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Estimating the ratio of non-CO_2/CO_2 climate impacts of aviation

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Office of Environment and Energy,
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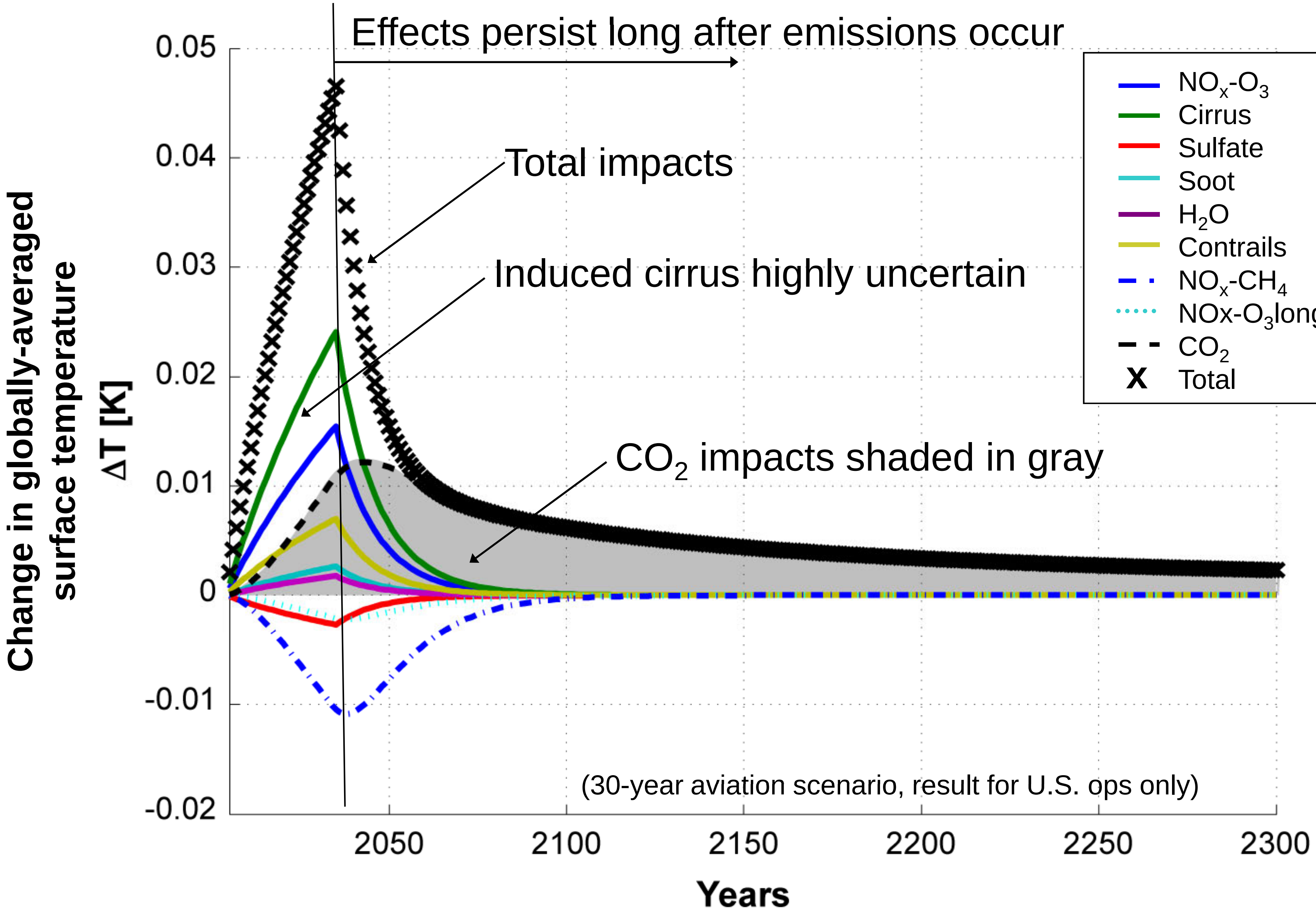
The APMT effort is managed by Maryalice Locke.

Outline

- Intro
- Methods and assumptions
- Details on
  - Metrics
  - Social cost of carbon, SCC
  - Background scenarios
  - Damage functions
  - Scientific uncertainties

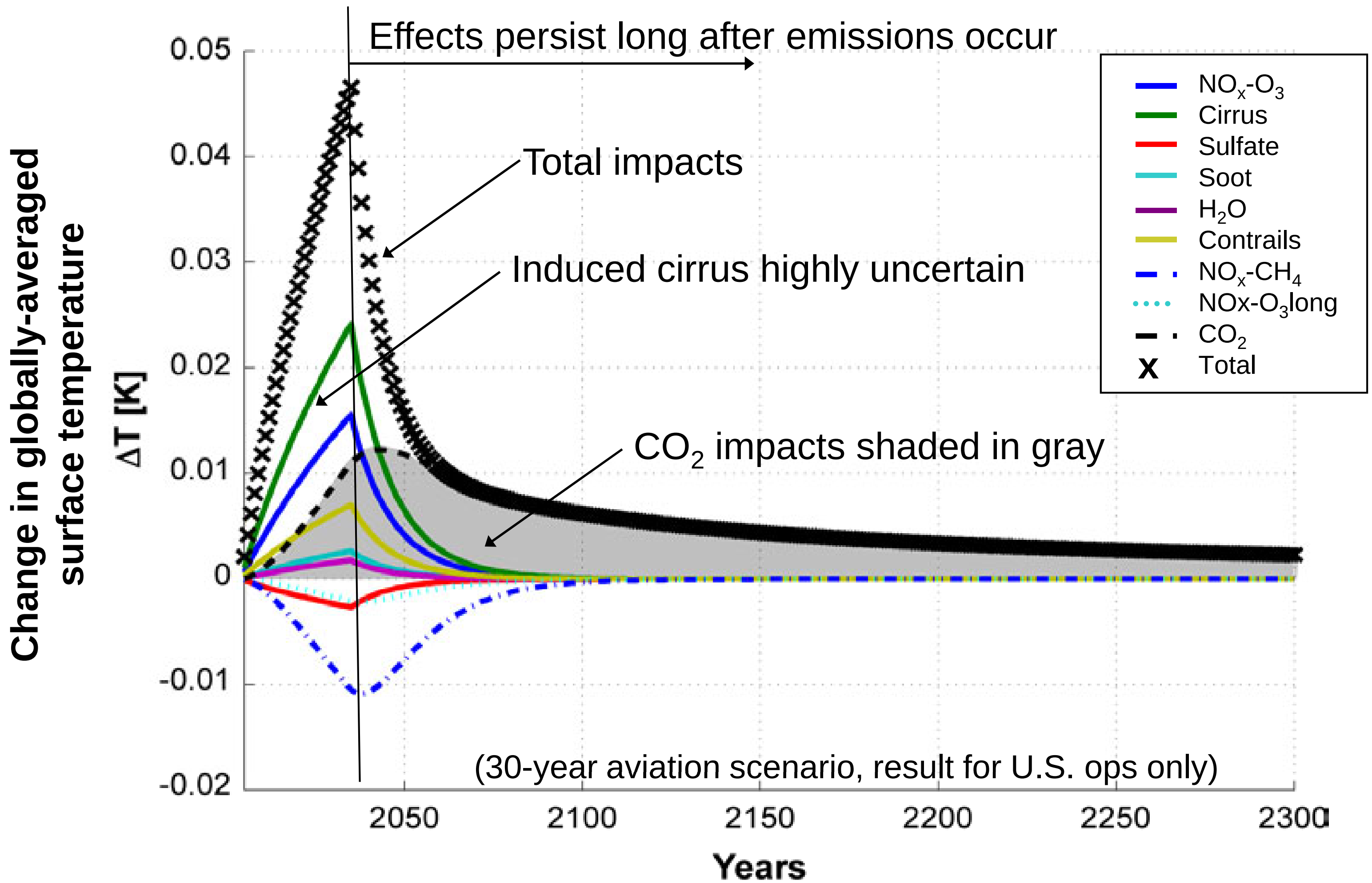
  } in the back-up charts
- Results
- Summary and main messages

Aviation climate impacts (30 yrs of emissions)



What is "the ratio"?

~ the **ratio of total area** (e.g. under the x's) **to CO_2 area** (gray)



What are we seeking?

- A ratio that may be applied to an estimate of the social cost of carbon (SCC) to represent the non-CO_2/CO_2 effects of aviation
- **We are not proposing a value for such a ratio**
- Rather, we are seeking to articulate (some of) the key questions that must be answered by scientists and policy-makers in choosing such a value (or range of values)

Factors that lead to different ratio estimates

- **Choice of metric**
  RFI, GWP, ΔT-years, NPV, etc.
- **Scientific uncertainties**
  contrails/cirrus, NO_x impacts, etc.
- **Economic modeling uncertainties**
  DICE, FUND, PAGE, etc.
- **Importance of long-term impacts**
  time windows, discount rates
- **Uncertain knowledge of the future**
  background emissions and GDP scenarios
- **Things not well assessed with models because they fall outside the capabilities of the models**

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Methods for this study

- Simplify (we lose some things when we do)
  - Adopt a globally-averaged, fleet-wide perspective
- Use a probabilistic impulse response function model (APMT) to project forward in time the results of other studies in the literature
  - Approximately replicate the behavior of different physical and economic models (e.g. MAGICC, FUND, DICE, PAGE)
- Separate prediction of the non-CO_2/CO_2 ratio from prediction of the baseline effect (e.g. the total impact of aviation on surface temperature, or the social cost of carbon)
- Run hundreds of cases for different damage functions, background scenarios, uncertain scientific parameters, discount rates, etc.
- **Determine how different uncertainties/assumptions influence estimates of the ratio of non-CO_2/CO_2 effects from aviation**

Our assumptions

Assumptions	Low Lens (Best case/low impact)	Mid Lens (Nominal)	High Lens (Worst case)
Climate sensitivity	2K	Beta distribution (alpha = 2.17, beta = 2.41) to generate [mean = 3.0, range 2.0-4.5] K	4.5K
NO_x-related effects	Stevenson et al. RF values (2004)	Discrete uniform distribution: Wild, Stevenson, Hoor et al (2009) values	Wild et al. RF values (2001)
Short-lived effects radiative forcing [Cirrus, Sulfates, Soot, H_2O, contrails]	[0, 0, 0, 0, 0] mW/m^2	Beta distribution [alpha, beta, (range)] [2.14, 2.49 (0 – 80)], [2.58, 2.17 (-10 – 0)], [1.87, 2.56 (0 – 10)], [2.10, 2.58 (0 – 6)], [2.05, 2.57 (0 – 30)] mW/m^2	[80, -10, 10, 6, 30] mW/m^2
Background scenario	IPCC SRES B2	IPCC SRES A1B	IPCC SRES A2
Damage function	5^{th} percentile of DICE (deterministic)	DICE 2007 (normal distribution)	95^{th} percentile of DICE (deterministic)

Also tested a range of damage functions and background scenarios consistent with "Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," Interagency Working Group on Social Cost of Carbon, United States Government, February 2010.

Metrics evaluated for ratio estimates

- **GWP** for 1-yr emissions pulse

  GWP_{20}, GWP_{100}, GWP_{500} (integrated radiative forcing with time windows*)

- **Integrated temperature change** for 1-yr emissions pulse

  LDP_{20}, LDP_{100}, LDP_{500} (with different time windows)

- **Marginal damage** (of one new unit of emissions integrated impact over hundreds of years)

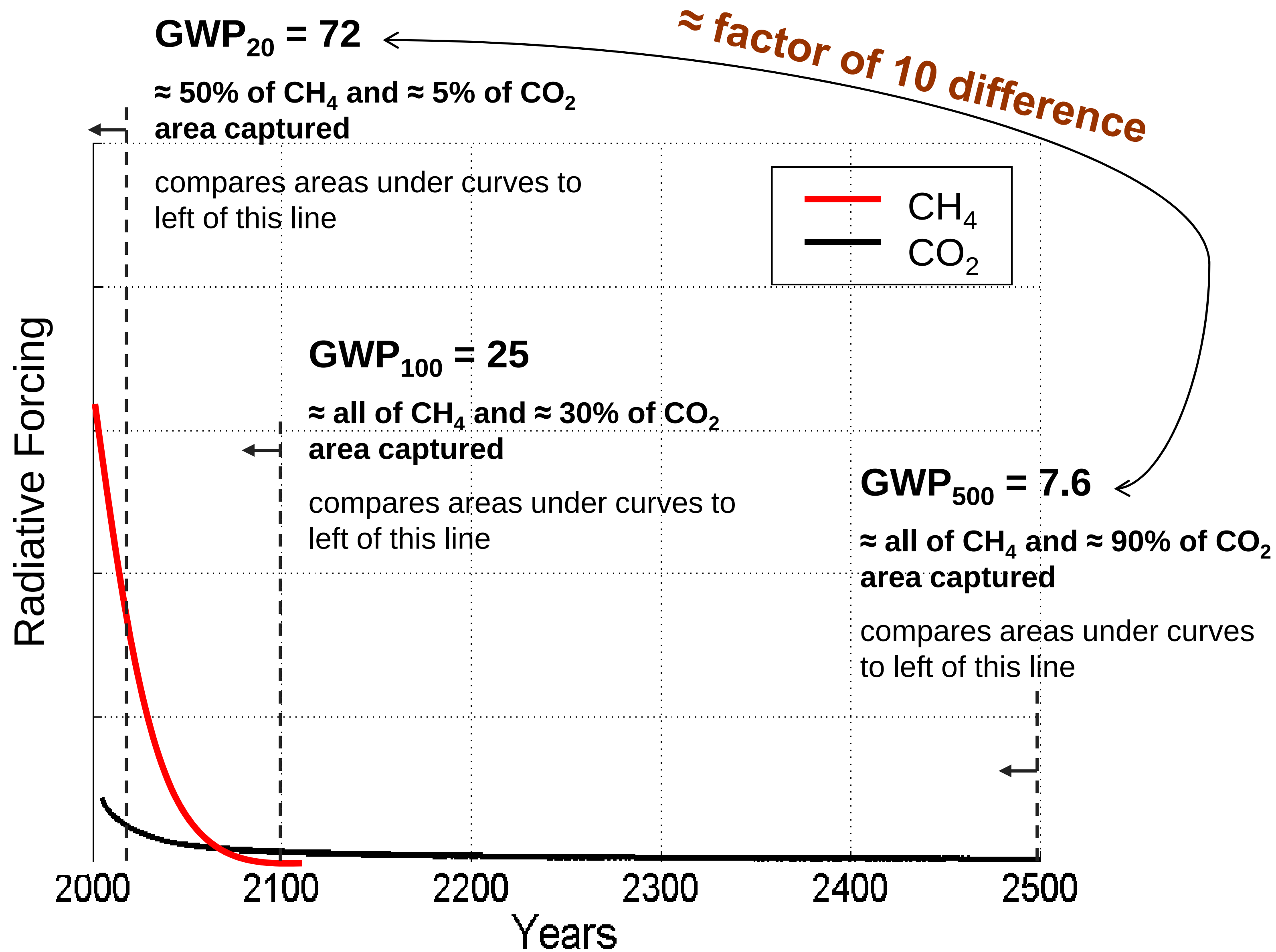
  $NPV_{2\%}$, $NPV_{3\%}$, $NPV_{7\%}$ (net present value with different discount rates*)

- **How sensitive are the ratios to background scenario, simplified climate model parameters, and aviation impact uncertainties?**

*Discount rates and time windows chosen to be consistent with EPA and IPCC practice, respectively

Comparing short- and long-lived effects

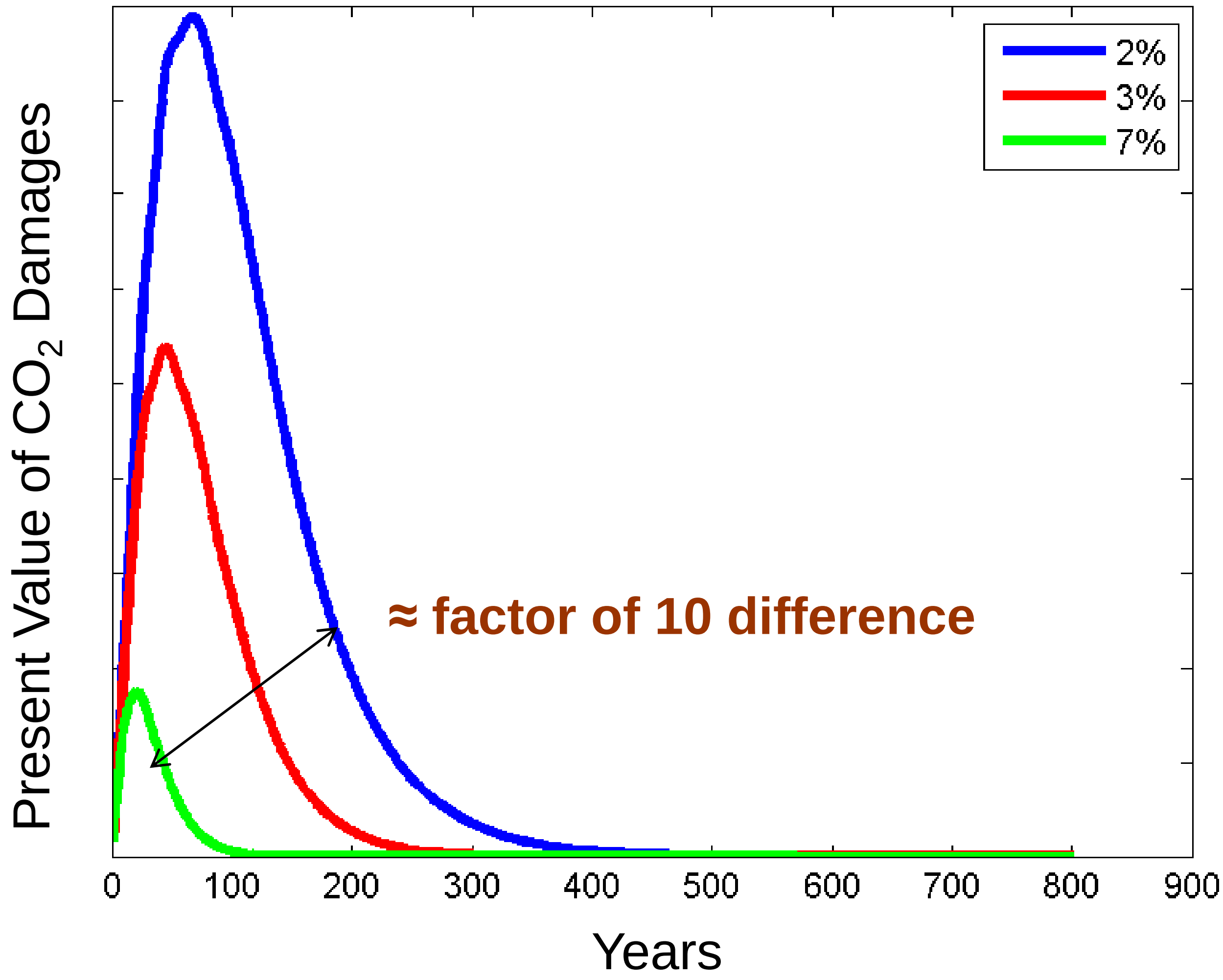
time-windowing, methane GWP example



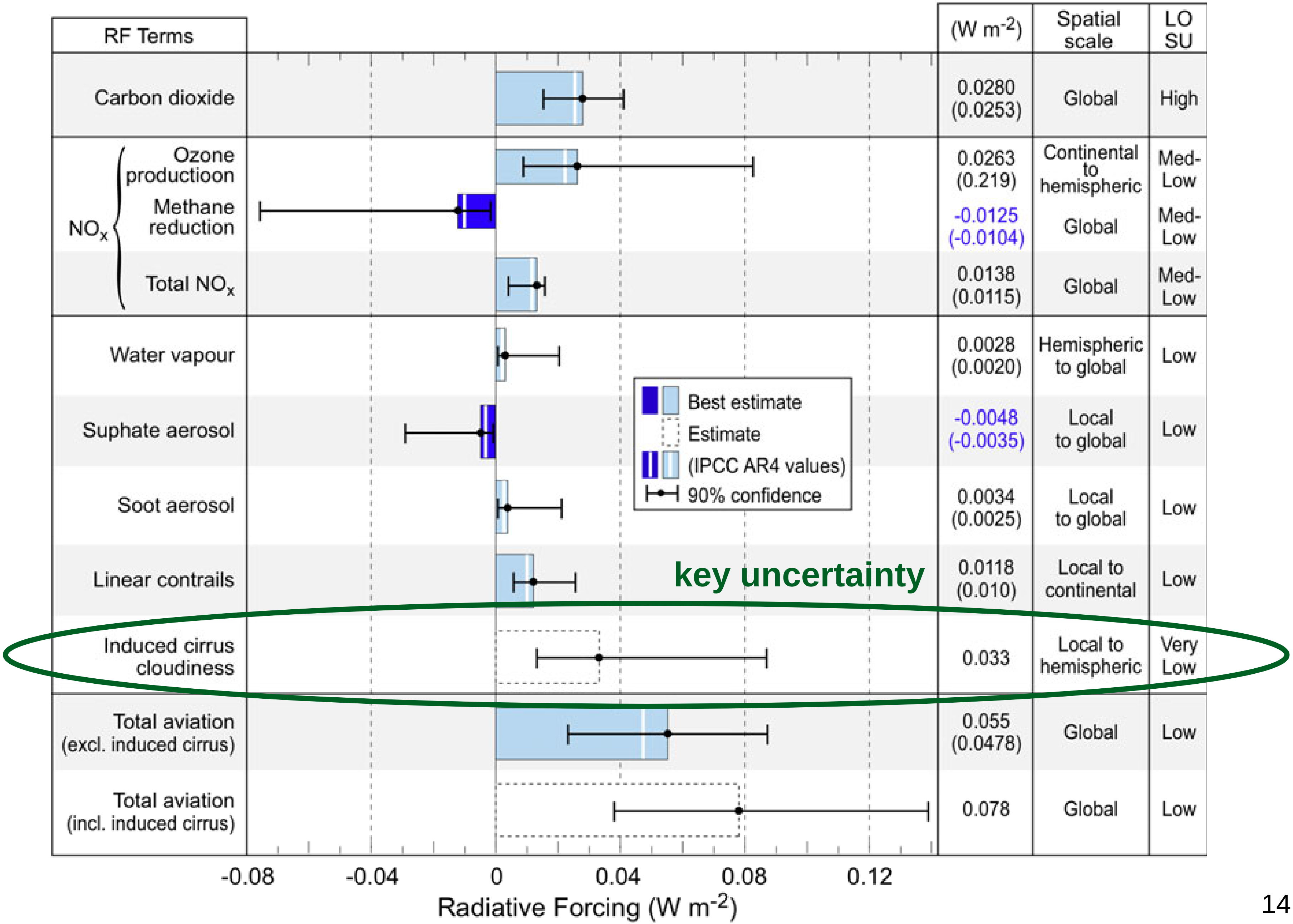
Here the lifetimes for CO_2 and CH_4 have been used accurately, but different vertical scales have been used for the two forcing agents; the CO_2 effects have been multiplied to make them larger and easier to see.

Social discounting

- To express future costs and benefits in present value
- Much stronger basis in economics literature than time-windowing



Scientific uncertainties (Lee et al., 2009)



Uncertainty in metrics

- If what matters is the ultimate impact (versus an intermediate scientific and/or physical parameter)
  - **Then the closer the metric is to serving as a surrogate for the impact, the smaller the uncertainty in the decision**
  - Often opposite to how much uncertainty there is in predicting the metric (uncertainty tends to grow as the metric becomes more relevant)
- For policy decisions, metrics that go beyond changes in radiative forcing or surface temperature—to damages—are preferred
  - In all cases quantifying the uncertainty is important

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We found:

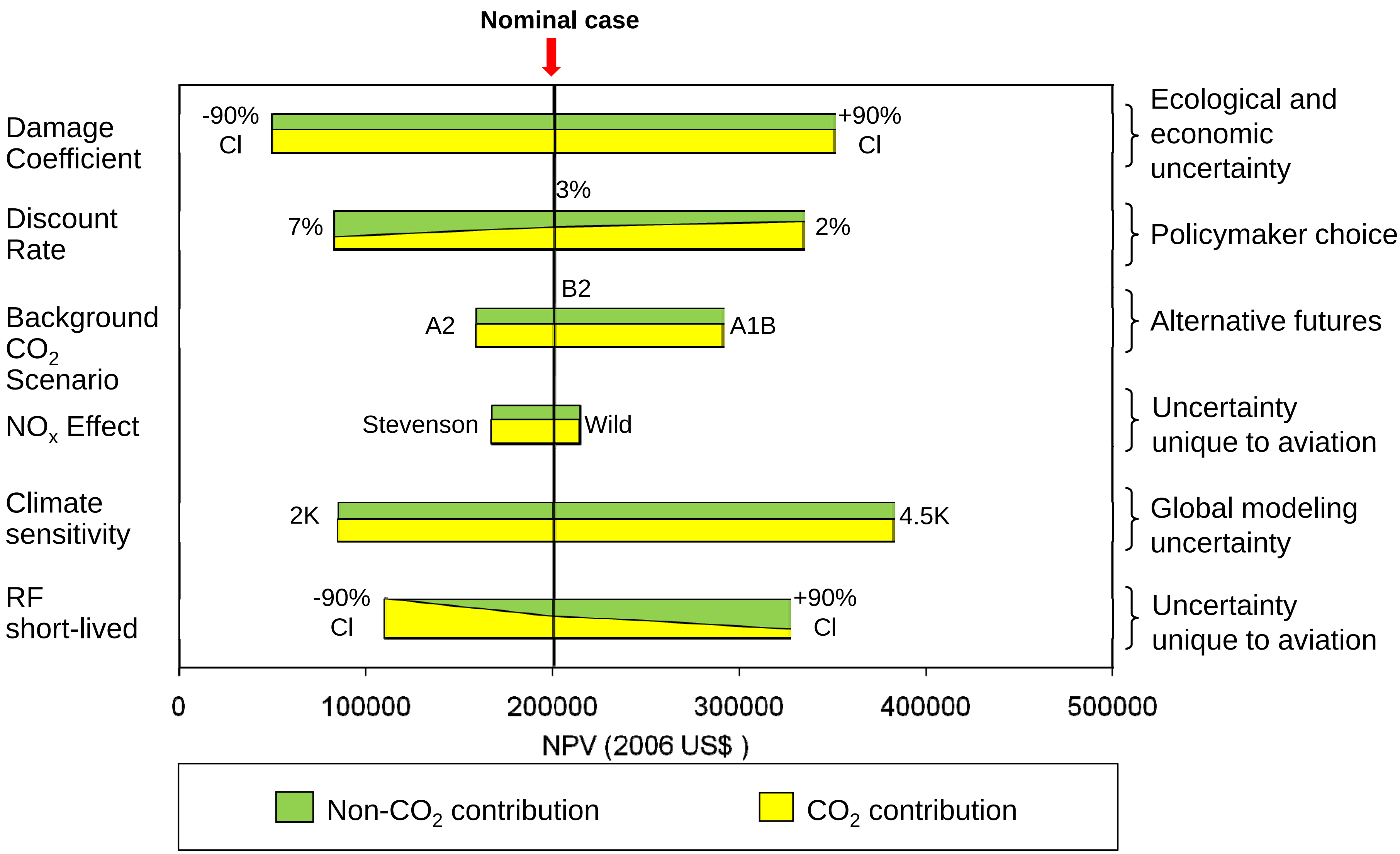
- Estimate of non-CO_2/CO_2 ratio is less sensitive to many of the uncertainties than is the estimate of the baseline effect (e.g. the total impacts of aviation on surface temperature, or social cost of carbon)

- **Dominant parameters influencing the non-CO_2/CO_2 ratio are:**
  - Discounting and/or time-windowing (economics and policy)
  - Magnitude of climate forcing assumed for contrails and aviation-induced cirrus (science and policy)

- The ratio is less sensitive to choice of metric
  - Regardless, can use appropriate metric for the application (e.g., NPV-based ratio for SCC, GWP-based ratio for GWP)

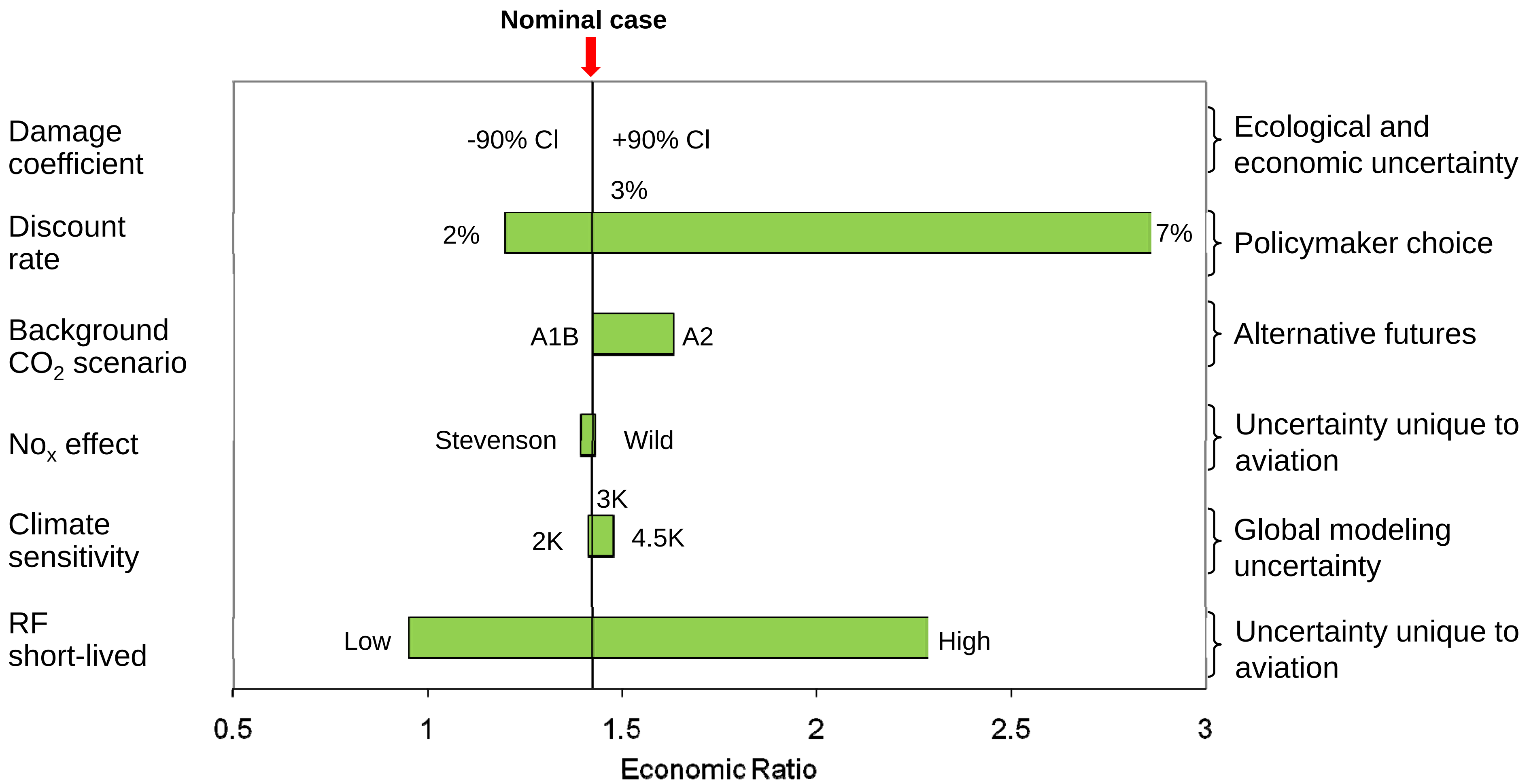
Influences on estimates of overall impact: NPV

different from influences on non-CO_2/CO_2 ratio



Influences on non-CO_2/CO_2 ratio: NPV metric

using only the DICE damage function distribution

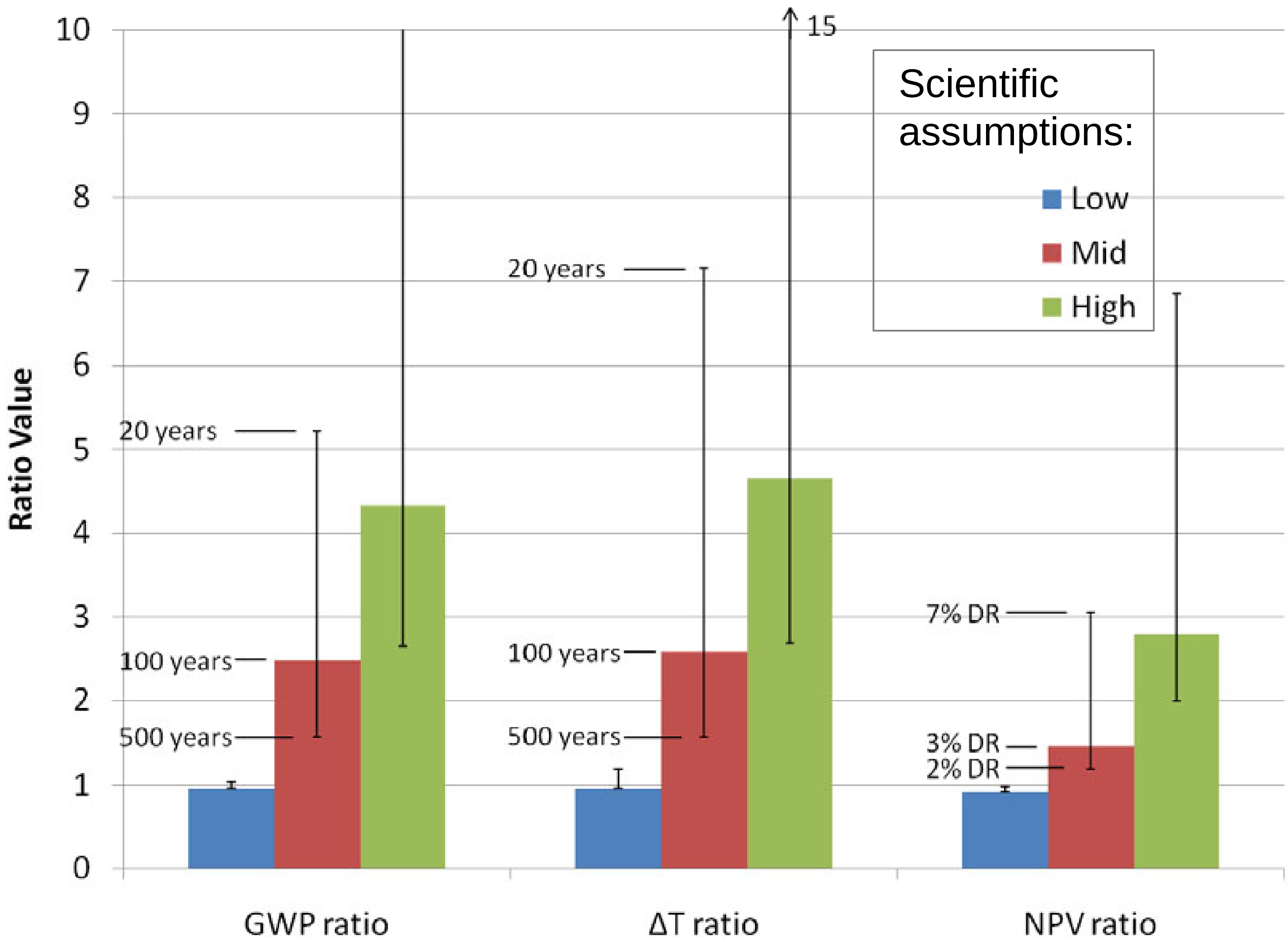


Non-CO_2/CO_2 ratio by effect: NPV metric

	2% Discount Rate			3% Discount Rate			7% Discount Rate		
	Low	Mid	High	Low	Mid	High	Low	Mid	High
CO_2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
NOx-total	-0.07	-0.09	-0.04	-0.09	-0.12	-0.03	-0.02	-0.03	0.18
Contrails	0.00	0.06	0.22	0.00	0.12	0.39	0.00	0.44	1.22
Cirrus	0.00	0.21	0.74	0.00	0.41	1.32	0.00	1.53	4.10
Sulfates	0.00	-0.02	-0.08	0.00	-0.05	-0.15	0.00	-0.17	-0.45
Soot	0.00	0.02	0.09	0.00	0.05	0.16	0.00	0.17	0.49
H_2O	0.00	0.02	0.06	0.00	0.03	0.10	0.00	0.11	0.31
Total Ratio	**0.9**	**1.2**	**2.0**	**0.9**	**1.4**	**2.8**	**1.0**	**3.1**	**6.9**

- Total Ratio = $\sum_i M_i$

Influence of scientific uncertainties, metrics, and windowing/discounting



Main messages

- **Two key influences on non-CO_2/CO_2 ratio**
  - Discount rate
  - Uncertainty in contrails/cirrus estimates
- **Metric choice**
  - If ratio is being applied to a GWP then use GWP-based ratio
  - If it is being applied to SCC, then use an NPV-based ratio
- **Other factors less important**
  - Background scenarios
  - Damage functions (PAGE, DICE, FUND?)
  - Scientific uncertainty in other effects (to the extent we know it)
  - Overall global modeling uncertainty (e.g. climate sensitivity)

Summary—key questions

- Given these findings, (some of) the key questions for scientists and policy-makers to arrive at an estimate for a ratio non-CO_2/CO_2 effects of aviation are:

  "What discount rate (or alternatively time-window) is appropriate?"

  "Is our understanding of climate impacts of contrails and aviation-induced cirrus cloudiness sufficient to adopt a best estimate for their effects?"

- Everyone would be more comfortable with a range of estimates (our recommendation), but for many applications a single number is needed

QUESTIONS?

Back-up charts

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Climate damages: metrics for impacts

- **CO_2 emissions →**

  → change in atmospheric CO_2 concentration

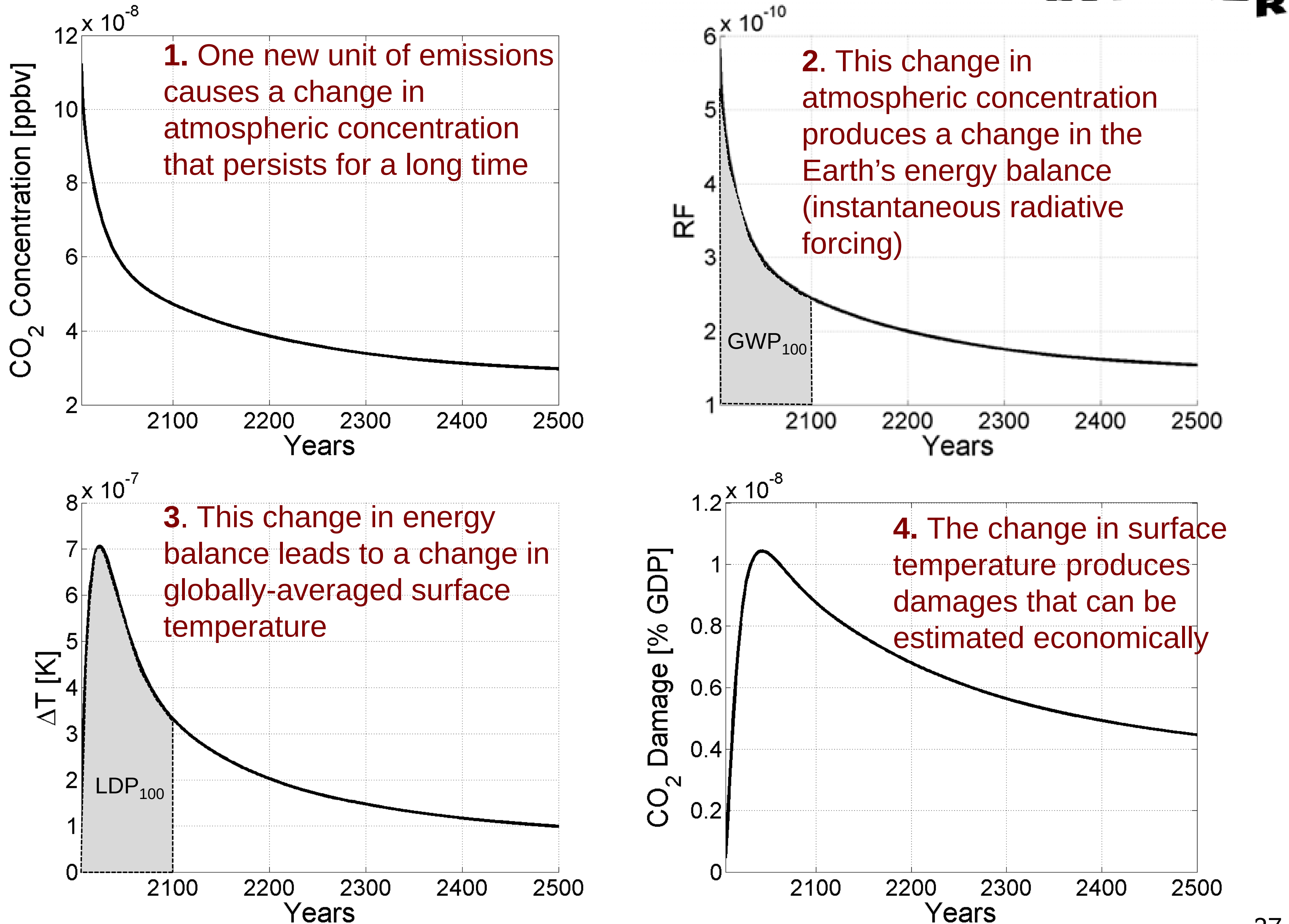
  → radiative forcing

  → change in surface temperature

  → change in health, welfare, etc.

- **Long-lived greenhouse gases** (CH_4, SF_6, N_2O, etc.)
  - IPCC convention is use of **100-yr Global Warming Potentials (GWP)**
  - CO_2 equivalent emissions = emissions of species i * GWP_i
  - GWP is ratio of areas under radiative forcing as a function of time curve (background and model dependent)
  - 20-, 100-, 500-year windows typically applied (in lieu of discounting)

Impacts of a new unit of CO_2 emissions



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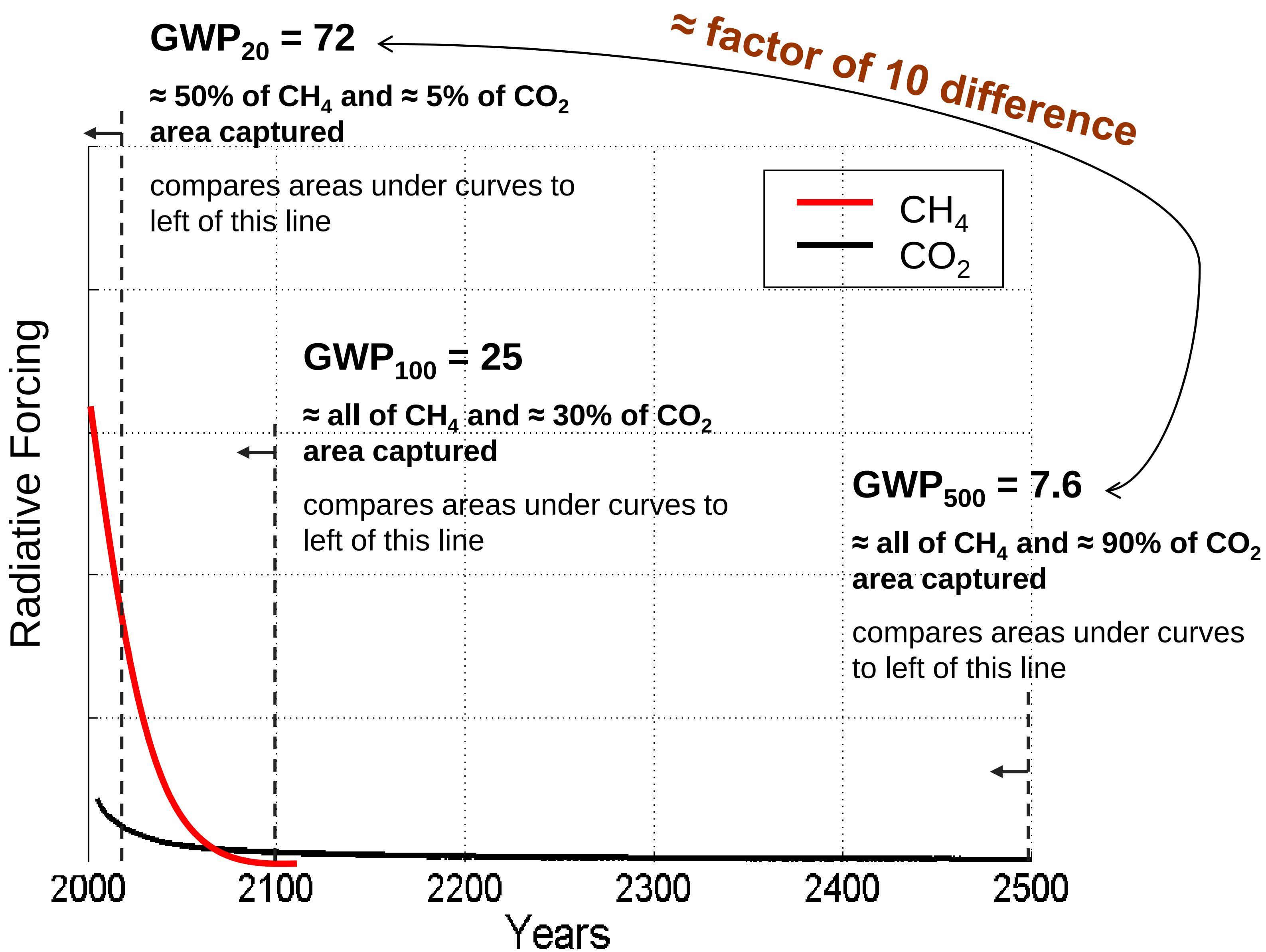
Comparing short- and long-lived effects

time-windowing, methane GWP example



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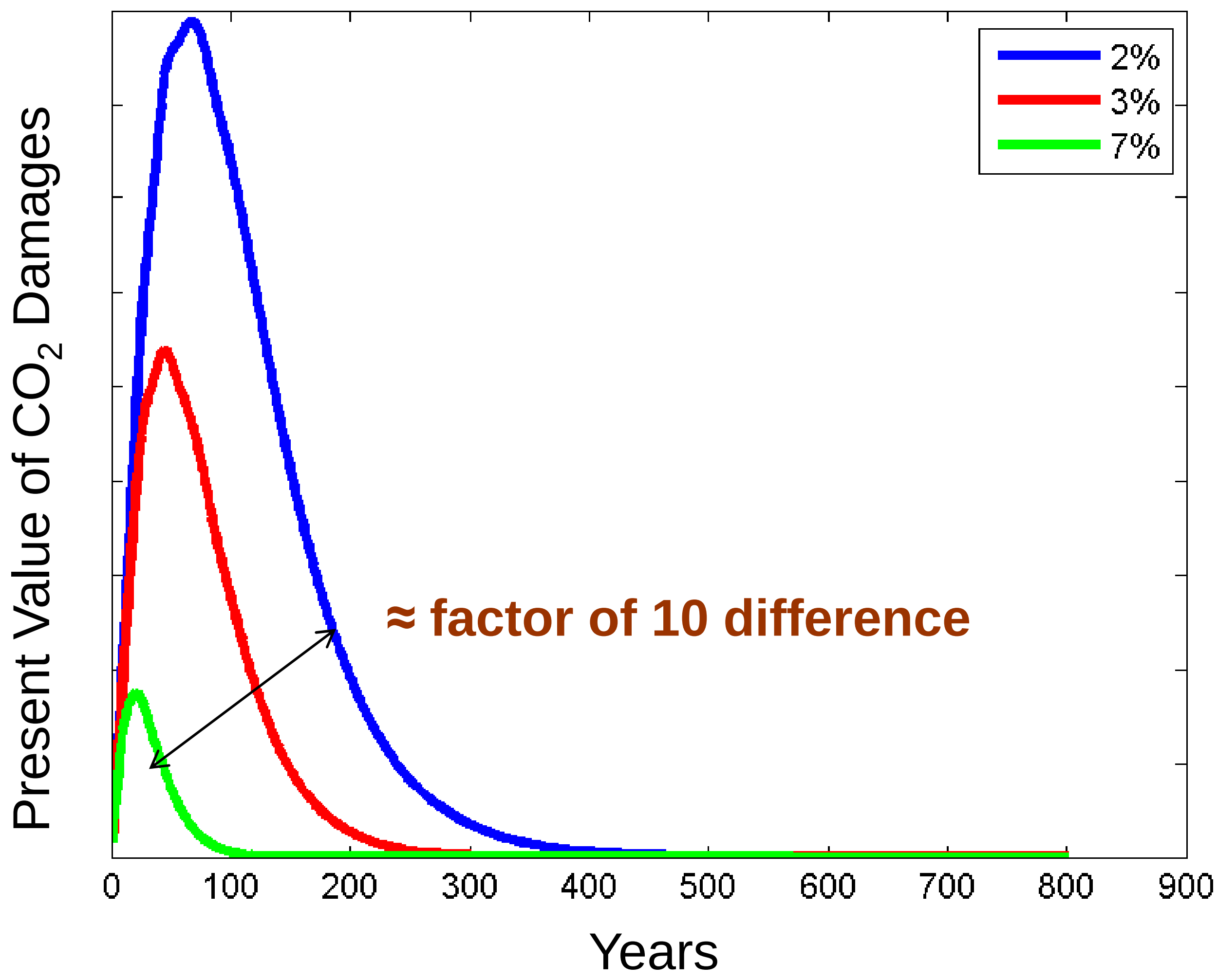

US EPA guidance on social cost of carbon*

- "For **incremental emissions reductions**, it is conceptually appropriate to use an approach that estimates the marginal value of changes in climate change impacts over time as an estimate for the monetized marginal benefit of the GHG emissions reductions projected for the proposal."
  - Almost everything from aviation is incremental with respect to the background
- "**The marginal value of GHG emissions is equal to the net present value of climate change impacts over hundreds of years of one additional net global metric ton of GHGs emitted to the atmosphere at a particular point in time.** This marginal value is sometimes referred to as the *social cost of carbon*."
  - Typically a pulse of emissions in a simplified climate model
  - This is the method used in the FAA Environmental Tool Suite/APMT

*Technical Support Document on Benefits of Reducing GHG Emissions U.S. Environmental Protection Agency (June 12, 2008)

SCC ranges: US EPA* and APMT-Impacts

- SCC estimates have wide ranges in EPA study and other literature
- **APMT produces $/tC estimates comparable to EPA analyses**

	2% Discount Rate			3% Discount Rate			7% Discount Rate		
	Low	**Mid**	**High**	**Low**	**Mid**	**High**	**Low**	**Mid**	**High**
Meta global	-11	249	583	-15	147	389	n/a	n/a	n/a
FUND global	-22	323	2548	-22	62	484	-11	-4	18
APMT-Impacts	49	211	1389	18	81	436	2	9	29

“Meta global” & “FUND global” are EPA studies based on Tol 2006

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US Interagency Working Group*

SCC for Regulatory Impact Analysis

- **APMT can be used as a surrogate for other models/assumptions**
- Five background scenarios: Stanford Energy Modeling Forum
- $/tC values for 2010 (in 2007 dollars) at 3% discount rate

EMF-22 Scenarios	DICE and APMT: DICE Mid	DICE and APMT: DICE 95th	DICE and APMT: APMT Mid	DICE and APMT: APMT High	PAGE and APMT: PAGE Mid	PAGE and APMT: APMT Mid	FUND and APMT: FUND Mid	FUND and APMT: APMT Mid
IMAGE	131	260	156	274	145	115	30	38
MERGE	81	154	109	192	82	81	29	24
Message	109	215	131	230	111	94	13	28
MiniCam	106	212	133	234	117	101	37	36
550 Avg	91	186	127	223	93	87	-1	25

* "Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866," Interagency Working Group on Social Cost of Carbon, United States Government, February 2010.

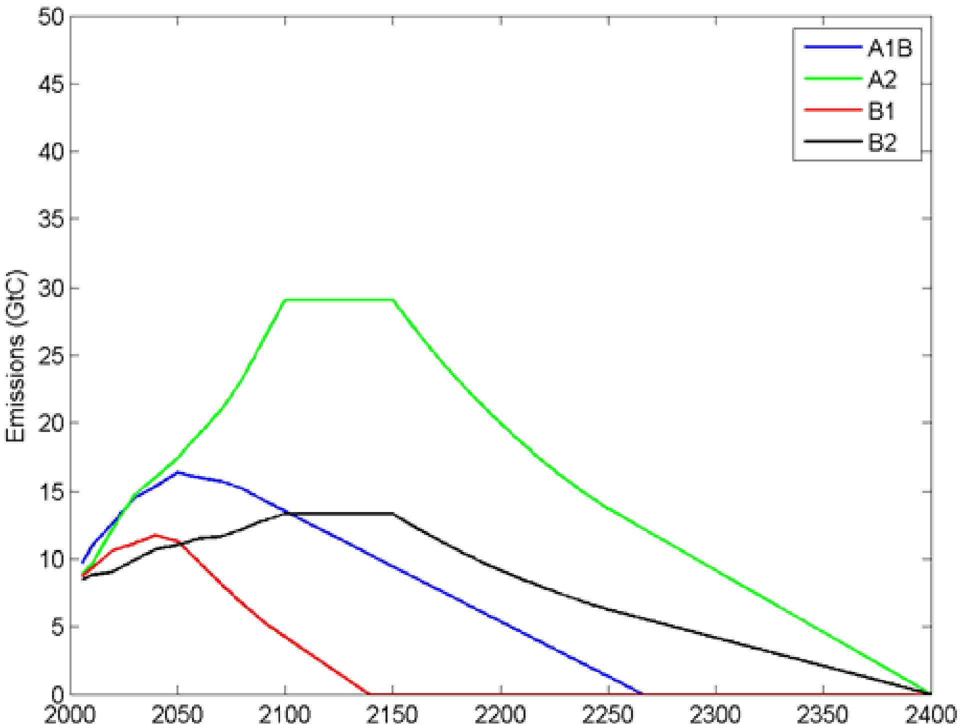
APMT Impacts-Climate

- APMT model has flexibility to be used as a surrogate to approximately replicate the assumptions and results of other models
  - DICE, FUND, PAGE, MAGICC, etc.
  - Probabilistic or deterministic
- Aviation-specific effects represented
- Set-up for the different assumptions of the recent US SCC study and then estimated ratio of non-CO_2/CO_2 effects for aircraft
  - While using different assumptions for aircraft effects representing low, mid, and high estimates from literature

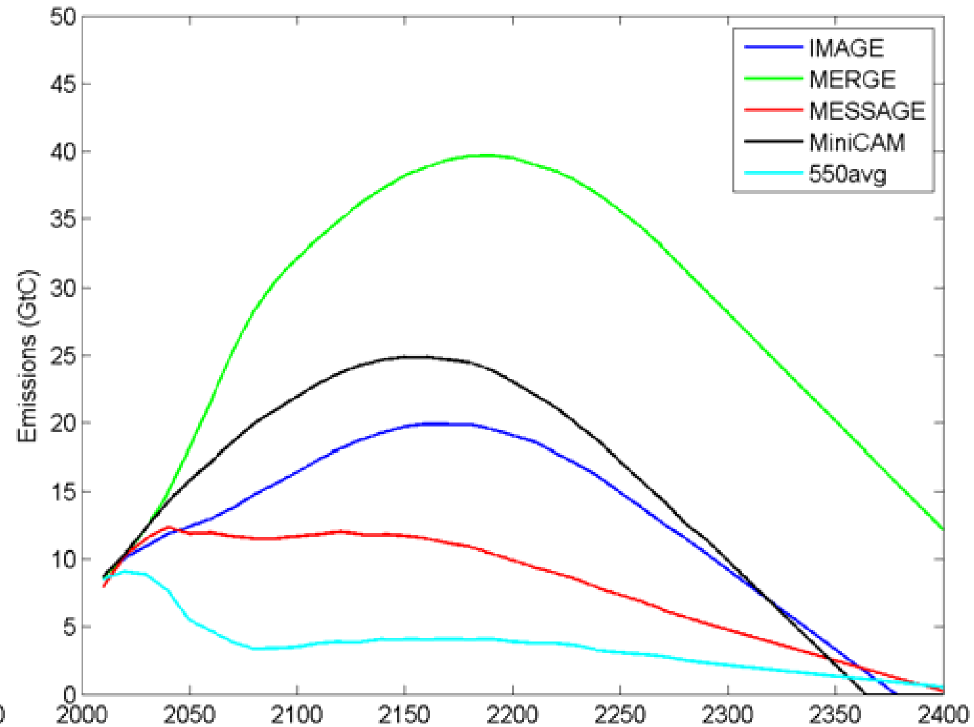
Background scenarios used in our study

CO_2 emissions shown, also used matched GDP scenarios from same sources

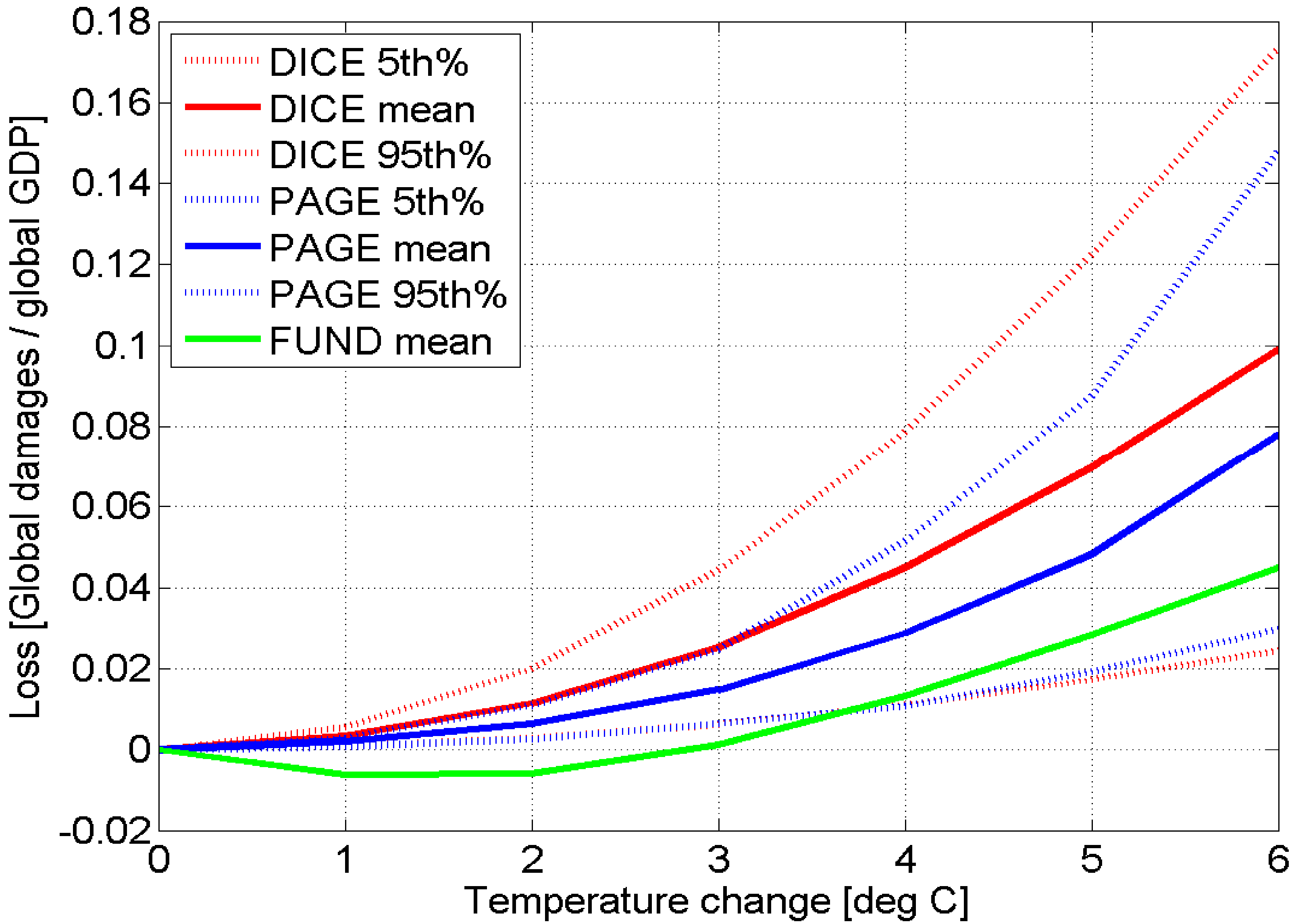
IPCC SRES
Used in many studies
Extension beyond 2100 a question



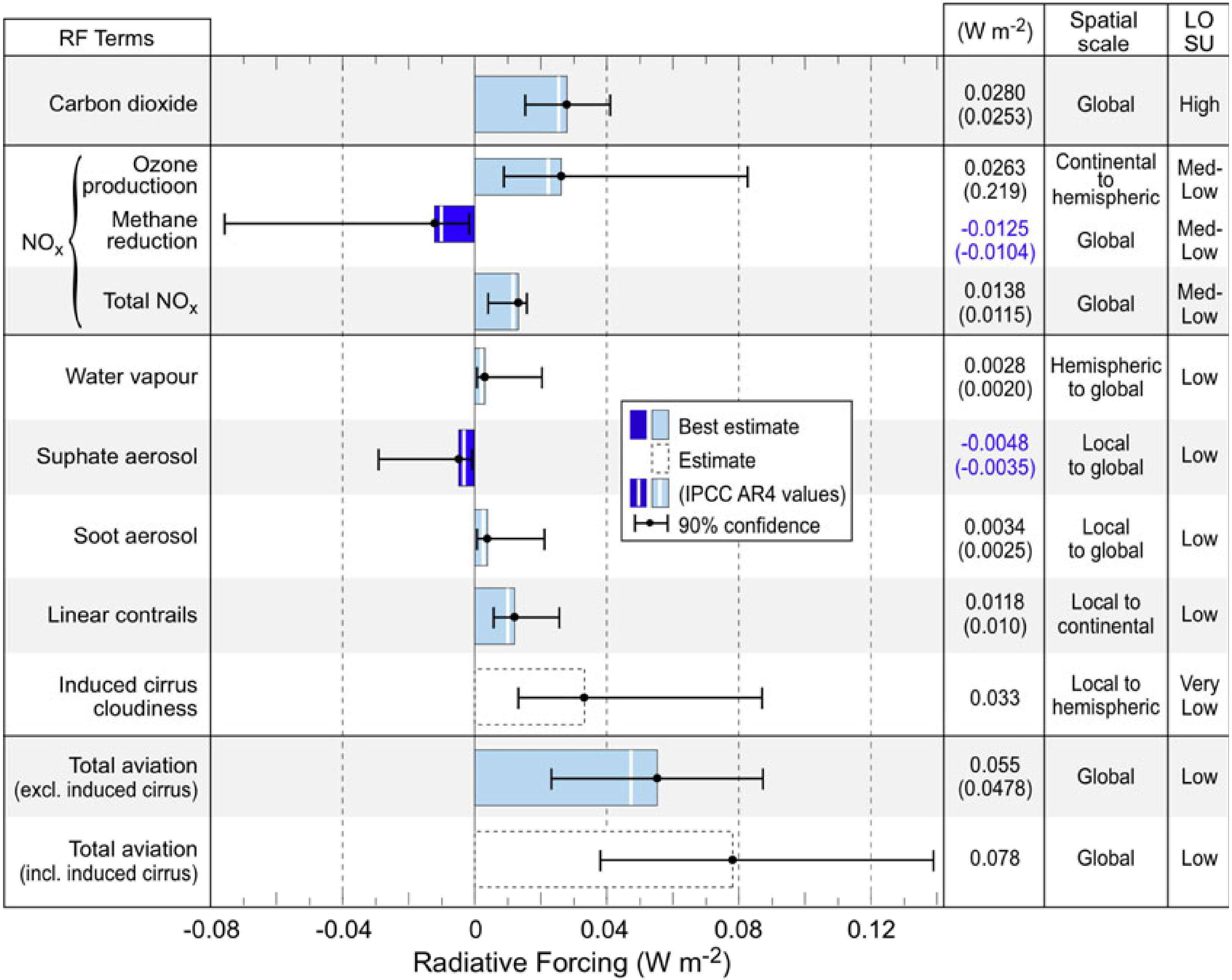
EMF-22
Used in the US Interagency Study on SCC



Damage functions
as used in US Interagency SCC study



Scientific uncertainties (Lee et al., 2009)



Our assumptions

Assumptions	Low Lens (Best case/low impact)	Mid Lens (Nominal)	High Lens (Worst case)
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Background scenario	IPCC SRES B2	IPCC SRES A1B	IPCC SRES A2
Damage coefficient	5^{th} percentile of DICE (deterministic)	DICE 2007 (normal distribution)	95^{th} percentile of DICE (deterministic)

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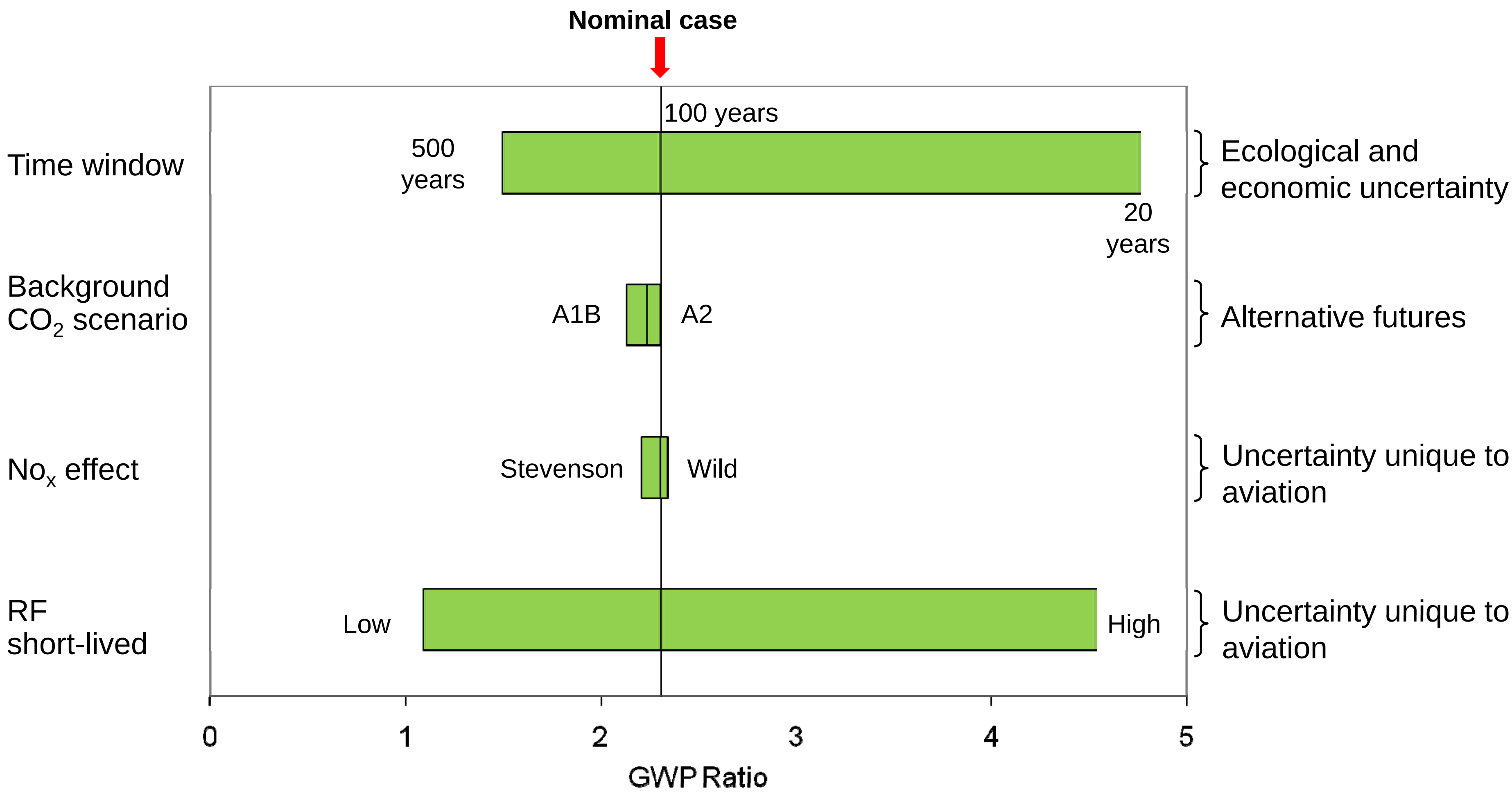
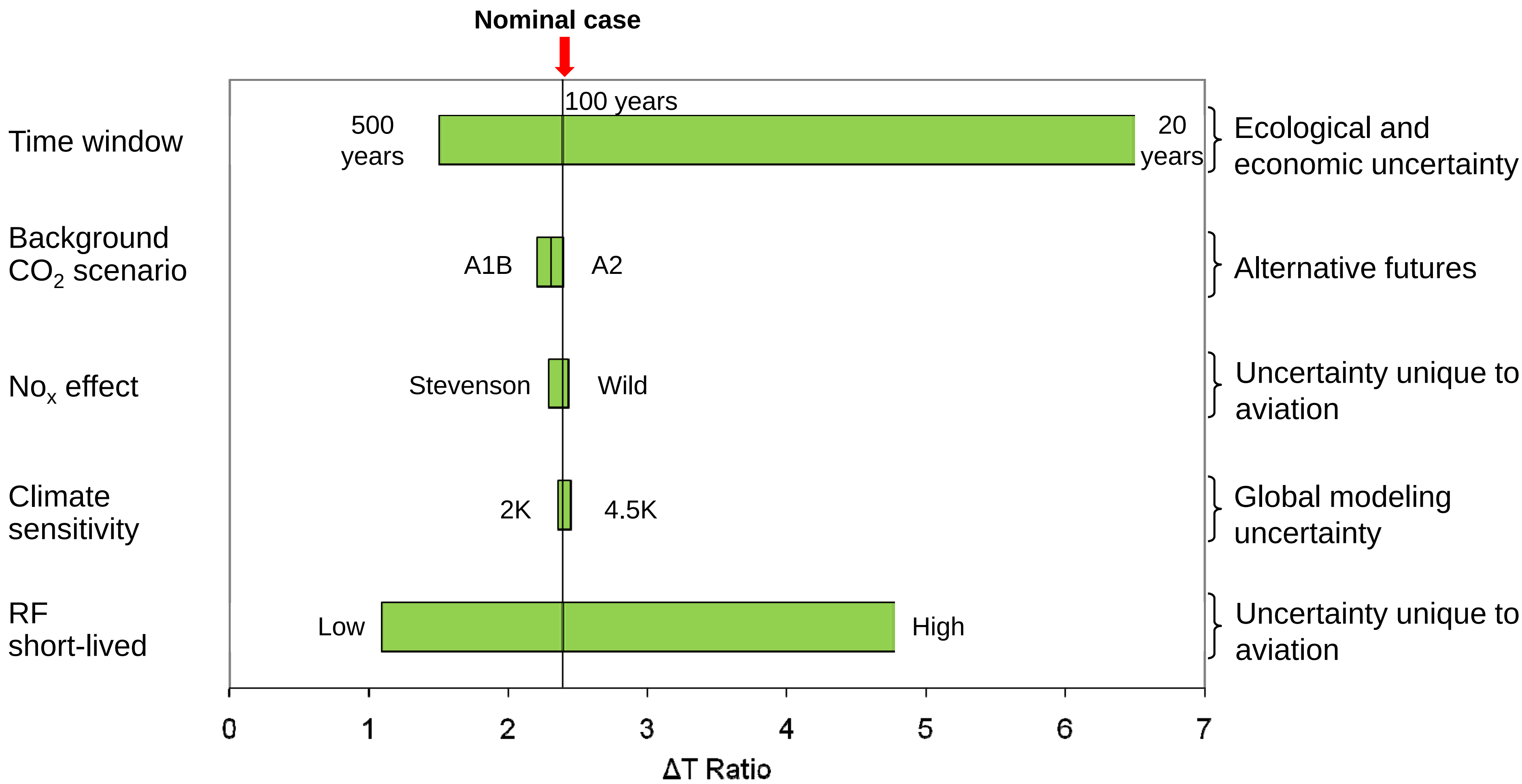
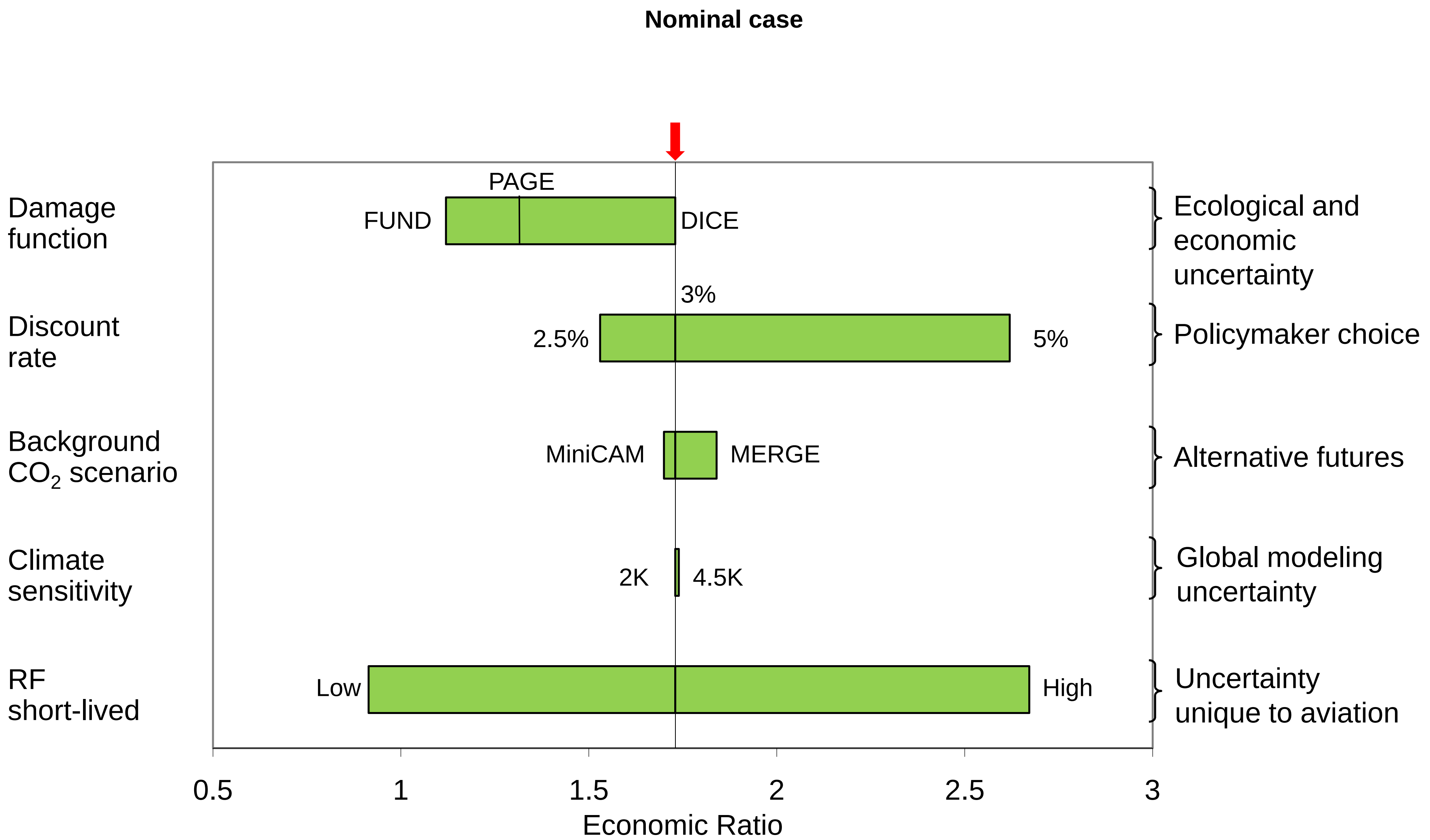
Influences on non-CO_2/CO_2 ratio: GWP metric



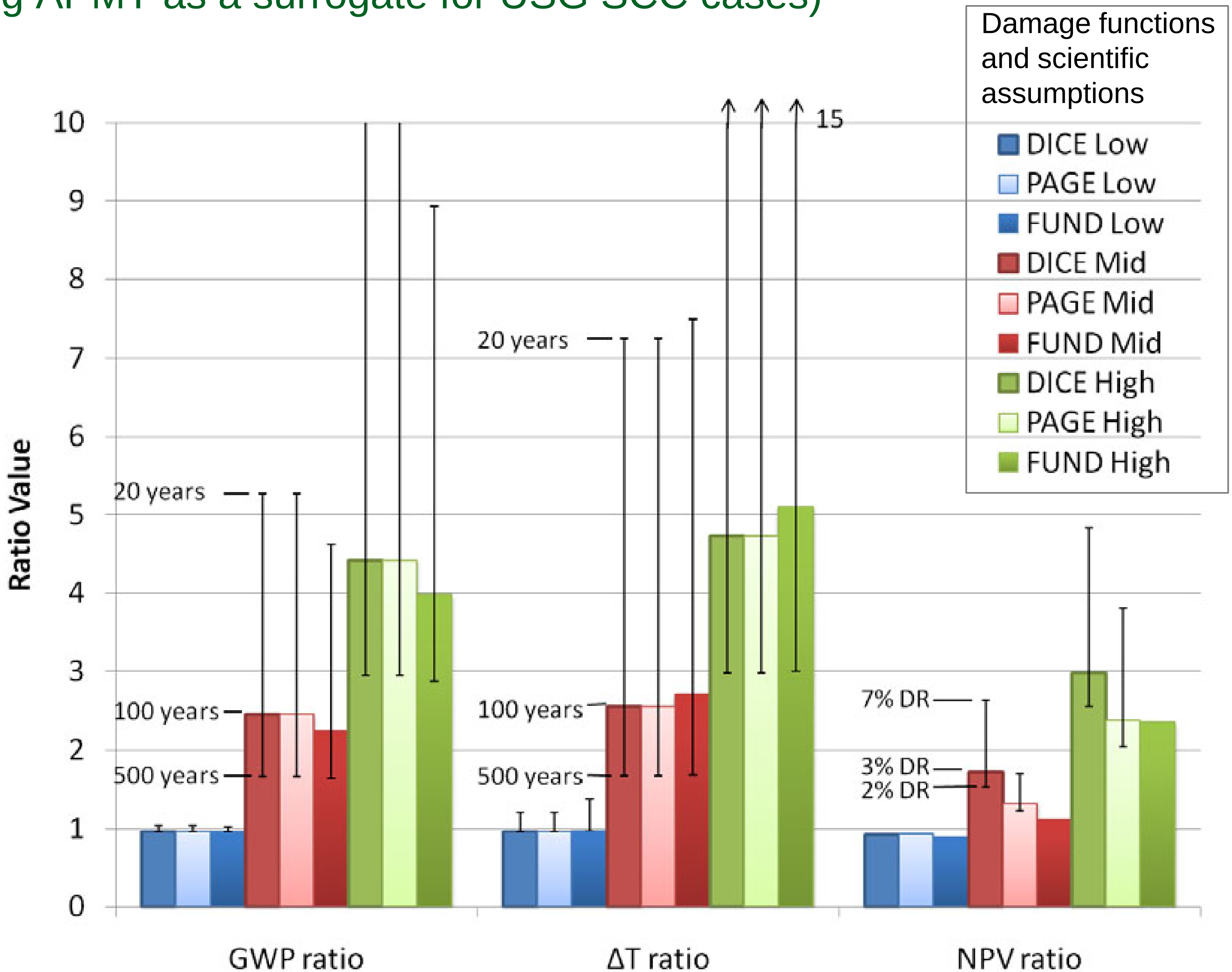
Influences on non-CO_2/CO_2 ratio: ΔT-yrs metric



Influences on non-CO2/CO2 ratio: NPV metric
using APMT as a surrogate for USG SCC cases



Influence of scientific uncertainties, metrics, and windowing/discounting
(using APMT as a surrogate for USG SCC cases)



Ratio and SCC change over time

- Annual growth rate on NPV ratios for analyses into the future
  - Additional units of CO_2 have less radiative forcing due to increased background concentration of CO_2 → denominator decreases

2% Discount Rate			3% Discount Rate			7% Discount Rate		
Low	Mid	High	Low	Mid	High	Low	Mid	High
0.2%	0.8%	1.0%	0.2%	1.1%	0.9%	0.2%	1.0%	0.6%

- US NHTSA recommends annual SCC growth rate of 2.4% for a discount rate of 3%*
- IPCC suggests increase of 2% to 4% per year on SCC
- APMT analysis suggests the following growth rates ought to be applied on the SCC as a function of discount rate:

2% Discount rate	3% Discount Rate	7% Discount Rate
1.3%	1.6%	3.6%

*US National Highway Traffic Safety Administration, values referenced from Final Regulatory Impact Analysis: Corporate Average Fuel Economy for MY 2011 Passenger Cars and Light Trucks