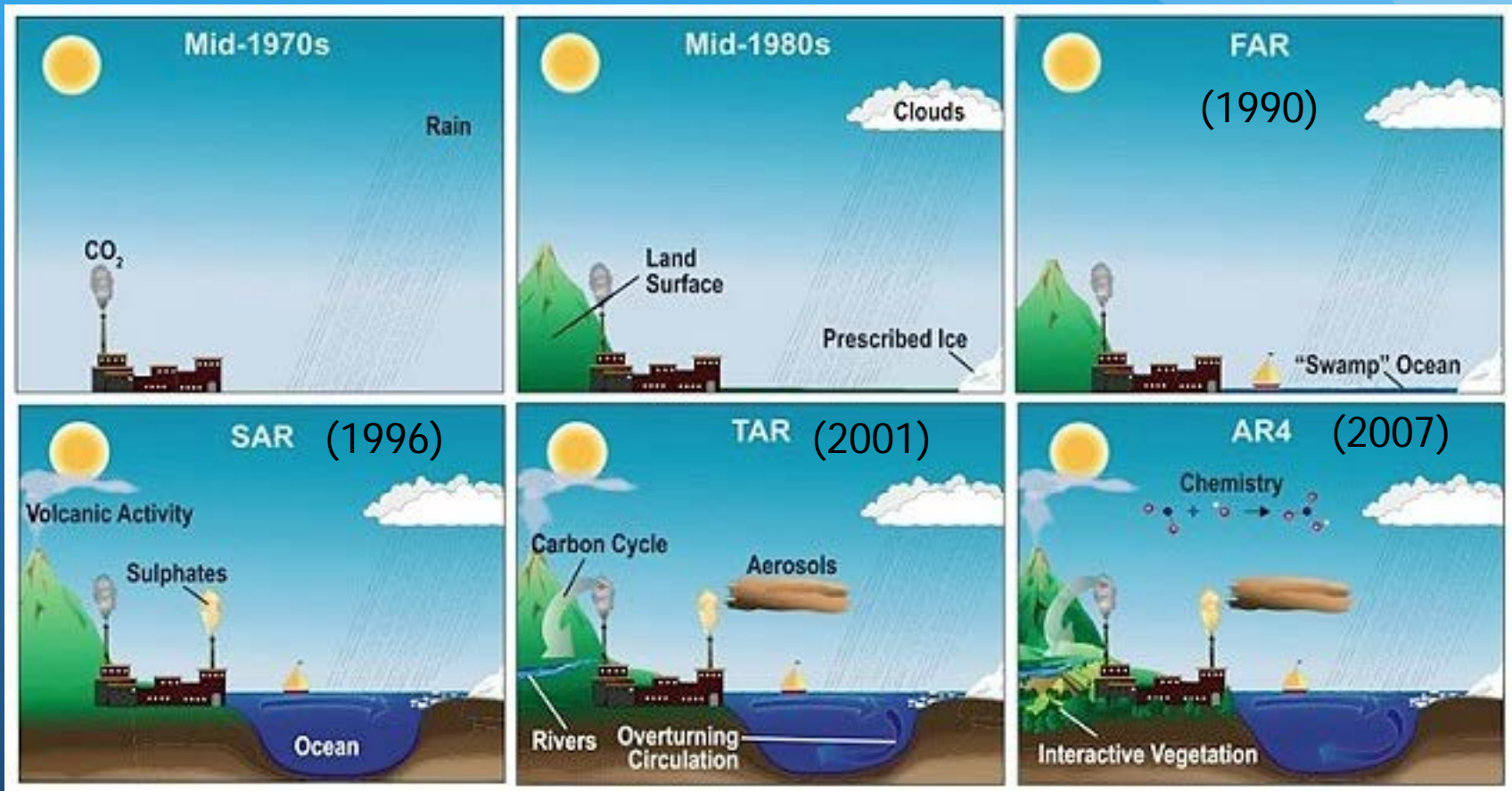
Parameterization

- Parameterization = process of including the effect of unresolved phenomena
- Usually based on:
 - Basic physics
 - Empirical formulation from observations
- Key parameterizations in a climate model: radiation, effects of unresolved turbulence and gravity waves, effects of convection on heat, clouds
- Behavior of a model is often critically dependent on parameterizations!

Climate model resolution has increased over time

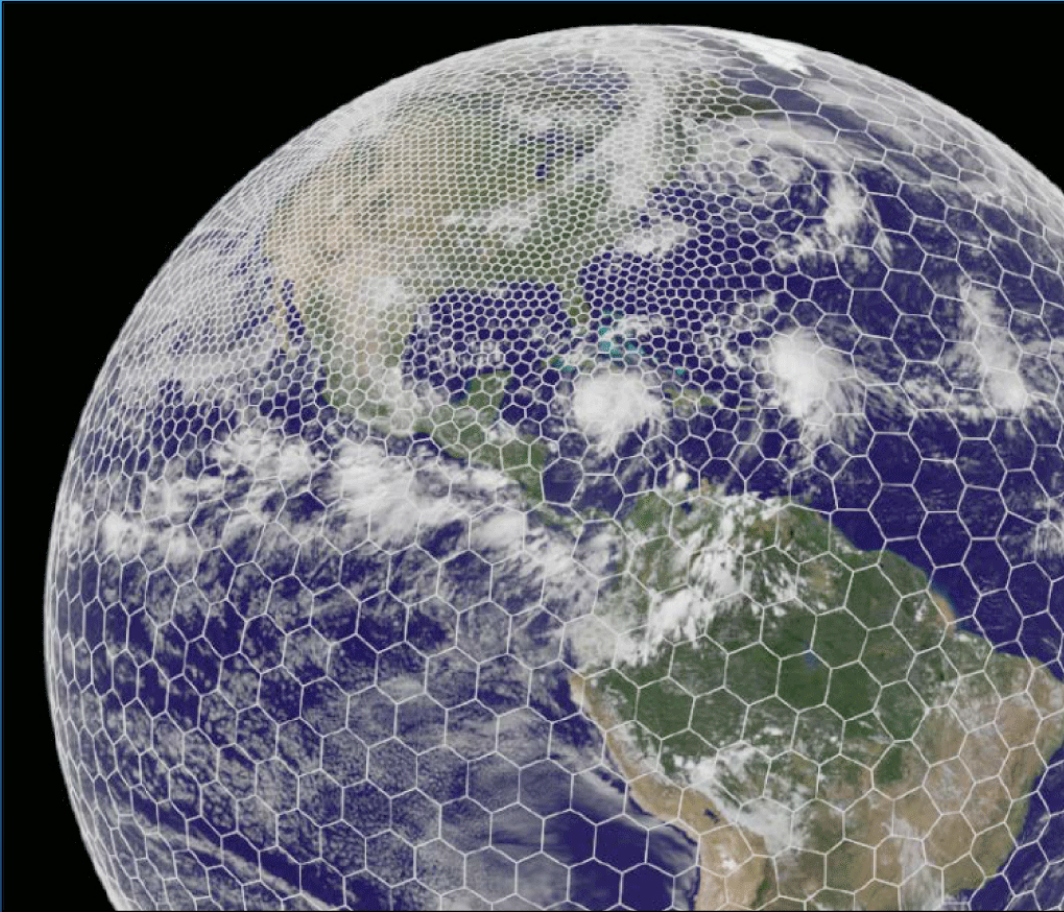


Climate model complexity has increases over time



AR5 (2013) interactive ocean marine biogeochemistry and some with ice sheets

The future: Models with unstructured grids

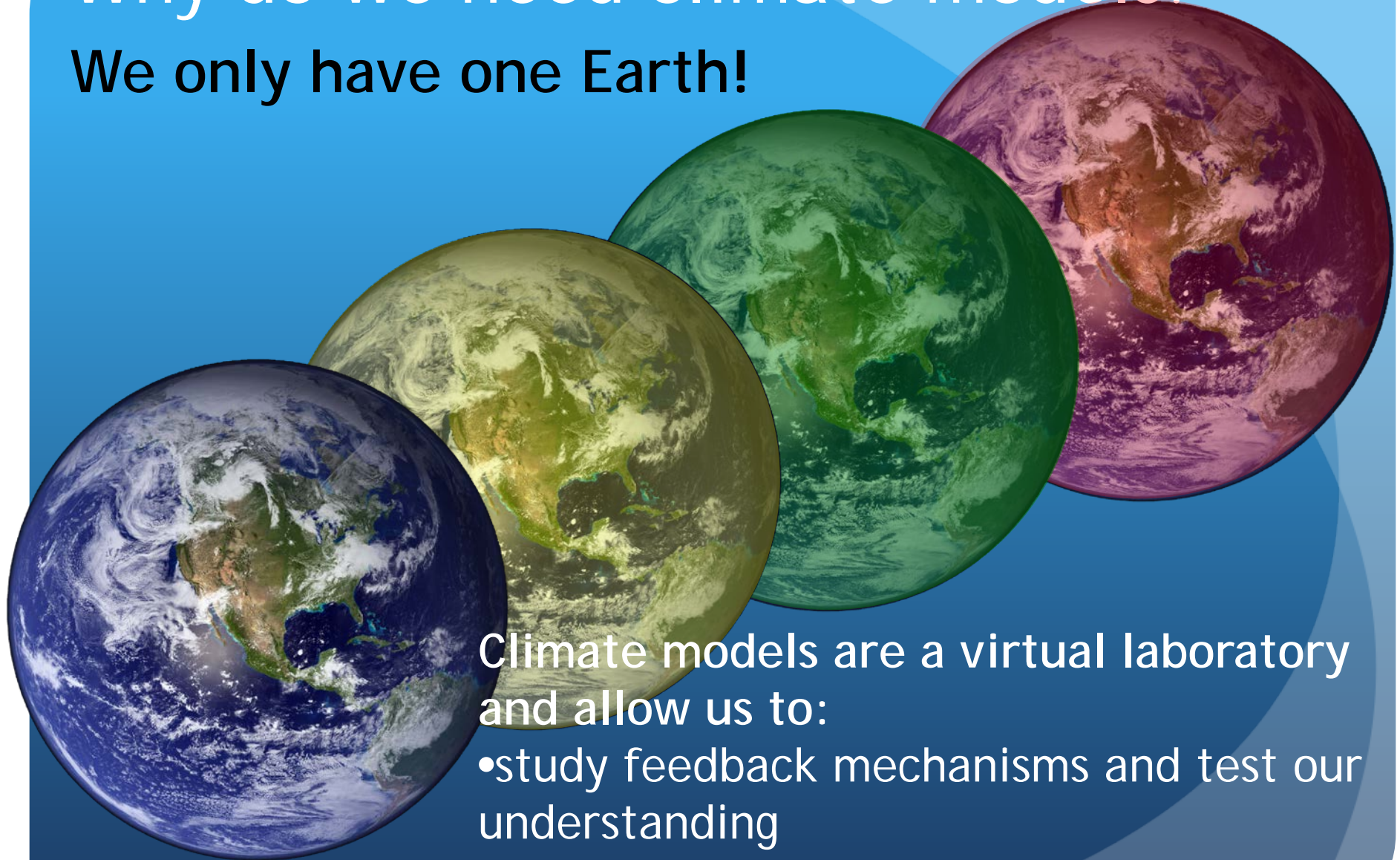


- These models allow for the refinement of resolution in regions of interest, while still being global and representing teleconnections
- First versions might be used in AR6

<https://mpas-dev.github.io/>

Why do we need climate models?

We only have one Earth!



Climate models are a virtual laboratory and allow us to:

- study feedback mechanisms and test our understanding
- project climate change into the future

How do we use climate models?

External Forcing

Solar radiation,
volcano's, greenhouse
gases

prescribed

Climate
model

©Australian Bureau of
Meteorology

Climate response

e.g., Global Surface Temperature



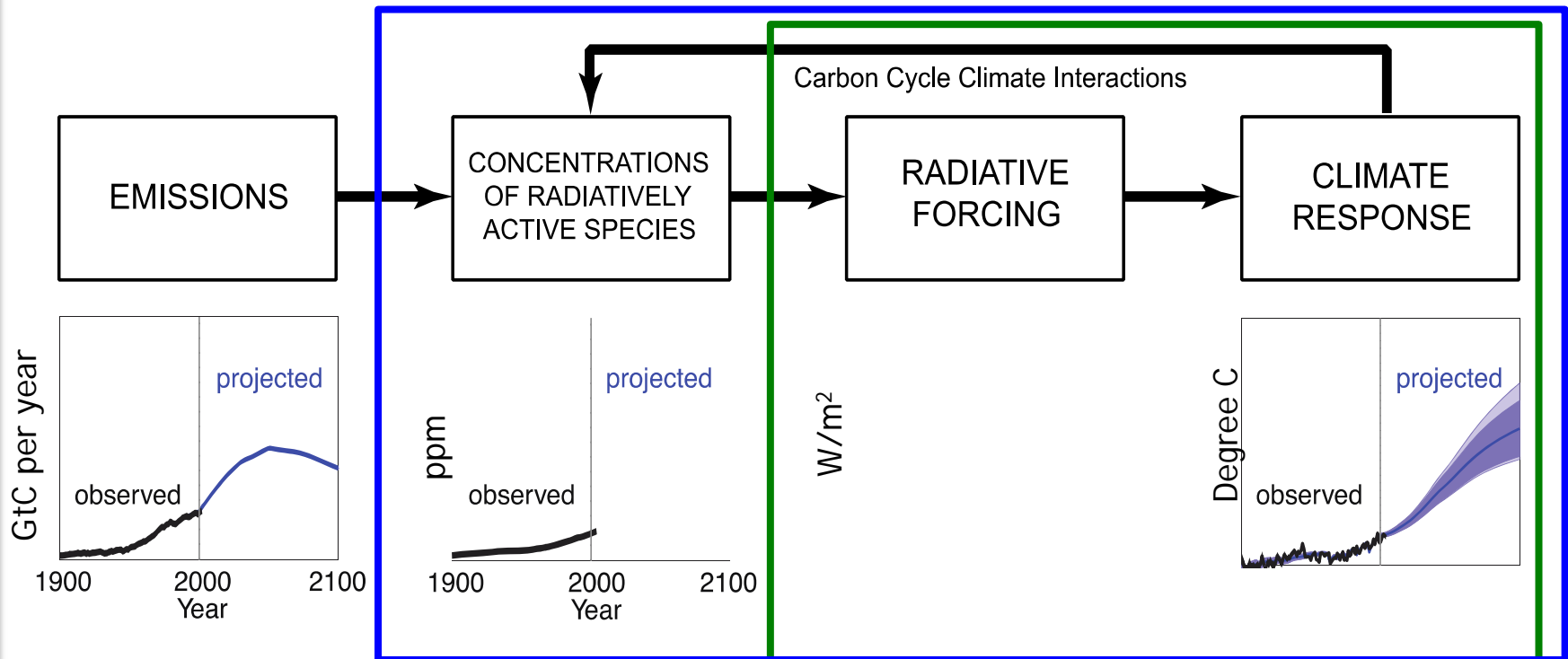
calculated

How do climate models use observational data?

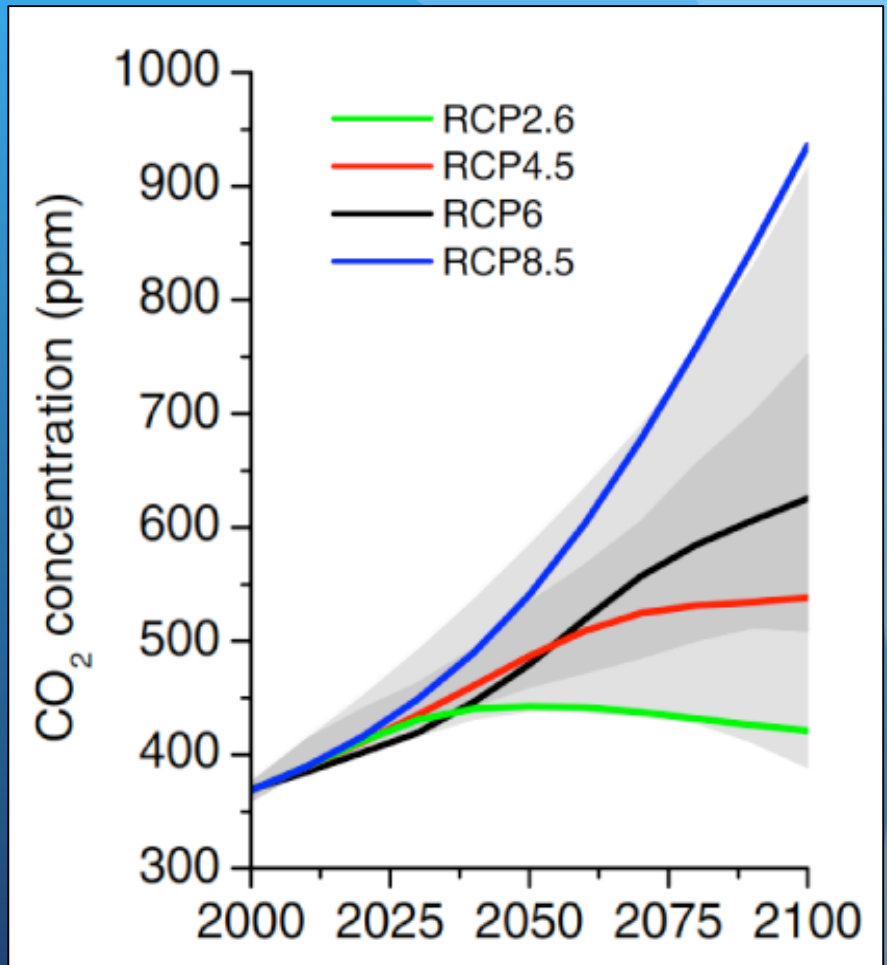
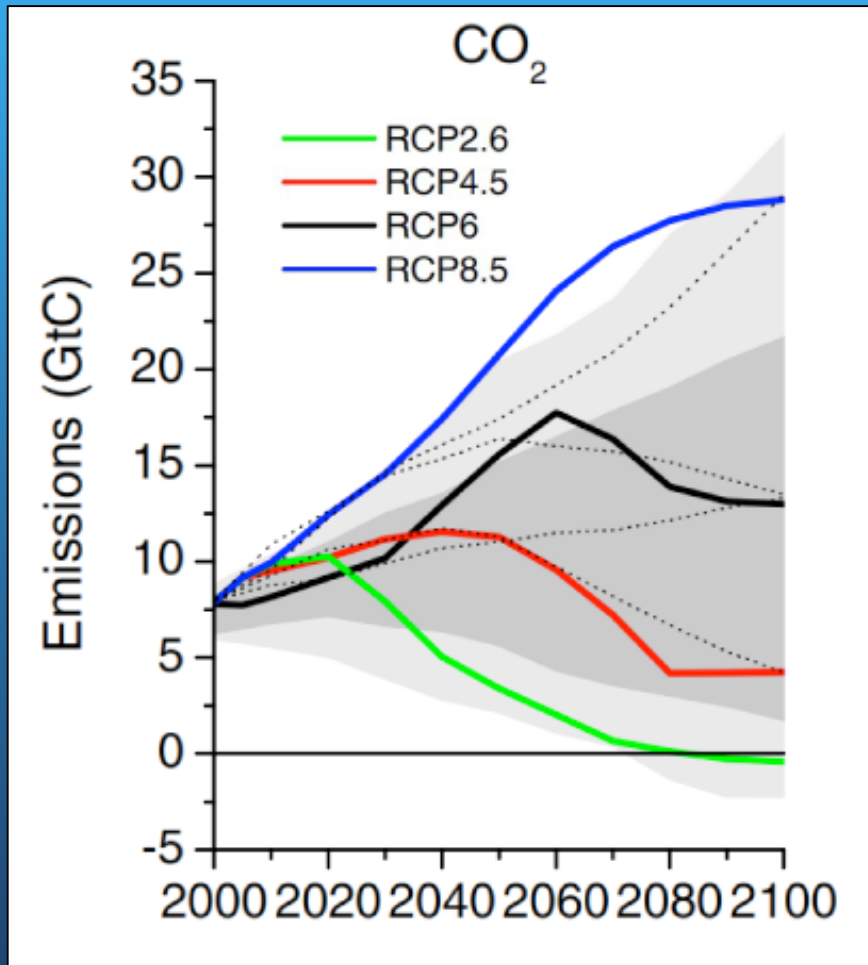
- Fully coupled global climate models are “free-running” → they do not use any observational data while running
- Observational data is used:
 - for the development of model parameterizations during model development
 - initialize the climate model (normally at 1850)
 - to assess model simulations (more on difficulties of that in my lecture on Friday)

From emissions to climate response

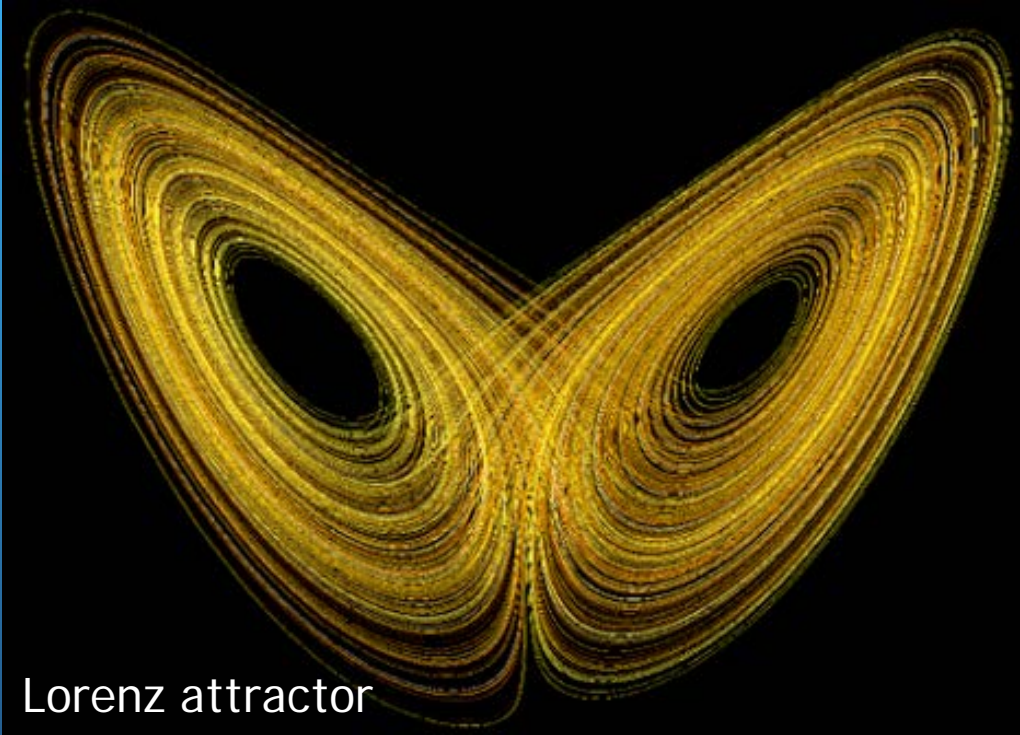
Earth System Model Climate Model



Future scenarios: CMIP5 Representative concentration pathways (RCPs)



Predictions of chaotic systems

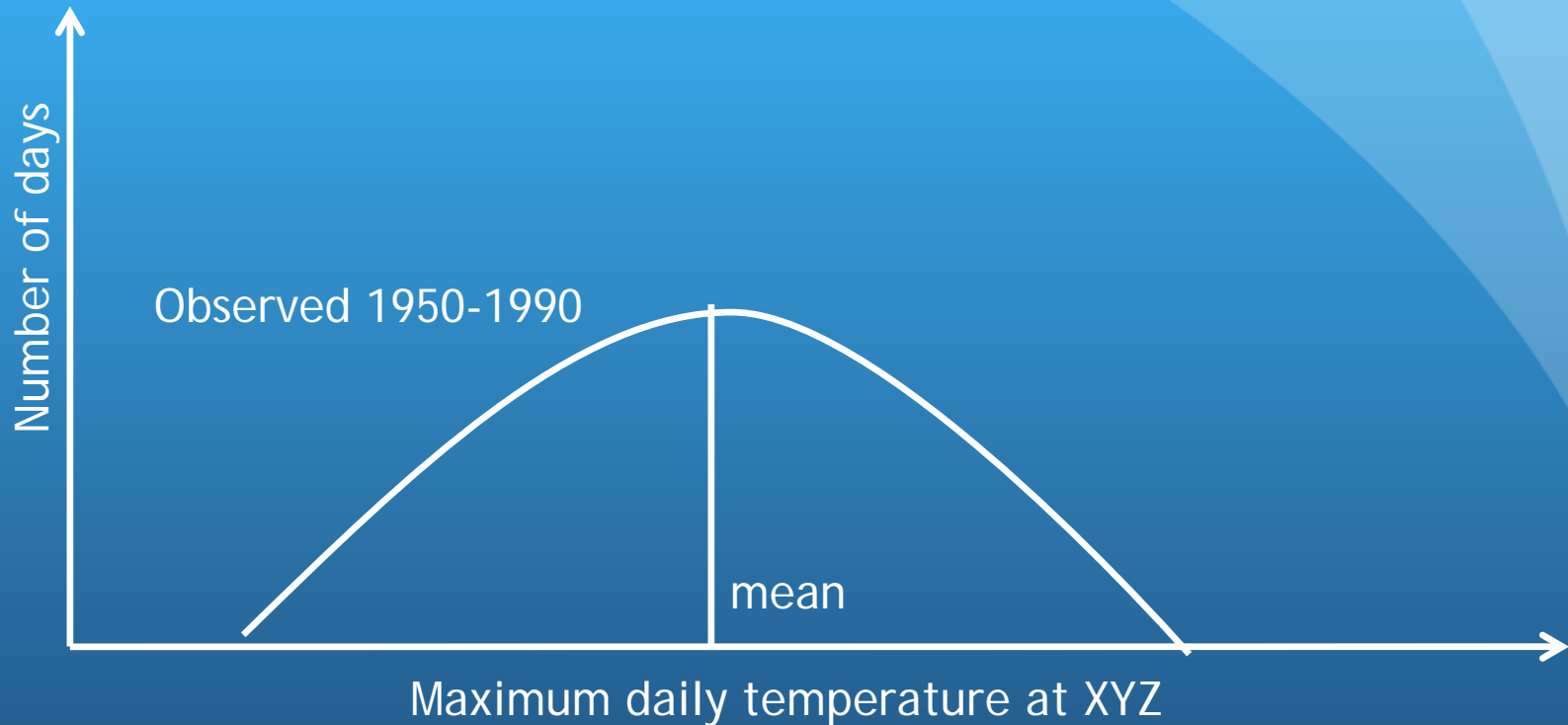


Lorenz attractor

Chaotic systems can not be exactly predicted, but their statistical properties can be

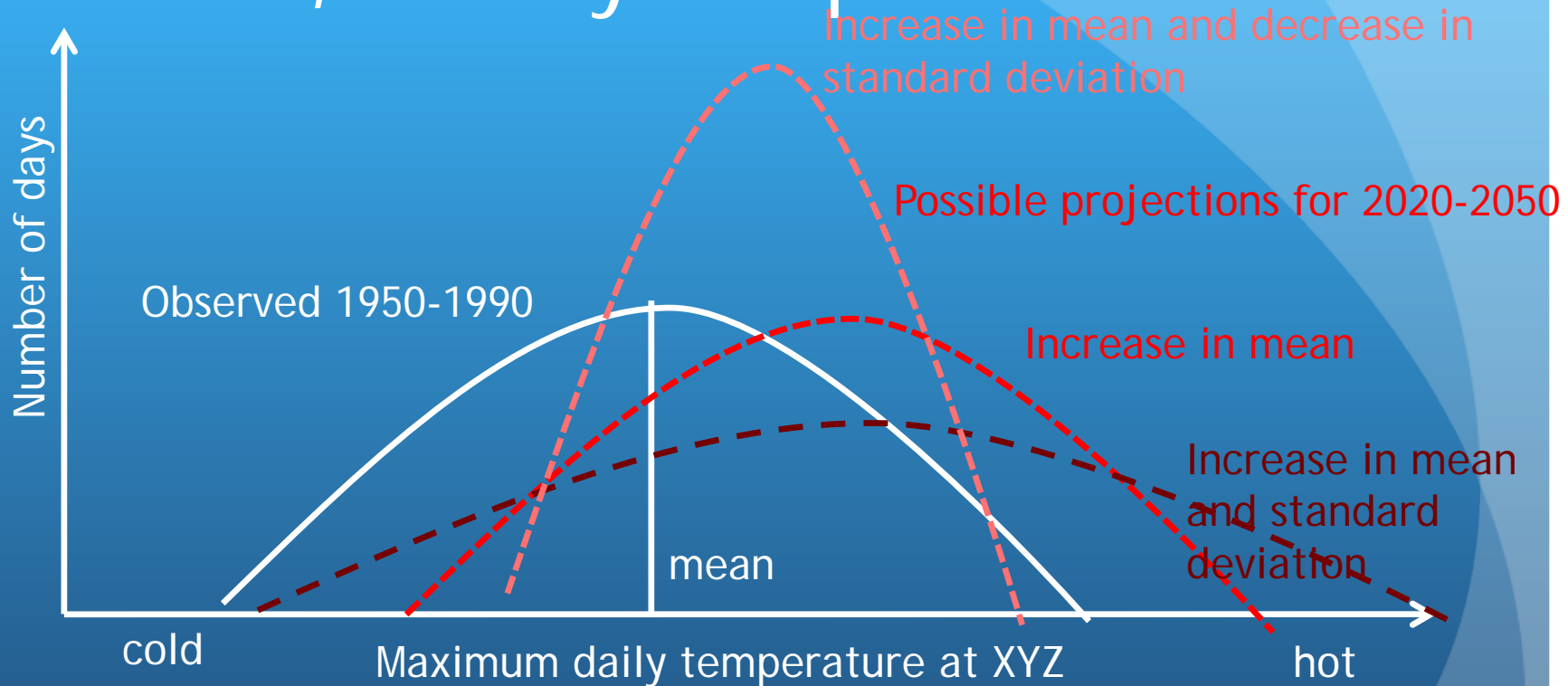
- Weather is a chaotic system, forecasts are always probabilistic predictions. Close to initialization forecast skill is largest
- Climate is the statistics of weather over a long time, and hence climate simulations are also probabilistic predictions

What can we predict with climate models, if they are probabilistic?



- Climate models can predict the statistics of weather → they predict the probability density function (PDF) of weather events (i.e, range of likelihood for certain events)

What can we predict with climate models, if they are probabilistic?

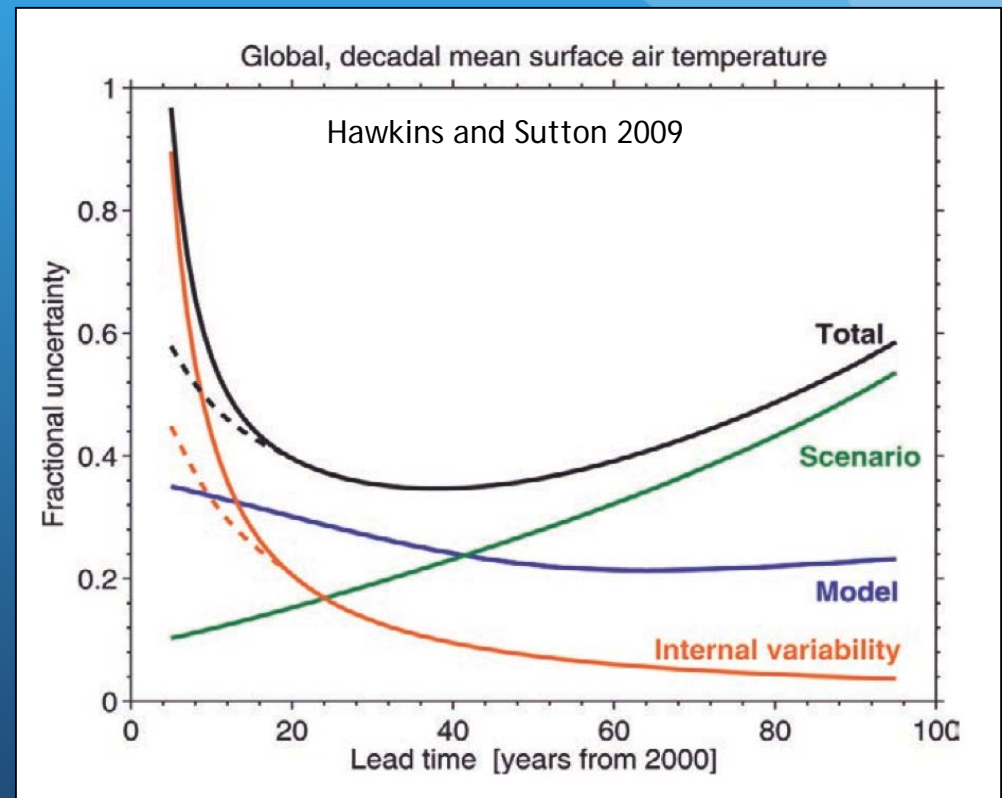


- Climate models can predict the statistics of weather → they predict the probability density function (PDF) of weather events (i.e, range of likelihood for certain events)

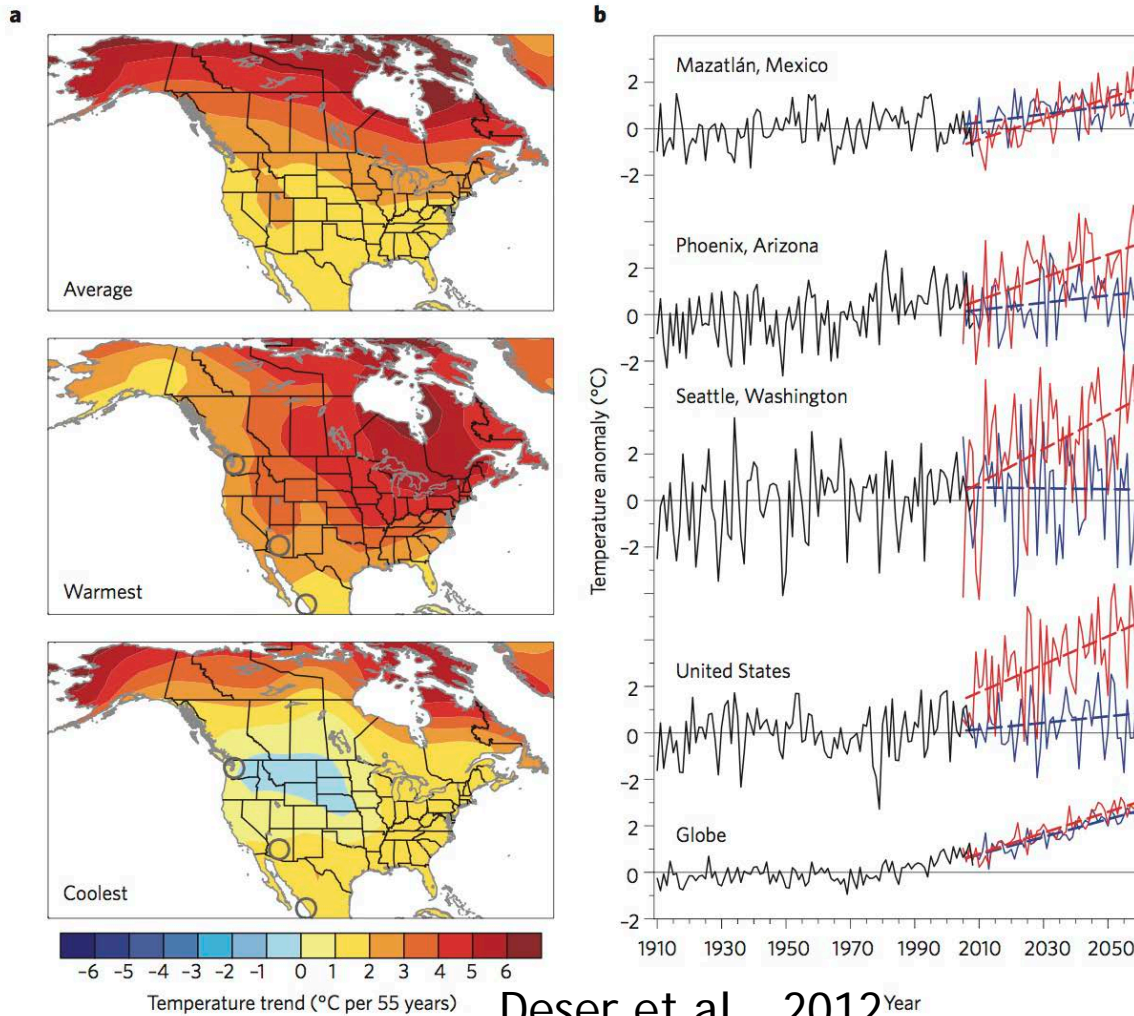
Model projection uncertainty

Uncertainty in climate models projections is due to:

- 1) Model uncertainty (scientific)
- 2) Scenario uncertainty (societal choices)
- 3) Internal variability (probabilistic system)

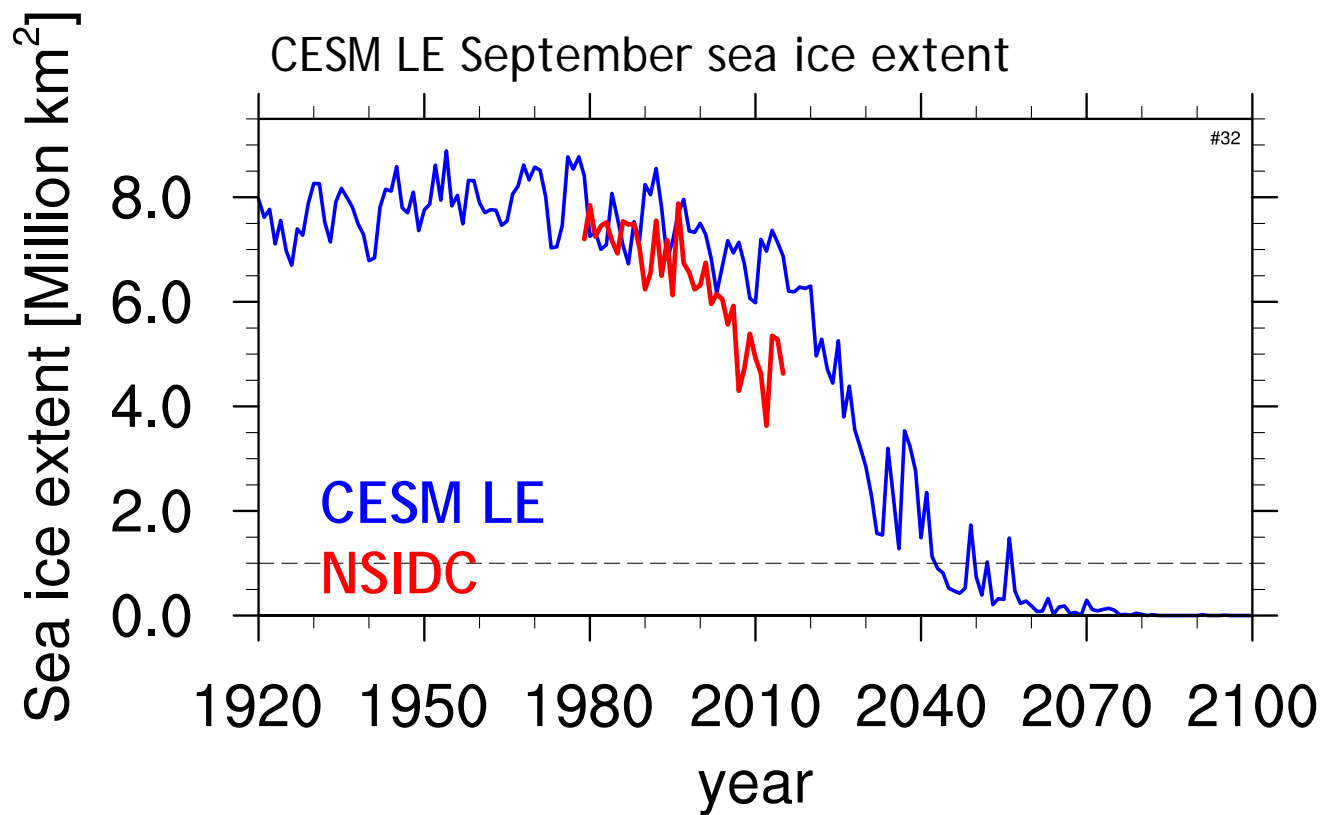


Internal variability uncertainty



- *Important sources of uncertainty on regional spatial scales and on short to medium (several decades) timescales.*
- Less important on global scales and for long periods (>50 years)
- Can not be reduced, only quantified

Internal variability uncertainty - Sept Arctic sea ice example



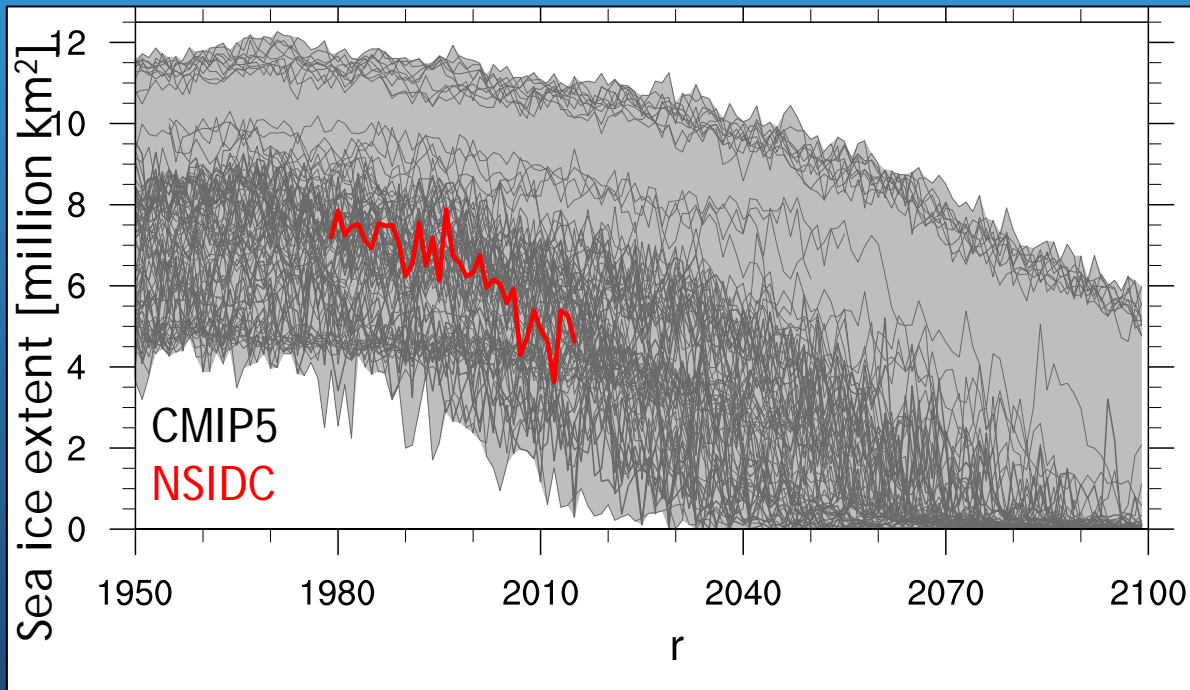
Jahn et al., 2016, GRL

Model uncertainty

- “If we had observations of the future, we obviously would trust them more than models, but unfortunately...observations of the future are not available at this time”, Tom Knutson and Robert Tuleya
- All models are based on certain assumptions and simplifications relative to the real world, introducing some level of uncertainty depending on how valid these assumptions are
- Over time, model uncertainty can potentially be reduced as models get more accurate and more processes are explicitly resolved (as resolution increases)

Model uncertainty – Sept Arctic sea ice example

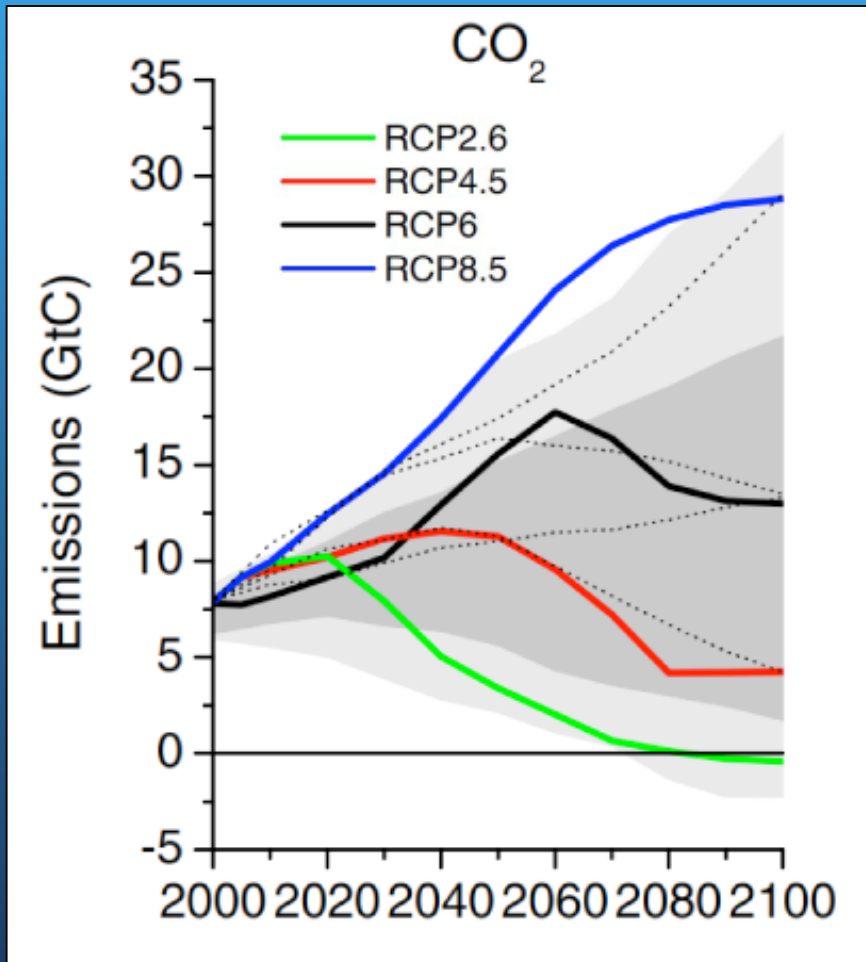
CMIP5 Arctic Sept. sea ice extent for scenario RCP8.5



Partially also reflecting internal variability, but differences in mean due to model differences /uncertainty

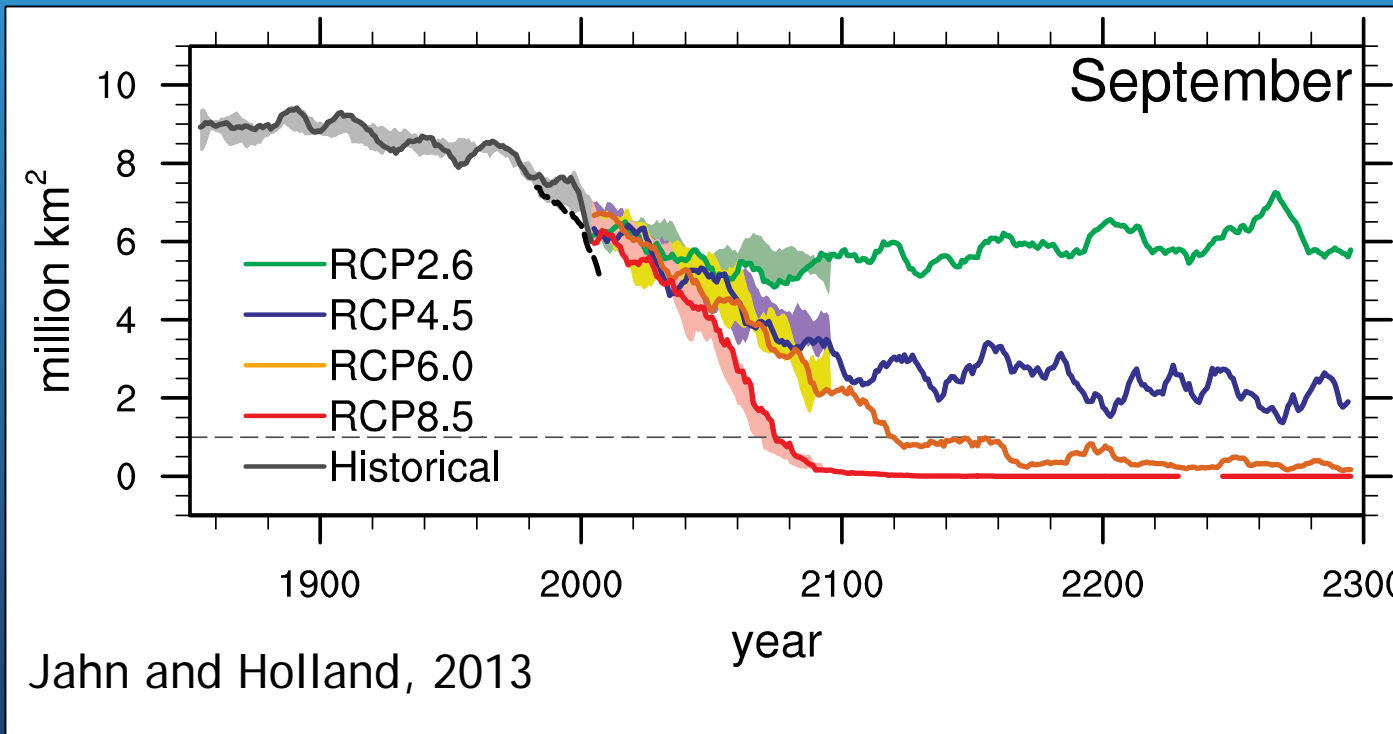
Scenario uncertainty/Societal uncertainty

- We don't know how our emissions will evolve in the future
- The emission scenarios are constructed to give a range of possibilities, but over long timescales (40+ years), the difference in the climate they lead to is large, introducing projection uncertainty due to the scenario spread
- Need a clear emission plan in order to reduce this uncertainty



Scenario uncertainty - Sept. Arctic sea ice example

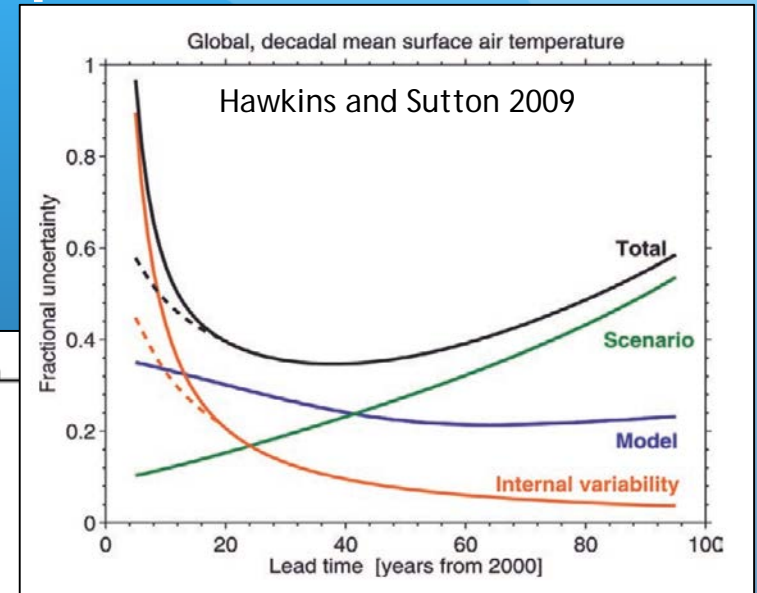
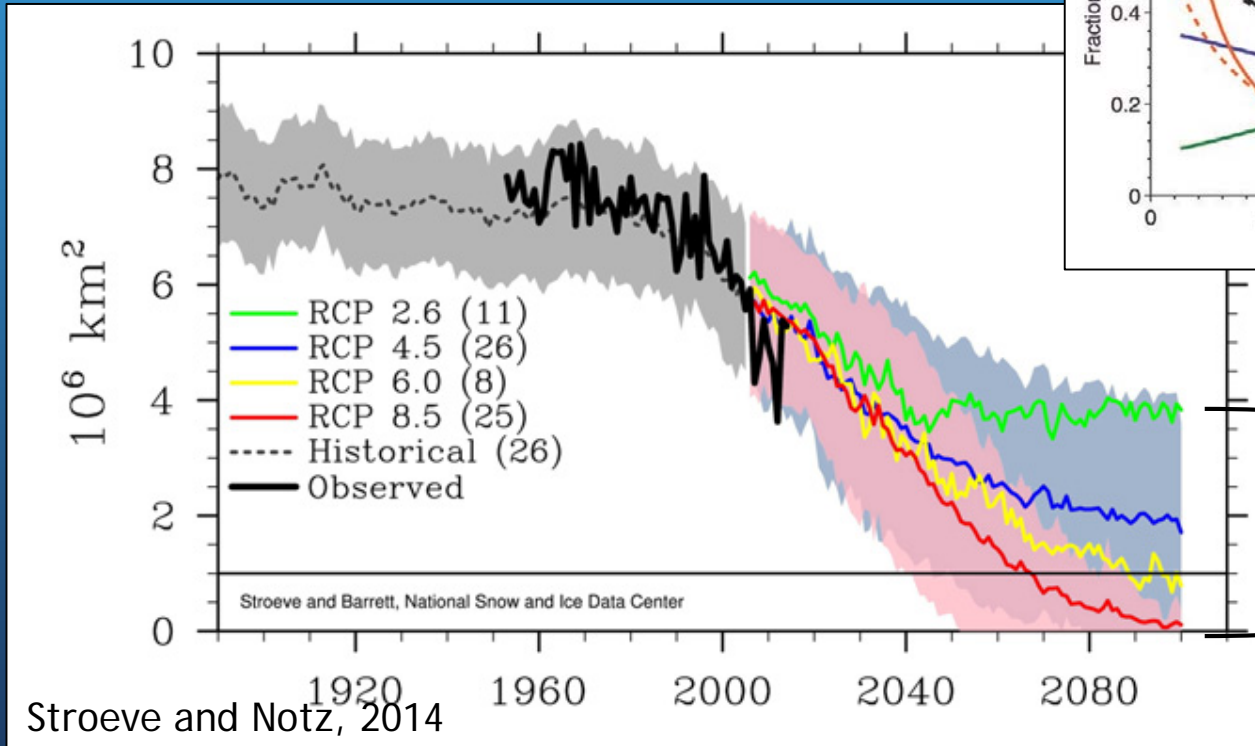
CCSM4 Sept Arctic sea extent for different scenarios



Also includes
internal
variability
uncertainty
(shading)

Combined projection uncertainty - Arctic Sea ice example

CMIP5 Sept Arctic sea extent for different scenarios



**Combined
projection
uncertainty
(model, scenario,
internal variability)**

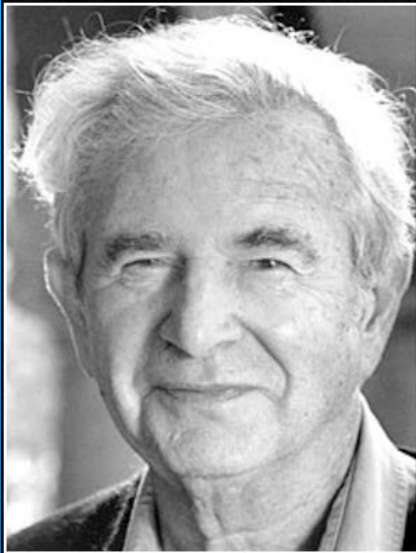
What can we use climate models for?

- Study climate phenomena in a complete and consistent dataset, then look for signatures of these phenomena in real world → help us understand our world
- Test importance of processes and detect lack of understanding of important processes
- Climate projections for the future, to assess risks and plan for or reduce climate change impacts
- Attribution and detection studies (lecture by Francis Zwiers on Wednesday)

What can we not use climate models for?

- Compare climate model output for a specific day or month with observations → would never expect internal variability to match
- Detailed forecasts of expected changes on the city scale for cities with very small uncertainties → resolution is too coarse and uncertainties are largest at small scales
- To study processes that are not included in models (→ make sure you know a bit about the model you use!)

Important to remember about models



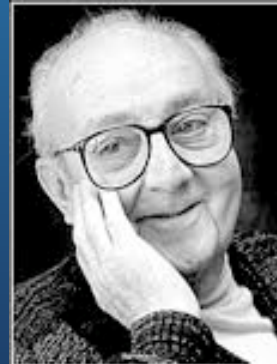
The purpose of models is not to fit the data but to sharpen the question.

— *Samuel Karlin* —

Statistician

AZ QUOTES

More on the fit to the data on Friday



All models are wrong, but some are useful.

— *George E. P. Box* —

Statistician

AZ QUOTES

Summary

- Climate models are built on our understanding of the climate system, consist of discretized equations solved for each grid point on earth
- Climate projections are always probabilistic, as the climate system is chaotic
- The main sources of uncertainty are: Model uncertainty, scenario uncertainty, internal variability uncertainty