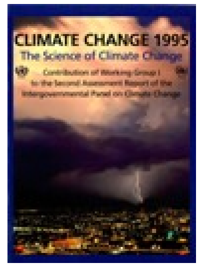
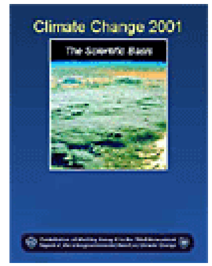
Sentrale spørsmål i forsking og samfunn: Klima: Hva vet vi? Hva bør vi gjøre?

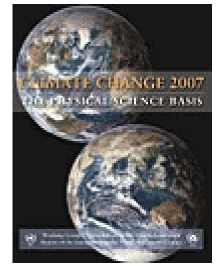
Bergen, 15 Sept 2016

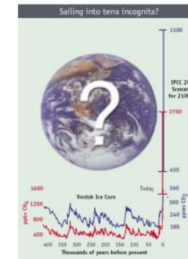
Climate change, the uncertainty monster and post normal science

Joseph Fourier
1768 - 1830



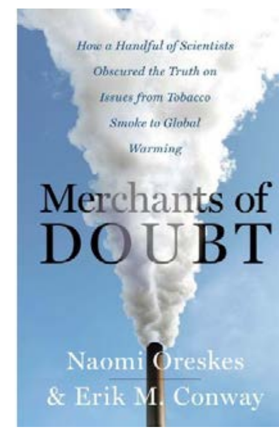






Global climate 2100?

Jeroen P. van der Sluijs *@Jeroen_vdSluijs*



Senter for vitenskapsteori

1824

MÉMOIRE

SUR

LES TEMPÉRATURES DU GLOBE TERRESTRE ET DES ESPACES PLANÉTAIRES.

PAR M. FOURIER.

LA question des températures terrestres, l'une des plus importantes et des plus difficiles de toute la philosophie naturelle, se compose d'éléments assez divers qui doivent être considérés sous un point de vue général. J'ai pensé qu'il serait utile de réunir dans un seul écrit les conséquences principales de cette théorie; les détails analytiques que l'on omet ici se trouvent pour la plupart dans les ouvrages que j'ai déja publiés. J'ai désiré surtout présenter aux physiciens, dans un tableau peu étendu, l'ensemble des phénomènes et les rapports mathématiques qu'ils ont entre eux.

La chaleur du globe terrestre dérive de trois sources qu'il est d'abord nécessaire de distinguer.

1° La terre est échauffée par les rayons solaires, dont l'inégale distribution produit la diversité des climats.

2° Elle participe à la température commune des espaces planétaires, étant exposée à l'irradiation des astres innombrables qui environnent de toutes parts le système solaire.

http://gallica.bnf.fr/ark:/12148/bpt6k32227.image.r=memoires+de+l%27academie+des+sciences.f808.langEN

1856

ART. XXXI.—*Circumstances affecting the Heat of the Sun's Rays;* by EUNICE FOOTE.

(Read before the American Association, August 23d, 1856.)

MY investigations have had for their object to determine the different circumstances that affect the thermal action of the rays of light that proceed from the sun.

Thirdly. The highest effect of the sun's rays I have found to be in carbonic acid gas.

One of the receivers was filled with it, the other with common air, and the result was as follows:

In Common Air.		In Carbonic Acid Gas.	
In shade.	In sun.	In shade.	In sun.
80	90	80	90
81	94	84	100
80	99	84	110
81	100	85	120

The receiver containing the gas became itself much heated—very sensibly more so than the other—and on being removed, it was many times as long in cooling.

An atmosphere of that gas would give to our earth a high temperature; and if as some suppose, at one period of its history the air had mixed with it a larger proportion than at present, an increased temperature from its own action as well as from increased weight must have necessarily resulted.

On comparing the sun's heat in different gases, I found it to be in hydrogen gas, 104°; in common air, 106°; in oxygen gas, 108°; and in carbonic acid gas, 125°.

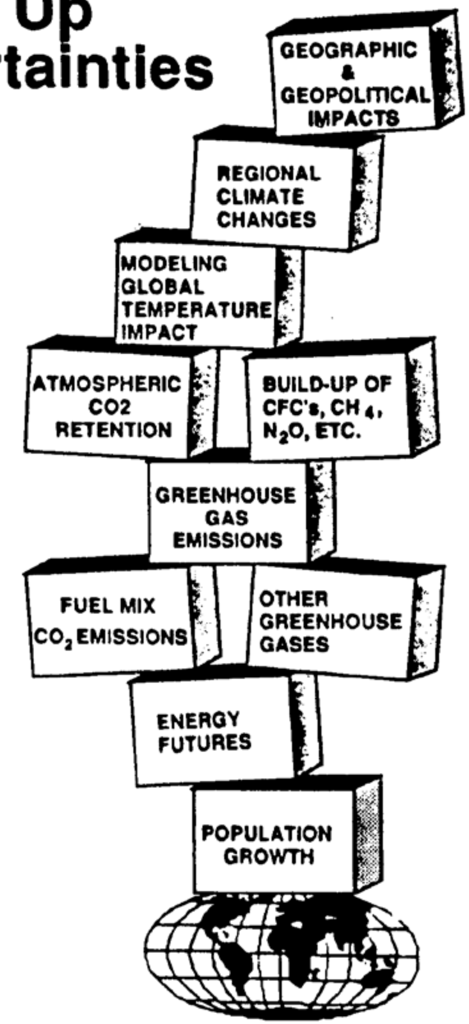
http://www.climatechangenews.com/2016/09/02/the-woman-who-identified-the-greenhouse-effect-years-before-tyndall/

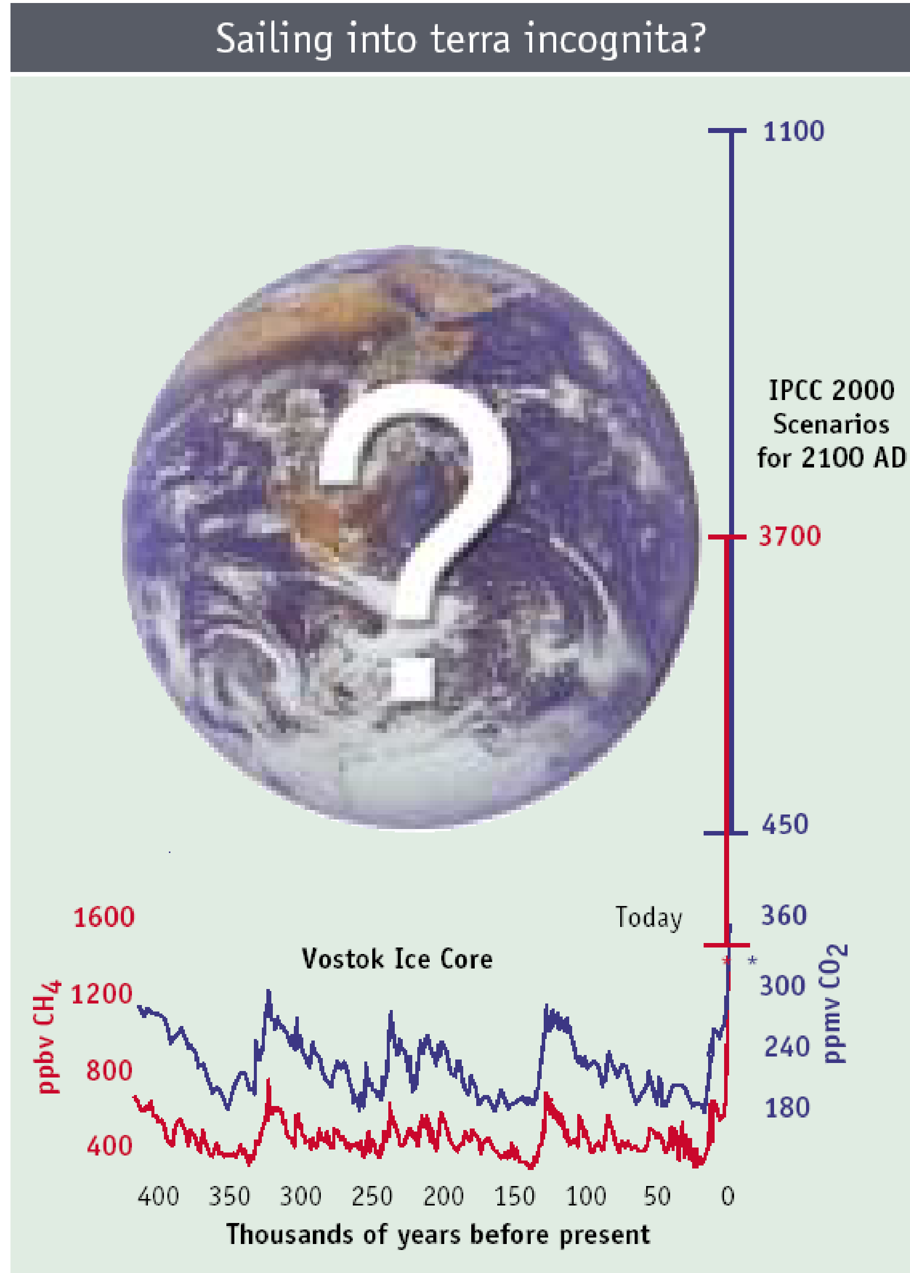
Period	Phase	Characteristics
1856-1985	Foundational period	Scientific concern
1985-1988	Agenda-setting phase	Emerging policy issue
1988-1990	Pre-negotiation period	Government involvement
1990-1992	Intergovernmental negotiations	UN FCCC: Mitigation
1992-2009	Post agreement phase COP1 – COP15	Elaboration & implementation UN FCCC
2009/2010	Climate gate / Himalaya gate	Polarization & erosion of trust
2011-present	??? *Welcome in the Post normal age*	Working deliberatively within imperfections
>2015		Prepare for > +2°C Adaptation ? Negative emissions ? Geo-engineering

Post-normal science: / Peter Gluckman, *Nature* 12 Mar 2014
http://www.nature.com/news/policy-the-art-of-science-advice-to-government-1.14838?WT.ec_id=NATURE-20140313

GLOBAL CLIMATE CHANGE

Piling Up Uncertainties





How does science-policy interface cope with uncertainties

Two strategies dominate:

- **Overselling certainty**
  - to promote political decisions (enforced consensus), or
- **Overemphasising uncertainty**
  - to prevent political action

- Both promote decision strategies that are **not fit for meeting the challenges** posed by the uncertainties and complexities faced.

- Need for a third voice next to alarmists and skeptics: coping with uncertainty, scientific dissent & plurality in science for policy.

A practical problem:

Protecting a strategic fresh-water resource

5 scientific consultants addressed same question:

“which parts of this area are most vulnerable to nitrate pollution and need to be protected?”

(Refsgaard, Van der Sluijs et al, 2006)

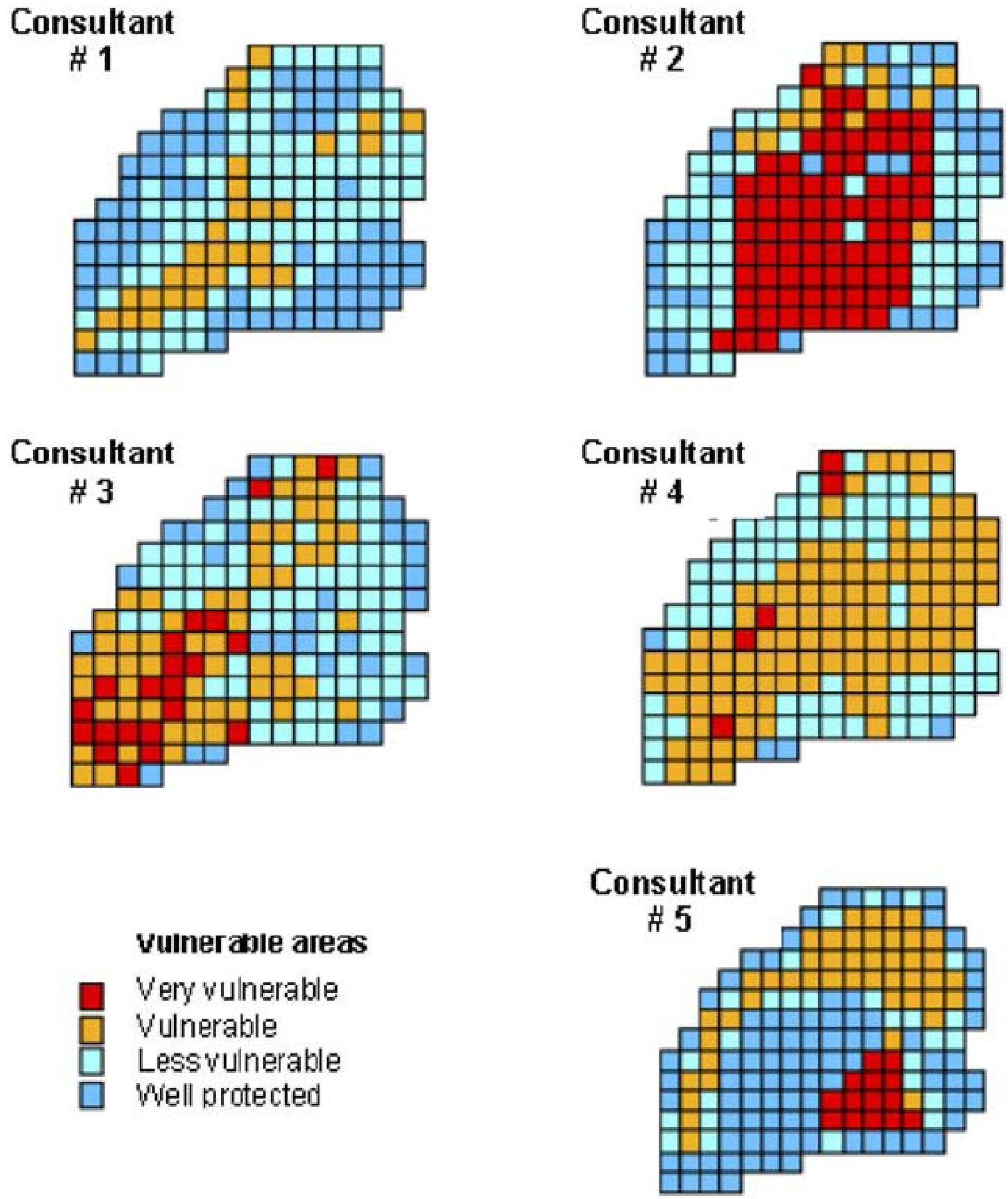


Fig. 1. Model predictions on aquifer vulnerability towards nitrate pollution for a 175 km^2 area west of Copenhagen [11].

3 framings of uncertainty

'deficit view'

- Uncertainty is provisional
- Reduce uncertainty, make ever more complex models
- *Tools:* quantification, Monte Carlo, Bayesian belief networks
  - ***Speaking truth to power***

'evidence evaluation view'

- Comparative evaluations of research results
- *Tools:* Scientific consensus building; multi disciplinary expert panels
- focus on robust findings
  - ***Speaking [consensus] to power***

'complex systems view / *post-normal* view'

- Uncertainty is intrinsic to complex systems
- Openly deal with deeper dimensions of uncertainty
- *Tools:* Knowledge Quality Assessment
  - ***Working deliberatively within imperfections***

J.P. van der Sluijs (2010). Uncertainty and complexity: the need for new ways of interfacing climate science and climate policy. In: P. Driessen P. Leroy, and W. van Vierssen, From Climate Change to Social Change: Perspectives on Science – Policy Interactions, International Books, Utrecht, 31-49.

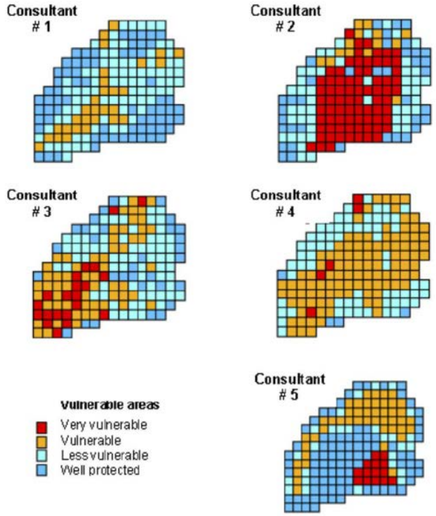
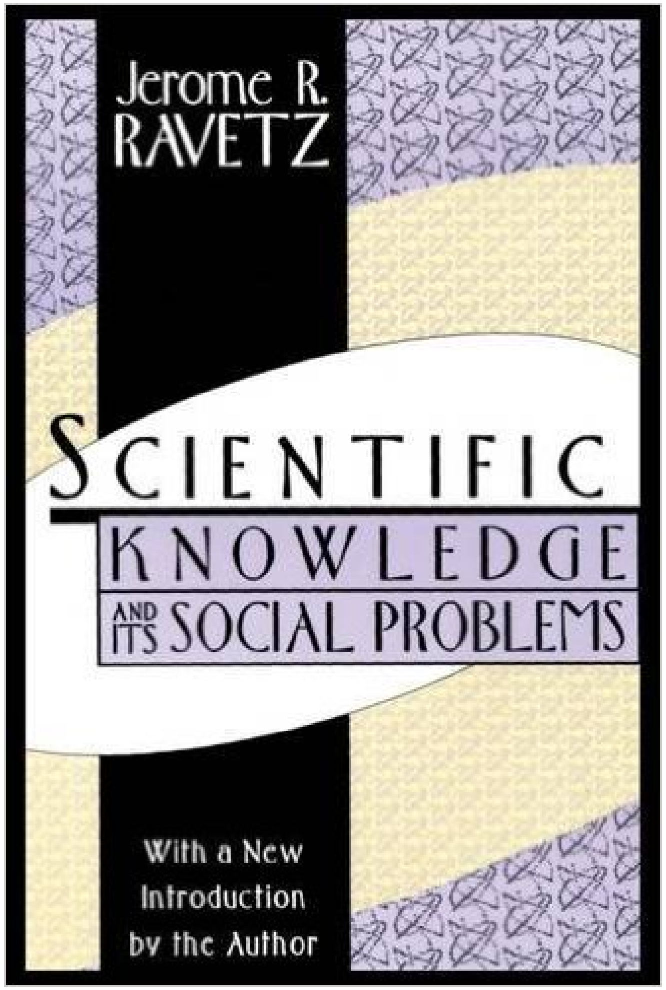
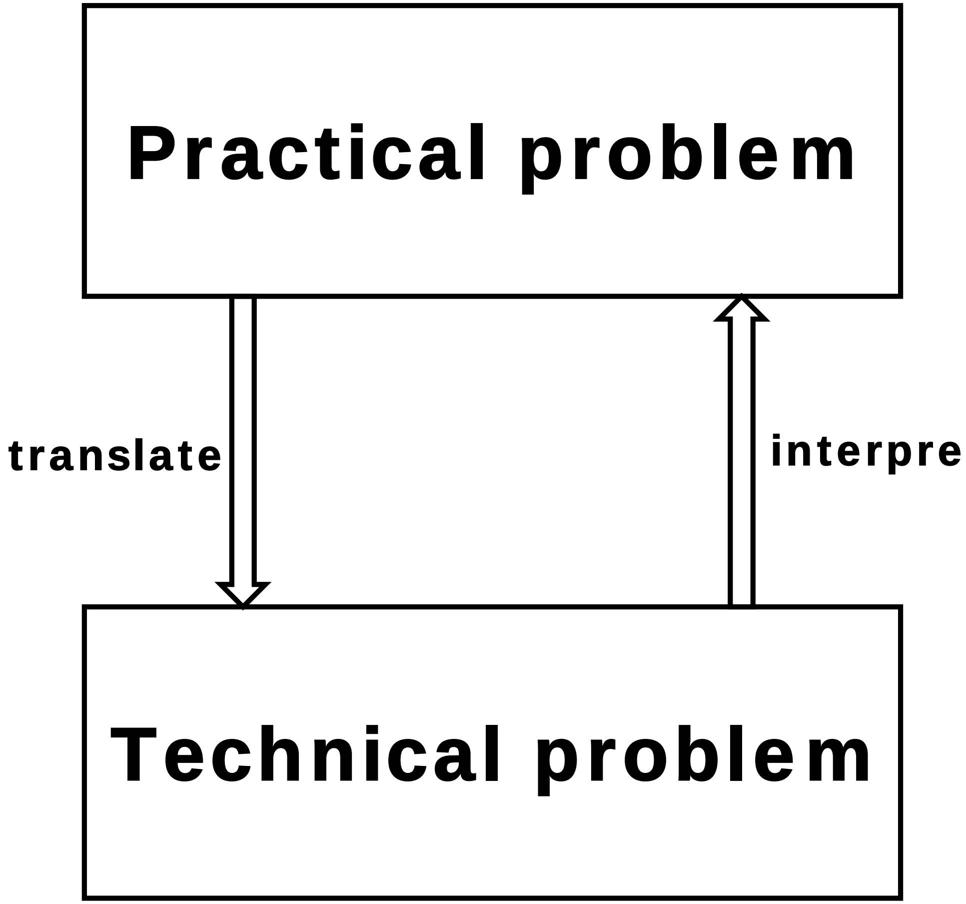


Fig. 1. Model predictions on aquifer vulnerability towards nitrate pollution for a 175 km^2 area west of Copenhagen [11].

How to act upon such uncertainty?

- **Bayesian** approach: 5 priors. Average and update likelihood of each grid-cell being red with data (but oooops, there is no data and we need decisions now)
- IPCC approach: Lock the 5 consultants up in a room and don't release them before they have **consensus**
- **Nihilist** approach: Dump the science and decide on an other basis
- **Precautionary** robustness approach: protect all grid-cells
- **Academic bureaucrat** approach: Weigh by citation index (or H-index) of consultant.
- Select the consultant that you **trust** most
- Real life approach: Select the consultant that best fits your **policy agenda**
- Post normal: explore the relevance of our ignorance: **working deliberatively within imperfections**





http://www.andreasaltelli.eu/file/repository/Scientific_Knowledge_and_Its_Social_Problems.pdf

Climate science for climate policy

The pitfall of *lamp-posting* in translating *practical problems* into *technical problems*

Searching where the light shines
may not help to solve the practical problem...

Uncertainty as a monster in the science–policy interface: four coping strategies

2005

Jeroen van der Sluijs

Copernicus Institute for Sustainable Development and Innovation, Utrecht University, Heidelberglaan 2, 3584 CS Utrecht, The Netherlands (E-mail: *j.p.vandersluijs@chem.uu.nl*)

Abstract Using the metaphor of monsters, an analysis is made of the different ways in which the scientific community responds to uncertainties that are hard to tame. A monster is understood as a phenomenon that at the same moment fits into two categories that were considered to be mutually excluding, such as knowledge versus ignorance, objective versus subjective, facts versus values, prediction versus speculation, science versus policy. Four styles of coping with monsters in the science–policy interface can be distinguished with different degrees of tolerance towards the abnormal: monster-exorcism, monster-adaptation, mon

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Keywords Ano

CLIMATE SCIENCE AND THE UNCERTAINTY MONSTER

BY J. A. CURRY AND P. J. WEBSTER

2011

An exploration of ways to understand, assess and reason about uncertainty in climate science, with specific application to the IPCC assessment process.

http://www.nusap.net/spe/UPEMmonsters.pdf
http://journals.ametsoc.org/doi/pdf/10.1175/2011BAMS3139.1

Uncertainty as a “monster”

- A monster is a phenomenon that at the same moment fits into two categories that were considered to be mutually excluding

(Smits, 2002; Douglas 1966)

  - knowledge – ignorance
  - objective – subjective
  - facts – values
  - prediction – speculation
  - science - policy

Responses to monsters

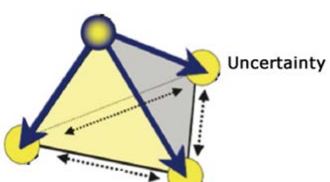
Different degrees of tolerance towards the abnormal:

- monster-exorcism (expulsion)
- monster-adaptation (transformation)
- monster-embracement (acceptance)
- monster-assimilation (rethinking)

There are many uncertainties in our predictions particularly with regard to the timing, magnitude and regional patterns of climate change, due to our incomplete understanding of:

- sources and sinks of greenhouse gases, which affect predictions of future concentrations
- clouds, which strongly influence the magnitude of climate change
- oceans, which influence the timing and patterns of climate change
- polar ice sheets which affect predictions of sea level rise

These processes are already partially understood, and we are confident that the uncertainties can be reduced by further research However, the complexity of the system means that we cannot rule out surprises



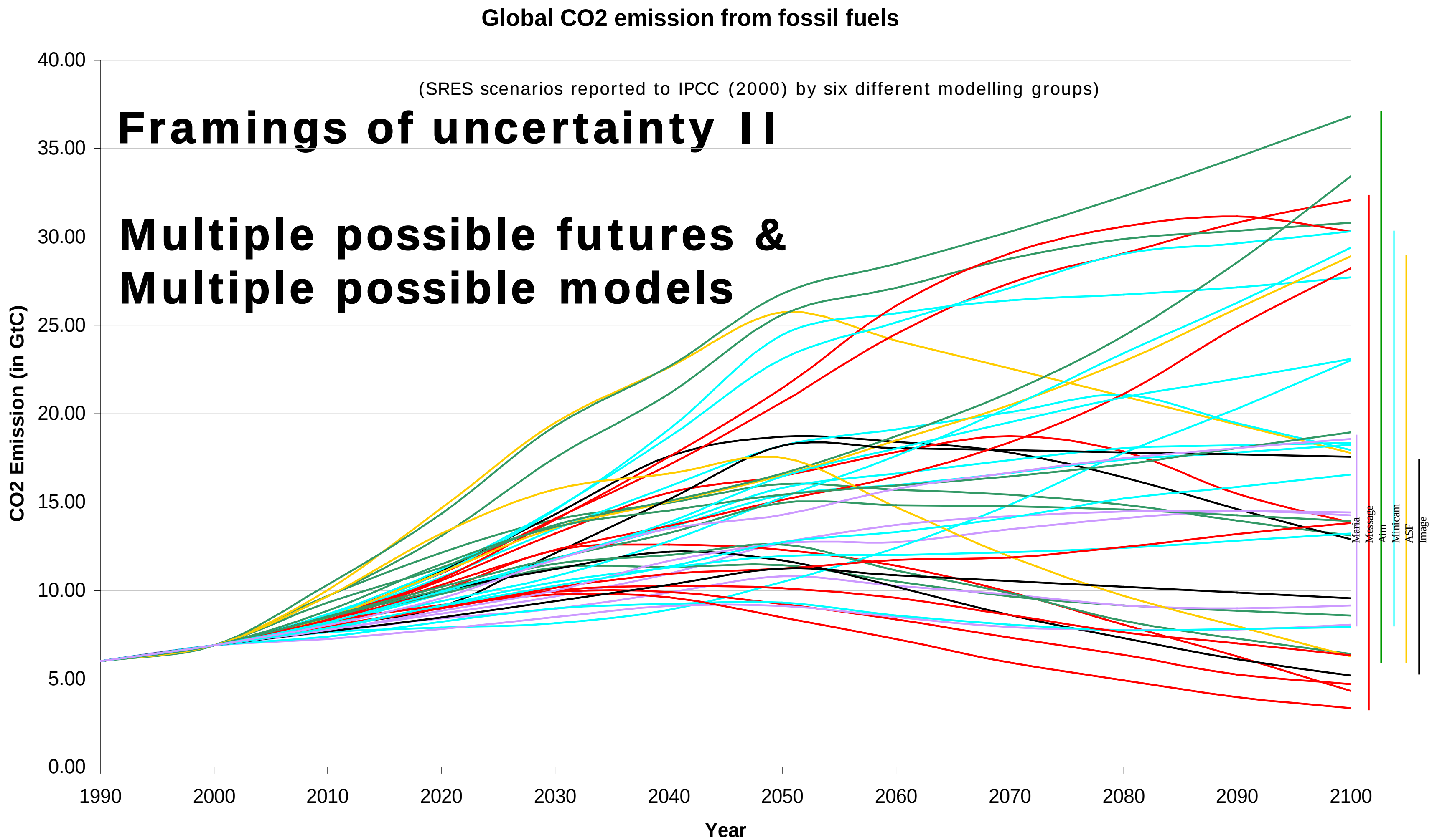
(IPCC AR1 Policy Makers Summary, 1990)
http://www.ipcc.ch/ipccreports/far/wg_I/ipcc_far_wg_I_spm.pdf

Former chairman IPCC on objective to reduce climate uncertainties:

- "*We cannot be certain that this can be achieved easily and we do know it will take time. Since a fundamentally chaotic climate system is predictable only to a certain degree, our research achievements will always remain uncertain.* ***Exploring the significance and characteristics of this uncertainty is a fundamental challenge to the scientific community***." (Bolin, 1994)

[Prof. Bert Bolin, 15 March 1925 – 30 December 2007]

IPCC 10 years after *“we are confident that the uncertainties can be reduced...”*



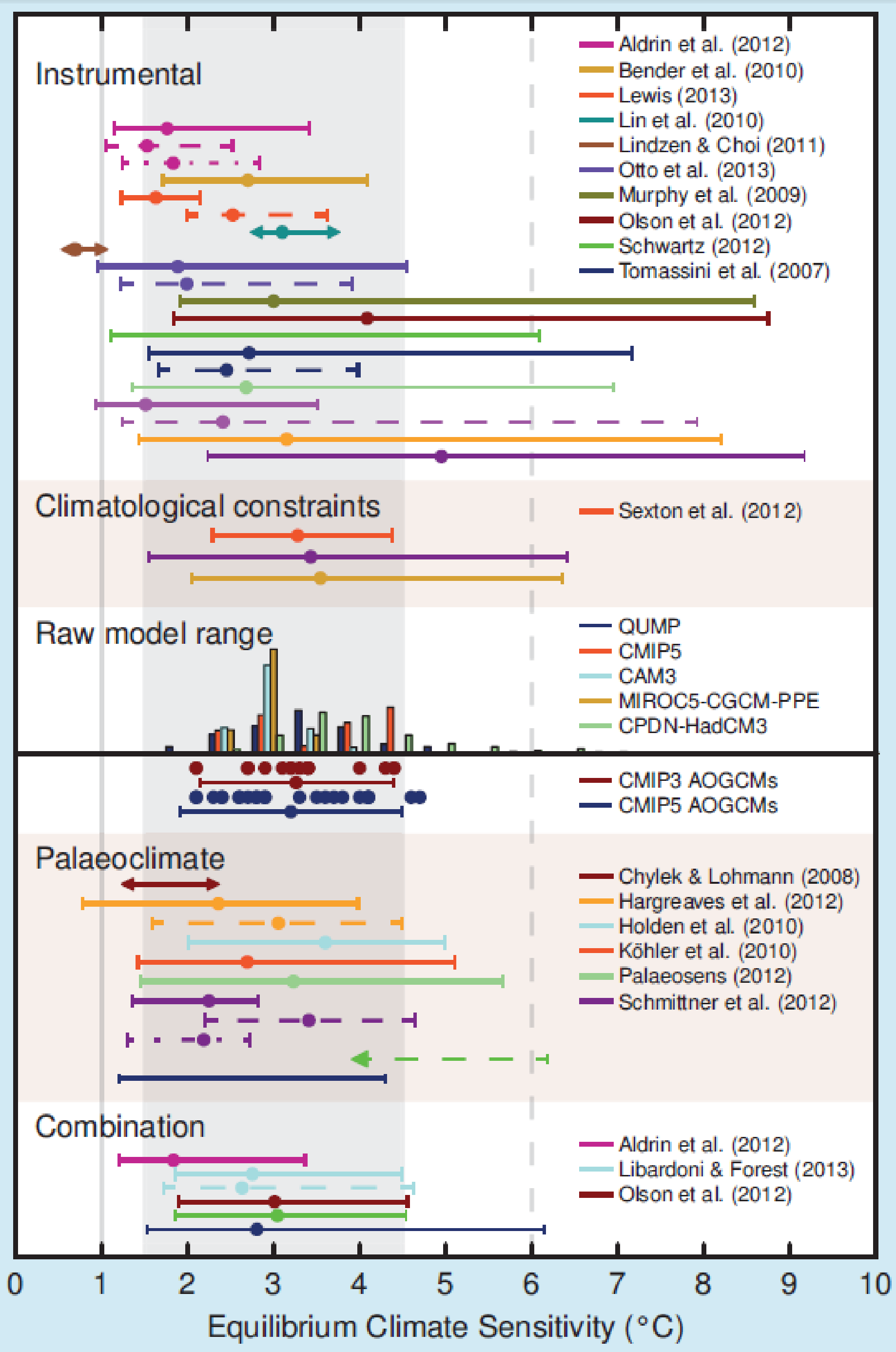
25 years after "we are confident that the uncertainties can be reduced..."

Evolution of knowledge on Climate Sensitivity over past 35 years

Assessment report	Range of GCM results (°C)	Concluded Range (°C)	Concluded best guess (°C)
NAS 1979	2-3.5	1.5-4.5	3
NAS 1983	2-3.5	1.5-4.5	3
Villach 1985	1.5-5.5	1.5-4.5	3
IPCC AR1 1990	1.9-5.2	1.5-4.5	2.5
IPCC AR2 1995	MME	1.5-4.5	2.5
IPCC AR3 2001	MME	1.5-4.5	Not given
IPCC AR4 2007	MME	2.5-4.5	3
IPCC AR5 2013	MME (0.5-9)	1.5-4.5*	Not given

*"Likely" (17-83%) range. Prior to AR4 ranges were not clearly defined.
MME = Multi Model Ensemble

(Van der Sluijs e.a. 1998, updated 2015)
http://sss.sagepub.com/content/28/2/291.short



IPCC AR5 Chapter 12

Probability density functions, distributions and ranges for equilibrium climate sensitivity

Grey shaded range:
likely 1.5°C to 4.5°C range

Grey solid line:
extremely unlikely less than 1°C

Grey dashed line:
very unlikely greater than 6°C.

http://www.climatechange2013.org/images/report/WG1AR5_Chapter12_FINAL.pdf

Scandal at the Netherlands Environmental Assessment Agency

RIVM / De Kwaadsteniet (1999)

"RIVM over-exact prognoses based on virtual reality of computer models"

Newspaper headlines:

- Environmental institute lies and deceits
- Fuss in parliament after criticism on environmental numbers
- The bankruptcy of the environmental numbers
- Society has a right on fair information, RIVM does not provide it

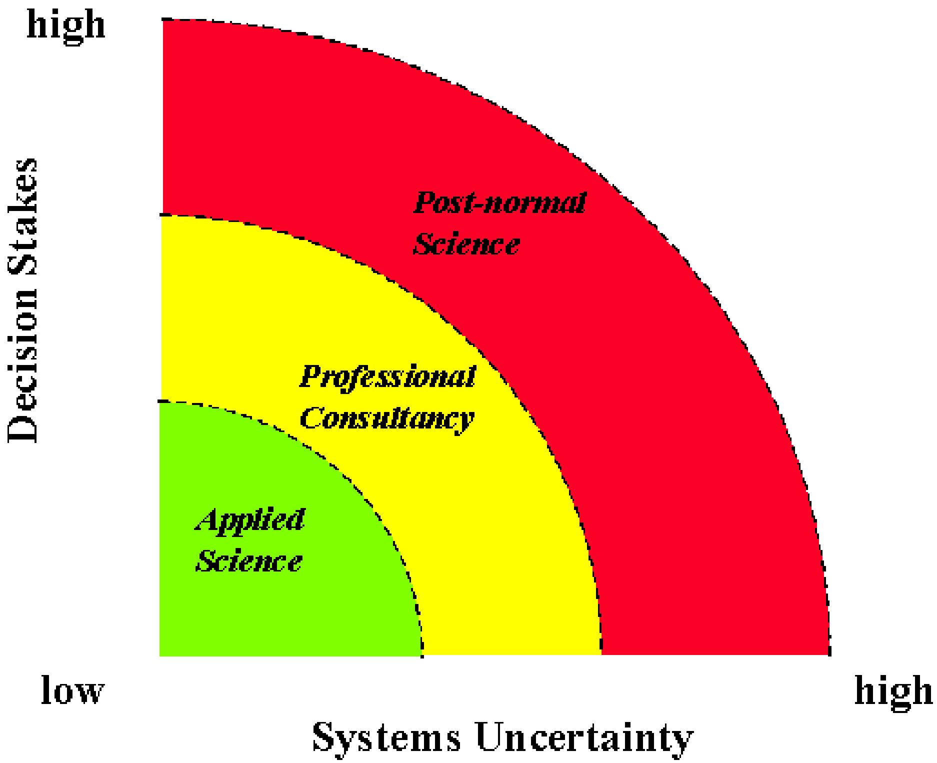
Insights on uncertainty

- More research tends to increase uncertainty
  - reveals unforeseen complexities
  - Complex systems exhibit irreducible uncertainty (intrinsic or practically)
- Omitting uncertainty management can lead to scandals, crisis and loss of trust in science and institutions
- In many complex problems unquantifiable uncertainties dominate the quantifiable uncertainty
- High quality $\neq$ low uncertainty
- Quality relates to **fitness for function** (robustness, PP)
- Shift in focus needed from reducing uncertainty towards reflective methods to explicitly cope with uncertainty and quality

Complex - *uncertain* - risks

Typical characteristics:

- Decisions urgent
- Stakes high
- Values in dispute
- Irreducible & unquantifiable uncertainty

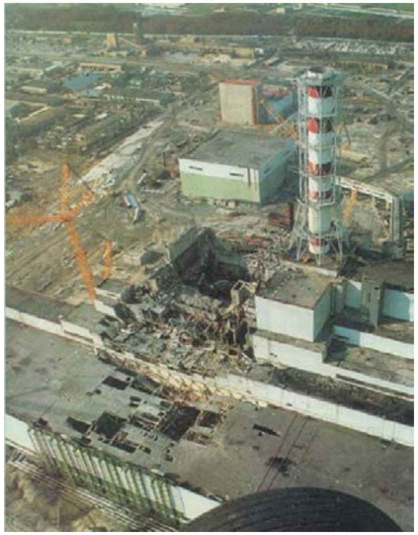


- Assessment: models, scenarios, assumptions, extrapolations
- (hidden) value loadings in problem frames, indicators chosen, assumptions made

- **Knowledge Quality Assessment!**

(Funtowicz & Ravetz, 1993)
http://www.uu.nl/wetfilos/wetfil10/sprekers/Funtowicz_Ravetz_Futures_1993.pdf

Ch-Ch syndrome 1986



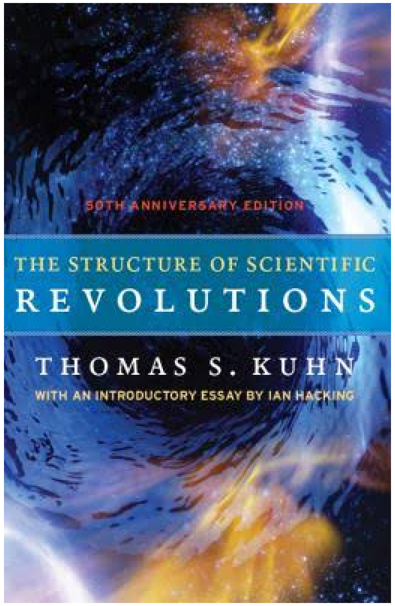
*“**The issue of quality control in science, technology and decision-making** is now appreciated as urgent and threatening. The experiences of **Ch**ernobyl and **Ch**allenger, both resulting from lapses of quality control, illustrate this problem. We have described the **"Ch-Ch Syndrome": the catastrophic collapse of sophisticated mega-technologies resulting from political pressure, incompetence and cover-ups** (Ravetz et al., 1986).”*

PNS and Risk Society

- *“The destructive impact of our industrial system on the natural environment is another manifestation of the Ch-Ch syndrome. Here the phenomena are less dramatic but more pervasive. The pathologies of the industrial system are transferred out, so that it degrades its environment while running "normally". This contradiction affects more than particular high technologies;* ***the very place of science in our civilization is called into question.”***

Funtowicz & Ravetz 1990

Normal science



Thomas Kuhn, The Structure of Scientific Revolutions (1962)

- 'normal science' = uncritical puzzle solving within an unquestioned framework, or 'paradigm'.
- What all scientists do most of the time, and most scientists do all the time.

Normal Science - continued

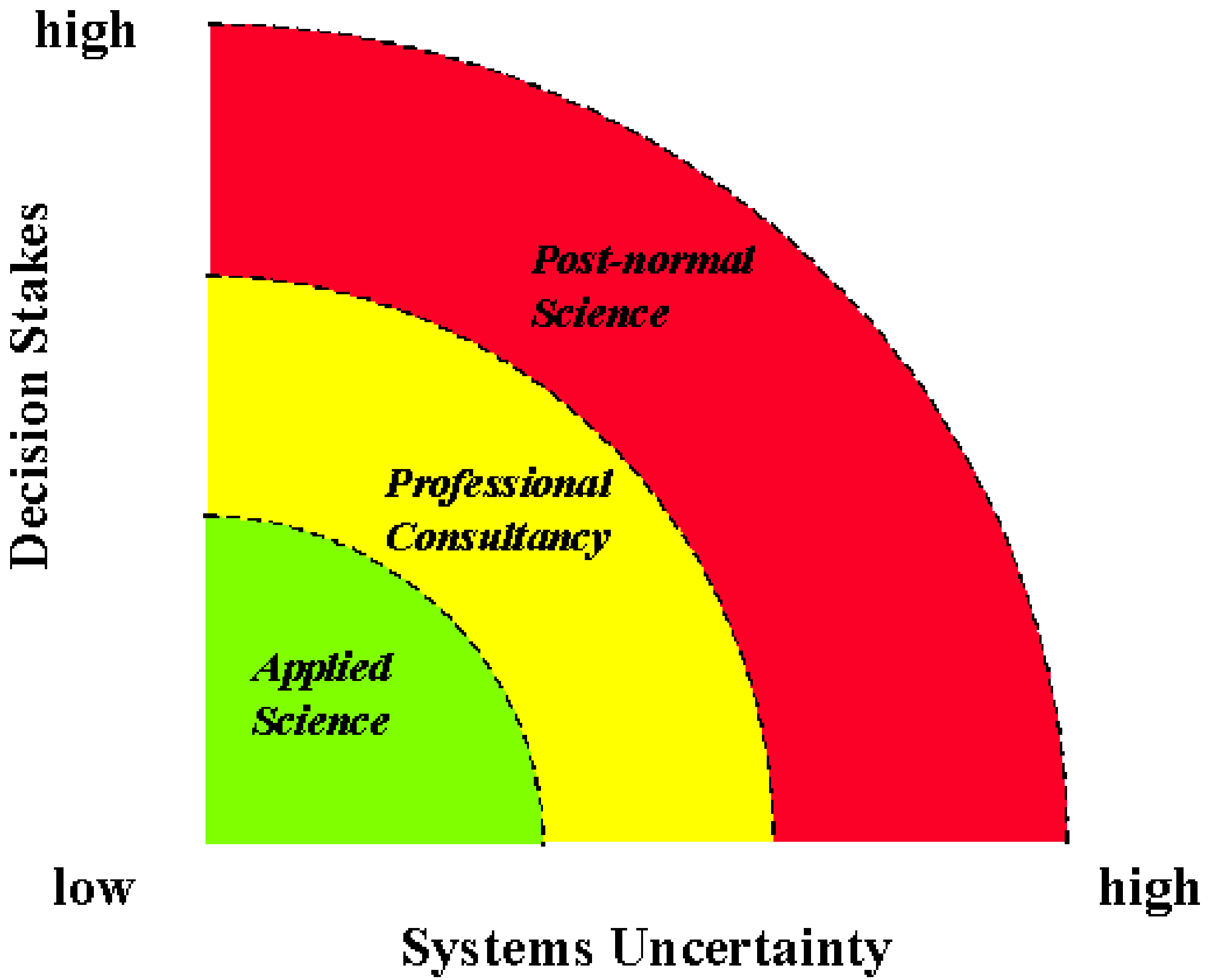
- Scientists are prepared for this rigorous effort by a dogmatic scientific training with textbooks where the answers to scientific questions can be found in the back.
- This is further reinforced by naive and simplistic accounts of how scientists discover truth.
- However successful this Normal Science approach is in traditional disciplinary research, it meets its limits when society is confronted with the need to resolve transdisciplinary policy issues regarding trans-national and trans-generational environmental risk on which yet no unquestioned frameworks exist.

In case of complex problems, "Speaking truth to power" model fails because:

- Truth cannot be known and is thus not a substantial aspect of the issue
- *"… good scientific work has a product, which should … correspond to Nature as closely as possible… But* ***the working judgements on the product are of its quality, and not of its logical truth****."*

(Funtowicz and Ravetz 1990, p. 30)

http://www.andreasaltelli.eu/file/repository/UQSP.pdf



Funtowicz and Ravetz, Science for the Post Normal age, *Futures*, 1993

http://www.uu.nl/wetfilos/wetfil10/sprekers/Funtowicz_Ravetz_Futures_1993.pdf

The alternative model: PNS

Extended participation:

working deliberatively within imperfections

- Science is only one part of relevant **evidence**
- Critical dialogue on strength and relevance of evidence
- Interpretation of evidence and attribution of policy meaning to knowledge is democratized
- **Tools for Knowledge Quality Assessment empower all stakeholders to engage in this deliberative process**

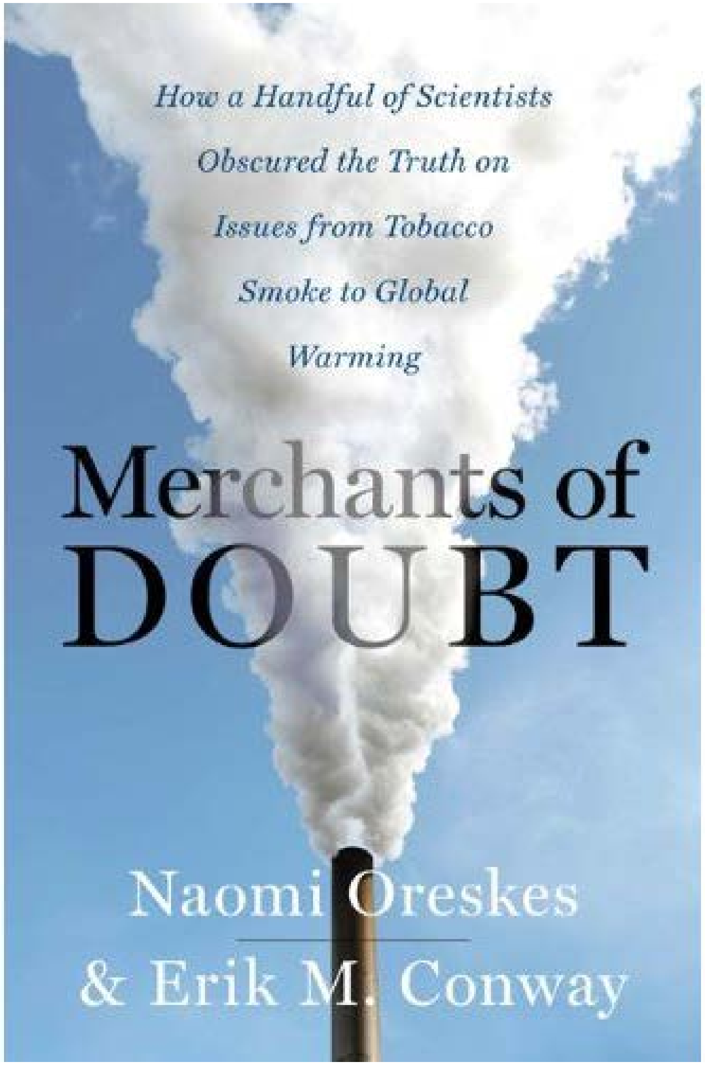
(Funtowicz, 2006; Funtowicz & Strand, 2007)
http://genok.no/wp-content/uploads/2013/04/Chapter-16

Elements of Post Normal Science

- Appropriate management of uncertainty quality and value-ladenness
- Plurality of commitments and perspectives
- Internal extension of peer community *(involvement of other disciplines)*
- External extension of peer community *(involvement of stakeholders in environmental assessment & quality control)*

3 sources that fuel dissent in scientific community

Conflicts of interests



Institutionalized practices

Published online 5 October 2011 | *Nature* **478**, 7 (2011) | doi:10.1038/478007a

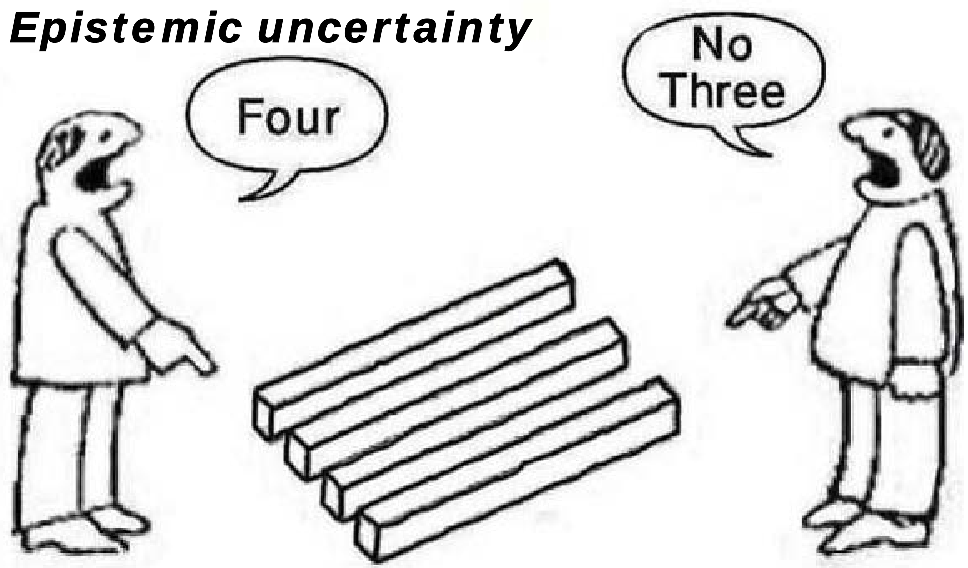
Column: World View

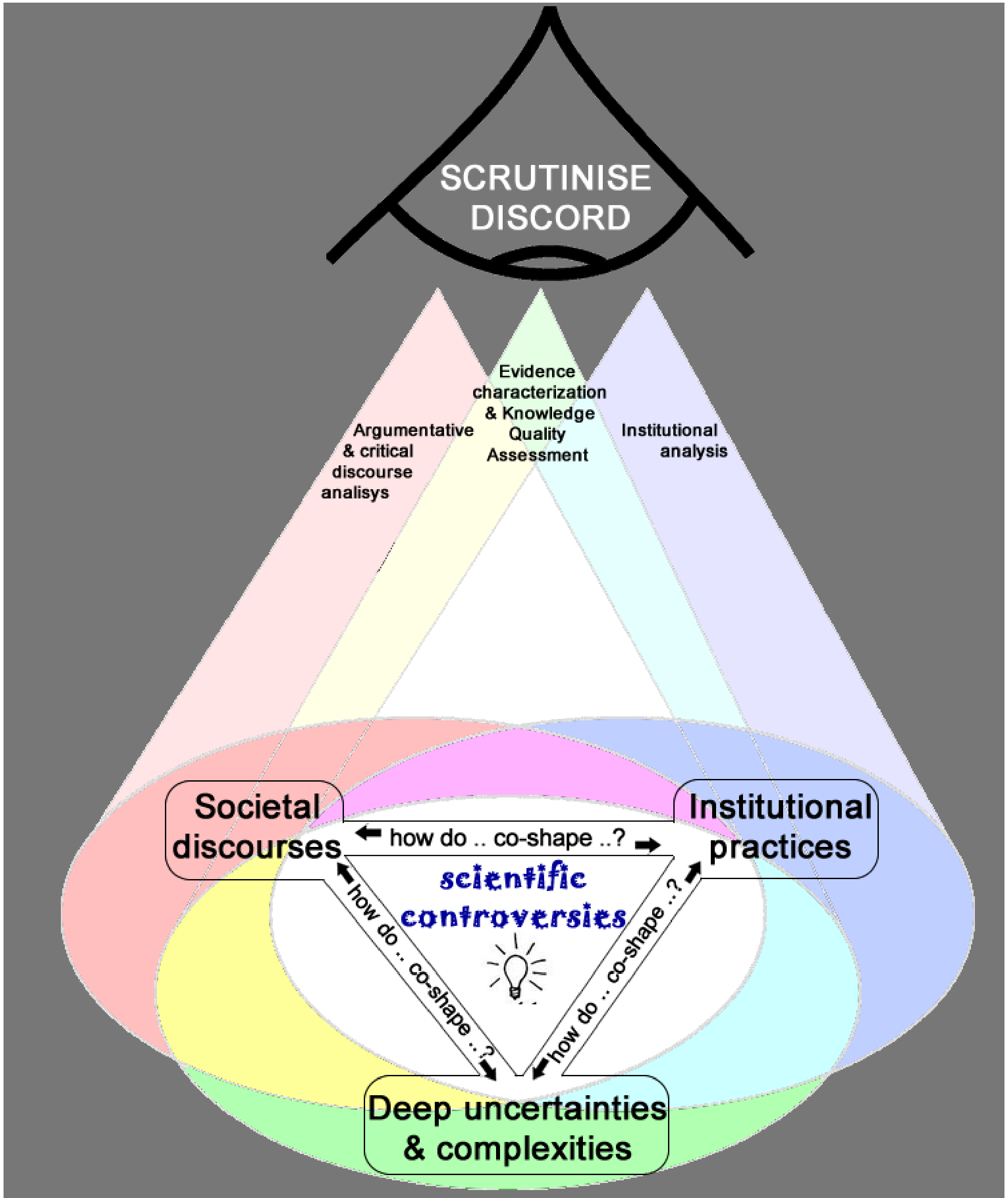
The voice of science: let's agree to disagree

Consensus reports are the bedrock of science-based policy-making. But disagreement and arguments are more useful, says Daniel Sarewitz.

Daniel Sarewitz

Epistemic uncertainty





New way of looking at scientific controversies

"By shining light on its dynamics from 3 different perspectives (**discourse analysis, evidence characterization**, **institutional analysis**) it seeks to reveal how 3 key factors (**deep uncertainties; societal discourses; institutional practices**) co-shape one another to produce the typical patterns that can be observed in scientific controversies."

Van der Sluijs, 2014

Trans science
(Alvin Weinberg, 1972)

- Research Questions that can be phrased scientifically but that in practice cannot be answered by science.

Refs:

- Alvin Weinberg (1972) Science and trans-science, Minerva, 10, 1972, 209-222.
- Alvin Weinberg (1991) Origins of Science and Trans-Science, Citation Classics 34 S18,
- Harvey Brooks (1972) Science and Trans-Science - Letter to the Editor, Minerva 10, 484-486.

Trans Science – Alvin Weinberg

- "Let us consider the **biological effects of low-level radiation insults to the environment, in particular the genetic effects of low levels of radiation on mice**. Experiments performed at high radiation levels show that the dose required to double the spontaneous mutation rate in mice is 30 roentgens of X-rays. Thus, if the genetic response ,to X-radiation is linear, then a dose of 150 millirems would increase the spontaneous mutation rate in mice by 0.5%. This is a matter of importance to public policy since the various standard-setting bodies had decided that a yearly dose of about 150 millirems (actually 170 millirems) to a suitably chosen segment of the population was acceptable. Now, **to determine at the 95 per cent. confidence leve**l by a direct experiment whether 150 millirems will **increase .the mutation rate by 0.5% requires about 8,000,000,000 mice!** Of course this number falls if one reduces the confidence level; at 60 per cent. confidence level, the number is 195,000,000. Nevertheless, **the number is so staggeringly large that, as a practical matter, the question is unanswerable by direct scientific investigation**."

Alvin Weinberg (1972) Science and trans-science, *Minerva*, 10, 209-222.

Why Most Published Research Findings Are False (Ioannidis, 2005)

There is increasing concern that most current published research findings are false. **The probability that a research claim is true may depend on study power and bias**, the number of other studies on the same question, and, importantly, the ratio of true to no relationships among the relationships probed in each scientific field. In this framework, **a research finding is less likely to be true when the studies conducted in a field are smaller; when effect sizes are smaller; when there is a greater number and lesser preselection of tested relationships; where there is greater flexibility in designs, definitions, outcomes, and analytical modes; when there is greater financial and other interest and prejudice; and when more teams are involved in a scientific field in chase of statistical significance**. Simulations show that for most study designs and settings, it is more likely for a research claim to be false than true. Moreover, for many current scientific fields, claimed research findings may often be simply accurate measures of the prevailing bias. In this essay, I discuss the implications of these problems for the conduct and interpretation of research.

http://www.plosmedicine.org/article/info:doi/10.1371/journal.pmed.0020124

Science for sale

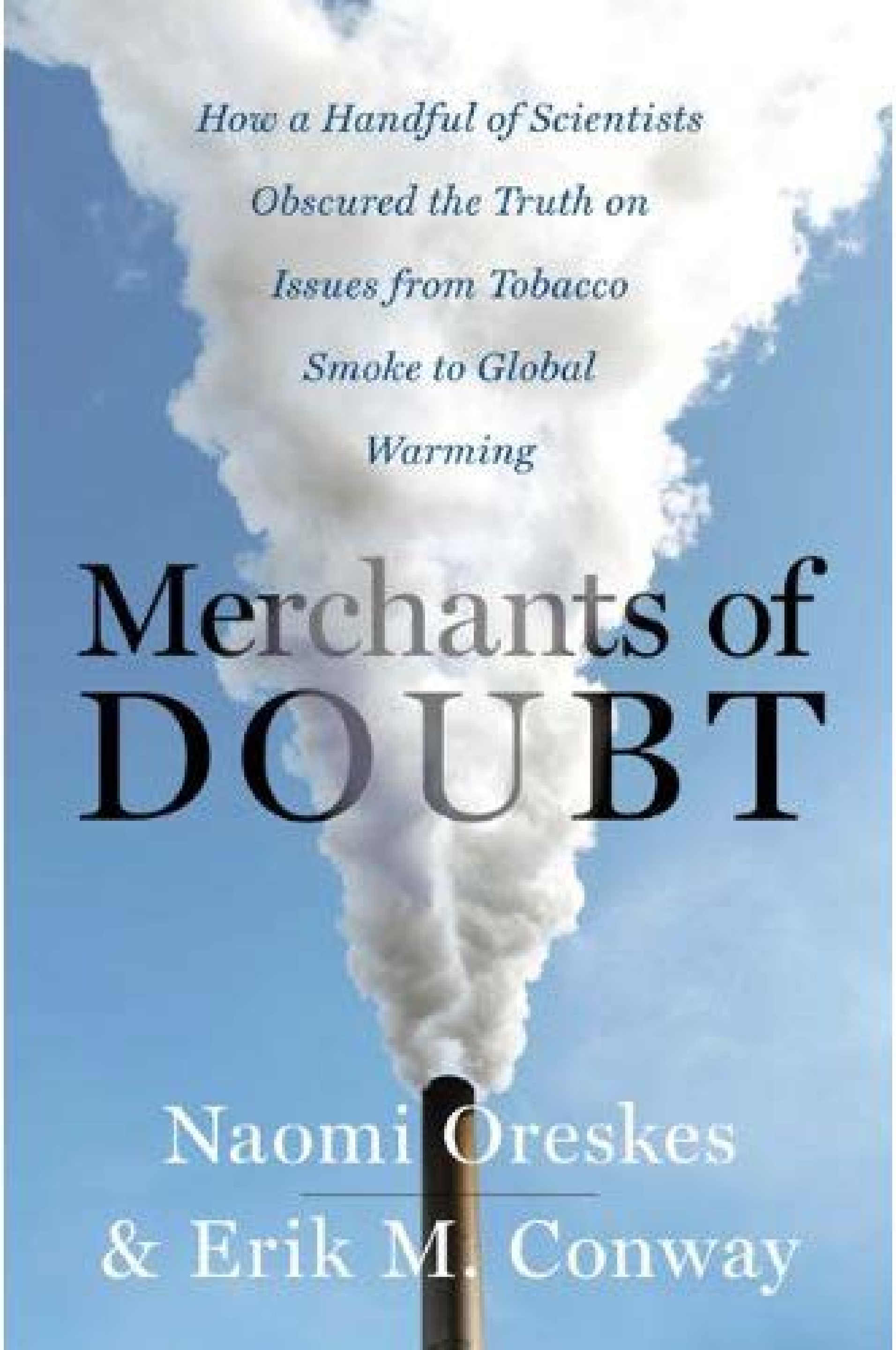
on the interaction between scientific researchers and their clients

Royal Netherlands Academy of Arts and Sciences, 2005

“because of … decreasing public funding of research, universities and research institutes become too dependent on specific external research contracts.”

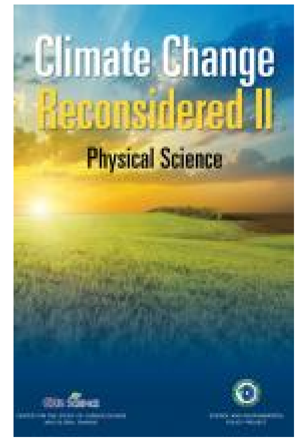
Derailments occur:
“the design of research, the collection and interpretation of data are sometimes adjusted to provide a favourable outcome for the client and the publication of research findings is sometimes prevented, delayed or adapted to the needs of the client. This applies to contract research funded by governments as well as interest groups and industry.”

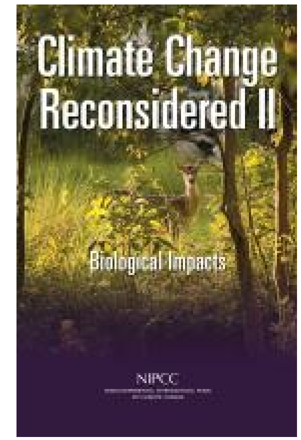
http://www.knaw.nl/Content/Internet_KNAW/publicaties/pdf/20051083.pdf



Nongovernmental International Panel on Climate Change (NIPCC)

The Heartland INSTITUTE





http://heartland.org/

CATO INSTITUTE

"Individual Liberty, Free Markets, and Peace"

http://www.cato.org

http://books.google.com/books?id=CrtoNFTuPwwC

Categories of
Deceitful Tactics and Abuse of the Scientific Process

source: P.H. Gleick, Pacific Institute, 2007

- Appeal to Emotion (appeal to ridicule, fear etc)
- Personal (“Ad Hominem”) Attacks
- Mischaracterizations of an Argument
- Inappropriate Generalization
- Misuse of Facts (inadequate sample)
- Misuse of Uncertainty
- False Authority
- Hidden Value Judgments (ideologies)
- Scientific Misconduct (fabrication etc.)
- Science Policy Misconduct (Packing Advisory Boards, selective funding)

http://web.archive.org/web/20130510073145/http://www.pacinst.org/publications/testimony/Gleick_Senate_Commerce_2-7-07.pdf

Uncertainty is more than a number

Dimensions of uncertainty:

- Technical (inexactness)
- Methodological (unreliability)
- Epistemological (ignorance)
- Societal (limited social robustness)

NUSAP: Qualified Quantities

Classic scientific notational system:

- **N**umeral **U**nit **S**pread

For problems in the post-normal domain, add two qualifiers:

- **A**ssessment & **P**edigree

  "Assessment" expresses expert judgement on reliability of numeral + spread

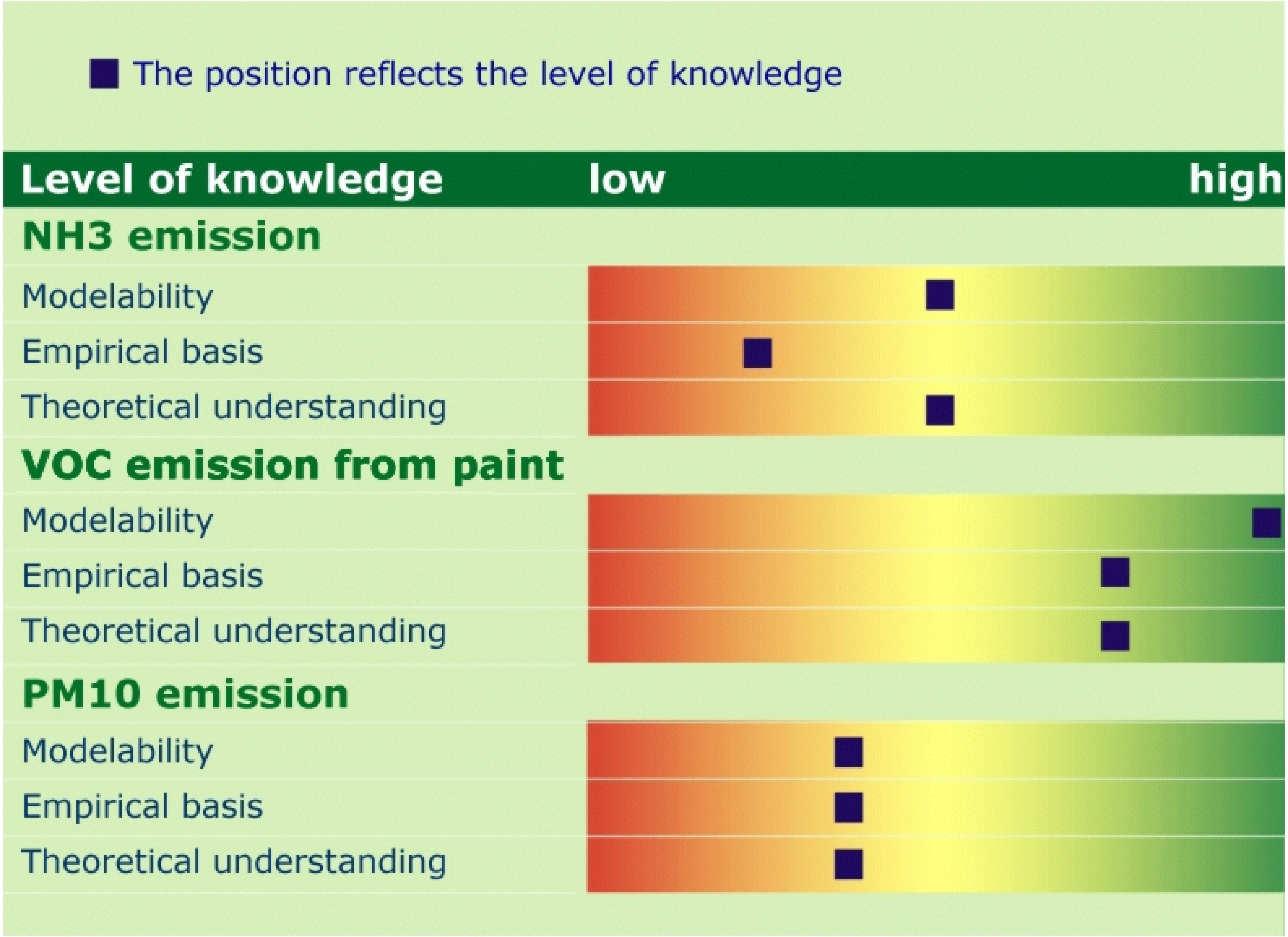
  "Pedigree" expresses multi-criteria evaluation of the strength of a number by looking at:

  - Background history by which the number was produced
  - Underpinning and scientific status of the number

Example Pedigree matrix parameter strength

Code	Proxy	Empirical	Theoretical basis	Method	Validation
4	Exact measure	Large sample direct mmts	Well established theory	Best available practice	Compared with indep. mmts of same variable
3	Good fit or measure	Small sample direct mmts	Accepted theory partial in nature	Reliable method commonly accepted	Compared with indep. mmts of closely related variable
2	Well correlated	Modeled/derived data	Partial theory limited consensus on reliability	Acceptable method limited consensus on reliability	Compared with mmts not independent
1	Weak correlation	Educated guesses / rule of thumb est	Preliminary theory	Preliminary methods unknown reliability	Weak / indirect validation
0	Not clearly related	Crude speculation	Crude speculation	No discernible rigour	No validation

Example: Air Quality



NL Environmental Assessment Agency (RIVM/MNP) Guidance: Systematic reflection on uncertainty & quality in:

Foci	Key issues
Problem framing	Other problem views; interwovenness with other problems; system boundaries; role of results in policy process; relation to previous assessments
Involvement of stakeholders	Identifying stakeholders; their views and roles; controversies; mode of involvement
Selection of indicators	Adequate backing for selection; alternative indicators; support for selection in science, society, and politics
Appraisal of knowledge base	Quality required; bottlenecks in available knowledge and methods; impact of bottlenecks on quality of results
Mapping and assessing relevant uncertainties	Identification and prioritisation of key uncertainties; choice of methods to assess these; assessing robustness of conclusions
Reporting uncertainty information	Context of reporting; robustness and clarity of main messages; policy implications of uncertainty; balanced and consistent representation in progressive disclosure of uncertainty information; traceability and adequate backing

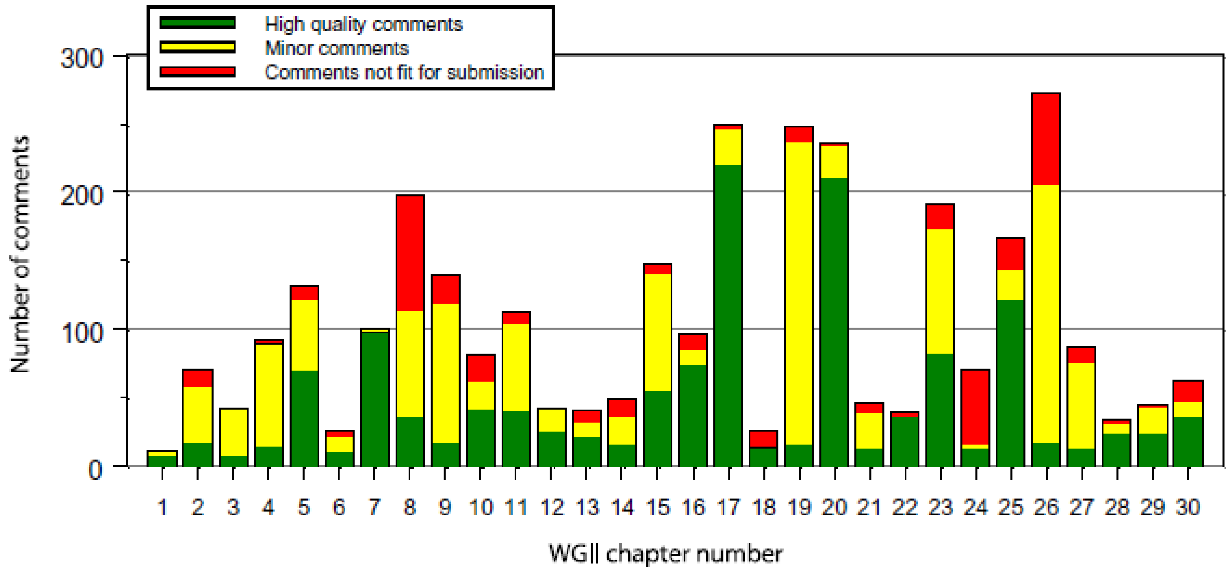
Crowdsourcing quality control

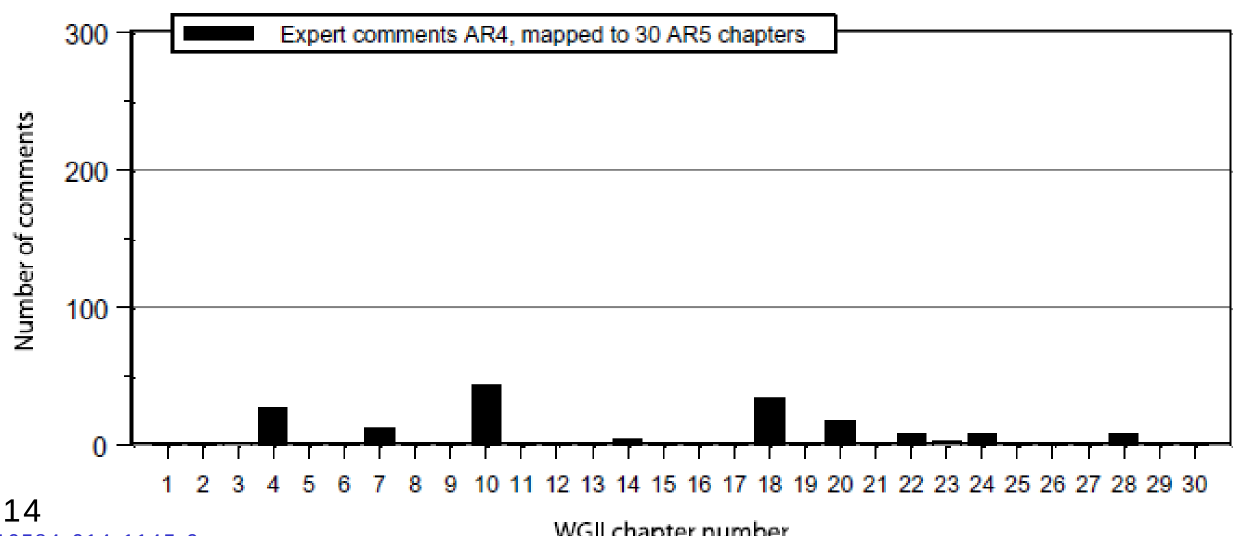
2013 Experiment by NL government

AR5 WGII review of SOD crowdsourced to

90 PhD Students from 43 countries

3,155 comments received, 1,407 included in government review





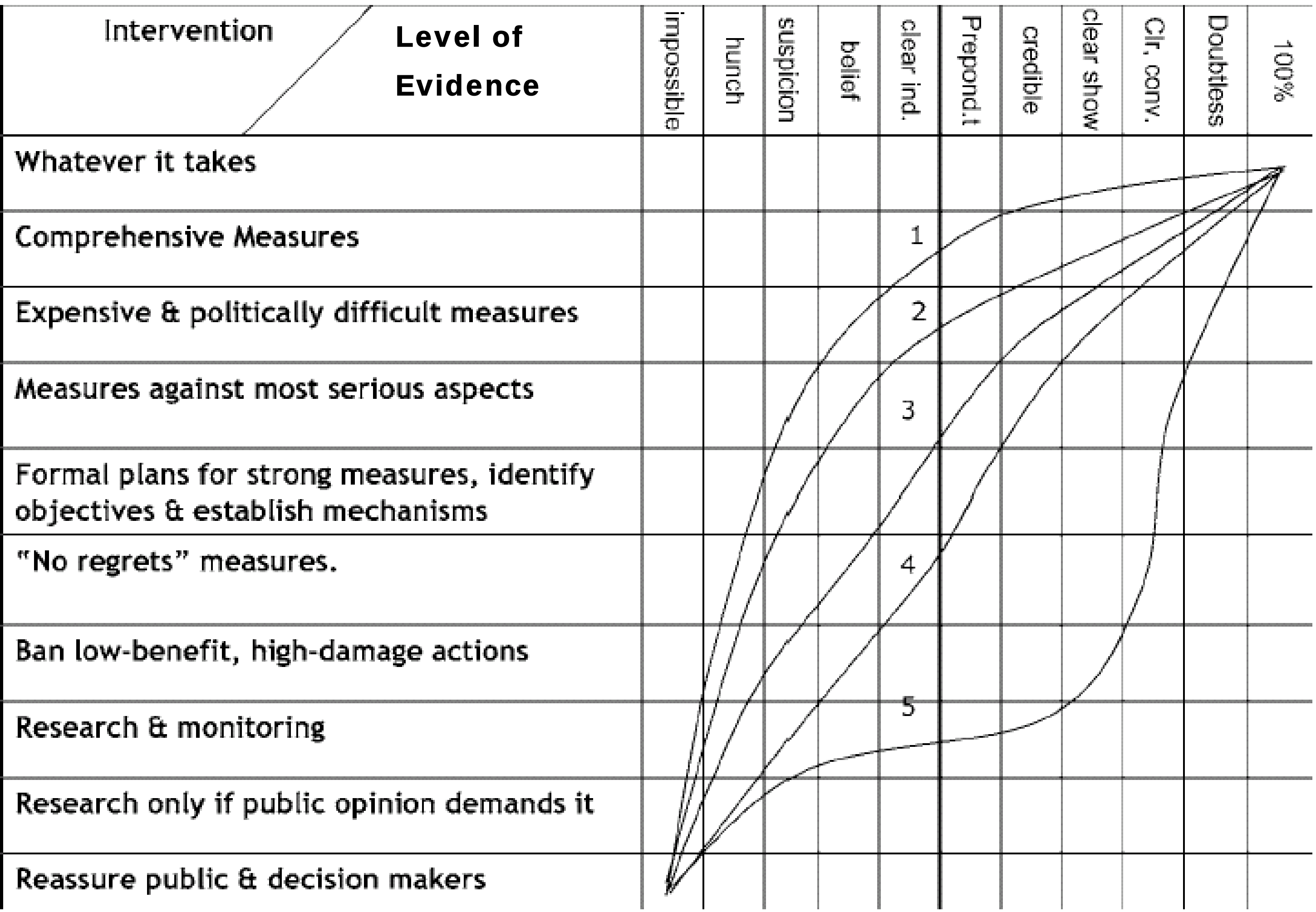
Van de Veer ea, 2014
http://dx.doi.org/10.1007/s10584-014-1145-9

Weiss 2003/2006 evidence scale

10. Virtually certain
9. Beyond a reasonable doubt
8. Clear and convincing Evidence
7. Clear showing
6. Substantial and credible evidence
5. Preponderance of the Evidence
4. Clear indication
3. Probable cause: reasonable grounds for belief
2. Reasonable, articulable grounds for suspicion
1. Hunch
0. No suspicion

http://link.springer.com/article/10.1023/A:1024847807590

Even where there is agreement on “level of evidence”, there usually is substantial societal disagreement on what level of intervention is justified.



Attitudes according to Weiss 2003:

1. Environmental absolutist

2. Cautious environmentalist

3. Environmental centrist

4. Technological optimist

5. Scientific absolutist

http://link.springer.com/article/10.1023/A:1024847807590

Plurality and uncertainty in risk assessment: lessons learned

- **Diversity of the knowledge base**:
  - Include the full spectrum of available scientific knowledge;
- **Robustness of the knowledge claims**
  - Include uncertainty, dissent and criticism in the analysis, synthesis and assessments;
- Make thorough **Knowledge Quality Assessment the key task in the science policy interface** and develop a joint language to communicate limitations to our knowledge and understanding clearly and transparently
  - Bayesian likelihood terminology is misleading, it unduly suggests certainty;
- Make use of **information of non-scientific sources** (local knowledge)
  - But scrutinize this information and be clear on its status;
- **Clarify values, stakes and vested interests** that play a role in research and in the political and socioeconomic context within which the research is embedded.

Further reading

- J.P. van der Sluijs (2012). **Uncertainty and dissent in climate risk assessment, a post-normal perspective**, *Nature and Culture* 7 (2) 174-195. http://dx.doi.org/10.3167/nc.2012.070204
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- J.P. van der Sluijs, R. van Est, M. Riphagen (2010) **Beyond consensus: reflections from a democratic perspective on the interaction between climate politics and science**, *Current Opinion in Environmental Sustainability*, 2, 409–415 http://www.sciencedirect.com/science/article/pii/S1877343510001090
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- A. Benessia, S. Funtowicz, M. Giampietro, A. Guimarães Pereira, J. Ravetz, A. Saltelli, R. Strand, J.P. van der Sluijs (2015) **Science on the verge**, Published by The Consortium for Science, Policy and Outcomes at Arizona State University. http://www.andreasaltelli.eu/file/repository/Science_on_the_Verge_FINAL_.pdf
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