Understanding the Social Cost of Carbon: A Technical Assessment

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The Social Cost of Carbon (SCC)

$37 per metric ton of CO_2

U.S. Government's "central" SCC estimate of the global societal damages from a metric ton of today's CO_2 emissions

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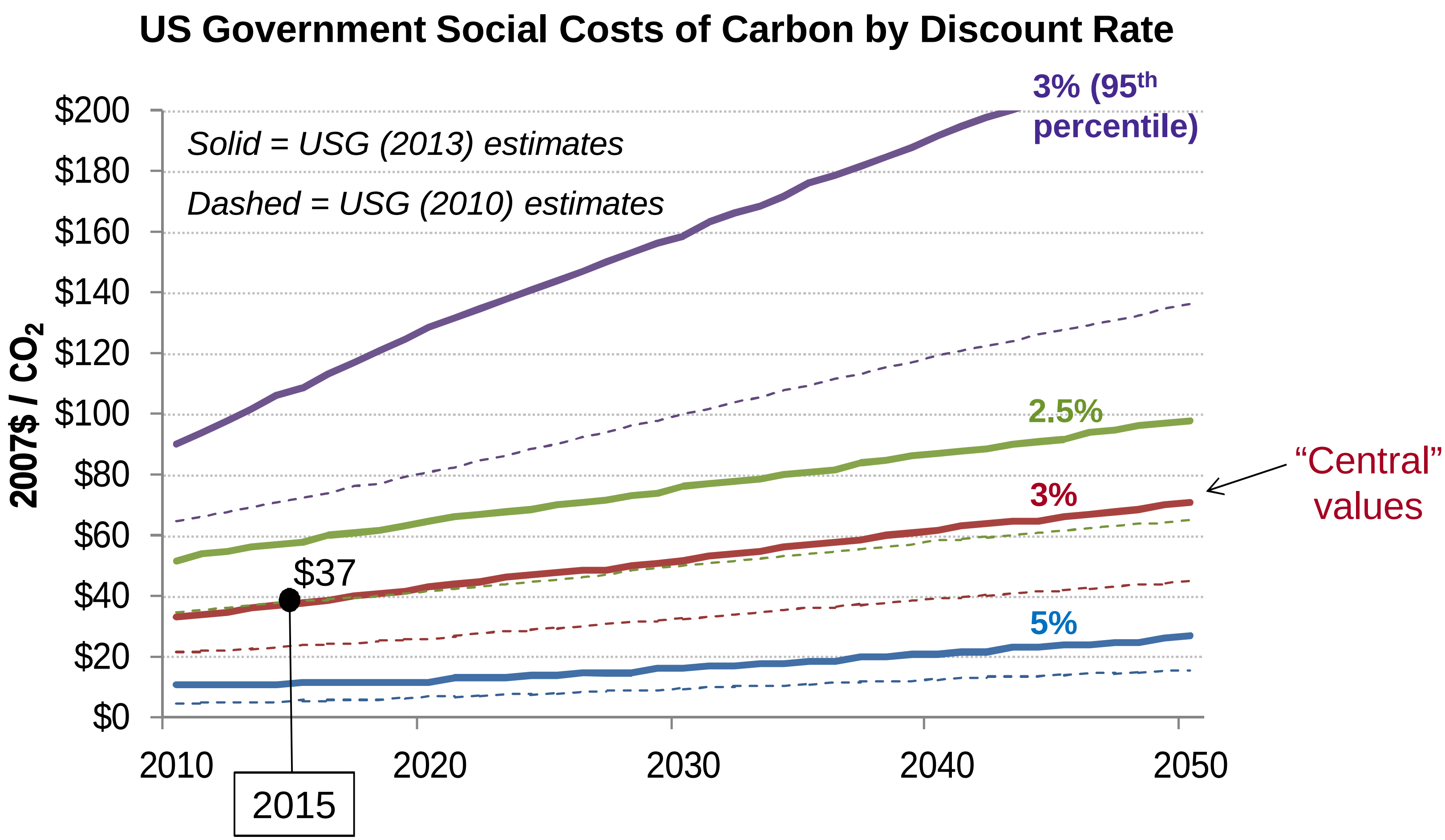
US Government SCC Values



Source: Developed from USG (2010) and USG (2013)

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Why Should We Care?

- SCC is an estimate of the damages to society from CO_2
- SCC is in use broadly in USG rulemakings (going back to 2008) – states and others using as well
- For foreseeable future, CO_2 (all GHGs) will be regulated under the Clean Air Act and efficiency policies
- USG legally obligated to value CO_2 (9th Circuit)
- USG SCC values recently updated in 2013 (significantly higher)
  - Revised SCC estimates attracting a great deal of attention
  - Variety of issues being raised – legal, process, & technical
- Two key technical challenges
  - **Robustness** – establishing confidence in SCC estimates
  - **Application** – using estimates properly
- General lack of technical information and understanding

The Social Cost of Carbon (SCC)

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U.S. Government's "central" SCC estimate of the global societal damages from a metric ton of today's CO_2 emissions

What does this mean?

Trying to Better Understand the SCC

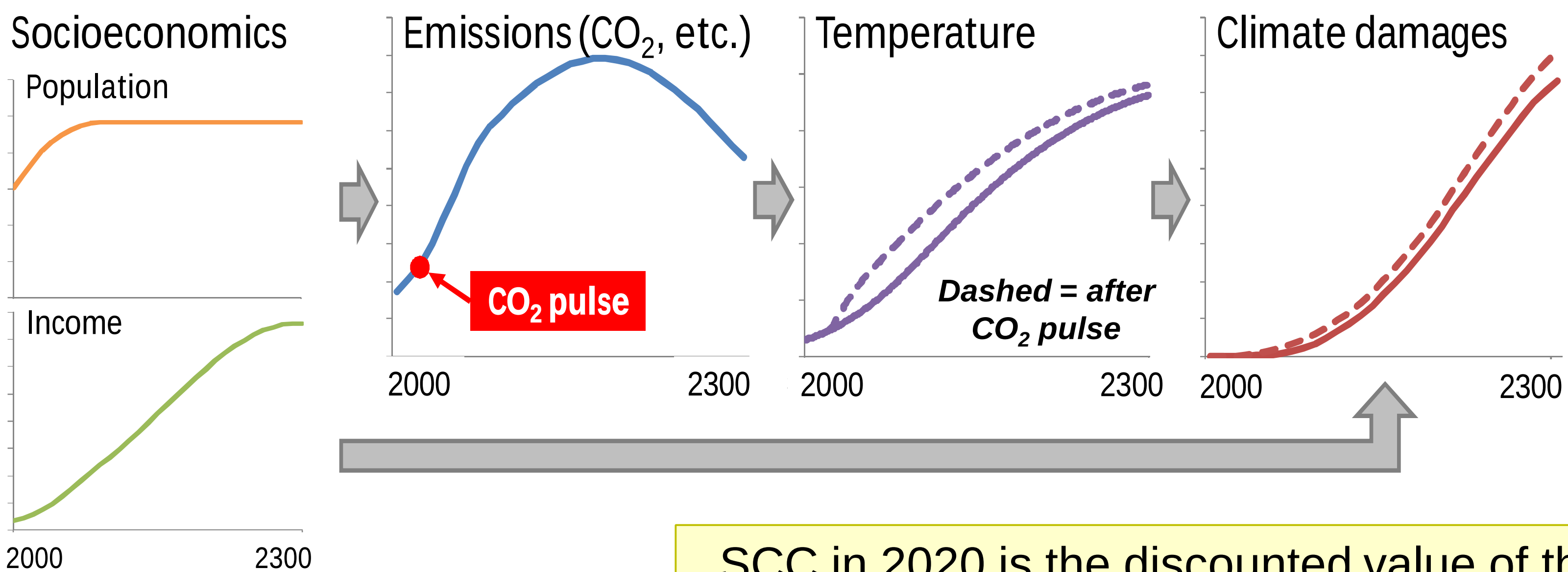
- Currently difficult to interpret and evaluate the SCCs

- EPRI has undertaken an initiative aimed at better understanding and advancing methods
  - Developing detailed understanding of modeling
  - Evaluating alternatives

Team: Steven Rose, Delavane Turner, Geoffrey Blanford, John Bistline, Francisco de la Chesnaye, Tom Wilson

The Social Cost of Carbon (SCC)

Definition: The net present value of global climate change impacts from one additional net global tonne of carbon dioxide emitted to the atmosphere at a particular point in time



SCC in 2020 is the discounted value of the additional impacts from the marginal emissions increase in 2020

Types of Impacts Being Monetized

- Health
- Agriculture
- Forestry
- Sea level
- Water resources
- Energy consumption (space cooling & heating)
- Migration
- Hurricanes
- Ecosystems
- Catastrophic

Based on sector specific impacts studies in the literature



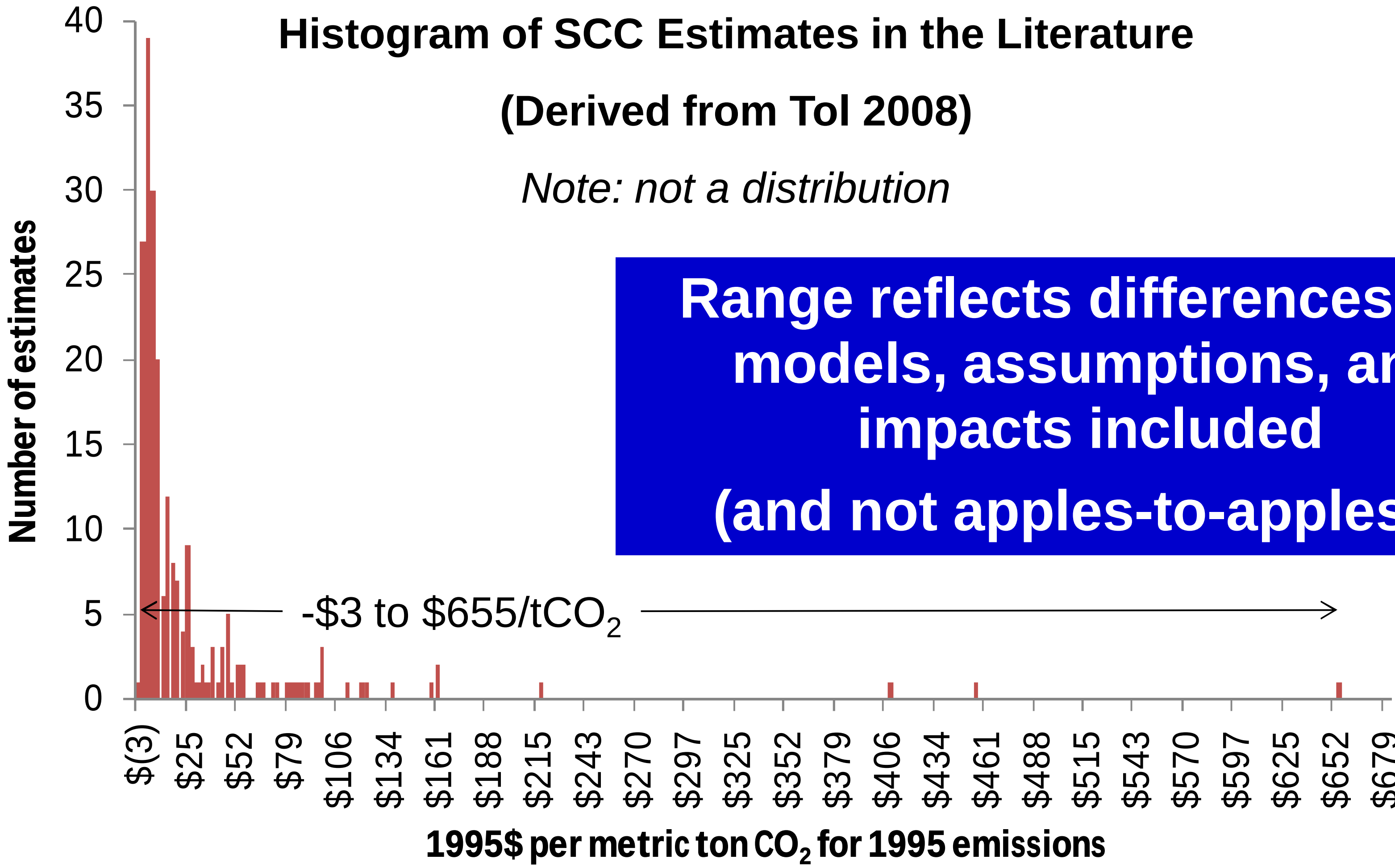






Impact types included and formulations vary by model

Vast Range of SCC Estimates Have Been Produced

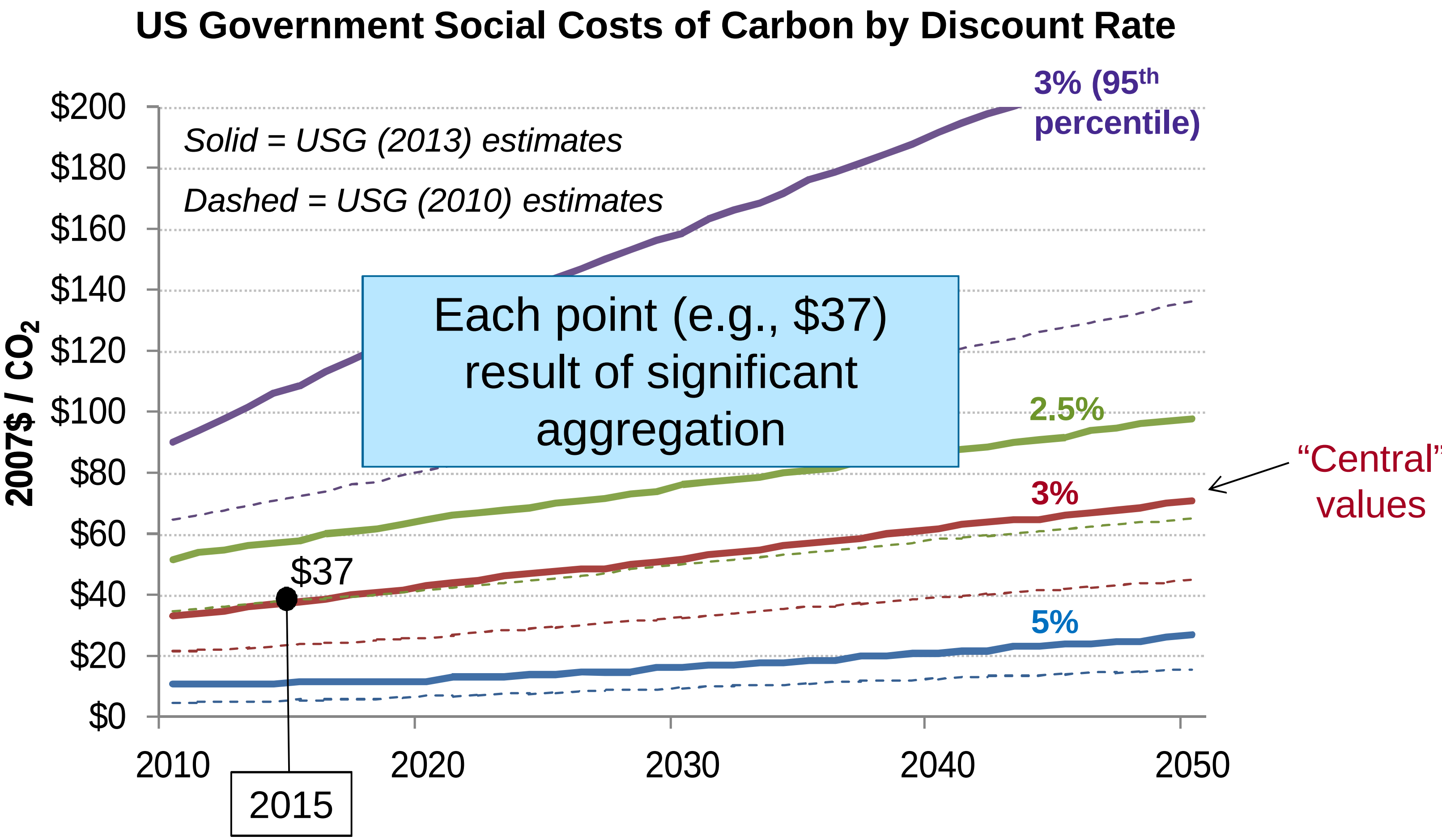


Range reflects differences in models, assumptions, and impacts included

(and not apples-to-apples)

Developed from Tol (2008) meta analysis of SCC estimates

US Government SCC Values



Source: Developed from USG (2010) and USG (2013)

USG SCC Approach

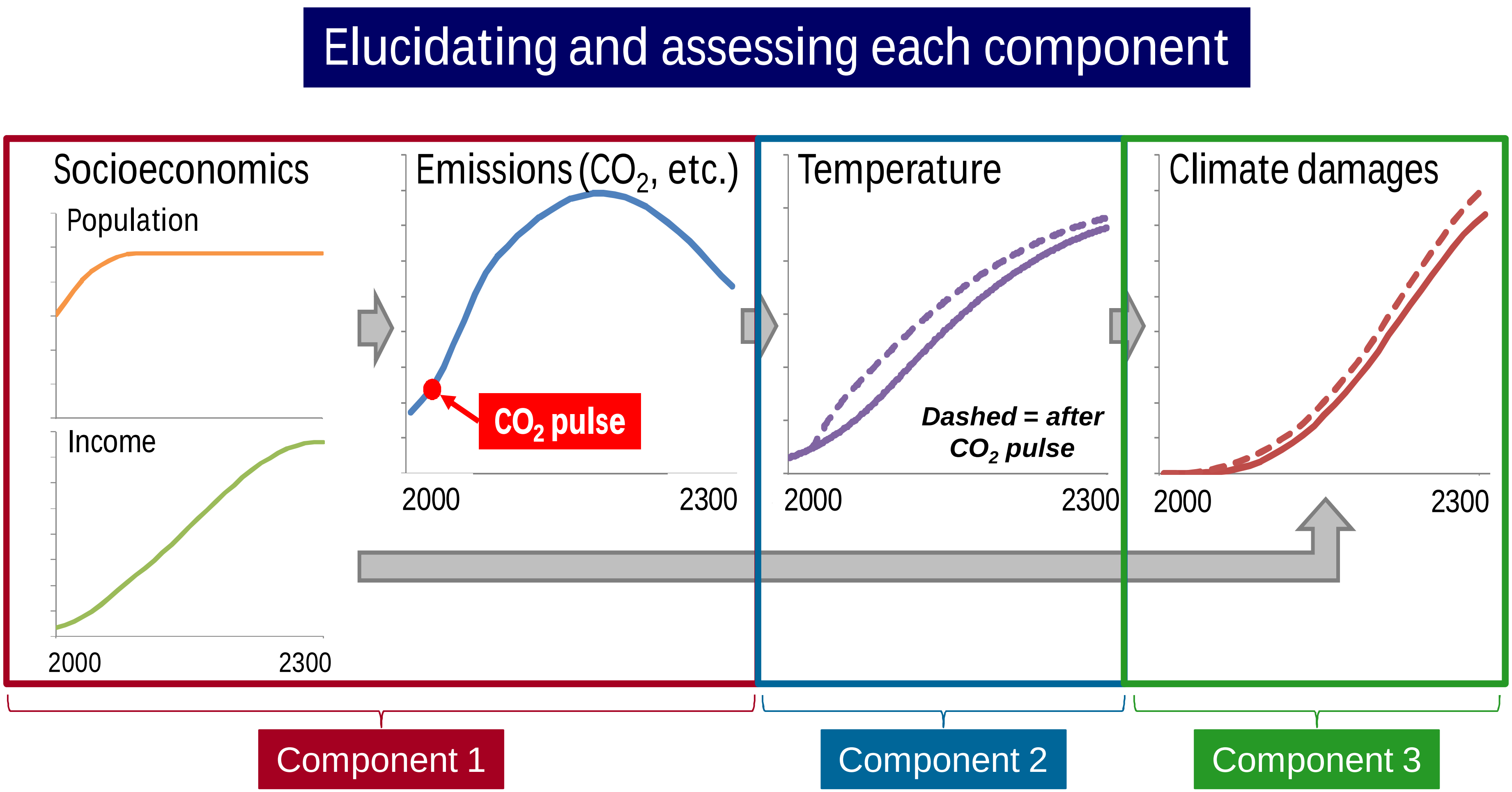
Feature	Detail
Multiple SCC models	3 models – DICE, FUND, PAGE
Standardized uncertainties	- 5 reference socioeconomic and emissions scenarios (each extended from 2100 to 2300) - 1 distribution for the climate sensitivity parameter
Model specific parametric uncertainties	In FUND and PAGE climate and damage components
Standardized discounting	3 constant discount rates – 2.5%, 3%, and 5%
Thousands of SCC results	150,000 SCC estimates for a given discount rate and year (3 models x 5 socioeconomic scenarios x 10,000 runs each)
Aggregation of results	- Average of 150,000 results for each discount rate and year - "3% (95th percentile)" value is 95th percentile from distribution of 150,000 results with 3% discounting

- ➢ USG estimates are the result of significant aggregation – over time, world regions, impact categories, many scenarios, & models.
- ➢ Making sense of the estimates requires delving into these details.

Our Study's Assessment Approach

- Examine the **inner workings** of the models to elucidate the key drivers and assess the main elements
- Specifically, learn about and **assess the raw modeling and results** – i.e., undiscounted and disaggregated to underlying facets
- **4 separate technical assessments**
  - 3 assessments of modeling causal chain components
    - *Reviewing modeling, programming component, running diagnostics, comparing*
    - *Exploring many perspectives*
  - 1 overall assessment of the USG experimental design

Technical Assessment by Causal Component



Study Objective

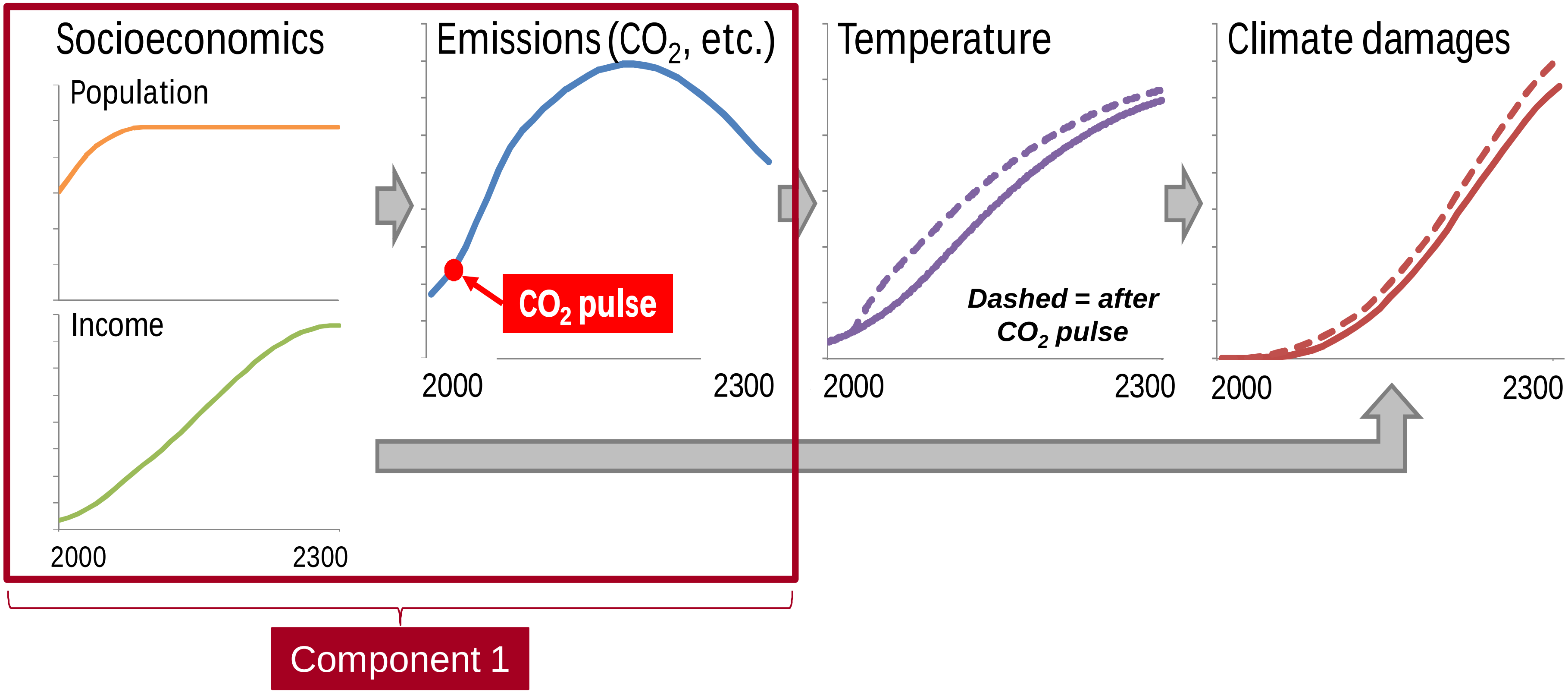
- Improved understanding of SCC modeling and estimates that informs public discussion, future SCC modeling and application, and future climate research

Key Questions

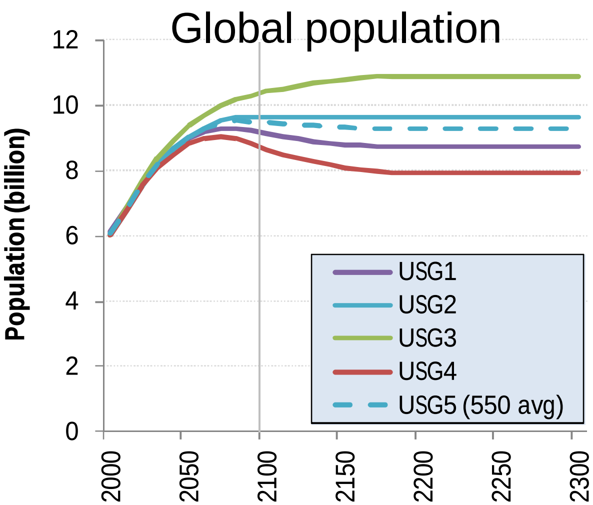
- How do the models behave, and are they different?
- What drives differences?
- Are differences useful information?
- Are there alternative uncertainties to consider?
- Are there additional uncertainties to consider?
- Are the estimates robust (insensitive to alternatives)?
- Are there opportunities to improve the overall USG SCC approach?

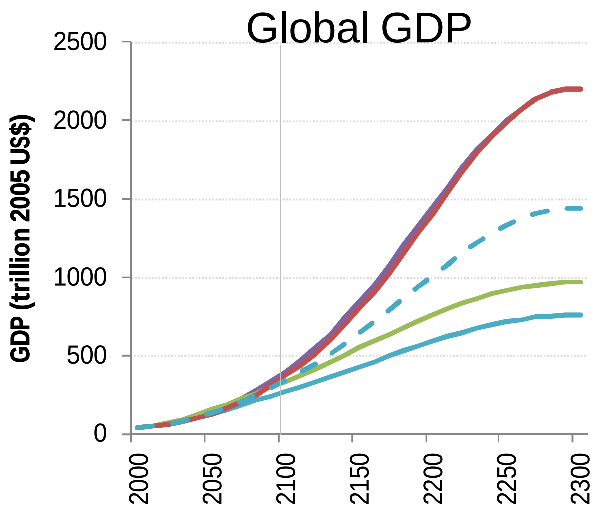
Socioeconomics & Emissions Component Assessment

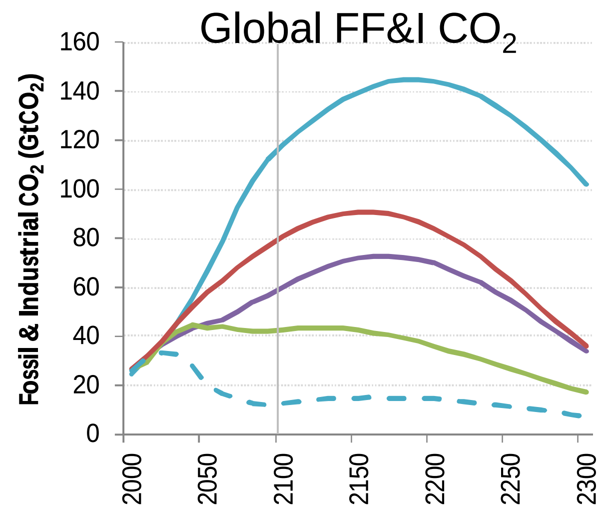
Elucidating and assessing each component

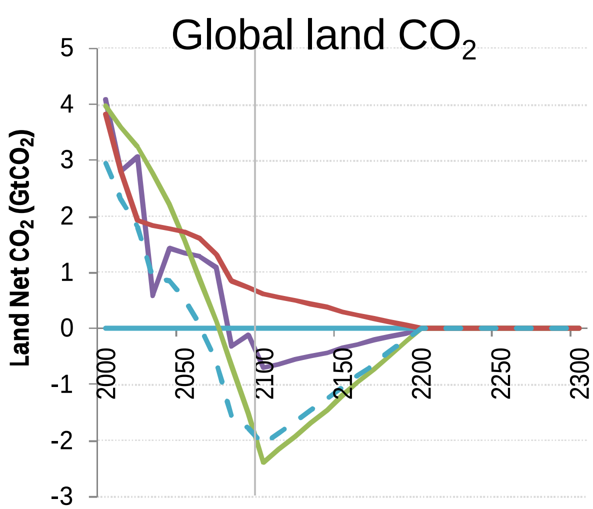


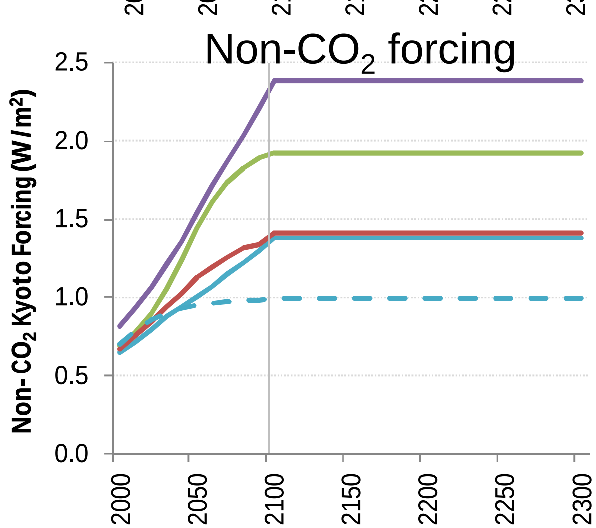
USG's Standardized Socioeconomic & Emissions Inputs into SCC Models











We observe inconsistencies in implementation across models

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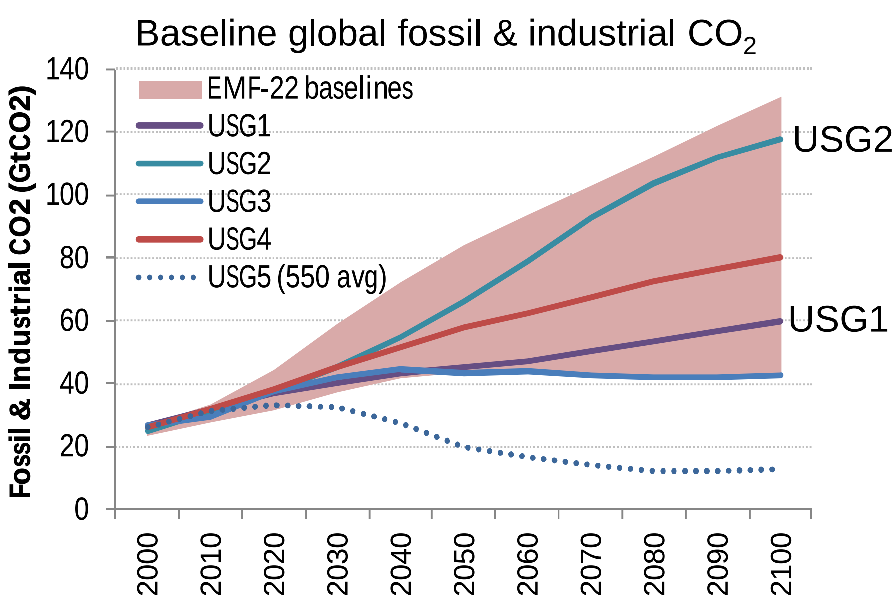
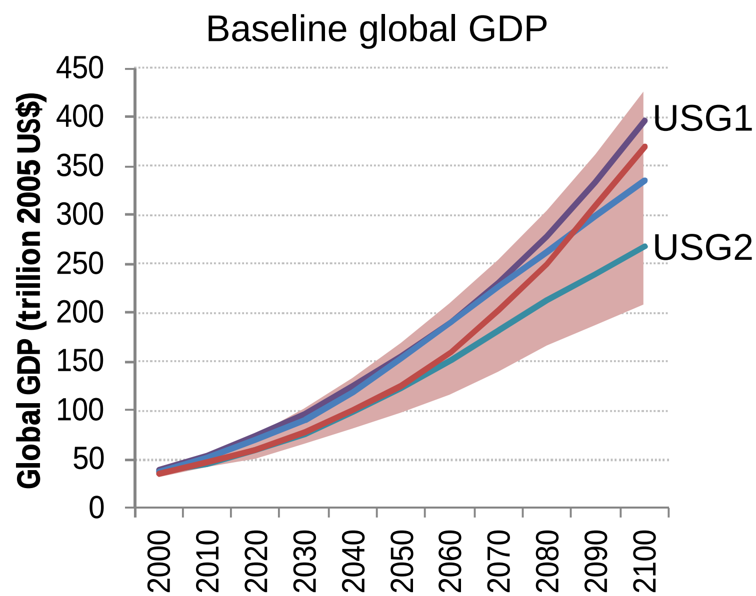
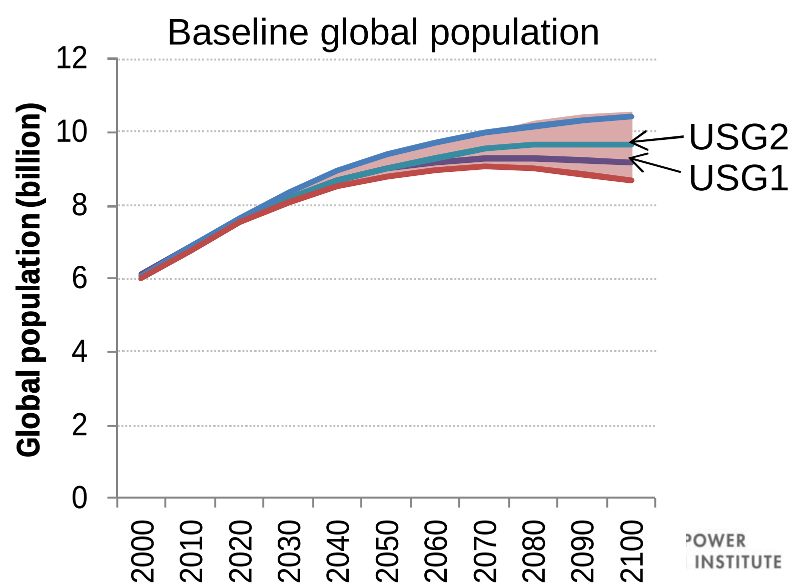
Socioeconomic and Emissions Uncertainty







<u>Very different socioeconomic structures</u>

USG1 ➔ low emissions from high econ growth

USG2 ➔ high emissions from low econ growth

Uncertainty in socioeconomic structure not considered

Is Socioeconomic Structure Important?

- Defines the relationship between society & emissions
- Implications for <u>both climate AND damage results</u>
  - Socioe structure ➔ Emissions ➔ Climate change
  - Socioe structure ➔ Societal size & composition ➔ climate vulnerability & adaptation

Drivers of climate damages in the models

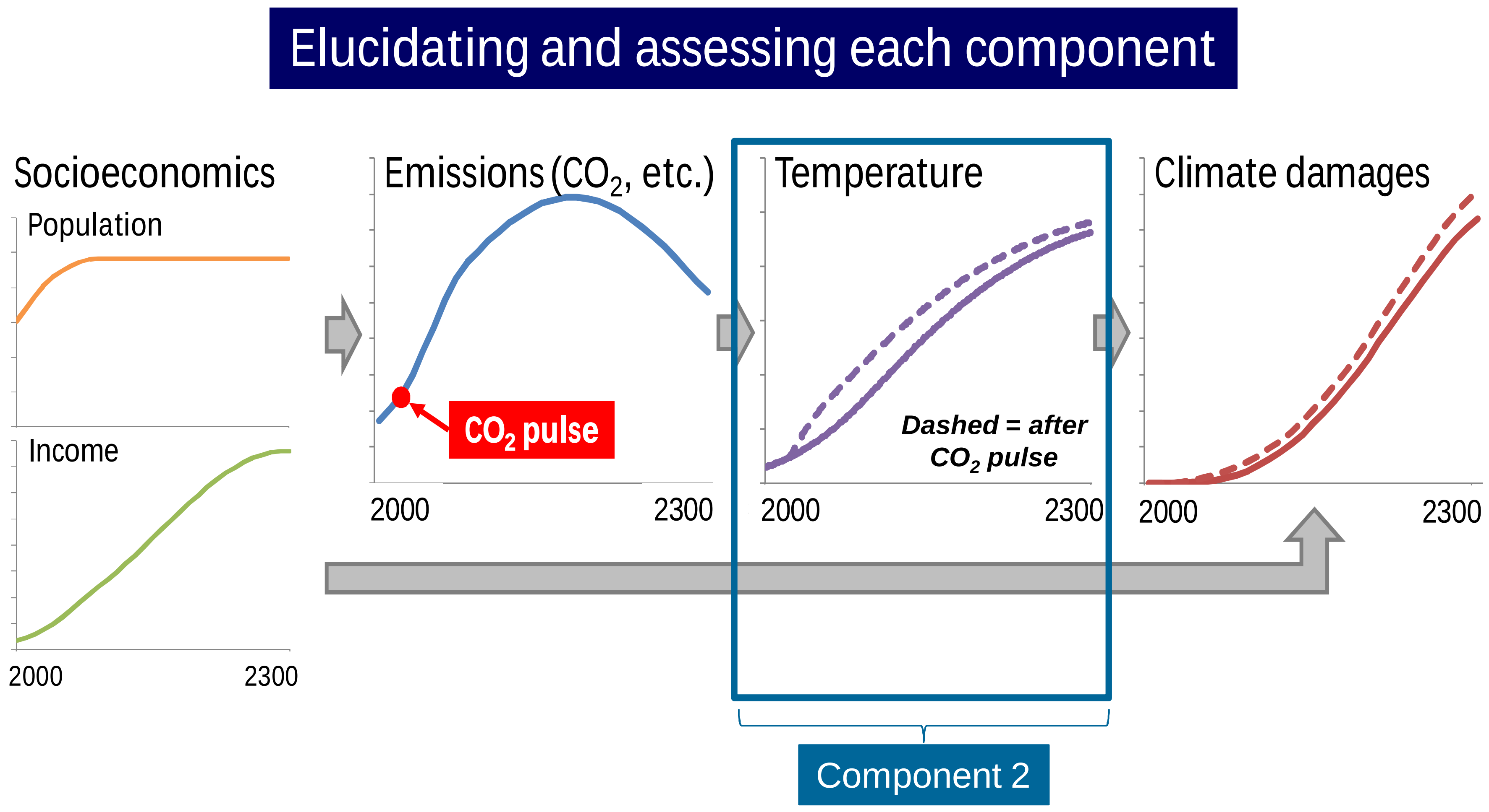
	Temp	CO_2 Conc	Total Income	Per Capita Income	Pop Size/Comp	Other
DICE	X		X			
FUND	X	X	X	X	X	X
PAGE	X		X	X		

Sensitivity of damages explicitly evaluated in damage component assessment

Socioeconomic/Emissions Component Assessment Key Observations

- Inconsistencies to address
  - Implementation of standardized socioe/emissions inputs
  - Socioe/emissions extensions to 2300
- Additional uncertainties to consider
  - Range of socioe/emissions, socioe structure, 2300 extensions
- Some futures not equally likely and shouldn't be weighted as such
- Average "policy" socioeconomic & emissions scenario is problematic

Climate Modeling Component Assessment



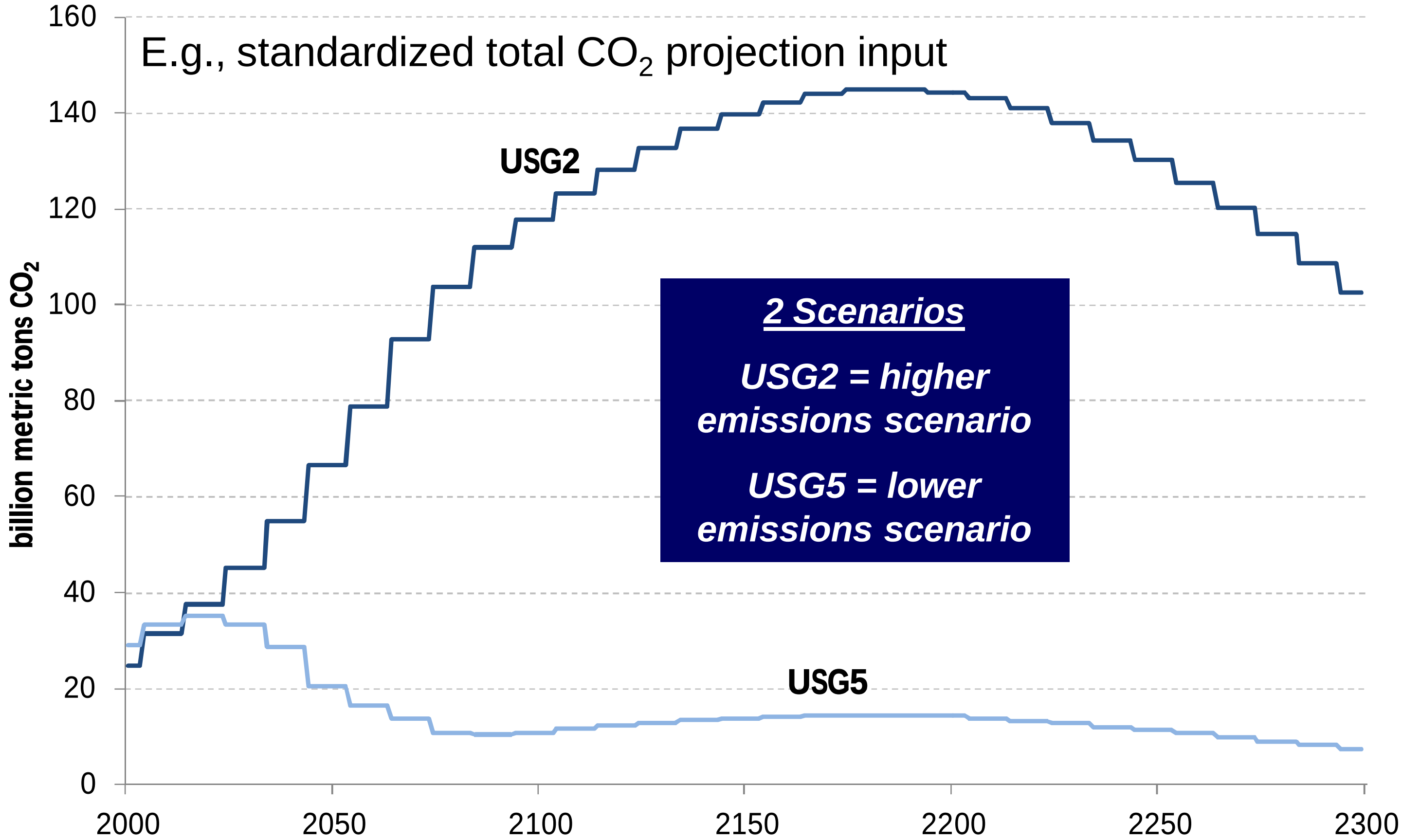
Climate Modeling Structure

- Structural differences across the three models in all characteristics
- Different model specific parametric uncertainties considered across models

Climate Modeling Structural Characteristics	
Atmospheric concentrations	
	CO_2
	Non-CO_2 Kyoto
	Non-CO_2 non-Kyoto
Radiative forcing	
	CO_2
	Non-CO_2 Kyoto
	Non-CO_2 non-Kyoto
Global mean temperature	
Regional temperatures	
Climate feedback	
Time steps	

We Isolate the Component & Run Diagnostics

Diagnostic Scenarios: We standardize the set of emissions & radiative forcing inputs (CO_2 & non-CO_2) and run deterministic and probabilistic scenarios



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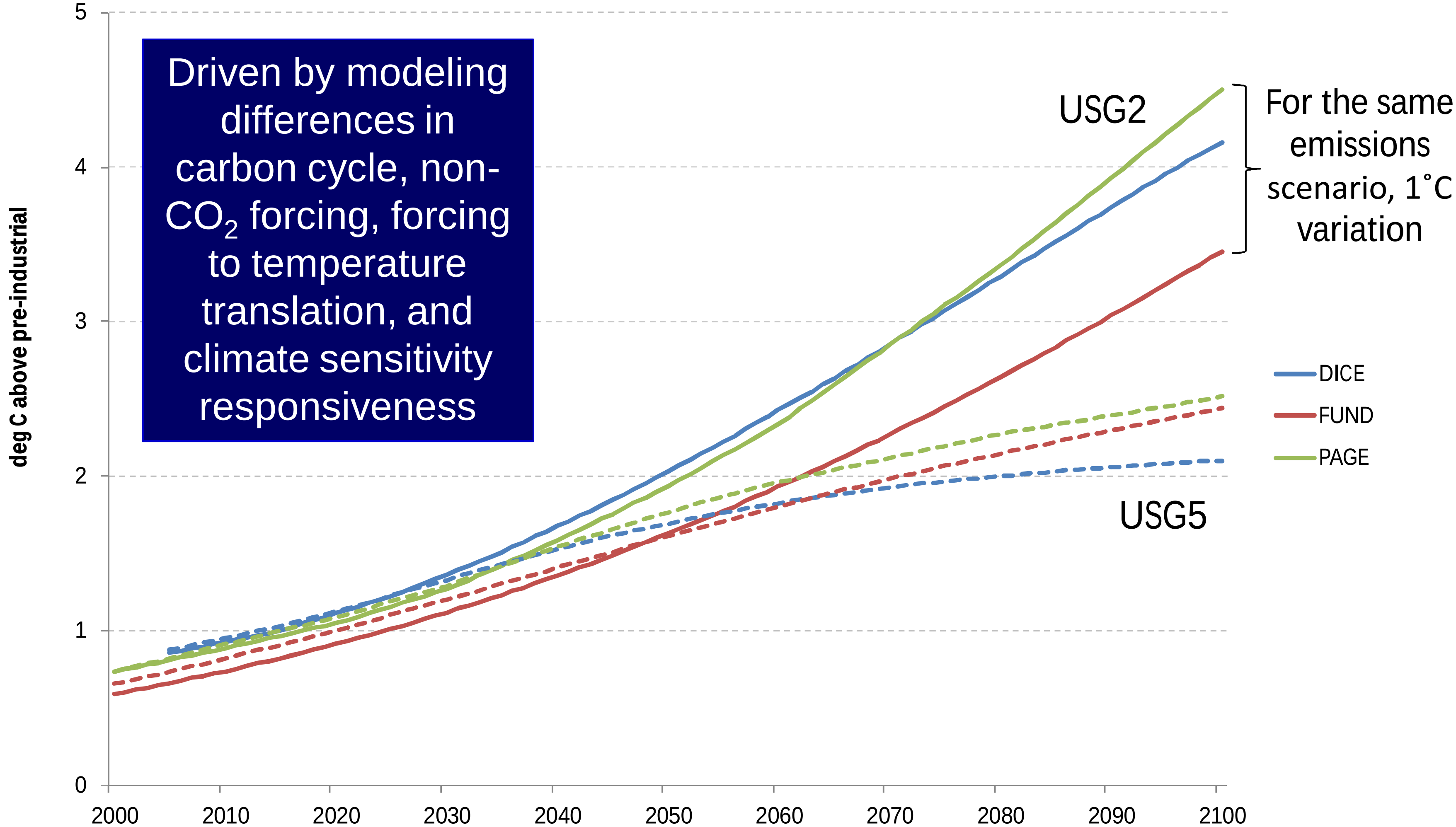
Projected Global Temperatures



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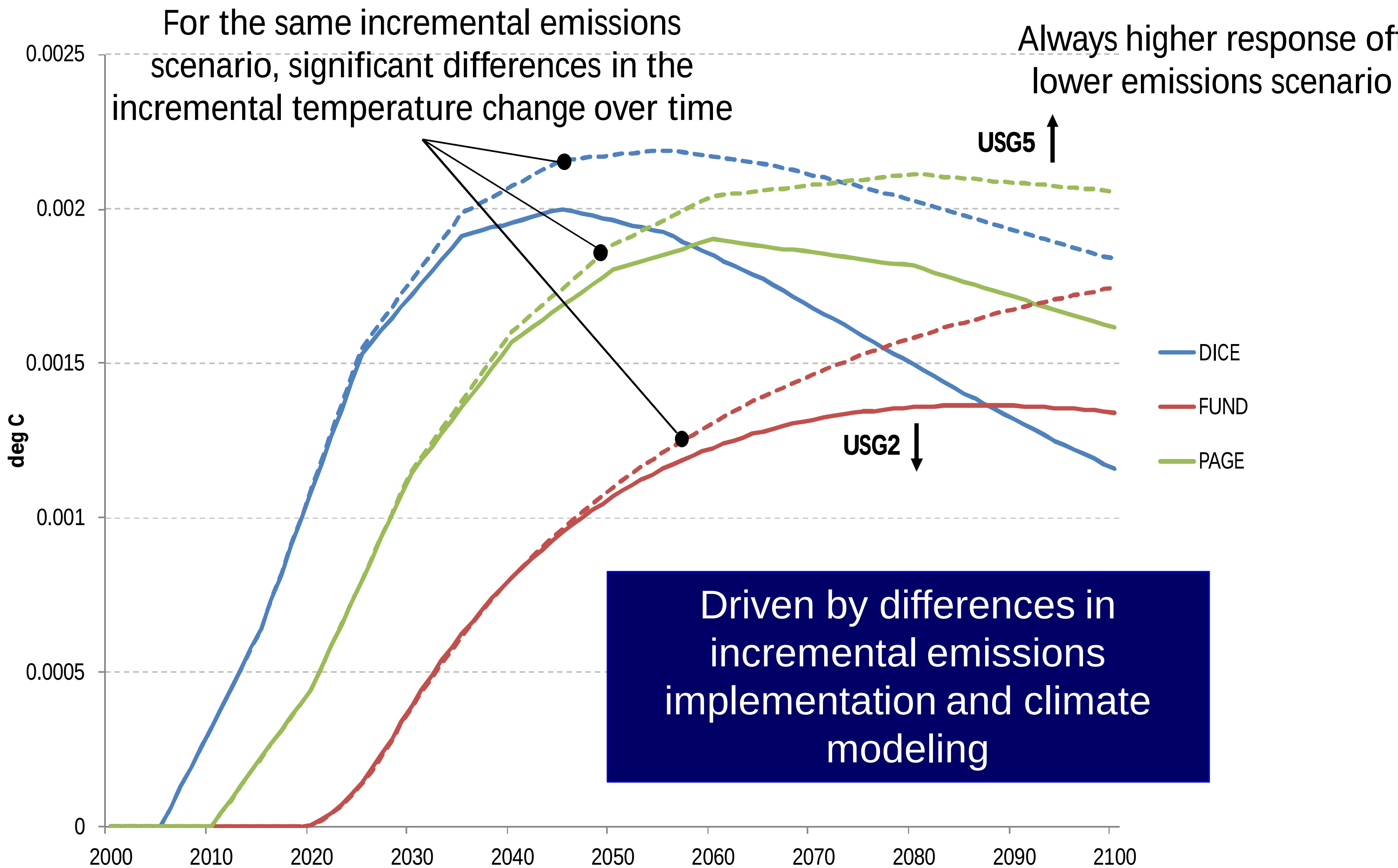
Projected Incremental Temperatures
(for a 1 billion tC pulse in 2020)



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Sensitivity of Climate Responses

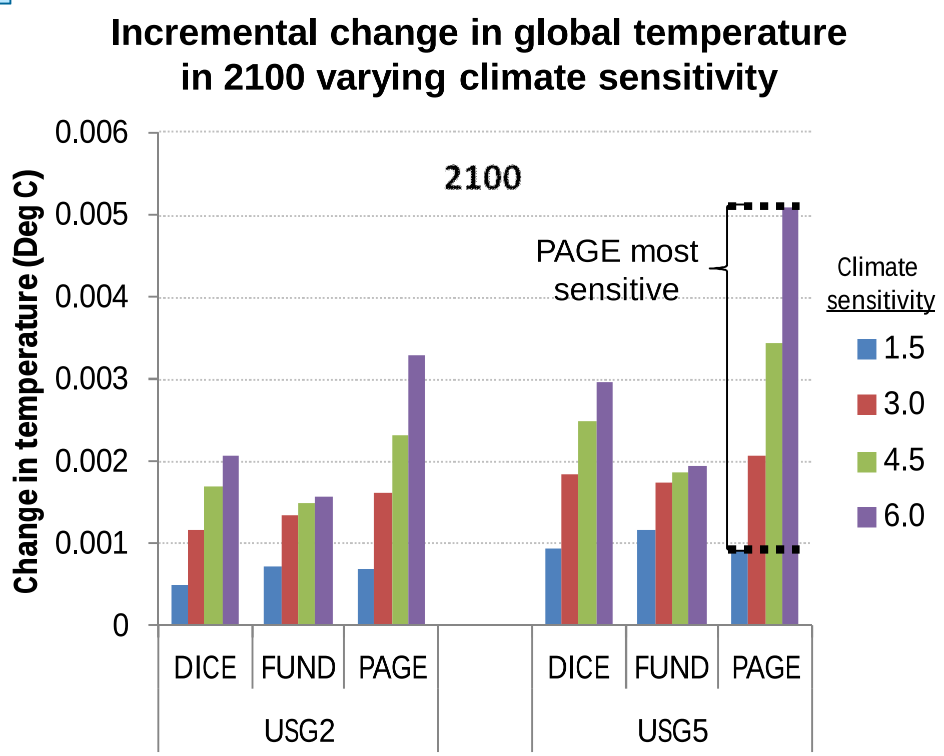
The climate models are not equally sensitive to alternative assumptions

Temperature to emissions

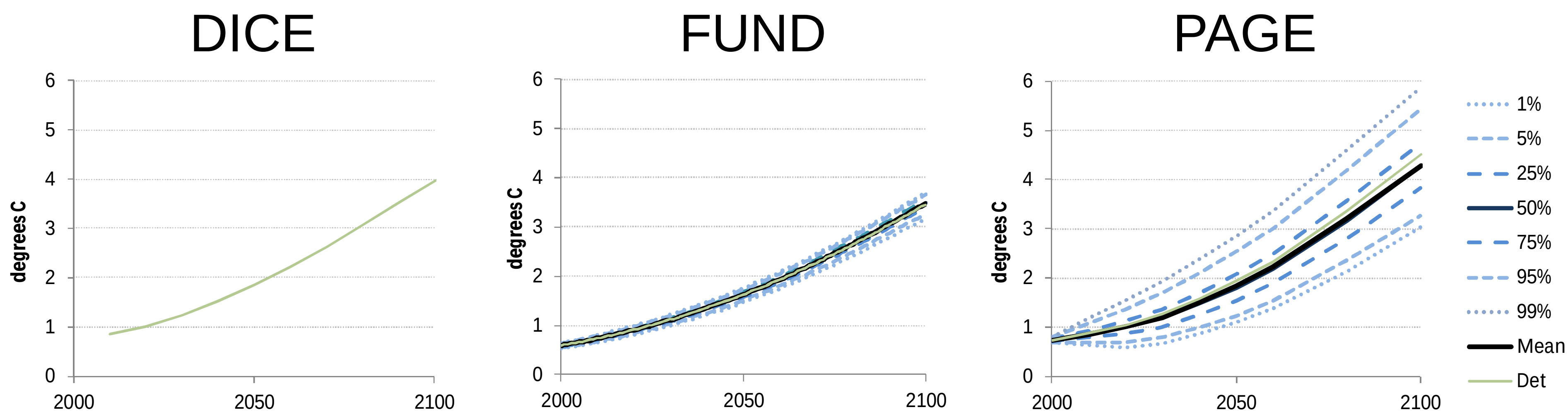
Most – DICE, Least - FUND

Temperature to climate sensitivity

Most – PAGE, Least – FUND

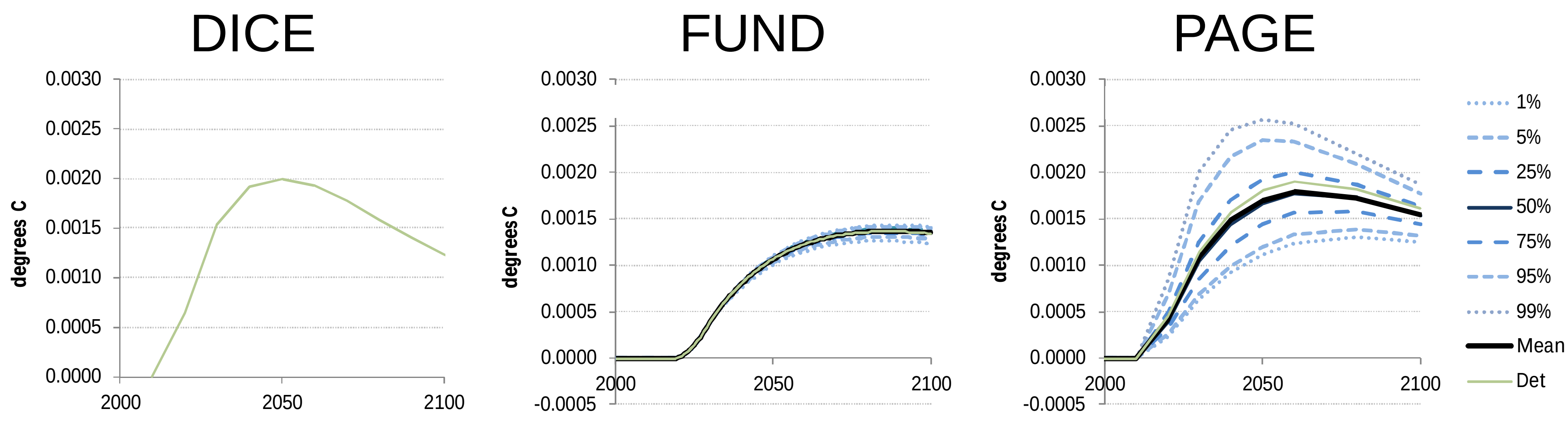


Model Specific Uncertainty – Temperature
(e.g., USG2 with climate sensitivity 3˚C)



Models considering significantly different uncertainty – PAGE substantially more

Model Specific Uncertainty – Incremental Temp
(e.g., USG2 with climate sensitivity 3 degC)



Models considering significantly different uncertainty – PAGE substantially more

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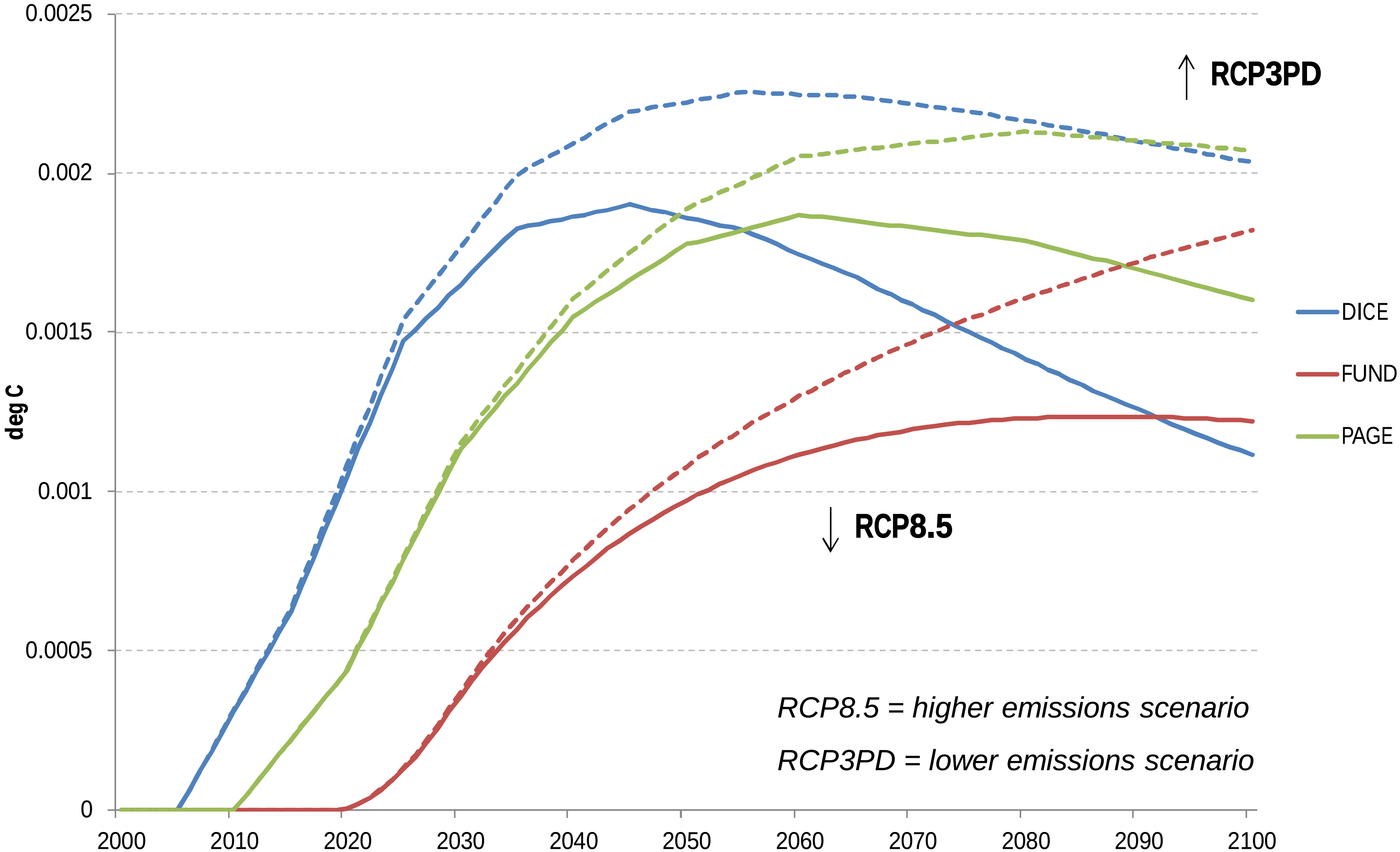
USG vs Other Modeling – Incremental Temp
(for a 1 billion tC pulse in 2020)



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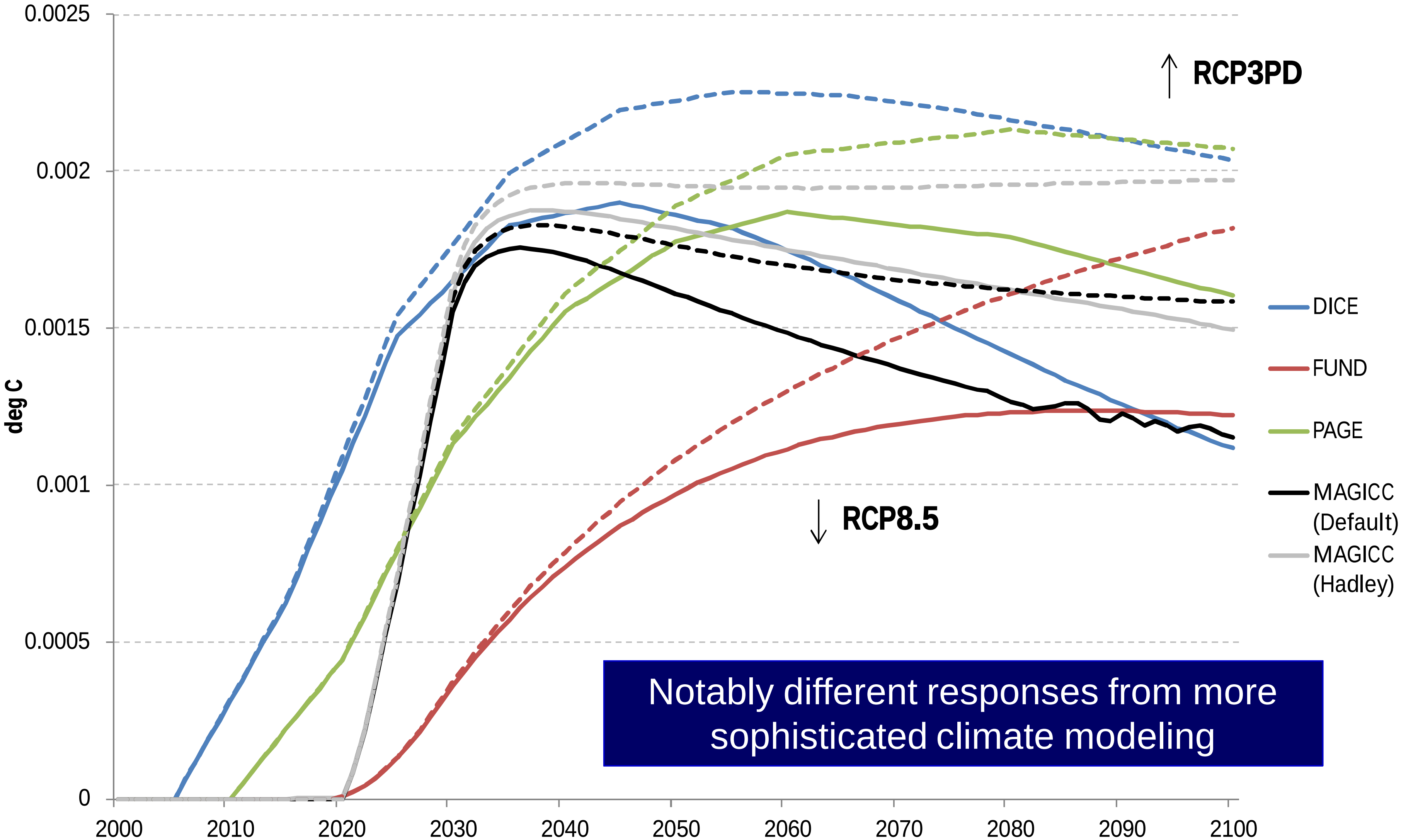
USG vs Other Modeling – Incremental Temp
(for a 1 billion tC pulse in 2020)



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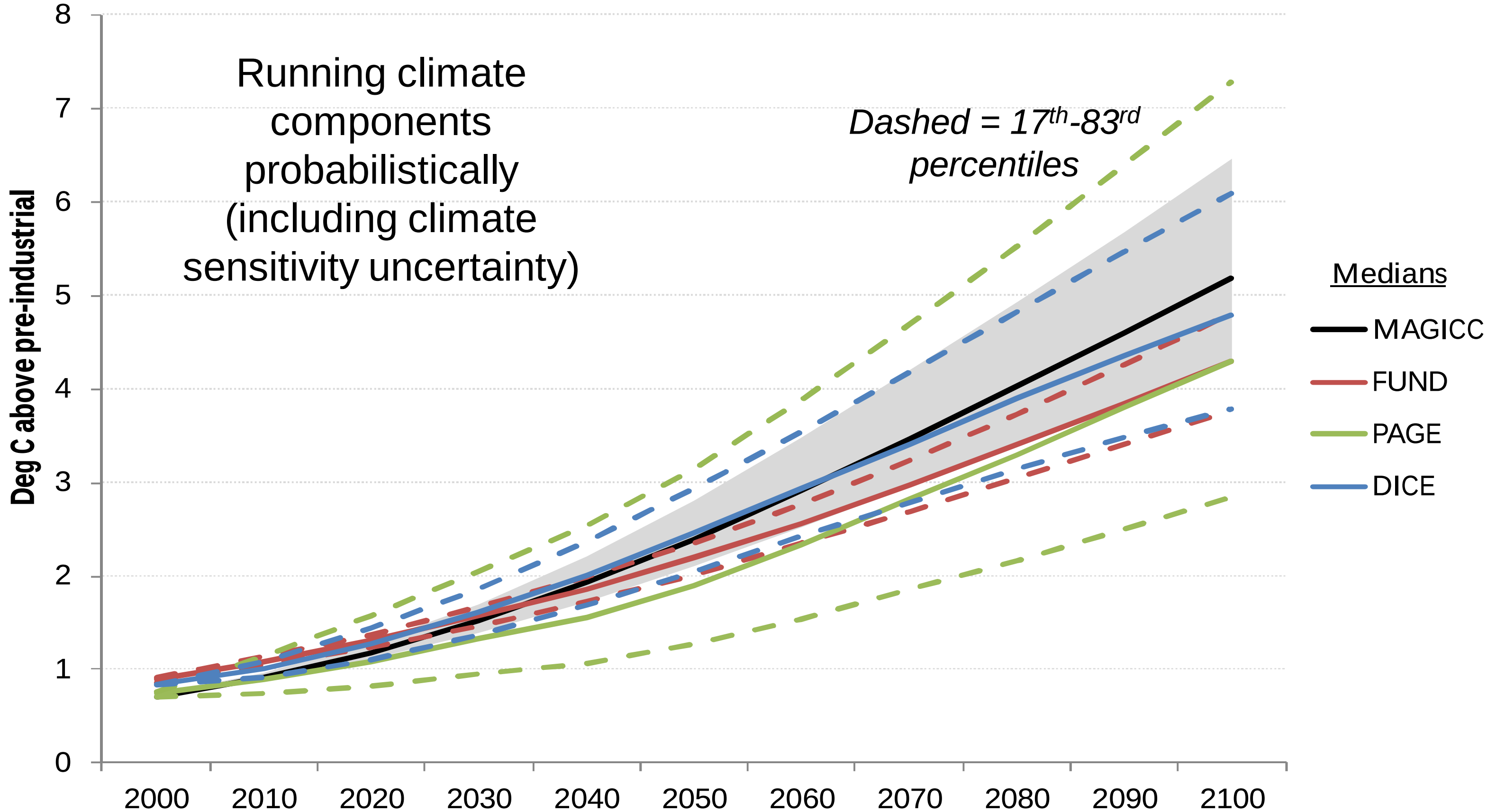
USG vs Other Modeling – Temp Uncertainty
(e.g., RCP8.5)



Notably different probabilistic result from more sophisticated climate & probabilistic modeling

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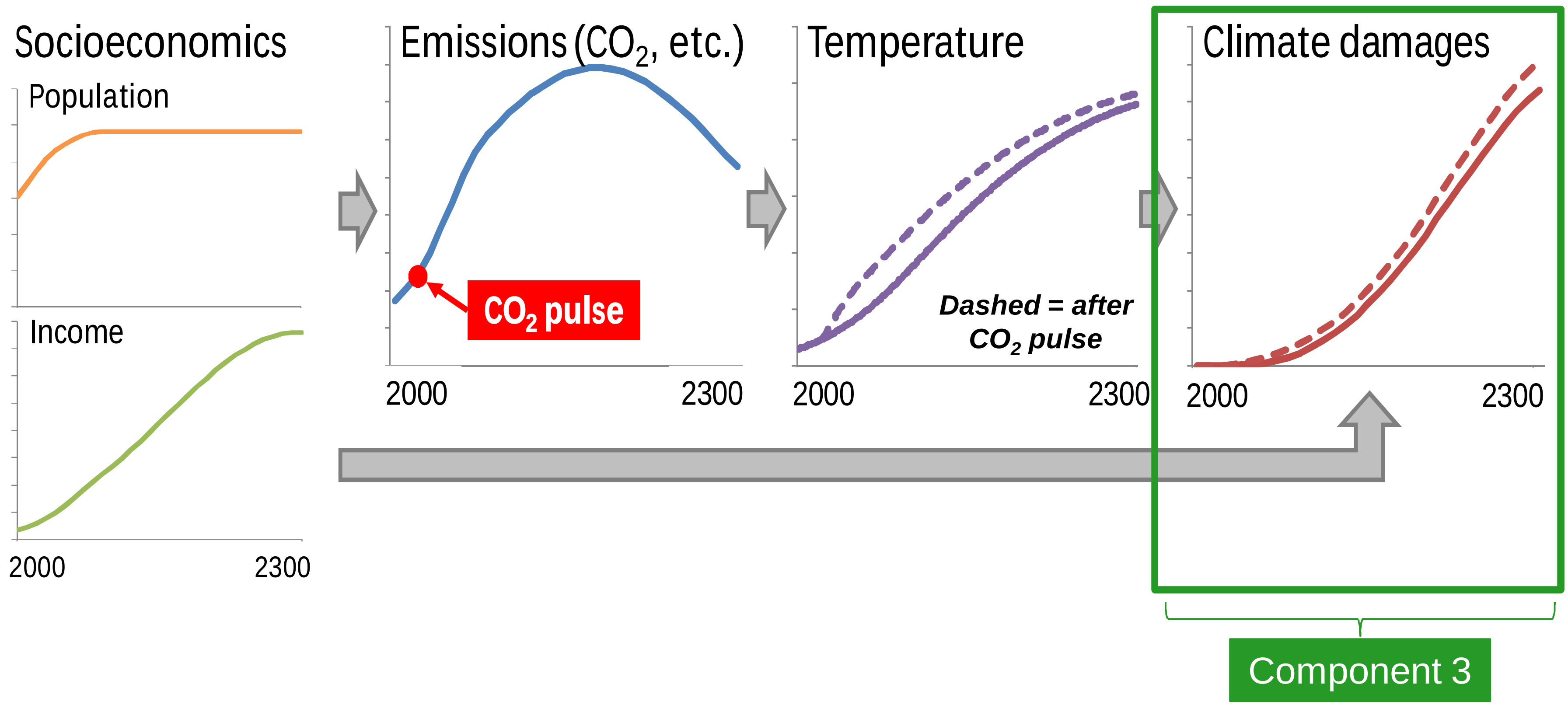
Climate Component Assessment Key Observations

- Significant differences in climate responses across models (to 2100 and 2300, in total and incremental climate)
- Important climate component structural differences
- Implementation inconsistencies affecting results
- Models representing & sampling different uncertainty spaces
- Alternative climate modeling produces different results
- Additional uncertainties to consider
  - Alternative climate modeling, alternative parametric uncertainty, alternative climate sensitivity distribution assumption

Climate Damages Component Assessment

Elucidating and assessing each component



Damage Modeling Structure

Structural differences across models

Different model specific parametric uncertainties

	DICE	FUND	PAGE
Regions	**1 global region**	**16 regions**	**8 regions**
Sectors	**2 sectors** Sea Level Rise, Aggregate non-SLR	**14 sectors** Sea Level Rise, Agriculture, Forests, Heating, Cooling, Water Resources, Tropical Storms, Extratropical Storms, Biodiversity, Cardiovascular Respiratory, Vector Borne Diseases, Morbidity, Diarrhea, Migration	**4 sectors** Sea Level Rise, Economic, Non-economic, Discontinuity
Damage drivers	Temperature, total income	Temperature (global & regional), CO_2 conc, ocean temp, population (size, composition), income (total, per capita), technological change	Regional temperature, income (total, per capita), regional damages scaled off EU
Damage specifications	Quadratic functions	Various functional forms	Power functions
Adaptation	Implicit (within calibrated net responses)	Mostly implicit, explicit for agriculture & SLR, increased resiliency with per capita income	Exogenous adaptation policy

We Isolate the Component & Run Diagnostics

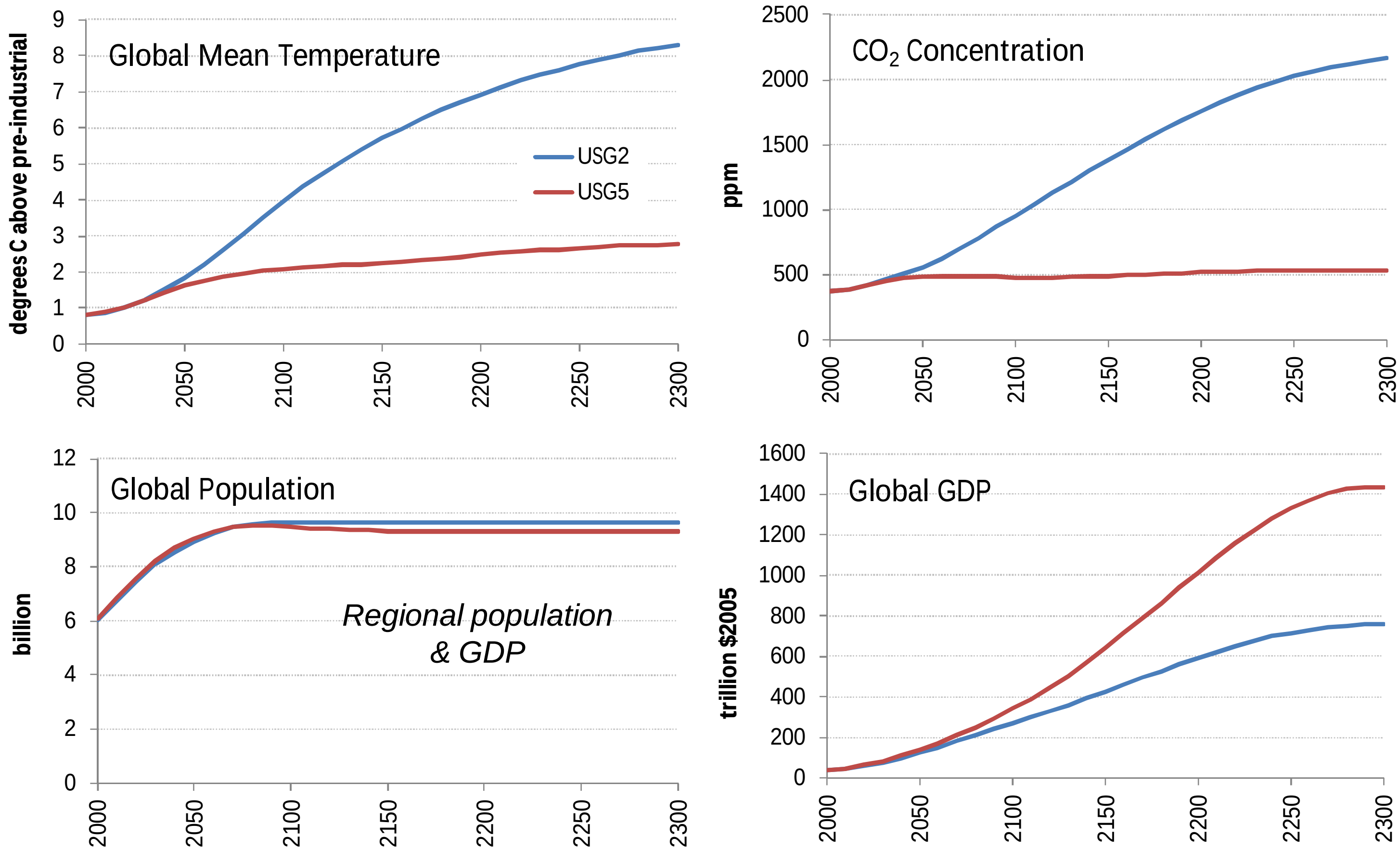
<u>Diagnostic Scenarios</u>: We standardize climate & socioeconomic inputs and run deterministic and probabilistic scenarios

<u>2 Scenarios</u>

USG2 = higher temp scenario (~4 deg C by 2100)

USG5 = lower temp scenario (~2 deg C by 2100)

Standardized input projections



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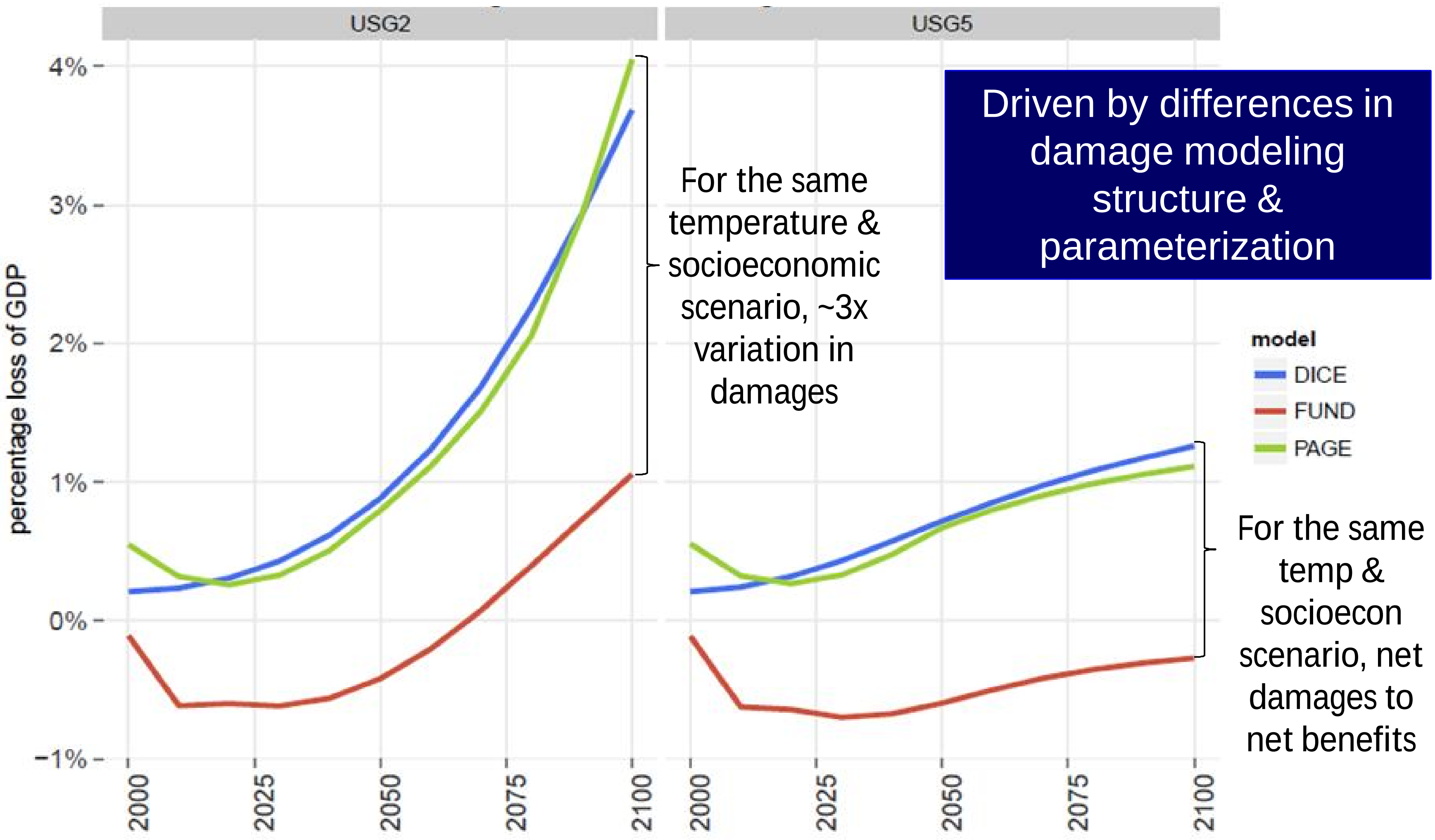
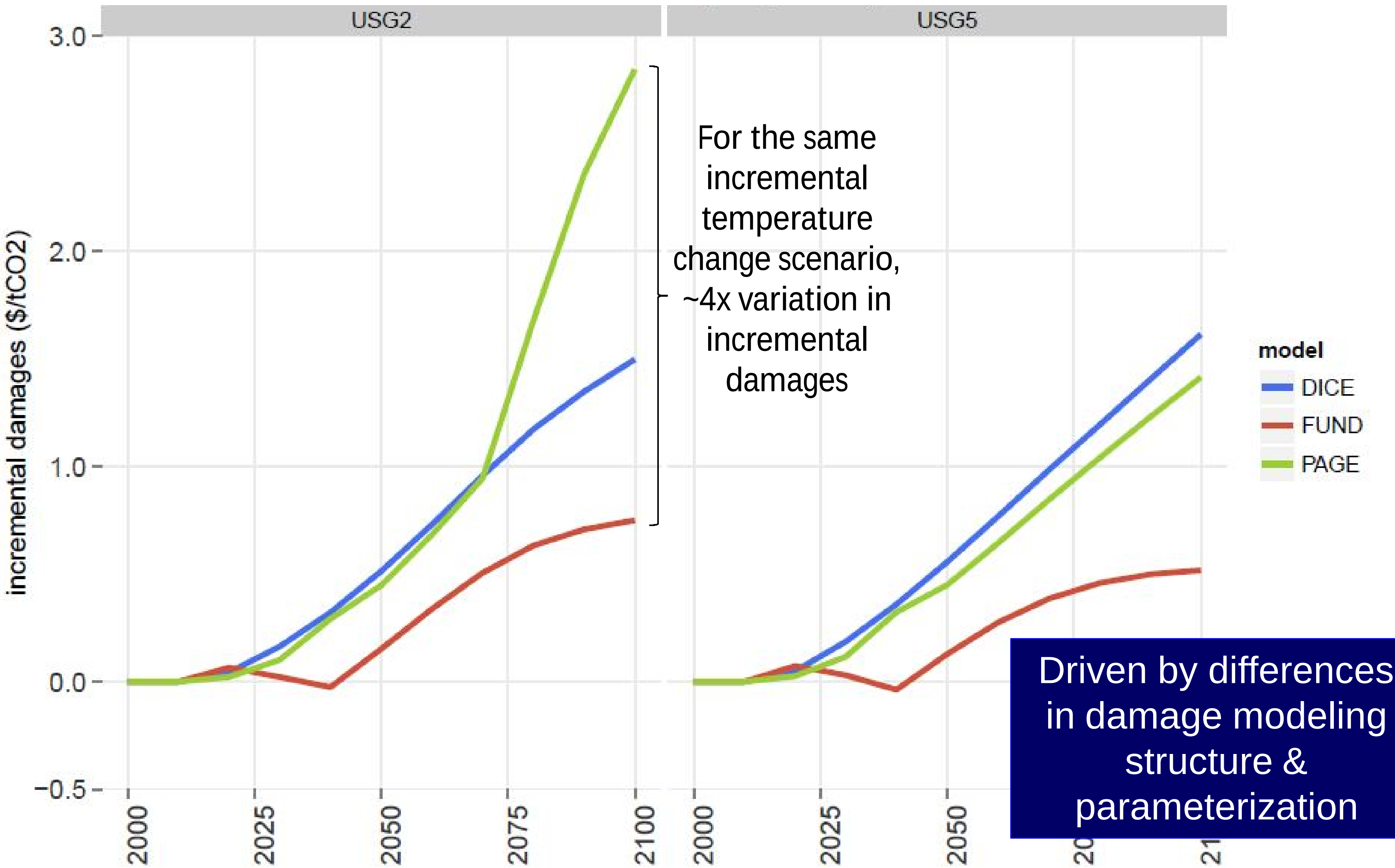
Projected Total Global Damages



Projected Incremental Global Damages

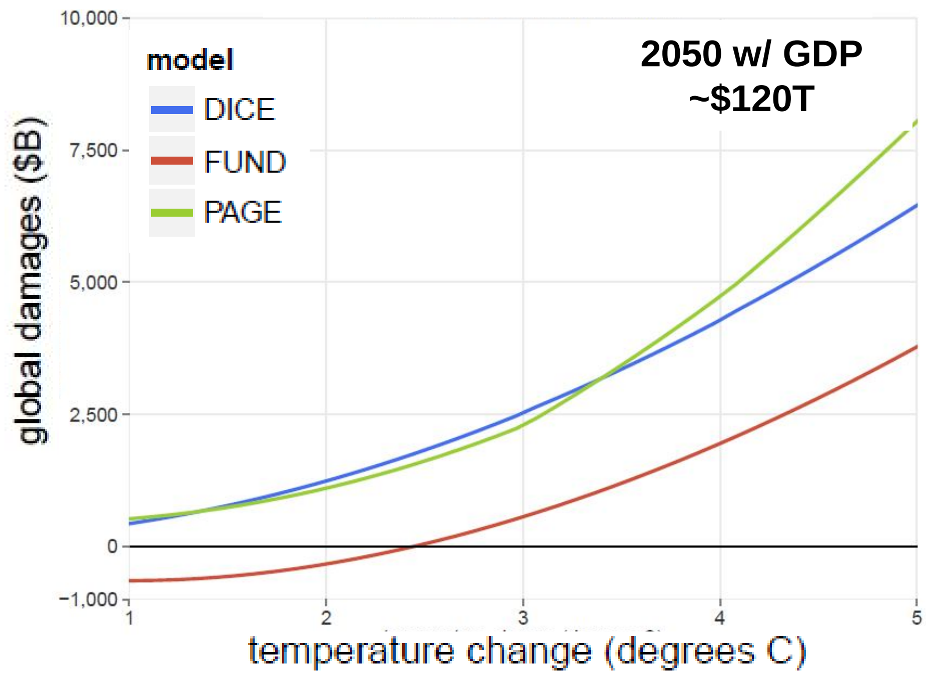
(standardized climate signal from a 1 billion tC pulse in 2020)

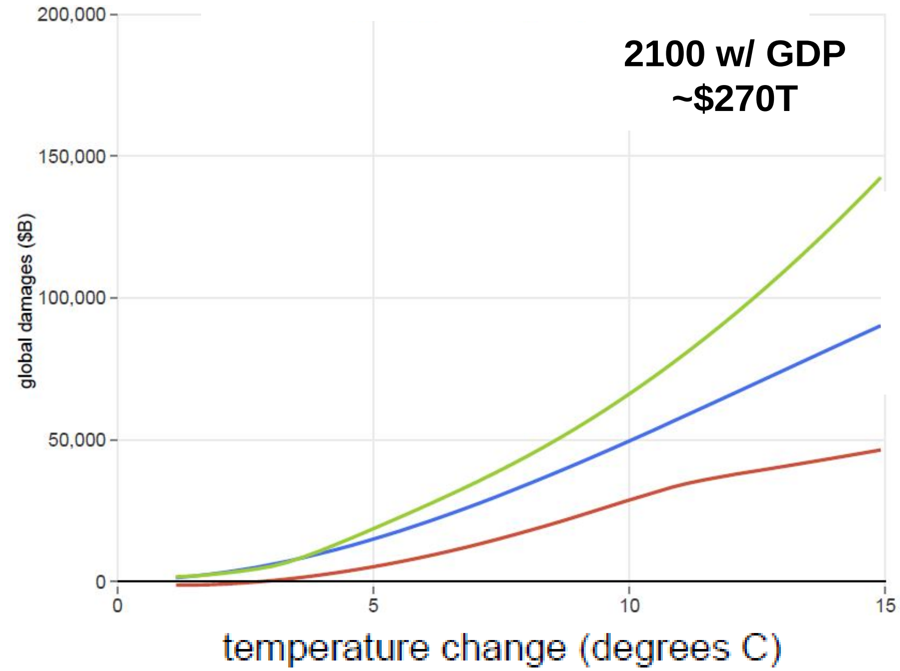


Driven by differences in damage modeling structure & parameterization

Damage Responsiveness to Temperature – Global Damages

Total climate damages as a function of global temperature





DICE and PAGE damages more responsive to warming

Figures with a USG2 reference socioeconomic condition

Damage Responsiveness to Income – Global Damages

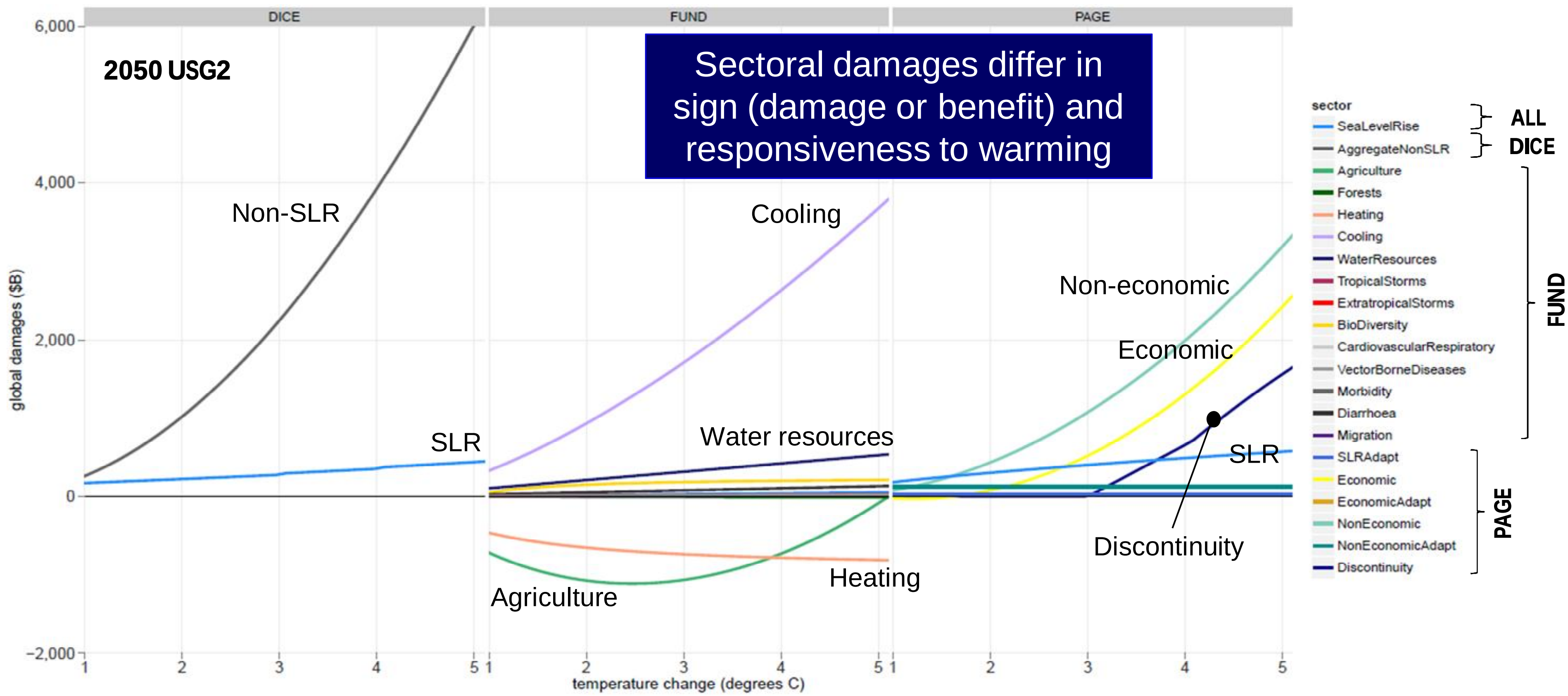
Total climate damages as a function of non-OECD income

FUND with increasing benefits with income at lower warming levels. DICE & PAGE more responsive to income at higher warming levels.

Figures with a USG2 reference climate condition

Damage Responsiveness to Temperature – Sectoral Damages

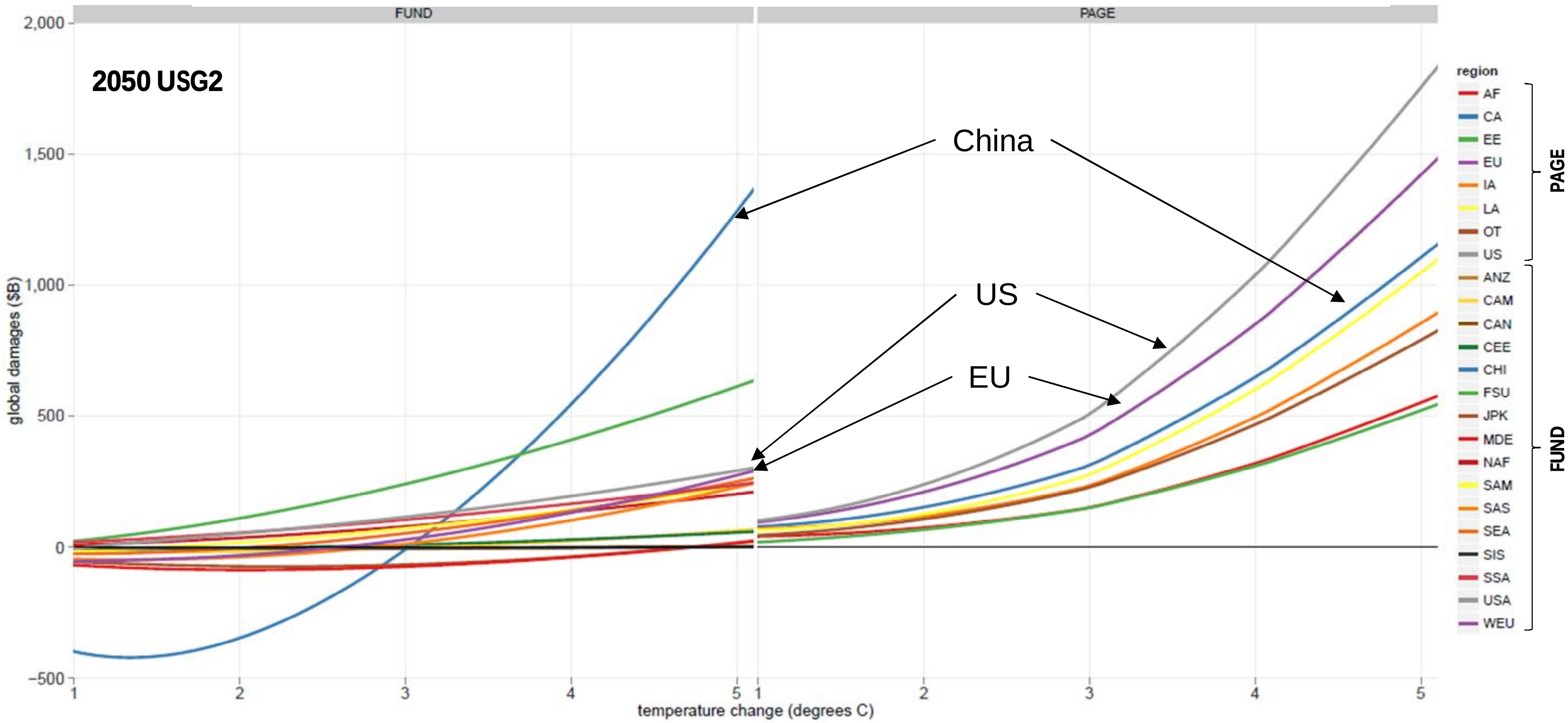
2050 sectoral climate damages as a function of global temperature



Particular sectors driving results

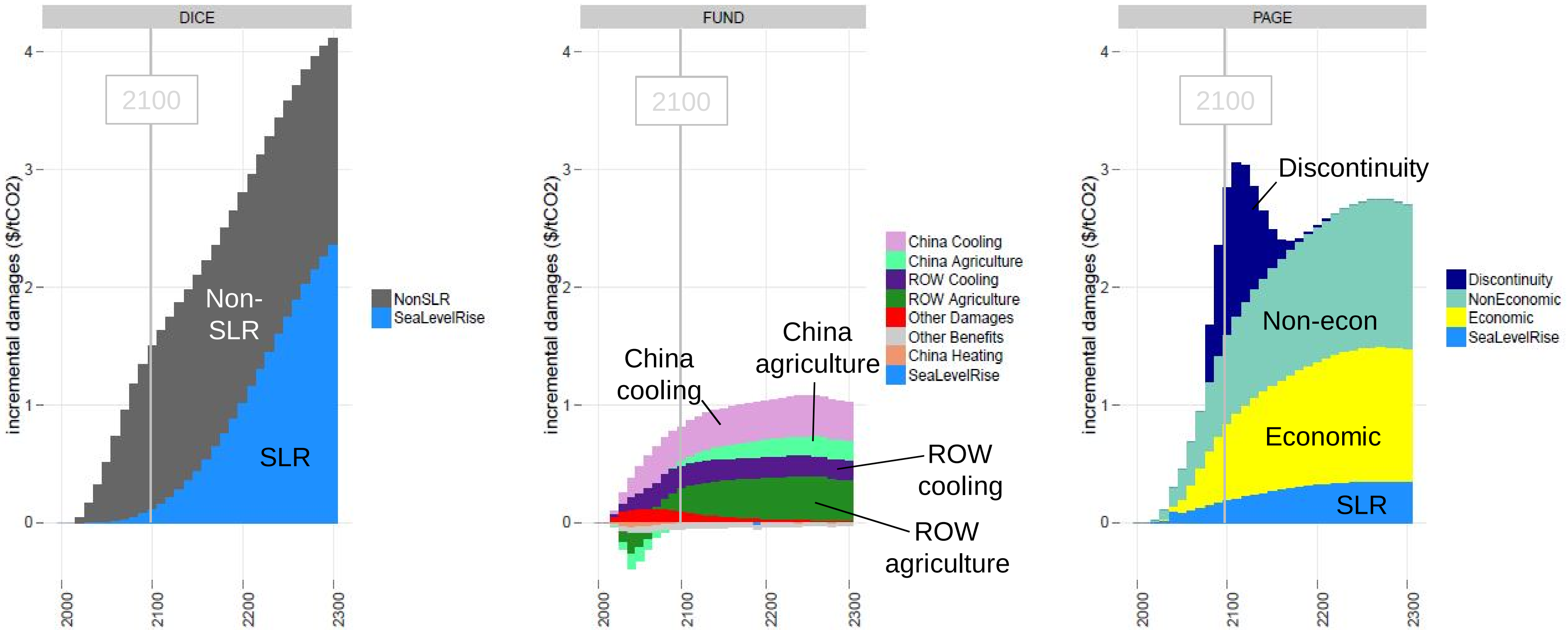
Damage Responsiveness to Temperature – Regional Damages

2050 regional climate damages as a function of global temperature



Regional damages not equally responsive to warming. FUND with net benefits for some regions. PAGE with net damages for all regions. FUND modeling individual regions. PAGE scaling damages off EU damages.

Key Parts of Incremental Damages
(USG2 scenario to 2300)



Model specific features dominate incremental damages

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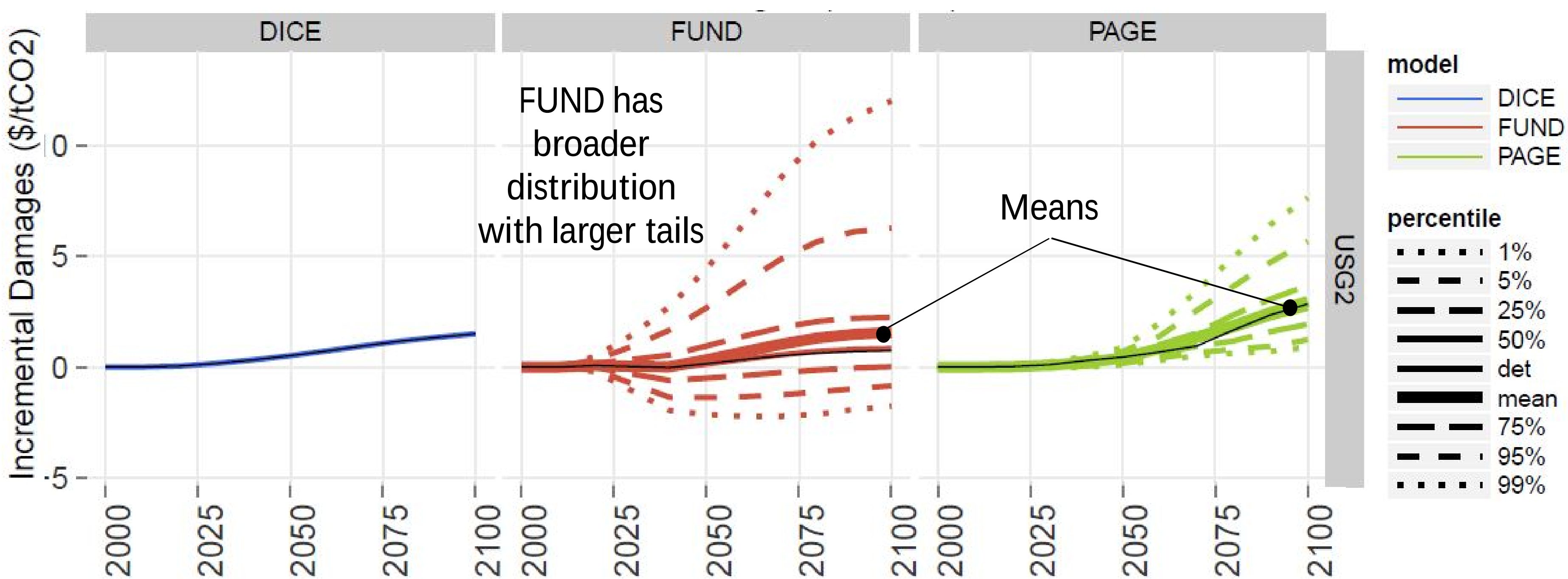
Model Specific Uncertainty – Incremental Global Damages (e.g., USG2 temperature & socioeconomics)



Models considering significantly different damage uncertainty – FUND modeling significantly more than PAGE and DICE, but PAGE has higher mean

Damage Specification Literature Sources

Damage formulations based on older climate impacts literature, with some formulations based on those from the other models

Model (version)	Damage type	Study	Basis	Links to SCC models
DICE (2010)	Aggregate non-SLR	IPCC (2007b), Tol (2009)[1]	Calibration	DICE, FUND, PAGE
	SLR coastal impacts	Undocumented		
FUND (v3.8)	Agriculture	Kane et al. (1992), Reilly et al. (1994), Morita et al. (1994), Fischer et al. (1996), Tsigas et al. (1996)	Calibration	
		Tol (2002b)	Income elasticity	
	Forestry	Perez-Garcia et al. (1995), Sohngen et al. (2001)	Calibration	
		Tol (2002b)	Income elasticity	
	Energy	Downing et al. (1995), (1996)	Calibration	
		Hodgson and Miller (1995)	Income elasticity	
	Water resources	Downing et al. (1995, 1996)	Calibration	
		Downing et al. (1995, 1996)	Income elasticity	
	Coastal impacts	Hoozemans et al. (1993), Bijlsma et al. (1995), Leatherman and Nicholls (1995), Nicholls and Leatherman (1995), Brander et al. (2006)	Calibration	
	Diarrhoea	WHO Global Burden of Disease (2000)[2]	Calibration	
		WHO Global Burden of Disease (2000)	Income elasticity	
	Vector-borne diseases	Martin and Lefebvre (1995), Martens et al. (1995, 1997), Morita et al. (1995)	Calibration	
		Link and Tol (2004)	Income elasticity	
	Cardiovascular and respiratory mortality	Martens (1998)	Calibration	
	Storms	CRED EM-DAT database,[3] WMO (2006)	Calibration	
		Toya and Skidmore (2007)	Income elasticity	
	Ecosystems	Pearce and Moran, (1994), Tol (2002a)	Calibration	
PAGE (2009)	SLR	Anthoff et al. (2006)[4]	Calibration & income elasticity	FUND
	Economic	Warren et al. (2006)[5]	Calibration	DICE, FUND, PAGE
	Noneconomic	Warren et al. (2006)	Calibration	DICE, FUND, PAGE
	Discontinuity	Lenton et al. (2008), Nichols et al., (2008), Anthoff et al. (2006), Nordhaus (1994)[6]	Calibration	DICE, FUND
	Adaptation costs	Parry et al. (2009)	Calibration	

Damage Component Assessment Key Observations

- Significant differences in damage responses across models (to 2100 and 2300, in total and incremental damages)
- Important damage component structural differences
- Model specific features driving results, e.g.,
  - DICE – damages increase quadratically
  - FUND – agricultural CO_2 fertilization, cooling demand, China damages, adaptation
  - PAGE – regional scaling, non-economic damages, discontinuity damages, adaptation
- Models representing & sampling different uncertainty spaces
- Additional uncertainty to consider – 2013 revisions

Overall Experimental Design Assessment

USG SCC experimental design features

1. Multiple models
2. Standardized uncertainties
3. Model specific parametric uncertainties
4. Standardized discounting
5. Tens of thousands of SCC estimates
6. Aggregation of estimates into USG SCC values

Experimental Design Issues

- **Significant structural differences across models** – Do they reflect differences in expert opinion? e.g.,
  - Socioeconomic/emissions – different sets of emissions and radiative forcing
  - Climate – carbon cycle, climate sensitivity, feedbacks, uncertainty
  - Damages – unique model specific factors that dominate results
- **Consideration of uncertainty** – we find reasonable alternative specifications, additional uncertainties, and artificial variation
- **Comparability and independence of model results** – Inconsistencies across modeling (implementation, structural, uncertainties) & inter-model relationships raise questions about statistical comparability which is required for averaging
- **Robustness of overall results** – Current results may not be robust (i.e., insensitive to reasonable alternatives) given our observations regarding (1) model sensitivity, and (2) existence of alternative assumptions and modeling
- **Experimental design challenges** – Issues with the overall design, in particular the multi-model approach (with consistency and comparability issues)

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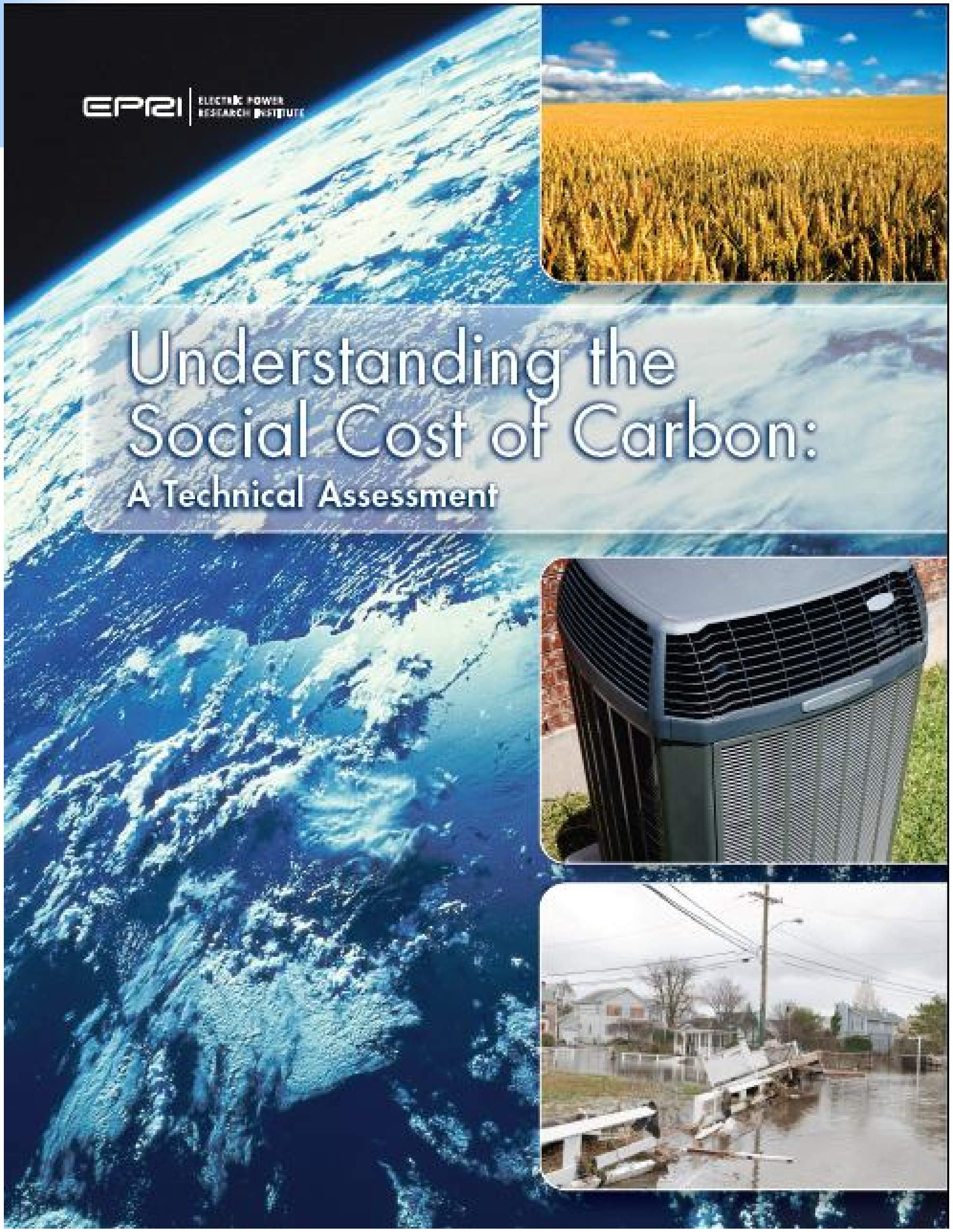
Recommendations

1. **Internal review of the modeling** – to evaluate differences, improve comparability and uncertainty representation, and enhance robustness
2. **Revisit experimental design** – worth revisiting given challenges of multi-model approach (e.g., chose best approach for each component)
3. **Evaluate robustness** – useful given sensitivity of models and issues with uncertainty considered. Will increase confidence in results.
4. **Peer review the approach and models** – USG SCC approach is novel and peer review would be valuable. Model review also practical given regulatory use.
5. **Provide additional documentation and justification** – will facilitate communications & interpretation, and increase public confidence
6. **Provide application guidance** – SCC application also an issue, guidance on proper application needed

Concluding Remarks

- The social cost of carbon is important
- However, the USG estimates are difficult to interpret and assess
- Better understanding of the modeling and what the estimates represent is needed
  - To inform public discussion,
  - Improve SCC modeling and application, and
  - Facilitate climate research broadly – impacts analyses in general, climate science, climate economics, & integrated assessment



New Study

Understanding the Social Cost of Carbon: A Technical Assessment

http://epri.co/3002004657

(full report & ES downloads)

- Objective: inform public social cost of carbon (SCC) discussion, future SCC modeling and use, and climate research broadly

Thank You!

Questions/comments:

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