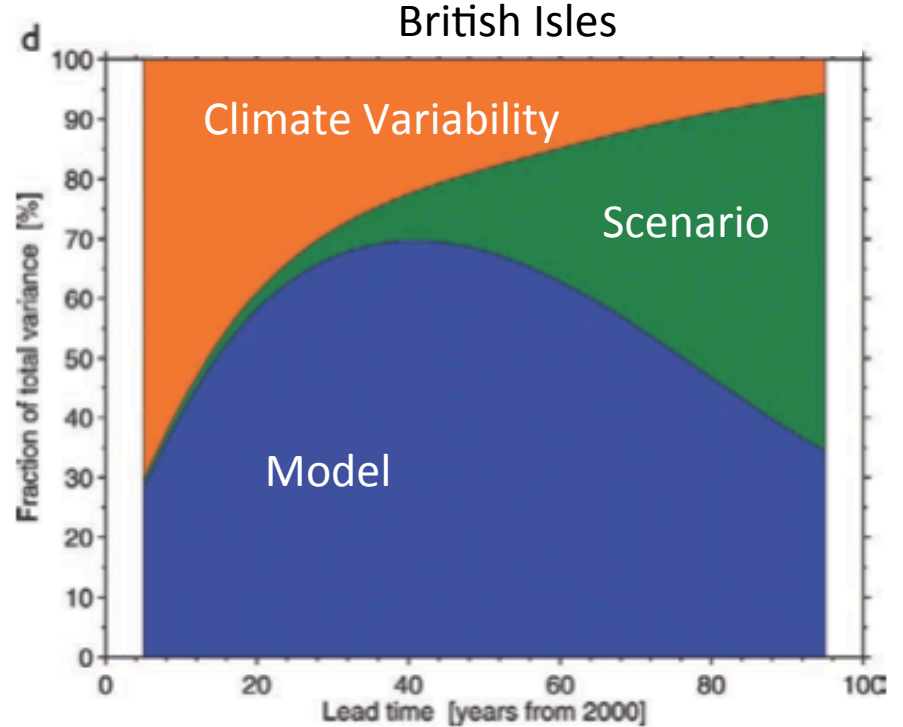
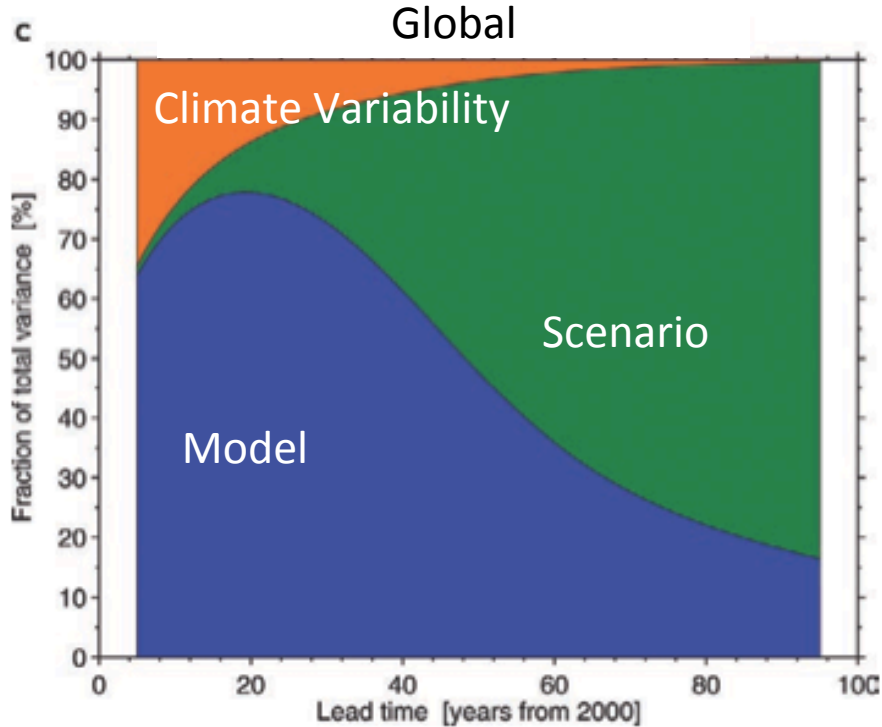


Fundamental Uncertainties in the Science



Planning for Local Government Climate Challenges:
Connecting Research and Practice

Hawkins and Sutton, 2009

Tempe, AZ
October 18, 2012

Brad Udall - bradley.udall@colorado.edu

Western Water Assessment
CIRES, University of Colorado

Talk Overview

- Concepts re Uncertainty
 - On Policy Making - Smith and Stern, 2011
 - On Climate Modeling - Stainforth et al., 2007
 - Known Issues – GCMs, Downscaling, Natural Variability, etc
 - Warnings from Nature and Science
 - Type 1 vs. Type 2 Errors
- Case Studies on Uncertainty, Projections
 - Australia via Kiem & Verdon-Kidd
 - Uncertainty – Morgan and Henrion
 - USGCRP SAP 5.2 on Uncertainty
 - NRC Report Informing Decisions



"Perhaps you'd like a second opinion?"

- **Conclusions and Musings**

- Note: Focus is on Climate Change and Modeling, but these concepts apply to all uncertainty issues and modeling
- Advice From Churchill...Doing the Right Thing...

Uncertainty in Science and its role in Climate Policy

- Terrific, Thought-Provoking Article Worth a Read
- Key Points
 - Science focuses on what is known or almost known
 - What is unlikely to be known can also aid policy maker
 - Large Uncertainties do not mean small risks
 - Uncertainty can support immediate action in some cases
 - A lack of certainty provides no rational argument against action
 - Varieties of uncertainty:
 - Imprecision – can be quantified by PDF
 - Ambiguity – impacts known but can't be quantified via PDF, e.g. 100 yr impacts
 - Intractability – not solvable, e.g. no equations or lack computers
 - Indeterminacy – also not solvable, e.g., a societal value or non-physical parameter
 - “Models can increase our understanding long before they start providing realistic numbers.”
 - Nice Discussion about Hydrological Uncertainties
 - These concepts not appreciated by both modeling community and Decision-Making community

Uncertainty in science and its role in climate policy

Leonard Smith and Nicholas Stern

Phil. Trans. R. Soc. A (2011) **369**, 1–24 doi:10.1098/rsta.2011.0149

Confidence, Uncertainty and Decision-Support Relevance in Climate Predictions

- Models can't be calibrated – simulating never before seen state
 - Contrast with Weather where models interpolate
 - Climate models: no archive over time, run once, projection times >> model life
- PDFs can be made but what they represent is not what we thought
 - We thought a 'PDF of the Future' initially
 - But models are only a Lower Bound on Range of Uncertainty
 - True Future PDF is wider
- At least 3 Sources of Uncertainty
 - Forcing
 - Emissions Scenario
 - Initial Conditions
 - Makes a Difference to End Results
 - Does Not Make a Difference to End Results
 - Model Imperfection
 - Model Uncertainty – e.g. parameters for physical processes
 - Model Inadequacy – incorrect formulation
- No rational way to weight models now

Confidence, uncertainty and decision-support relevance in climate predictions

D.A Stainforth, M.R Allen, E.R Tredger and L.A Smith

Phil. Trans. R. Soc. A 2007 **365**, 2145-2161 doi: 10.1098/rsta.2007.2074

Some Known GCM - LSM Uncertainties

- Emissions Scenarios
- Models show consistent errors (biases)
- Known Problems: El Nino, Monsoons, Mountains, Blocking, Extremes
- Natural Variability Critical – inherent limits to predictability exist
- Models Constantly Changing
- Can't Verify Model Output
- Won't get any better for at least 10 years – See WUCA -- and maybe not even then...
- How much hydro cycle enhanced?
- Downscaling Issues
 - CRB Flows can change by > 10%
- Land Surface Models
 - Sensitivity to T & P Varies

“The First Principle is you must not fool yourself and you are the easiest person to fool.” ~ Feynman

REGION	SEASON	temperature BIAS					% precipitation BIAS				
		MIN	25	50	75	MAX	MIN	25	50	75	MAX
North America											
ALA	DJF	-9.8	-2.4	-0.8	1.9	8.2	3	33	51	89	179
	MAM	-7.4	-1.4	0.2	1.0	3.8	25	58	86	108	197
	JJA	-4.9	-1.6	-0.4	0.4	3.1	8	18	40	54	113
	SON	-5.7	-1.6	-0.6	1.4	4.8	14	33	52	65	113
	ANN	-5.2	-1.8	-0.4	0.6	3.7	14	41	53	59	106
CGI	DJF	-12.5	-4.5	-2.4	-0.5	4.8	-14	5	14	29	98
	MAM	-6.3	-2.6	-1.1	1.0	5.5	-4	19	29	45	97
	JJA	-4.4	-2.7	-0.9	0.9	4.7	4	13	16	30	47
	SON	-7.5	-3.8	-1.9	-0.4	6.6	0	10	15	21	72
	ANN	-7.	-3.2	-2.0	0.3	5.3	0	12	21	29	69
WNA	DJF	-4.7	-2.7	-0.9	-0.5	0.9	32	66	93	103	192
	MAM	-4.6	-2.9	-2.0	-1.0	0.1	37	62	71	93	158
	JJA	-7.5	-1.3	-0.4	0.9	2.2	-9	22	28	45	98
	SON	-4	-1.8	-1.2	-0.3	1.1	10	45	61	75	110
	ANN	-3.8	-1.8	-1.3	-0.5	0.7	29	53	65	74	130
CNA	DJF	-4.0	-2.4	-0.8	0.8	3.0	-37	-6	7	20	84
	MAM	-4.1	-1.3	-1.1	0.6	2.8	-17	-3	8	25	41
	JJA	-1.8	-0.3	0.4	1.6	3.5	-34	-21	-12	15	39
	SON	-3.8	-1.3	-0.6	0.4	2.3	-37	-24	-16	0	24
	ANN	-3.2	-1.0	-0.5	0.6	2.6	-18	-8	2	5	21
ENA	DJF	-4.6	-2.8	-1.6	-0.6	3.4	-18	-2	17	25	55
	MAM	-4.5	-2.1	-1.3	-0.7	2.4	-5	13	21	27	38
	JJA	-3.7	-1.4	-0.9	-0.5	2.3	-10	-2	13	18	45
	SON	-4.2	-2.0	-1.2	-0.6	2.0	-30	-17	-4	6	25
	ANN	-4.2	-2.1	-1.2	-0.6	2.2	-7	1	9	17	27

Regional Climate Change Assessments

Validation required

nature

Vol 463 | Issue no. 7283 | 18 February 2010

Transparency and quality control are essential in the highly uncertain business of assessing the impact of climate change on a regional scale.

Climate scientists are engaged in a lively debate about how — or whether — the Intergovernmental Panel on Climate Change (IPCC) should reform itself (see *Nature* 463, 730–732; 2010). At a minimum, the panel needs to hold itself to the highest possible standards of quality control in future assessments.

But so do climate scientists themselves — especially those who study the links between global climate change and its potential regional effects on factors such as weather patterns, ecosystems and agriculture. Governments faced with the need to make difficult, disruptive and politically fraught decisions about when and how to respond to climate change are understandably eager for certainty. But certainty is what current-generation regional studies cannot yet provide. Researchers need to resist the pressures to overstate the robustness of their conclusions, and to be as open as possible about where the uncertainties lie.

As an example of the scientific challenges involved, imagine a regional authority wanting to plan for water resources in a river basin over the next four decades. An applicable study might be probabilistic in approach. It could take into account a range of global greenhouse-gas-emission trajectories, and involve multiple runs of global climate models using different values for a number of parameters. However, such models cannot reproduce some important atmospheric phenomena such as circulation trapping, and cannot be validated against real climate behaviour over decadal timescales. The multiple runs will produce a probability distribution of precipitation which itself will contain intrinsic uncertainties. These outcomes then need to be fed into a catchment model with its own range of parameters and limitations of knowledge, and which in turn needs to be coupled to models of water demand as local housing and populations change over the period (M. New *et al. Phil. Trans. R. Soc. A* 365, 2117–2131; 2007, and other papers in that issue).

Climate projections at the national level are crucial for such efforts. One such study was published last year, when the UK Met Office

produced its climate projections of the next eight decades, including analysis down to a resolution of 25-kilometre squares (<http://ukclimateprojections.defra.gov.uk>). The British government is now conducting a national climate-change risk assessment, due for completion in early 2012, that uses the projections. But such an application could well be problematic: it is likely that the projections reflect the limitations of the models and analyses as much as probabilities intrinsic to the real world. Yet regional planners and others might easily miss the detailed discussions of uncertainties, and misguidedly seize on these projections as a solid basis for investment decisions. And depressingly for decision-makers, the more the uncertainties are explored, the greater the ranges in the projected possible outcomes are likely to become.

This combination of projections and risk analysis is one way in which an over-reliance by decision-makers on modelling may be setting up the scientific community for a loss of trust. What is more, like regional-impact studies, such analyses often appear not in peer-reviewed journals but in 'the grey literature' — in reports, or on websites. Yet they are no less important in representing the outputs of climate science, and need to be included in the IPCC assessment. For these reasons, such grey studies should be transparently peer reviewed as a part of their commission.

Uncertainties about future climate effects do not undermine the case for action to reduce greenhouse-gas emissions. But there is a long way to go in the science before regional-impact studies provide a suitable basis for detailed planning. Whatever the pressures, statements by scientists and government agencies about such studies need to be well qualified, and policies based on them need to be kept as flexible as possible. It is intrinsic to this research, after all, that scientists' best judgements will be subject to change.

"Grey-literature studies should be transparently peer reviewed as a part of their commission."

Recent Science Articles on Similar Themes

PREDICTING CLIMATE CHANGE

Vital Details of Global Warming Are Eluding Forecasters

Decision-makers need to know how to prepare for inevitable climate change, but climate researchers are still struggling to sharpen their fuzzy picture of what the future holds

SCIENCE VOL 334 14 OCTOBER 2011

“Many regional modelers don’t do an adequate job of quantifying issues of uncertainty.”

“We are not confident predicting the things people are most interested in being predicted.”

“The problem is that precision is often mistaken for accuracy.”

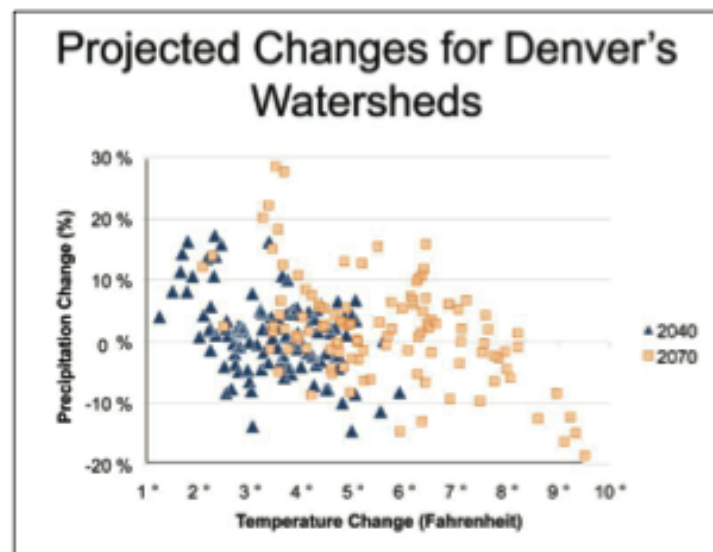
~ Christopher Bretherton
University of Washington

ADAPTATION TO CLIMATE CHANGE

Time to Adapt to a Warming World, But Where’s the Science?

With dangerous global warming seemingly inevitable, users of climate information—from water utilities to international aid workers—are turning to climate scientists for guidance. But usable knowledge is in short supply

25 NOVEMBER 2011 VOL 334 SCIENCE



A fuzzy future. Sixteen climate models run under three greenhouse gas emission scenarios consistently showed warmings (horizontal spread), but some projected more precipitation and others less (vertical spread).

The 4 Outcomes and 2 Types of Errors from Predictions

		Predicted Outcome	
		Not Occur	Occur
Actual Outcome	Occur	<p>Error: Event Occurred but not predicted</p> <p>Statistics: Type 2 Error Mythology: Trojan Horse Judicial: Guilty Goes Free Medicine: False Negative Burglar: Fail to Alarm</p>	<p>Good Prediction: Event Occurred and Predicted</p> <p>True Positive</p>
	Not Occur	<p>Good Prediction: Event Didn't Occur and not predicted</p> <p>True Negative</p> <p>Note: Lack of a Prediction is a Prediction</p>	<p>Error: Event Didn't Occur but Predicted</p> <p>Statistics: Type 1 Error Mythology: Cry Wolf Judicial: Convict Innocent Medicine: False Positive Burglar: False Alarm</p>

Note: Which error is worse is entirely contextual

Lessons From Taylor – Russell Diagrams on Errors

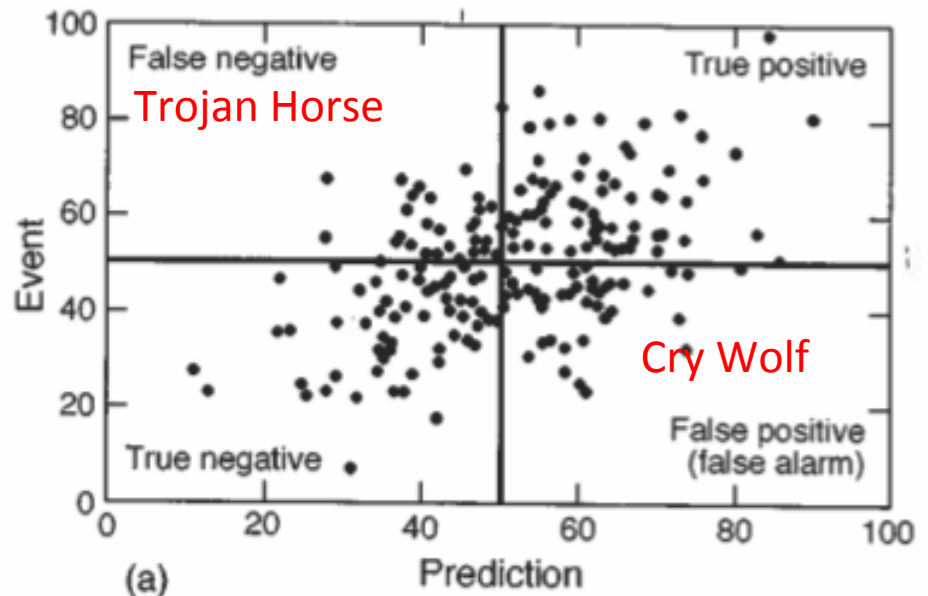
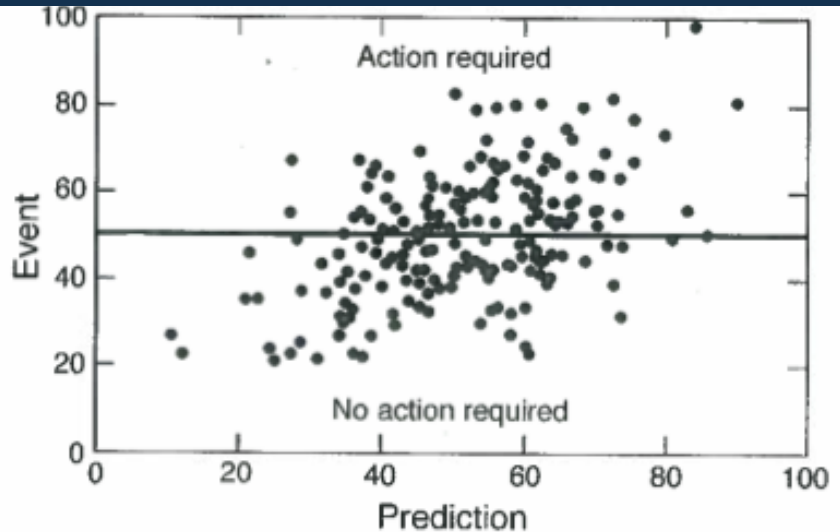
Diagram shows Predictions versus actual outcomes. Scatter represents uncertainty.

Step 1: Pick a threshold for something bad to occur, e.g., Wind Speeds during Hurricane

Step 2: Pick a Decision Cutoff for Societal Action

Here: Cutoff same as threshold at 50

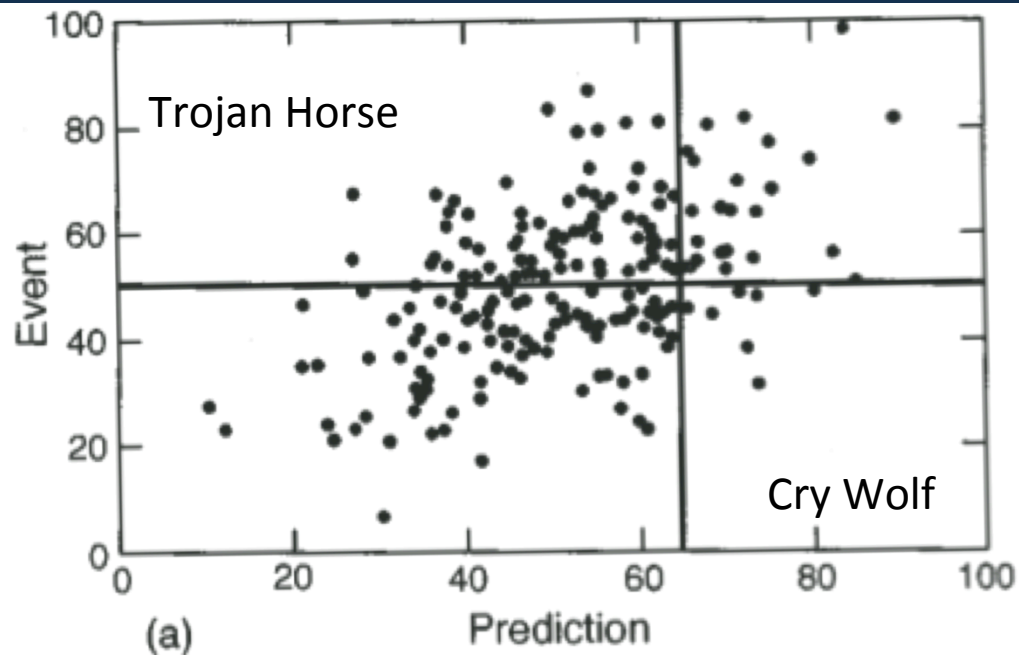
You've now determined the four outcomes: True Positive, True Negative, Cry Wolf, Trojan Horse



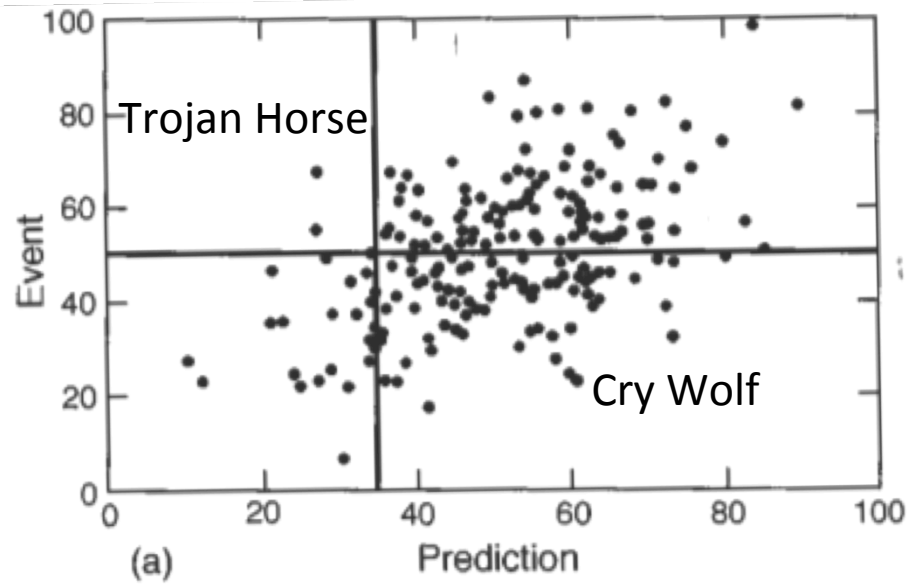
Lessons from Taylor-Russell Diagrams: Can't Reduce Cry Wolf and Trojan Horse at the Same Time

By Adjusting the Decision Cutoff you can reduce either Cry Wolf Errors or Trojan Horse Errors but not both at the same time.

Top: Decision Cutoff at 65
Minimizes Cry Wolf Errors at the expense of increasing Trojan Horse Errors



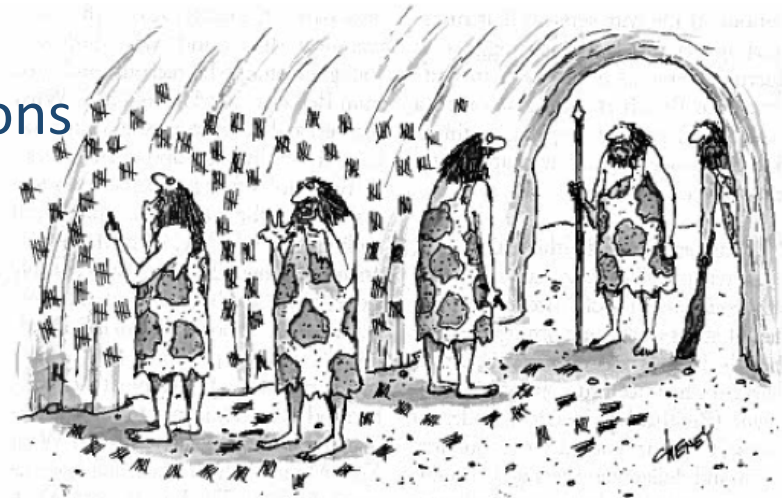
Bottom: Decision Cutoff at 35
Minimizes Trojan Horse Errors at the expense of increasing Cry Wolf Errors



In response to poorly perceived prediction outcomes, society sometimes oscillates over time between different Decision Cutoffs and hence rate of the two errors.

Talk Overview

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- Conclusions and Musings
 - Note: Focus is on Climate Change and Modeling, but these concepts apply to all uncertainty issues and modeling
 - Advice From Churchill...Doing the Right Thing...



"It will take longer than we thought to go digital."

An Australian Example – Kiem and Verdon-Kidd

Steps toward “useful” hydroclimatic scenarios for water resource management in the Murray-Darling Basin

Anthony S. Kiem¹ and Danielle C. Verdon-Kidd¹

Received 29 July 2010; revised 8 February 2011; accepted 21 March 2011; published 16 June 2011.

[1] There is currently a distinct gap between what climate science can provide and information that is practically useful for (and needed by) natural resource managers. Improved understanding, and model representations, of interactions between the various climate drivers (both regional and global scale), combined with increased knowledge about the interactions between climate processes and hydrological processes at the regional scale, is necessary for improved attribution of climate change impacts, forecasting at a range of temporal scales and extreme event risk profiling (e.g., flood, drought, and bushfire). It is clear that the science has a long way to go in closing these research gaps; however, in the meantime water resource managers in the Murray-Darling Basin, and elsewhere, require hydroclimatic projections (i.e., seasonal to multidecadal future scenarios) that are regionally specific and, importantly, take into account the impacts, and associated uncertainties, of both natural climate variability and anthropogenic change. The strengths and weaknesses of various approaches for supplying this information are discussed in this paper.

Citation: Kiem, A. S., and D. C. Verdon-Kidd (2011), Steps toward “useful” hydroclimatic scenarios for water resource management in the Murray-Darling Basin, *Water Resour. Res.*, 47, W00G06, doi:10.1029/2010WR009803.

KVK - Identified Shortcomings with Current Approach

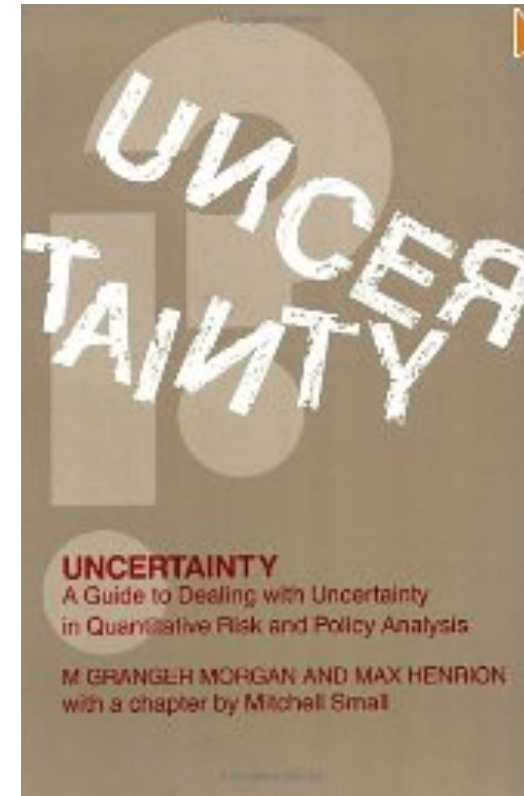
- Failure to simulate synoptic patterns that drive rainfall, especially extremes
- Large Scale Processes not well simulated: ENSO, IOD, Others
 - Not understood, either
- Of 39 GCM runs, 22 show increases, 17 show decreases in precipitation
- None of the models could reproduce the drying trend since mid 1990s
- GCMs couldn't distinguish between wet coastal strip and dry interior 300 km away
- Climate model outputs at monthly and submonthly scale do not reproduce historical climate and show significant biases
 - Downscaling (Bias Correction and Change Factor) introduce 'false precision' and introduce an additional layer of uncertainty
 - Bias Corrections assumed to be stationary over time
- Climate to Hydrology Connection is Poorly Understood
 - Current Hydrology models calibrated to current conditions, not future
 - When does such calibration cease to be useful?

KVK - “A 5-Step Way Forward”

- Step 1: Communication Between Climate Scientists, Hydrologists, and Water Resource Managers
 - Define what is ‘practically useful’
 - Disconnects about what can be expected and How to act in face of uncertainty
- Step 2: Quantify Baseline Risk Associated with Natural Climate Variability
 - Need to understand paleoclimate better
 - How dry can it get and for how long?
 - Need to understand drivers of variability
 - Stochastic Framework needed to integrate both
- Step 3: Incorporate the Projected Impacts of Anthropogenic Change
 - Identify physical processes driving hydroclimate
 - Identify or Develop models that simulate these processes
 - Determine how processes will change in the future and apply changes in stochastic framework
- Step 4: Develop Appropriate Adaptation Strategies
 - Need Reliable Probabilities of Uncertainties
 - Robust Quantification of Uncertainties Needed
 - Identify Win-win Adaptation Strategies
- Step 5: Ongoing Communication
 - Address Intensity, Time Span, Frequency

10 Commandments for Good Policy Analysis

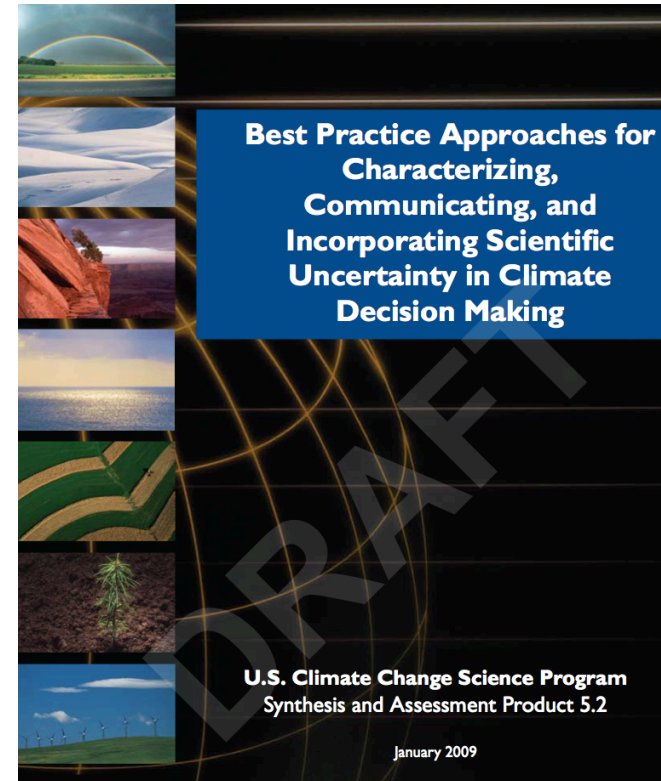
1. Do your homework with literature, experts and users
 - Iterate, reframing as necessary
2. Let the problem drive the analysis
 - Avoid hammers looking for nails
3. Make the analysis as simple as possible but not simpler
 - Simpler: can explain easier
 - No Simpler: don't overlook important detail
4. Identify all significant assumptions
 - Policy concerns and decisions
5. Be explicit about decision criteria and policy strategies
 - Subset of 4 above, but critical to note
6. Be explicit about uncertainties
 - Technical, Scientific, Economic, Political
 - Model Functional Form
 - Disagreements among Experts
7. Perform Systematic sensitivity and uncertainty analysis
 - Vary inputs in models to expose sensitivities
8. Iteratively refine the problem statement and the analysis
 - Add and/or Subtract from analysis if sensitivity so indicates
9. Document clearly and completely
 - Too important to leave until the end
10. Expose the work to peer review
 - Yes, even policy analysis, not just technical work



Morgan and Henrion,
1990

Lessons from SAP 5.2 – Uncertainty Guidance for Researchers

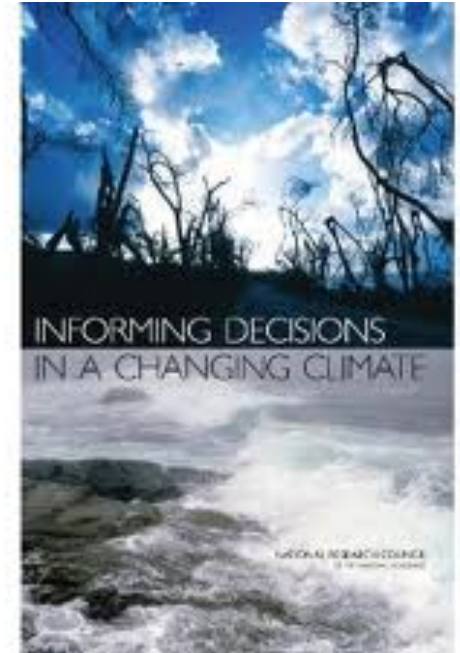
- Does what we are doing make sense?
- Are there other important factors that are equally or more important than the factors we are considering?
- Are there key correlation structures in the problem that are being ignored?
- Are there standard assumptions and judgments about which we are not being explicit?
- Is information about the uncertainties related to research results and potential policies being communicated clearly and consistently?



M. Granger Morgan, Hadi Dowlatabadi, Max Henrion, David Keith, Robert Lempert, Sandra McBride, Mitchell Small, and Thomas Wilbanks

Informing Decisions in a Changing Climate, NRC 2009

- EPA and NOAA asked NRC to study informing decisions
 - Stationary Climate Assumption No Longer Tenable
- 6 Key Principles
 - Begin with Users Needs
 - Give Priority to Process over Products
 - Link Information Users and Providers
 - Build Connections Across Disciplines
 - Seek Institutional Support
 - Design Process for Learning
- Other Ideas
 - Use “Deliberation with Analysis”
 - Broadly Scan for New Information, Including Overseas
 - USGCRP Should support Research on Decisions, not just climate
 - Maintain and Expand Observing Systems
 - Support Students with Specialized Decision Support Knowledge
 - Undertake National Initiative for Decision Support
- Note: Almost nothing on forecasts, projections



Some Musings and Conclusions - 1

- Churchill's Advice – Need to Think!
- Water Users have gotten smarter, not so sure about some researchers
 - WUCA a case in point
 - No one, far as I know, is using hydrologic outputs to make decisions
 - 1 km downscaling by ecological researchers
- Science Needs to Have Better, Much Better Communication with Decision Makers
 - Push Back on What we Can and Cannot Do with Decision Makers
 - We must show full range of futures and explain different risks with each – credibility!
 - Uncertainty can in fact be a cause for action
- Need to Have Better Language around Uncertainty
 - Not all uncertainty the same
 - Like Smith & Stern Language: Imprecision, Ambiguity, Intractable, Irreducible
 - Need to discuss Emissions, Variability, El Nino etc in these terms in addition to other knowledge about these effects
 - Can we create a food label for these projects showing uncertainty?
 - Avoid being overly deterministic and precise when there is no basis other than our ability to produce model output of unknown quality?

Some Musings and Conclusions - 2

- Projections least valuable part of modeling
 - “We Model for Insights not Answers”
 - “Plans are Nothing, Planning is Everything”
 - Physical Mechanisms, Counter-intuitive findings, Data Issues, Learning ALL trump projections
- Modeling as thinking...
 - Writing is thinking with words, modeling is thinking with numbers
 - Writing generates multiple insights, so should modeling
 - Turning the crank to blindly produce outputs is not thinking
 - Simple Models are ok, too
- Cry Wolf versus Trojan Horse Errors
 - Be aware that lowering one raises the other
 - Think about which kind of error is more important to avoid for the issue at hand
 - Science historically has focused on avoiding Cry Wolf
- Specialization leads to blindness
 - Are Really Smart People doing collectively dumb things?
 - We need to bring other disciplines into this discussion
 - The less you want to read Smith and Stern, Stainforth et al, the more you need to read them!
- Easy to Dump on Models, not so easy to define a healthy relationship
 - This is our challenge

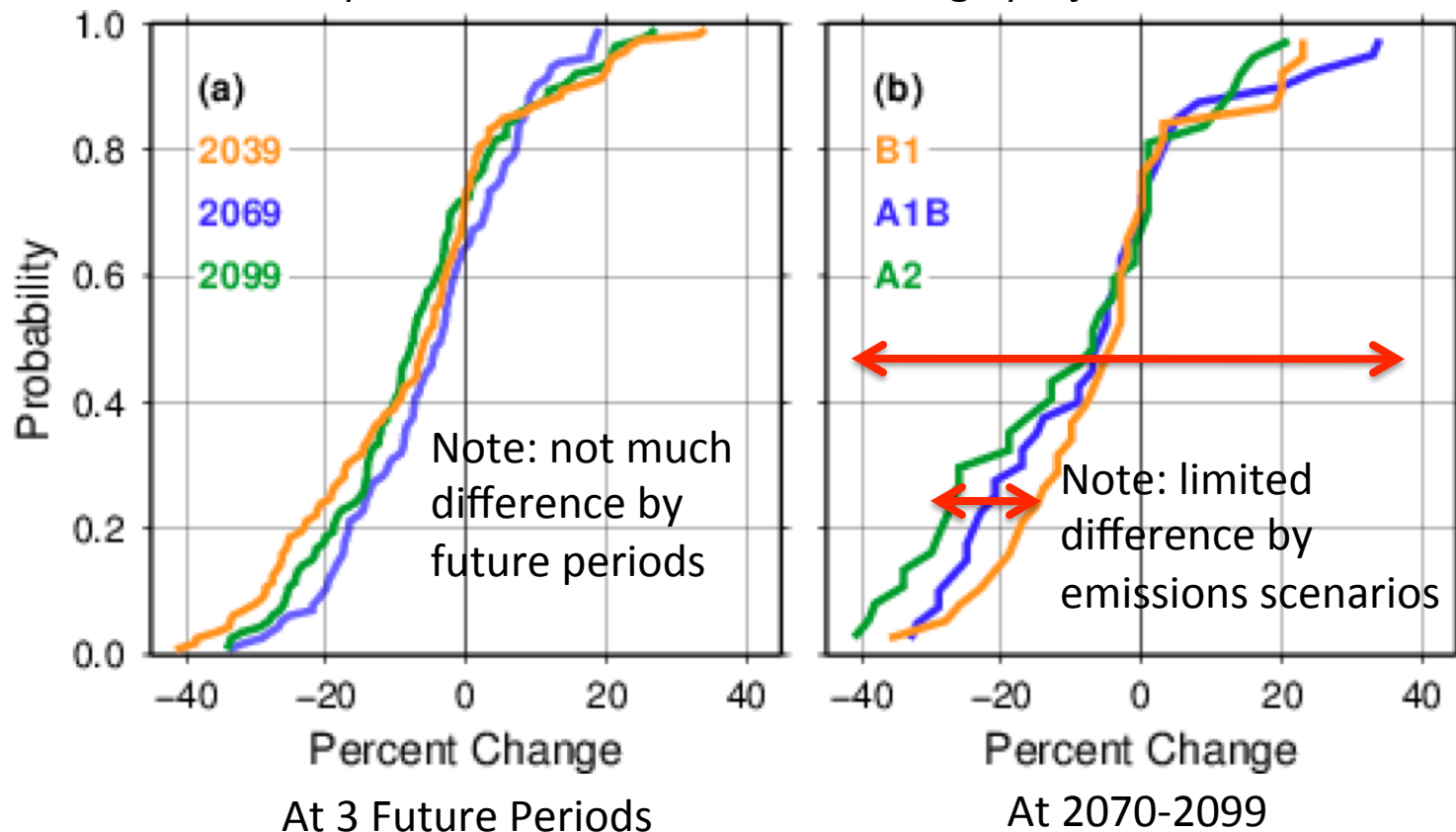
A Wetter Colorado River?

Rasmussen et al., 2011: increased Precip due to better topography

Harding et al., 2012: Don't forget 30% of runs which show greater precip

□ Unforced internal model variability and model choice dominate

empirical CDFs of streamflow change projections



Slide from Andy Wood

Mysteries vs. Puzzles

Two Kinds of Problems

Malcolm Gladwell on Enron Collapse



Mystery: problem where the answer is obscured by lots of details. The answer is there but most of us can't see it.

Puzzle: problem where we are missing a crucial piece of information. We need to search for the information.

The solutions required are very different.

View climate as a mystery, not as a puzzle.

The WITH A NEW
AFTERWORD BY
THE AUTHOR
TIPPING POINT

*How Little Things Can
Make a Big Difference*

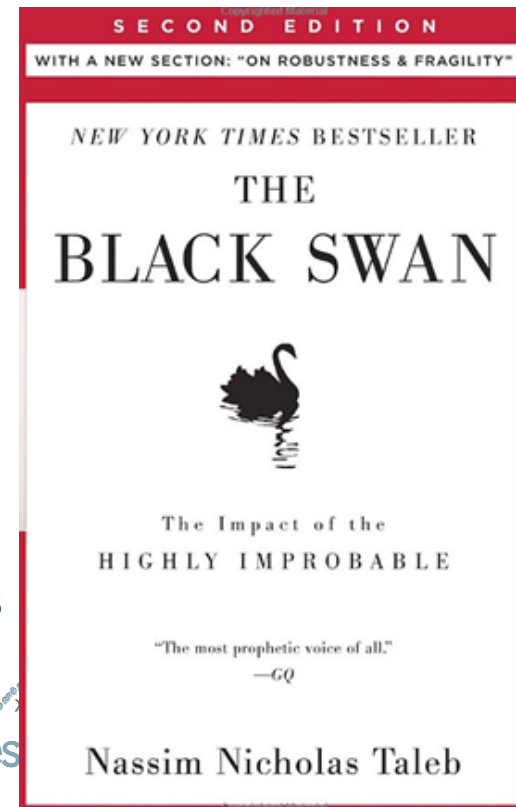
MALCOLM
GLADWELL

*"A fascinating book that makes you see the world
in a different way." —FORTUNE*



Black Swans

- Society Changing Event – Outlier and Extreme
 - 2008 Market Crash
 - Gulf Oil Spill
 - 9/11
 - 2005 Tsunami
- Happen all the time and change history
- We fool ourselves into thinking that we can predict these
- Instead of predicting, need to adjust to existence
- We fixate on what we know, rather than what we don't know
 - Knowledge makes us more confident than we should be
- Will occur more frequently in 21st century
- Taleb loathes normal distribution
 - Poorly describes risk profile for many vulnerabilities
 - 'Fat Tails' Exist in many phenomenon
- Name comes from Australia and first sightings of Black Swans



If you increase accuracy of predictions you can reduce Both Cry Wolf and Trojan Horse Errors at the same time

Often, however, this is not an option.

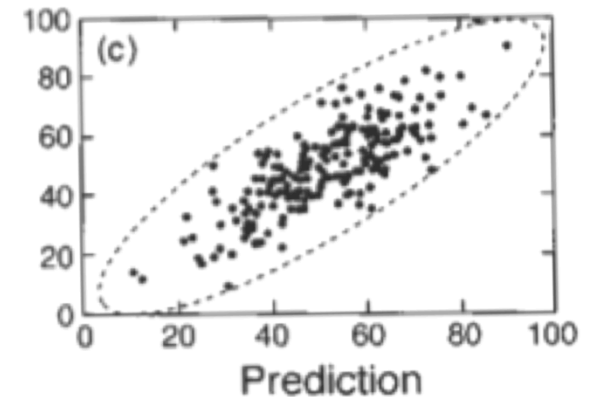
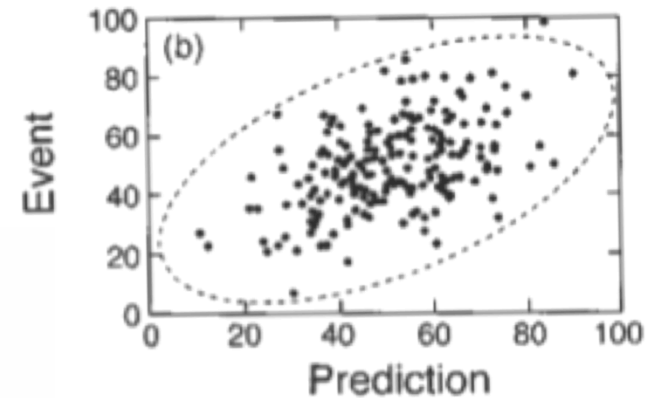
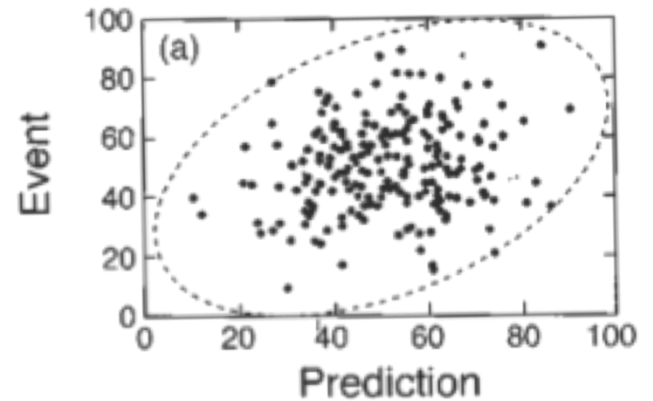
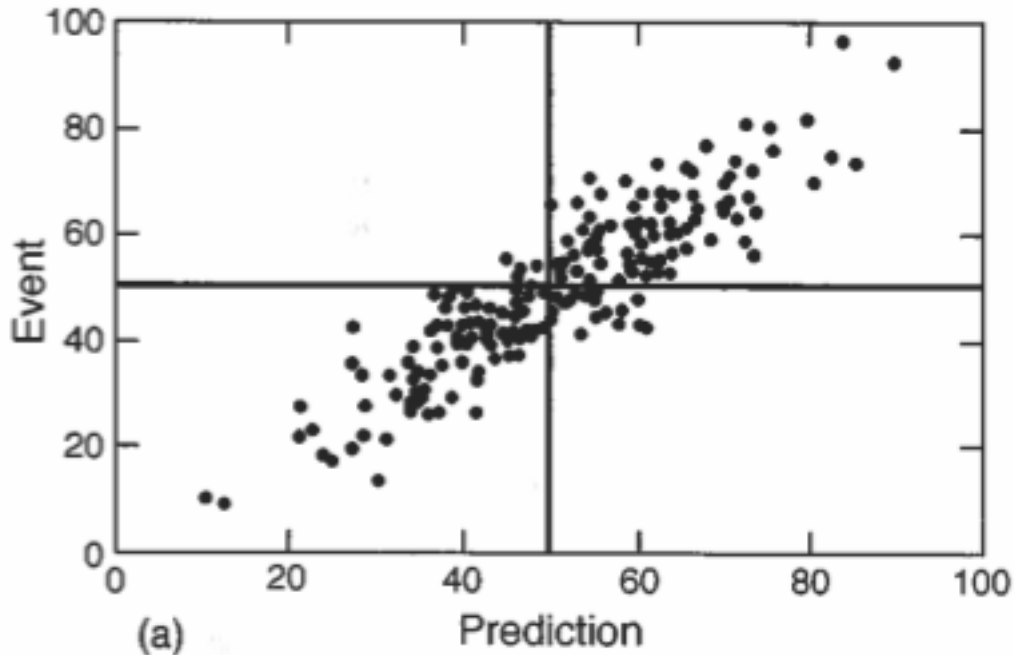


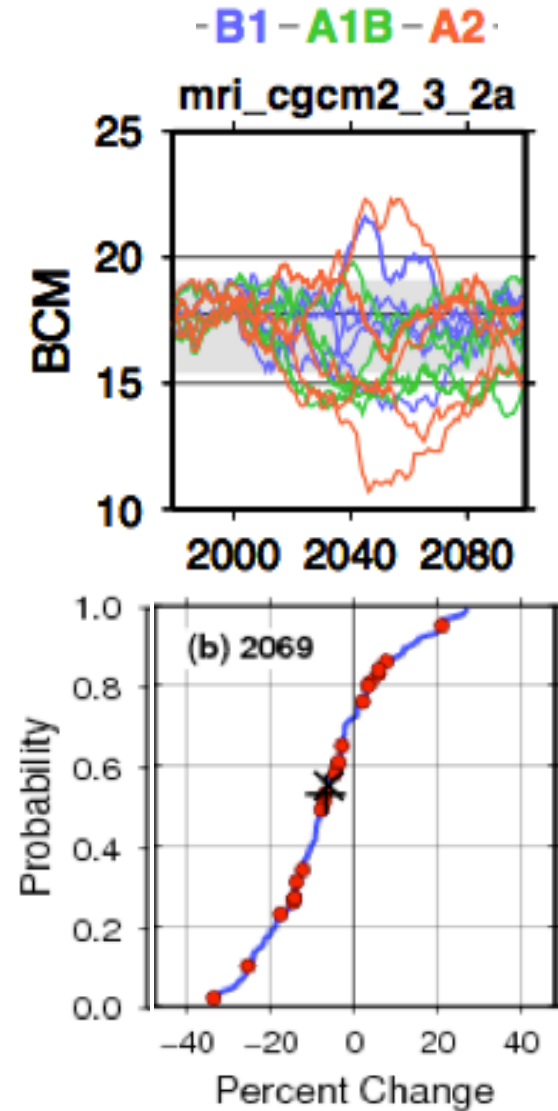
Fig. 3.1 Scatterplots representing various levels of uncertainty.

KVK - Key Quote re Projections of Extremes

- “Until climate models can be shown to satisfactorily simulate the physical mechanisms we know are important for regional scale hydrology, their outputs should be used with caution as there is the danger that the “worst-case scenario” projected by current climate models may not actually be the worst case possible for water resource managers in terms of extreme events, particularly if the baseline is inappropriately assessed [e.g., Verdon-Kidd and Kiem, 2010].
- This has been recently demonstrated in eastern Australia with the December 2010 and January 2011 flooding and prior to that with the Big Dry drought, which lasted more than a decade; both of these events were far more severe than anything projected by any climate models under even the worst emissions scenarios and out to at least 2070.”

Deser et al, Uncertainty in Backyard

- “While there is undoubtedly much room for model improvement, we show that natural climate variability poses inherent limits to climate predictability and the related goal of adaptation guidance at many places in North America.”
- “On the other hand, low natural variability in some locations leads to a more predictable future in which anthropogenic forcing can be much more readily identified, even on small scales.”
- “We call for a more focused dialogue between scientists, policymakers, and the public to improve communication, avoid raising expectations for accurate regional predictions everywhere, and recognize that in some locations more useful predictability can be expected.”
- Harding et al on CRB Projections: at Mid-century one GCM with 4 runs shows -30% and +30%



“Uncertainty in the Backyard: Communicating the Role of Natural Variability in Future North American Climate”

Clara Deser, Reto Knutti, Susan Solomon and Adam S. Phillips

January 17, 2012, Perspective submitted to Nature Climate Change