Implications of Variability for Economic Assessments of Climate Change:
Physical Stochasticity in Integrated Assessment Models

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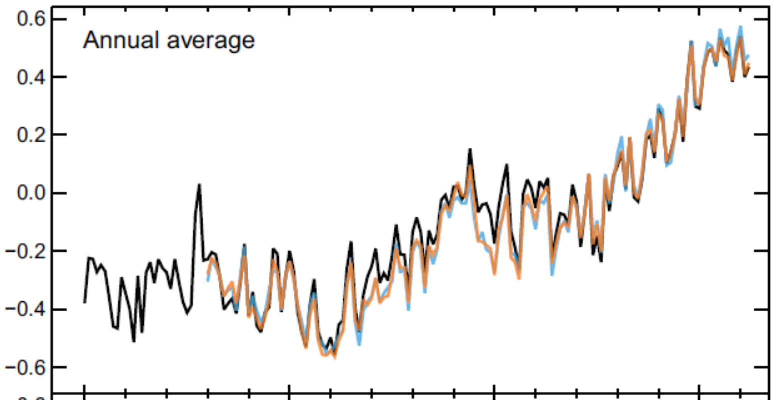
Workshop on Climate and the Economy, Soesterberg, 16 July 2019



IPCC, WG1, SPM, Fig 1.

Grantham Research Institute on Climate Change and the Environment
Centre for Climate Change Economics and Policy
CATS Centre for the Analysis of Time Series
The University of Warwick
The Grantham Foundation
ESRC Economic & Social Research Council
LSE The London School of Economics and Political Science

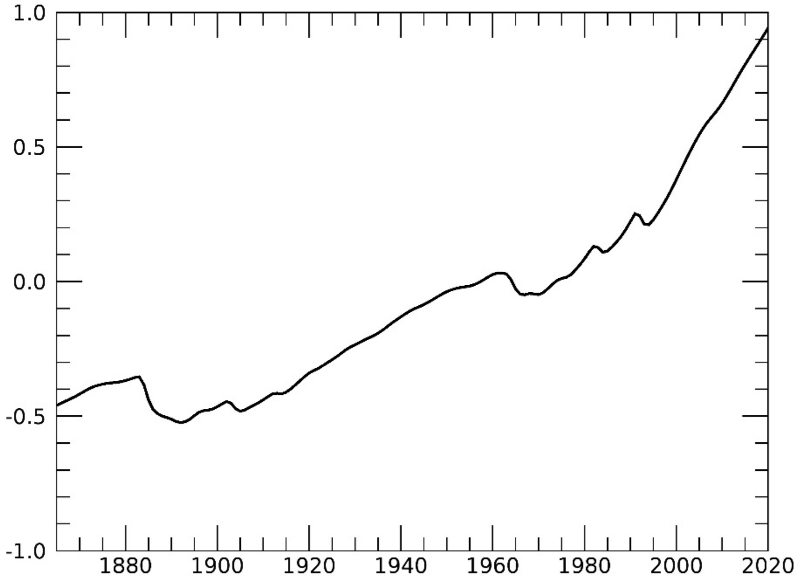
Warnings

- Work in progress
- I’m presenting

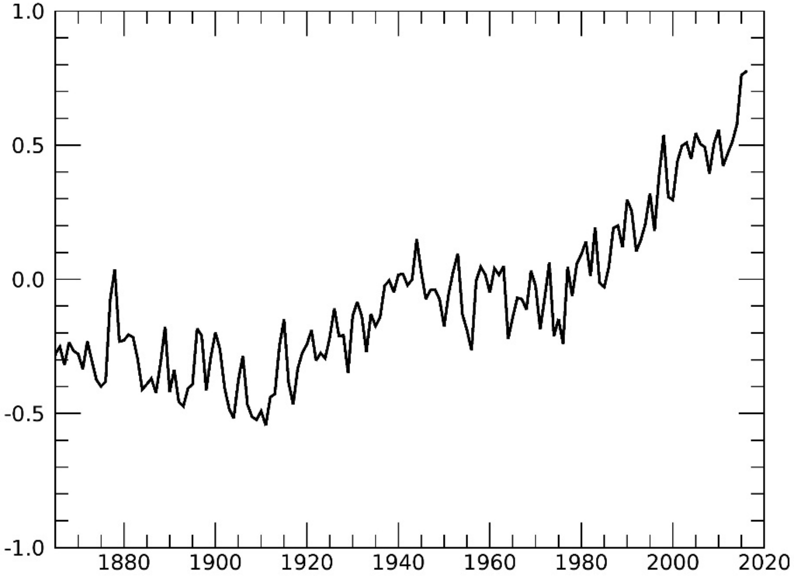
The Starting Point

Historic Global Mean Temperature Anomalies

As would be Modelled by IAMs (DICE/PAGE/FUND)



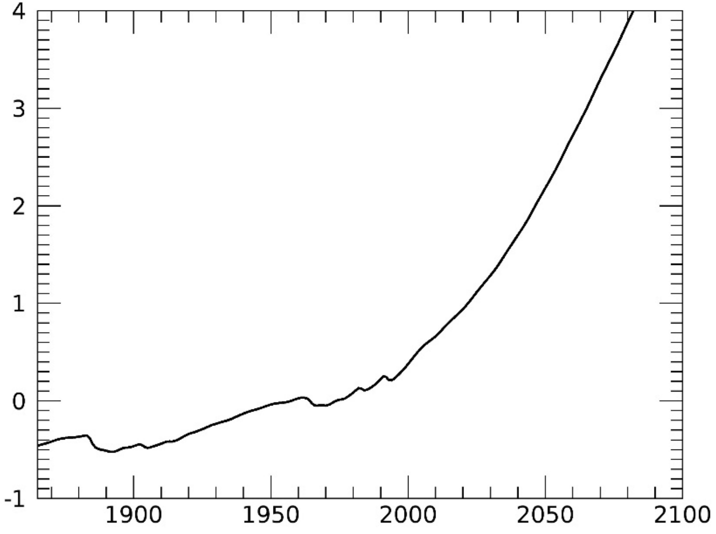
As Observed (HadCRUT4)



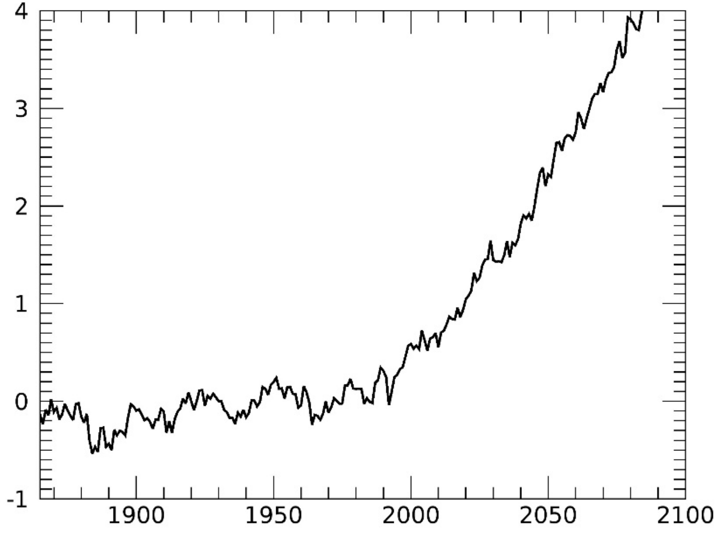
The Starting Point

Historic And Future Global Mean Temperature Anomalies

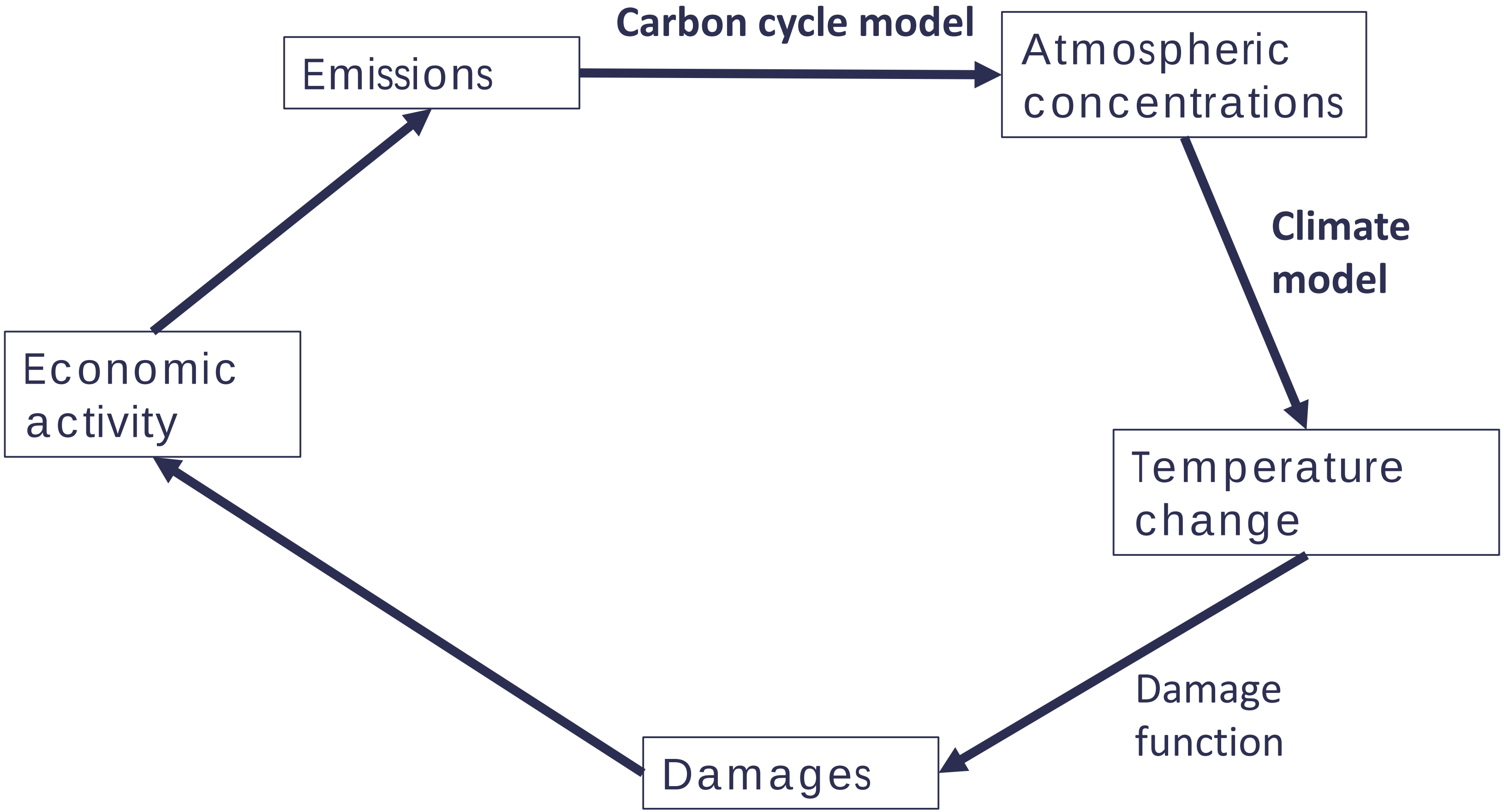
As would be Modelled by IAMs (DICE/PAGE/FUND)



Example CMIP5 simulation

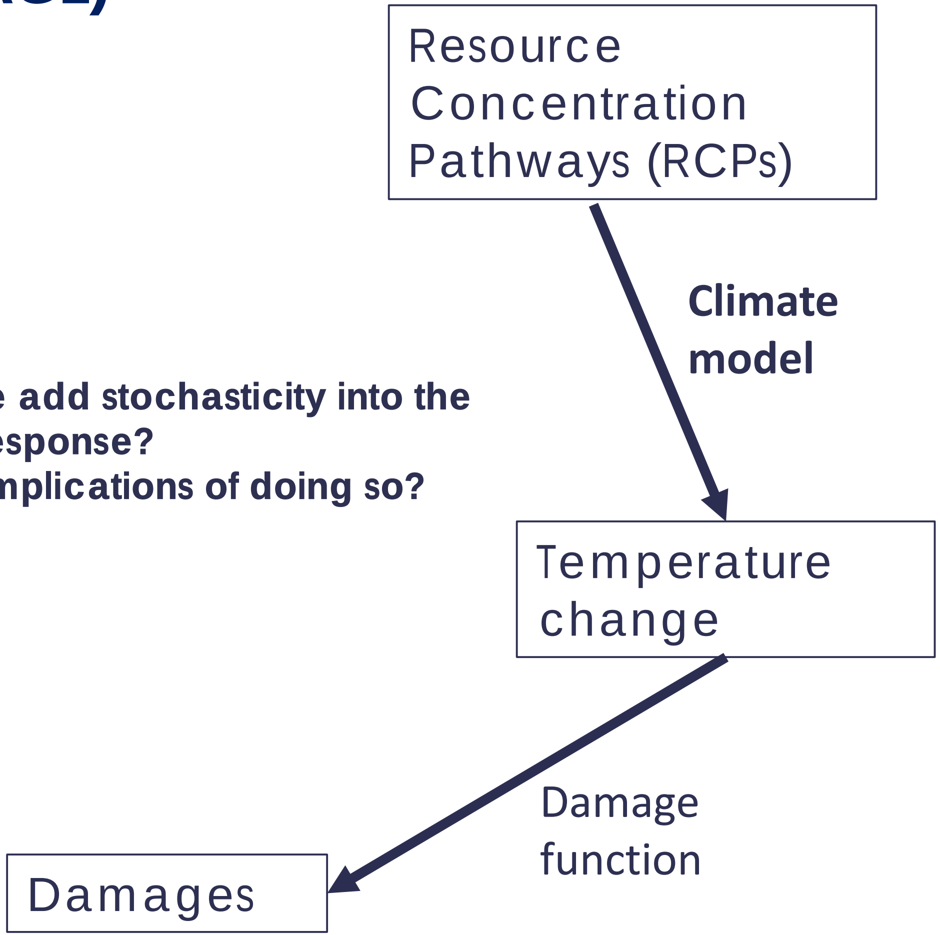


Simple IAMs (DICE/FUND/PAGE)

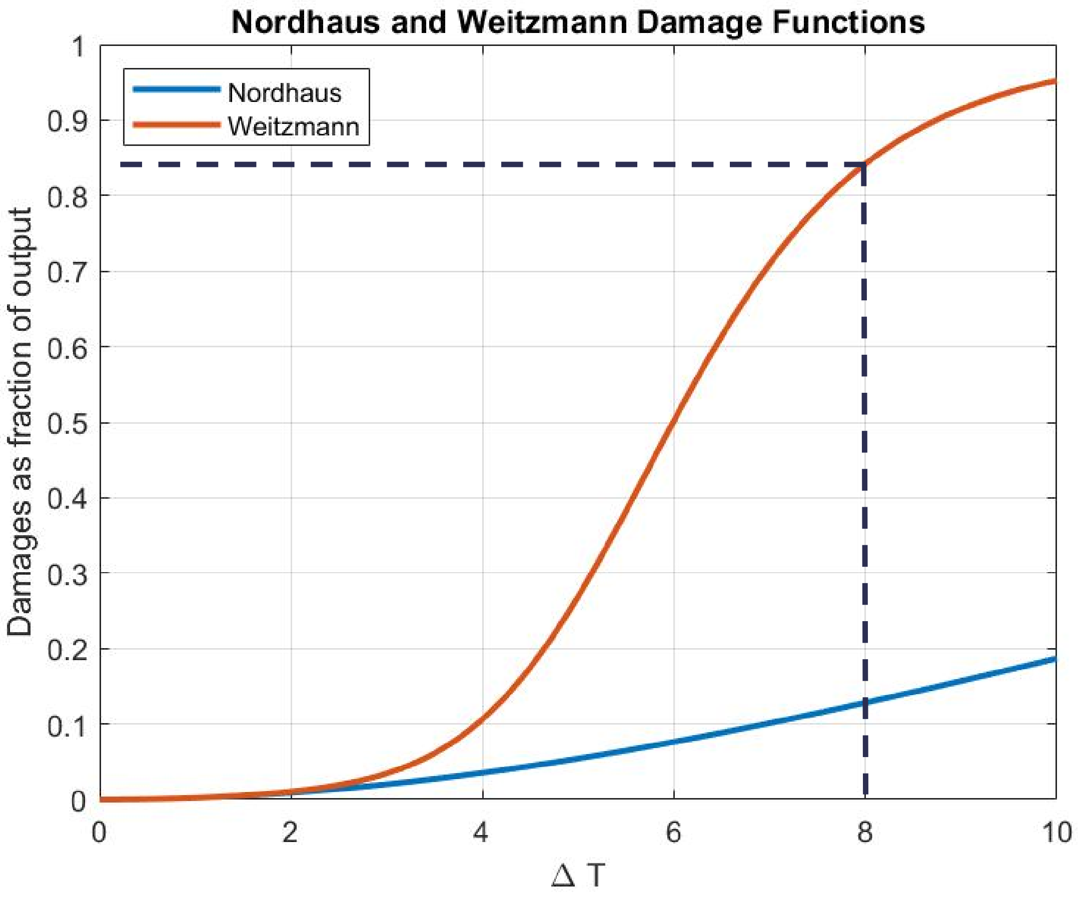


Simple IAMs (DICE/FUND/PAGE)

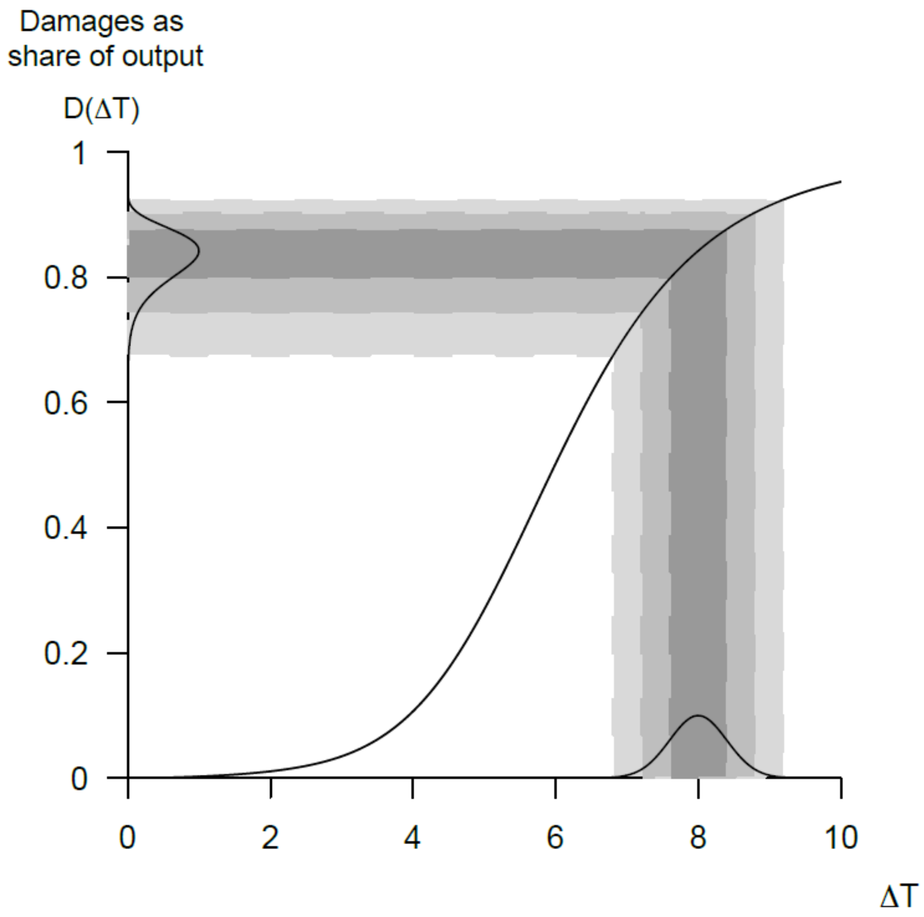
How should we add stochasticity into the temperature response?
What are the implications of doing so?



Damage Functions



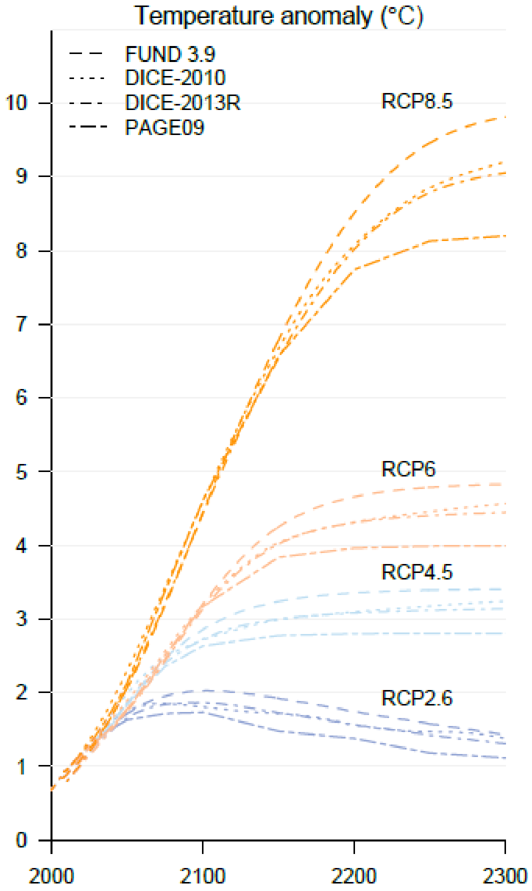
Damage Functions and Uncertainty in ΔT



A simple energy balance model

$$C_{eff}\frac{d\Delta T}{dt} = F(t) - \lambda\,\Delta T$$

ΔT: Change in global mean temperature
F: Radiative forcing by comparison to ~ 1750
C_{eff}: Effective heat capacity of the climate system.
λ: Feedback parameter



From: Calel and Stainforth, BAMS, June 2017

See, for instance: Andrews and Allen 2008; Senior and Mitchell 2000; Dickinson 1986

A simple stochastic energy balance model

$$C_{eff} d\Delta T = F(t)dt - \lambda \, \Delta T dt + \sigma_Q dW_t$$

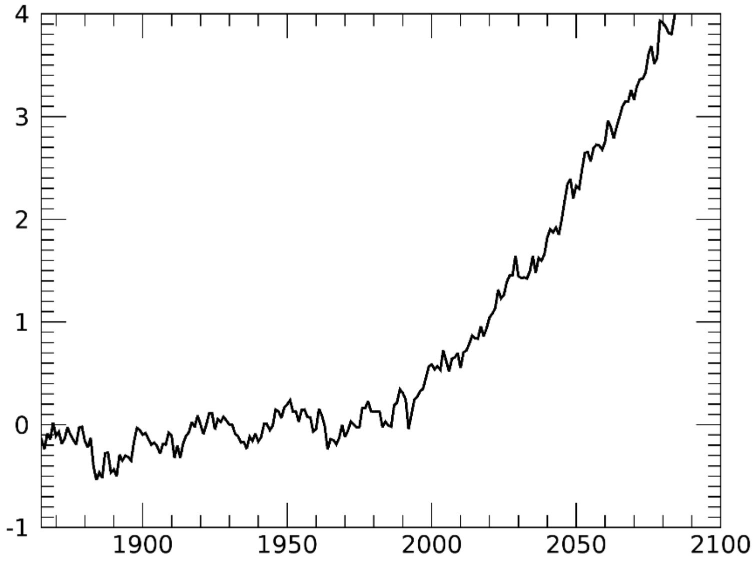
or equivalently

$$C_{eff} d\Delta T = F(t)dt - \lambda \, \Delta T dt + \sqrt{\sigma_Q^2 dt} N_t^{t+dt}(0,1)$$

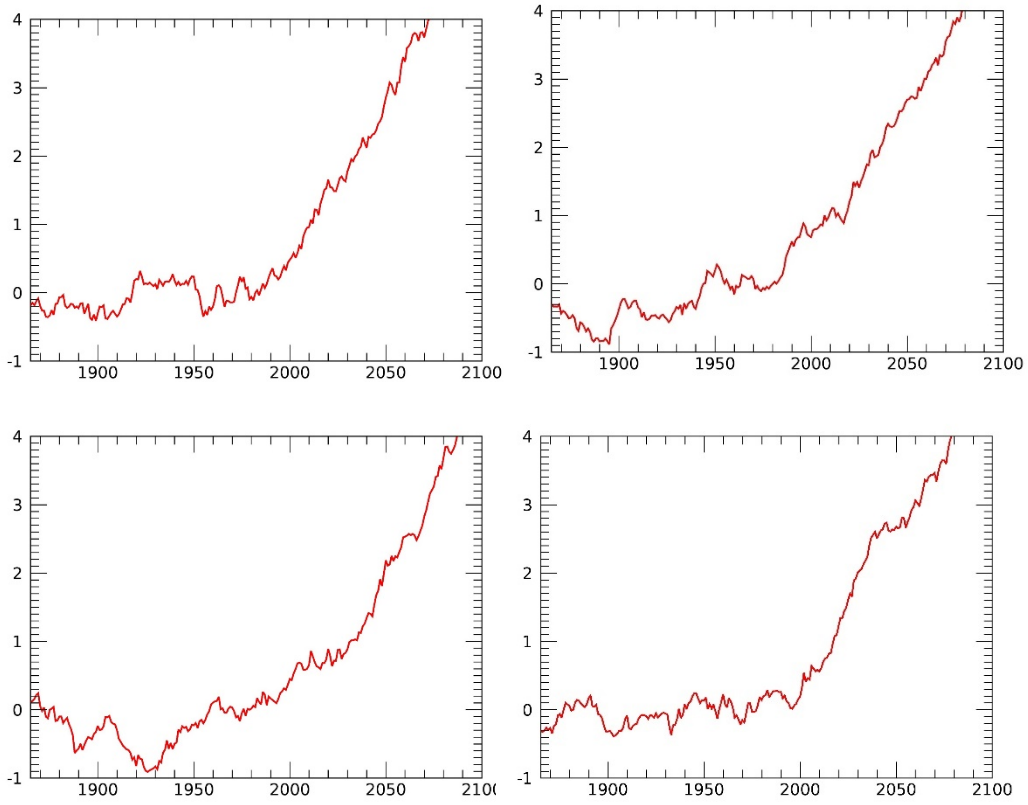
ΔT: Change in global mean temperature
F: Radiative forcing by comparison to ~ 1750
C_{eff}: Effective heat capacity of the climate system.
λ: Feedback parameter

More realistic simulations?

Example CMIP5 simulation



Hasselmann model trajectories

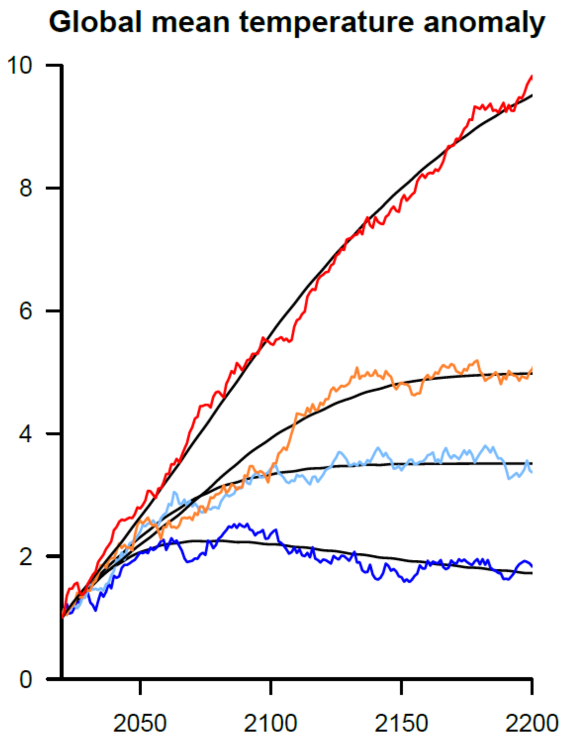


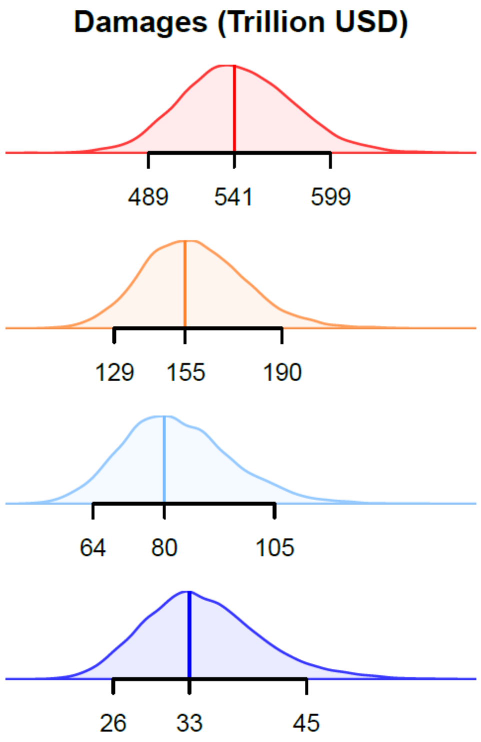
The economic and simulation assumptions

- Start date of simulations: 2020
- Initial per capita consumption: $10,666
  (Aggregate consumption: $80 Trillion)
- Initial population: 7.5B
- Growth rate: 2%/yr
- Pure rate of time preference: 4.4%
- Linear utility function
- Population growth as in DICE 2016.
- Damage function: Weitzman

- Size of trajectory ensembles: 8000
- Fixed lambda = 1.2 $Wm^{-2}K^{-1}$
- Fixed C_{eff} = 0.8E9 $Jm^{-2}K^{-1}$

Economic Consequences





5-95% range as a fraction of the deterministic value:

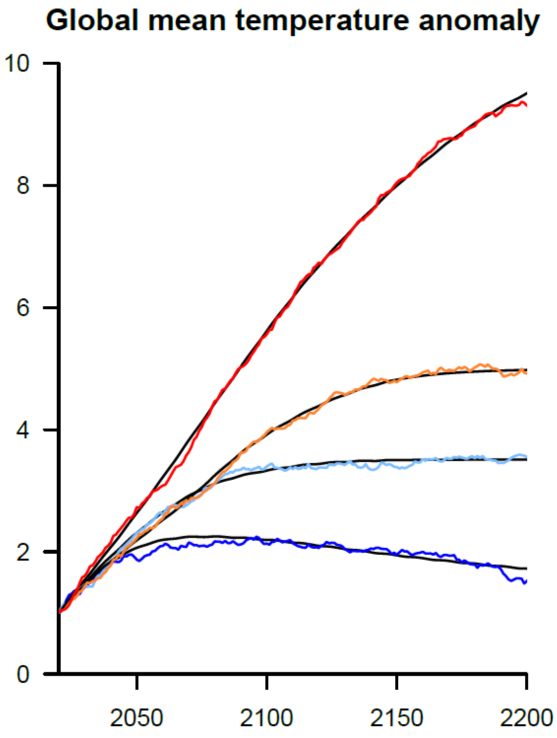
-9% to 10%

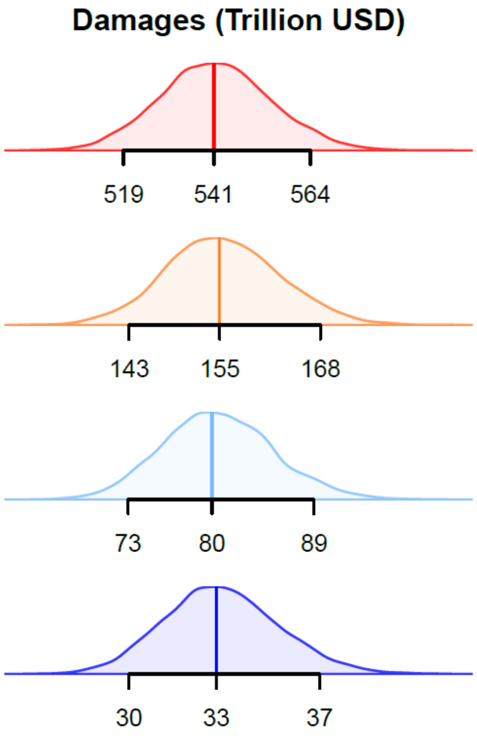
-16% to 22%

-20% to +30%

-23% to +35%

With smaller variability





5-95% range as a fraction of the deterministic value:

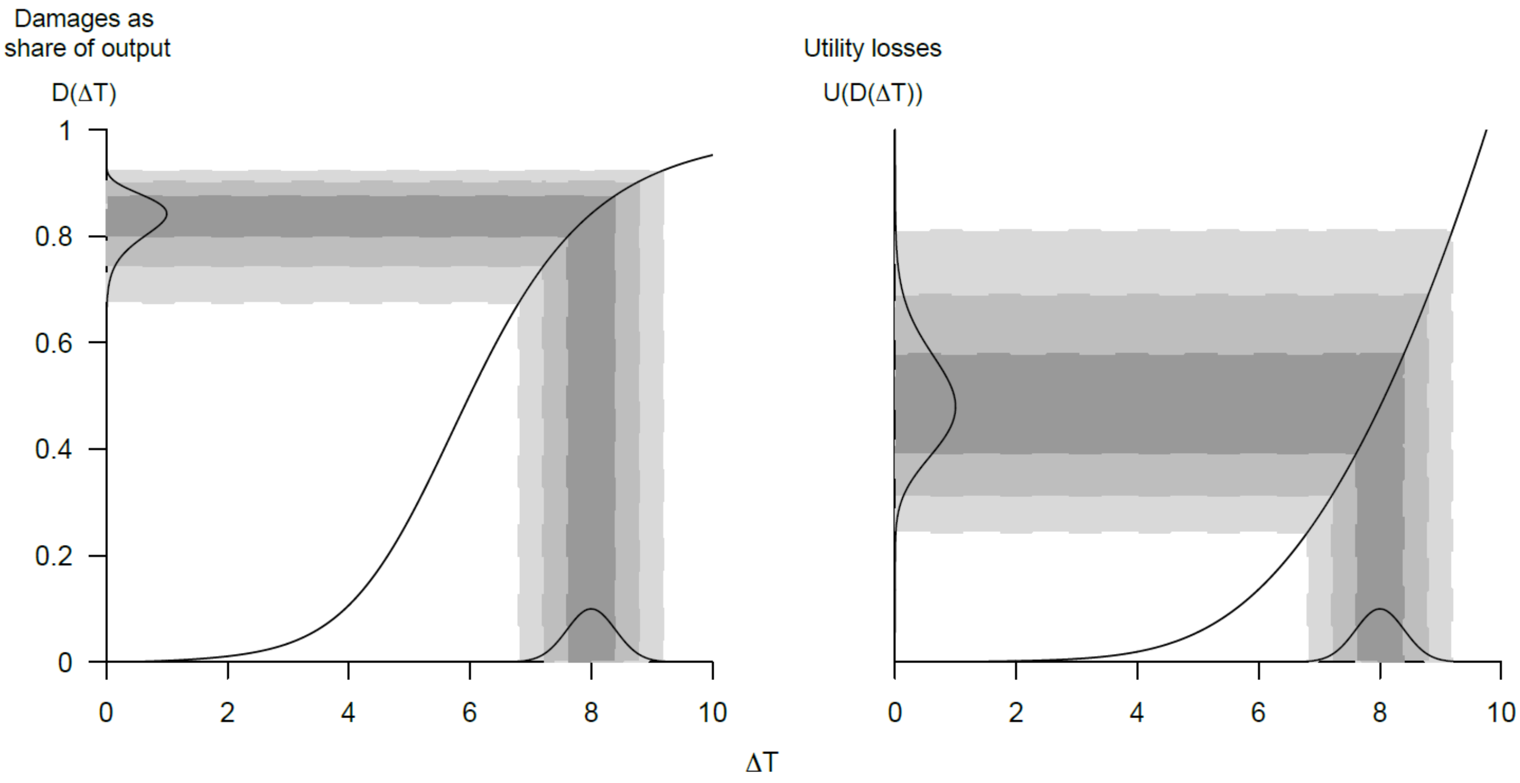
-4% to 4%

-7% to 8%

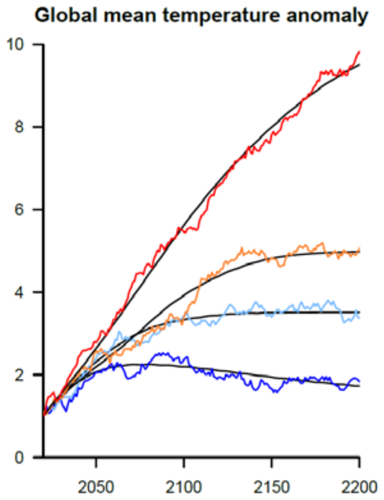
-9% to +11%

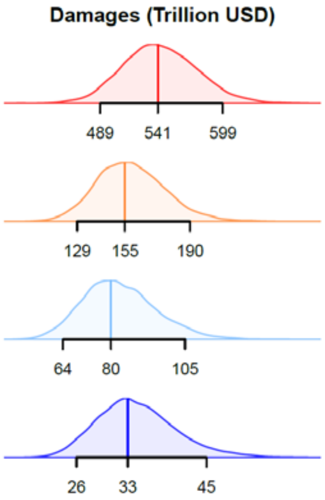
-10% to +12%

Expected Utility



Expected Utility



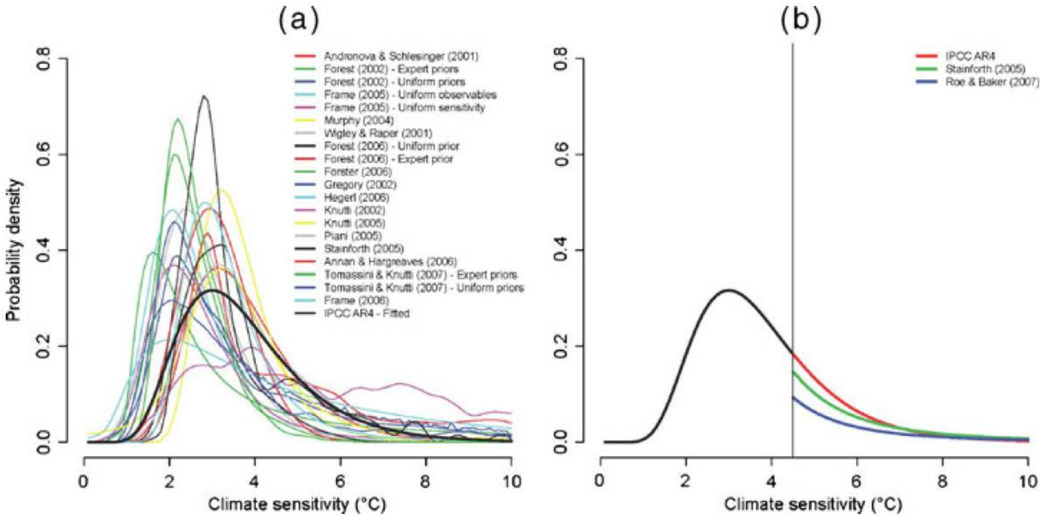


Change in total utility-adjusted dollar value of consumption under deterministic trajectory.	Additional change due to stochasticity (fractional additional change w.r.t. deterministic case)
$2,496 Trillion	**$20 trillion (0.8%)**
$284 Trillion	**$9 trillion (3%)**
$129 trillion	**$5 trillion (4%)**
$49 trillion	**$2 trillion (4%)**

$$U = \frac{\left(C * D(\Delta T)\right)^{1-\eta} - 1}{1 - \eta}$$

η= 1.45, ρ =1.5
Discount rate, r, = 4.4%

Does physical uncertainty matter?



"Tall Tales and Fat Tails",
Calel, Stainforth and Dietz,
Climatic Change, 2013

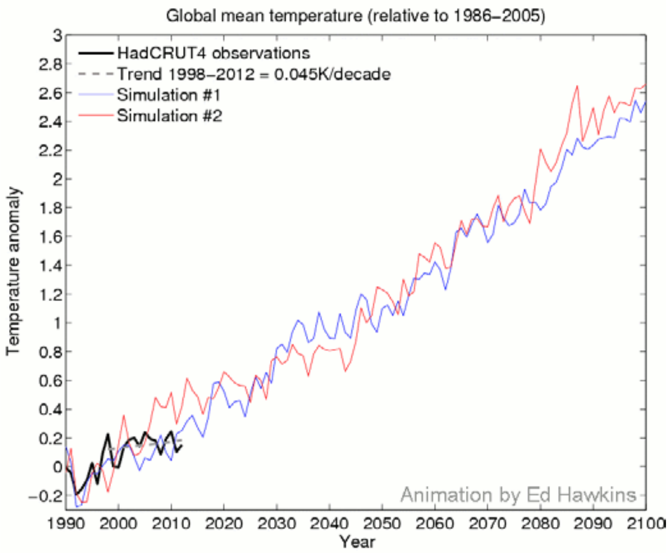
Table 2 Value of 500 ppm policy with varying effective heat capacity

Climate sensitivity distribution	Increase in stationary equivalent (%)		
	$0.6\ GJm^{-2}K^{-1}$	$1.2\ GJm^{-2}K^{-1}$	$1.8\ GJm^{-2}K^{-1}$
IPCC AR4	1.26	0.80	0.47
Stainforth et al. (2005)	49.63×10^3	19.96×10^2	0.75
Roe and Baker (2007)	75.74×10^5	43.88×10^4	76.70

Fitting Observations

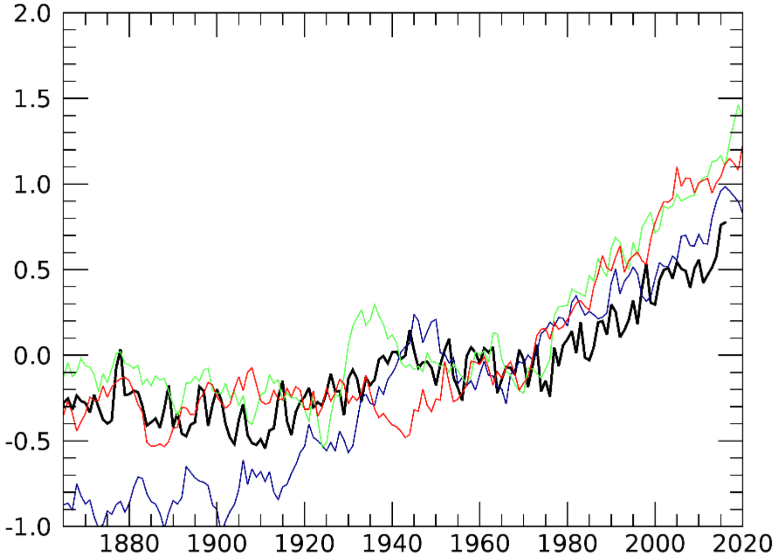
- **We want models that can reproduce the past but a “bad” match with past observations for individual simulations isn’t necessarily indicative of a bad model.**
  Do we have sample sizes to evaluate properly?

One GCM, Two Initial Condition trajectories



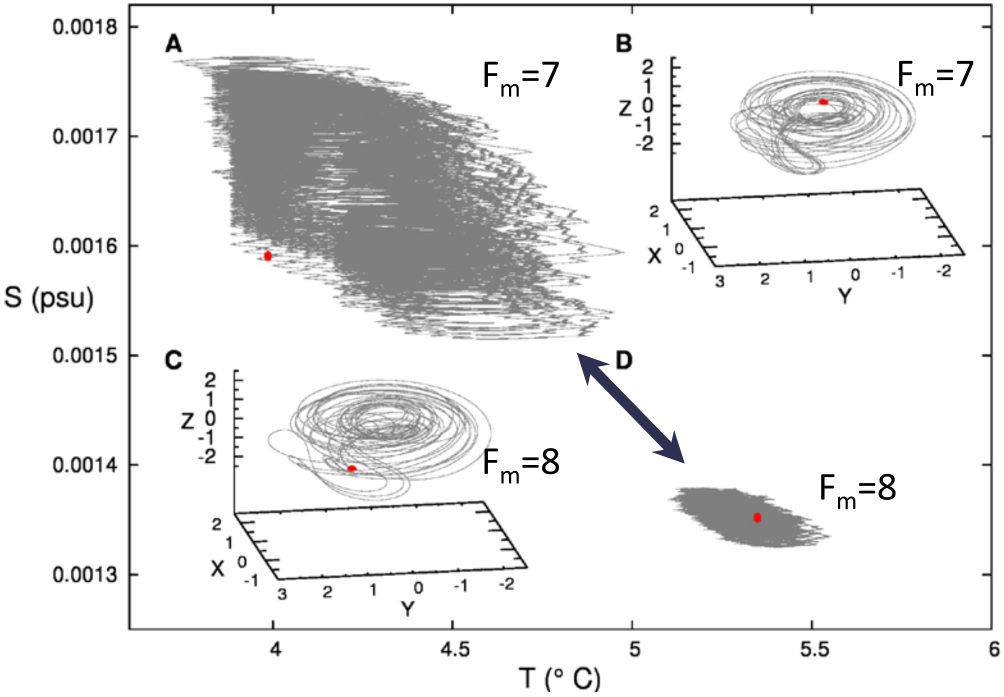
Plot from Ed Hawkins, Reading University

Hasselmann model trajectories



The Essence of Predicting Climate and Predicting the Consequences of Climate Change

- Extrapolation to a new, previously unobserved state of the system.
- 21st century climate to some extent parallels the quantification of the transient behaviour as we move from one attractor to another.



Daron and Stainforth, Env.Res.Lett., 2013