



Netherlands Environmental Assessment Agency

# **Keep It Simple or Stupid: on the performance of small climate models**

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Chris Hope, Malte Meinshausen, Gian-Kasper Plattner



# MESSAGES



- “Climate / carbon cycle” uncertainty in IAMs matters for climate policy!
- IAMs mostly within large uncertainty range “expert models”... but not always.
- Feedbacks poorly covered in IAMs
- Diagnostic runs are powerful tools.

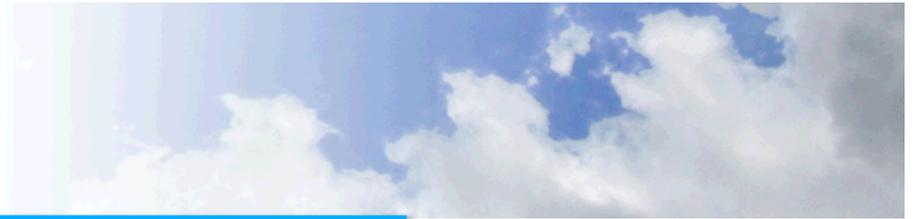


# IAM vs. Complex Climate Model



- IAM models not intended to create new knowledge on climate science, but integrated knowledge in economic framework
  - → aim to reflect outcomes of complex climate models and their uncertainty?
- Complex climate models strong tradition of diagnostic runs / validation → something interesting to learn from?

# Simple or stupid?



*Simplicity is the highest form of sophistication.*  
—Leonardo

*DICE is neglecting first-order physical principles*



**Bill Nordhaus**



**Fortunat Joos**

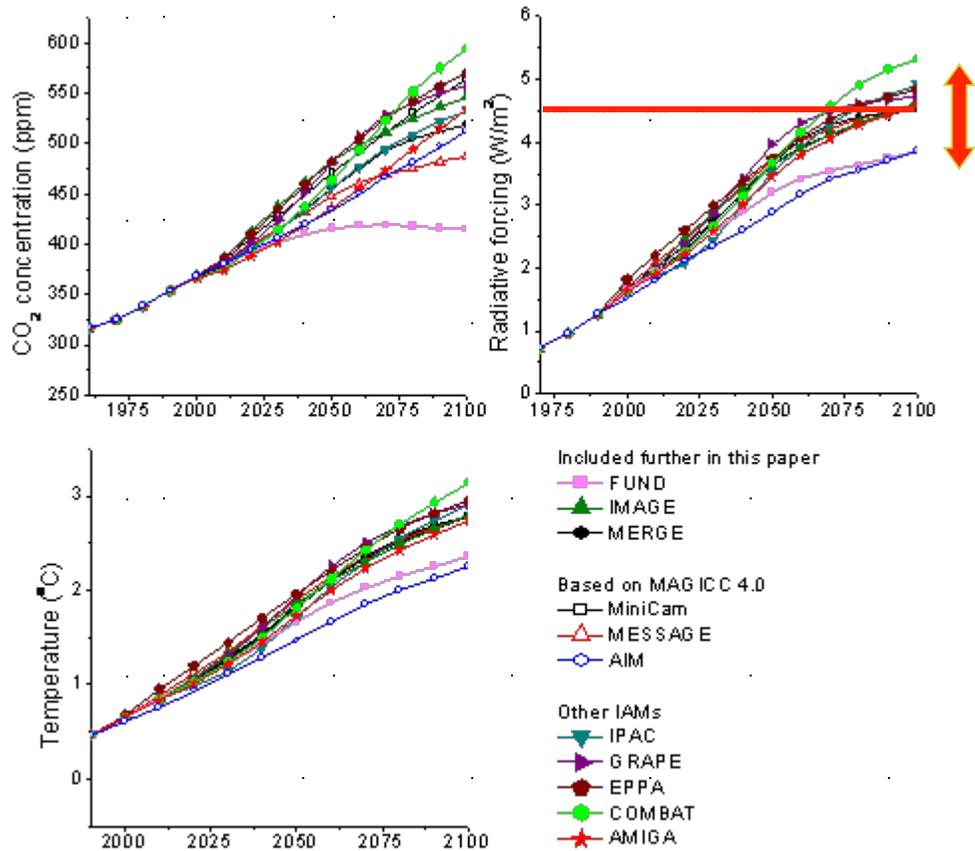
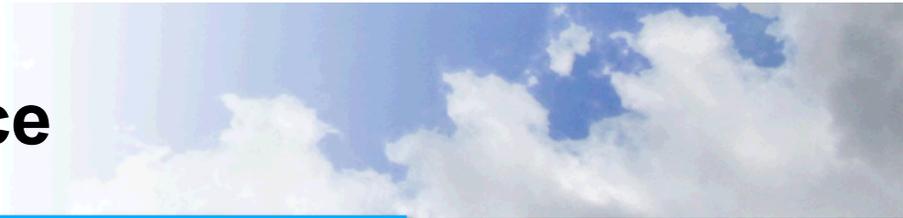
Critical assumptions in IAMs include : 1) discounting, 2) economic growth, 3) economic response to control policy, 4) long term forecasting.



**Charles Kohlstad**



# EMF-21: showing relevance

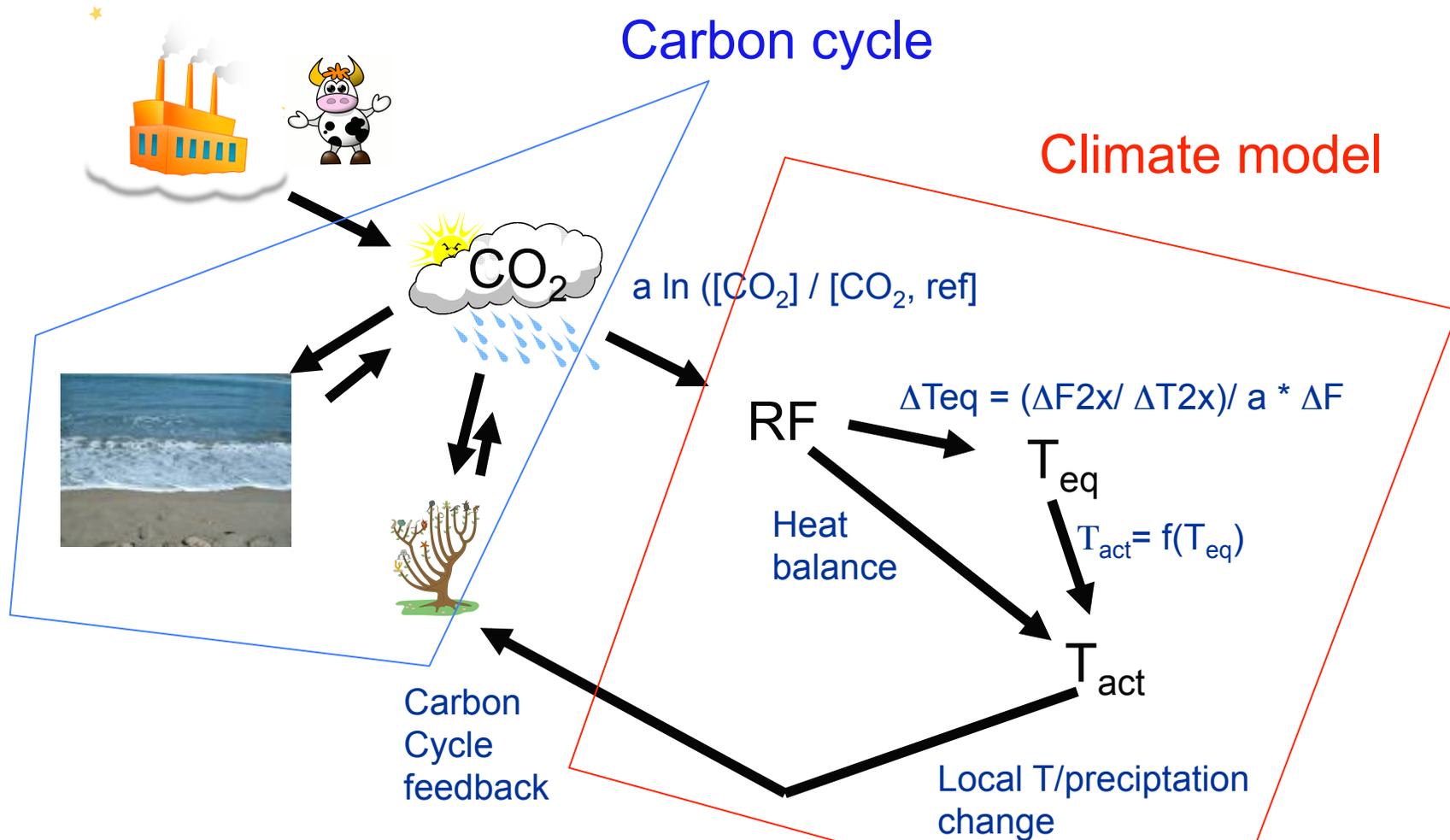


Runs of a 4.5 W/m<sup>2</sup> scenario from different models in MAGICC

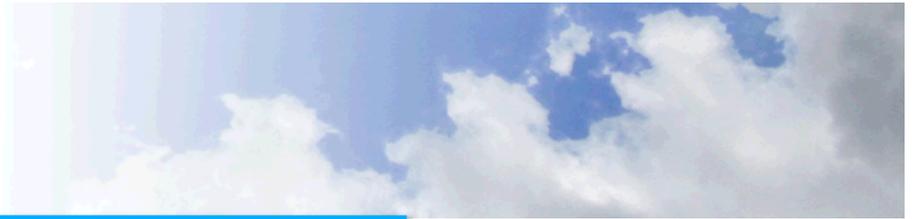
10,000s billions of \$ difference !



# Climate system and carbon cycle

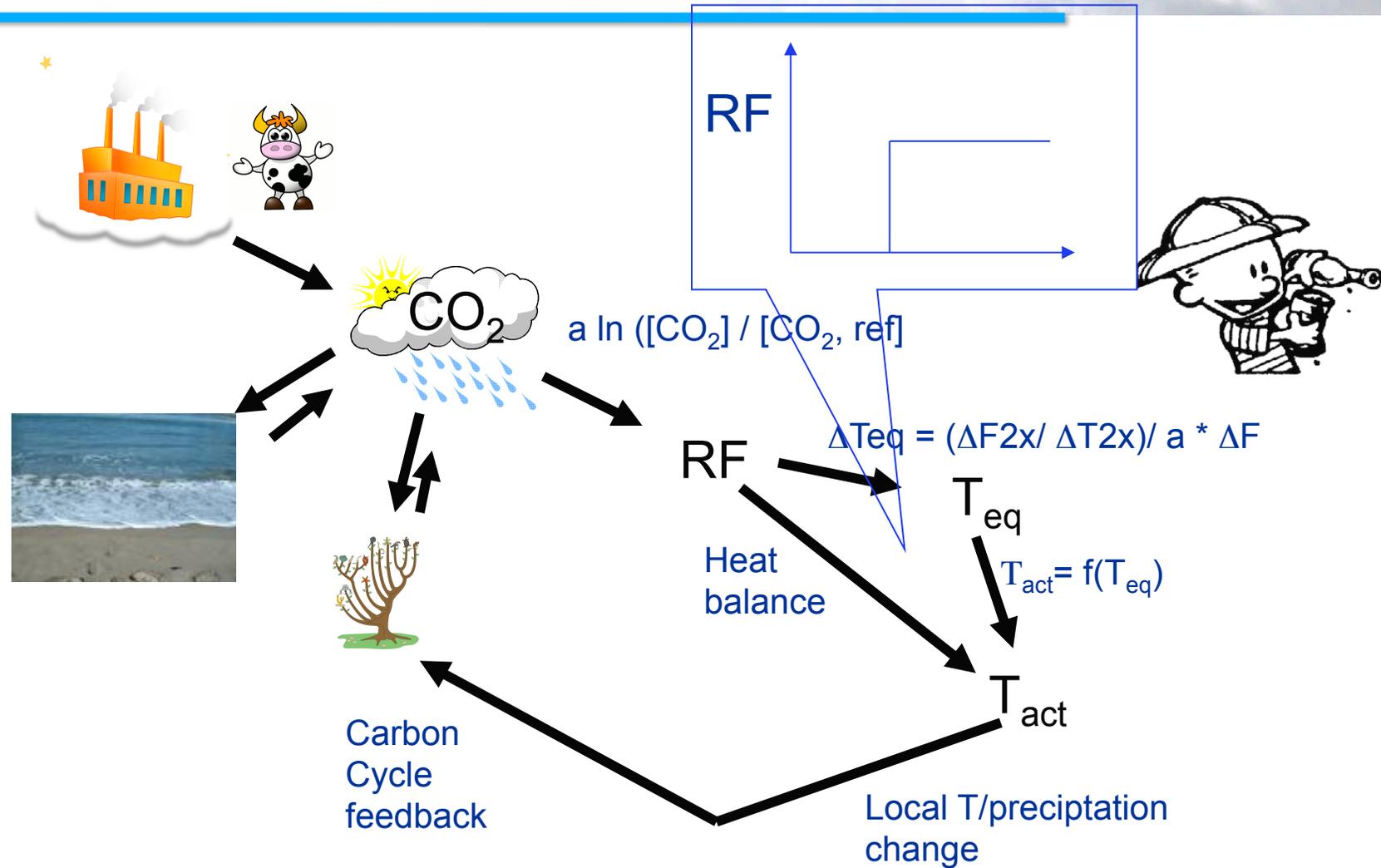


# IAMs included



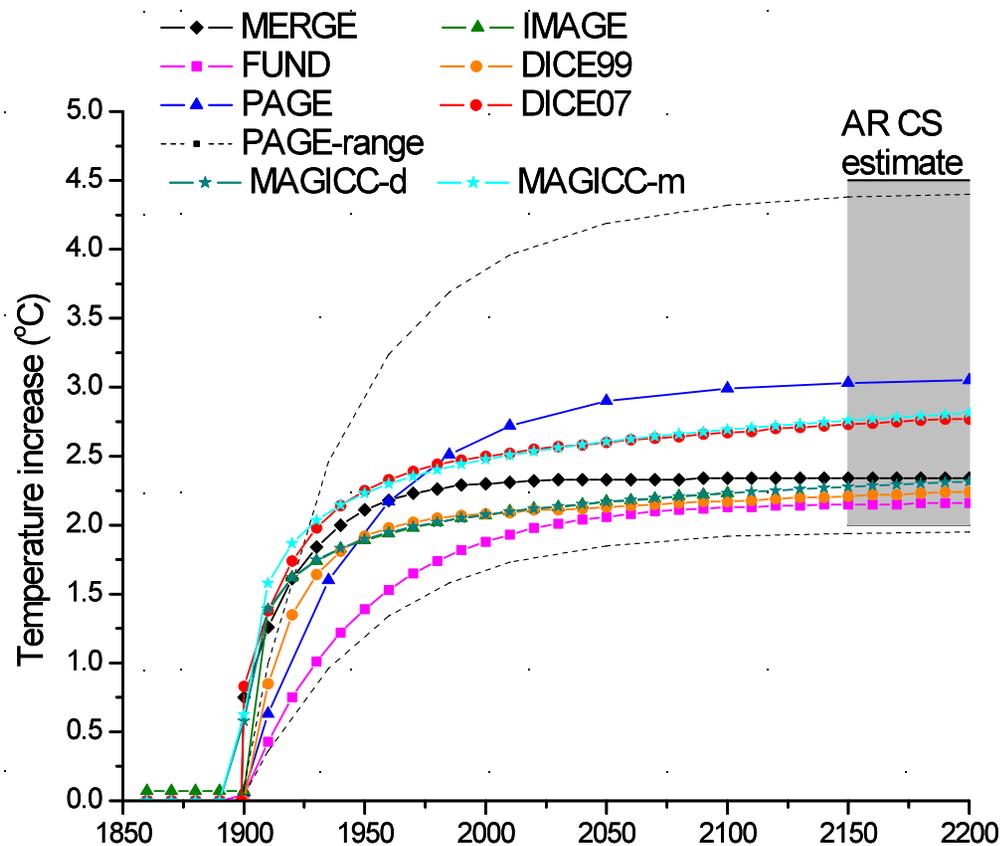
	IAM	Carbon cycle	Climate
DICE99	Agg. growth	3 boxes	2 box atm/oc
DICE07	Agg. growth	3 boxes	2 box atm/oc
FUND	Agg. Growth	Pulse	$T_{act}=f(T_{eq})$
IMAGE	Process oriented	Complex (grid)	MAGICC+
MAGICC4	SCM	6 boxes	Energy balance
MERGE	Agg. growth	Pulse	$T_{act}=f(T_{eq})$
PAGE	Agg. growth	Pulse	$T_{act}=f(T_{eq})$

# Equilibrium temperature responses



# Equilibrium temperature responses

Pulse: double radiative forcing



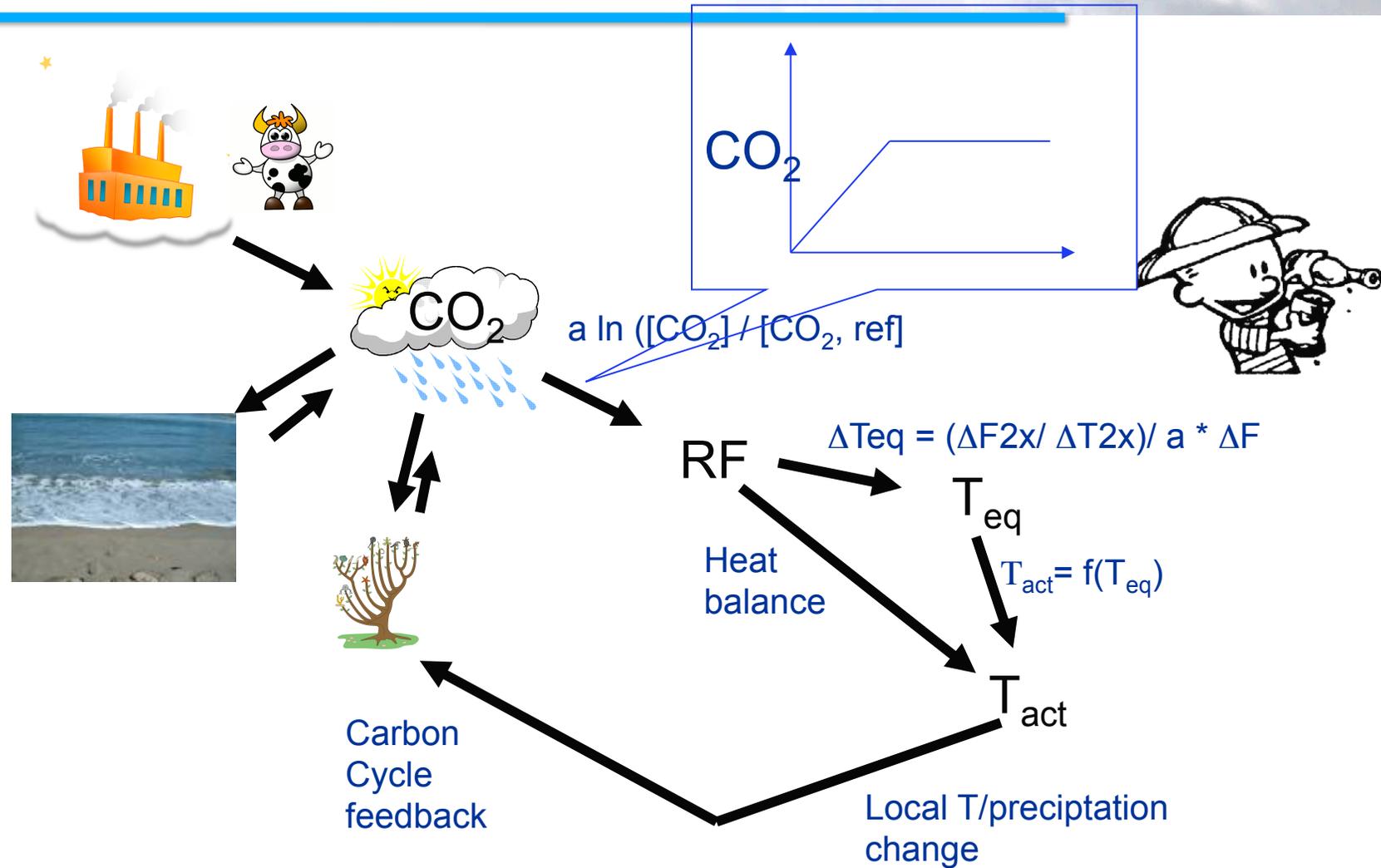
$$\Delta T_{eq} = (\Delta F_{2x} / \Delta T_{2x}) / a * \Delta F$$

TAR: 2.5 (1.5-4.5)

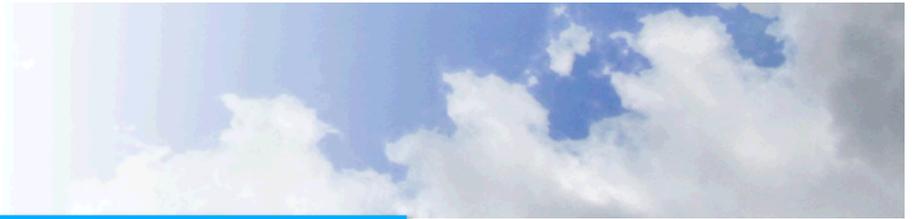
AR4: 3.0 (2.0-4.5)

$$T_{act} = f(T_{eq})$$

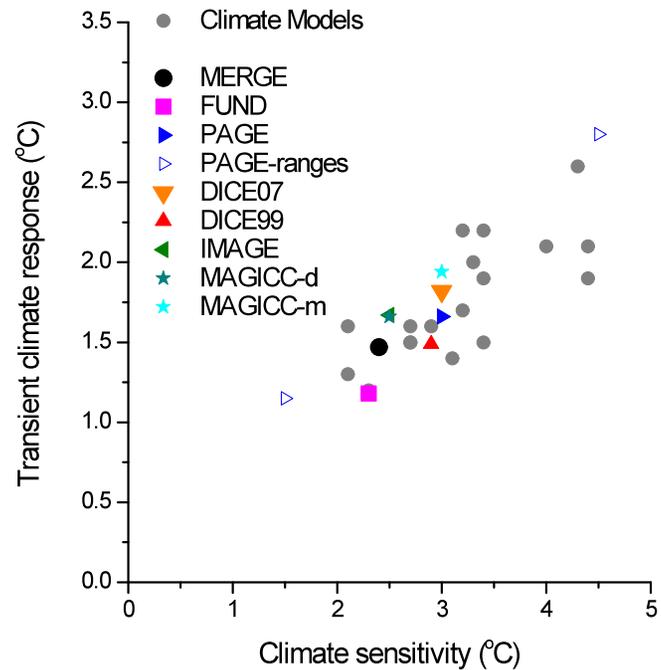
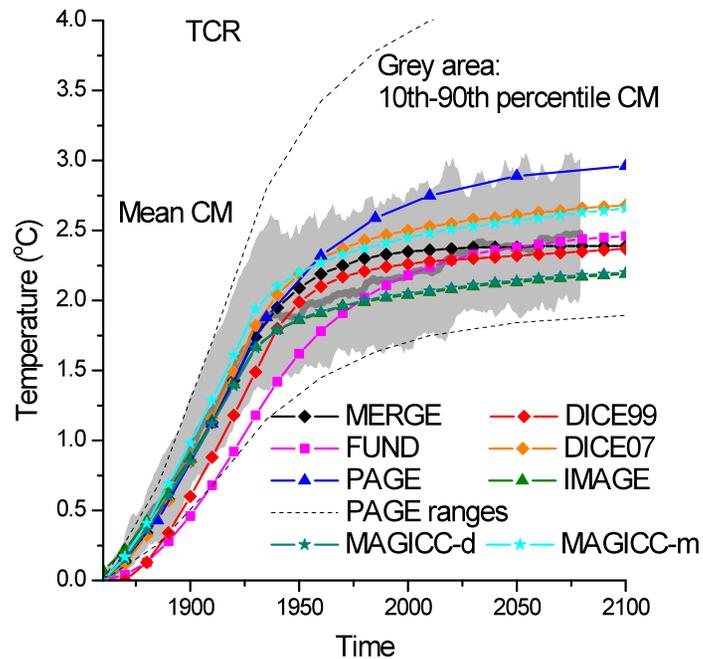
# Transient climate response



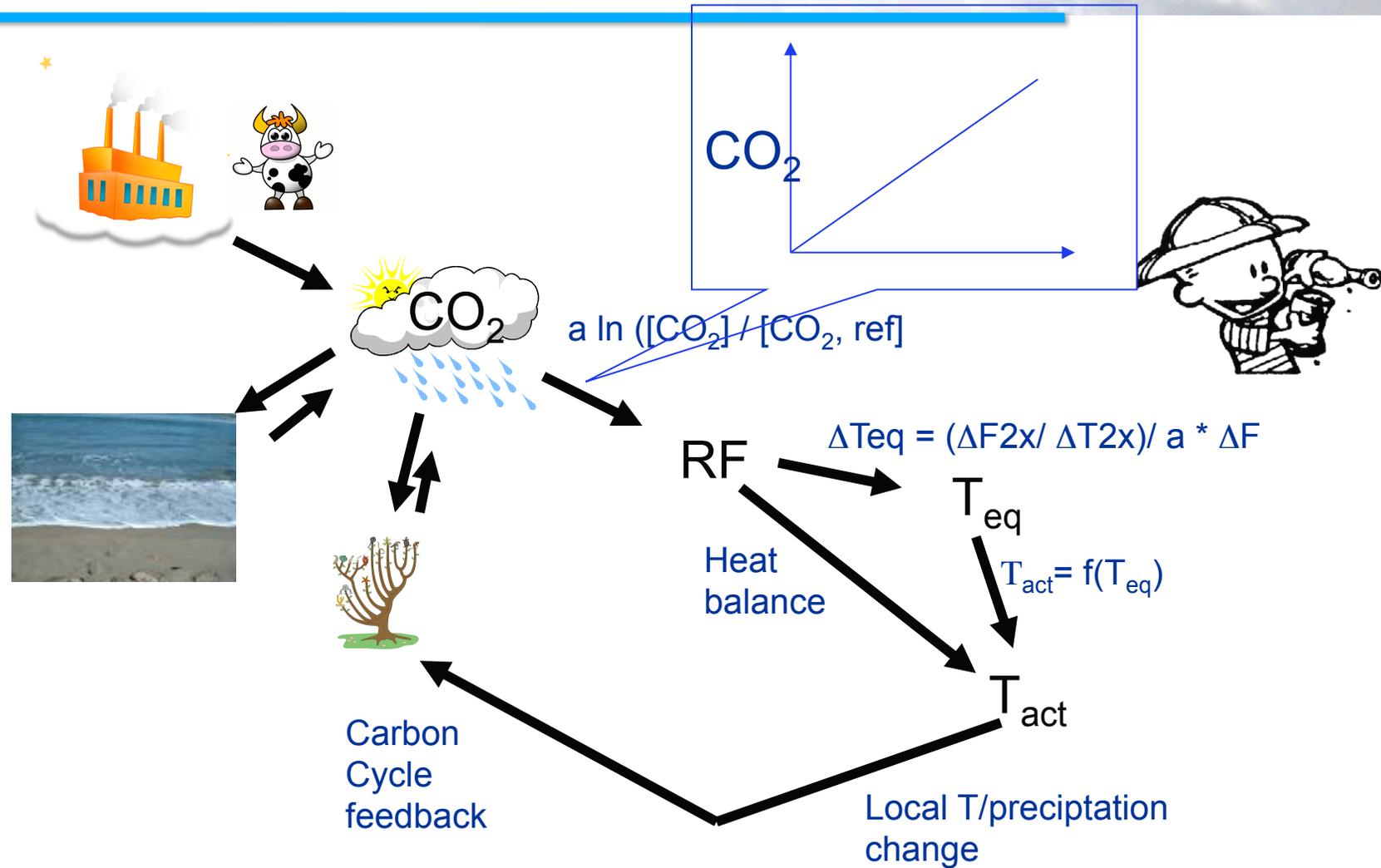
# Transient climate response



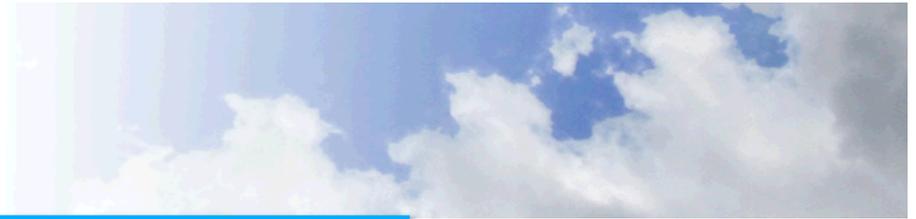
1% increase in [CO<sub>2</sub>] until doubling



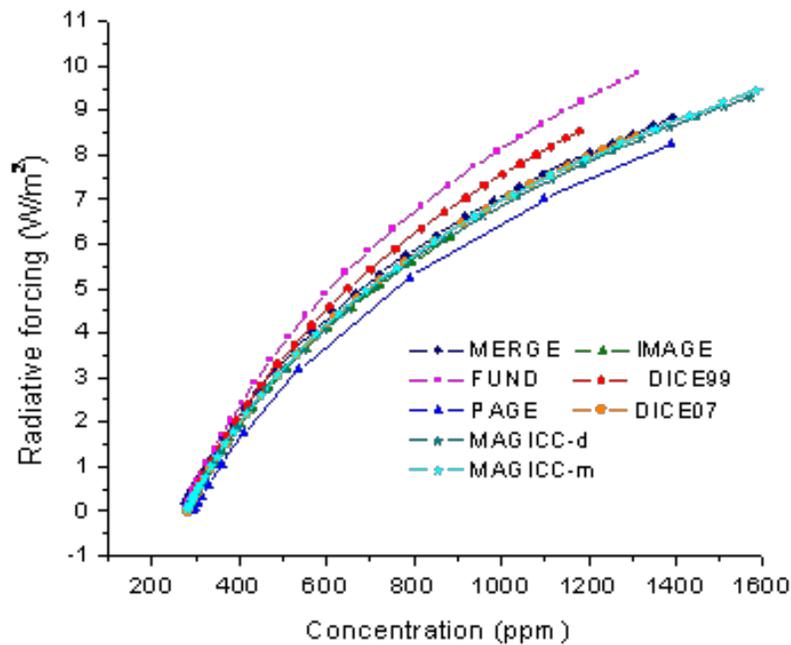
# Climate system and carbon cycle



# Radiative forcing



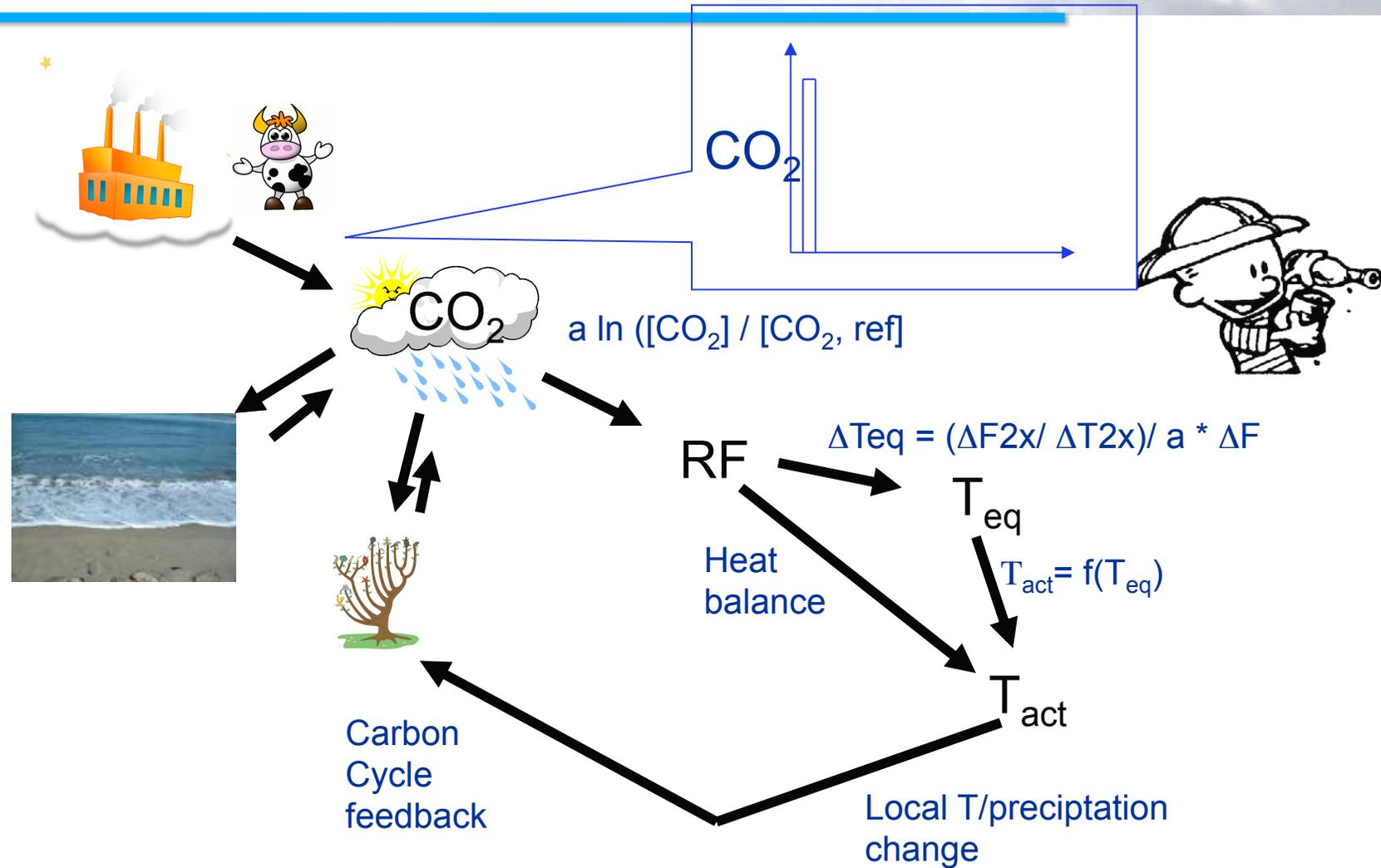
Increase in [CO<sub>2</sub>]



$$RF = a \ln ([CO_2] / [CO_{2, ref}])$$

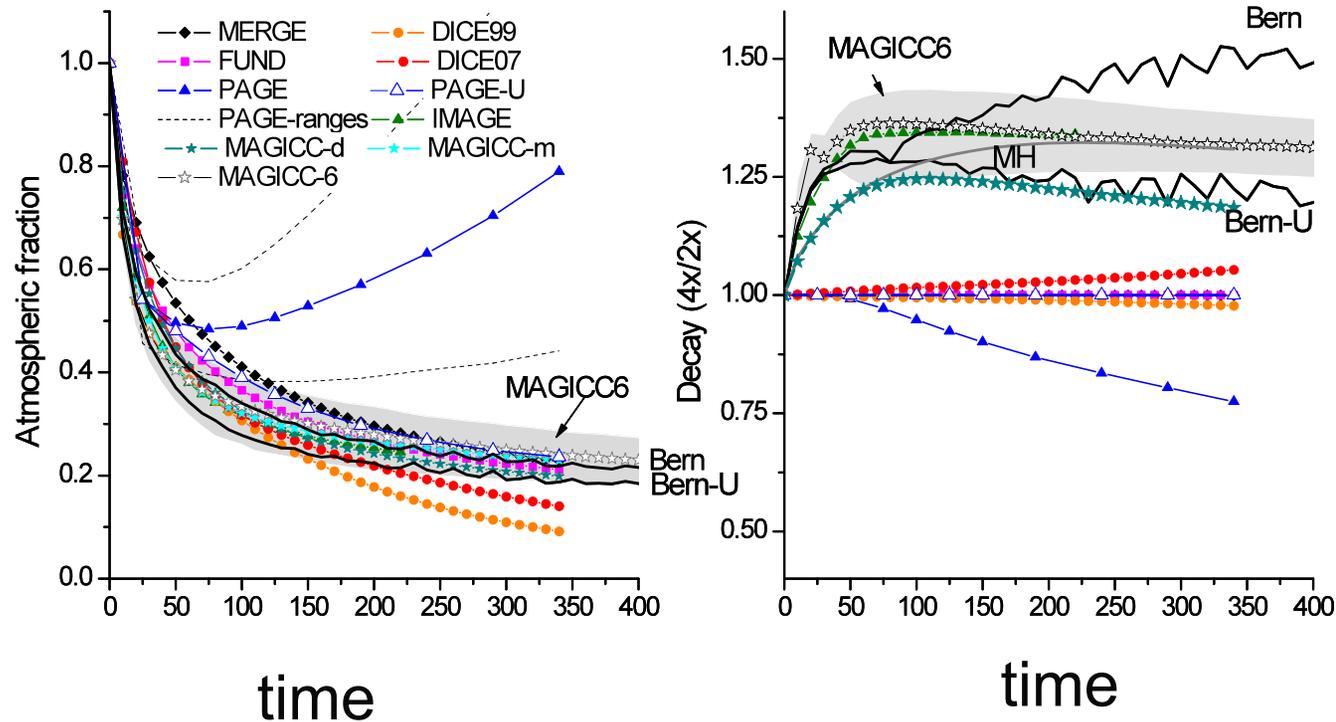


# Climate system and carbon cycle

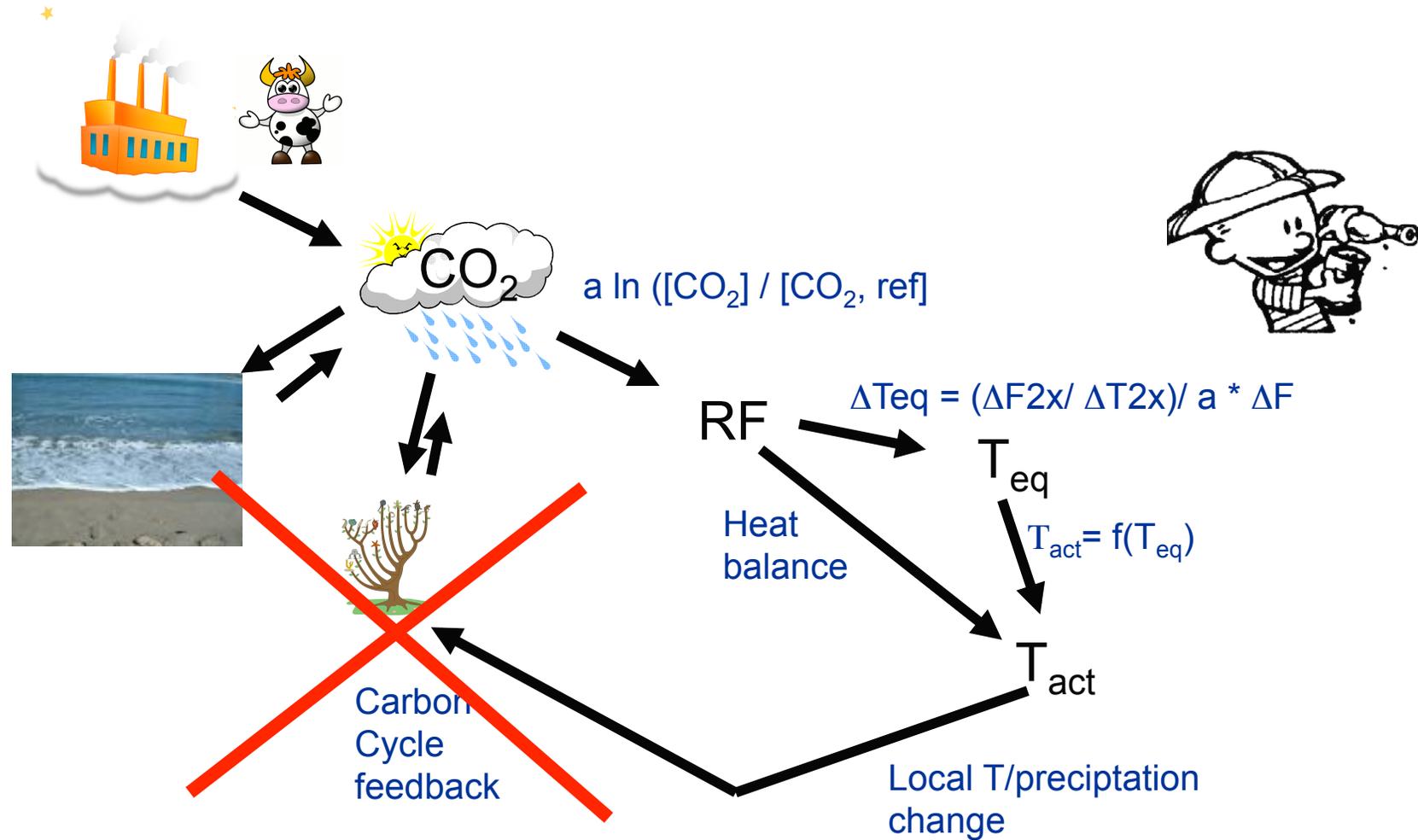


# Removal of CO<sub>2</sub> from the atmosphere

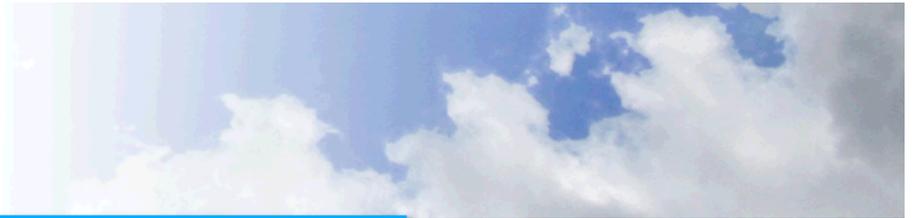
## Double/quadruple [CO<sub>2</sub>] and let it decay



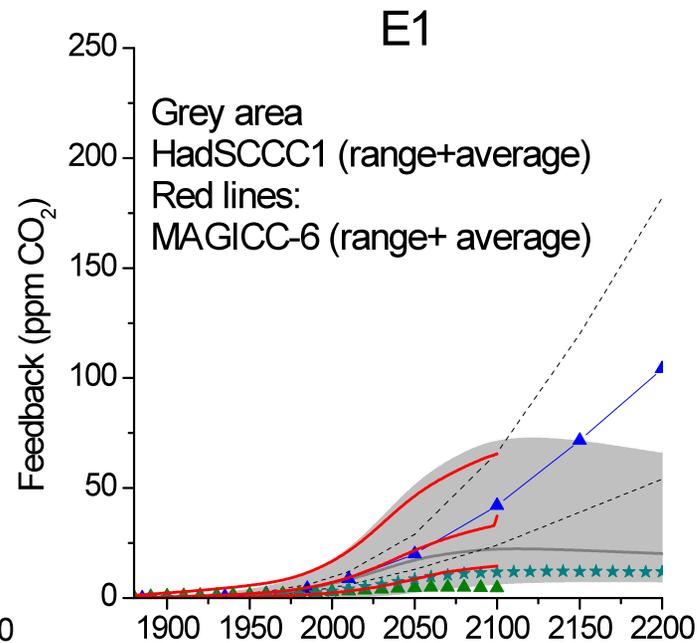
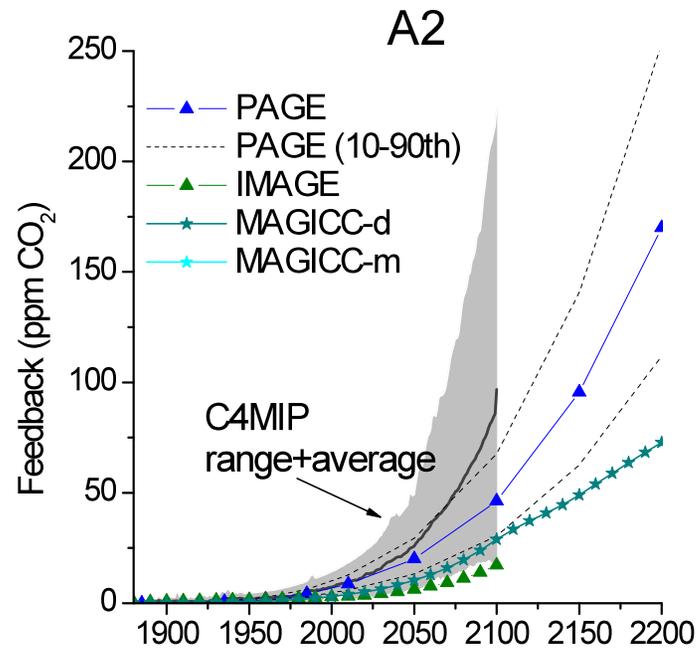
# Climate system and carbon cycle



# Carbon cycle feedbacks



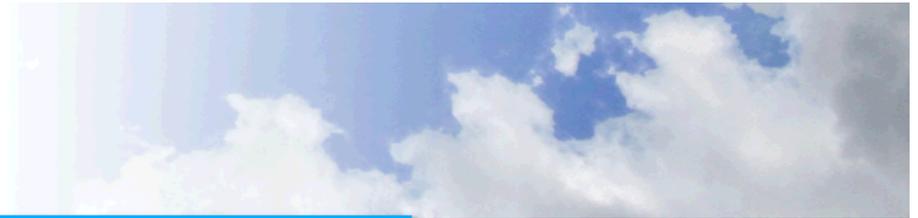
## Map impact of climate feedback



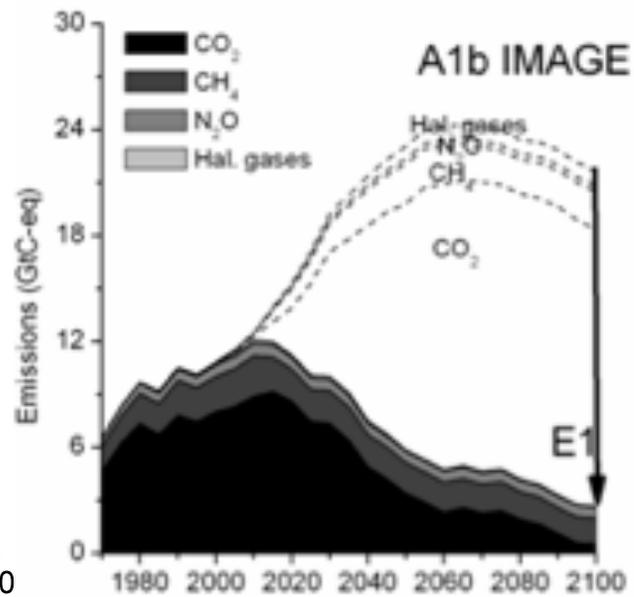
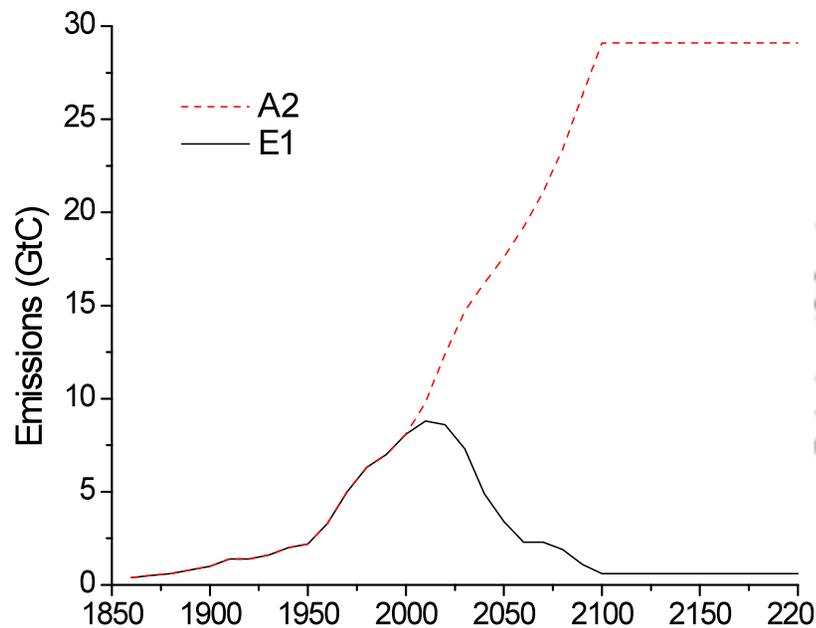
## Wide range of results



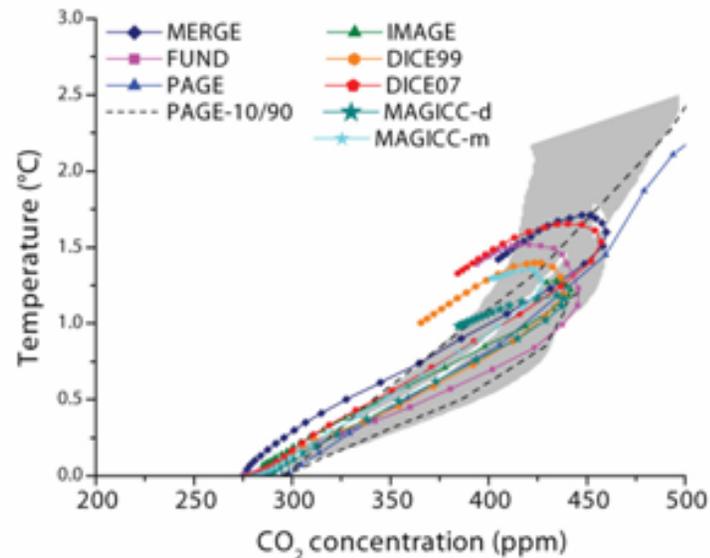
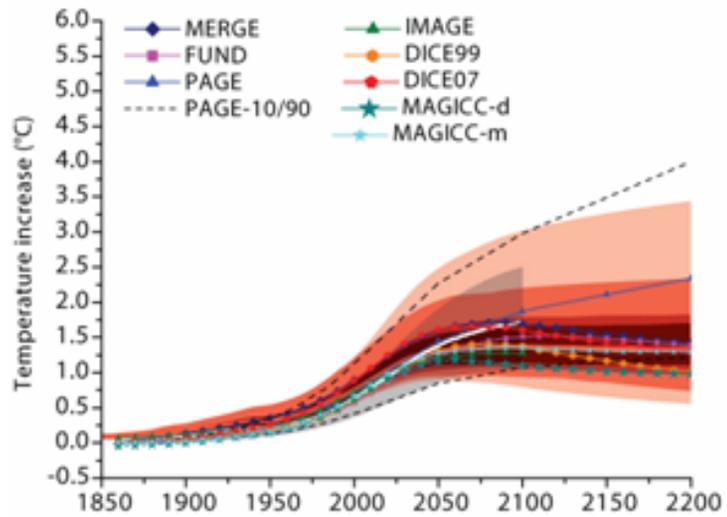
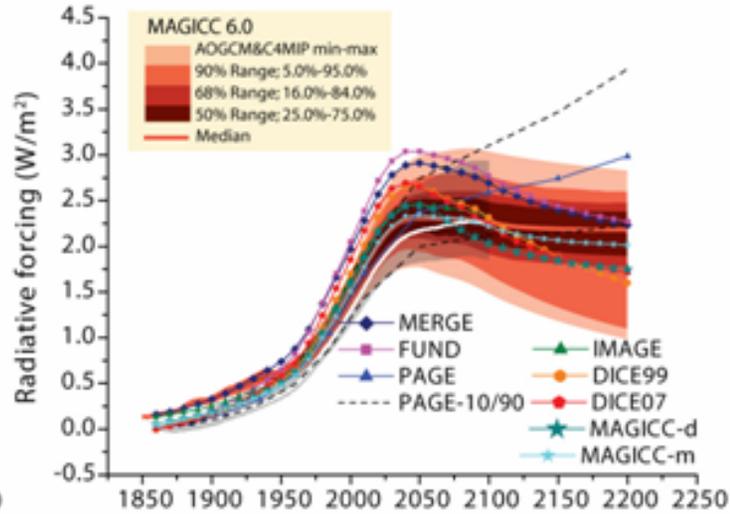
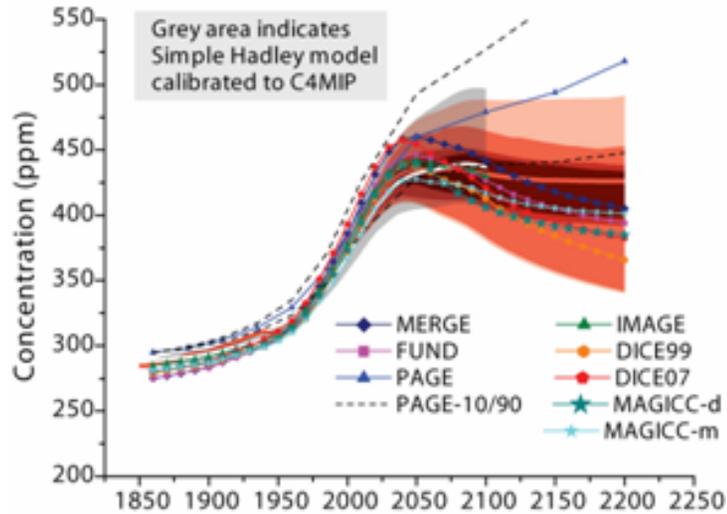
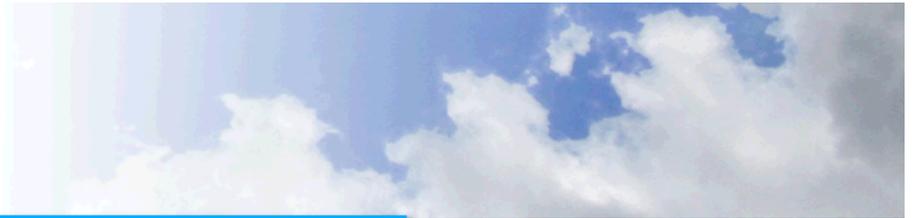
# High vs. low emissions



## Run low and high emission profile



# E1 scenario (2/2)

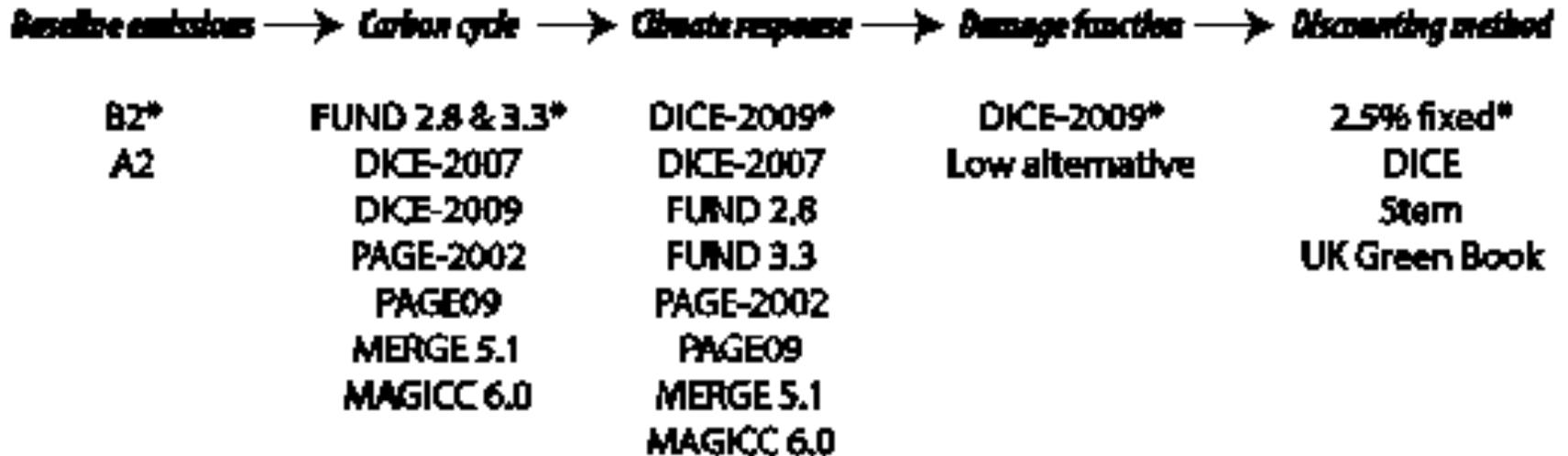




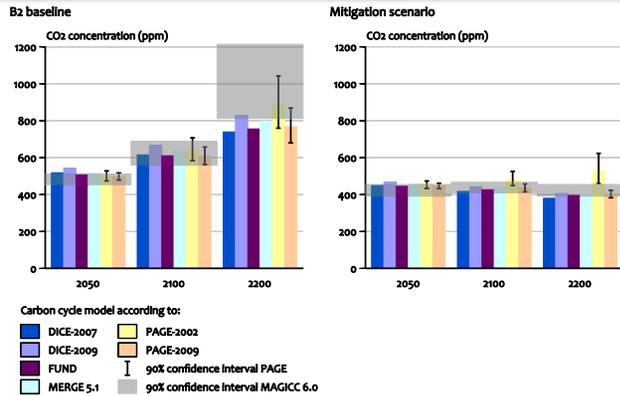
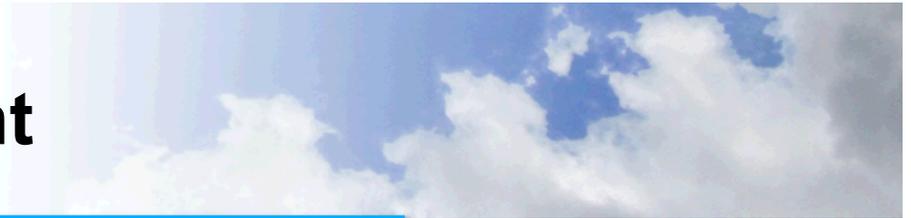
- Does this matter?
- Use a simple IAM (FAIR) and use it to calculate the monetary damage of climate change under 2 scenarios (baseline + 450)
- Vary climate, carbon cycle to function like various IAMs
- Use MAGICC-6 to bound “CM model range”
- Also vary discount rate for climate impacts, damage curve



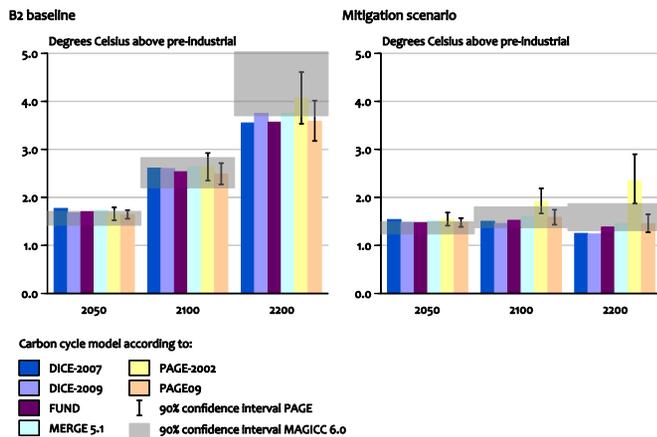
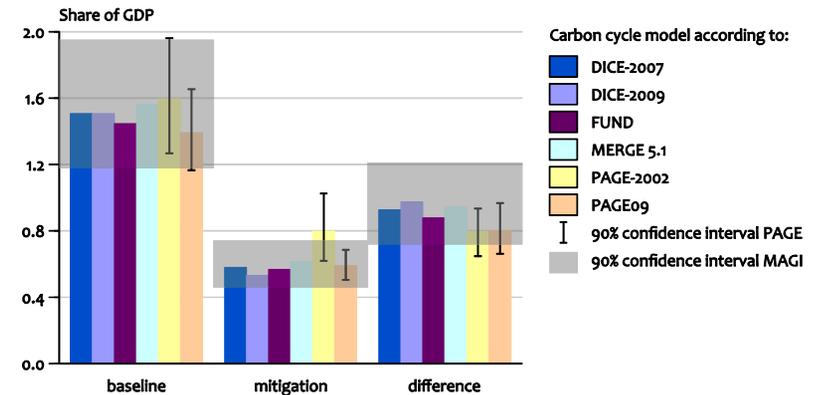
# What does this mean for IAM application: eg. Cost-Benefit Analysis



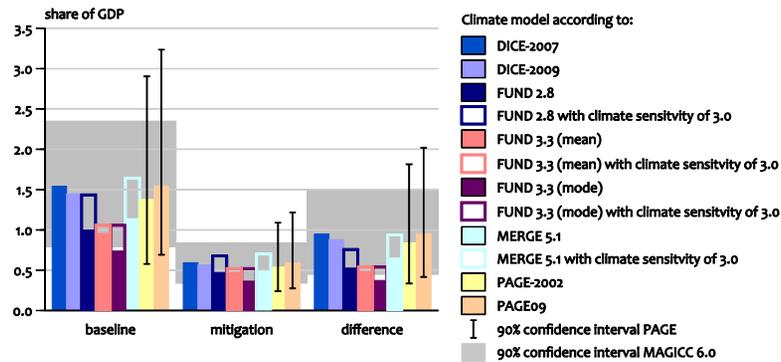
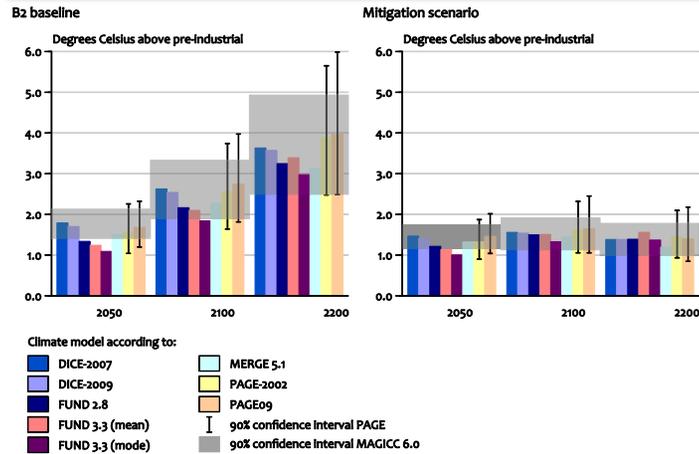
# Only carbon cycle different



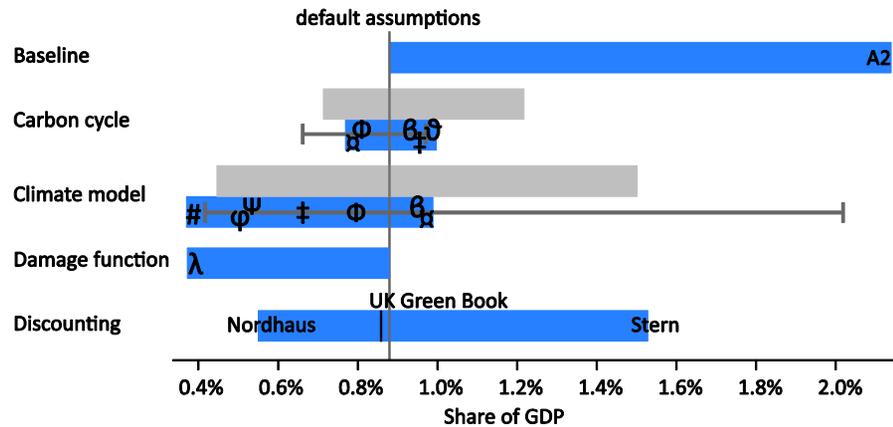
## Discounted monetary damage as % of GDP



# Only climate representation different



# Contribution of different uncertainties



Legend:

$\hat{\Phi}$  = DICE-2007;  $\Phi$  = DICE-2009;  $\ddagger$  = MERGE 5.1;  $\Phi$  = mean PAGE-2002;  
 $\hat{\Phi}$  = mean PAGE-2009;  $\Psi$  = FUND 2.8;  $\Phi$  = mean FUND 3.3;  $\#$  = mode FUND 3.3;  
 $\lambda$  = Alternative damage function;  $|—|$  = 90% confidence interval PAGE09;  
 = 90% confidence interval MAGICC 6.0

# Implications for IAM research



- What is a good IAM climate / carbon cycle representation: in the uncertainty range, or near the middle? Should IAMs more run uncertainty range as part of their standard work.
- The value of diagnostic runs, formulate similar experiments for other IAM elements (allow to qualify models)
  - Simple to run (for different types of models; should represent the model)
  - Simple to interpret
  - Ideally, should be comparable with certain observations

# Implications for IAM research

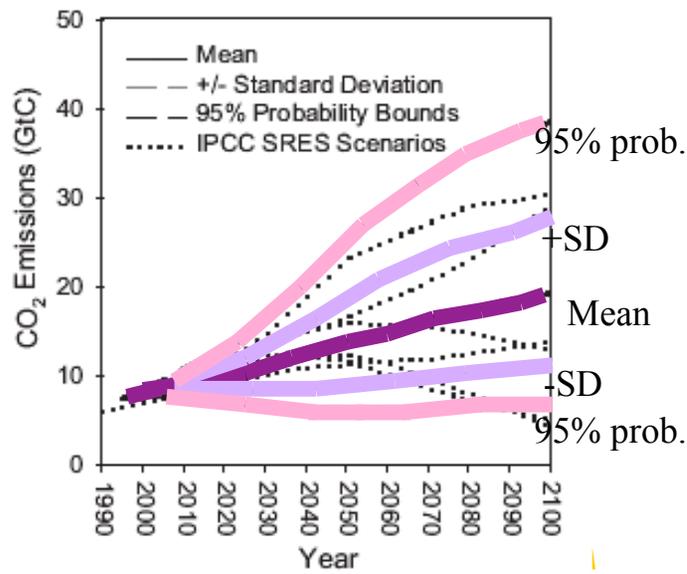


- Diagnostic runs (continued)
  - *Standard carbon tax run - record reduction rate (cheap / expensive model)*
  - *Standard population/GDP run: high/low emission model*
- Did not look into S, BC, CH4 etc.
- What parameters do we focus at? Emissions, temperature?

# Two main scenario methods (handling uncertainty in different ways)

Probabilistic  
Scenario development

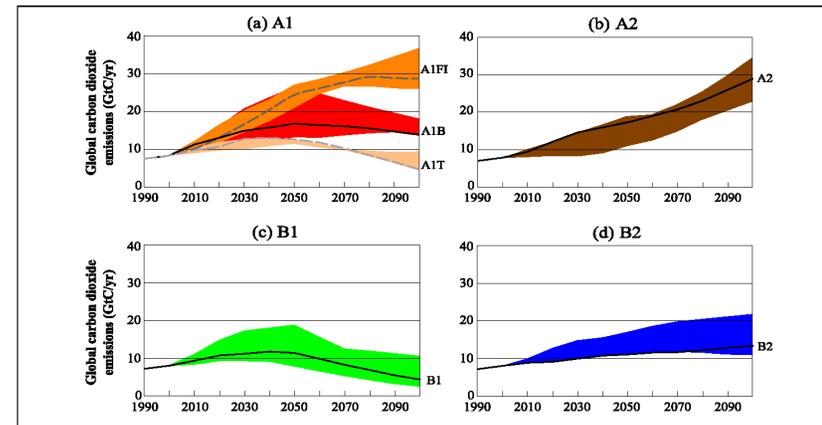
*Estimate best-guess and uncertainties of all relevant parameter in model; gives best-guess outcome + uncertainty range*



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Webster et al (2001)

A set of storyline  
based scenarios

*Develop storylines around major uncertainties – and use storyline to estimate consistent values for other parameters. Explore the future.*



Nakicenovic et al (2000)

Simple climate models  
Detlef van Vuuren – 29 October 2008

# Two main scenario methods (handling uncertainty in different ways)

Probabilistic  
Scenario development

- ✓ Good in addressing ontic uncertainty and epistemic uncertainty that can be expressed in statistical terms

- ✓ Uses scientific rigidity of the model
- ✓ Users can easily interpret results
- ✓ In policy-studies one can use only mean case

- ✓ But:
  - ✓ How to deal with unknown pdfs?
  - ✓ How good is the model?
  - ✓ What is not modelled?

A set of storyline  
based scenarios

- ✓ Good in addressing epistemic uncertainty; especially the more conditional statements

- ✓ Strong in exploring, allows creativity, flexible in including non-modelled elements
- ✓ Necessary if major uncertainties with unknown trends and consequences.

- ✓ But:
  - ✓ Difficult to use / understand
  - ✓ Hard to use in policy analysis
  - ✓ Risk of becoming fairy-tales

# Two main scenario methods (handling uncertainty in different ways)

Probabilistic  
Scenario development

A set of storyline  
based scenarios

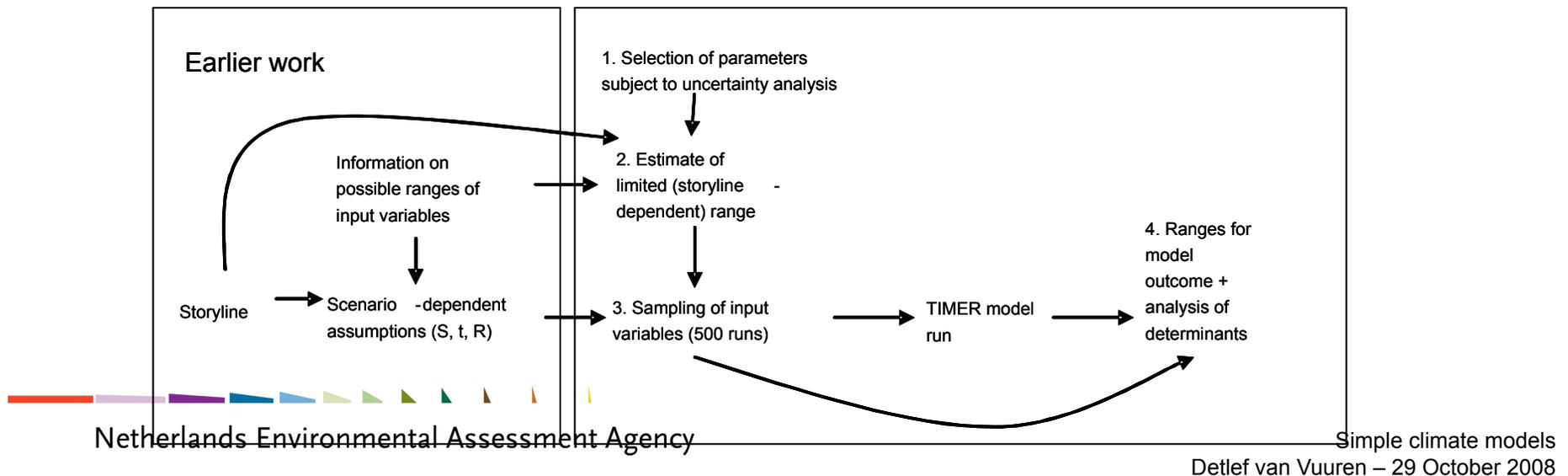
Combine the 2 approaches:

- Scenarios for the factors for which pdf do not make sense
- Use scenario approach to add consistency in assumptions where 'stylized facts' exists... but no formal theory.
- But use pdf where it add rigidity
- E.g. question whether globalisation occurs is storyline choice... but if we assume it is there, we can assume a range of high economic growth rates.

# Conditional probabilistic assessment

Several steps:

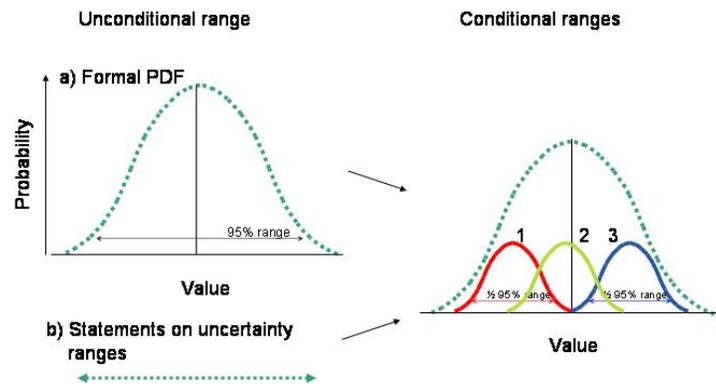
- 1. Sensitivity analysis / expert elicitation to select most useful parameters to include
- 2. Estimate central values + ranges within IPCC SRES storylines
- 3. Monte-Carlo analysis
- 4. Determine ranges for outcome variables and identify contribution of input variables.



# Step 2. Estimate parameter values and ranges

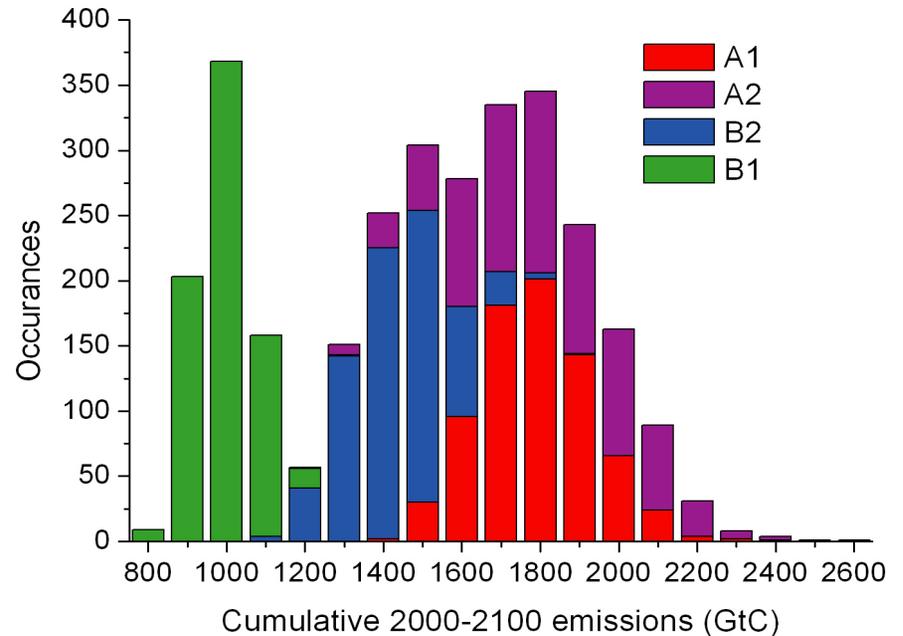
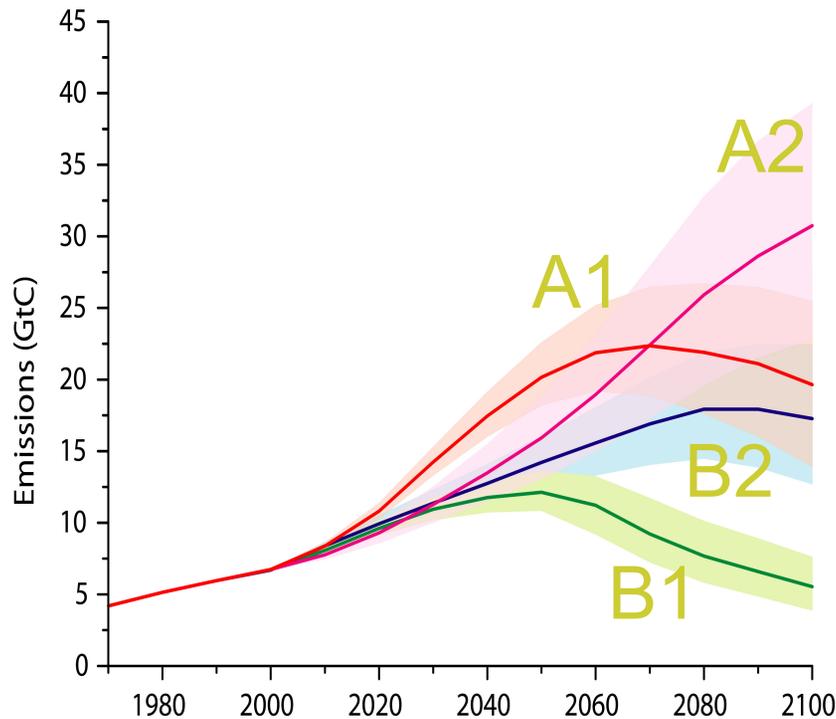
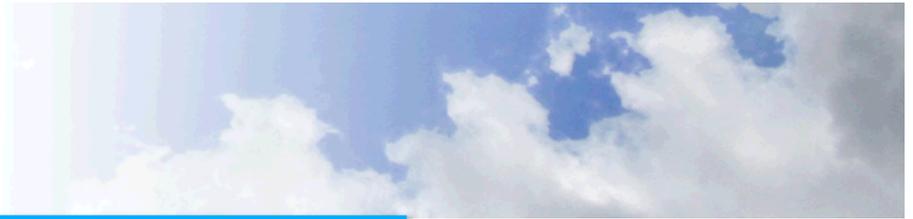
	A1			A2	B1	B2
Storyline	Globalization; liberalization;			Heterogeneous world; self-reliance; fragmentation	Globalization; orientation on social and environmental sustainability ;	<i>Local solutions to sustainability ; regional emphasis</i>
Population	Low			High	Low	Medium
Economic growth	Very high			Low in developing countries; medium in industrialized countries	High	Medium
Attitude towards environmental protection	Reactive			Reactive	Proactive	Proactive
Main goal for the energy system	Reliable, cheap energy for everybody			Security of energy supply	Energy services within sustainable limits	Combination of different goals
Primary energy use	Very high			High	Low	Medium
Technology development	Rapid			Slow	Rapid	Medium
Type of technology development	Balanced (A1B)	Primarily fossil fuels (A1FI)	Primarily non-fossil energy (A1T)	Balanced	Primarily energy efficiency and non-fossil energy	Balanced

Simplification:  
 All regions 100% correlated  
 All distributions normal  
 All parameters 100% non correlated



PDFs for 26  
 Input parameters,  
 Scenario dependent

# Monte-Carlo outcomes



➤ 90% interval for each scenario shows a spread of 40% around the central value.

➤ Strong overlap A1, A2, B2

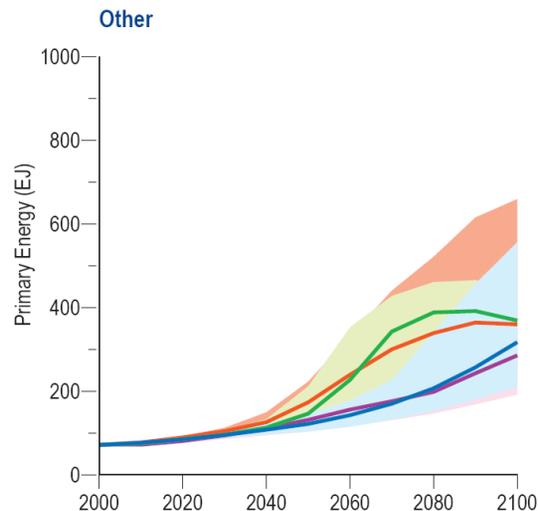
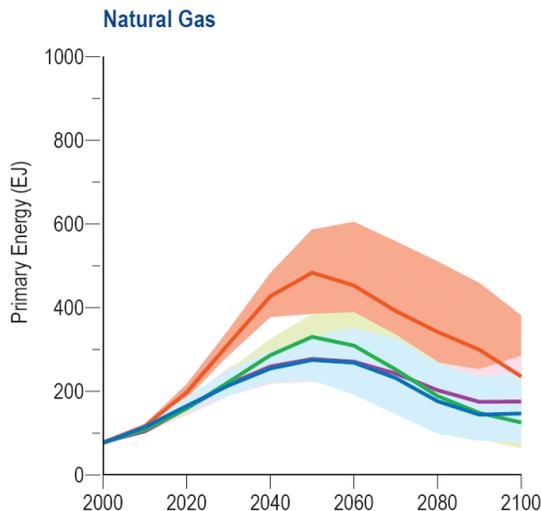
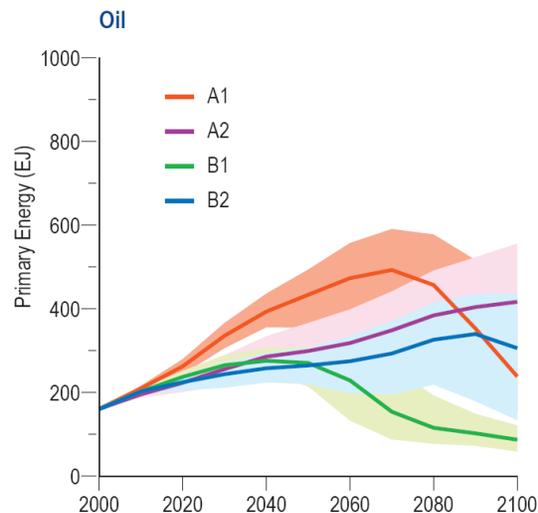
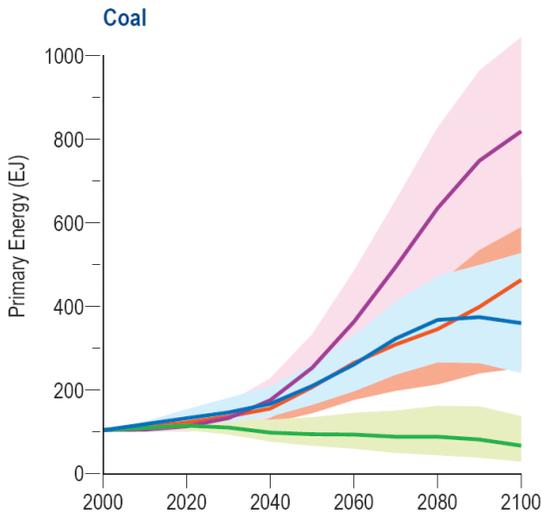
➤ Spread A2 particularly large

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# Pathways for major energy carriers

- “Peak oil” – “Peak gas” but for very different reasons (resource, population, alternatives)
- Very widespread in outcomes for coal



		CO <sub>2</sub>		En/GDP C-fac		Coal	Oil	Natural gas	bio energy	Nuclear power	Renew. energy
<i>Driving forces</i>	Population	0.29 0.26 0.81 0.37	0.01 0.01 0.06 0.04	0.04 0.11 0.22 0.05	0.19 0.16 0.66 0.3	0.18 0.22 0.65 0.25	0.17 0.22 0.55 0.2	0.11 0.16 0.32 0.16	0.2 0.18 0.62 0.28	0.19 0.23 0.41 0.19	
	GDP	0.58 0.63 0.5 0.69	0.74 0.66 0.59 0.66	0.11 0.14 0.21 0.2	0.19 0.21 0.34 0.35	0.4 0.48 0.43 0.45	0.2 0.26 0.28 0.25	0.16 0.14 0.19 0.2	0.29 0.31 0.37 0.49	0.15 0.13 0.23 0.19	
	Size of industry	0.07 0.07 0.05 0.07	0.1 0.11 0.13 0.11	0.02 0.02 0.01 0.01	0.04 0.03 0.05 0.05	0.05 0.08 0.03 0.05	0.03 0.04 0.02 0.03	0.03 0.03 0.03 0.03	0.02 0.02 0.03 0.03	0.03 0.04 0.02 0.03	
<i>Energy demand</i>	AEEI	0.53 0.4 0.21 0.41	0.57 0.55 0.52 0.59	0.14 0.16 0.18 0.16	0.34 0.27 0.21 0.36	0.19 0.17 0.14 0.16	0.29 0.3 0.16 0.21	0.23 0.22 0.11 0.21	0.37 0.28 0.2 0.36	0.25 0.27 0.09 0.16	
	Payback time	0.07 0.07 0.04 0.06	0.09 0.11 0.12 0.1	0.01 0.02 0.01 0.01	0.03 0.03 0.03 0.04	0.06 0.06 0.06 0.05	0.04 0.05 0.03 0.03	0.02 0.04 0.03 0.03	0.04 0.03 0.03 0.04	0.04 0.05 0.03 0.03	
	Structural change	0.21 0.29 0.21 0.29	0.24 0.39 0.53 0.42	0.05 0.09 0.15 0.09	0.11 0.15 0.18 0.2	0.09 0.13 0.17 0.14	0.11 0.18 0.15 0.14	0.09 0.15 0.11 0.14	0.13 0.16 0.18 0.22	0.11 0.18 0.11 0.13	
<i>Technology dev. rates</i>	Fossil fuels	0.02 0.06 0 0.01	0.03 0.03 0.03 0.03	0.05 0.1 0.06 0.11	0.28 0.2 0.12 0.19	0.18 0.13 0.12 0.16	0.35 0.26 0.21 0.26	0.3 0.22 0.18 0.25	0.2 0.2 0.12 0.14	0.11 0.09 0.05 0.06	
	Renewables (power)	0.09 0.13 0.04 0.11	0.03 0.05 0.04 0.05	0.19 0.2 0.24 0.29	0.12 0.19 0.08 0.17	0.02 0.02 0.02 0.02	0.06 0.08 0.04 0.06	0.05 0.03 0.03 0.03	0.25 0.42 0.15 0.16	0.74 0.72 0.73 0.83	
	Nuclear power	0.03 0 0.01 0.01	0.01 0 0.03 0.01	0.07 0.01 0.14 0.03	0.04 0.01 0.04 0.02	0.01 0.01 0.01 0.01	0.02 0.01 0.02 0	0.03 0.01 0.04 0.02	0.38 0.18 0.26 0.29	0.02 0.01 0.03 0.01	
	Bioenergy	0.04 0.08 0.02 0.03	0.01 0.01 0.01 0.01	0.17 0.17 0.14 0.16	0.06 0.02 0.01 0.04	0.04 0.14 0.08 0.08	0.05 0.08 0.02 0.05	0.27 0.28 0.37 0.26	0.01 0.02 0.01 0.02	0.02 0.01 0.01 0.01	
	Energy demand	0.11 0.1 0.05 0.08	0.13 0.14 0.13 0.13	0.02 0.03 0.02 0.02	0.06 0.05 0.04 0.06	0.07 0.07 0.06 0.06	0.06 0.07 0.04 0.04	0.05 0.07 0.03 0.05	0.08 0.07 0.05 0.07	0.06 0.08 0.03 0.04	
	H2 technologies	0.01 0.01 0 0	0 0 0 0	0.02 0.01 0.01 0.01	0.03 0.01 0.01 0.02	0.03 0.01 0.01 0.02	0.01 0.01 0.01 0.01	0.01 0.01 0.01 0.01	0.01 0.01 0.01 0.01	0.02 0.02 0.02 0.02	0.01 0 0 0
	Thermal power plants	0.03 0.03 0.02 0.03	0.03 0.03 0.04 0.03	0.02 0.03 0.03 0.03	0.05 0.05 0.03 0.05	0.01 0.01 0.01 0.01	0.02 0.01 0.01 0.02	0.02 0.01 0.01 0.01	0.04 0.05 0.04 0.05	0.03 0.02 0.02 0.02	
	Oil resources	0.09 0.11 0.03 0.06	0.04 0.03 0.04 0.03	0.19 0.19 0.12 0.2	0.13 0.1 0.08 0.1	0.6 0.49 0.37 0.52	0.25 0.21 0.2 0.25	0.19 0.19 0.2 0.2	0.06 0.08 0.03 0.05	0.03 0.04 0.02 0.03	
	Gas resources	0.04 0.02 0.05 0.05	0.01 0.01 0.02 0.01	0.14 0.04 0.25 0.2	0.25 0.21 0.17 0.22	0.14 0.11 0.08 0.17	0.46 0.41 0.44 0.48	0.26 0.19 0.15 0.21	0.21 0.2 0.16 0.14	0.15 0.12 0.11 0.1	
	Coal Resources	0.01 0 0 0.01	0 0 0.01 0	0.02 0.01 0.07 0.02	0.02 0.01 0.02 0.02	0.01 0.01 0.02 0.01	0.01 0.01 0.01 0.01	0.02 0.02 0.03 0.03	0.01 0 0.03 0.01	0 0 0.02 0.01	
	Nuclear resources	0 0 0 0	0 0 0 0	0.01 0.01 0.01 0.01	0 0 0.01 0.01	0.01 0.01 0.01 0.01	0.01 0.01 0.01 0.01	0.02 0.01 0.02 0.02	0.01 0.01 0.01 0.01	0.01 0.01 0.02 0.01	
	Wind resource	0.03 0.03 0.01 0.02	0.01 0.01 0.01 0.01	0.06 0.04 0.04 0.05	0.03 0.05 0.01 0.03	0.02 0.01 0.01 0.02	0.01 0.01 0.01 0.01	0.01 0.01 0.01 0.01	0.01 0.01 0.02 0.03	0.05 0.07 0.02 0.03	0.21 0.18 0.1 0.14
PV resource	0 0 0 0	0 0 0 0	0.01 0 0 0.01	0 0 0 0	0 0 0 0.01	0 0 0 0	0.01 0 0.01 0	0.01 0.01 0.01 0.01	0.01 0.01 0.01 0.01		
Residues resource	0.01 0.01 0.01 0.01	0 0 0 0	0.05 0.04 0.08 0.06	0.02 0.01 0.01 0.02	0.01 0.01 0 0.01	0.01 0.02 0.01 0.01	0.14 0.11 0.21 0.14	0.01 0.02 0.02 0.01	0.01 0.01 0.01 0.01		
Biomass resource	0.02 0.04 0.01 0.01	0.01 0.01 0 0.01	0.08 0.16 0.08 0.04	0.03 0.03 0 0.01	0.01 0.07 0.03 0.01	0.03 0.08 0.01 0.02	0.11 0.23 0.16 0.06	0.01 0.03 0 0.01	0.01 0.02 0.01 0.01		
<i>Other</i>	Fuel preferences	0.29 0.35 0.12 0.21	0.07 0.08 0.08 0.07	0.71 0.68 0.56 0.59	0.59 0.71 0.3 0.45	0.04 0.12 0.03 0.05	0.24 0.34 0.17 0.2	0.34 0.36 0.21 0.34	0.29 0.43 0.24 0.27	0.16 0.18 0.12 0.14	
	Credit factor	0.01 0.01 0 0.01	0 0.01 0 0.01	0.02 0.02 0.01 0.02	0.01 0.01 0.01 0.01	0.01 0.01 0.01 0.02	0.01 0.02 0.01 0.01	0.01 0.01 0.01 0.01	0.01 0.01 0.01 0.01	0.06 0.08 0.02 0.05	
	Taxes	0.02 0.05 0.01 0.02	0.03 0.05 0.04 0.03	0.03 0.05 0.01 0.02	0.02 0.01 0.01 0.01	0.02 0.07 0.02 0.01	0.03 0.02 0.01 0.01	0.02 0.06 0.02 0.03	0.02 0.01 0.02 0.02	0.03 0.03 0.02 0.02	
	ST price uncertainty	0.03 0.02 0.03 0.05	0.04 0.04 0.04 0.04	0.13 0.1 0.24 0.22	0.14 0.14 0.21 0.22	0.03 0.04 0.06 0.07	0.16 0.17 0.2 0.27	0.19 0.17 0.22 0.22	0.14 0.14 0.15 0.16	0.11 0.09 0.12 0.12	
	Trade	0.02 0.02 0 0.03	0.01 0.01 0.02 0.01	0.07 0.05 0.08 0.09	0.01 0.01 0.09 0.07	0.02 0.01 0.07 0.04	0.06 0.06 0.08 0.11	0.07 0.05 0.14 0.07	0.08 0.1 0.12 0.08	0.07 0.04 0.08 0.05	

# Lessons for current project



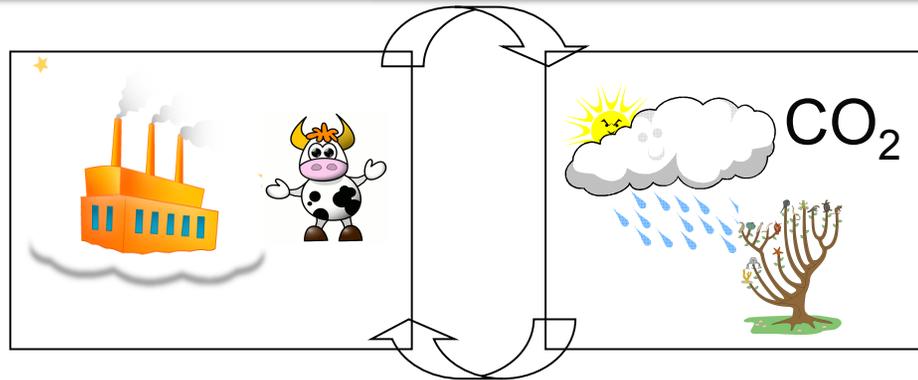
- Conditionality of findings: harmonise or categorize?
- Consider conditionality while defining experiment



# IAMs, ESMs, EMICs, AOGCMs and DGVMs

Simple

IAM

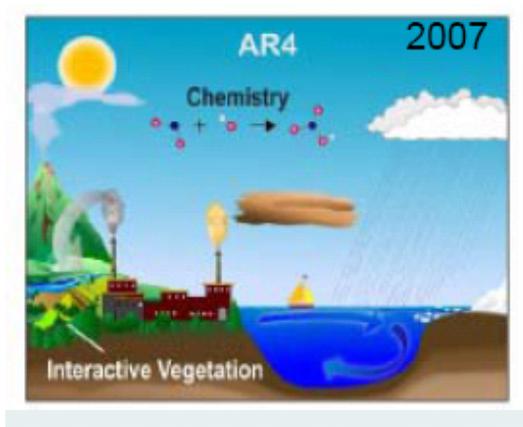


Policy advice  
Interaction

Run time:  
Seconds to hours

EMICS

AOGCM  
ESM



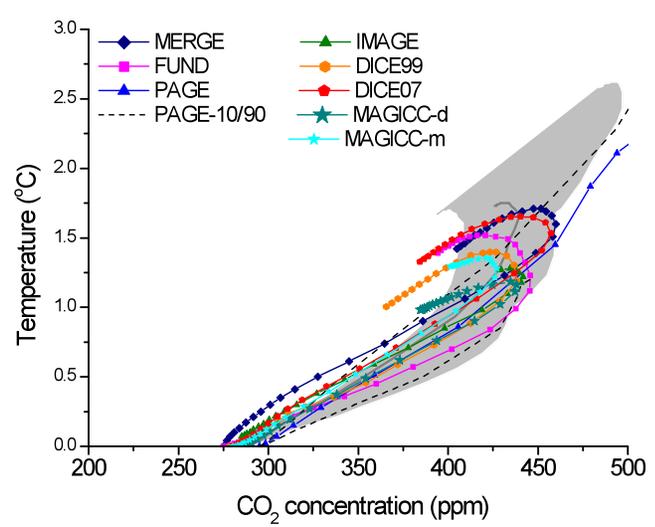
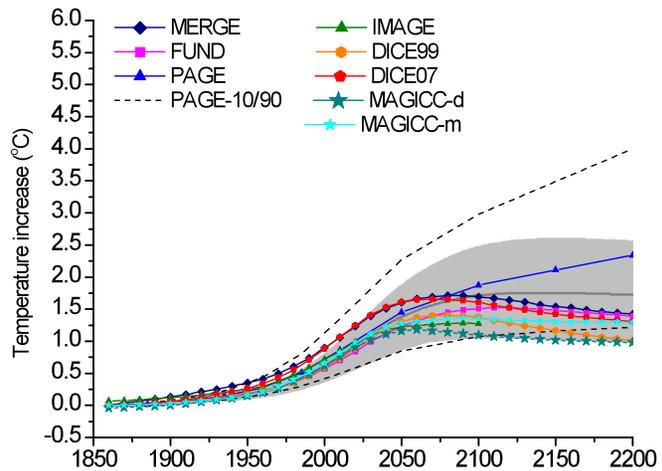
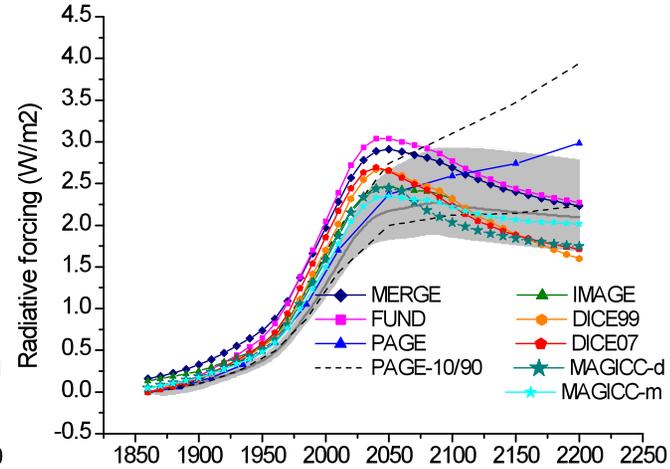
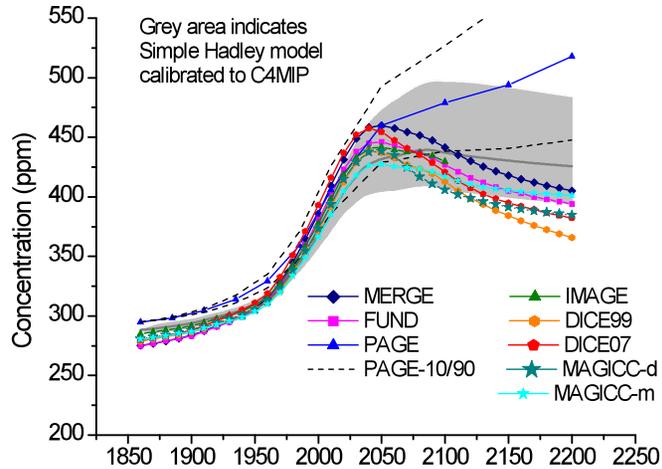
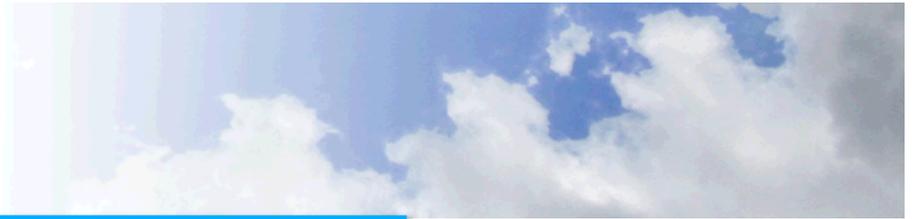
DGVMs

Science!  
Natural system

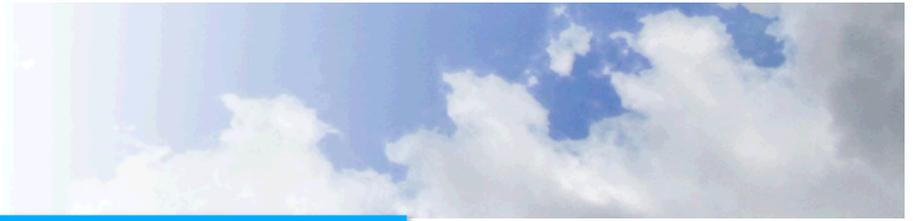
Run time: months

Complex

# E1 scenario (1/2)



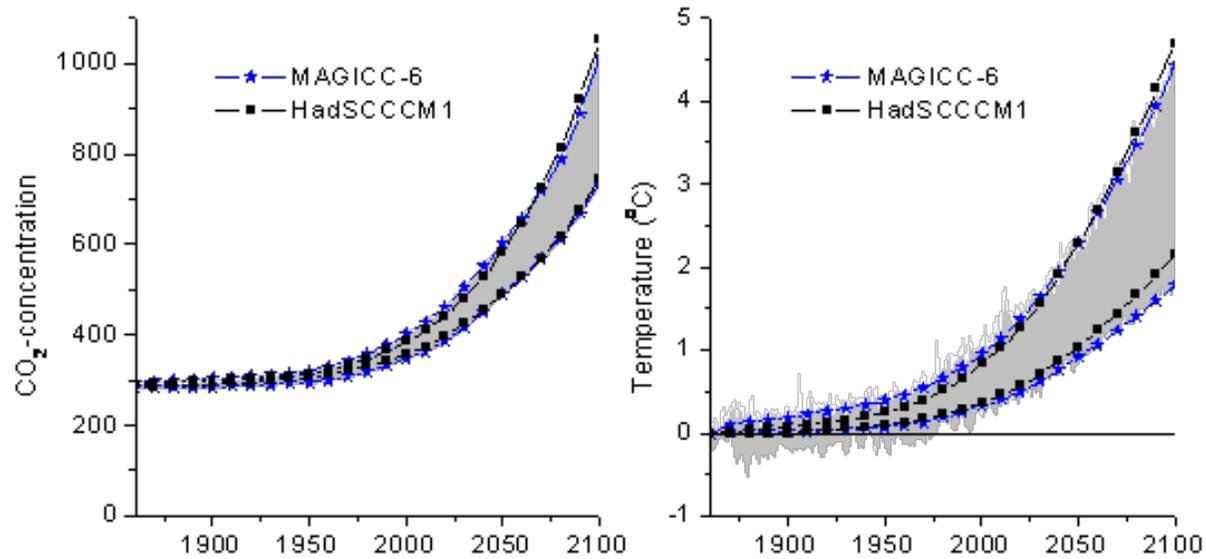
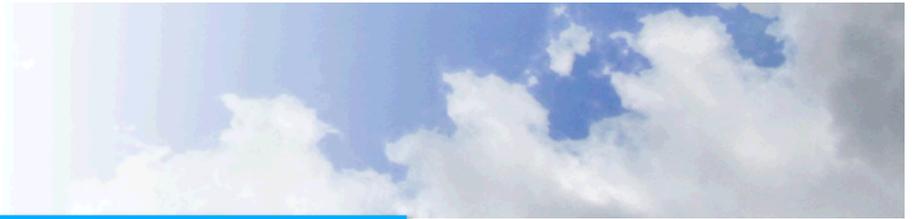
# MESSAGES



- “climate / carbon cycle” uncertainty in IAMs matters for climate policy!
- IAMs mostly within large uncertainty range “expert models”... but not always.
- Feedbacks poorly covered in IAMs
- Strong need for low stabilisation scenarios in ESMs/GCMs



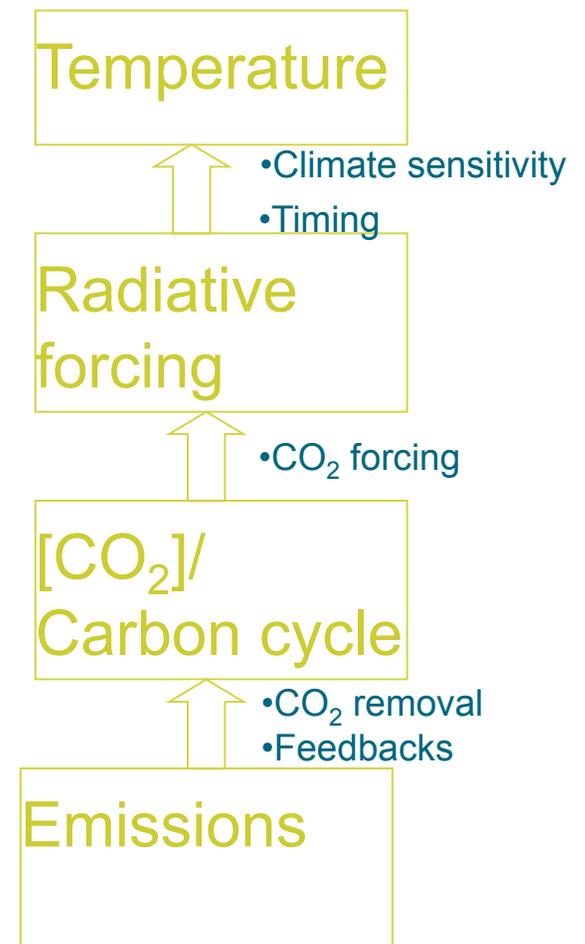
# Expert models



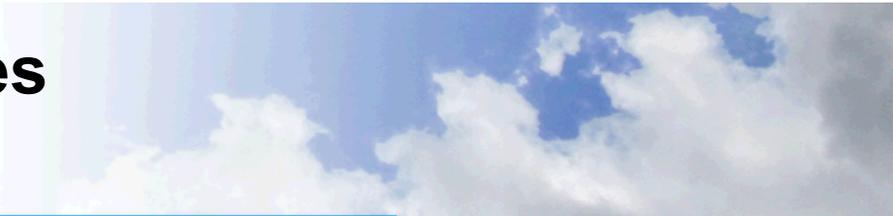
# Questions



- ***What are the equilibrium temperature responses?***
- ***What does the transient climate response look like?***
- ***What does the relationship between greenhouse gas concentration and radiative forcing look like?***
- ***How does the carbon cycle behave?***
- ***How does the climate – carbon cycle feedback behave in IAMs?***
- ***Results for high emissions scenario (C4MIP experiment, A2)***



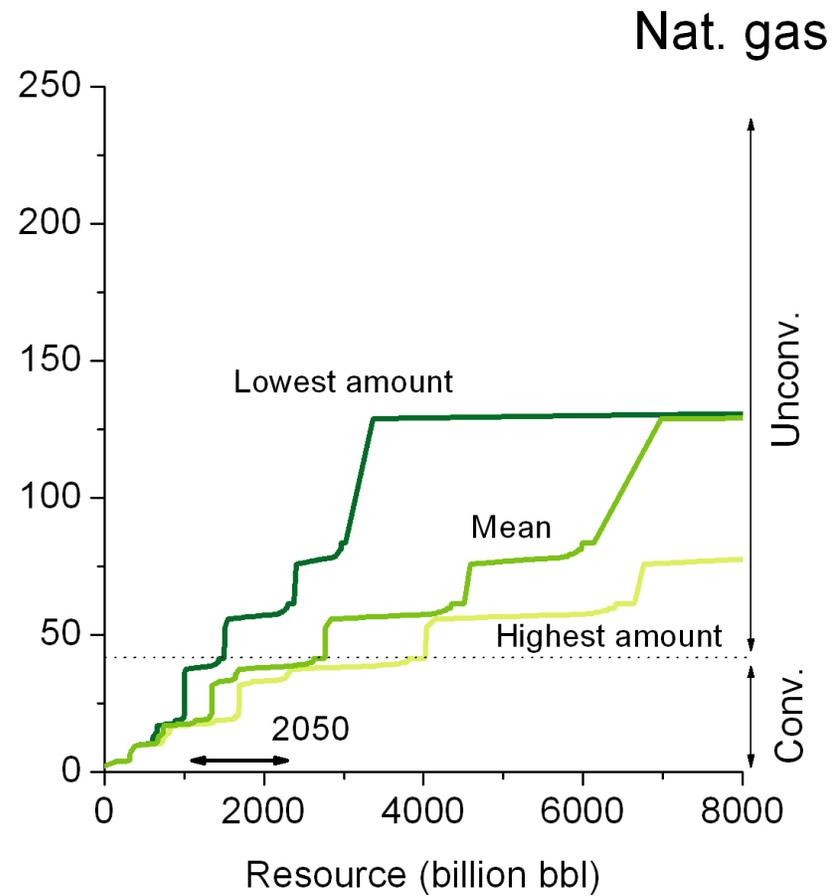
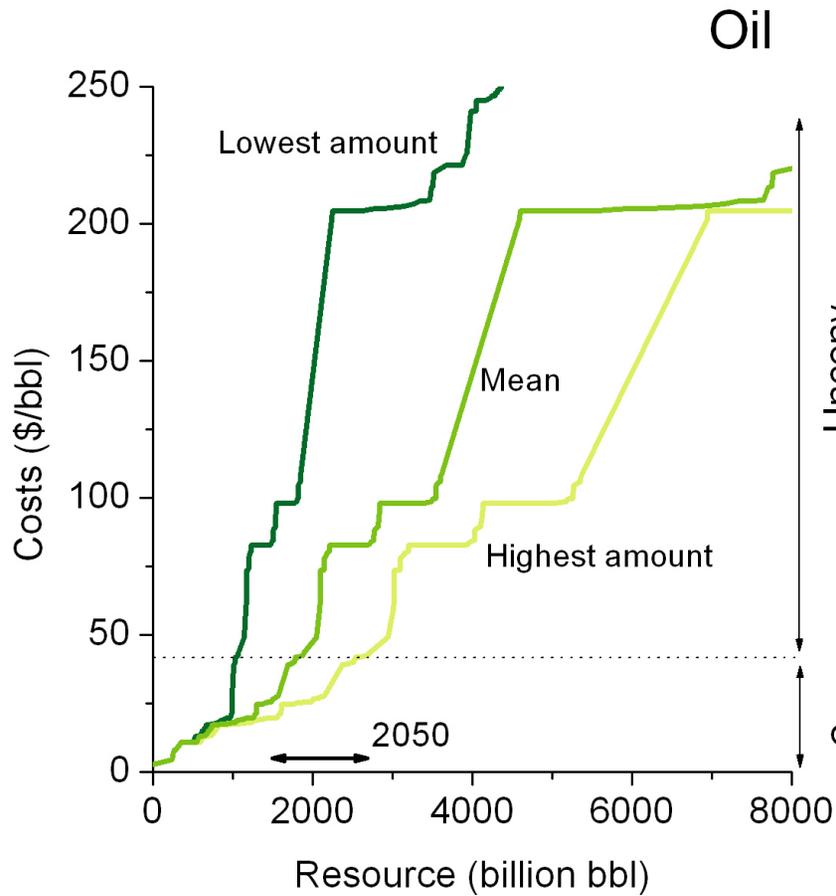
# Examples of sampling ranges



	A1	A2	B1	B2	Rationale
<b>GDP (% growth in constant\$ in the 2000-2100 period)</b>					
Default values	2.7	1.2	2.3	2.2	Here global values are shown. However, in reality we use regionally defined growth rates consistent with the IMAGE 2.3 implementation of the IPCC SRES scenarios.
Sample ranges	2.4-3.2	1.0-1.5	2.0-2.7	1.6-2.4	Regionally defined ranges based on the historically founded values.
<b>Share industry (% of GDP in 2100)</b>					
Default values (% of total GDP)	0.36	0.35	0.27	0.37	Based on the IMAGE 2.3 implementation of the SRES scenarios and underlying WorldScan calculations (IMAGE-team, 2001).
Sample ranges	0.32-0.40	0.31-0.39	0.24-0.31	0.33-0.41	0.04 used on the basis of current variation among OECD regions (15% range in total).
<b>Population in 2050 and 2100 (billion)</b>					
Default values	8.2/6.9	10.4/12.5	8.2/6.9	9.0/9.1	Both default values and ranges are based on O'Neill (2004).
Sample ranges	7.6-8.6/ 5.6-8.2	8.5-13.7 9.2-16.0	7.6-8.6/ 5.8-8.0	8.3-10 7.5-10.8	

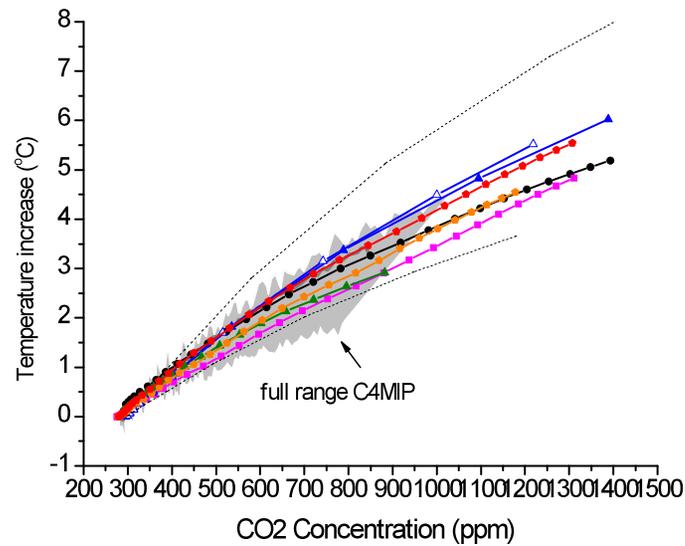
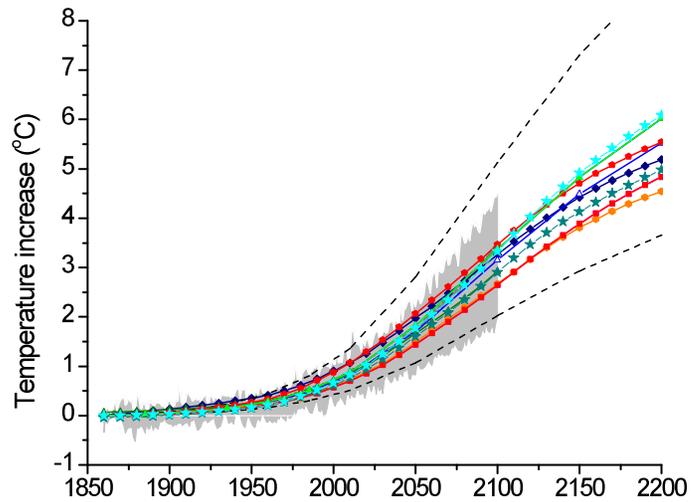
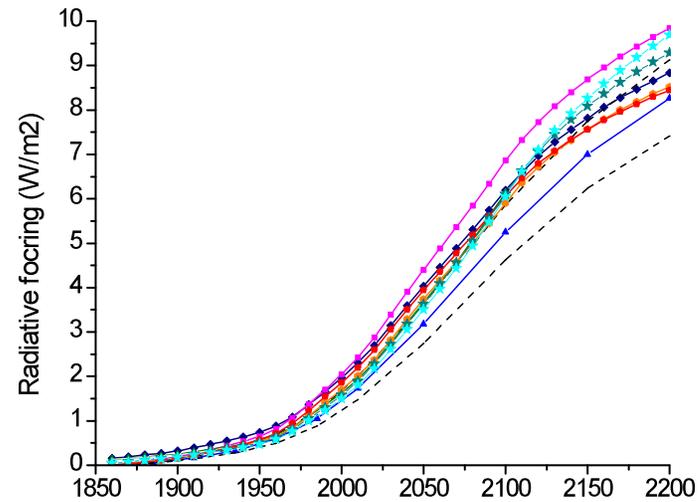
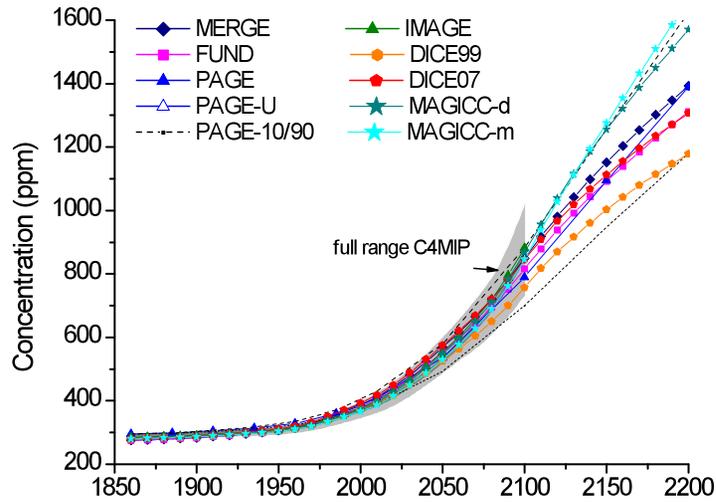
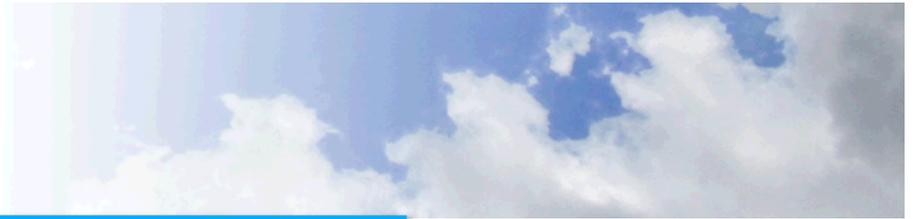


# Energy resource estimates (USGS)

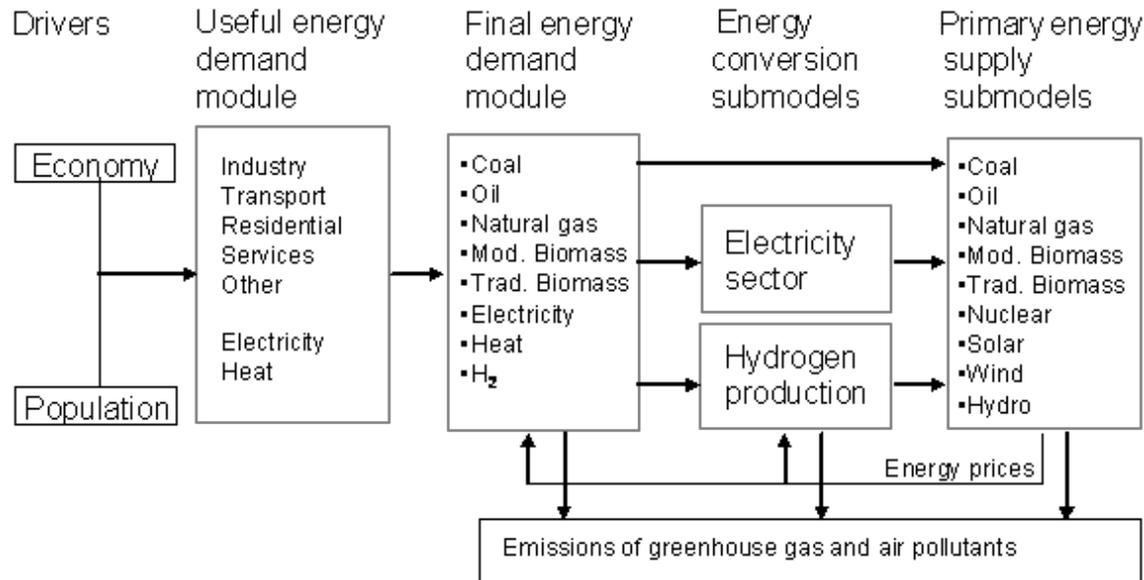
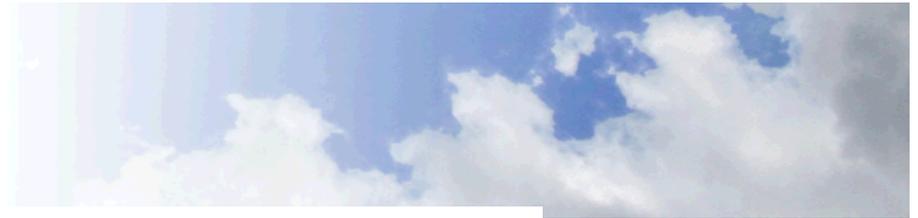


➔ **Largest uncertainty in unconventional resources**  
 Netherlands Environmental Assessment Agency

# A2 scenario



# Step 1. Select variables



## Uncertain input variables

Population	AEEI	Taxes	Tech.	Resources
GDP	PBT	Fuel pref.	Credit	Tech.
Structure	SC			Trade
	Tech.			ST-prices



# Two main scenario methods (handling uncertainty in different ways)

Probabilistic  
Scenario development

A set of storyline  
based scenarios



There is no value in providing users a set of lines that go all over the place. It is the moral task of experts to determine what are the most likely assumptions – and therefore the most likely outcomes. Scientists deal with uncertainty by indicating the most likely outcome – and an uncertainty range.

“Future emissions are the product of a large range of very uncertain factors such as population, technology, socio-economic development etc. Storylines are used to define a consistent set of assumptions. Scenarios can help exploring some of these futures; they are not predictions.”



# Two main scenario methods (handling uncertainty in different ways)

Probabilistic  
Scenario development

A set of storyline  
based scenarios



Decision-makers need to address risks. Risks are determined by impacts AND probability. For instance, information that an asteroid can destroy the earth can only be properly assessed, if one knows that changes are 1 in a billion.

“The probabilistic approach only attempts to assign subjective probabilities in a situation of ignorance forms a dismissal of uncertainty in favor of spuriously constructed expert opinion”.

