# Uncertainty in the World of Post Normal Science.

Jim Zidek[1]

[1]University of British Columbia

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# Outline

- Historical notes
- Uncertainty vs information
- Quantifying uncertainty
- Uncertainty in postnormal science
- The post-truth era

# Epochs in environmental statistics

- **1983–:** Acid rain
- **1990–:** Air pollution and health effects
- **2000–:** Climate change and mitigation

# Selected Grants from Peter's CV

- **1996–2001:** National Center for Environmental Statistics
- **2007–2009:** PIMS Research Group in Environmetrics
  - **2008:** One month workshop on water, Institute of Mathematical Statistics, National University of Singapore
- **2011–2016:** Statistical Methods for Atmospheric and Oceanic Sciences.

# Statistics in regulatory policy making

- **2005–2008:** I am appointed as a member of the US EPA Clean Air Scientific Advisory Committee for ozone

$\boxed{\text{We had all become post–normal scientists!}}$

# “Post–normal science” e.g. climate change (Funtowicz and Ravetz 2003)

**Characterized by: ”...radical uncertainty; plurality of legitimate perspectives....**

**uncertain facts; conflicting values; high stakes; urgency of decisions**

**the paradigm of seeking “truth” must be modified. “Such products may even be ...an irrelevance.”**

# **Grinell 2015, *Nature*:**

*"In my view, a better way to assess and discuss risk is by using a method of inquiry called post-normal science (**PNS**)... to assist decision–making at the interface between environmental science & public policy."*

## Key Elements of PNS:

- **QUALITY OF INFORMATION**
- **LARGE AMOUNTS OF UNCERTAINTY**

# But what is information?

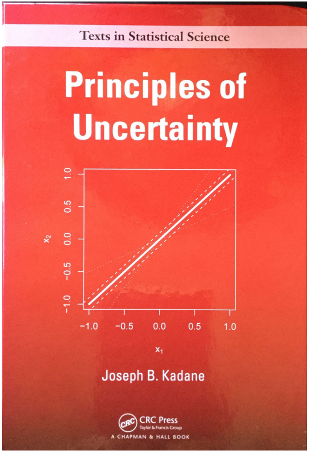
*"No other concept in statistics is more elusive in its meaning and less amenable to a generally agreed on definition" (Basu 1975)*

# And what is uncertainty?

- **BERNARDO AND SMITH 2001:** “incomplete knowledge in relation to a specified objective.”
- **HELTON 1997:** dichotomizes it:
  - “aleatory” (stochastic e.g fair coin toss)
  - “epistemic” (due to ignorance)
- **PARSONS 2001:** 16 different species of “uncertainty”

# Quantifying uncertainty

- **Lindley 2002; Kadane 2011:** “The language of uncertainty” is “Probability”
- **Frey & Rhodes 1996, O,Hagan 1988:** “Uncertainty” is “probability”
- **National institute of standards and technology:** “Uncertainty” is “variance”
- **Shannon 19??, Renyi 1961:** “Uncertainty” is “entropy”
- **Ebrahami & Soofi 1999:** “Uncertainty” is “entropy” or “variance”




**Mostly about probability!**

# Does more information reduce uncertainty?

**“DEMO”**

# Suppose we measure uncertainty by *Probability*

Let $p = P(Y \in C)$ quantify uncertainty about outcome $\{Y \in C\}$.

- $p = 0$ and $p = 1$ represent states of complete certainty
- $p = \frac{1}{2}$ represents state of maximal uncertainty

**But additional information $\{Y \in A\}$ may not reduce our uncertainty about outcome by that measure.**

**Example:** $Y \sim U[0, 1]$, $C = (0, \frac{1}{8})$, $A = (0, \frac{1}{4})$. Then $\frac{1}{8} = P(Y \in C) < P(Y \in C | Y \in A) = \frac{1}{2} =$ **complete uncertainty**!!

# What if we measure uncertainty by *Variance*

**Theorem 1 (van Eeden and Zidek 2003)**

- $Y^{\text{real}}$ with density symmetric about $0$
- $A = (-c, c)$

$\Rightarrow Var(Y|Y \in A) \uparrow$ in $c$ in agreement with intuition.

**OPEN QUESTION What if the density is not symmetric?**

**Theorem 2 (van Eeden and Zidek 2003)**

- $Y \sim N(\eta, 1)$
- $A = (-c, c)$

$\Rightarrow Var(Y|Y \in A) < V(Y)$.

**REMARK:** Theorem 1 $\Rightarrow Var(Y|Y \in A) \uparrow$ in $c$ when $\eta = 0$.

**CHALLENGING QUESTION:** If $\eta \neq 0$ is

$$Var(Y| - c < Y < c) \uparrow$$

in $c$? Prize offered for answer: $100. Jiahua Chen collects: it is YES! (**Chen, van Eeden and Zidek 2013**).

**OPEN RESEARCH QUESTIONS:**

- What if $A$ is not symmetric about $0$?
- What happens when $Y$ is not normally distributed?
- Other uncertainty metrics? [Some work on entropy **van Eeden and Zidek 2003**]

# But how does uncertainty affect information?

## Welcome to the murky world of PNS

- A world of **big science**
- Driven by **values**; determines research funding & types of data collected
- Relies on **extended peer review** systems e.g. CASAC Ozone Committee
- **Information** of variable and uncertain quality
- **Uncertainty** quantitative & qualitative. About data quality; experts' qualifications; published research;.....

- **Facts** are replaced by **"systems"** about which uncertainty varies
- **High stakes** attach to decisions (e.g. policies)

# Iconic representation of PNS

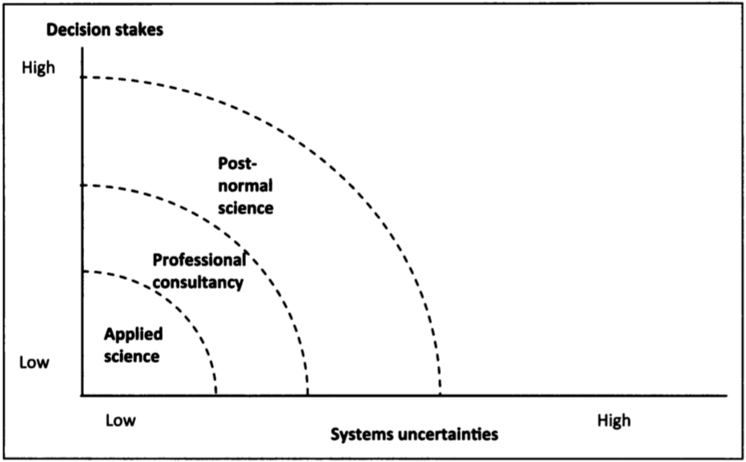
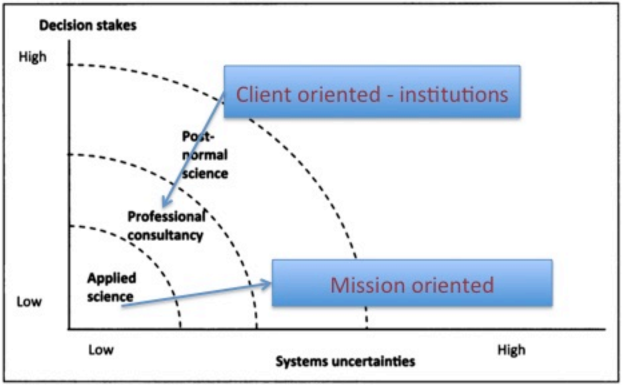



**Figure 1.** Modes of inquiry for different levels of uncertainty and decision stakes (Funtowicz and Ravetz 1991, 145).

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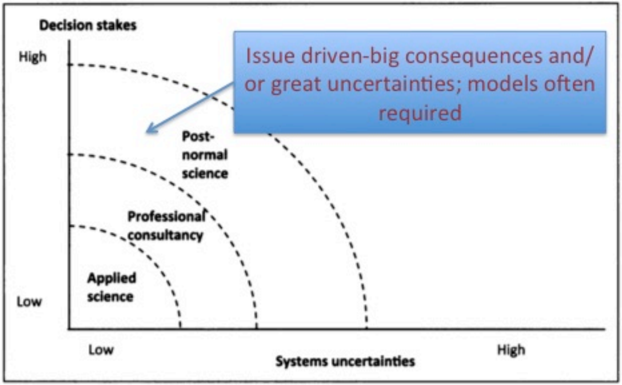


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# But what about those models?

*Oreskes, Schrader-Frechette & Belitz (1994) Science, 263, 641-646*

- highly influential attack on **models**
  - physical models cannot be shown to represent reality – validation meaningless/pointless
  - cited over 95 times so far in 2017
  - used to justify not validating!

Oreskes et al attack common model assessment practices:

- verification
- validation
- verifying numerical solutions
- calibration
- confirmation

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E.g. Argument against value of **Confirmation:**

$\boxed{\textit{Agreement between model data \& real data} \Rightarrow \textit{truth}}$

**A logical fallacy** called *“affirming the consequence”*

*EXAMPLE:* ***Assumption H says:*** *“It is raining.”*
***Model says:*** *“If H, Jim will work at home .”*
*You visit & find me at home. You conclude H valid since model prediction agrees with observation perfectly!*

**NOTES:**

- Poor predictions would imply bad model!
- But good predictions don’t imply good model!
  - many “good models” possible
  - wrong assumptions can cancel each other

## Oreskes conclusions:

*“The primary purpose of models is heuristic...useful for guiding further study but not susceptible to proof... [Any model is] a work of fiction. ... A model, like a novel may resonate with nature, but is not the ‘real thing’.”*

# Doing post normal science

- Collect relevant data
- Obtain assessments of panel of experts
- Convene “extended panel of reviewers” representing groups with legitimate perspectives e.g. Americal Lung Association
- Assess quality of data, experts, reports & associated uncertainties
- Form conclusions

**Dealing with ALL the uncertainty:**

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Use Numerical–Units–Spread–Assessment–Pedigree (NUSAP) matrix.

- "*Numerical*" could be data average or relative risk
- *Units* of measurement
- "*Spread*" could be a standard error
- "*Assessment*" could be "significance level" or something qualitative
- "*Pedigree*" characterized by Pedigree matrix to assess quality of data; experts; scientific reports; etc.

**Example (van der Sluijs, Kloprogge, Risby , & Ravetz):**
Pedigree matrix for analysis of data re VOC in paint

| Code | *Proxy* | *Empirical* | *Method* | *Validation* |
|---|---|---|---|---|
| 4 | Exact measure | Large sample direct measurements | Best available practice | Compared with indep. mmts of same variable |
| 3 | Good fit or measure | Small sample direct measurements | Reliable method commonly accepted | Compared with indep. mmts of closely related variable |
| 2 | Well correlated | Modeled/ derived data | Acceptable method limited consensus on reliability | Compared with mmts not independent |
| 1 | Weak correlation | Educated guesses / rule of thumb estimate | Preliminary methods unknown reliability | Weak / indirect validation |
| 0 | Not clearly related | Crude speculation | No discernible rigor | No validation |

**Table 1.** Pedigree matrix for emission monitoring. Note that the columns are independent.

## After consulting the experts on the data sources:

| | *Proxy* | *Empirical* | *Method* | *Validation* | *Strength* |
|---|---|---|---|---|---|
| NS-SHI | 3 | 3.5 | 4 | 0 | 0.7 |
| NS-B&S | 3 | 3.5 | 4 | 0 | 0.7 |
| NS-DIY | 2.5 | 3.5 | 4 | 3 | 0.8 |
| NS-CAR | 3 | 3.5 | 4 | 3 | 0.8 |
| NS-IND | 3 | 3.5 | 4 | 0.5 | 0.7 |
| Th%-SHI | 2 | 1 | 2 | 0 | 0.3 |
| Th%-B&S | 2 | 1 | 2 | 0 | 0.3 |
| Th%-DIY | 1 | 1 | 2 | 0 | 0.25 |
| Th%-CAR | 2 | 1 | 2 | 0 | 0.3 |
| Th%-IND | 2 | 1 | 2 | 0 | 0.3 |
| Imported | 3 | 4 | 4 | 2 | 0.8 |
| VOC % | 1 | 2 | 1.5 | 0 | 0.3 |

**Table 2**. Pedigree scores for input parameters. The strength-column, averages and normalizes the scores on a scale from 0 to 1.

# NUSAP Diagostic Plot

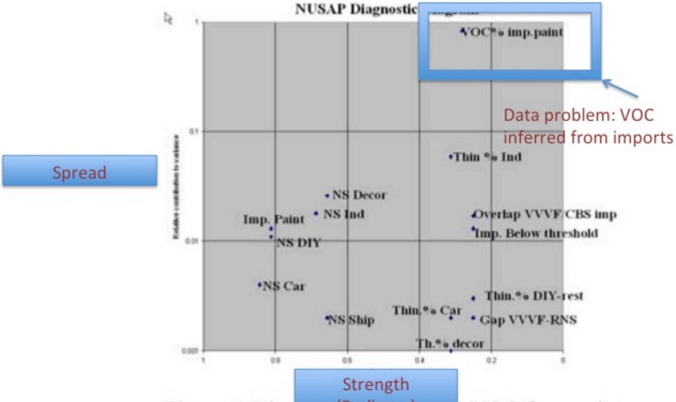


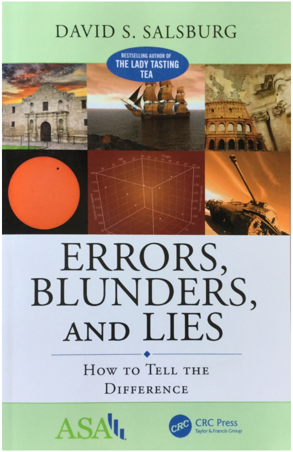

**Figure 1** Diag... r VOC from paint

# Concluding comments

- **“Brussels Declaration on Ethics and Principles for Science and Society Policy-Making.”:**
  - 20 recommendations about science in regulatory policy
  - *“The application of science is not without risks and uncertainties, and these factors should be openly acknowledged and identified. ”*

- **Baltimore JSM 2017 panel: What role should statisticians play in environmental policy and regulation?**
  - Organized by Megan Higgs (Neptune and Company)
  - Will explore uncertainty in this context.

- Post normal science enters era of “**post–truth**”; See Royal Statistical Society Panel 2017.




2017 Chapman & Hall/CRC Press Publication

- Simplest questions about relationship between measures of uncertain and quality of information are difficult to answer and the issue has not been much explored.
- The world if post–normal–science presents new statistical challenges owing to the way in which the work is done e.g. by extended peer review groups.
- Characterizing qualitative uncertainty needs to be explored by statistical scientists. Is it susceptible to analytical theory?
- New issues about uncertainty arising in the new era of post–truth

**CONGRATULATIONS PETER!!!!!**

Contact information Email: jimstat.ubc.ca

Webpage: http://www.stat.ubc.ca/ jim/