

Expert elicitation



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Summer school on uncertainty
in energy and integrated
assessment models

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U.S. Environmental Protection Agency

Expert Elicitation Task Force White Paper

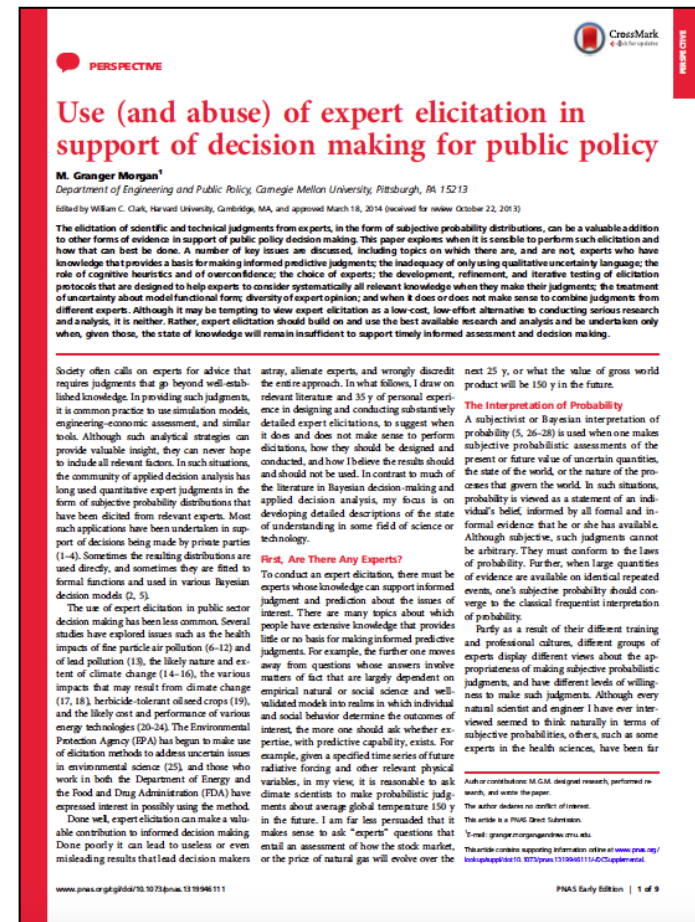
August 2011

Prepared for the
Science and Technology Policy Council
U.S. Environmental Protection Agency
Washington, DC 20460

U.S. Environmental Protection Agency, 2011.
Expert Elicitation Task Force. White Paper.
Washington DC: US EPA.

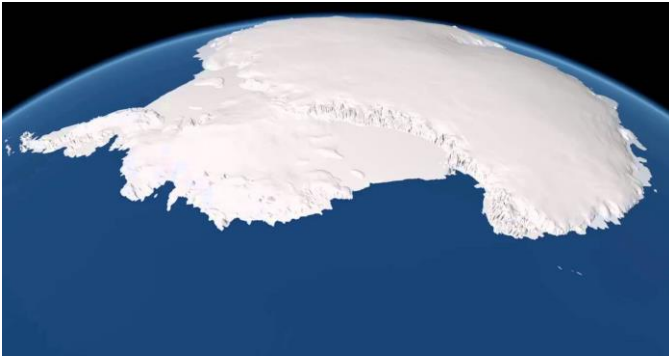
(download as it is difficult to find it online)

Morgan G.M., 2014.
**Use (and abuse) of expert elicitation in
support of decision making for public policy.**
PNAS 111(20):7176-7184.



When would you use an expert elicitation?

Antarctic ice sheet melting given global warming of 1.5°C?



Future oil price?



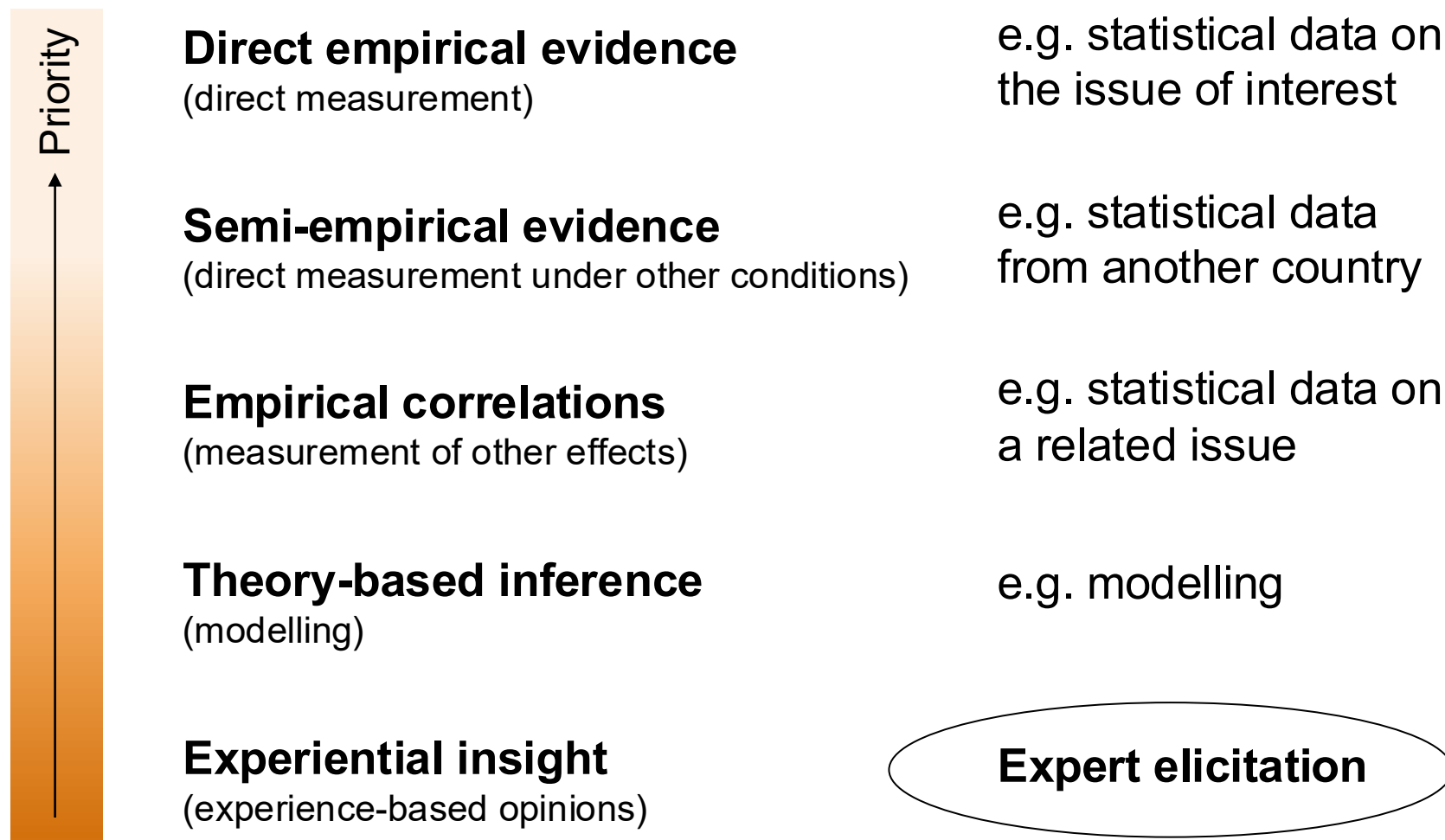
Overnight costs of small modular nuclear reactors?



Future installed capacity of solar PV?

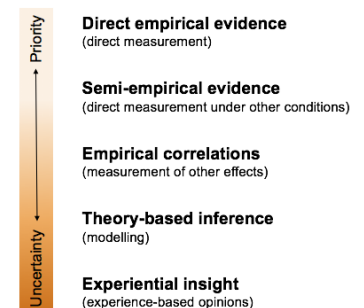
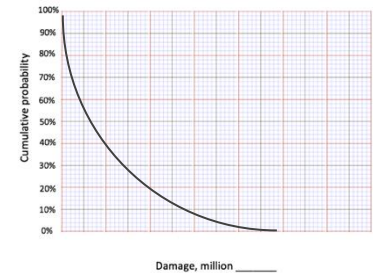


Types of evidence



The aims of expert elicitation

- ◆ Collect quantitative evidence, using judgements of knowledgeable experts in interviews, surveys or workshops
- ◆ Inform timely assessment and decision making under deep uncertainties and the lack of other evidence
- ◆ Complement – rather than replace – other types of evidence, e.g. basic science, data collection, modelling



Application examples of expert elicitation

◆ Natural or environmental phenomena

- Climate response to future radiative forcing (Zickfeld et al. 2010, PNAS)
- Antarctic ice sheet loss in the 21st century (Oppenheimer et al. 2016, Nature Climate Change)

◆ Characteristics of new/future technologies

- Future costs of solar PV (Curtright et al. 2008, Environmental Science & Technology)
- Costs, safety, and feasibility of small modular nuclear reactors (Abdulla et al. 2013, PNAS)

◆ New or poorly understood risks

- Induced seismicity by Enhanced Geothermal Systems (Trutnevyte & Azevedo, 2018, Environmental Research Letters)
- Mortality impacts of ambient fine particulate matter (Roman et al. 2008, Environmental Science & Technology)

◆ Policy assessment

- Impacts of R&D spending on energy technology development (Anadon et al., 2016, Climatic Change)

◆ Other cases (that “pass” the clairvoyant test)

Clairvoyant test (*Hellseher*)



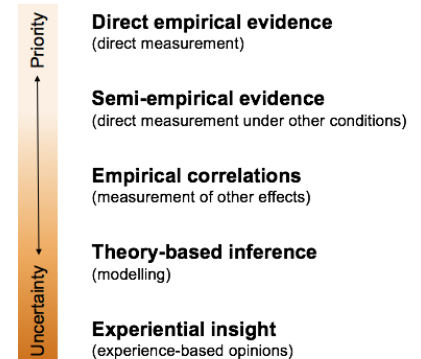
Tip: Pose questions that experts can reliably answer, e.g. where empirical natural and social science is in principle possible

Goals for today

- ◆ Understand the overall principles of expert elicitation

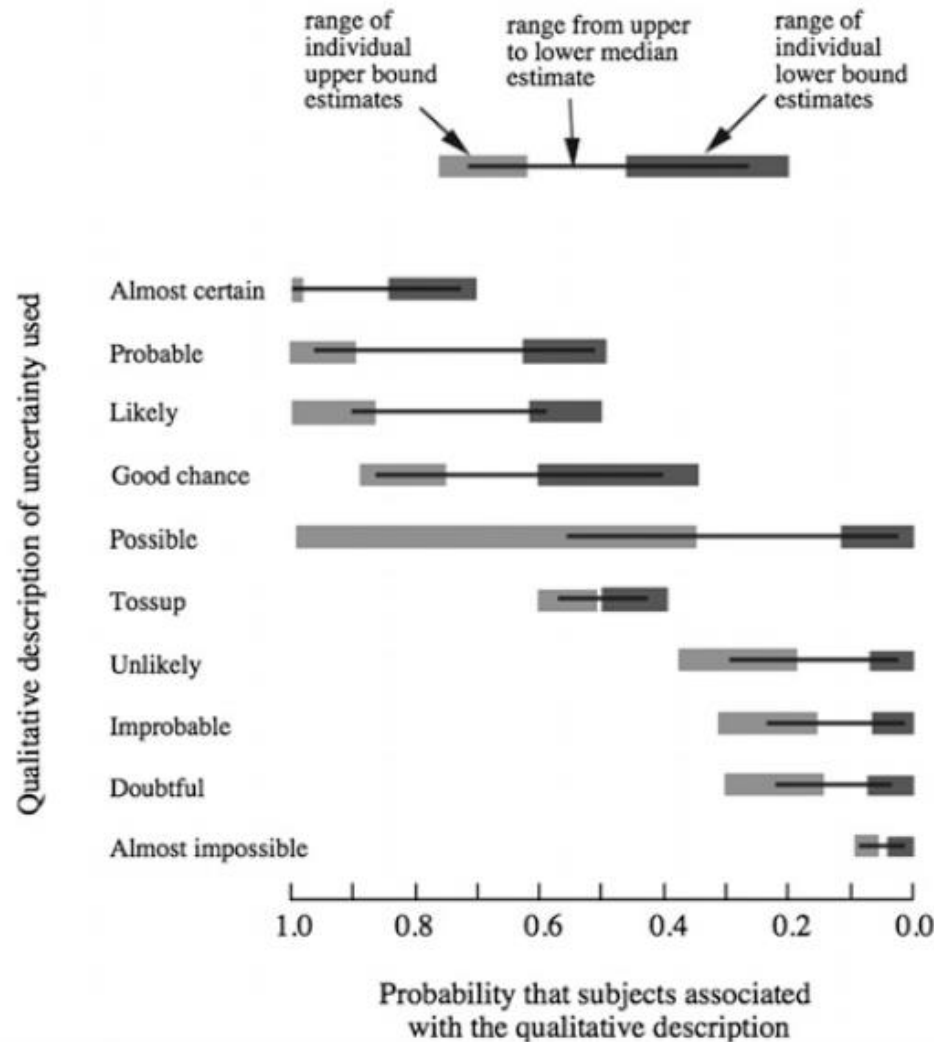


- ◆ Look into some practicalities of expert elicitation



Quantitative estimates vs. qualitative words

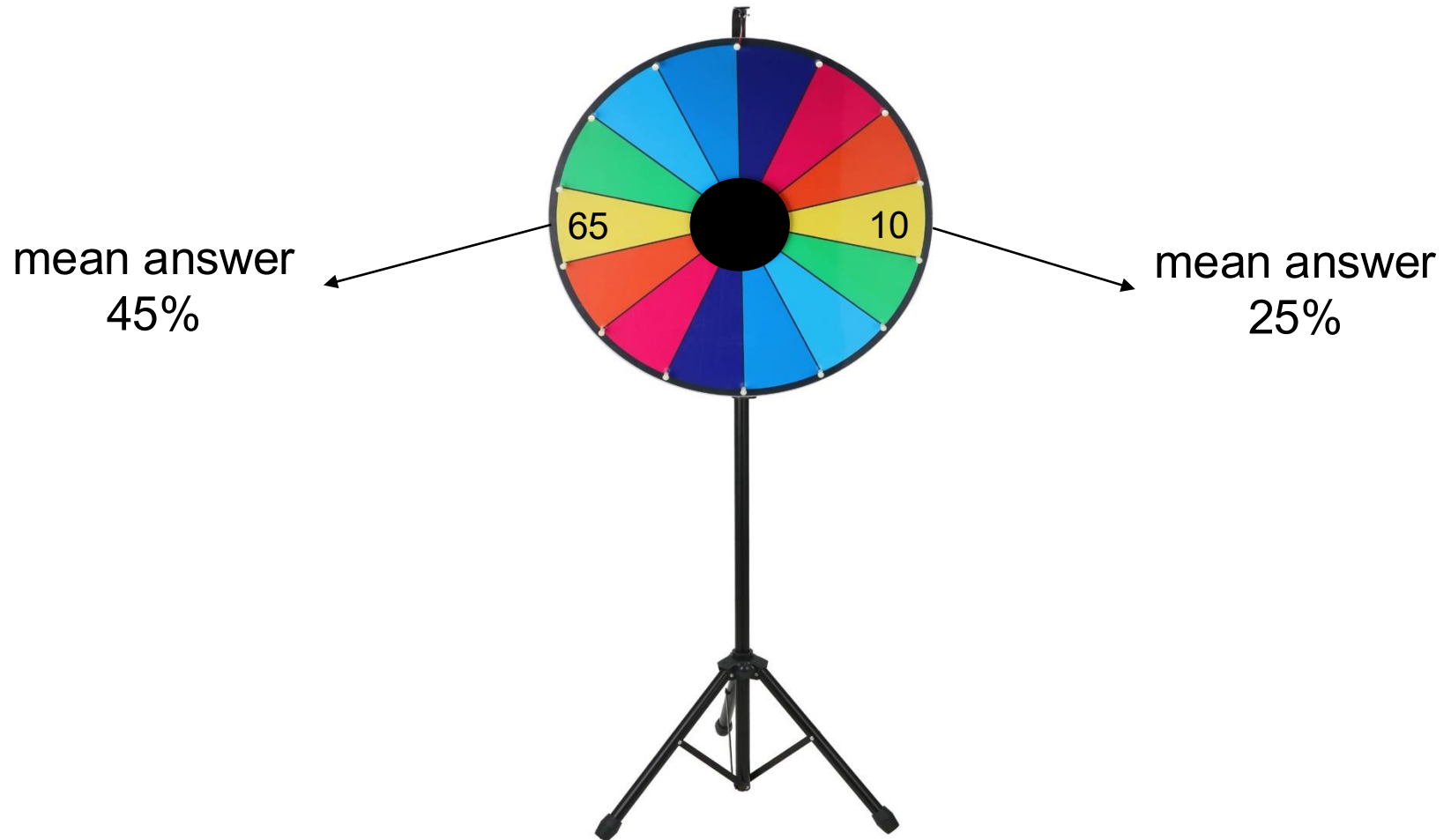
20 respondents



Tip: Elicit quantitative probabilities and other values, not qualitative

Anchoring and adjustment bias

What is the percentage of African countries in the UN?



Availability bias

If a random word is taken from an English text, is it more likely that the word:

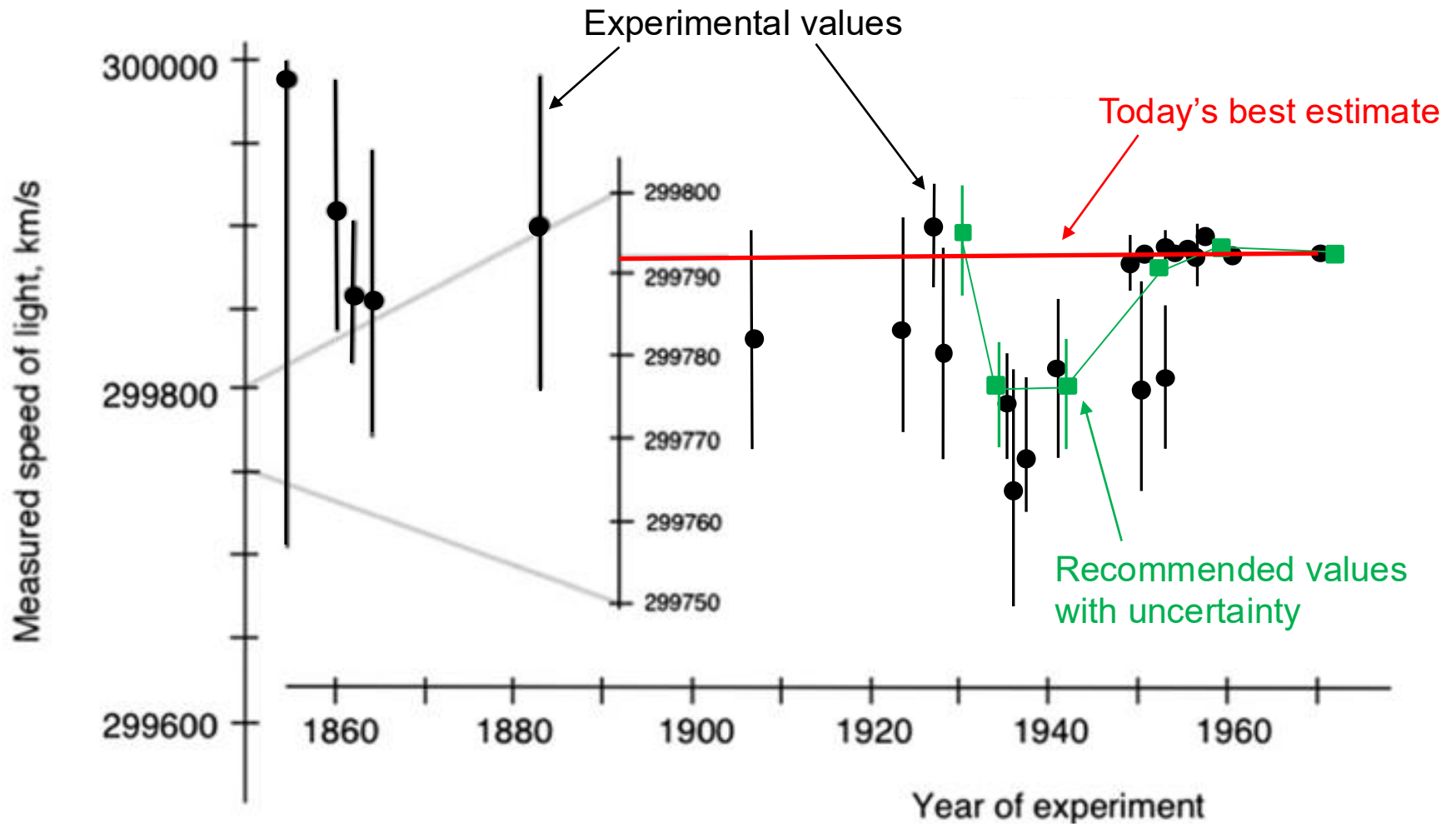
starts with letter K?

K is the third letter?

chosen by 2/3 of participants

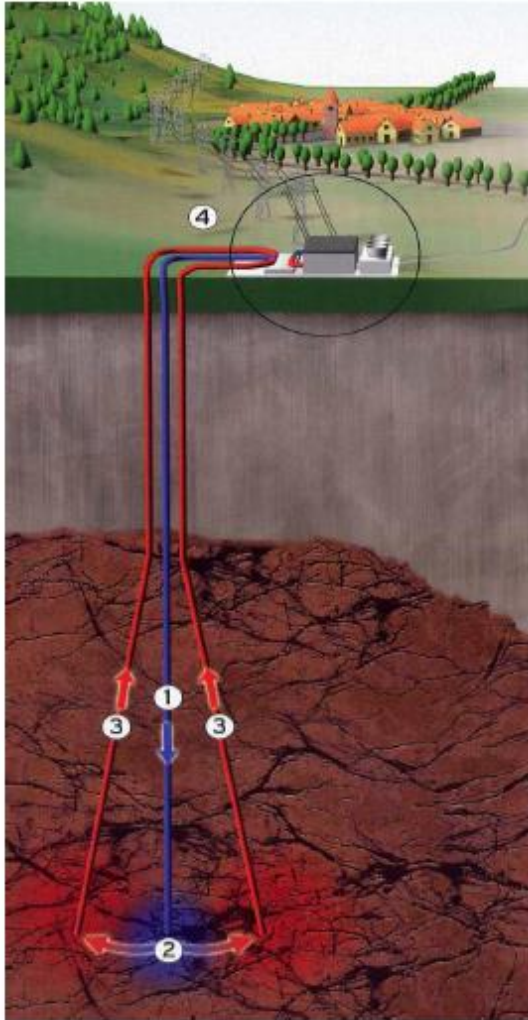
chosen by 1/3 of participants

Overconfidence



Redrawn from: Henrion & Fischhoff (1986), Morgan (2014)

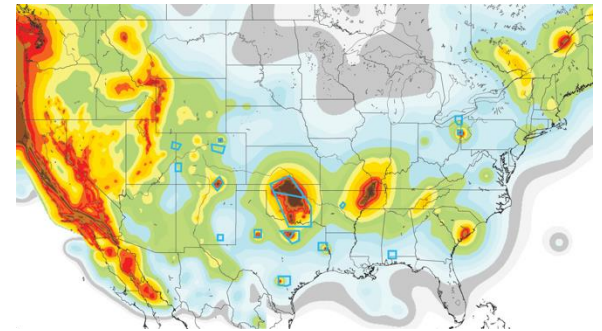
Expert elicitation on induced seismicity by Enhanced Geothermal Systems (EGS)



The New York Times 2006



Hand 2015 Science



Expert elicitation method

Structured 2-hour interviews with 14 international experts from 6 countries

EGS plant⁷

The EGS plant has 8.9 MW_{el} gross capacity and 5.5 MW_{el} net capacity. It is used for electricity generation only and is the nth-of-a-kind plant (i.e. technology development costs are behind us).

During 6 days of hydraulic fracturing a reservoir of 80 million m³ is created at a depth of 5 km, i.e. the depth of the reservoir's center. The cumulative injected volume during stimulation is 40 000 m³. The maximum injection rate is 75 l/s. The maximum wellhead pressure is 30 MPa.

A triplet of wells is installed for operation with 1 km distance between the wells. The temperature at 5 km depth is 190°C. The re-injected water temperature is 60°C.

During EGS operation the injected water volume is 12 700 m³/day (i.e. two wells at 73.5 l/s). Wellhead pressure is 15 MPa. Water loss in the reservoir is 2%.

The plant is equipped with a magnitude-based traffic light system:

- M < 2.3: green (regular operation and continued pumping);
- M ≥ 2.3: yellow (continued pumping, but without flow increase);
- M ≤ 2.9: orange (pumping at a slow rate, or stopping of pumping, or bleeding of the wells);
- M > 2.9: red (stopping of pumping and bleeding the wells off).

Reservoir size	80 million m ³
Reservoir depth	5 km
Reservoir temperature and re-injected water temperature	190°C / 60°C
Stimulation parameters	40 000 m ³ ; 75 l/s; 30 MPa
Operation parameters	12 700 m ³ /day; 2-73.5 l/s; 15 MPa

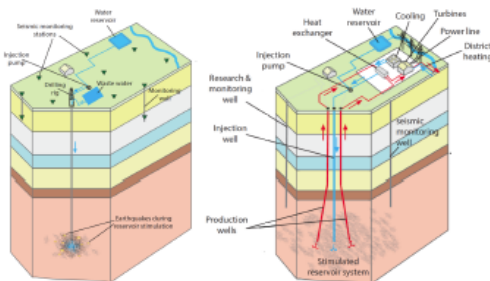
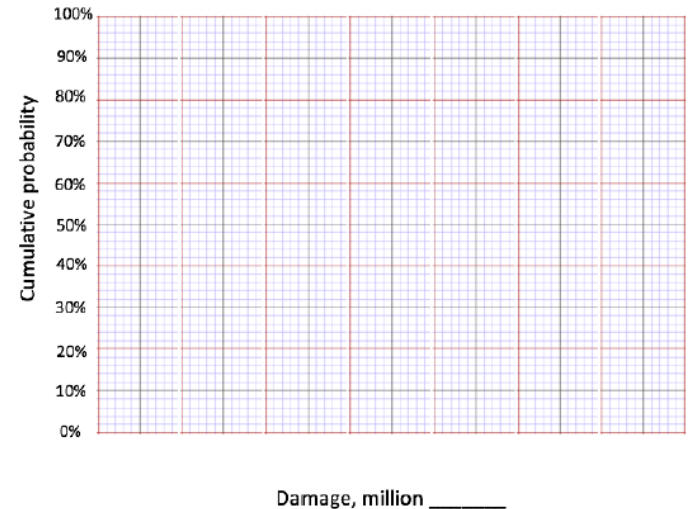
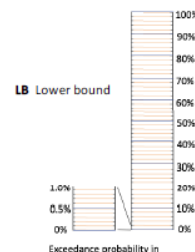
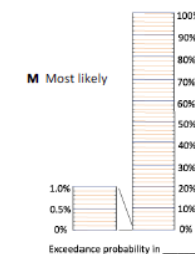
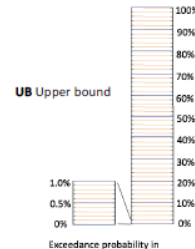


Figure: EGS reservoir stimulation (left) and EGS operation (right). These figures are redrawn and adapted from TA Swiss report⁷.



To what extent do these factors influence your estimate of induced seismicity hazard?

Not at all Very much

Cumulative injected volume, including setting of the traffic light system ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Depth of the reservoir ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Distance to critically pre-stressed extended faults ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Tips: – Involve domain experts – Pretest extensively
– Record, transcribe and delete if you choose anonymity

"Passing" the clairvoyant test

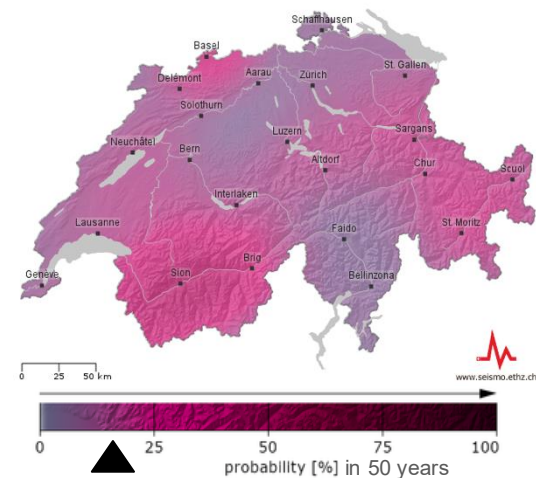
EGS plant

- ◆ 8.9 MW_{el} gross
- ◆ 5 km depth, 80 million m³ reservoir
- ◆ 6-day stimulation: 40 thousand m³, 75 l/s, 30 MPa
- ◆ 30-year operation: 2 x 73.5 l/s, 15 MPa, 190°C/60°C, 2% water loss
- ◆ Magnitude-based traffic light system (red at M>2.9)

Tip: Define the case and the questions well

Geological context

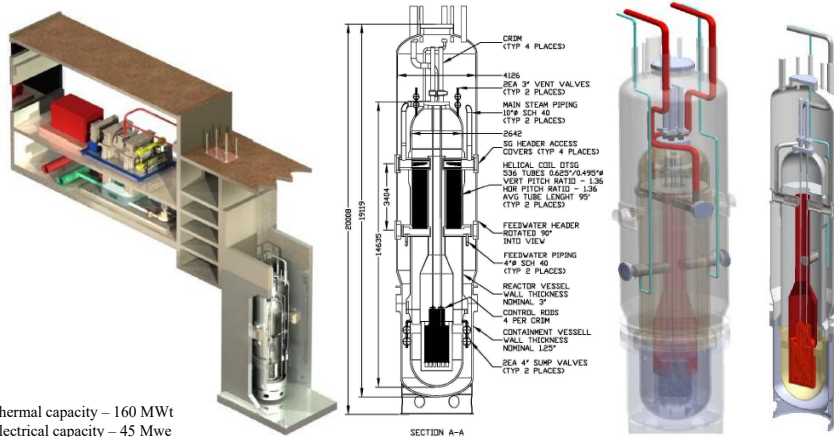
- ◆ Non-volcanic area, granite rock
- ◆ No known critically pre-stressed faults
- ◆ Tectonic M_≥7 at 0.01% in 1 year, Ø50km
- ◆ Tectonic M_≥5 at 0.4% in 1 year, Ø30km



"Passing" the clairvoyant test

Part IV. Background information on SMR number 1

We will consider two SMR technologies in this elicitation. Publicly-available images and statistics are presented here:



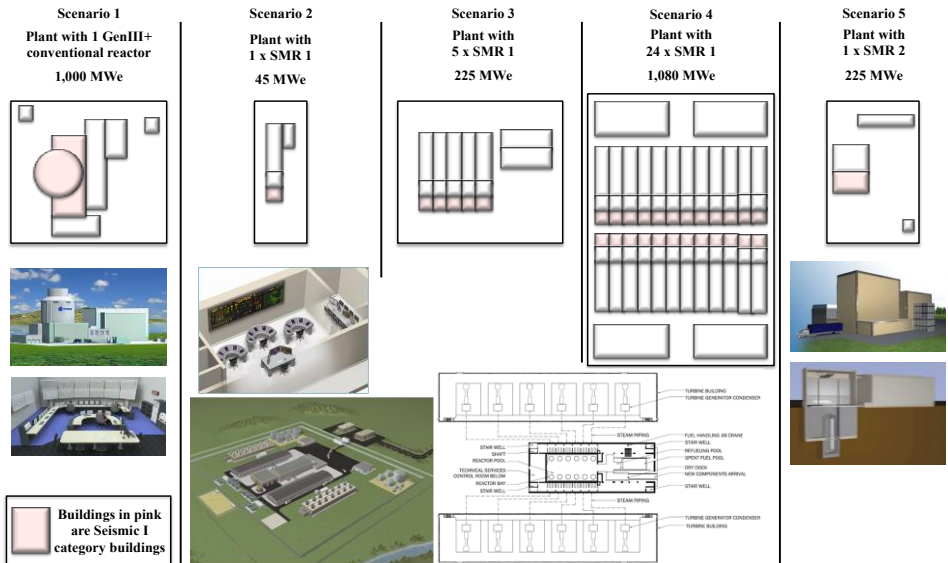
Thermal capacity – 160 MWt
Electrical capacity – 45 Mwe
Capacity factor – greater than 90 percent
Containment dimensions – 60 ft. by 14 ft. (diameter) containment vessel module
RPV dimensions – 45 ft. by 9 ft. (diameter) reactor vessel module
RPV weight – 300 tons as shipped from fabrication
Fuel – standard LWR fuel in 17 x 17 configuration. 24 assemblies. Each 6 ft. long.

We shall call this design SMR Number

The picture to the left is taken from CleanTechnica (http://c1.cleantechnica.com/files/2008/07/nuscale_power_module.jpg). The pictures in the center and to the right are taken from Dr. Jose Reyes' (NuScale CTO) "Introduction to NuScale Design" pre-application presentation to the Nuclear Regulatory Commission (July 24, 2008).

Tip: Cut the problem into tangible pieces, formulate the case and the questions precisely

Part IV. We would like to explore the 5 scenarios below



Scenario 1: the picture at the top is from the Institute for Southern Studies (<http://www.southernstudies.org/images/sitepieces/AP1000Reactor.jpg>), and the picture at the bottom is from the IAEA (http://aris.iaea.org/sonar/image/p00179_image016.jpg). Scenarios 2 through 4: the pictures are from the IAEA, clockwise from top (control room: <http://aris.iaea.org/sonar/image/NuScale%20-%20Fig%208%20-%20Control%20Room.png>, twelve-unit plant blueprint: <http://aris.iaea.org/sonar/image/NuScale%20-%20Fig%209%20-%2012%20unit%20model.png>, and twelve-unit plant layout: <http://aris.iaea.org/sonar/image/NuScale%20-%20Fig%2010%20-%2012%20unit%20layout.png>). Scenario 5: the picture at the top is from the Westinghouse website (http://www.westinghousenuclear.com/smr/smr_main_header.png) and the picture at the bottom is a snapshot taken from the Westinghouse SMR video (<http://www.westinghousenuclear.com/smr/smr.wmv>).

Reducing biases

6. Pitfalls of expert elicitation⁴

Overconfidence, along with some of the effects of the “cognitive heuristics” we all use in making judgments under uncertainty, can lead to important pitfalls in the elicitation of expert judgments. Figure below shows one example of overconfidence, when for two decades the recommended value of the speed of light with confidence intervals did not include the present best-measured value.

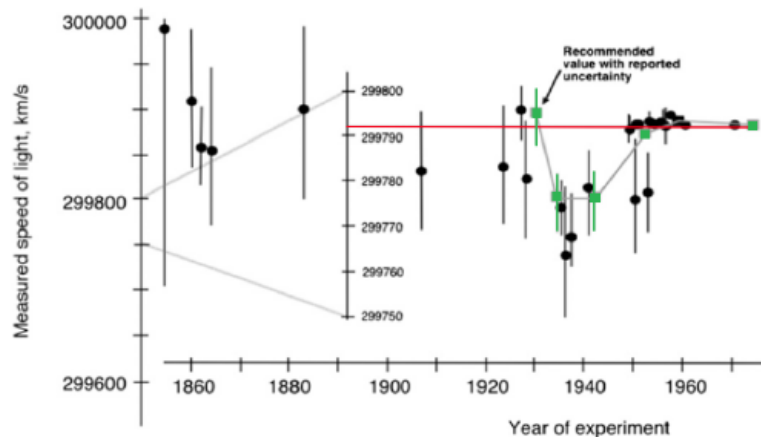


Figure: Published estimates of the speed of light (black boxes), recommended values with uncertainty (blue boxes), and today's best-measured value (red line). *Source:* This figure is taken from Morgan⁵ and is based on data from Henrion and Fischhoff⁶, who report a number of overconfidence cases when evaluating physical constants.

Various strategies are available to minimize these effects. Morgan⁵ provides an overview.

In order to reduce such pitfalls, during quantitative elicitation we will:

- first ask for your **lower bound** estimate (i.e., the lowest possible case) and how this value might end up being even lower;
- then for your **upper bound** estimate and how it might end up being even higher;
- only then will we ask for your “**most likely**” or “best guess” estimate;
- due to the multi-disciplinary nature of induced seismicity assessment, we will ask you to self-report what you believe to be your **level of knowledge** with respect to questions we ask.

Tip: At the start, tell the experts about these effects

Reducing availability bias

7.1. Factors that may influence your estimate of induced seismicity hazard

To start with, we have listed factors that could influence your estimate of induced seismicity hazard, applicable to EGS plants.

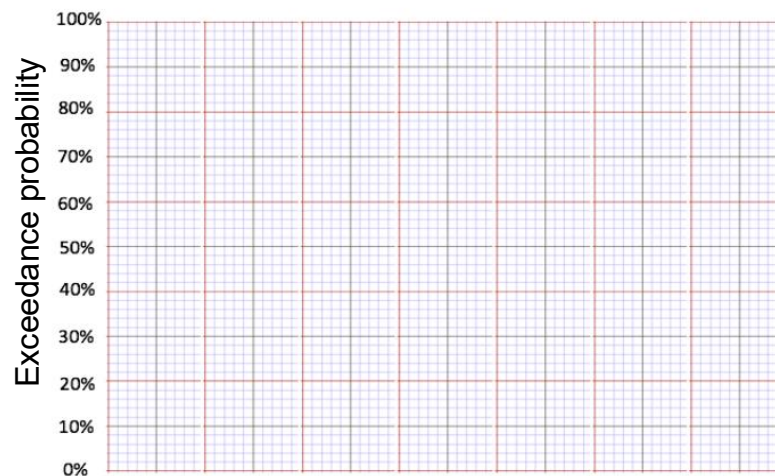
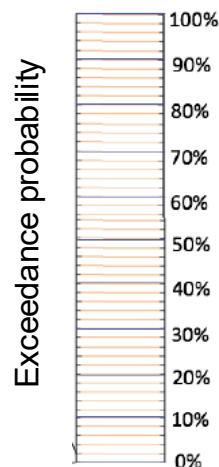
To what extent do these factors influence your estimate of induced seismicity hazard?

	Not at all						Very much
Cumulative injected volume, including setting of the traffic light system	☐	☐	☐	☐	☐	☐	☐
Depth of the reservoir	☐	☐	☐	☐	☐	☐	☐
Distance to critically pre-stressed extended faults	☐	☐	☐	☐	☐	☐	☐
Injection rate, including setting of the traffic light system	☐	☐	☐	☐	☐	☐	☐
Natural seismicity	☐	☐	☐	☐	☐	☐	☐
Tectonic stress regime	☐	☐	☐	☐	☐	☐	☐
Type of injection fluid	☐	☐	☐	☐	☐	☐	☐
Wellhead pressure	☐	☐	☐	☐	☐	☐	☐
Other: _____	☐	☐	☐	☐	☐	☐	☐
Other: _____	☐	☐	☐	☐	☐	☐	☐

Tip:

- Before eliciting judgements, help experts recall the available evidence and their mental models

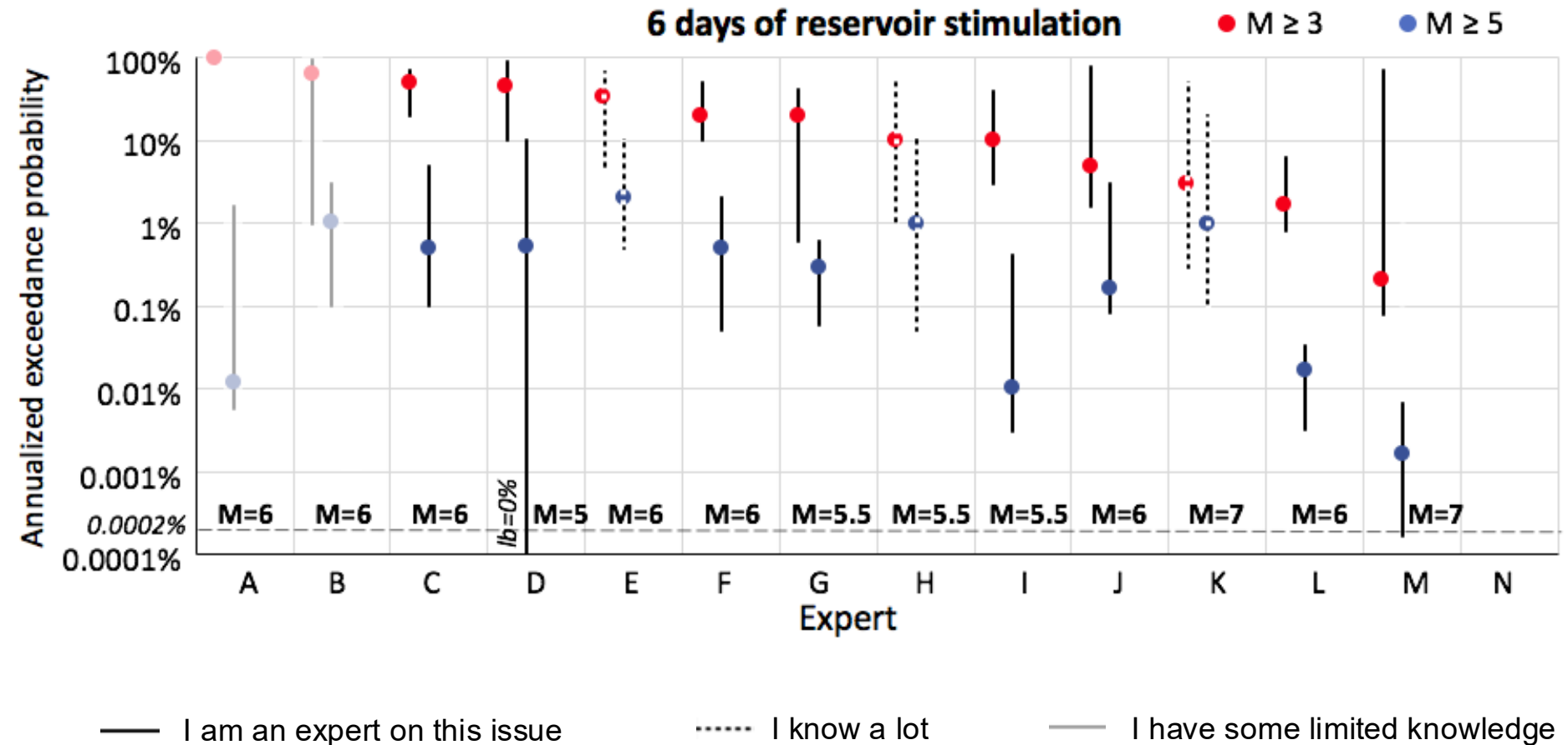
Reducing overconfidence and anchoring and adjustment bias



Tips:

- Let the experts choose their own scale not to anchor them
- Start with eliciting higher and upper bounds, not best-guess estimates
- Prompt them with additional questions, e.g. “Can you imagine a realistic scenario where it could be higher?” See Supplementary Material in (Morgan, 2014)
- If their opinion diverges from literature, ask them to explain
- Beware that some experts might struggle with probabilities

Exceedance probabilities of EGS induced earthquakes



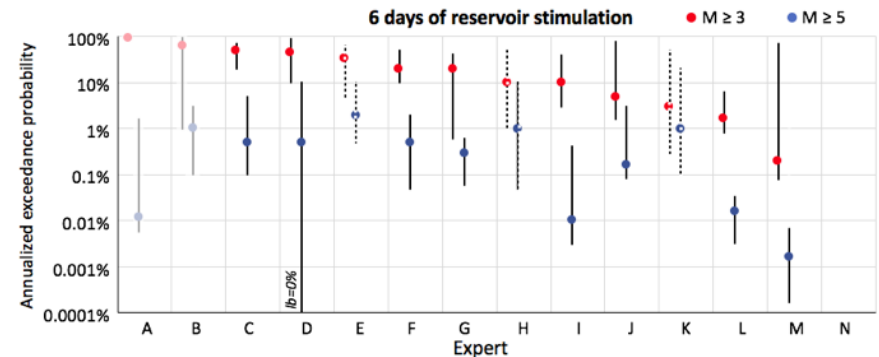
Influencing factors, uncertainty, and gains through future research

		Influence on the final hazard outcome							Contribution to uncertainty							Uncertainty reduction due to future research and data collection						
		↓ Not at all			↓ Very high ↓				↓ Not at all			↓ Very high ↓				↓ Not at all			↓ Very high ↓			
<i>Faults</i> <i>EGS design and operation</i>	Distance to extended faults	0	0	0	0	2	5	6	0	1	0	1	2	3	4	0	3	0	1	0	3	4
	Cumulative injected volume	0	2	0	0	3	5	3	0	1	6	1	2	0	1	0	1	3	1	1	2	3
	Depth of the reservoir	0	0	1	5	3	4	0	0	3	4	1	2	1	0	1	3	2	0	3	2	0
	Wellhead pressure	0	1	2	2	4	3	1	0	2	0	6	1	2	0	1	0	1	4	4	1	0
	Injection rate	0	1	4	0	5	2	1	0	1	3	5	1	1	0	0	2	2	2	3	2	0
<i>Tectonics</i>	Tectonic stress regime	2	0	2	2	2	4	1	0	2	2	1	3	2	1	0	1	5	1	0	2	2
	Natural seismicity	1	1	3	2	2	3	1	0	0	2	2	4	2	1	0	0	1	2	4	3	1
<i>Fluid</i>	Type of injection fluid	2	5	2	3	1	0	0	1	6	1	2	0	1	0	1	3	5	2	0	0	0

Source: Trutnevyte & Azevedo, 2018

Summary of this expert elicitation

- ◆ We have observed a **vast diversity in quantitative expert judgements** about the probabilities of felt and damaging EGS induced earthquakes and magnitudes of the largest events
- ◆ Expert **mental models** of what influences induced seismicity hazard, related uncertainties, and what future research could achieve diverge too



	Influence on the final hazard outcome						Contribution to uncertainty						Uncertainty reduction due to future research and data collection					
	↓ Not at all	↓	↓	↓	↓	↓	↓ Not at all	↓	↓	↓	↓	↓	↓ Not at all	↓	↓	↓	↓	↓
Distance to extended faults	0	0	0	0	2	6	0	1	0	1	2	3	4	0	3	0	1	0
Cumulative injected volume	0	2	0	0	3	5	0	1	6	1	2	0	1	0	1	3	1	1
Depth of the reservoir	0	0	1	5	3	4	0	3	4	1	2	1	0	1	3	2	0	3
Wellhead pressure	0	1	2	2	4	3	0	2	0	6	1	2	0	1	0	1	4	4
Injection rate	0	1	4	0	5	2	0	1	3	5	1	1	0	0	2	2	2	3
Tectonic stress regime	2	0	2	2	2	4	0	2	2	1	3	2	1	0	1	5	1	0
Natural seismicity	1	1	3	2	2	3	0	0	2	2	4	2	1	0	0	1	2	4
Type of injection fluid	2	5	2	3	1	0	1	6	1	2	0	1	0	1	3	5	2	0

Shedding light on the existing schools of thought

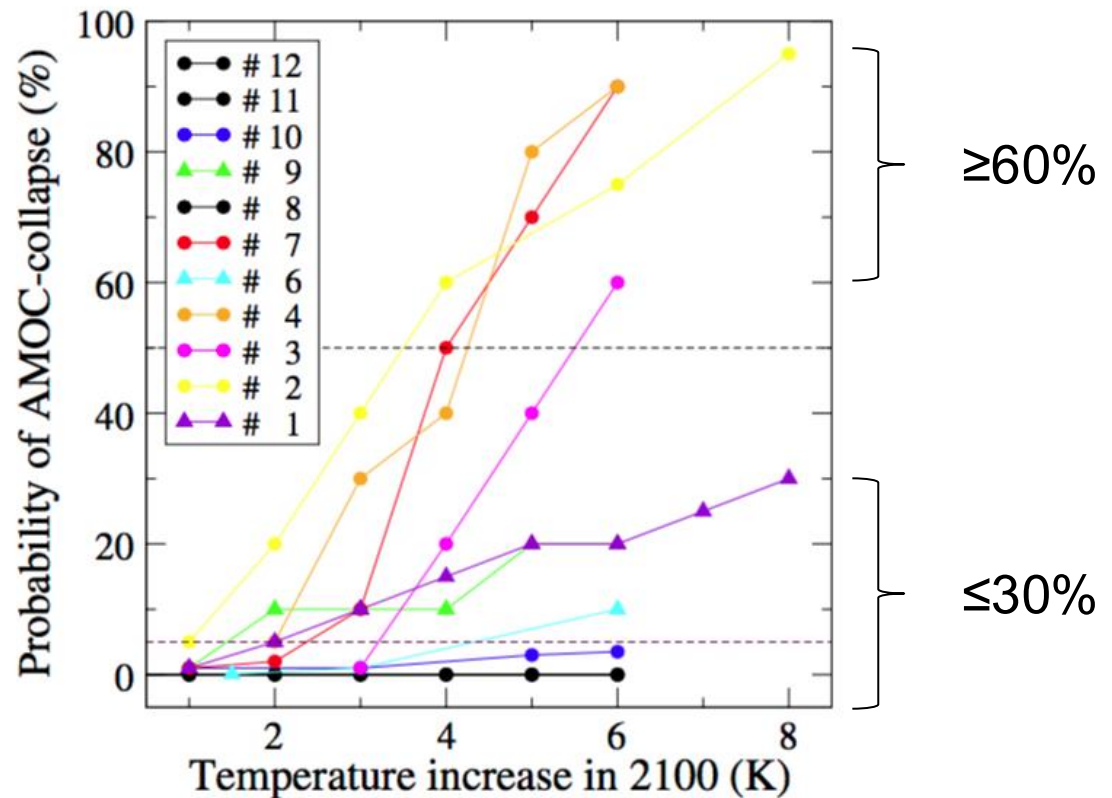
Climatic Change (2007) 82:235–265
DOI 10.1007/s10584-007-9246-3

Expert judgements on the response of the Atlantic meridional overturning circulation to climate change

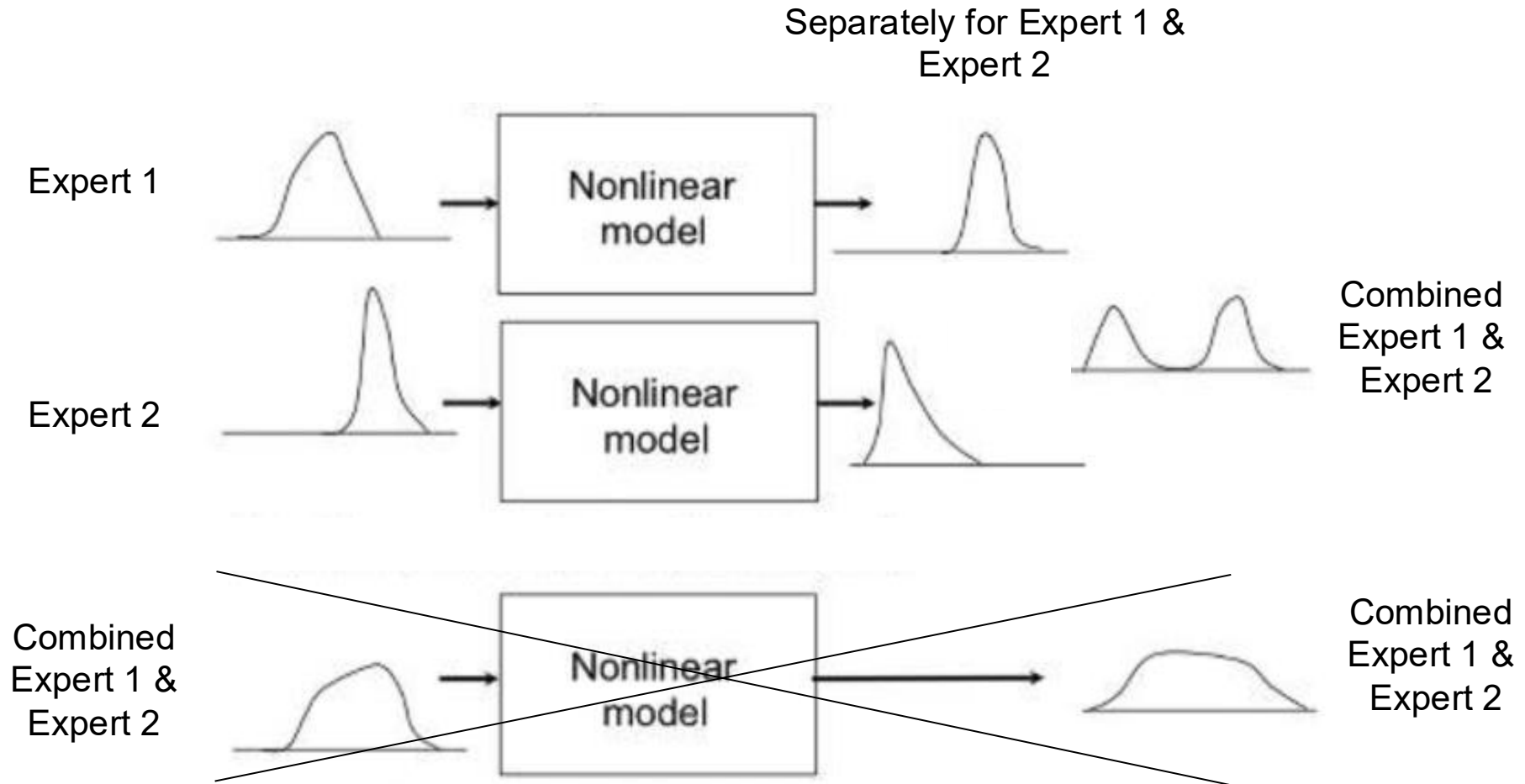
Kirsten Zickfeld · Anders Levermann ·
M. Granger Morgan · Till Kuhlbrodt ·
Stefan Rahmstorf · David W. Keith

Tips:

- Beware of the diversity in expert judgements
- Choose experts to represent different camps
- Elicit individual judgments first

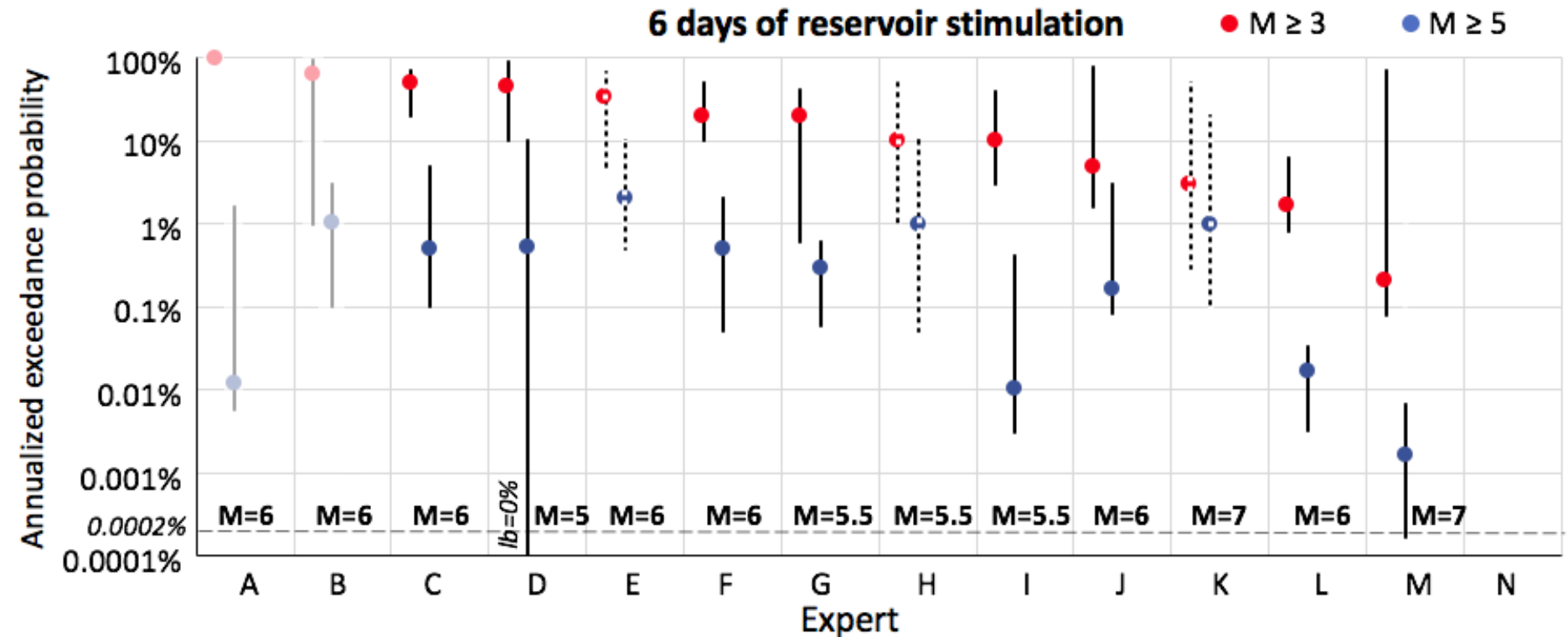


Combining expert judgement



Tip: In case of very diverse expert judgements, it is more suitable to do a sensitivity analysis to different expert opinions rather than combine them.

Exceedance probabilities of EGS induced earthquakes



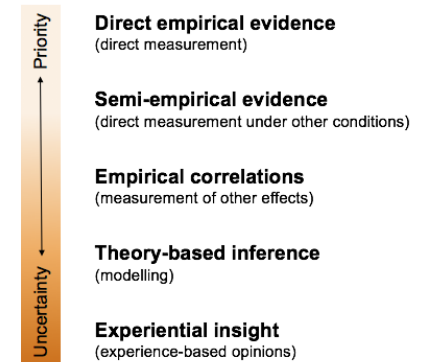
Tip: “Science is not a matter of majority vote. Sometimes it is the minority outlier who ultimately turns out to have been correct.” (Morgan, 2014)

Goals for today

- ◆ Understand the overall principles of expert elicitation



- ◆ Look into some practicalities of expert elicitation



Get in touch with questions and comments!



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Questions to elicit probability distribution

Your favorite band is planning a concert somewhere in your town. How much the ticket will cost? Not what you would like it to cost and not what you would be able to pay.

- Lower bound: What is the lowest that it could cost?
- Lower bound 2: What if they play in a large hall, where you get the back seats or buy the last-minute ticket at the door?
- Upper bound: What is the highest it could cost?
- Upper bound 2: Can you tell me a case where it would be higher? What if the band plays in a small place with limited entrance only?
- Most likely: What is the most likely?
- Check: It is not symmetrical, right?