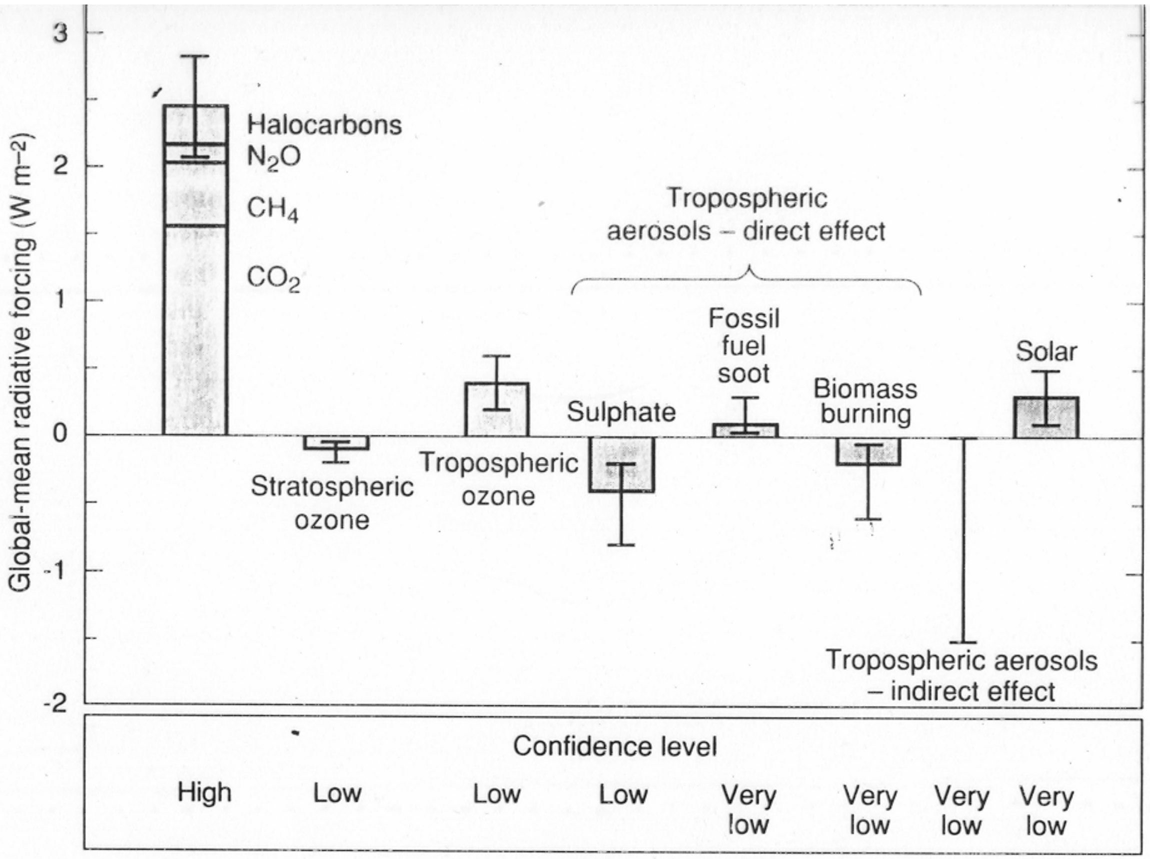


**Figure 2.16:** Estimates of the globally and annually averaged anthropogenic radiative forcing (in $Wm^{-2}$) due to changes in concentrations of greenhouse gases and aerosols from pre-industrial times to the present day and to natural changes in solar output from 1850 to the present day. The height of the rectangular bar indicates a mid-range estimate of the forcing whilst the error bars show an estimate of the uncertainty range, based largely on the spread of published values; our subjective confidence that the actual forcing lies within this error bar is indicated by the "confidence level". The contributions of individual gases to the direct greenhouse forcing is indicated on the first bar. The indirect greenhouse forcings associated with the depletion of stratospheric ozone and the increased concentration of tropospheric ozone are shown in the second and third bar respectively. The direct contributions of individual tropospheric aerosol components are grouped into the next set of three bars. The indirect aerosol effect, arising from the induced change in cloud properties, is shown next; our quantitative understanding of this process is very limited at present and hence no bar representing a mid-range estimate is shown. The final bar shows the estimate of the changes in radiative forcing due to variations in solar output. The forcing associated with stratospheric aerosols resulting from volcanic eruptions is not shown, as it is very variable over this time period; Figure 2.15 shows estimates of this variation. Note that there are substantial differences in the geographical distribution of the forcing due to the well-mixed greenhouse gases ($CO_2$, $N_2O$, $CH_4$ and the halocarbons) and that due to ozone and aerosols, which could lead to significant differences in their respective global and regional climate responses (see Chapter 6). For this reason, the negative radiative forcing due to aerosols should not necessarily be regarded as an offset against the greenhouse gas forcing.

(IPCC 1996) (WGI)

THE THIRD ASSESSMENT REPORT

# CROSS CUTTING ISSUES GUIDANCE PAPERS

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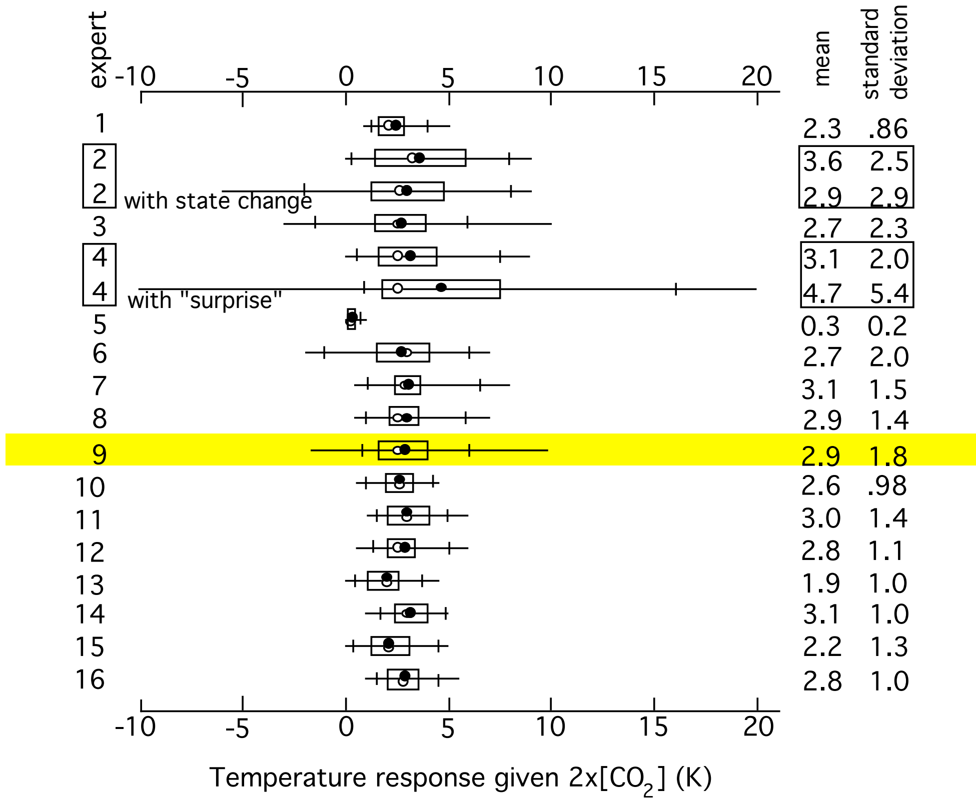
# An example:

David Keith and I conducted a set of expert elicitations among 16 leading climate scientists in 1994. The figure summarizes their estimates of climate sensitivity for a $2xCO^2$ climate change.




Source: Morgan and Keith, 1995.

At the end of the interview, after the experts had designed a \$$10^9$/yr 15yr research program designed to *reduce* this and other key uncertainties, we asked the experts to tell us how they thought their estimates of climate sensitivity might change.

# Overall…

…the experts estimated that, after a $\$10^9$/yr 15 year research program designed to *reduce* the key uncertainties we'd been discussing, the chances that the uncertainty in their best estimate of climate sensitivity might *grow* by > 25% ranged from a low of 8% to a high of 40%!

Like all experienced scientists, they knew that research does not always reduce uncertainty.

Source: Morgan and Keith, 1995.

| Expert Number | Chance climate sensitivity uncertainty grows >25% after a 15yr. $\$10^9$/yr research program |
|---|---|
| 1 | 10 |
| 2 | 18 |
| 3 | 30 (Note 1) |
| 4 | 22 |
| 5 | 30 |
| 6 | 14 |
| 7 | 20 |
| 8 | 25 |
| 9 | 12 |
| 10 | 20 |
| 11 | 40 |
| 12 | 16 |
| 13 | 12 |
| 14 | 18 |
| 15 | 14 |
| 16 | 8 |

Note 1: Expert 3 used a different response mode for this question. He gave a 30% of an increase by a factor of ≥2.5.

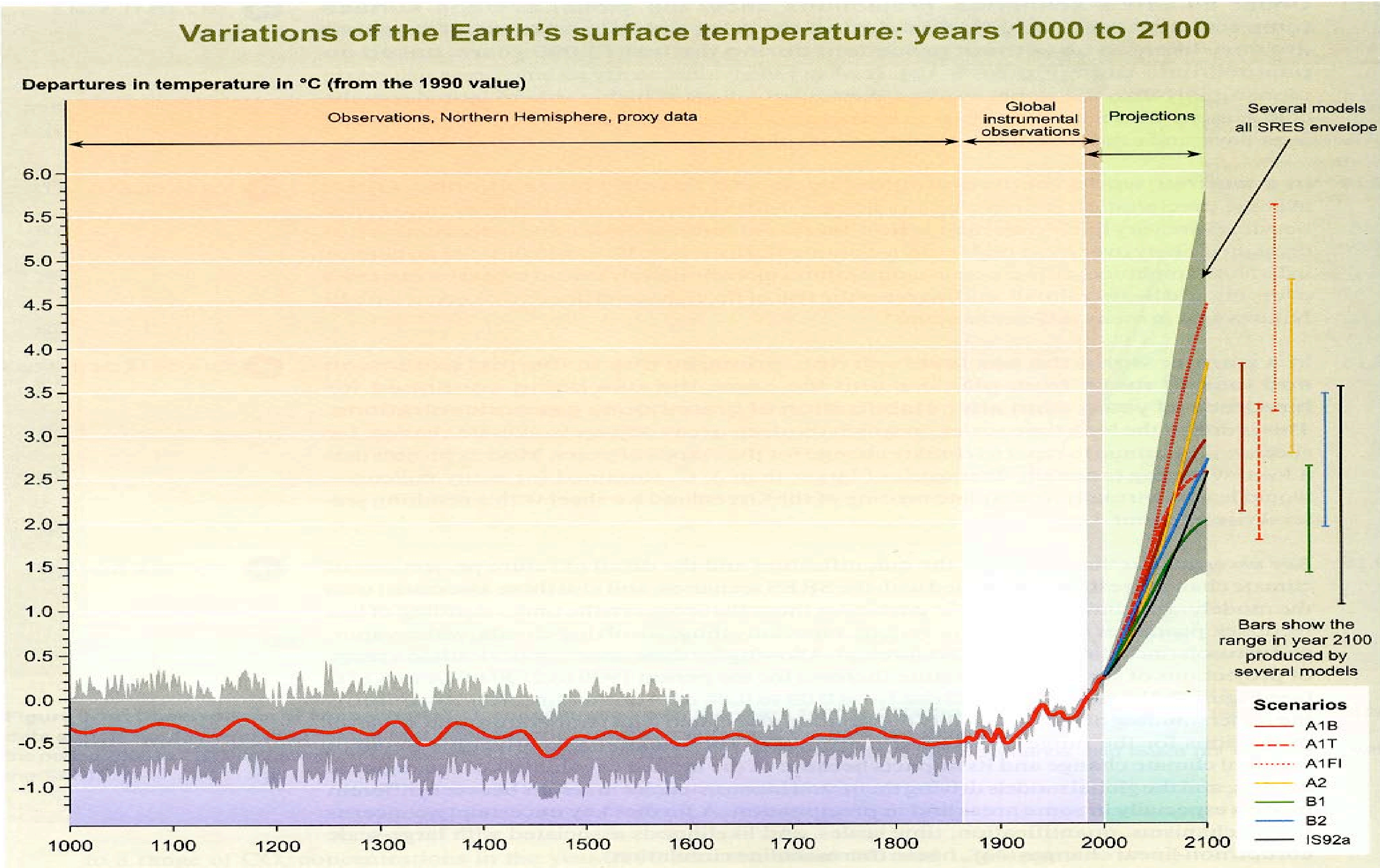



**Figure 9-1b: Variations of the Earth's surface temperature: years 1000 to 2100.** Over the period 1000 to 1860, observations are shown of variations in average surface temperature of the Northern Hemisphere (corresponding data from the Southern Hemisphere not available) constructed from proxy data (tree rings, corals, ice cores, and historical records). The line shows the 50-year average, and the grey region the 95% confidence limit in the annual data. From the years 1860 to 2000, observations are shown of variations of global and annual averaged surface temperature from the instrumental record. The line shows the decadal average. Over the period 2000 to 2100, projections are shown of globally averaged surface temperature for the six illustrative SRES scenarios and IS92a as estimated by a model with average climate sensitivity. The grey region "several models all SRES envelope" shows the range of results from the full range of 35 SRES scenarios in addition to those from a range of models with different climate sensitivities.

WGI TAR SPM Figures 1b & 5d

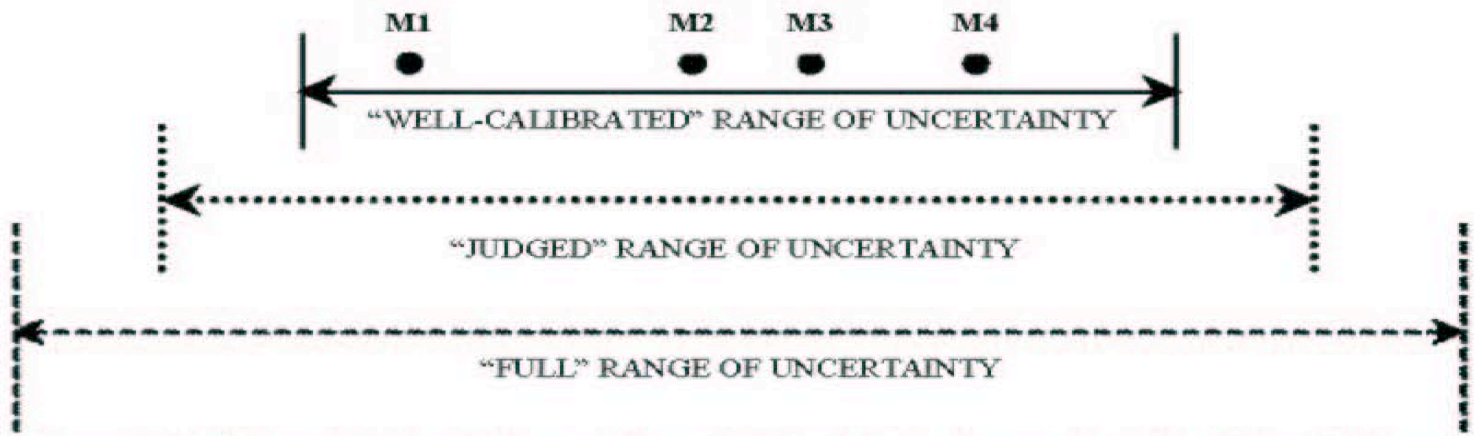



**Figure 2**. Schematic depiction of the relationship between "well-calibrated" scenarios, the wider range of "judged" uncertainty that might be elicited through decision analytic survey techniques, and the "full" range of uncertainty, which is drawn wider to represent overconfidence in human judgments. M1 to M4 represent scenarios produced by four models (e.g., globally averaged temperature increases from an equilibrium response to doubled $CO_2$ concentrations). This lies within a "full" range of uncertainty that is not fully identified, much less directly quantified by existing theoretical or empirical evidence[i]. (from Schneider and Kuntz-Duriseti, 2002).

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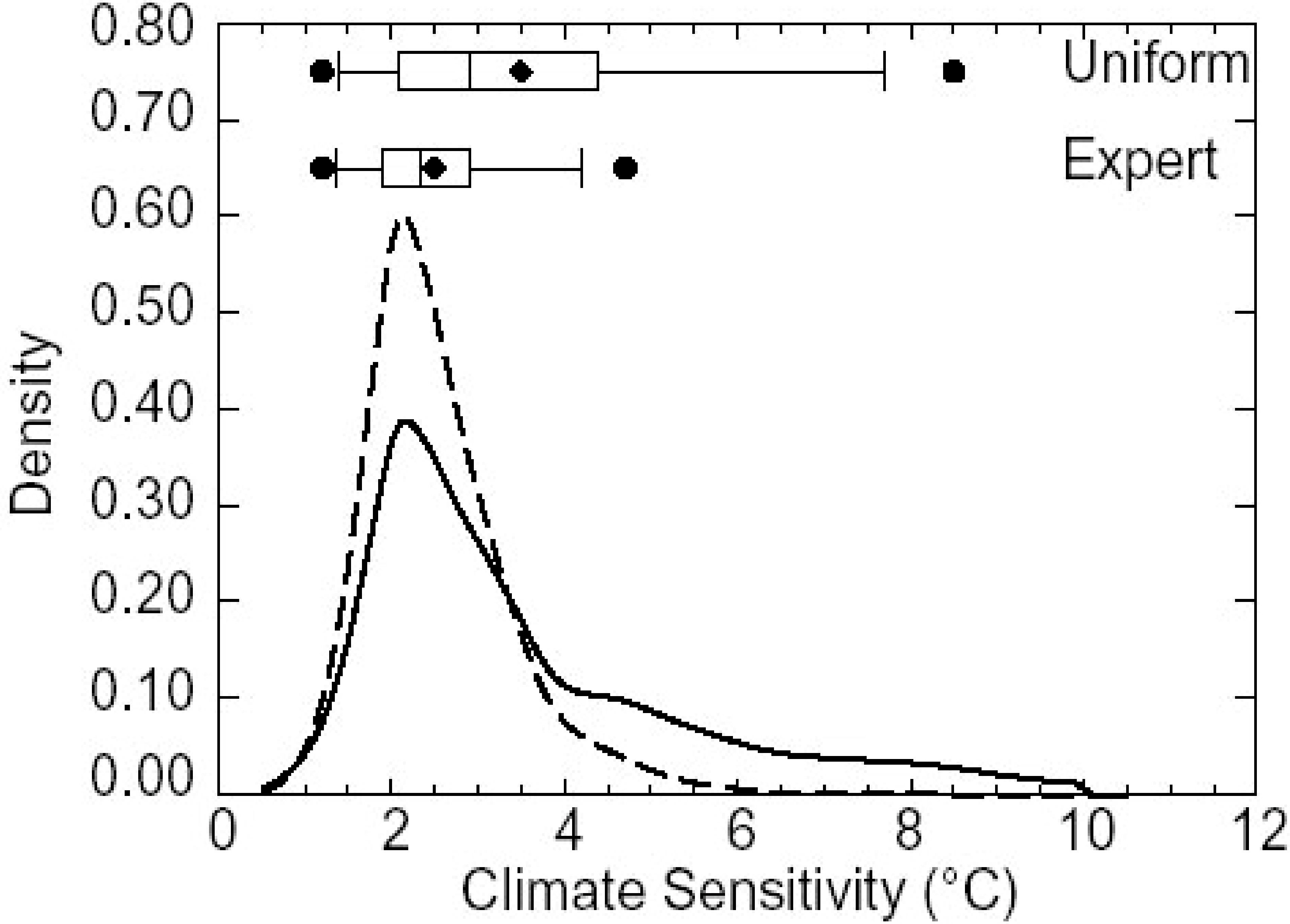
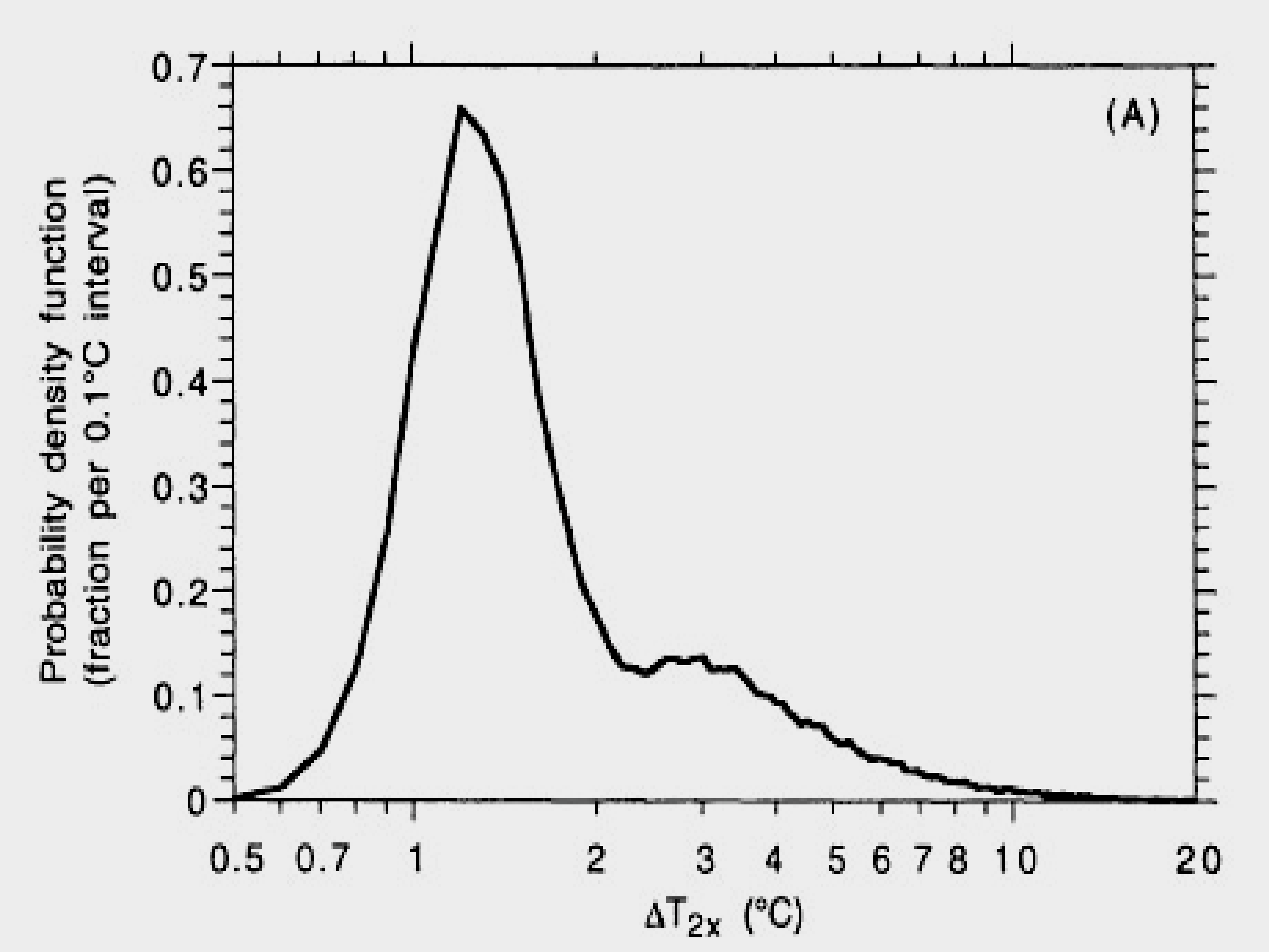
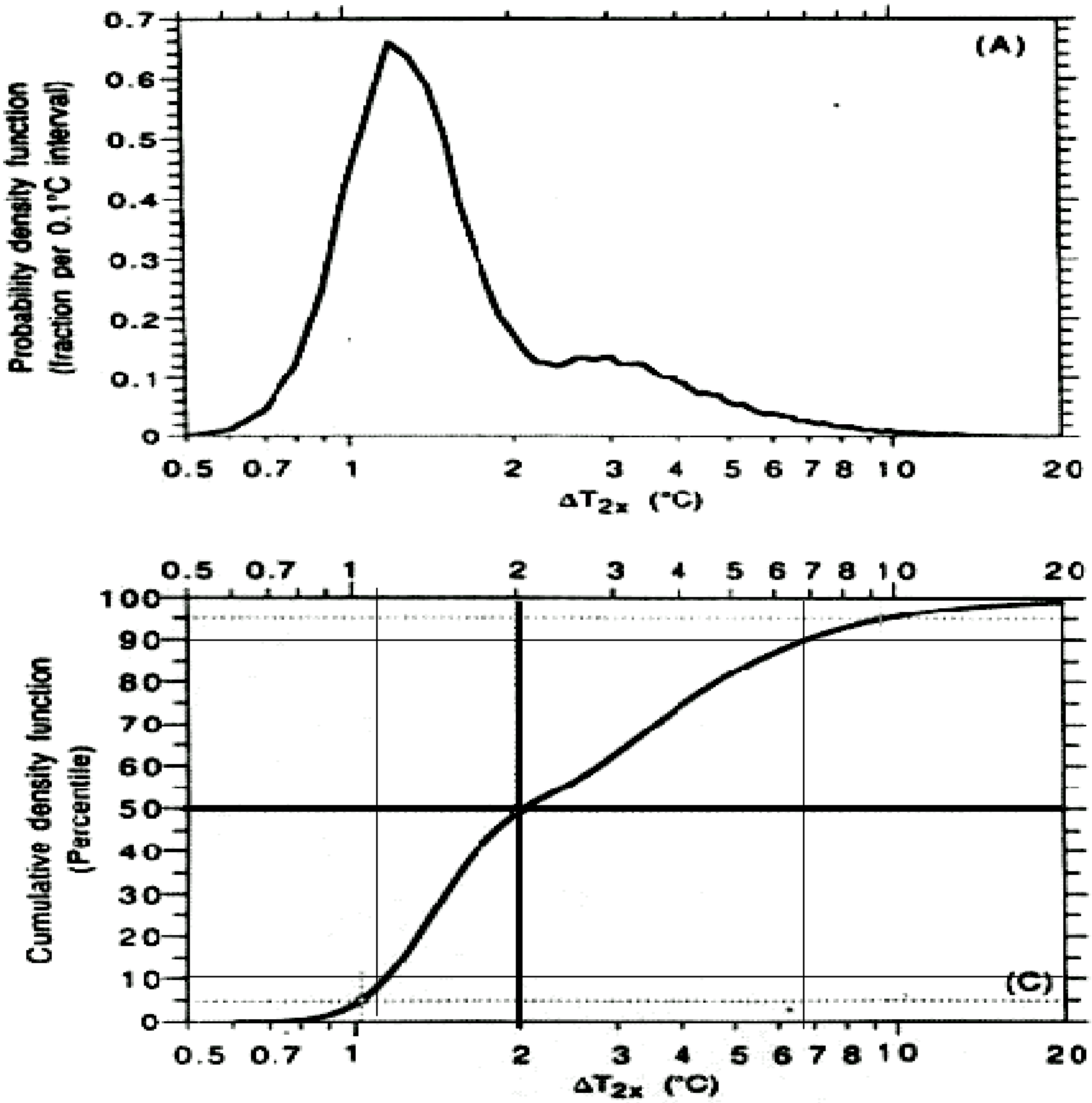
[i] Jones, R.N., 2000: Managing uncertainty in climate change projections: Issues for impact assessment. An editorial comment. Climatic Change 45(3-4): 403-419.



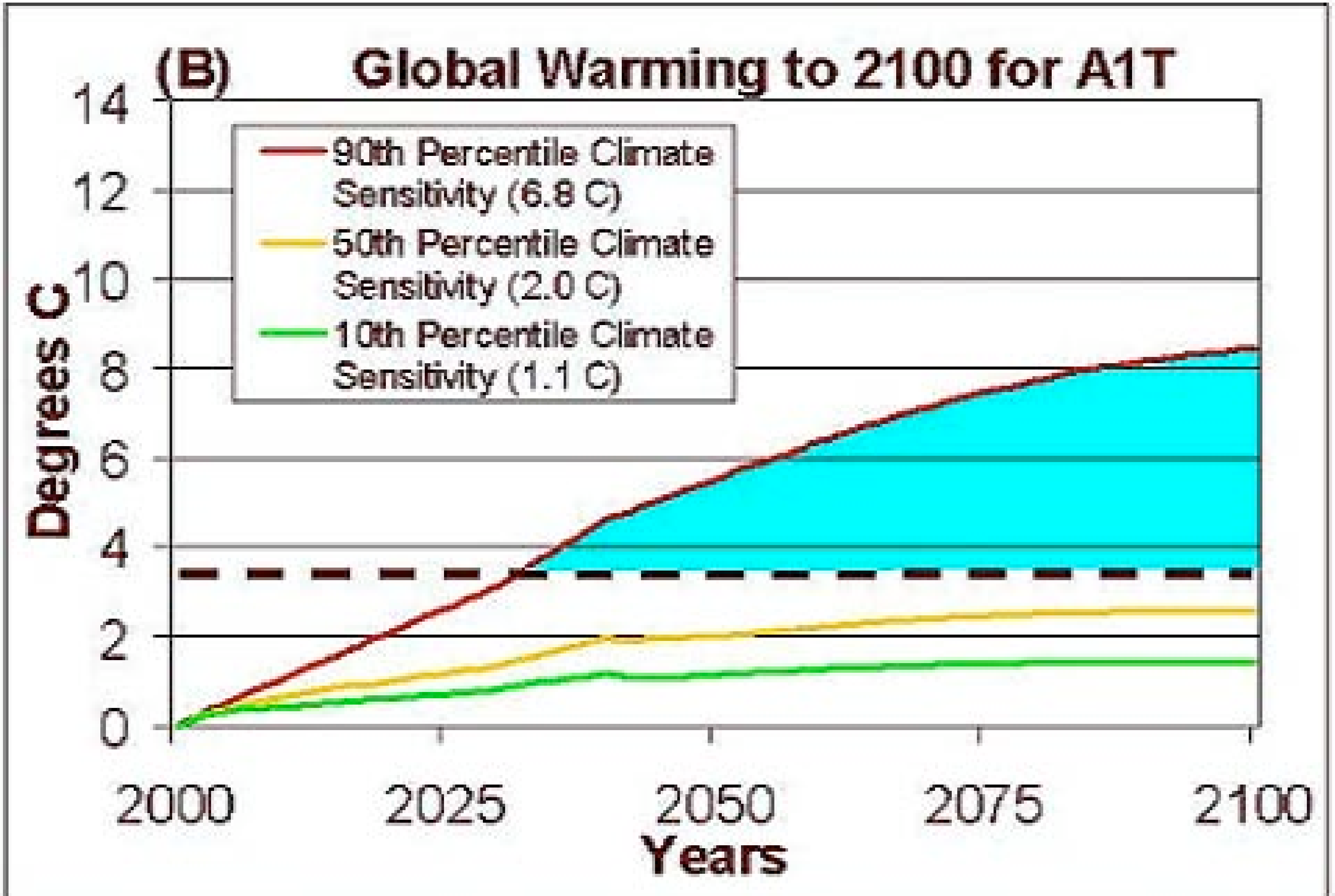
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Density
Uniform
Expert
0
2
4
6
8
10
12
Climate Sensitivity (°C)



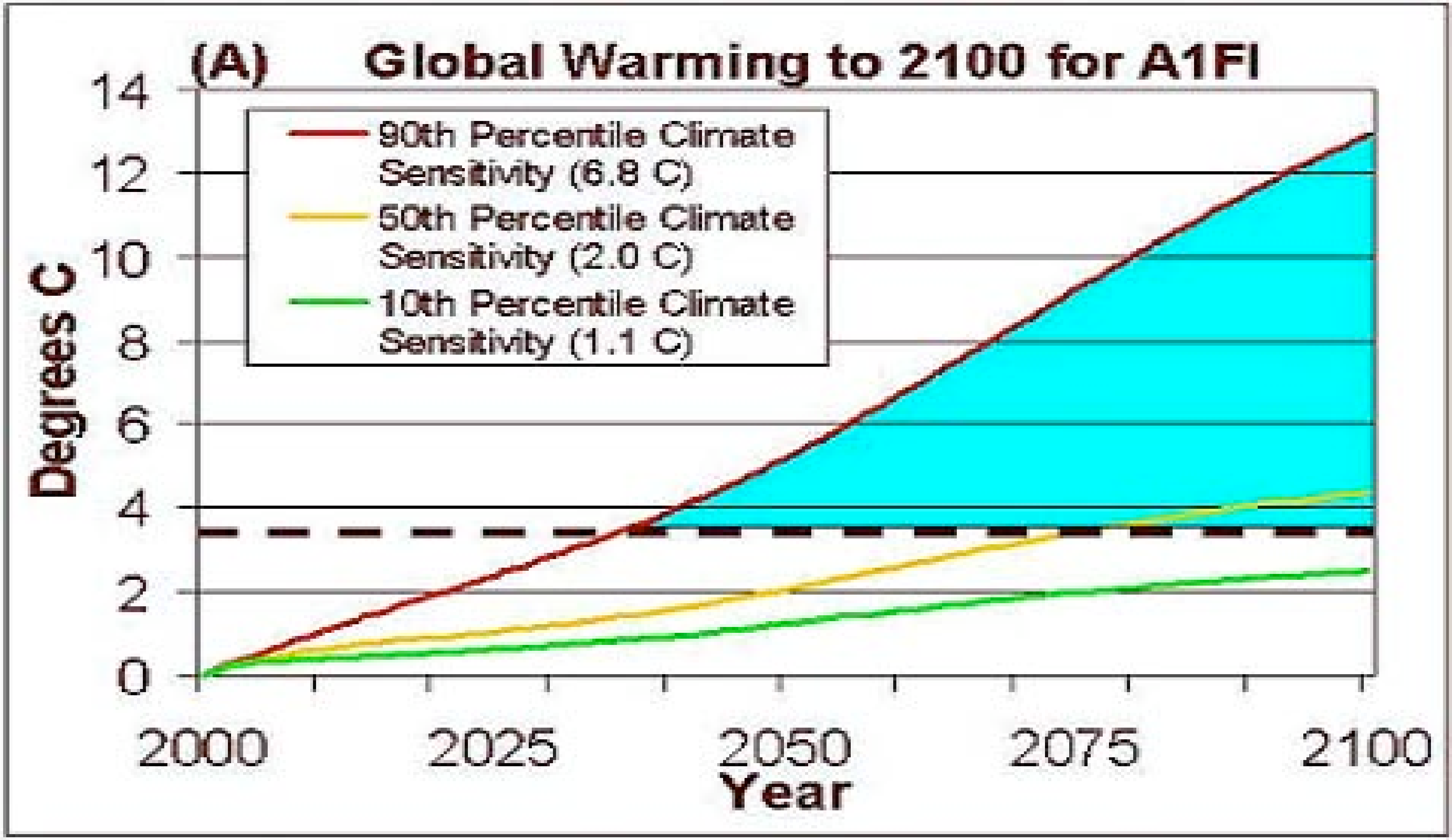
(A)
Probability density function (fraction per 0.1°C interval)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.5
0.7
1
2
3
4
5
6
7
8
10
20
$\Delta T_{2x}$ (°C)



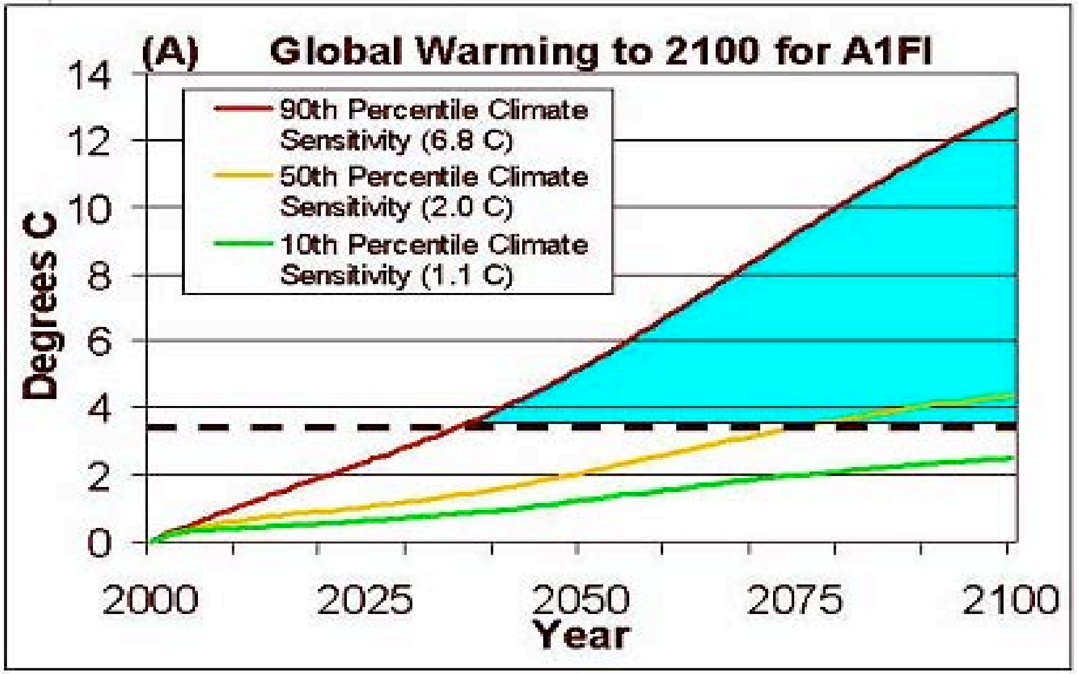
(A)
Probability density function
(fraction per 0.1°C interval)
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7
0.5 0.7 1 2 3 4 5 6 7 8 10 20
ΔT2x (°C)
(C)
Cumulative density function
(Percentile)
0 10 20 30 40 50 60 70 80 90 100
0.5 0.7 1 2 3 4 5 6 7 8 10 20
ΔT2x (°C)

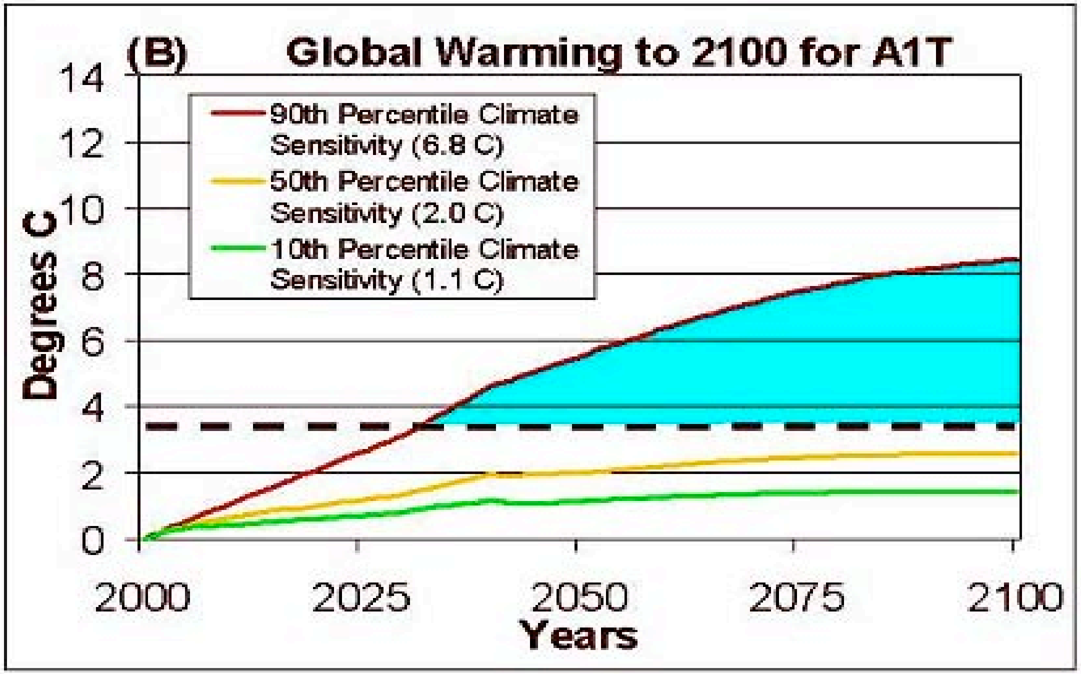


(B) Global Warming to 2100 for A1T
14
12
10
8
6
4
2
0
Degrees C
90th Percentile Climate Sensitivity (6.8 C)
50th Percentile Climate Sensitivity (2.0 C)
10th Percentile Climate Sensitivity (1.1 C)
2000
2025
2050
2075
2100
Years



(A) Global Warming to 2100 for A1FI
90th Percentile Climate Sensitivity (6.8 C)
50th Percentile Climate Sensitivity (2.0 C)
10th Percentile Climate Sensitivity (1.1 C)
Degrees C
14
12
10
8
6
4
2
0
2000
2025
2050
2075
2100
Year


(A) Global Warming to 2100 for A1FI
90th Percentile Climate Sensitivity (6.8 C)
50th Percentile Climate Sensitivity (2.0 C)
10th Percentile Climate Sensitivity (1.1 C)
Degrees C
0
2
4
6
8
10
12
14
2000
2025
2050
2075
2100
Year


(B) Global Warming to 2100 for A1T
90th Percentile Climate Sensitivity (6.8 C)
50th Percentile Climate Sensitivity (2.0 C)
10th Percentile Climate Sensitivity (1.1 C)
Degrees C
0
2
4
6
8
10
12
14
2000
2025
2050
2075
2100
Years

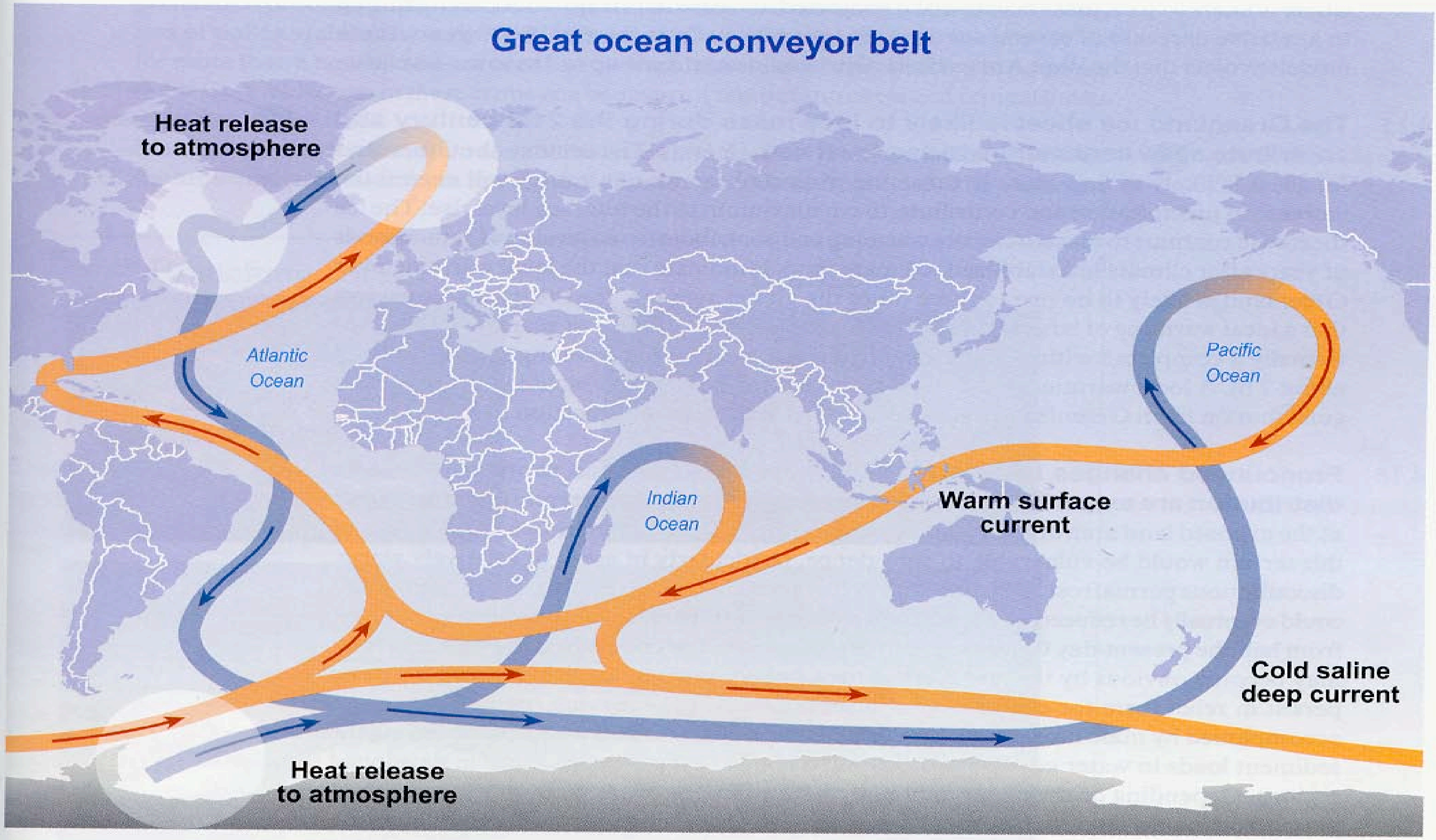



**Figure 4-2: Schematic illustration of the global circulation system in the world ocean consisting of major north-south thermohaline circulation routes in each ocean basin joining in the Antarctic circumpolar circulation.** Warm surface currents and cold deep currents are connected in the few areas of deepwater formation in the high latitudes of the Atlantic and around Antarctica (blue), where the major ocean-to-atmosphere heat transfer occurs. This current system contributes substantially to the transport and redistribution of heat (e.g., the poleward flowing currents in the North Atlantic warm northwestern Europe by up to 10°C). Model simulations indicate that the North Atlantic branch of this circulation system is particularly vulnerable to changes in atmospheric temperature and in the hydrological cycle. Such perturbations caused by global warming could disrupt the current system, which would have a strong impact on regional-to-hemispheric climate. Note that this is a schematic diagram and it does not give the exact locations of the water currents that form part of the THC.

Thermohaline Catastrophe Behavior

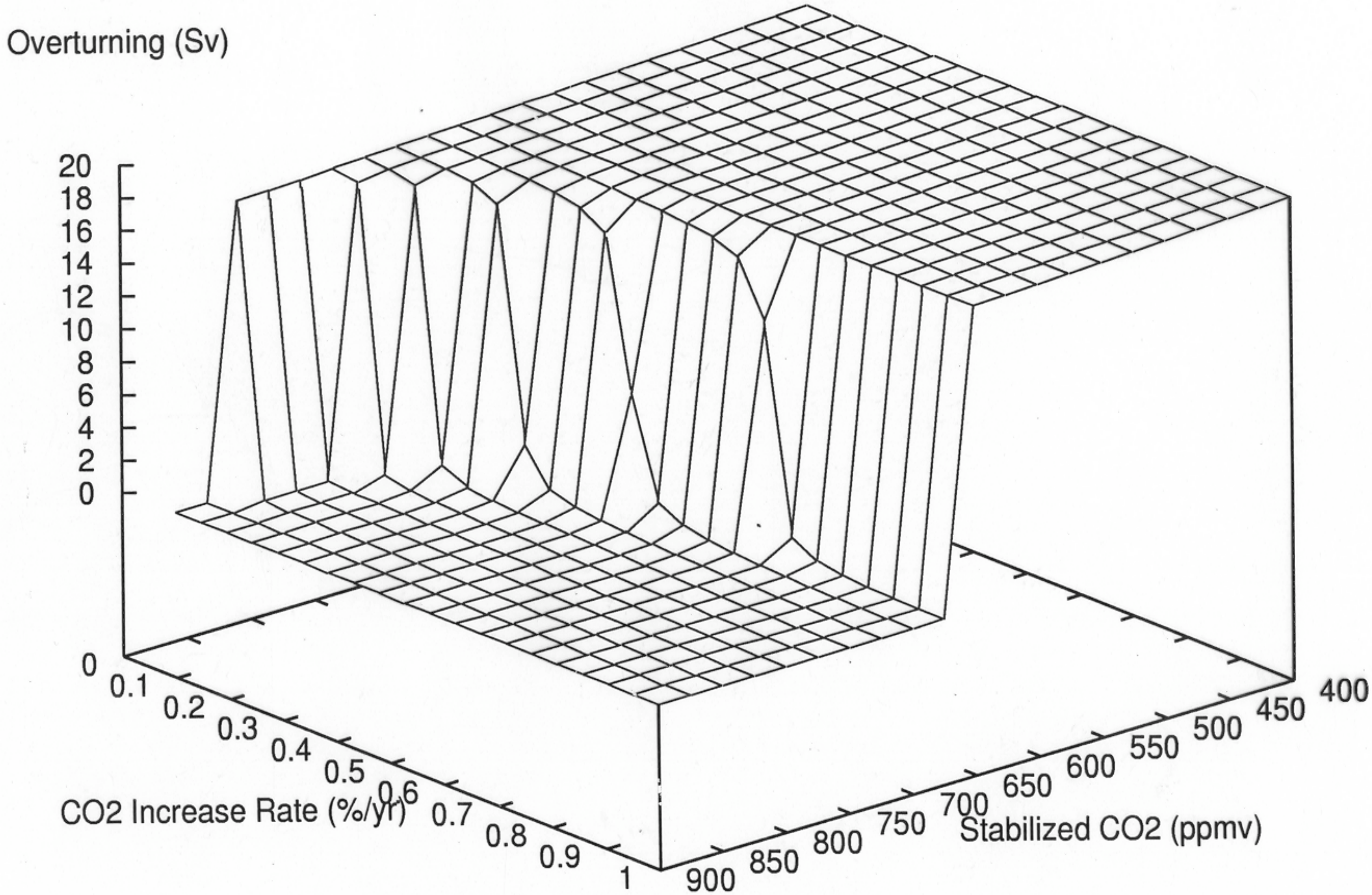
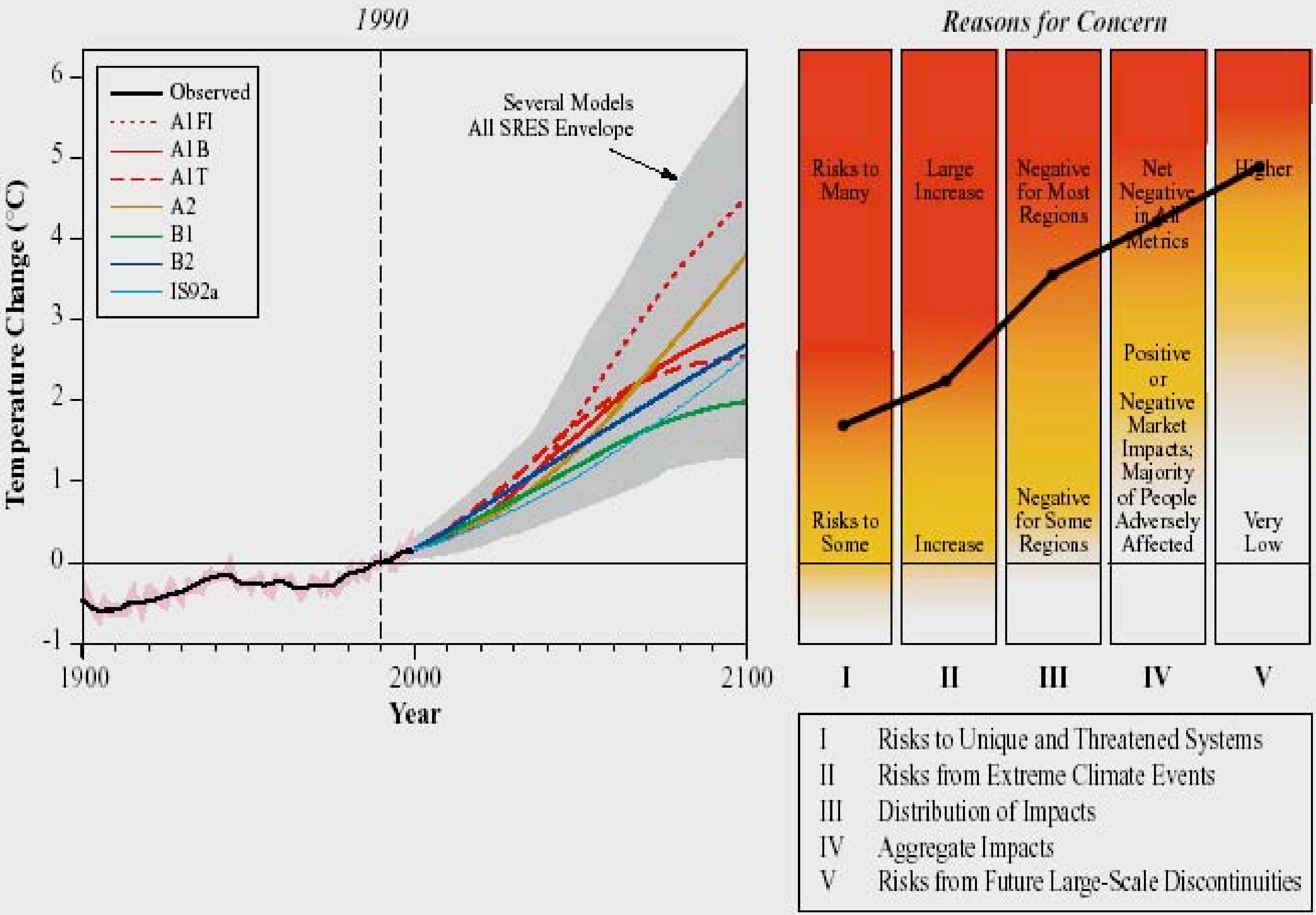



Figure 11

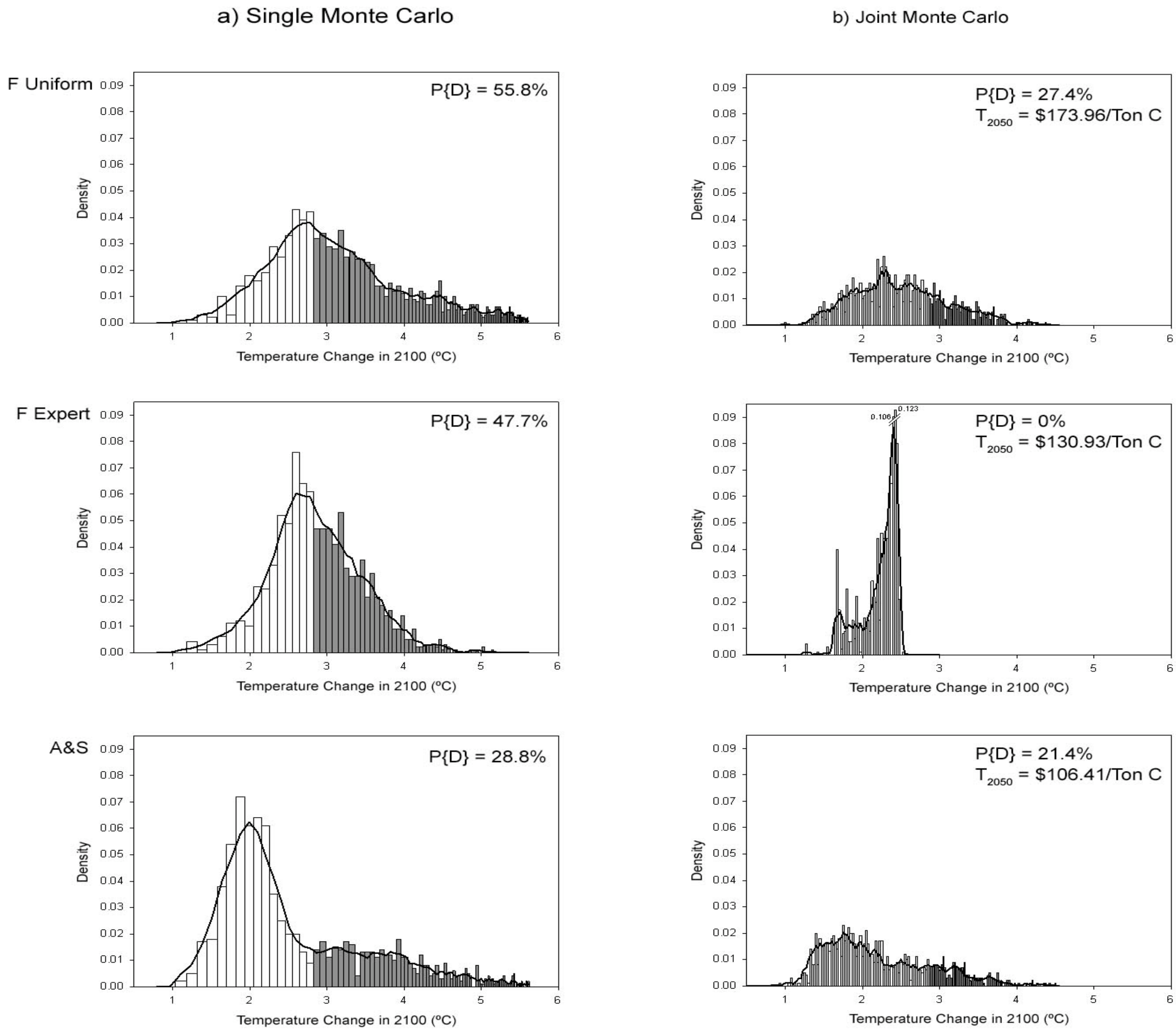
# Reasons for Concern About Climate Change Impacts.



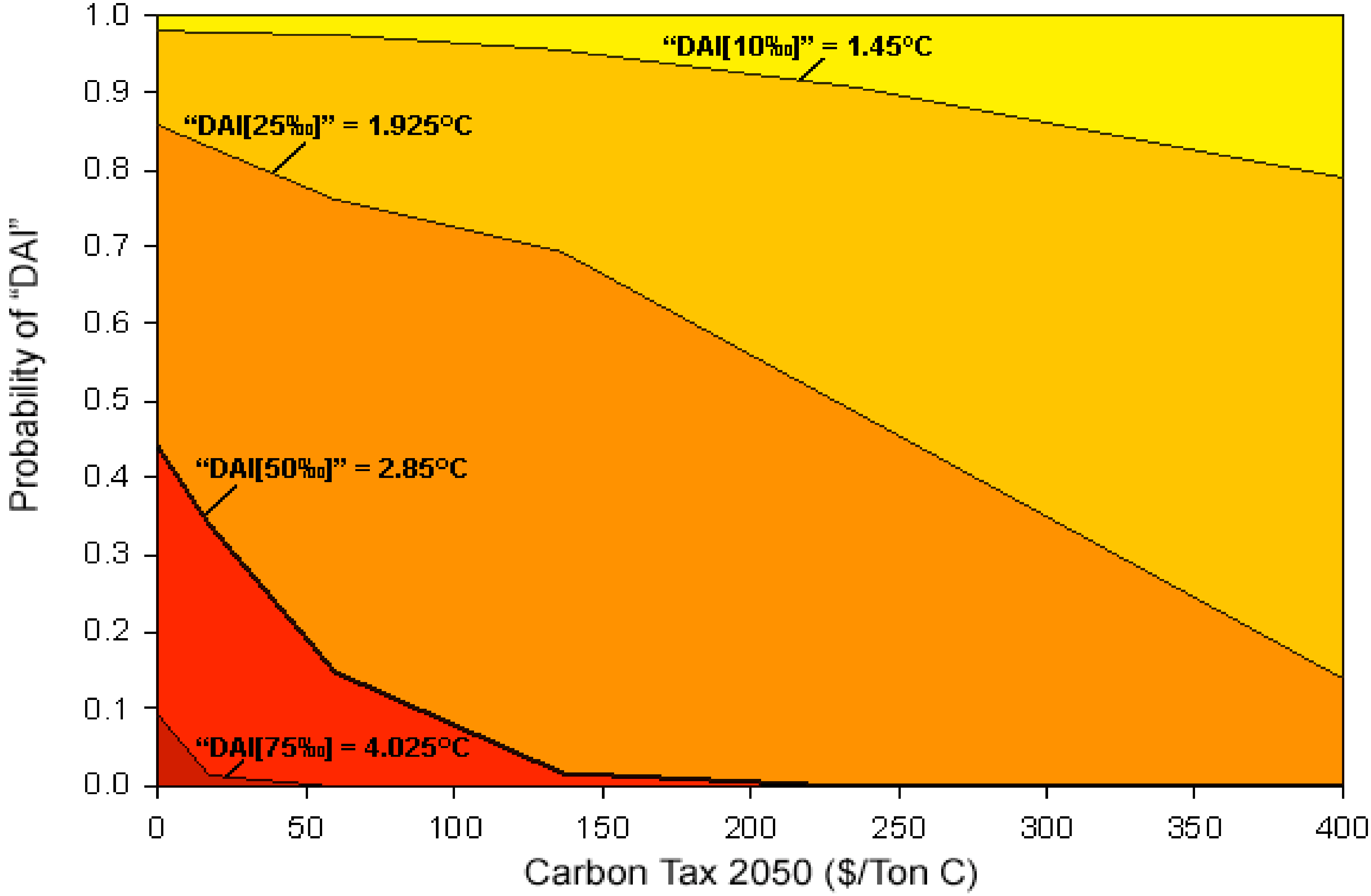
# What is the probability of dangerous climate change?

**This elicits three fundamental questions:**

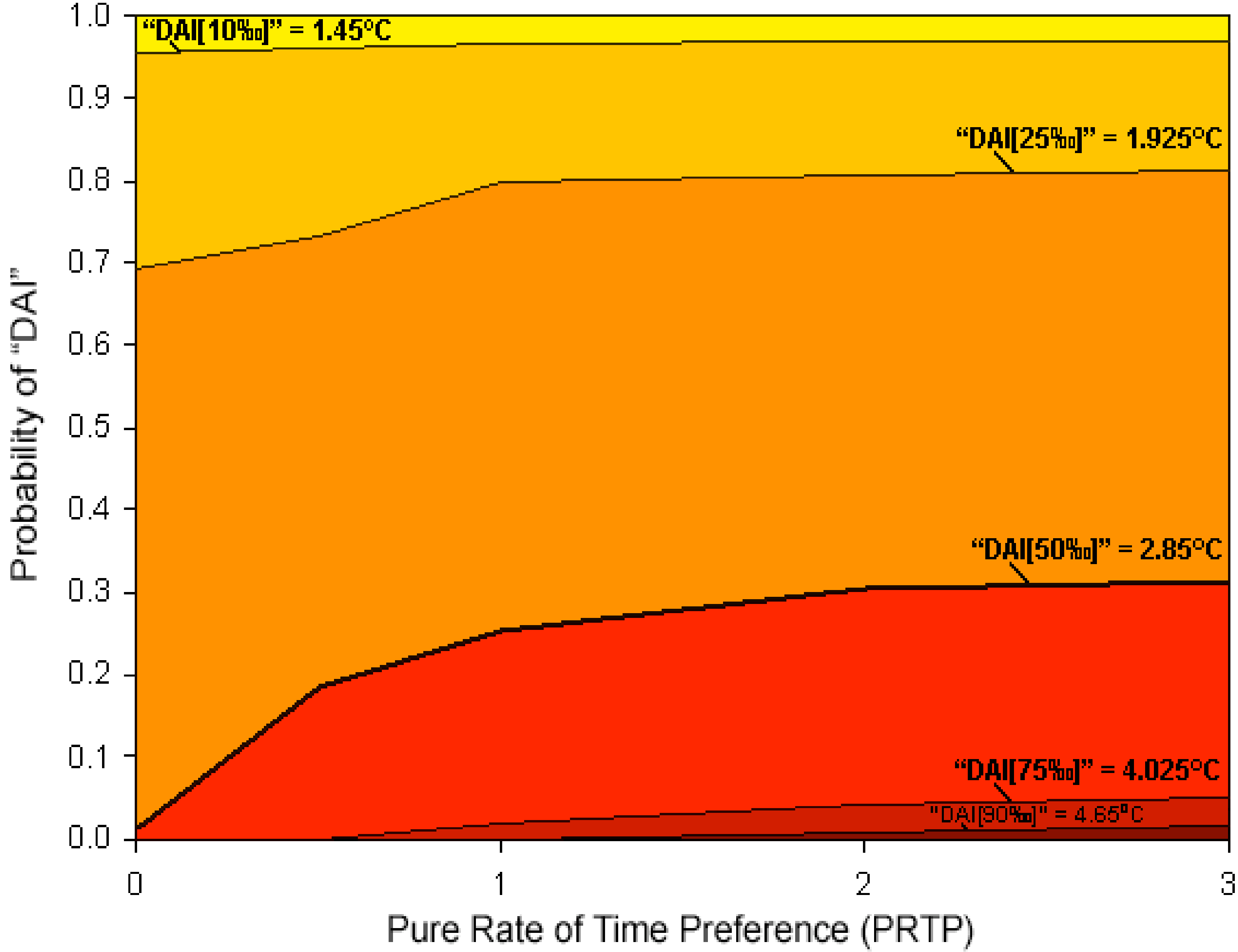
- What is “dangerous” climate change?
- What sorts of climate change scenarios are out there, and how do we assign probabilities to them?
- What “solutions” have been proposed, and how are they affected by projected probabilities and consequences (or lack thereof)?



a) Single Monte Carlo
b) Joint Monte Carlo
F Uniform
P{D} = 55.8%
P{D} = 27.4%
T2050 = $173.96/Ton C
F Expert
P{D} = 47.7%
P{D} = 0%
T2050 = $130.93/Ton C
0.106
0.123
A&S
P{D} = 28.8%
P{D} = 21.4%
T2050 = $106.41/Ton C
Density
Temperature Change in 2100 (ºC)



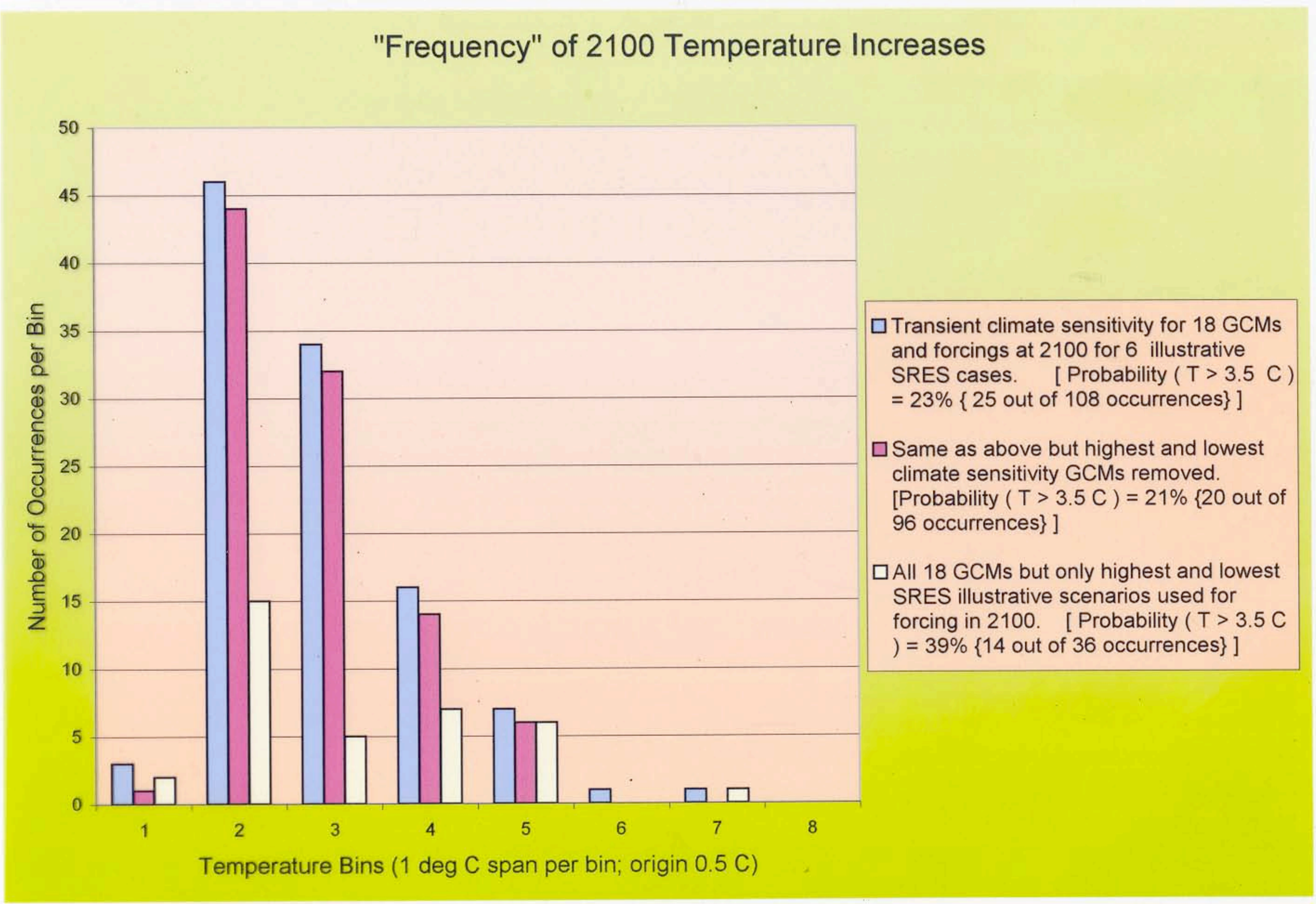
“DAI[10%]” = 1.45°C
“DAI[25%]” = 1.925°C
“DAI[50%]” = 2.85°C
“DAI[75%] = 4.025°C
Probability of “DAI”
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
50
100
150
200
250
300
350
400
Carbon Tax 2050 ($/Ton C)



"DAI[10%ile]" = 1.45°C
"DAI[25%ile]" = 1.925°C
"DAI[50%ile]" = 2.85°C
"DAI[75%ile]" = 4.025°C
"DAI[90%ile]" = 4.65°C
Probability of "DAI"
Pure Rate of Time Preference (PRTP)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
1
2
3

## Type 1 versus Type 2 errors and their consequences

| **Decision** | Forecast proves false | Forecast proves true |
|---|---|---|
| Accept forecast—policy response follows | **Type I error** | Correct decision |
| Reject or ignore forecast—no policy response | Correct Decision | **Type 2 error** |


"Frequency" of 2100 Temperature Increases
Number of Occurrences per Bin
0
5
10
15
20
25
30
35
40
45
50
1
2
3
4
5
6
7
8
Temperature Bins (1 deg C span per bin; origin 0.5 C)
Transient climate sensitivity for 18 GCMs and forcings at 2100 for 6 illustrative SRES cases. [ Probability ( T > 3.5 C ) = 23% { 25 out of 108 occurrences} ]
Same as above but highest and lowest climate sensitivity GCMs removed. [Probability ( T > 3.5 C ) = 21% {20 out of 96 occurrences} ]
All 18 GCMs but only highest and lowest SRES illustrative scenarios used for forcing in 2100. [ Probability ( T > 3.5 C ) = 39% {14 out of 36 occurrences} ]

# The inadequacy of qualitative language

Qualitative uncertainty language (i.e., words such as "likely" and "unlikely") is inadequate for use in policy and decision making because:

- the same words can mean very different things to different people;
- the same words can mean very different things to the same person in different contexts;
- important differences in experts' judgments about mechanisms (functional relationships), and about how well key coefficients are known, can be easily masked in qualitative discussions.

# Words mean different things to different people

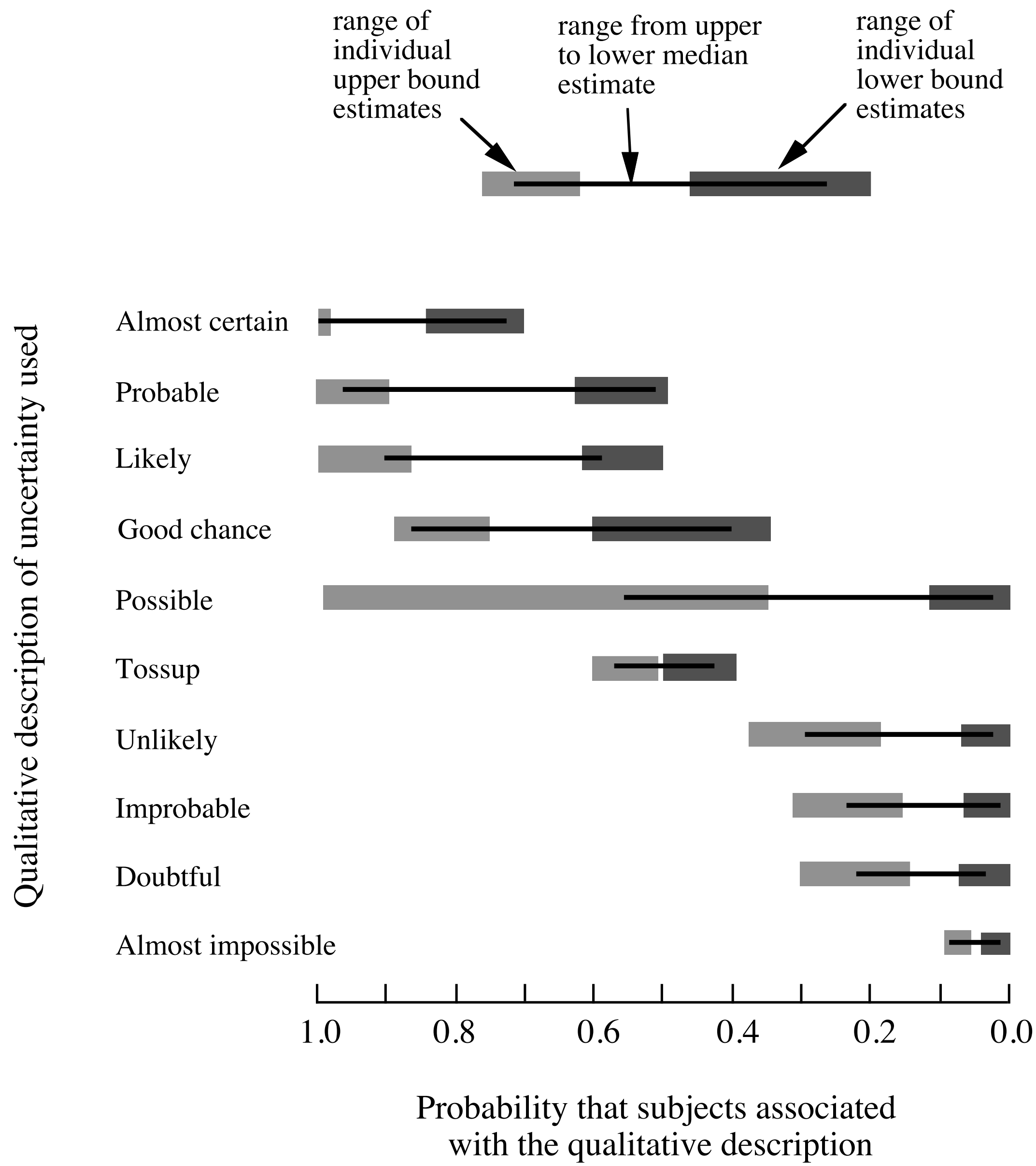



Figure adapted from Wallsten et al., 1986

# Ex Com of EPA SAB

The minimum probability associated with the word "likely" spaned four orders of magnitude.

The maximum probability associated with the word "not likely" spaned more than five orders of magnitude.

There was an overlap of the probability associated with the word "likely" and that associated with the word "unlikely"!


Figure from Morgan, 1998.

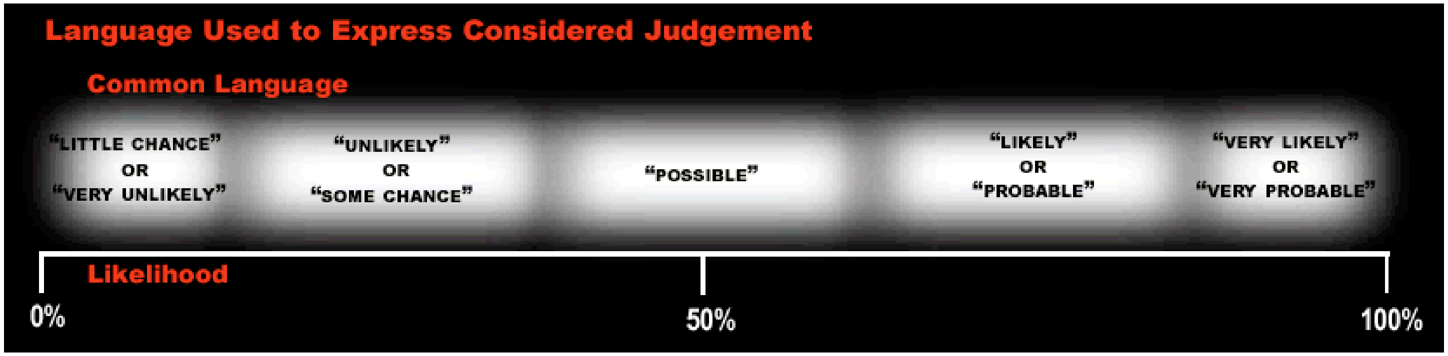
# The bottom line

Without at least some quantification, qualitative descriptions of uncertainty convey little, if any, useful information.

The climate assessment community is gradually learning this lesson.

As he'll shortly explain, Schneider and colleagues have worked to get a better treatment of uncertainty incorporated in the past and current rounds of IPCC. Progress is uneven, but awareness is growing. Individual investigators are pushing the process along.

At Morgan's insistence, US national assessment synthesis team gave quantitative definitions to five probability words and tried to use them consistently throughout the overview report.



THE THIRD ASSESSMENT REPORT

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**Box 2**

**Examples of sources of uncertainty**

*Problems with data*

1. Missing components or errors in the data
2. "Noise" in the data associated with biased or incomplete observations
3. Random sampling error and biases (non-representativeness) in a sample

*Problems with models*

4. Known processes but unknown functional relationships or errors in the structure of the model
5. Known structure but unknown or erroneous values of some important parameters
6. Known historical data and model structure, but reasons to believe parameters or model structure will change over time
7. Uncertainty regarding the predictability (e.g., chaotic or stochastic behavior) of the system or effect
8. Uncertainties introduced by approximation techniques used to solve a set of equations that characterize the model.

*Other sources of uncertainty*

9. Ambiguously defined concepts and terminology
10. Inappropriate spatial/temporal units
11. Inappropriateness of/lack of confidence in underlying assumptions
12. Uncertainty due to projections of human behavior (e.g., future consumption patterns, or technological change), which is distinct from uncertainty due to "natural" sources (e.g., climate sensitivity, chaos)

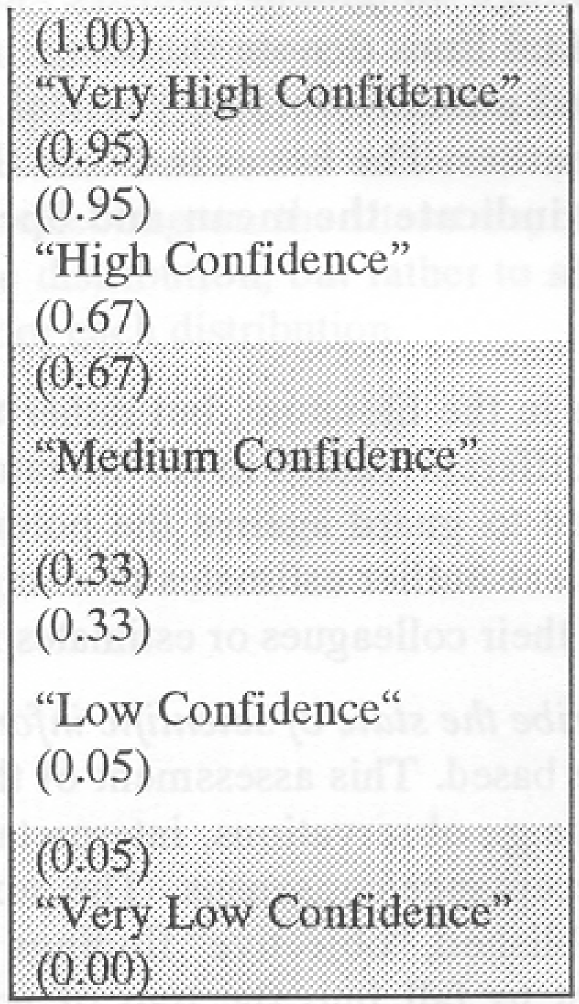



Figure 3. Scale for Assessing State of Knowledge

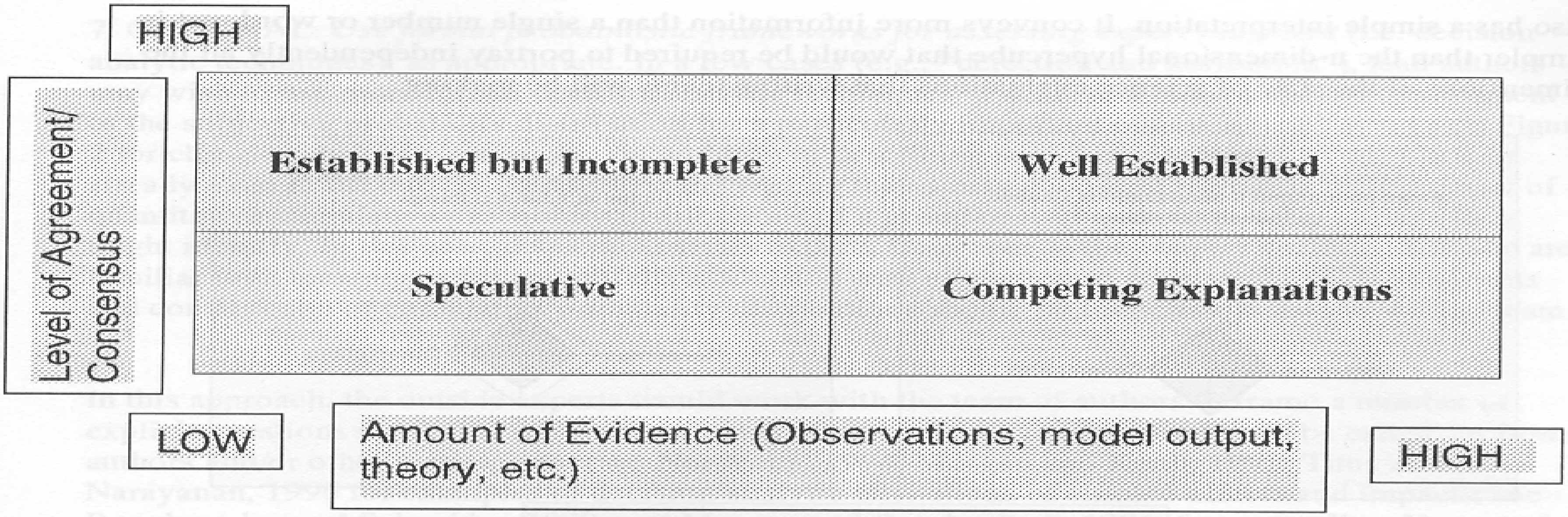



**Figure 4. Supplemental Qualitative Uncertainty Terms.**

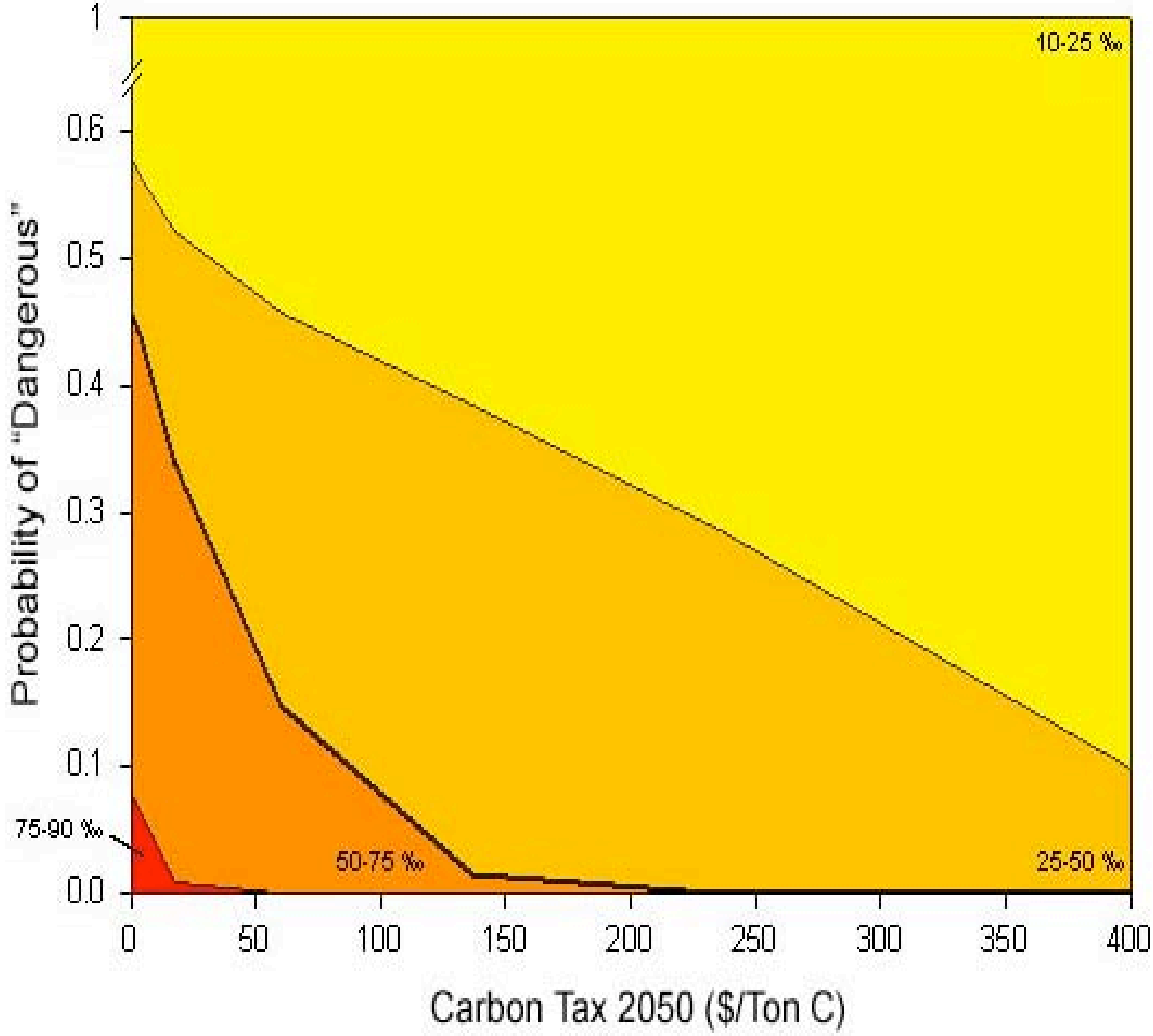
**Key to qualitative "state of knowledge" descriptors:**

***Well-established*: models incorporate known processes; observations largely consistent with models for important variables; or multiple lines of evidence support the finding)**

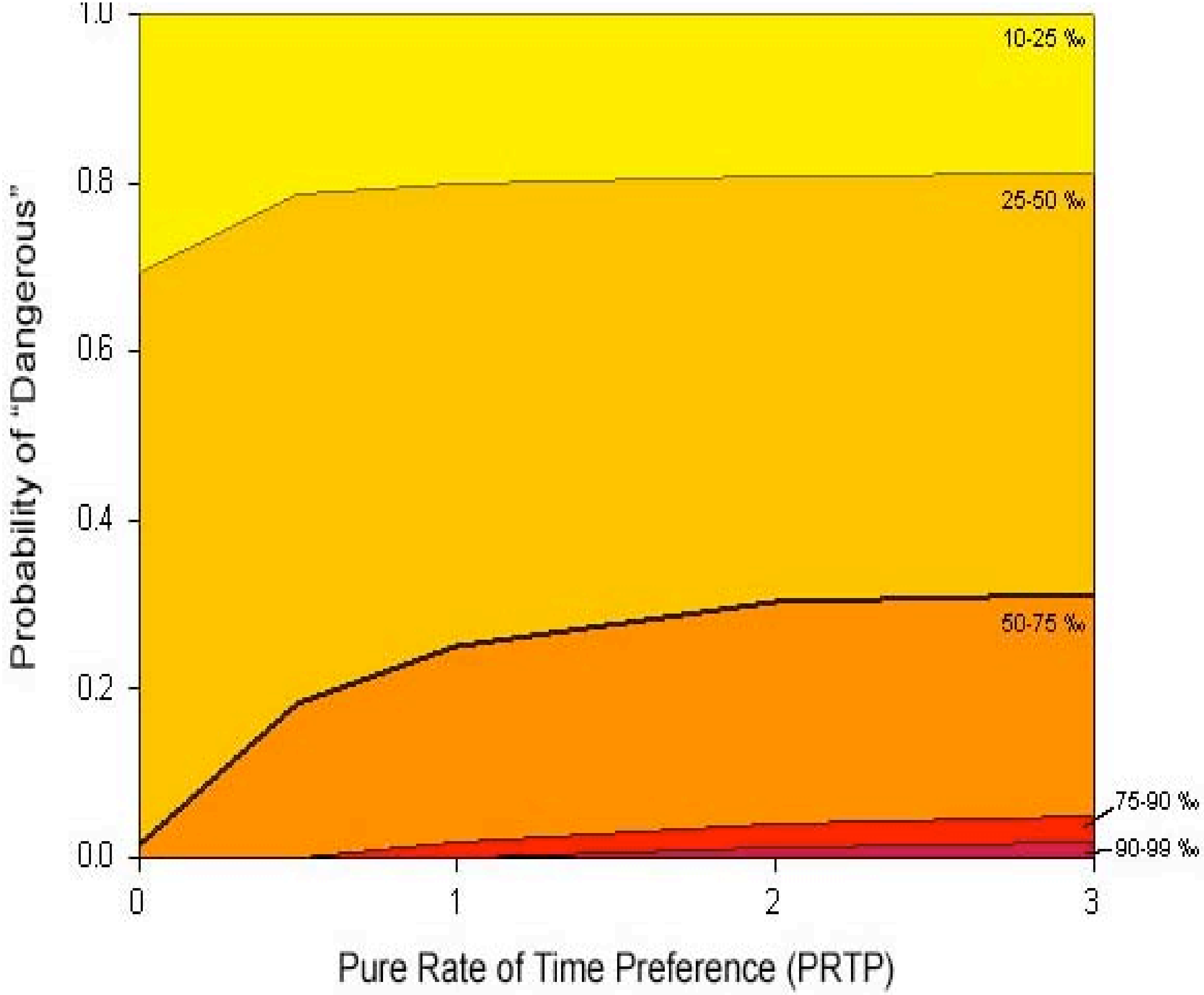
***Established but Incomplete:* models incorporate most known processes, although some parameterizations may not be well tested; observations are somewhat consistent with theoretical or model results but incomplete; current empirical estimates are well founded, but the possibility of changes in governing processes over time is considerable; or only one or a few lines of evidence support the finding**

***Competing Explanations*: different model representations account for different aspects of observations or evidence, or incorporate different aspects of key processes, leading to competing explanations**

***Speculative*: conceptually plausible ideas that haven't received much attention in the literature or that are laced with difficult to reduce uncertainties or have few available observational tests**



Probability of "Dangerous"
1
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
50
100
150
200
250
300
350
400
Carbon Tax 2050 ($/Ton C)
10-25 %
25-50 %
50-75 %
75-90 %



10-25 ‰
25-50 ‰
50-75 ‰
75-90 ‰
90-99 ‰
Probability of "Dangerous"
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
Pure Rate of Time Preference (PRTP)