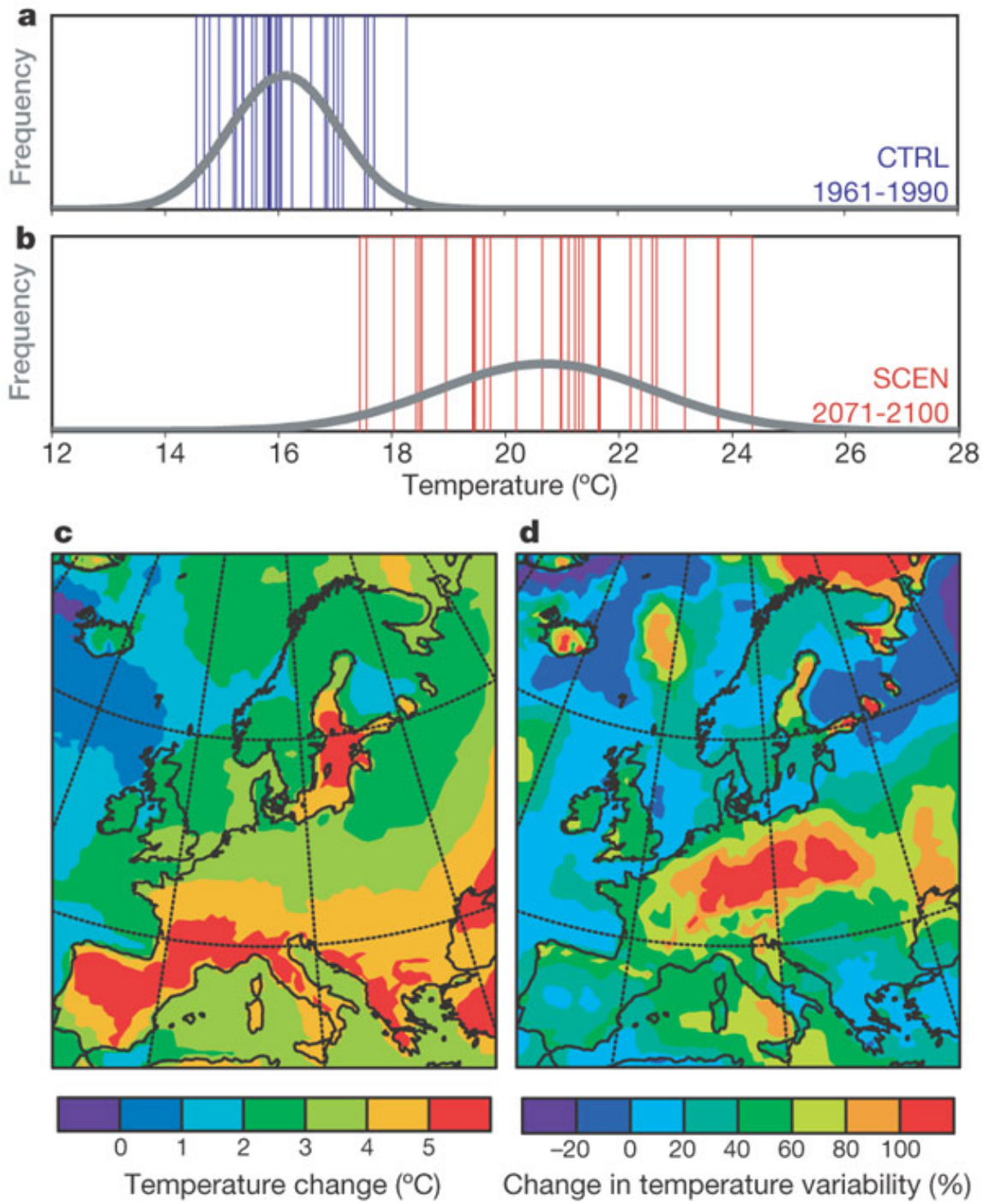
Dealing with Uncertainty in Climate Change Adaptation and Mitigation

Dr. Marc Neumann, BC3



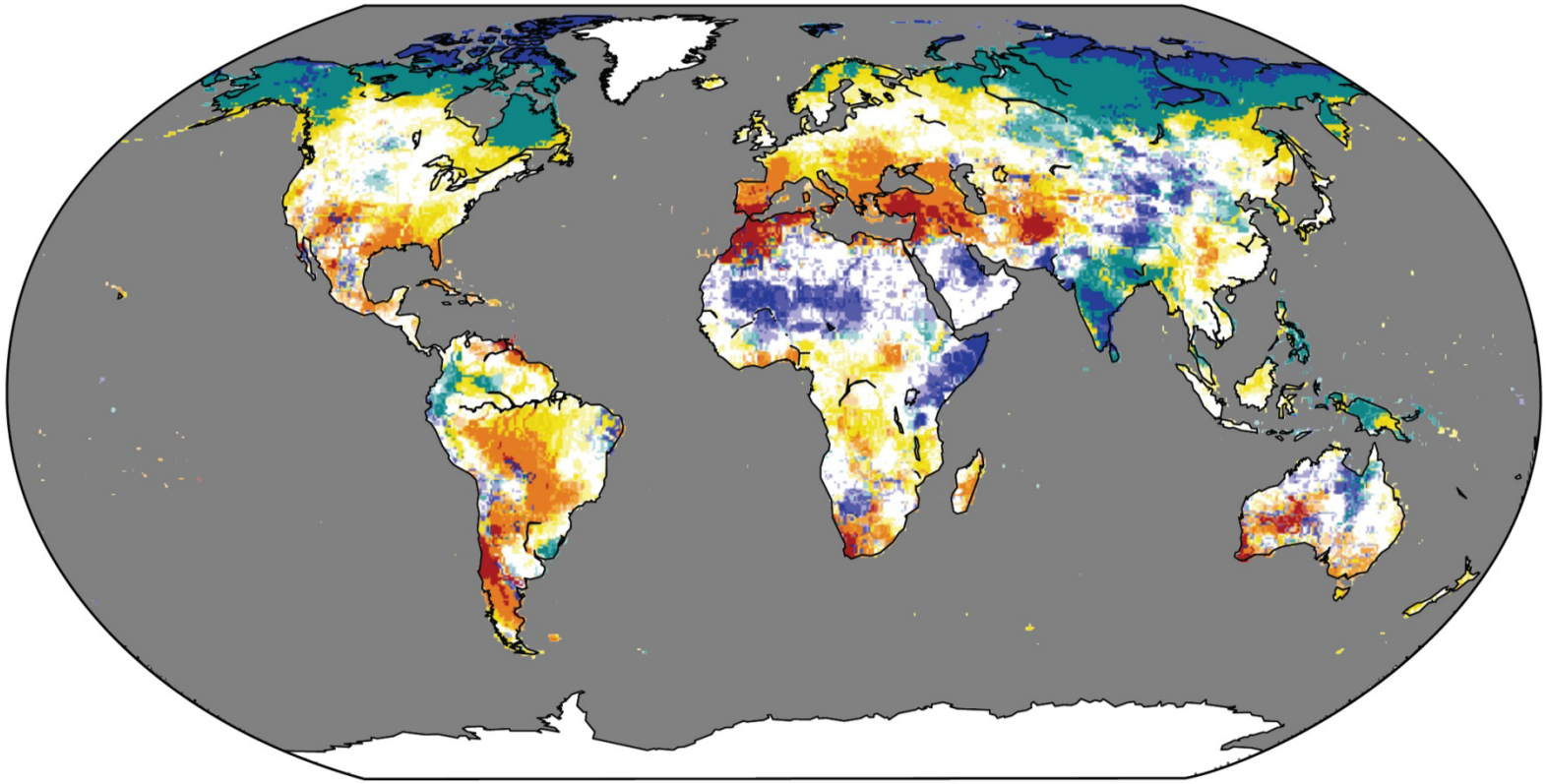
a, **b**, Statistical distribution of mean summer temperatures at a grid point in northern Switzerland.

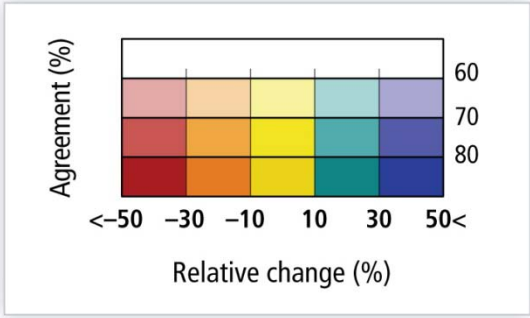
c, Change in average

d, Change in variability (relative change in standard deviation)

Schär et al. 2004, Nature

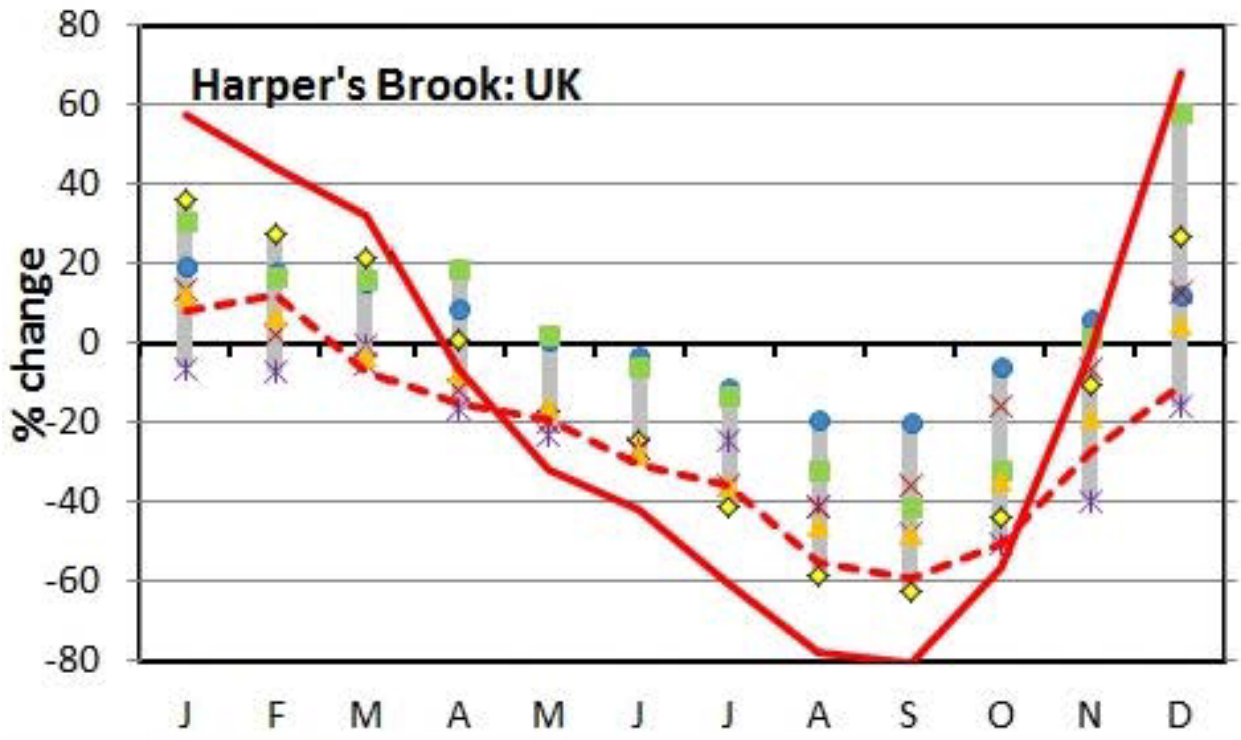
Mean annual streamflow



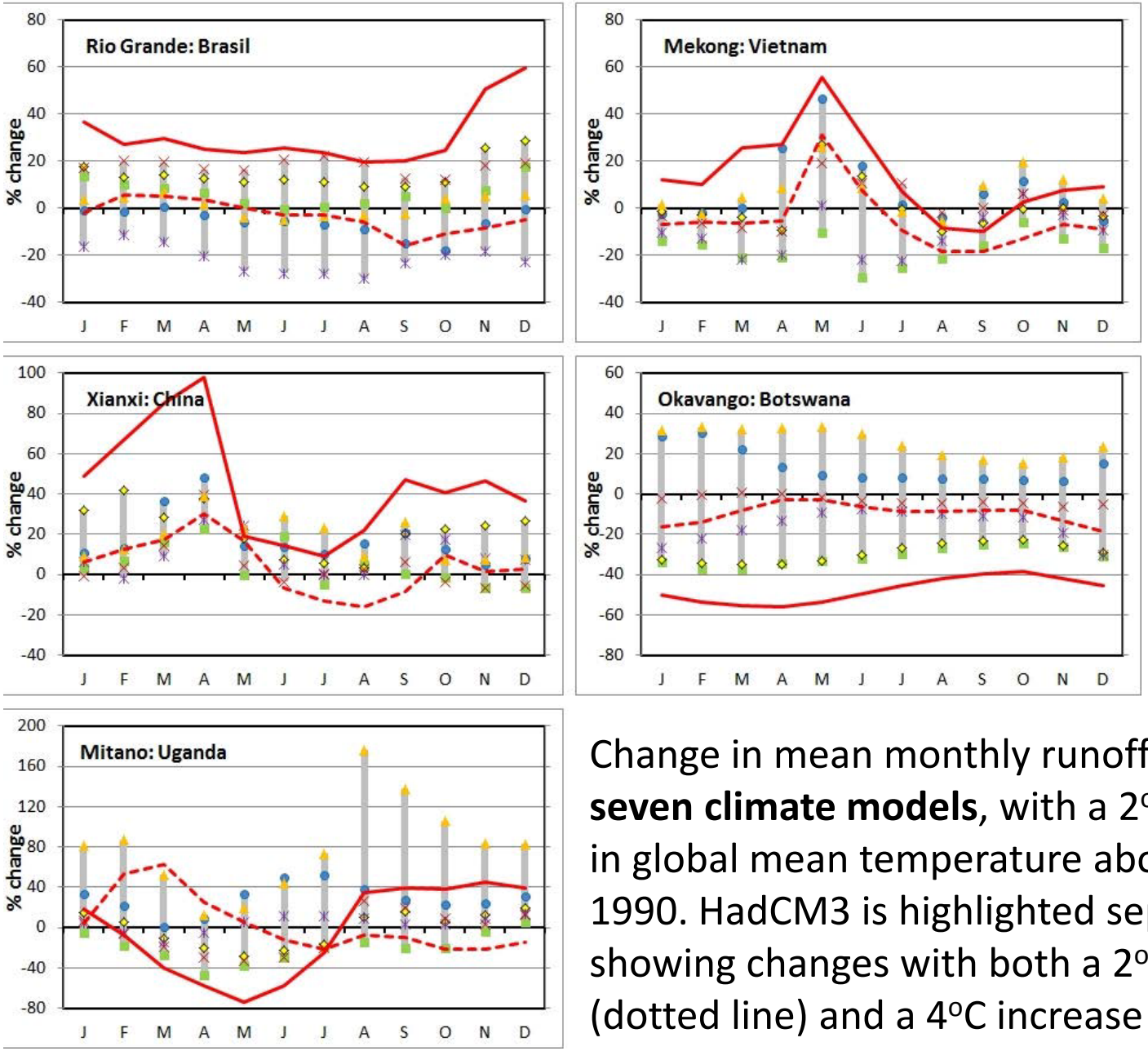


Multi-model mean change across **5 General Circulation Models (GCMs)** and **11 Global Hydrological Models** (GHMs); saturation shows the agreement on the sign of change across all 55 GHM–GCM combinations (for a global mean temperature rise of 2°C above 1980–2010). *[source: WGII AR5 Fig 3.4]*

Monthly runoff



Change in mean monthly runoff across **seven climate models**, with a 2°C increase in global mean temperature above 1961-1990. HadCM3 is highlighted separately, showing changes with both a 2°C increase (dotted line) and a 4°C increase (solid line). *[source: WGII AR5 2014, Fig.3-5]*



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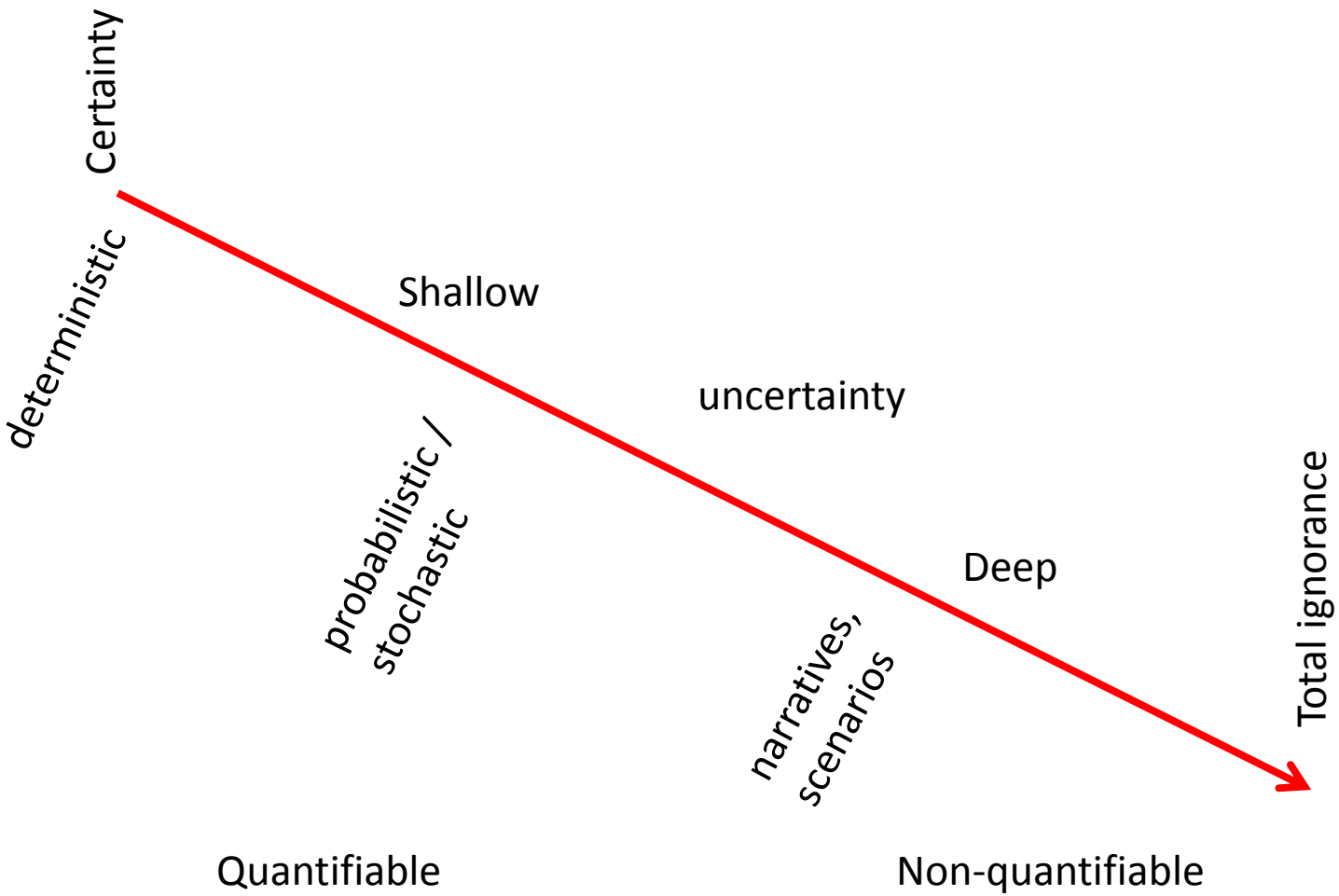
Chain of Uncertainty

1. **Emission scenario**
2. **Global climate** model
3. **Downscaling** to **regional** level
4. **(Local weather** patterns**)**
5. **Impact** models
6. **Economic valuation** of impacts

Types of Uncertainty

- Epistemic uncertainty
  - lack of knowledge, partially reducible by further investigation
- Aleatory uncertainty (natural variability)
  - spread of values from a well specified population, irreducible, frequency distribution
- Ambiguity/Vagueness
  - Capability of being understood in two or more ways; double or dubious signification

Levels of uncertainty



Risk vs. uncertainty

- Civil Engineering:

  Risk = Probability(Flood)*Cost(Flood)

- Intergovernmental Panel on Climate Change (IPCC - AR5):

  Risk ← Hazard * Exposure * Vulnerability

Interpretation of uncertainty

Likelihood scale (A)	
Term	Likelihood of the outcome
Virtually certain	
Very likely	
Likely	
About as likely as not	
Unlikely	
Very unlikely	
Exceptionally unlikely	

A: For each term provide **single estimate** on a scale from 0 to 100%

B: For each term provide a **range (from – to)** on a scale from 0 to 100%

IPCC – AR5 Treatment of Uncertainty

Guidance Note for Lead Authors of the IPCC Fifth Assessment Report on Consistent Treatment of Uncertainties

IPCC Cross-Working Group Meeting on Consistent Treatment of Uncertainties Jasper Ridge, CA, USA, 6-7 July 2010

Michael D. Mastrandrea, Christopher B. Field, Thomas F. Stocker, Ottmar Edenhofer, Kristie L. Ebi, David J. Frame, Hermann Held, Elmar Kriegler, Katharine J. Mach, Patrick R. Matschoss, Gian-Kasper Plattner, Gary W. Yohe, and Francis W. Zwiers

IPCC – AR5 Treatment of Uncertainty

"Each key finding is based on an author team's evaluation of associated evidence and agreement. The confidence metric provides a qualitative synthesis of an author team's judgement about the validity of a finding, as determined through evaluation of evidence and agreement. If uncertainties can be quantified probabilistically, an author team can characterize a finding using the calibrated likelihood language or a more precise presentation of probability."

IPCC AR5 – confidence metric

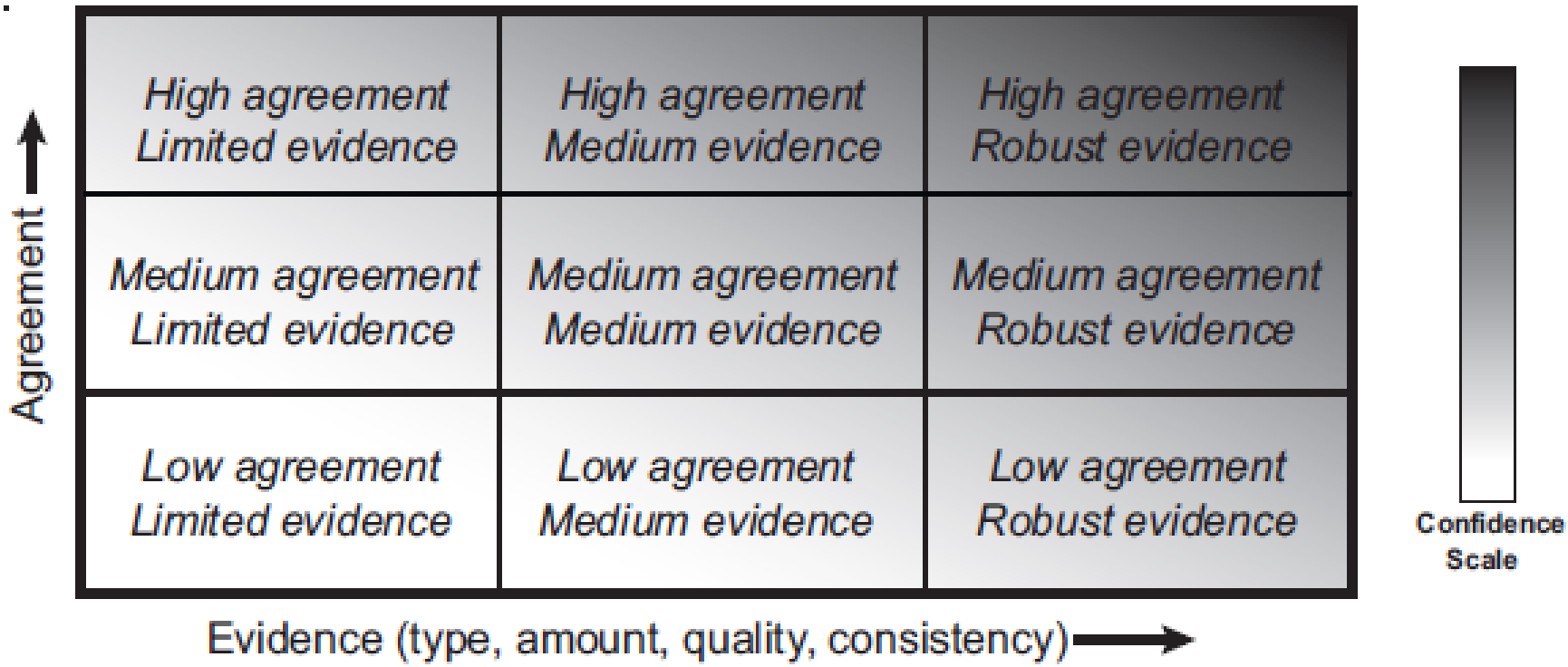


Figure 1: A depiction of evidence and agreement statements and their relationship to confidence. Confidence increases towards the top-right corner as suggested by the increasing strength of shading. Generally, evidence is most robust when there are multiple, consistent independent lines of high-quality evidence.

IPCC AR5 - calibrated likelihood language

Table 1. Likelihood Scale	
Term*	**Likelihood of the Outcome**
Virtually certain	99-100% probability
Very likely	90-100% probability
Likely	66-100% probability
About as likely as not	33 to 66% probability
Unlikely	0-33% probability
Very unlikely	0-10% probability
Exceptionally unlikely	0-1% probability

Technical Summary IPCC AR 5 Example heat waves (Table TS.2)

Observed:

Very likely decrease in the number of cold days and nights and increase in the number of warm days and nights, on the global scale between 1951 and 2010. [WGI AR5 2.6.1]

Medium confidence that the length and frequency of warm spells, including heat waves, has increased globally since 1950. [WGI AR5 2.6.1]

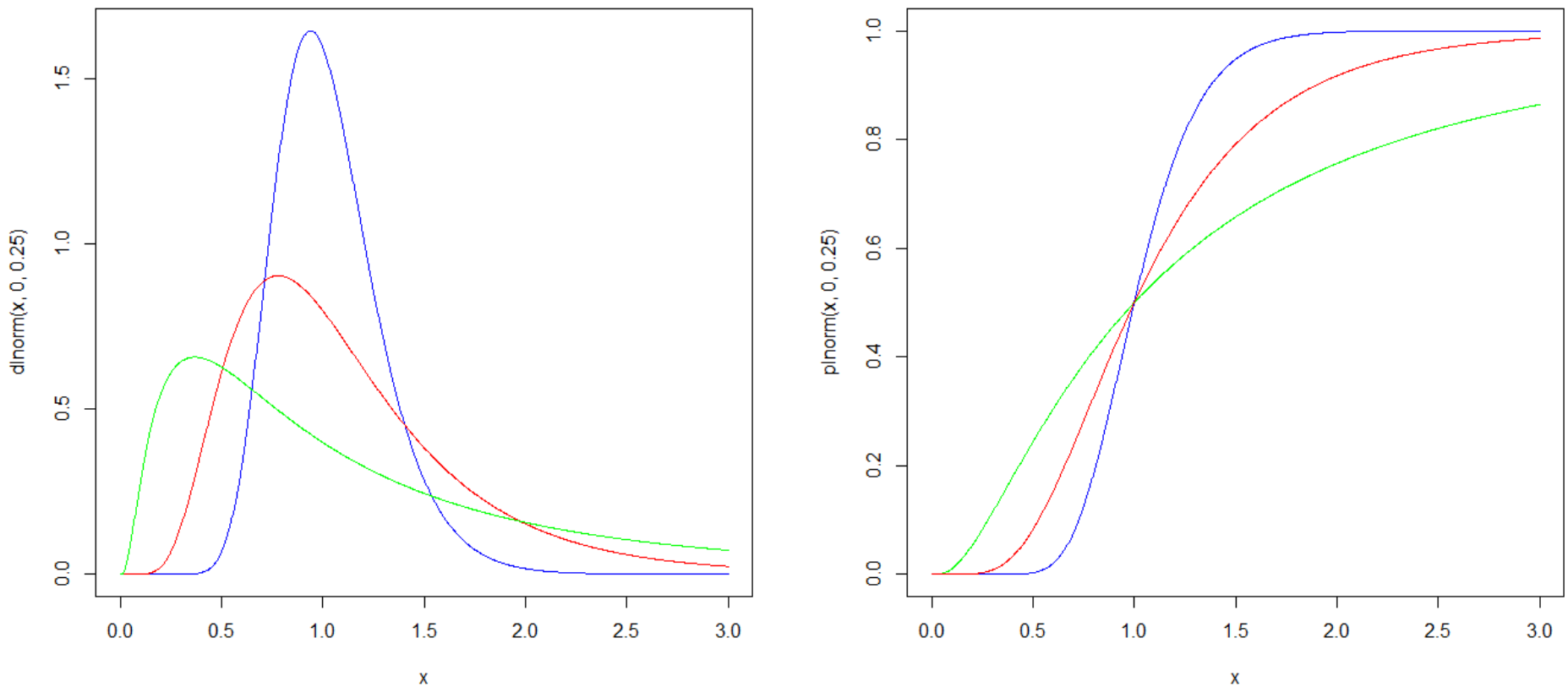
Projected:

Virtually certain that, in most places, there will be more hot and fewer cold temperature extremes as global mean temperatures increase, for events defined as extremes on both daily and seasonal time scales. [WGI AR5 12.4.3]

Uncertainty in modelling

- Parameter uncertainty
  - Bayesian
    - Random variables
    - Prior distributions (expressing degrees of belief)
    - Learning with data → posterior distributions
  - Frequentist
    - Error estimates (co-variance) obtained from statistical regression (mapping of random measurement error to parameters)
- Model structure uncertainty

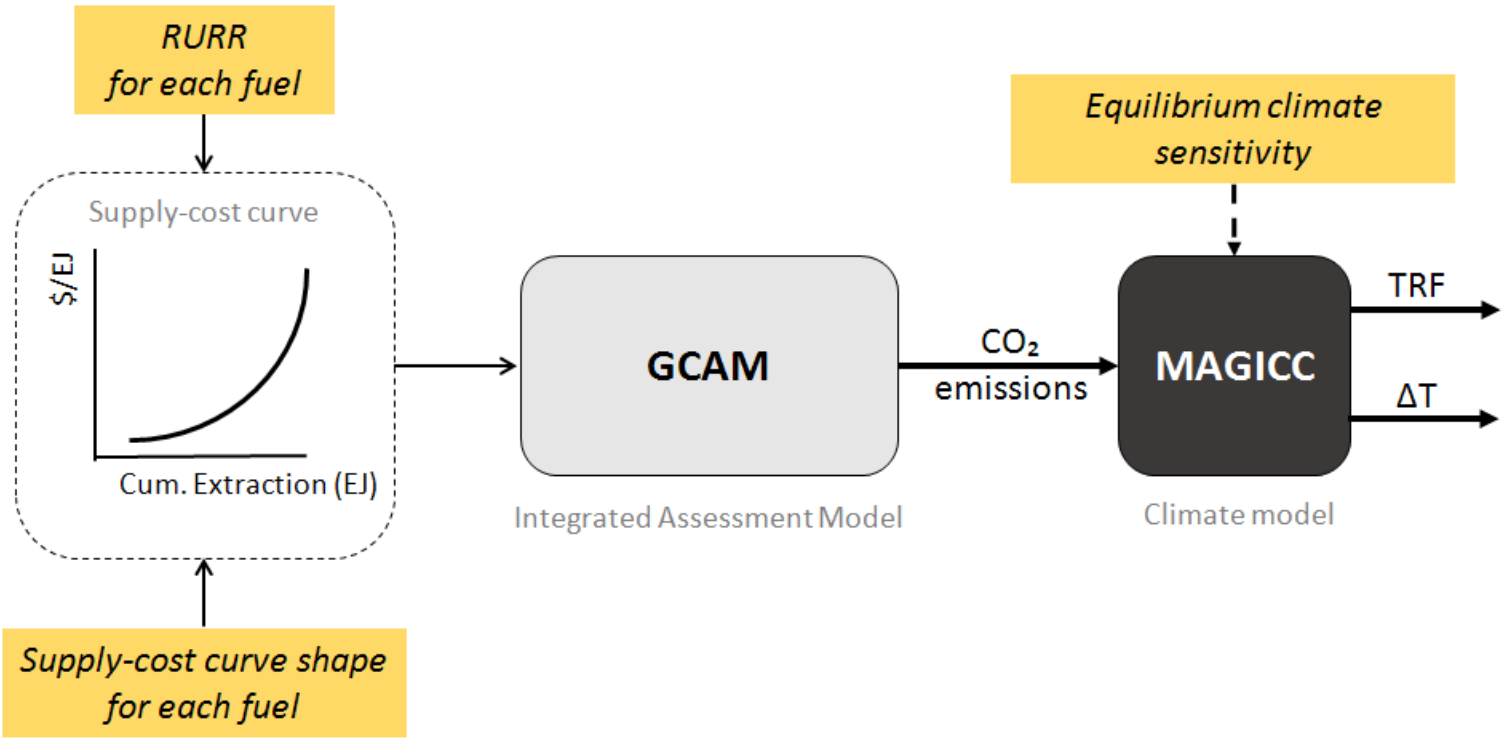
Parameter uncertainty



Uncertainty analysis

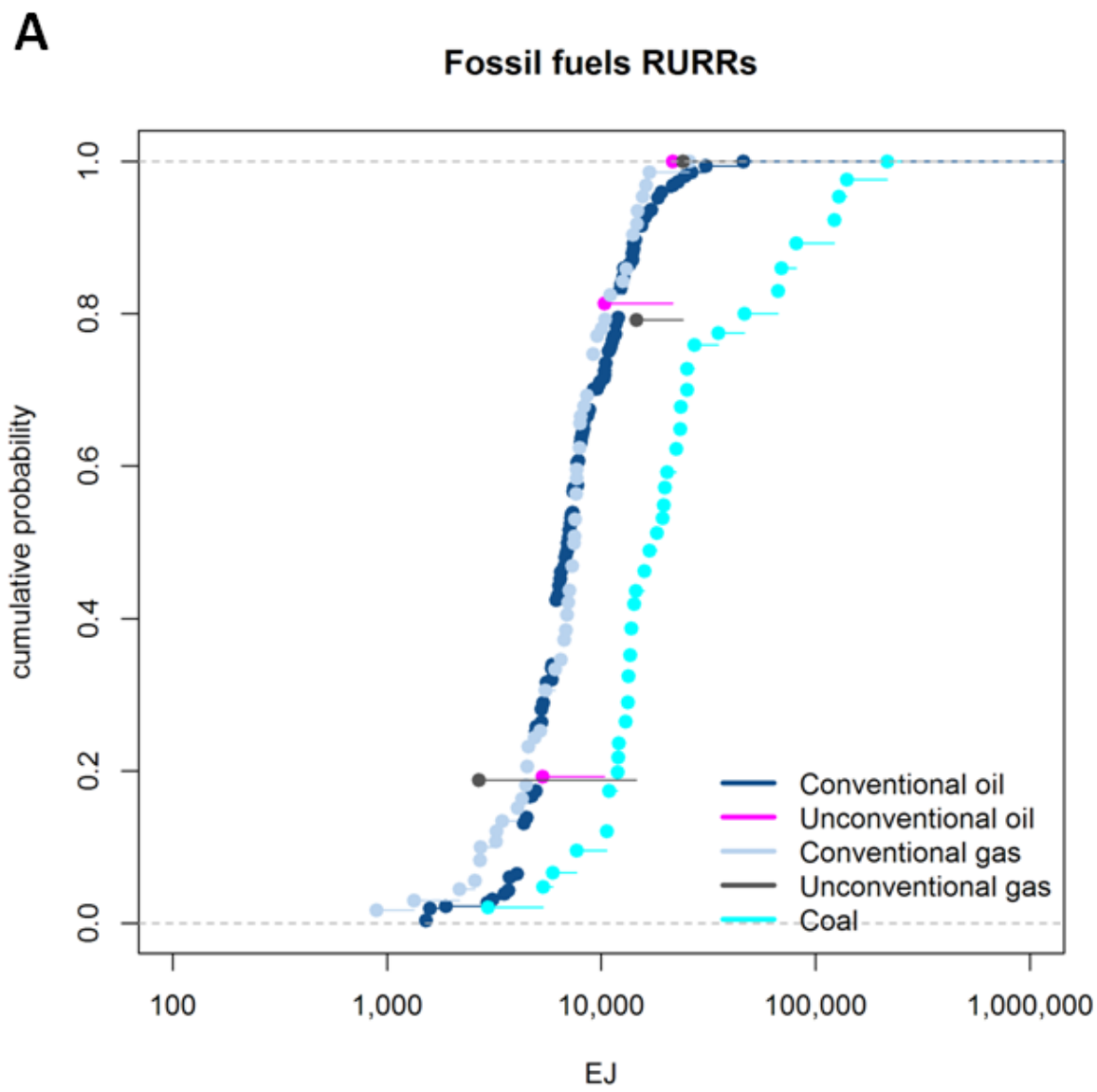
- Identifying sources of uncertainty
- Quantifying uncertainty
- Propagating uncertainty
- Assessing uncertainty of outcomes
- Assessing sensitivity

Identifying sources of uncertainty



Capellán-Pérez, I., Arto, I., Polanco-Martínez, J.M., González-Eguino, M., and Neumann, M.B. (2016) Likelihood of climate change pathways under uncertainty on fossil fuel resource availability. *Energy & Environmental Science* 9, 2482-2496.

Quantifying uncertainty



Uncertainty propagation

- Monte Carlo simulation

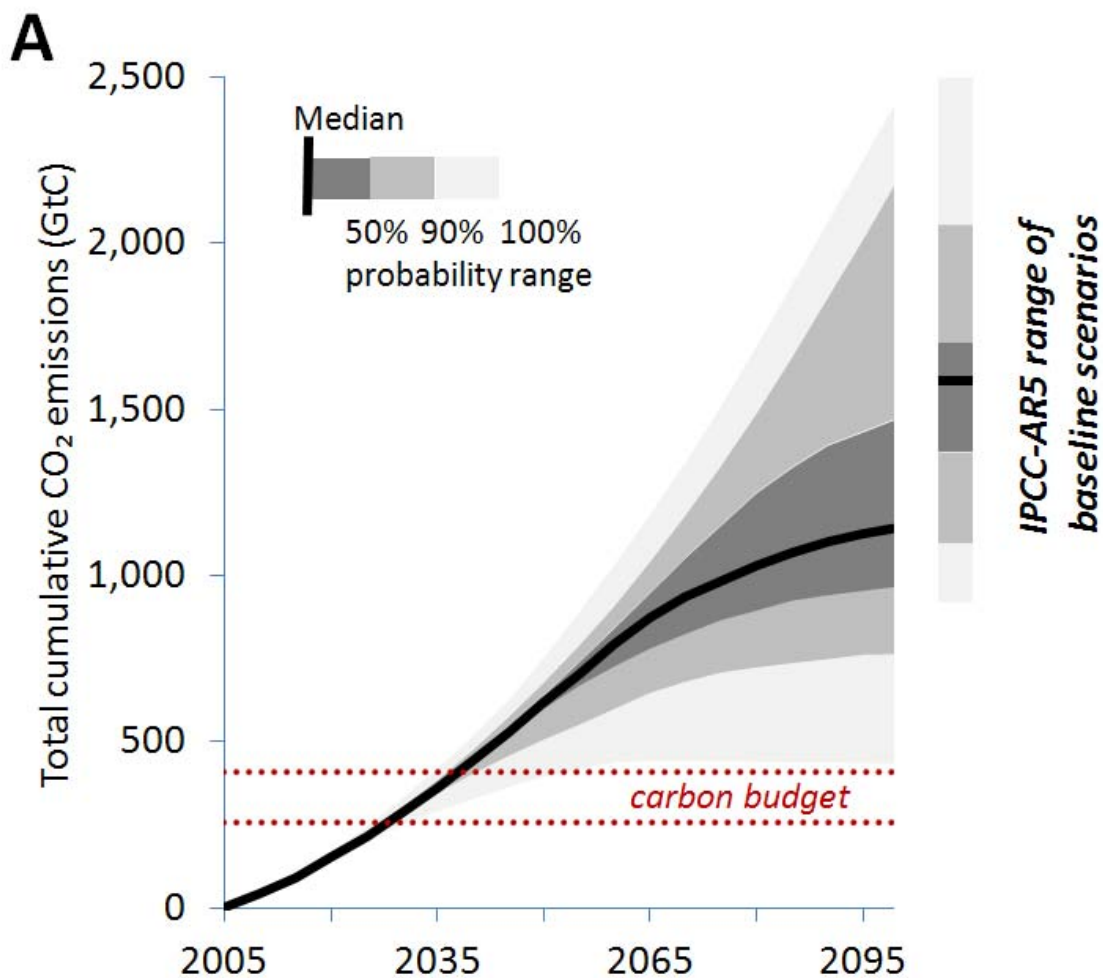
Repeat n times

1. Draw a random sample for each parameter
2. Run simulation
3. Store output

Analyse output :

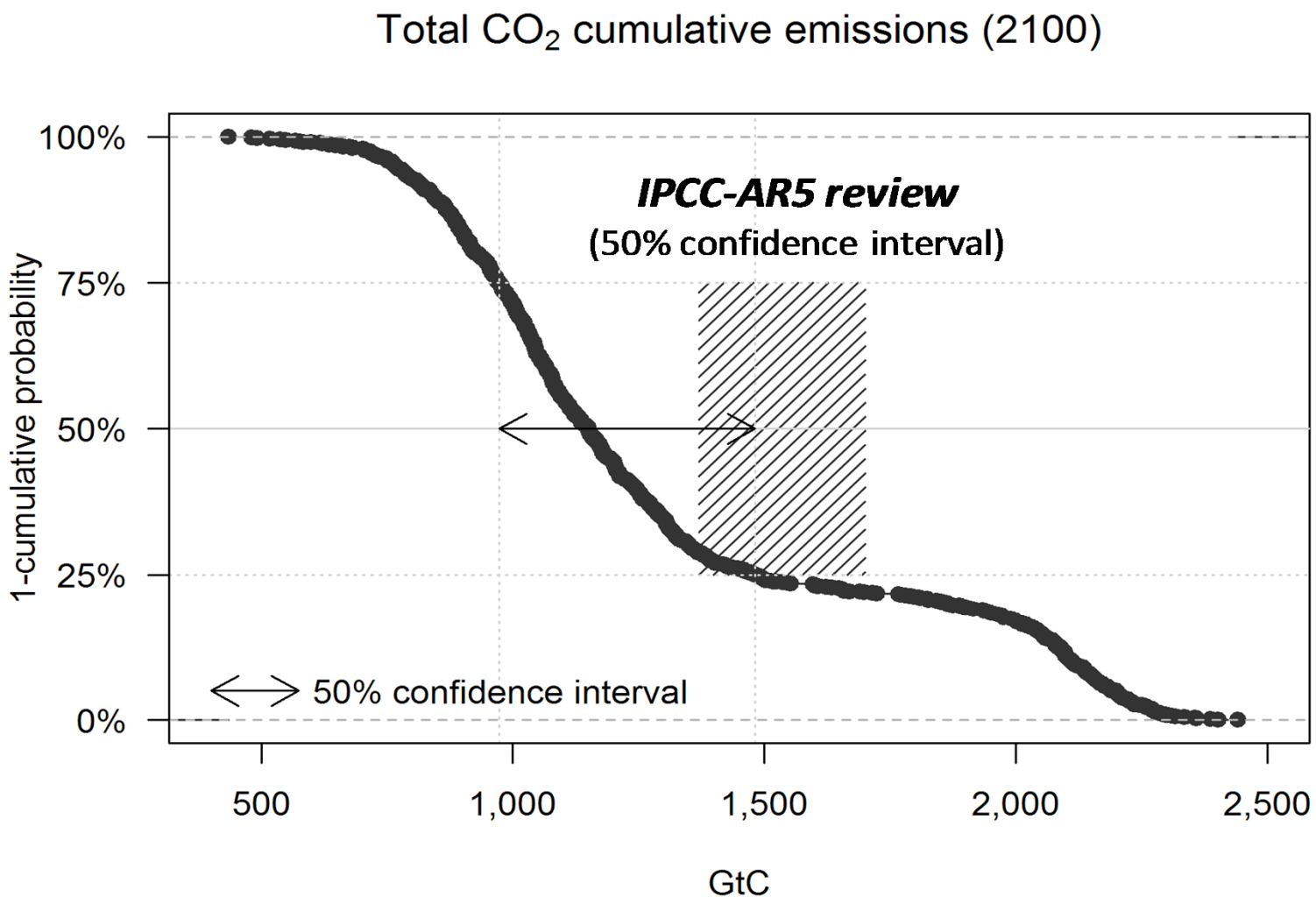
- *mean, standard deviation, quantiles*
- *histogram, empirical cumulative distribution function*

Cumulative CO_2 emissions

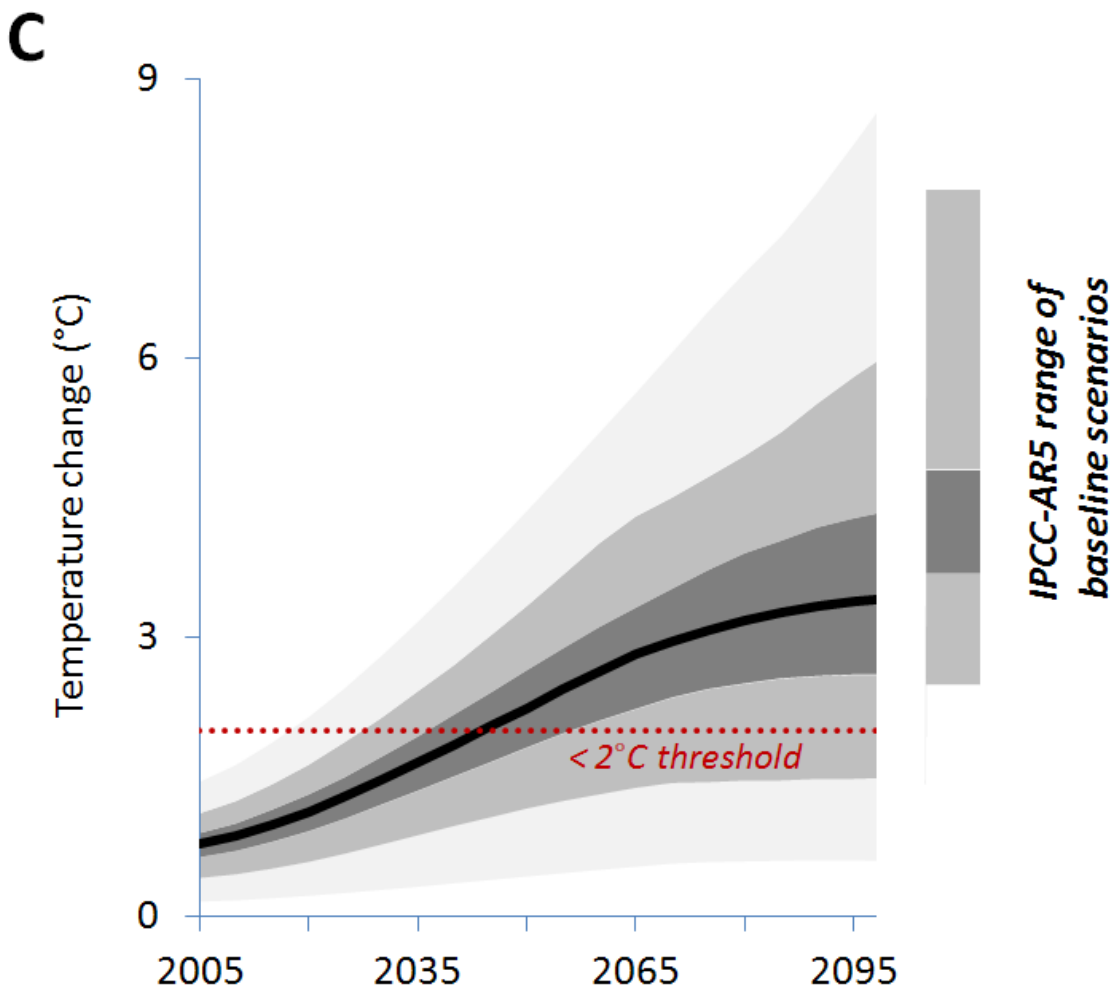


CO_2 cumulative emissions 2100

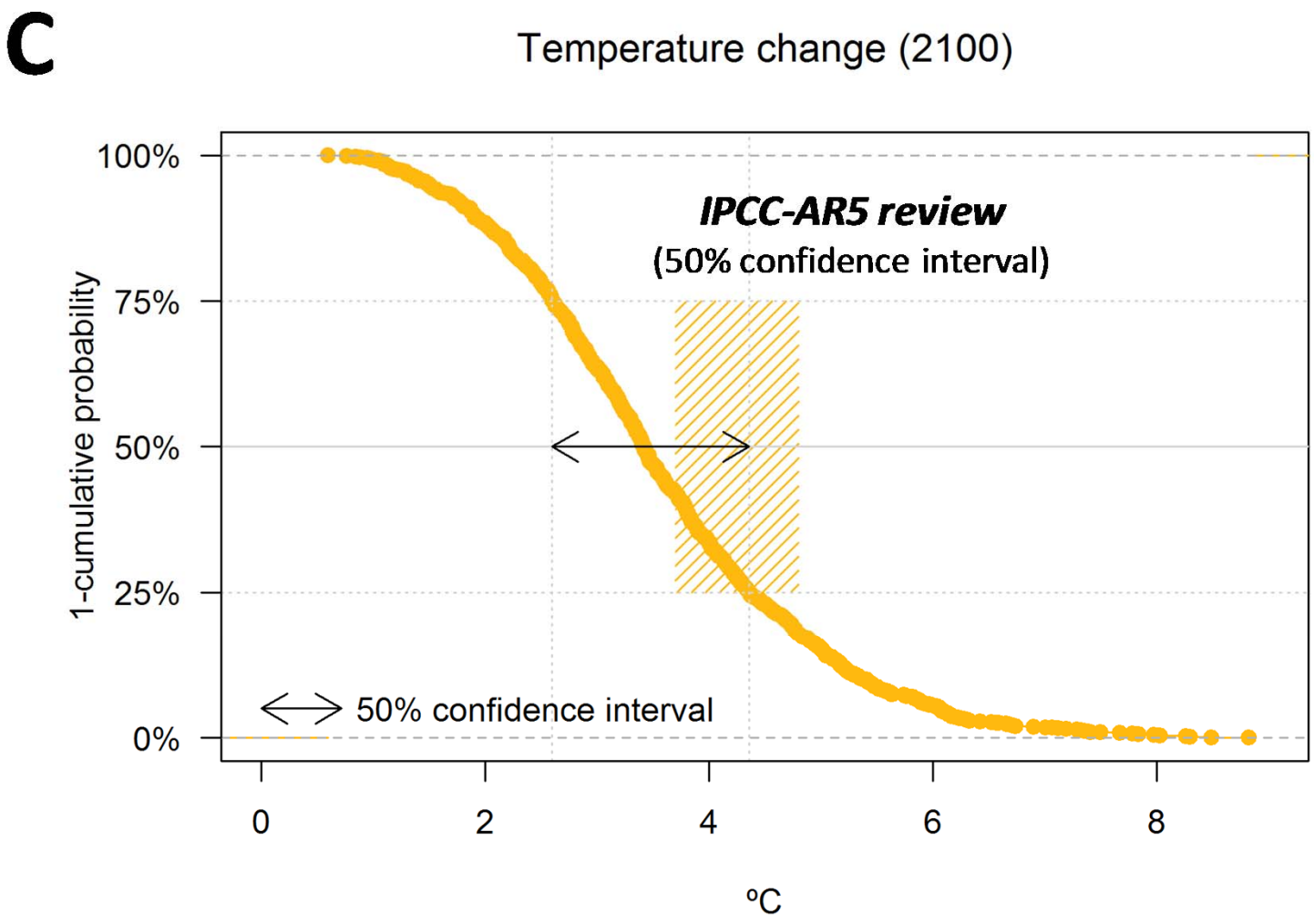
A



Temperature change



Temperature change in 2100



Sensitivity analysis

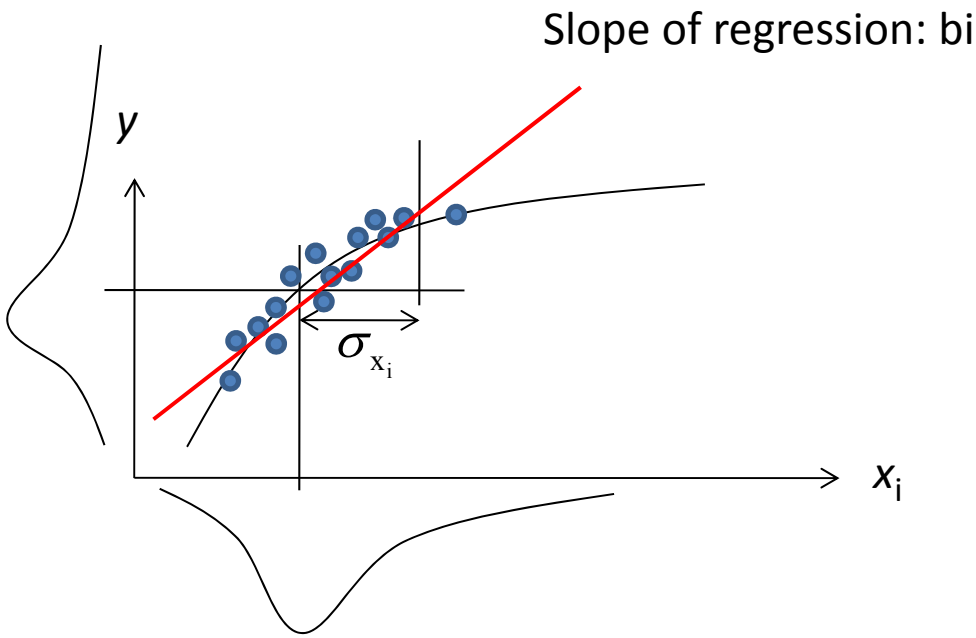
Many sensitivity analyses are based on changing one parameter at a time (**local sensitivity analysis**), often assessing the impact of a small perturbation to that parameter.

Global sensitivity analysis relaxes these assumptions by looking at the effect of varying a parameter:

i) while all others are also varying and

ii) across the entire distribution.

Global Sensitivity Analysis (Standardised Regression Coefficients)



$$y = \sum b_i \cdot x_i + a$$

$$\beta_i = b_i \cdot \frac{\sigma_{x_i}}{\sigma_y}$$

$\beta_i^{\ 2}$ Variance contribution of x_i to y

$R^2 > 0.7$: Saltelli et al. (2004)

Global Sensitivity Analysis

Table 2 Fraction of variance in climate outcomes for the year 2100 explained by the main inputs (squared standardized regression coefficients, SRC^2)

	Total cumulative CO_2 emissions	Total radiative forcing	Temperature change
Conventional oil RURR	0.014	0.020	0.003
Unconventional oil RURR	0.003	0.007	0.002
Natural gas RURR	0.022	0.043	0.012
Coal RURR	**0.730**	**0.676**	**0.138**
ECS	—	0.017	**0.702**
Other inputs	0.004	0.005	0.001
Total (R^2)	0.774	0.766	0.857

For total cumulative CO_2 emissions and total radiative forcing, the coal RURR explains 73% and 68% of the uncertainty respectively, whereas for the temperature change, coal RURR explains only 14%, with equilibrium climate sensitivity (ECS) explaining 70%. Total (R^2) represents the coefficient of determination of the total multivariate regression.

Caveat

Models are concepts, i.e. thought experiments!

Including uncertainty can either reduce or increase our overconfidence in our models

→Be explicit about assumptions and limitations

→Study of limitations as a continuous process

Climate Change

- System of systems
  - Complexity
  - Feedbacks
  - Non-linearity
- Emergence of new properties, structures, processes, knowledge, values, rules

→ Limits of predictability

Adaptation – look for

- **Satisficing** for a wide range of possible futures
- **Flexible** and **adaptive**
- **Low-regret**
- Address issues of the **present**
- With **co-benefits** to other sectors
- **Source control: Mitigation** [Precautionary principle]