THE STORYLINE APPROACH TO THE CONSTRUCTION OF USEABLE CLIMATE INFORMATION AT THE LOCAL SCALE

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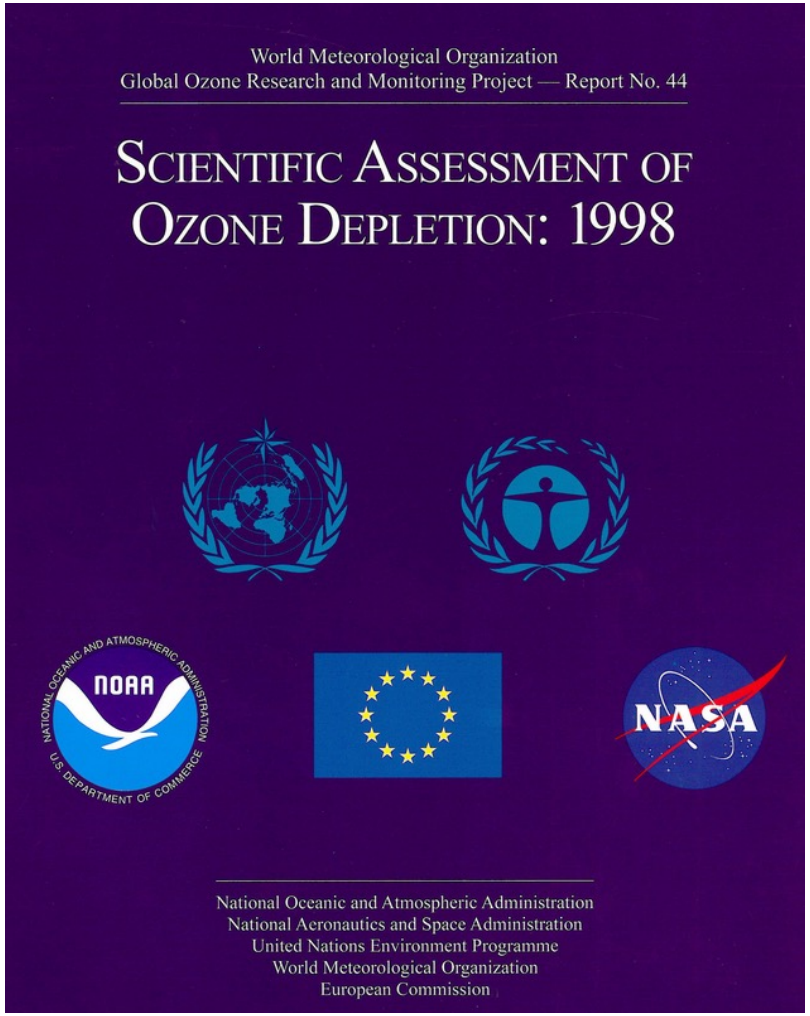
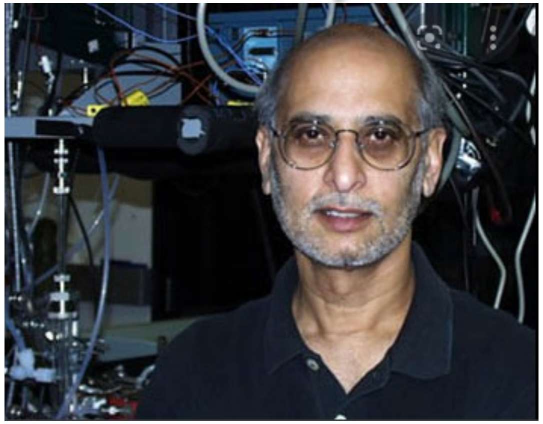
XAIDA

Chapter 7. Lower Stratospheric Processes (Lead Authors: A.R. Ravishankara and Theodore G. Shepherd)

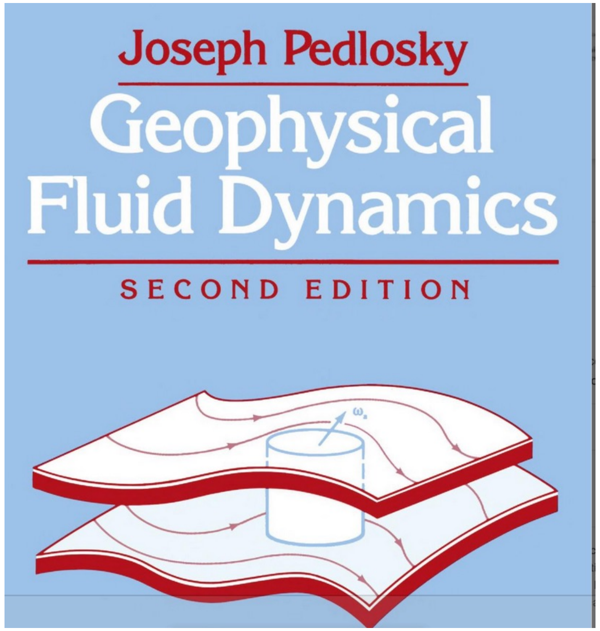


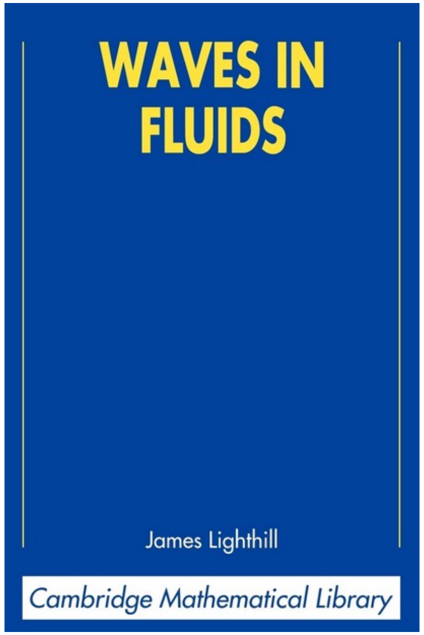
Ravi to Ted: "Why do you dynamicists never give a straight answer to a question?"



- Why *is* (fluid) dynamics such a fuzzy topic?
  - The systems we consider are generally **not spatially extensive**, so we cannot benefit from spatial aggregation (in contrast with, e.g., Earth's energy budget)
  - The phenomena of interest are **emergent**, without clear definitions, and do not follow in a straightforward way from the governing equations
  - In general, **many mechanisms are at play**, and they play out differently in different situations

A study in contrasts: two landmark textbooks in geophysical fluid dynamics for my generation





The heart of the matter

- Climate risk involves three aspects:
  - Internal variability (extreme weather and climate events)
  - Changes in the possible weather and climate states (climate change)
  - Human-managed aspects of vulnerability and exposure
- Only the first of these is subject to a (frequentist, or aleatoric) probabilistic treatment, and even that may be highly uncertain for the most extreme events
  - The second is subject to epistemic uncertainty (even for a given climate forcing)
  - The third is also uncertain, and needs to be cast in the decision space
    - Requires the concept of causality, and counter-factuals
- Ultimately, probability is degree of belief (and proclivity to action), hence is **subjective**
  - Our challenge is to develop a scientific language for meaningfully representing and communicating this complex web of uncertainty
  - Needs to combine multiple lines of evidence, and extend into the decision space

Can a narrative provide scientific evidence for decision-making?

- An apocryphal story of a conversation on 18 March 2020......

I'm going to see the Queen...
That's what I do every
Wednesday. Sod [coronavirus].
I'm going to go and see her.

You can't go and
see the Queen.
What if you go and
give her
coronavirus?

Yeah...I
can't go

nature

EDITORIAL · 20 MARCH 2019

It's time to talk about ditching statistical significance

Looking beyond a much used and abused measure would make science harder, but better.

- An obvious point is that $p < 0.05$ should not be interpreted dichotomously (as True/False), but the issue runs much deeper than this
- Climate-change science is anchored in physical understanding, yet frequentist statistical practices absolutely dominate published climate-change science
- This creates a **disconnect between physical reasoning and statistical practice**
    - See Shepherd (2021 Climatic Change) for discussion and some examples

The Journal of Socio-Economics 33 (2004) 587–606

Mindless statistics

Gerd Gigerenzer*

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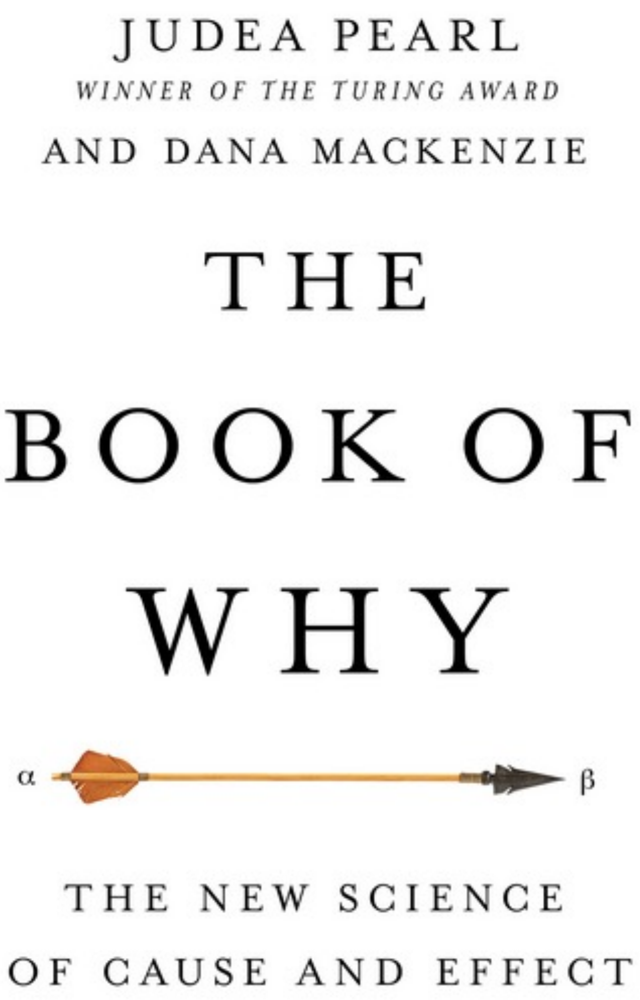
Abstract

Statistical rituals largely eliminate statistical thinking in the social sciences. Rituals are indispensable for identification with social groups, but they should be the subject rather than the procedure of science. What I call the "null ritual" consists of three steps: (1) set up a statistical null hypothesis, but do not specify your own hypothesis nor any alternative hypothesis, (2) use the 5% significance level for rejecting the null and accepting your hypothesis, and (3) always perform this procedure. I report evidence of the resulting collective confusion and fears about sanctions on the part of students and teachers, researchers and editors, as well as textbook writers.

Gigerenzer refers to the social sciences, but is it really any different in climate science?

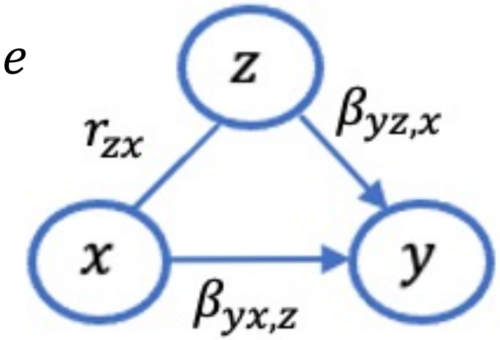


- **Causality** is not usually discussed in statistics textbooks
- However, understanding the causality involved in a particular situation is crucial for setting up the statistical analysis, and for interpreting the results
  - The mathematics is agnostic about causality, but the physical interpretation is not!
  - e.g. in an observed correlation between x and y, whether z is a **confounder** or a **mediator** depends on the direction of causation between x and z

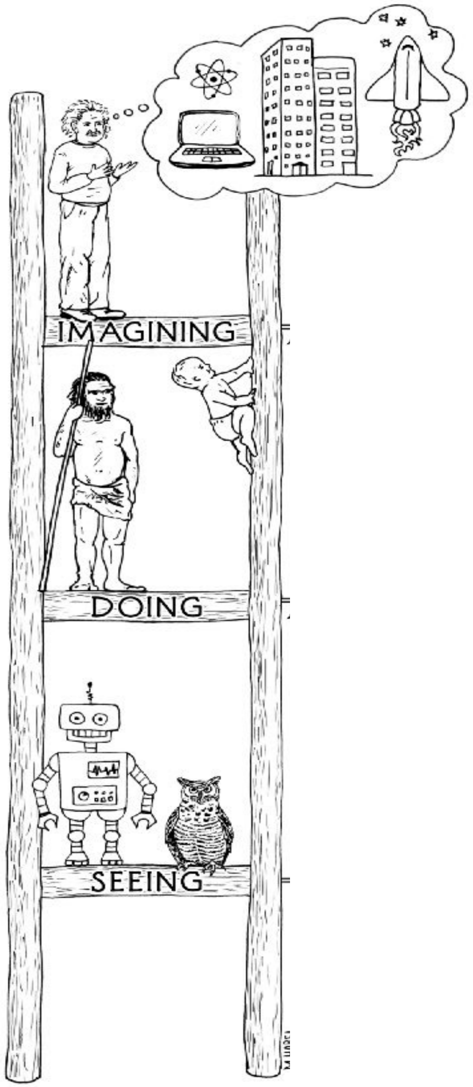
$$y_i = \beta_{yx,z} x_i + \beta_{yz,x} z_i + noise$$

$$\Longrightarrow \quad r_{yx} = \underbrace{\beta_{yx,z}}_{\text{Direct}} + \underbrace{\beta_{yz,x} r_{zx}}_{\text{Indirect}}$$

(special case of the **path-tracing rule**)



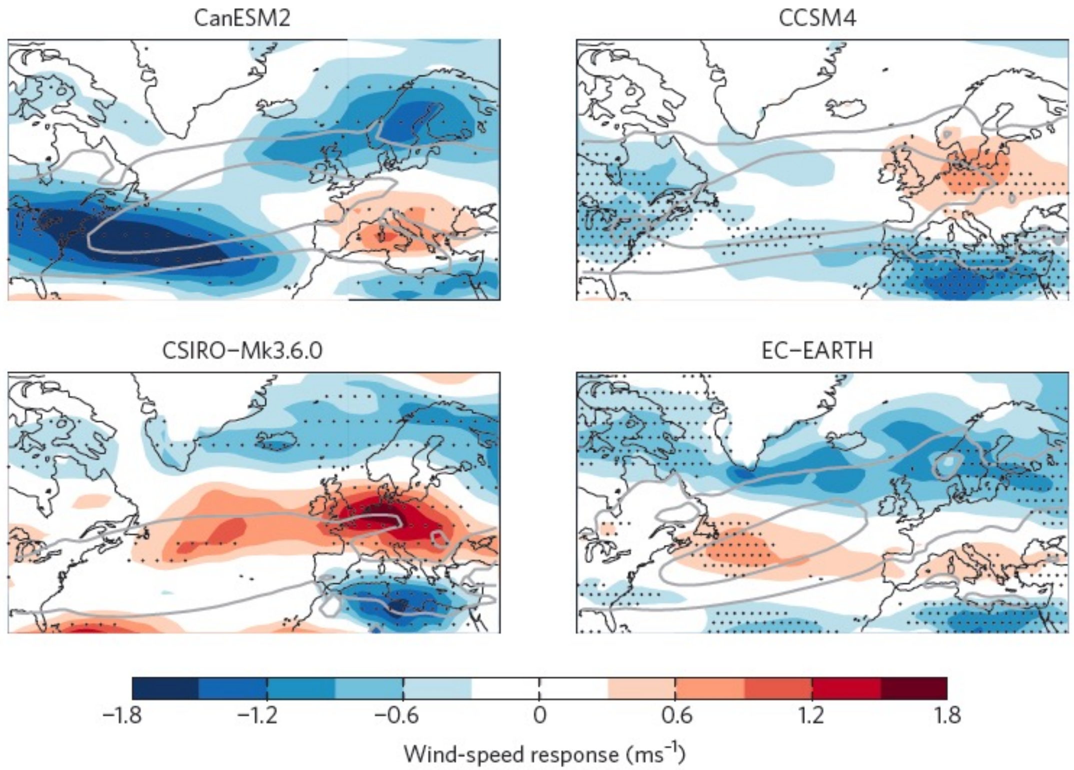
Kretschmer et al. (2021 BAMS)



Pearl's 'Ladder of Causation'

- Even the lowest level (that of association) is not 'mindless', as it takes account of how unusual the observation is, and its possible association with other factors
- For climate extremes and their impacts, learning by seeing (e.g. ML) is challenged by statistical non-stationarity and by unprecedented events
  - Need to know when and where ML can be trusted, and embed that information within a wider **causal framework**
- For climate extremes and their impacts, learning by intervention is generally not possible in the real world
  - How to extract the **reliable** information from intervention in climate models is an unsolved problem
- Our concerns (attribution and risk assessment) invariably involve counter-factual questions, which require **causal reasoning**

- *Why do we need physical climate storylines?* Climate models can **disagree on the nature of the atmospheric circulation response** to global warming
  - Has direct implications for precipitation and for weather-related extremes such as droughts and heat waves
  - The average of such different projections has no meaning!

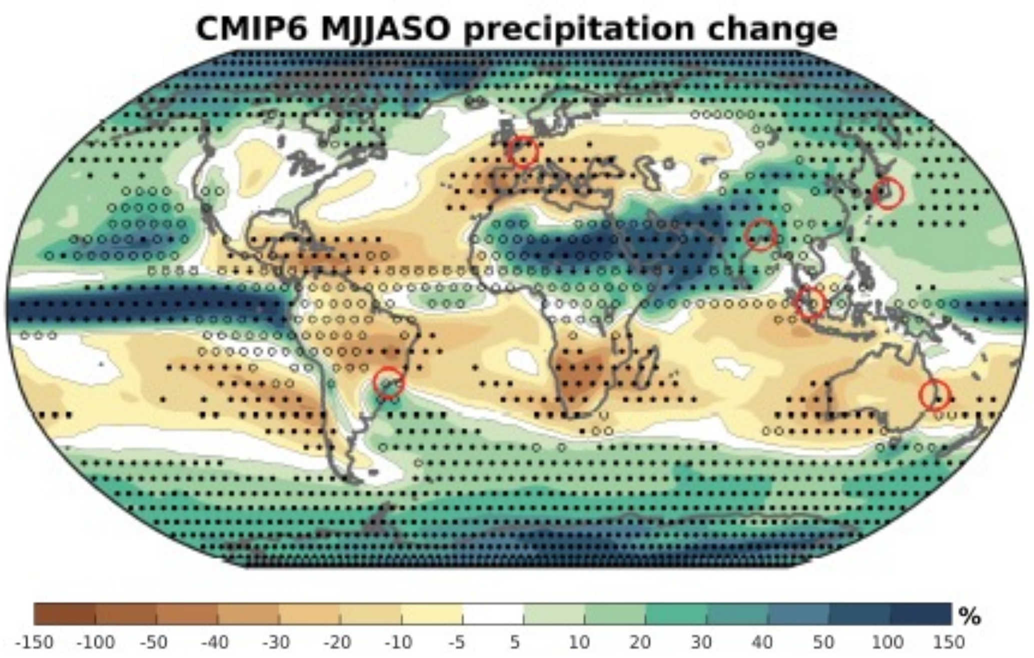


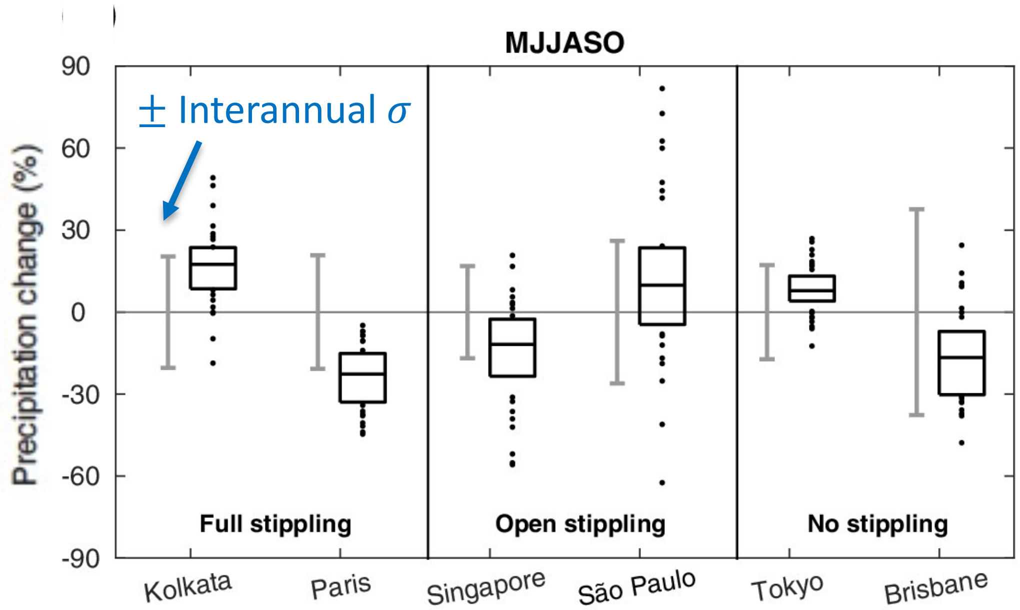
Wintertime lower tropospheric zonal wind speed climatology (contours) and end-of-century response to RCP 8.5 (shading)

Shepherd (2014 Nature Geosci.)

- Because of such dynamical uncertainty, the **uncertainty of the nature of precipitation changes over many regions** stands in contrast to the certainty of regional warming
- In this figure, full stippling indicates robustness in sign (as in the IPCC stippling), whilst open stippling indicates the potential for large, but non-robustly projected, changes
  - The latter includes many tropical regions

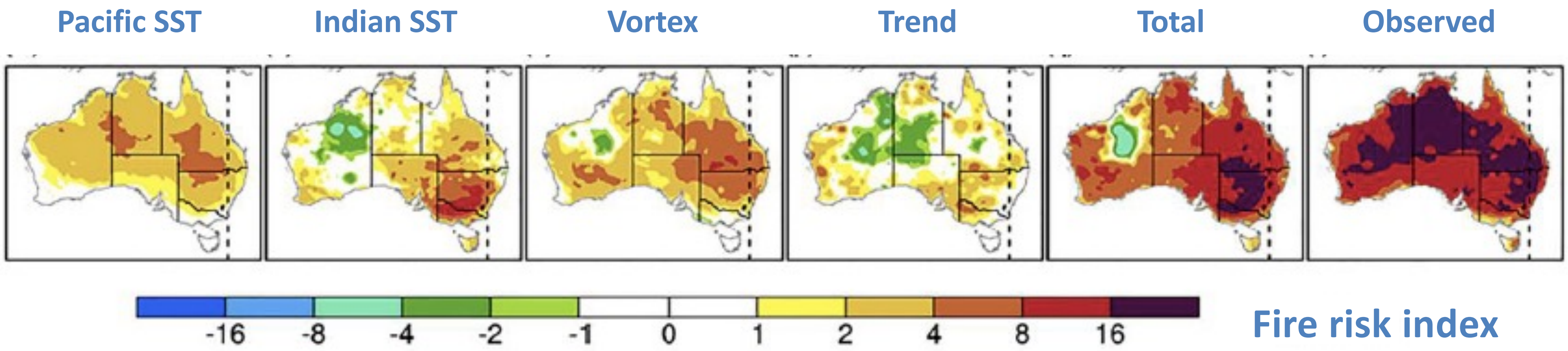
Changes over 21st century under RCP8.5





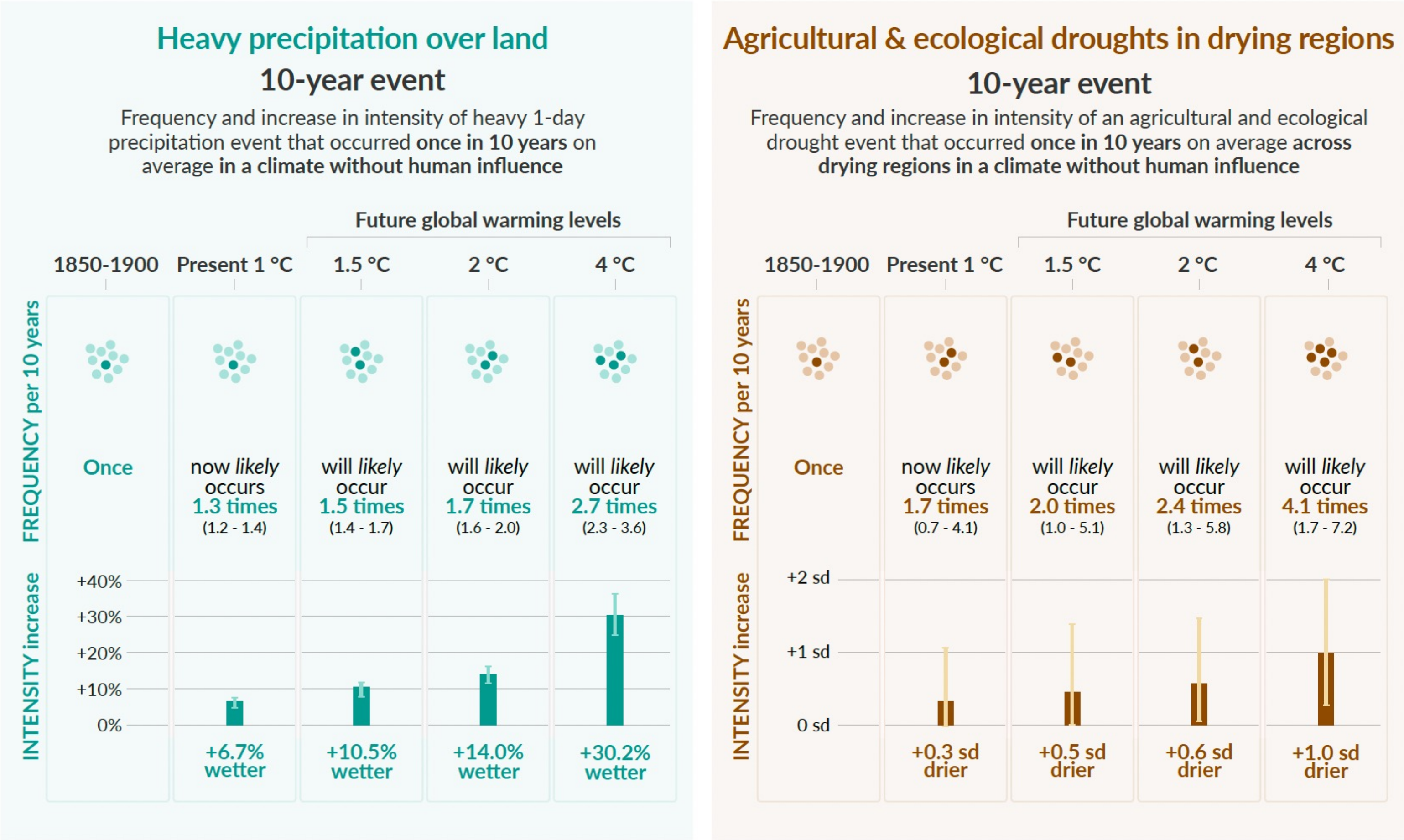
Zappa, Bevacqua & Shepherd (2021 Int. J. Clim.)

- In most extreme events, the role of **unusual dynamical conditions** is generally a very important causal factor
  - **How those dynamical conditions could change** represents a major source of uncertainty in climate information for adaptation
- For the 2019 Australian wildfires, long-term warming ("Trend") was actually only a minor contributor to increased fire risk, which mainly arose from **drying associated with unusual dynamical states (atmospheric circulation)**



Lim et al. (2021 BAMS)

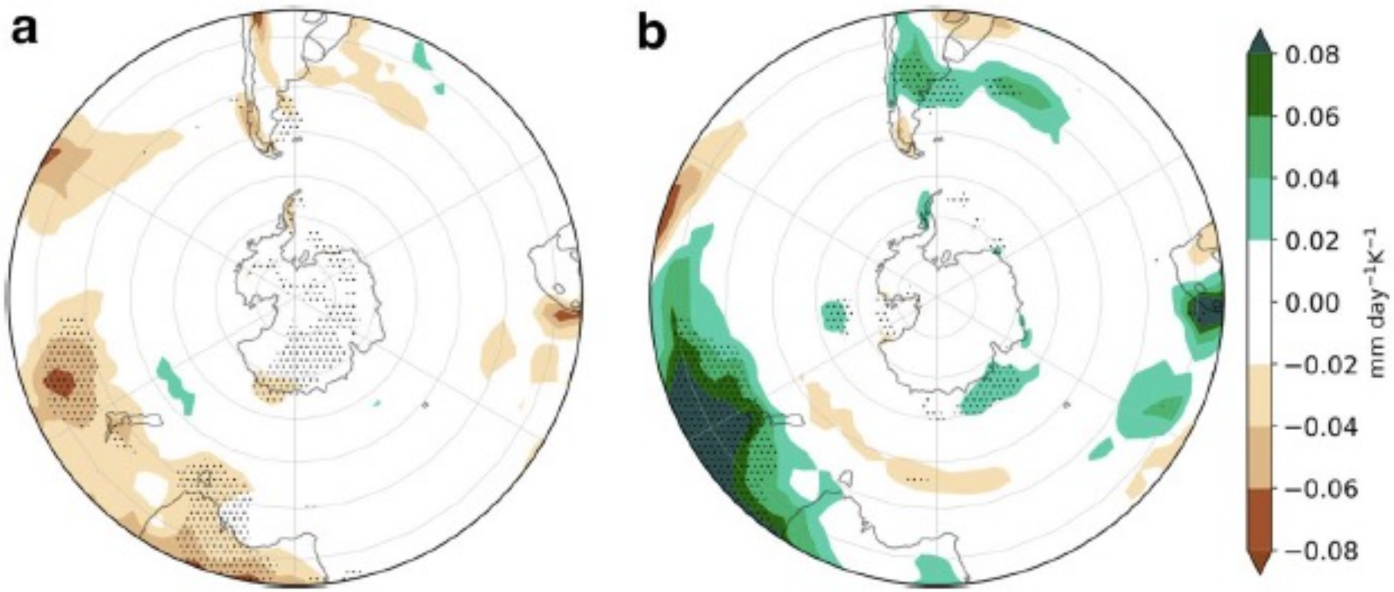
- Climate scientists tend to describe changes in extreme events **probabilistically**, which requires **aggregation**



IPCC AR6 WGI Summary for Policymakers (SPM), 2021

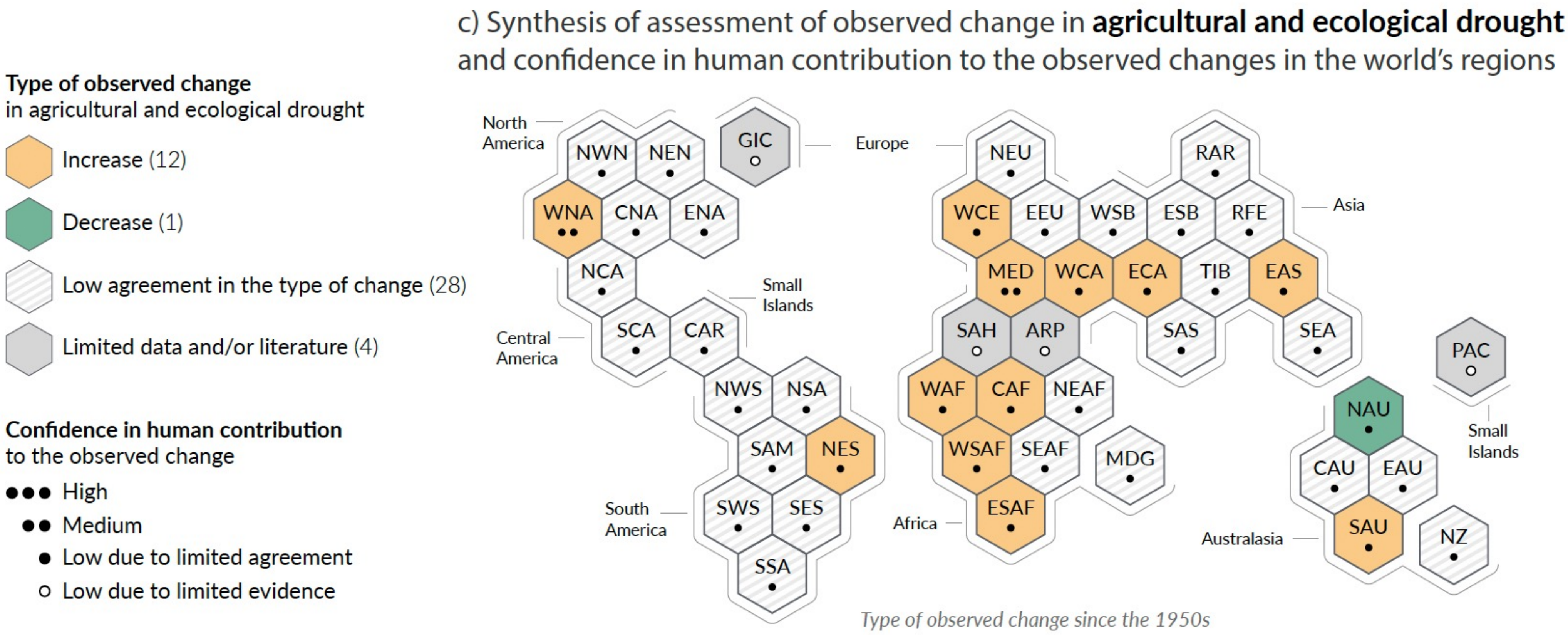
- In the IPCC, the uncertainty around dynamical aspects of climate change has typically been managed through **generalization**, e.g. a focus on zonally averaged quantities
- However, **generalization can be locally misleading**: precipitation changes in austral summer from a strengthening of the Southern Annular Mode (SAM) are completely different depending on whether the SAM change is induced by tropical warming (left) or by a delay in the breakdown of the stratospheric polar vortex (right)

One corresponds to a strengthening of the westerlies, the other to a poleward shift



Mindlin et al. (2020 Clim. Dyn.)

- At the regional scale, the traditional probabilistic attribution of changes in extremes is challenged by **uncertainties in model projections**, and by **lack of verifying data**



SPM of AR6 WGI report (2021)

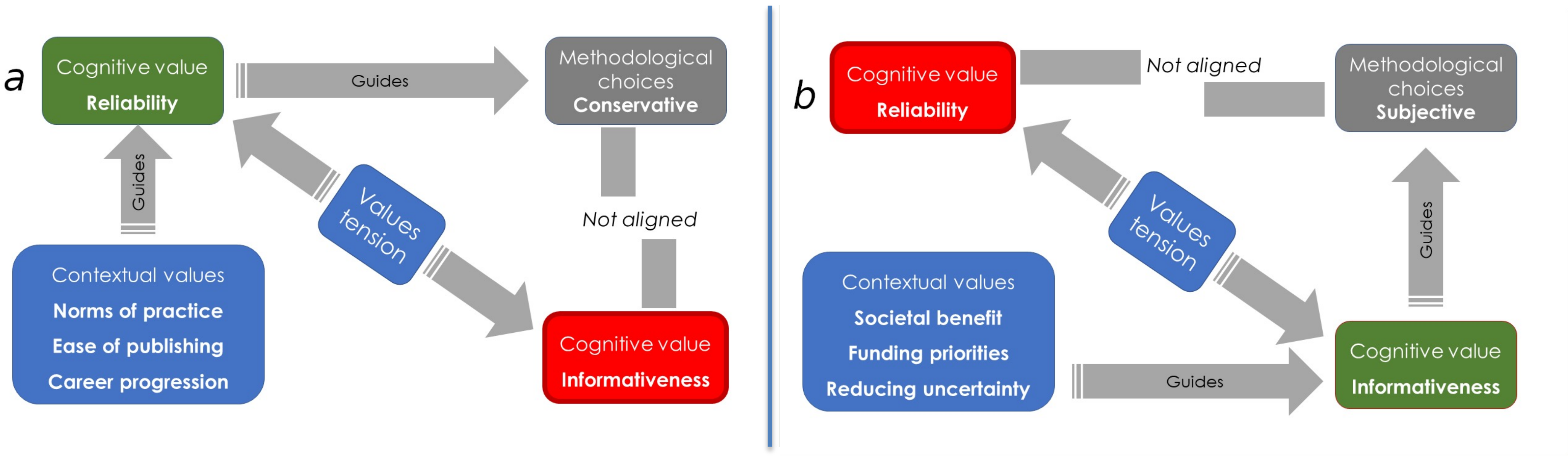
nature climate change
2021
ARTICLES
https://doi.org/10.1038/s41558-021-01125-3

Climate services promise better decisions but mainly focus on better data

Kieran Findlater[1,2], Sophie Webber[3], Milind Kandlikar[1,2] and Simon Donner[4]

- "...the traditional domination of 'hard facts' over 'soft values' [is] inverted… traditional scientific inputs… become 'soft' in the context of the 'hard' value commitments that will determine the success of policies for mitigating the effects of [climate change]" (Funtowicz & Ravetz 1993 Futures)
- We should derive a conceptual framework from reality, rather than deriving 'reality' from a conceptual framework (paraphrase from E.F. Schumacher's *Small is Beautiful,* 1973)
    - Requires **inverting the construction of climate information**

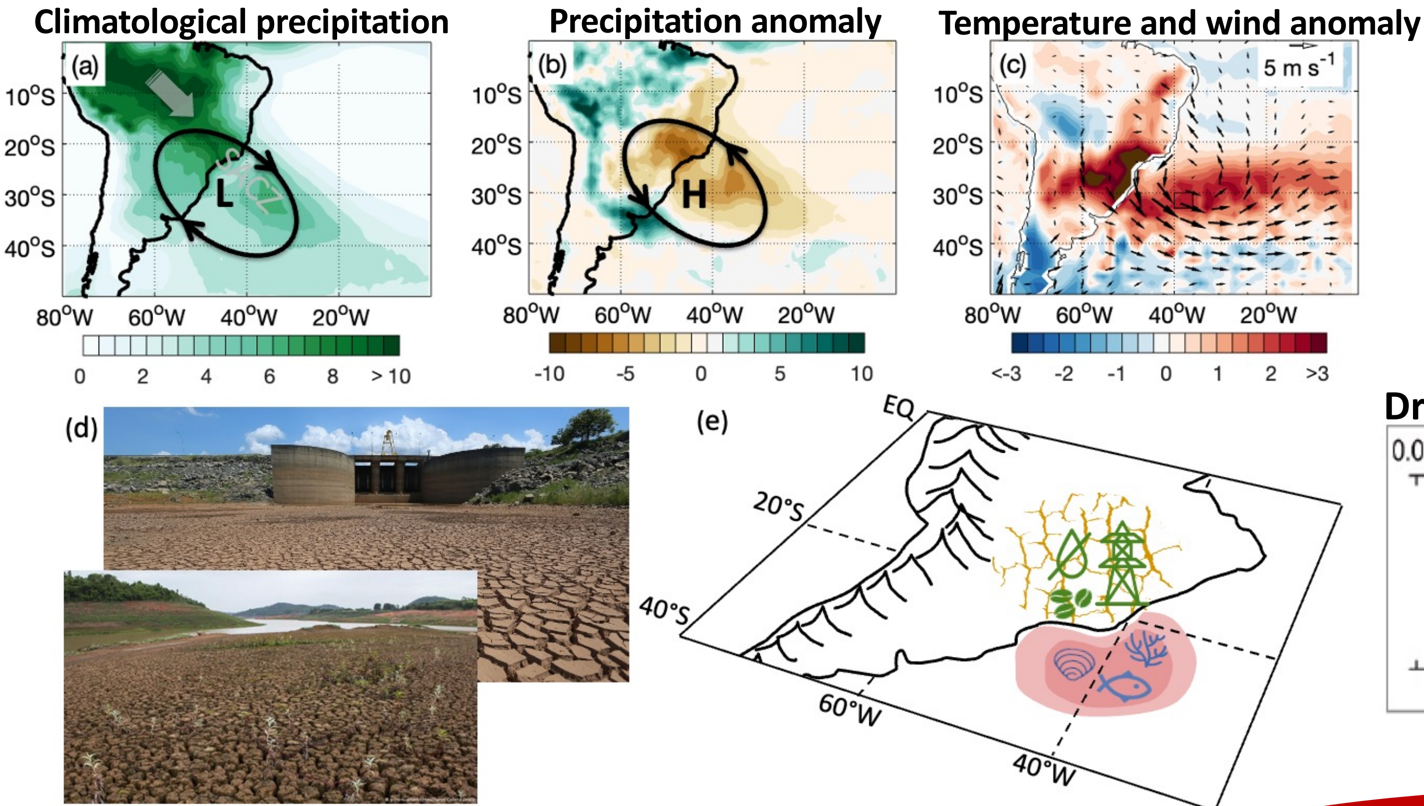
- Contextual (social) values shape how we do our science, and **the inevitable trade-off between reliability and informativeness**
  - See Lloyd & Oreskes (2018 Earth's Future) and Shepherd (2019 PRSA)
  - Reliability guards against false alarms (Type 1 errors); informativeness guards against missed warnings (Type 2 errors)



Jack et al. (BAMS, in revision)

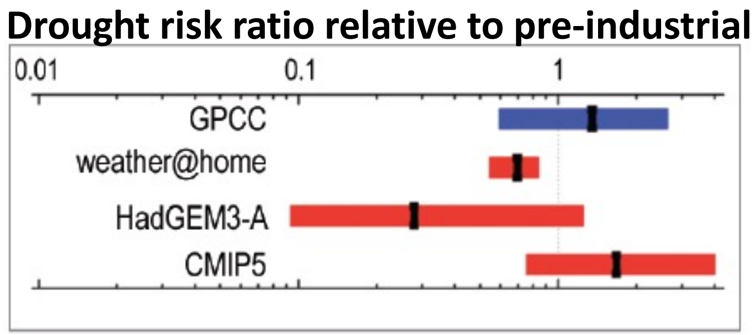
Example: a compound extreme event in southeast Brazil

- Anomalous anti-cyclonic circulation led to failure of 2013/14 South American monsoon
- Caused drought and heatwaves, affected food-water-energy nexus: correlated risk



Rodrigues & Shepherd (2022 PNAS Nexus)

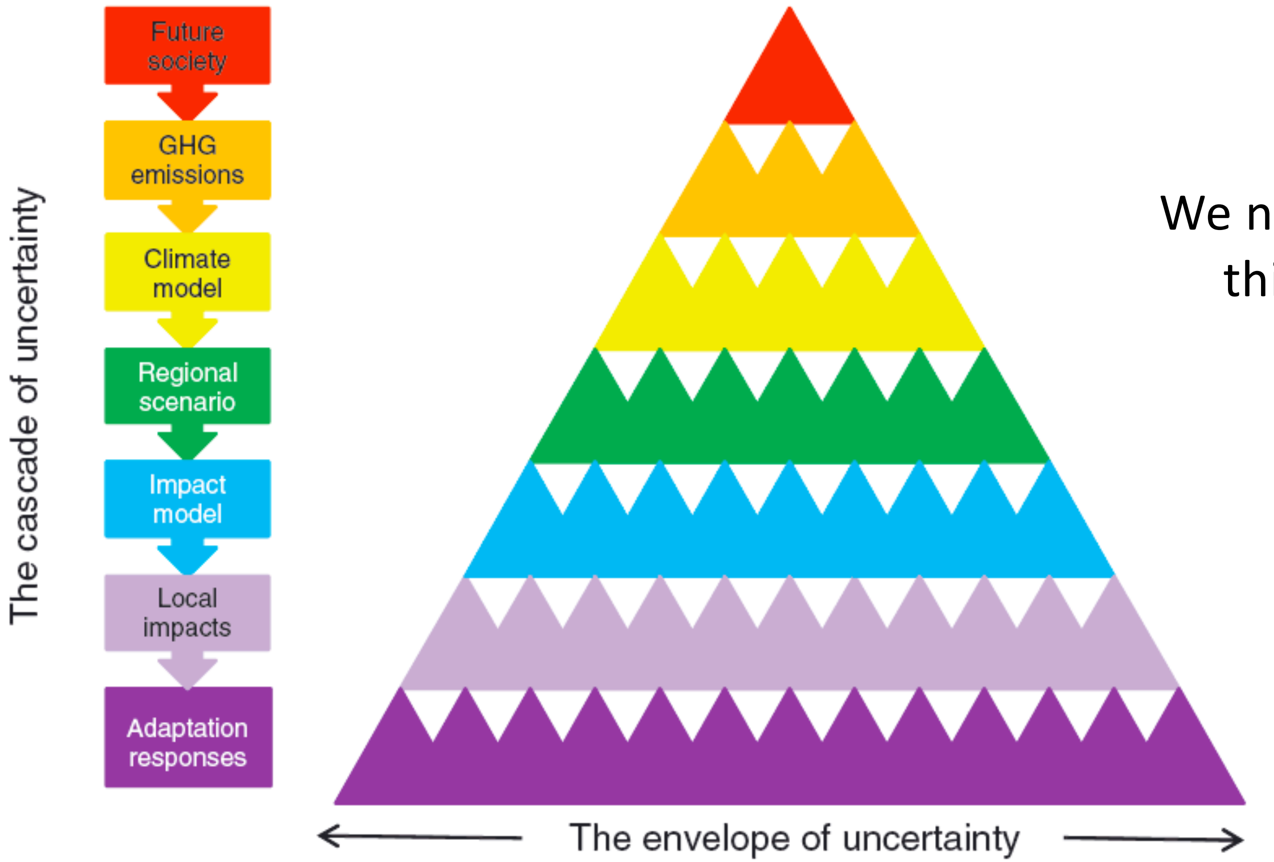
- A probabilistic attribution study of the event found "insufficient evidence" that climate change increased drought risk



Martins et al. (2017 BAMS)

We can ask: **insufficient for whom?**

- Consideration of all the uncertainties in climate change in the traditional way leads to a "**cascade of uncertainty**" which obscures the climate information content



We need to navigate this somehow!

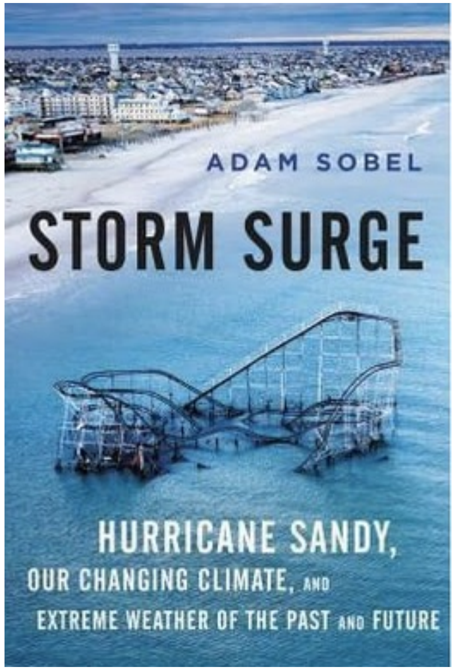
Wilby & Dessai (2010 Weather)

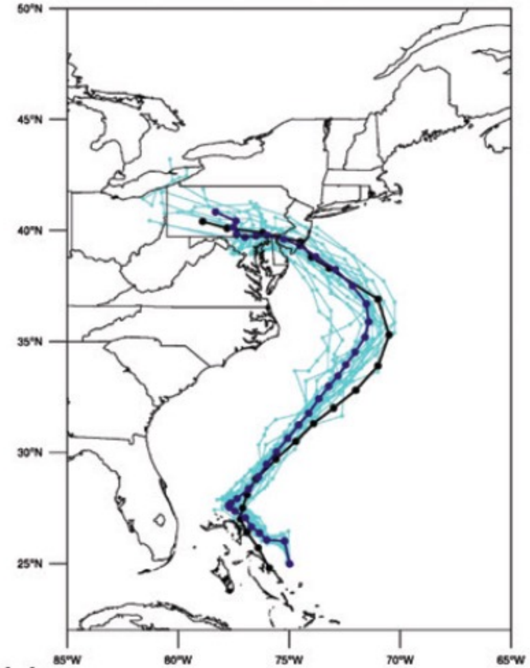
- Even when aggregation is reliable, **it is not informative about individual cases**
  - A famous example (Bortkiewicz 1898)

Pandit (2015 Anaesthesia)

- Number of Prussian cavalry units suffering a death of a soldier by horsekick in a given year (collected over a 20-year period)
  - Follows a Poisson distribution
- Shows that the deaths happened "by chance", even though **each one surely has a tragic story behind it**
- This sort of dialectic between aggregate and individual occurs across many disciplines
  - Events in the real world are not iid

- Ultimately, **every extreme event is unique**, and this uniqueness matters for impacts





- **Hurricane Sandy** (2012) was unusual in its rapid westward steering and its merger with an extratropical storm, **both the result of a strongly deformed jet stream**
- US weather forecasters didn't even have a protocol for handling such an event
- It seems almost meaningless to ask if such a freak event would become more likely in the future

- But we do know that sea level will be higher, and storms will hold more moisture
- Thus we can legitimately ask (and plausibly answer) the counter-factual questions:
  - How much were the impacts of Sandy increased by climate change?
  - How much worse might they be in the future?

- From the *Good Practice Guidance Paper on Detection and Attribution Related to Anthropogenic Climate Change* (IPCC 2010)

> To avoid *selection bias* in studies, it is vital that the data are not preselected based on observed responses, but instead chosen to represent regions / phenomena / timelines in which responses are expected, based on process-understanding.

> Confounding factors (or influences) should be explicitly identified and evaluated where possible.

- Recommendations work against any consideration of **the local** (Shepherd & Sobel 2020 Comp. Stud. South Asia, Africa & Middle East)
  - The process of abstraction and generalization in mainstream climate science "detaches knowledge from meaning" (Jasanoff 2010), and represents a form of epistemic injustice

"We believe what we see, and not what we are told" (Dr Santosh Nepal, ICIMOD, 2021)

- Yet the most severe climate impacts are often exacerbated by the **human-modified environment**
  - Rather than being a ‘confounding effect’ for the effects of climate change, **the urban heat island effect is a threat multiplier for heat waves**

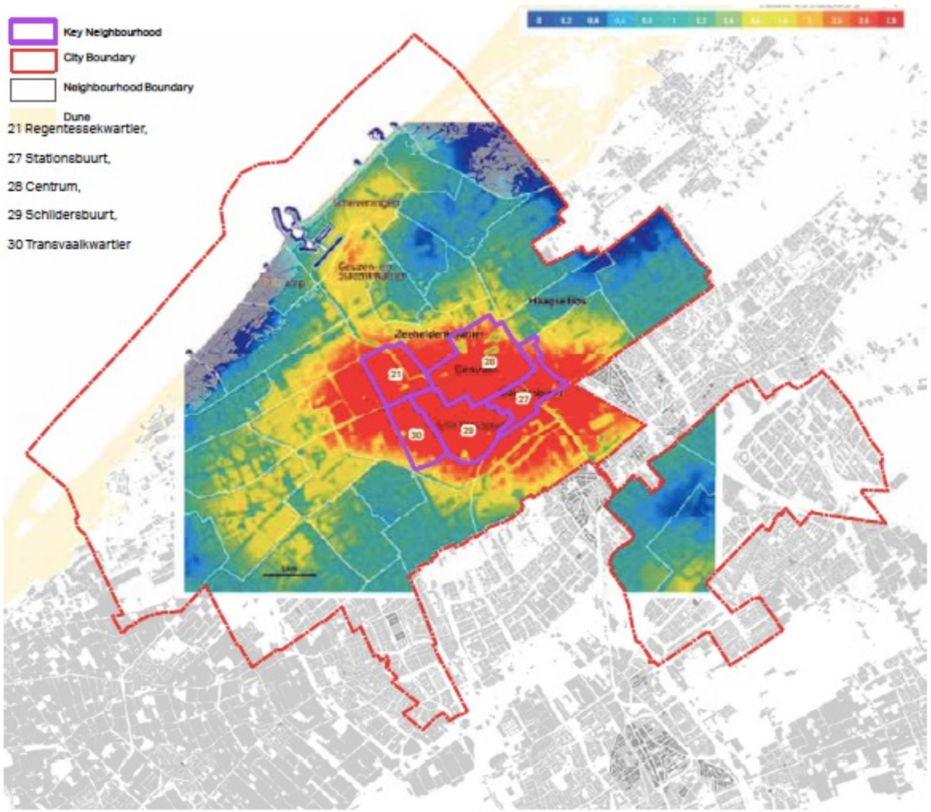


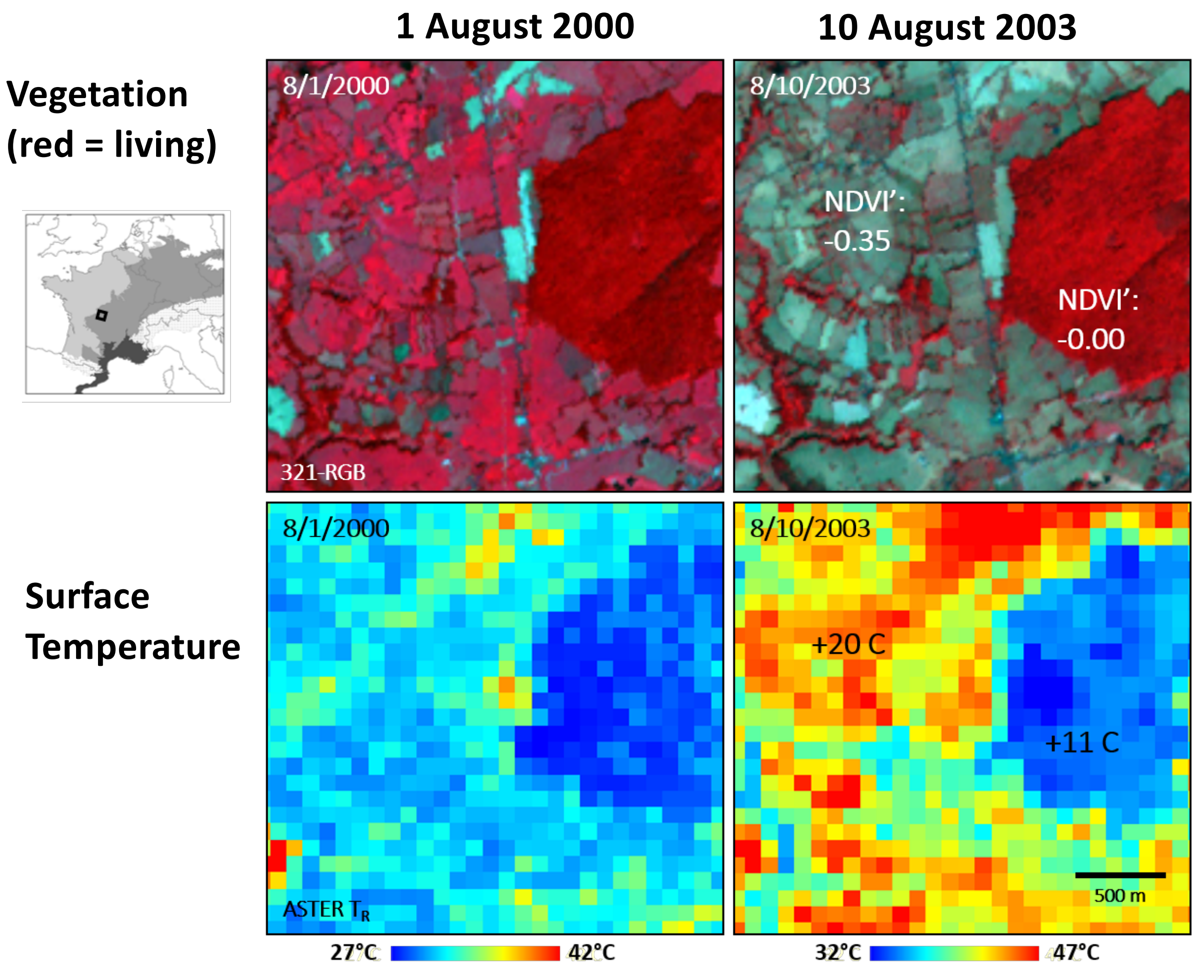
Figure 2-8: The urban heat island effect in The Hague – increased heat will affect more vulnerable neighbourhoods in The Hague

Urban heat island effect in The Hague, based on a recent heat wave

Not surprisingly, the poor neighbourhoods were disproportionately affected

From The Hague Resilience Assessment (January 2018)

- **We actually have a huge amount of climate information, even at the local scale**, from both observations and modelling — it's just that the information is **conditional**



- The summer 2003 heat wave in central France
- Temperature difference between 2000 and 2003 was 11°C in forested areas, but 20°C where the vegetation died out
- We may not be able to predict the statistics of heat waves in the future, but we can predict their implications, and how to manage their impacts

Zaitchik et al. (2006 Int. J. Clim.)

DISCOVERING BRITAIN

Royal Geographical Society with IBG

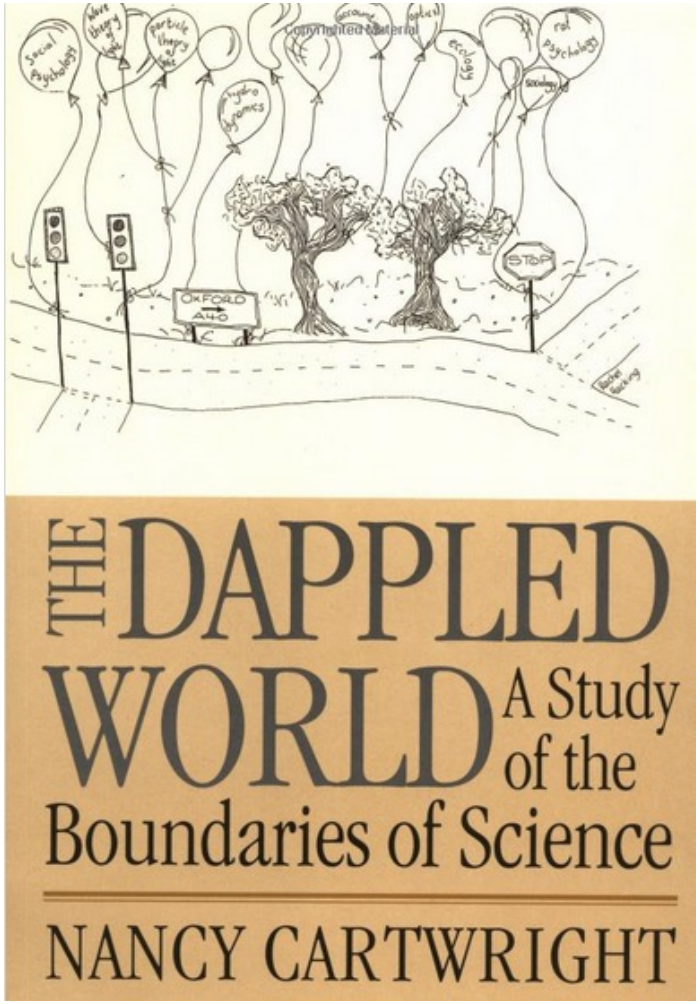
EVERY LANDSCAPE HAS A STORY TO TELL

Have fun exploring them with free walks, trails and viewpoints from

www.discoveringbritain.org

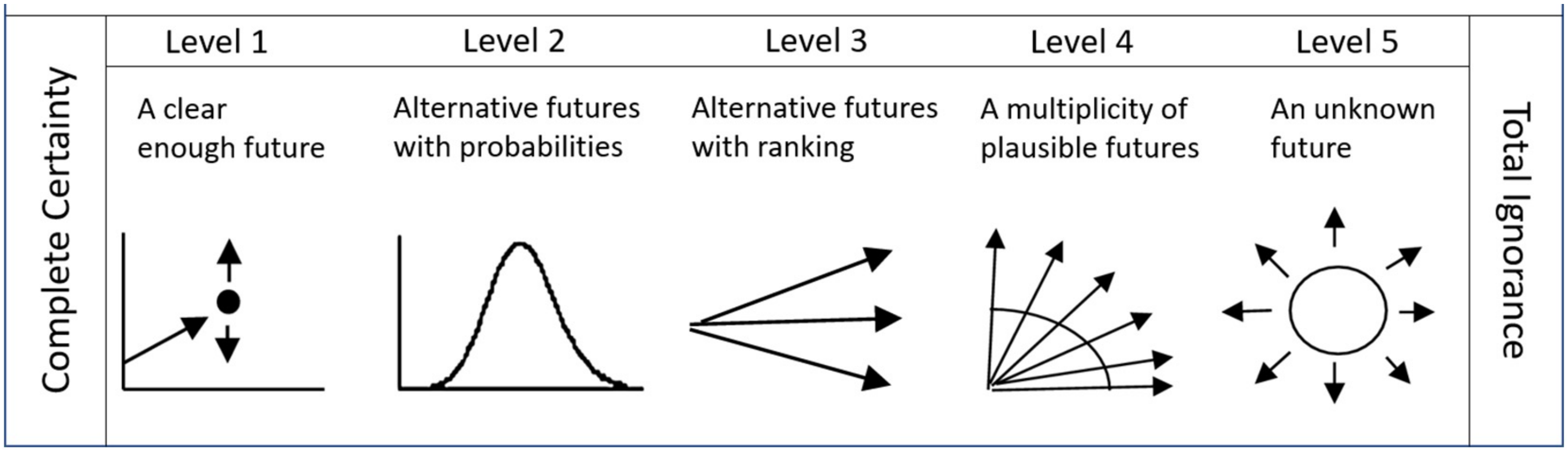
- We need to embrace landscapes, not remove them

- Nature is anyway governed by a *patchwork* of scientific laws (Cartwright 1999)



- Scientists are pressured to issue ‘single, definitive’ statements (Stirling 2010 Nature)
- We need a language for expressing a **‘plural, conditional’ state of knowledge**
  - There are many decision-making methods that deal with deep uncertainty (Weaver et al. 2013 WIREs Clim Change; Rosner et al. 2014 Water Resources Res)

Levels of uncertainty



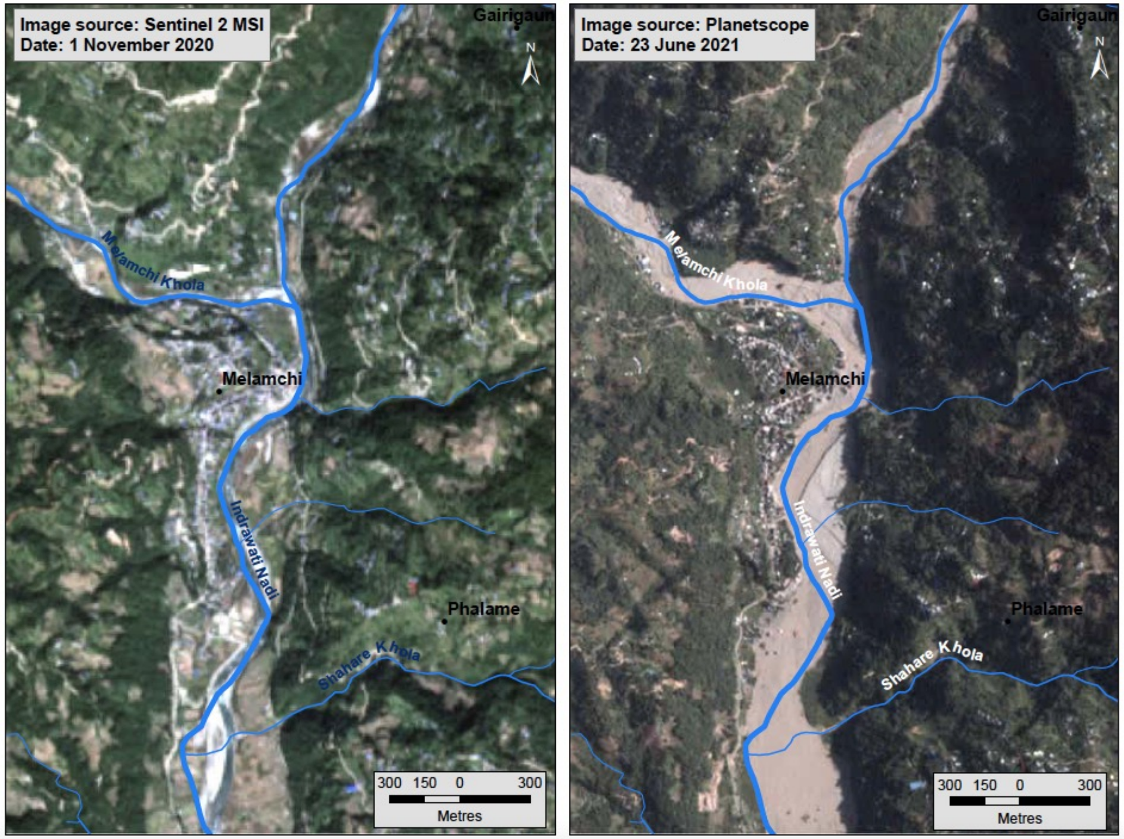
Adapted from Marchau et al. (2019)

Narrative in science

"Natural historians have too often been apologetic, but most emphatically should not be in supporting a plurality of legitimately scientific modes, including a narrative or historical style that explicitly links the explanation of outcomes *not only to spatiotemporally invariant laws of nature, but also, if not primarily, to the specific contingencies of antecedent states*, which, if constituted differently, could not have generated the observed result." [emphasis added)

Stephen Jay Gould, *The Structure of Evolutionary Theory* (2002)

- So **why not climate scientists too?** (see Shepherd & Lloyd 2021 Climatic Change)

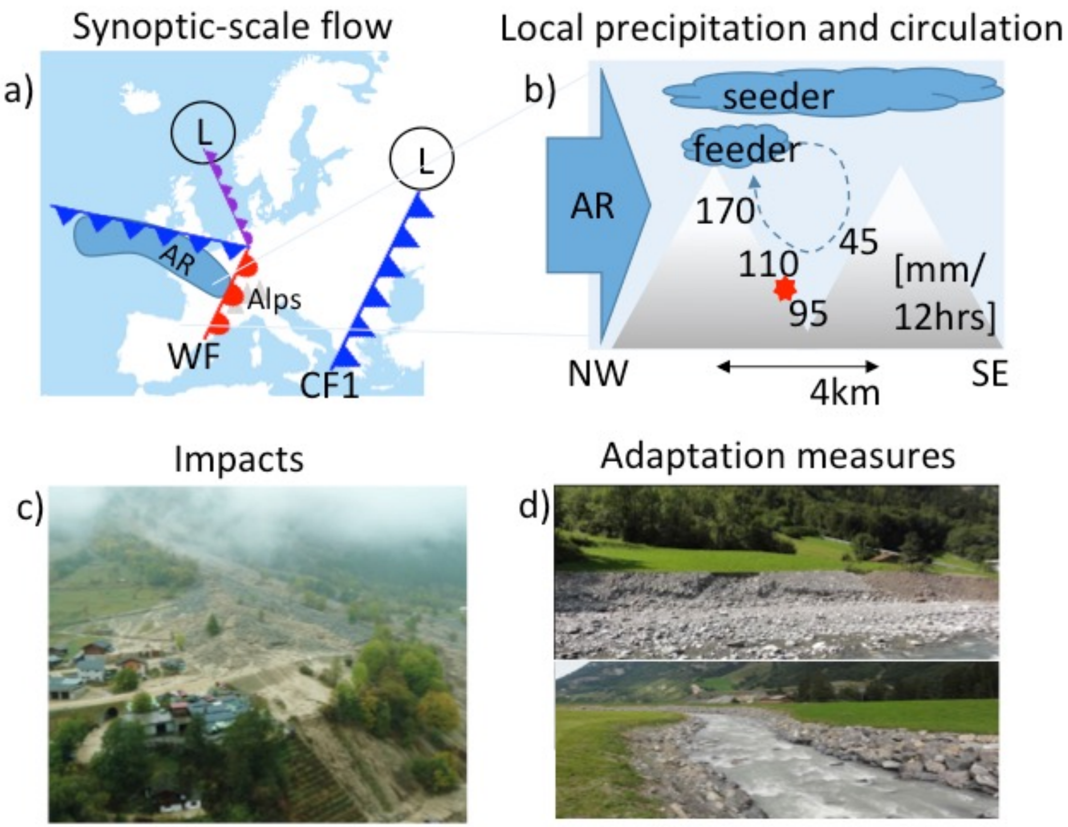


Debris outflow from the Melamchi (Nepal) flood disaster of 15 June 2021 (ICIMOD 2021)

- **Storylines:** physically-based unfoldings of past climate or weather events, or of plausible future events or pathways (Shepherd et al. 2018 Climatic Change)
  - Definition now incorporated in IPCC Glossary (see also Box 10.2 of AR6 WGI report)
  - An **unforecasted rain-on-snow event in the Swiss Alps**: four typologies of use

Providing a physical basis for partitioning uncertainty

Exploring the boundaries of plausibility

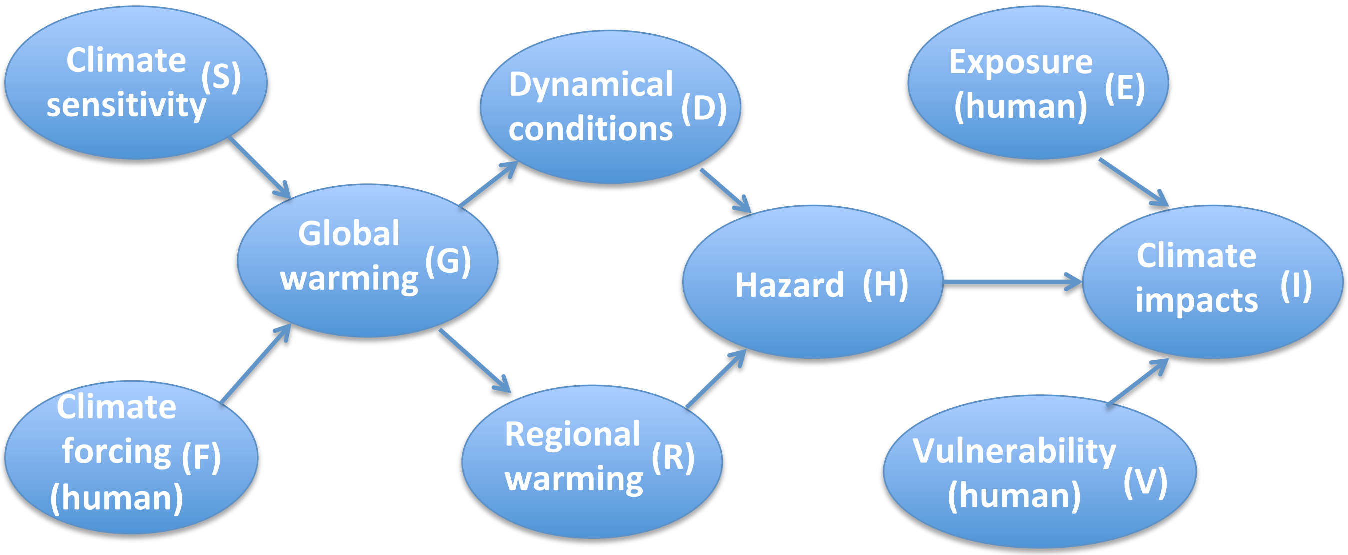


Improving risk awareness

Strengthening decision-making

Shepherd et al. (2018 Climatic Change)

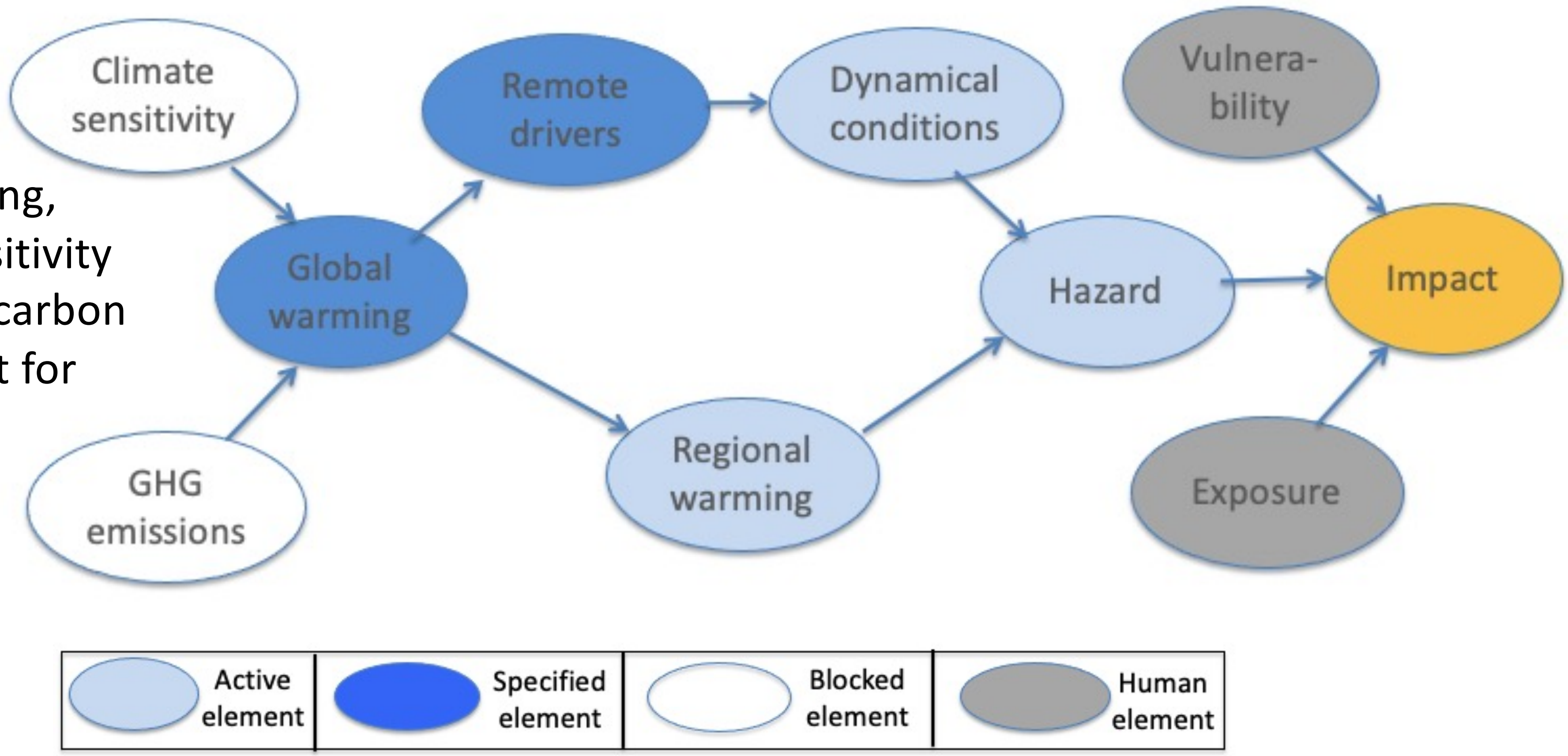
- **Storylines** are a way of navigating the cascade of uncertainty
  - **Causal networks** provide a means for representing **conditional** information
  - Storylines can be seen as **instantiations** of a causal network, by conditioning on one or more nodes: e.g. global warming levels and dynamical conditions
- The uncertainty space is thereby represented **discretely**, through a range of storylines
  - Builds in **self-consistency**, which is essential for consideration of correlated risk



Shepherd (2019 Proc. Roy. Soc. A)

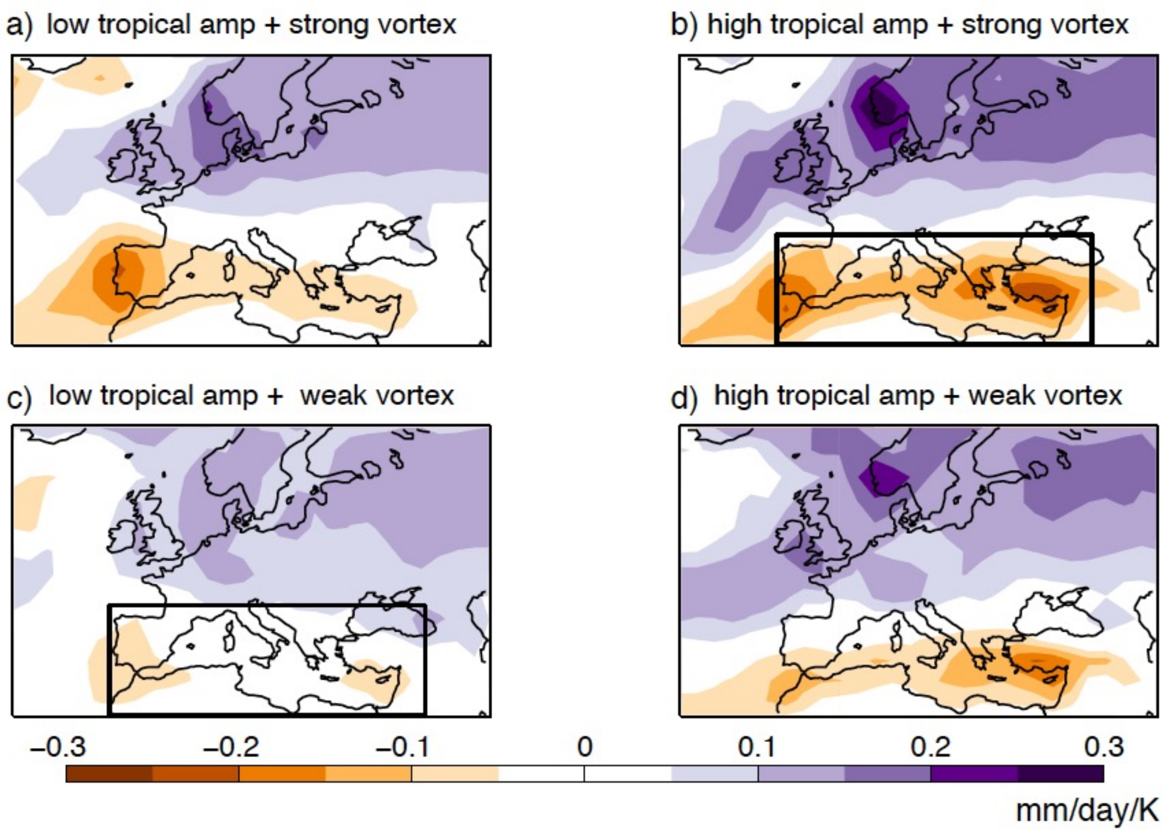
A dynamical (circulation drivers) storyline of regional climate change

In this framing, climate sensitivity matters for carbon budgets, not for impacts



After Shepherd (2019 Proc. Roy. Soc. A); in IPCC AR6 WGI Chapter 10, Box 10.2, Figure 1

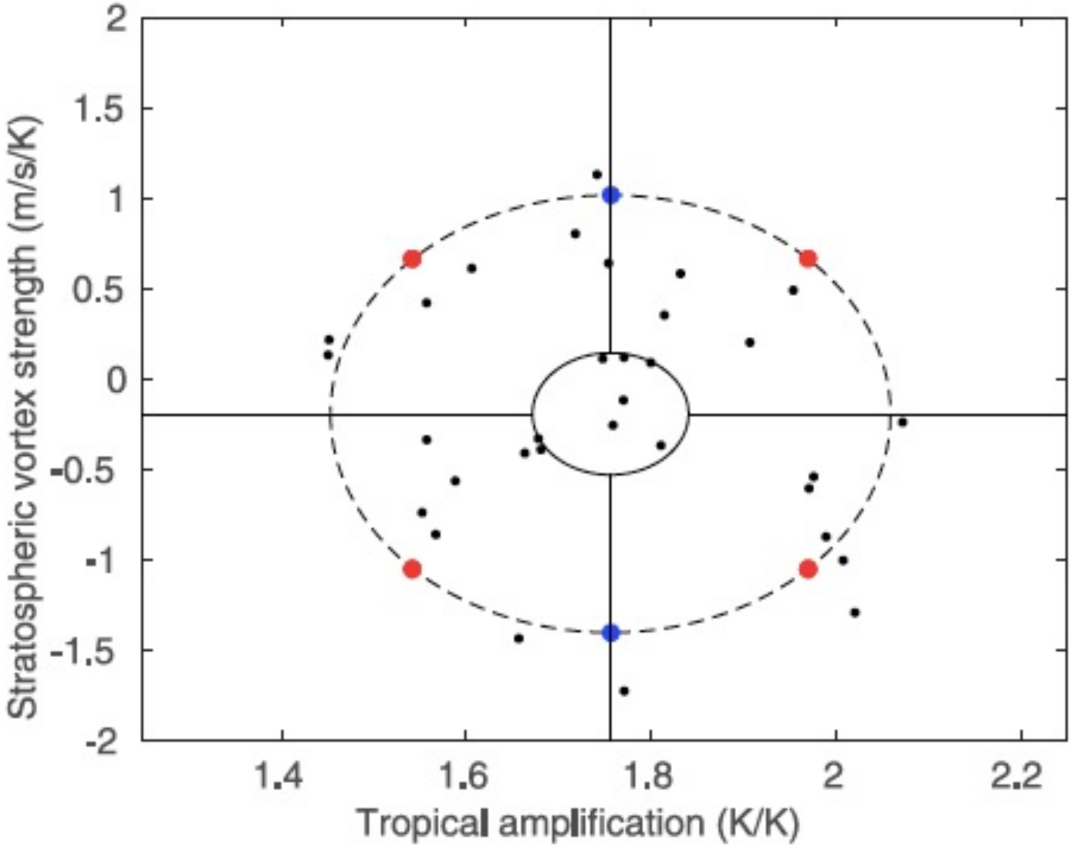
- **Example of dynamical storylines:** four storylines of **future cold-season Mediterranean drying** (a major climate vulnerability for southern Europe)
  - So far as we know, any one of these could be true



These could each be used to interpret the observed changes, to articulate multiple causal hypotheses

Zappa & Shepherd (2017 J. Clim.)

Remote driver responses across the CMIP5 ensemble



- The storylines **can be given a probabilistic interpretation**, if you are comfortable with that
- Can be refined in the future, based on new knowledge (e.g. elimination of one of the storylines as implausible)

Zappa & Shepherd (2017 J. Clim.)

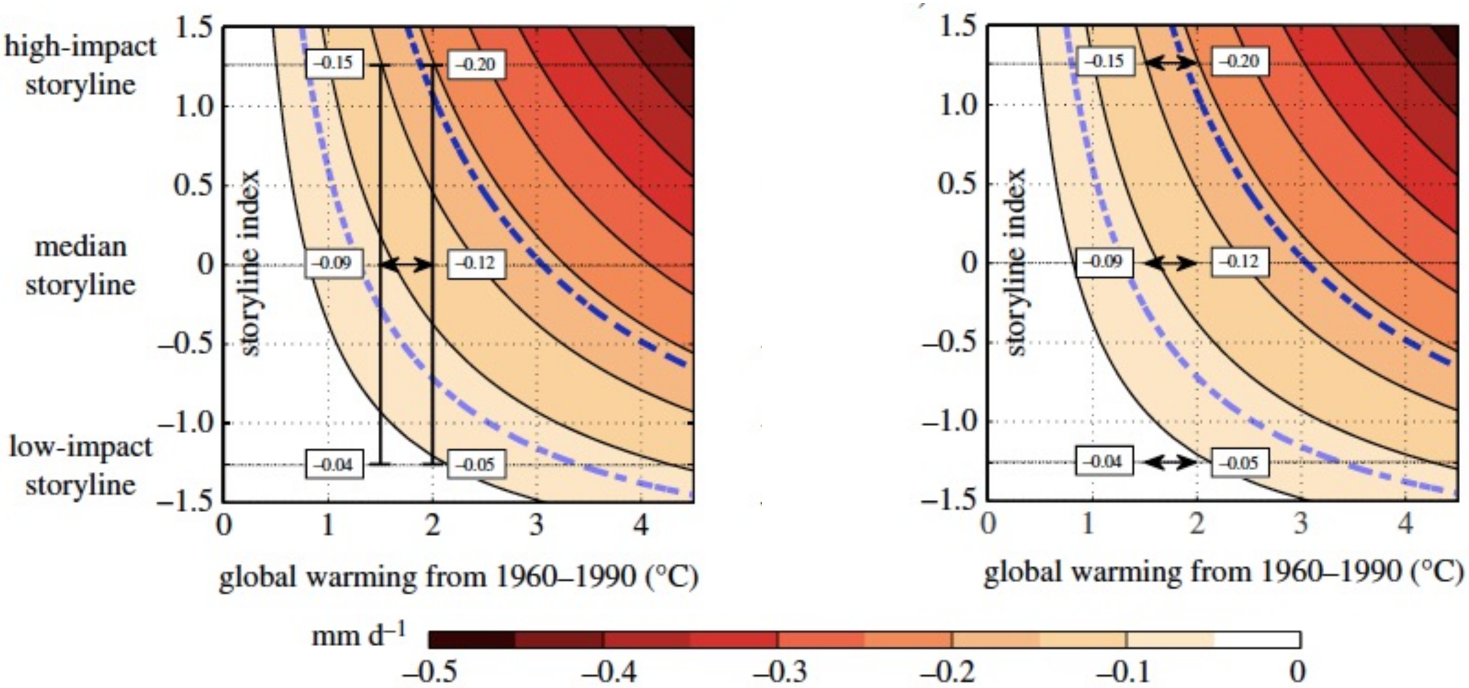
Sensitivity of cold-season Mediterranean drying to global warming level

Traditional view of 1.5 C vs 2.0 C:

- 0.03 to 0.15 mm/day at 1.5 C
- 0.05 to 0.20 mm/day at 2.0 C
- Indistinguishable within uncertainties

Storyline view of 1.5 C vs 2.0 C:

- 0.15 vs 0.20 mm/day for high-impact storyline
- 0.03 vs 0.05 mm/day for low-impact storyline
- Distinguishable for any storyline

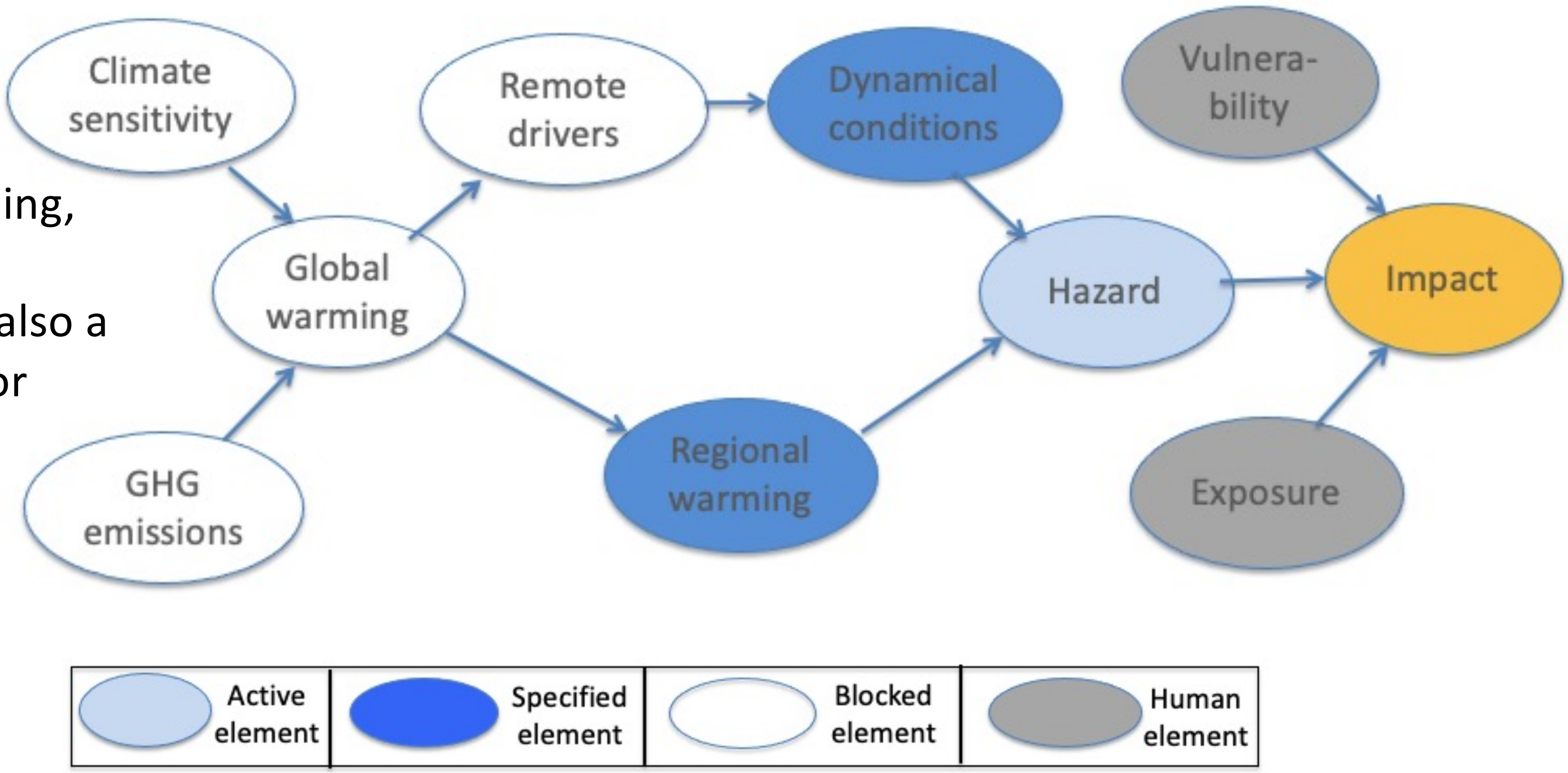


The key is the **conditionality** of the representation

Zappa & Shepherd (2017 J. Clim.)

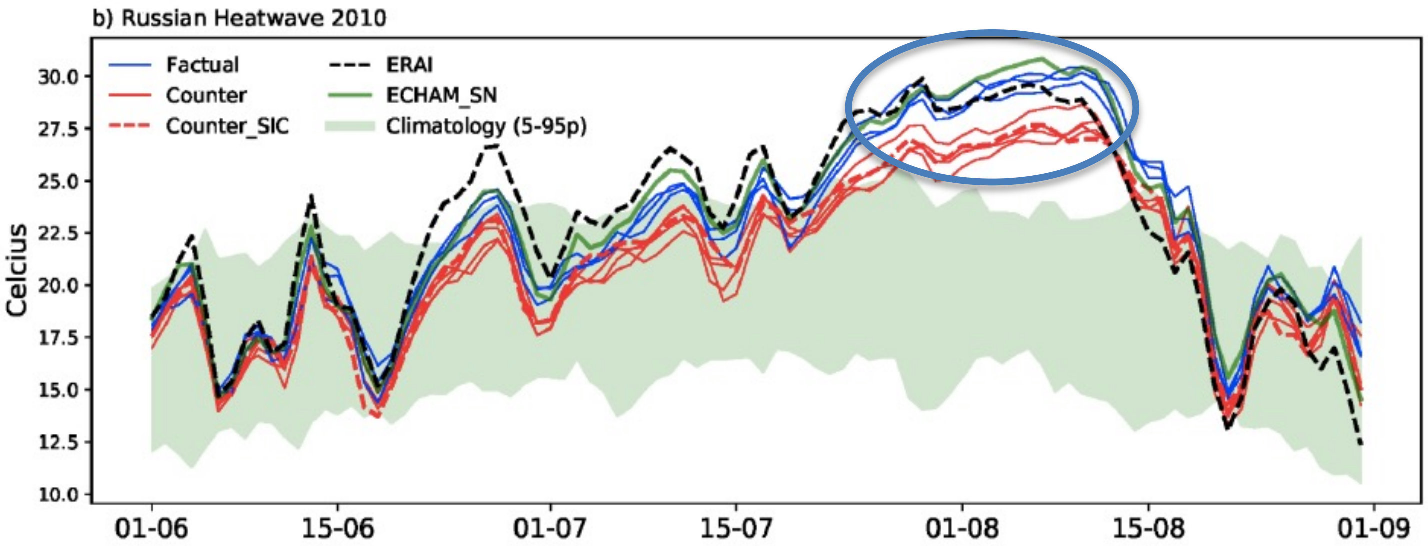
An event storyline

In this framing, the human element is also a causal factor (decision context)



After Shepherd (2019 Proc. Roy. Soc. A); in IPCC AR6 WGI Chapter 10, Box 10.2, Figure 1

- **A storyline of an observed event can be constructed in various ways**, e.g. by imposing the observed dynamical conditions in a climate model together with warmer ocean temperatures and increased greenhouse gas concentrations to fill in the 'physics'
  - Called the 'pseudo global warming method' in regional climate modelling (Schär et al. 1996 GRL); in this case, imposed through global spectral nudging
- Allows use of weather-resolving atmospheric models; physically self-consistent
- Removes the arbitrariness in event definition; users can define event as they wish

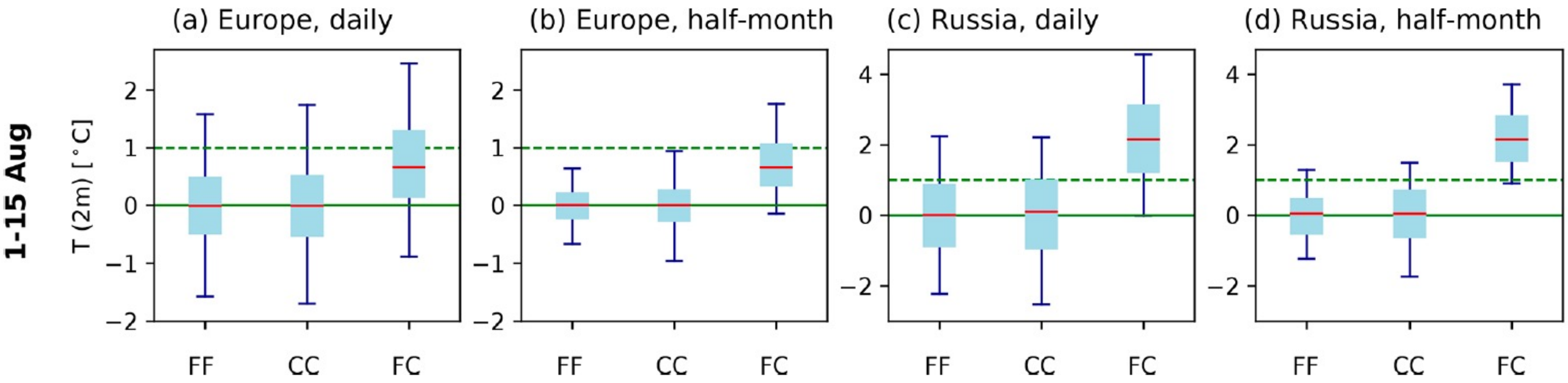


Very high signal-to-noise ratio achieved in both space and time

Could drive an impact model this way

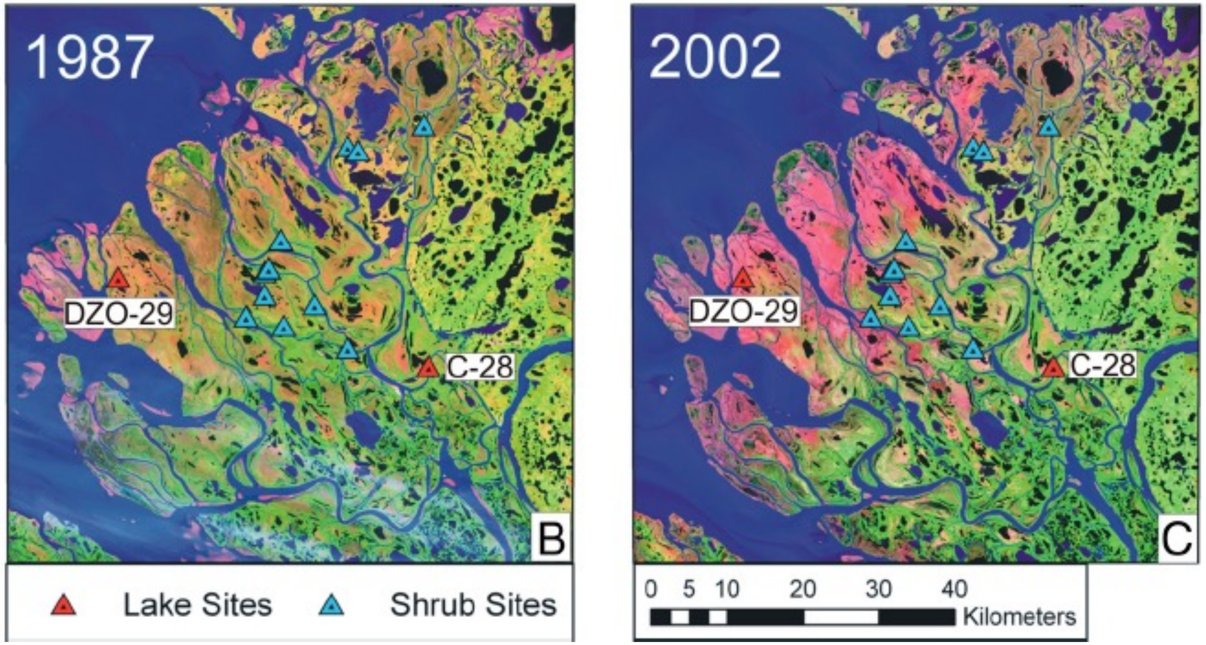
van Garderen, Feser & Shepherd (2021 NHESS)

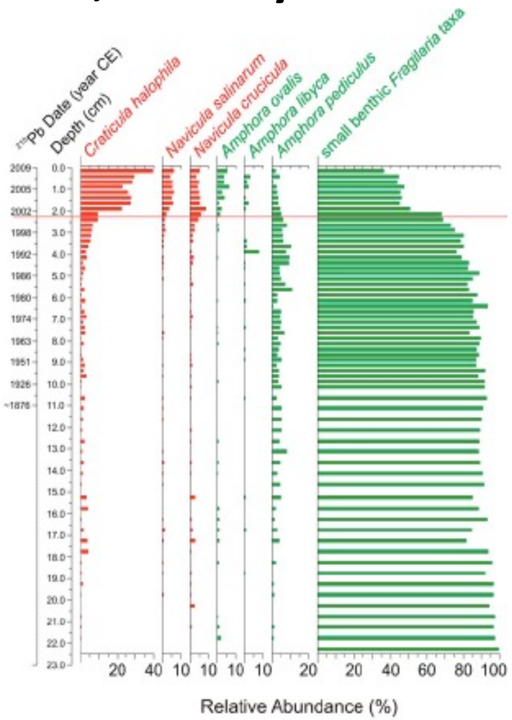
- The use of small ensembles confirms that **the climate-change signal is robust**, and not a statistical artefact (the butterfly effect is controlled by nudging)
  - Robustness can also be addressed by performing past and future counterfactuals
  - Heavy precipitation events are more challenging!
- Information is complementary to the unconditional approach (see Table 2 of this paper)



van Garderen, Feser & Shepherd (2021 NHESS)

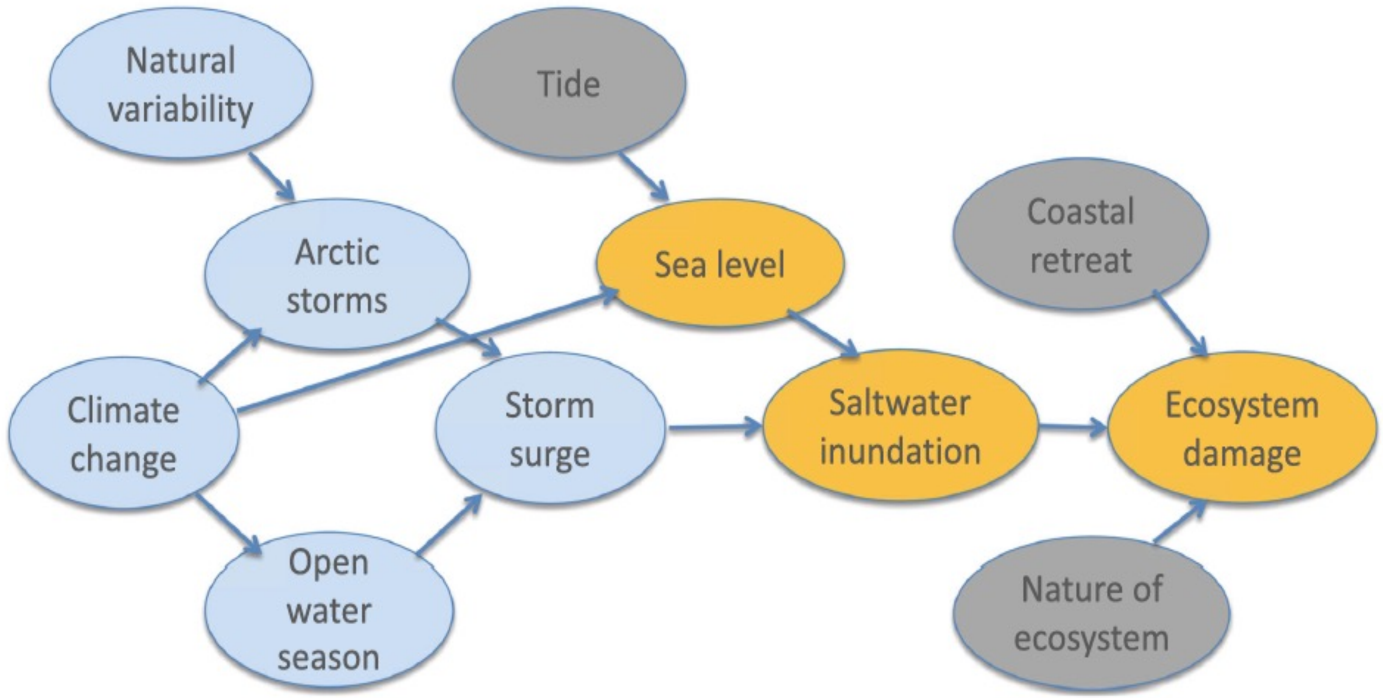
- **Example: Arctic ecosystem collapse**
  - A saltwater storm surge in the Mackenzie Delta (Canadian Arctic coast) in late September of 1999 led to irreversible changes from freshwater (green) to brackish (red) species, unmatched in over 1000 years (right)
  - Such a **singular event** is best described through a **narrative, or storyline**





Pisaric et al. (2011 Proc. Natl. Acad. Sci. USA)

- Pisaric et al. (2011) discuss all the factors below, and conclude that the only essential ones were the longer open-water season from climate change, and the Arctic storm
  - There is no assessment of “statistical significance”, or of likelihood



- The storyline approach aligns well with the forensic approach to attribution in the ecosystem literature
- It also aligns well with liability under tort law (Lloyd & Shepherd 2021 Climatic Change)

Lloyd & Shepherd (2020 Ann. NY Acad. Sci.)

- How can we ensure that storylines are not **"just so stories"**?
- The answer lies in probability theory, and the logic of Bayesian reasoning

"We get no evidence for a hypothesis by merely working out its consequences and showing that they agree with some observations, because it may happen that a wide range of other hypotheses would agree with those observations equally well. To get evidence for it we must also examine its various contradictories and show that they do not fit the observations." (Harold Jeffreys, *Theory of Probability*, 3rd ed., 1961)

- See Shepherd (2021 Climatic Change) for more discussion on this point

- Storylines can be regarded as **scientific hypotheses**
- The consistency of a hypothesis H with the data D can be computed as $P(D|H)$
  - Known as the likelihood function; requires a well-defined hypothesis
  - When H is the null hypothesis, this is the well-known p-value
- But we are actually interested in whether the data supports the hypothesis, $P(H|D)$
- **Bayes' theorem** tells us: $P(H|D) = \frac{P(D|H)}{P(D)} P(H)$
- $P(H)$ reflects the relevance of prior knowledge: "strong claims require strong evidence"
- $P(D)$ requires consideration of **all** possible explanations for the data: if $\neg H$ is the negation (or complement) of H (possibly including several explanations), then

$$P(D) = P(D|H)P(H) + P(D|\neg H)P(\neg H)$$

- As an aside: **nowhere** in any climate science publication have I seen any explicit consideration of these two factors, which strongly affect the inference that can be obtained from a p-value! (see further discussion in Shepherd 2021 Climatic Change)

- It is convenient to work with the '**odds**' form of Bayes' theorem

$$\frac{P(H|D)}{P(\neg H|D)} = \underbrace{\frac{P(D|H)}{P(D|\neg H)}}_{\textbf{Bayes factor}} \times \frac{P(H)}{P(\neg H)}$$

($\neg H$ = negation of H)

- Thus: in order to estimate the probability of a hypothesis being true, it is not enough to consider $P(D|H)$; **we also need a well-defined alternative hypothesis** $\neg H$ whose likelihood function $P(D|\neg H)$ can also be calculated
    - We cannot just 'go fishing' with a vaguely specified alternative hypothesis
    - In particular, **we need to consider all plausible explanations of the data**
    - This is part and parcel of dynamical storylines based on remote drivers (e.g. Zappa & Shepherd 2017 J. Clim.); but how about event storylines?

Use of event storylines in extreme event attribution

- According to Cranor (2005 Law Philos.), there are five steps involved in establishing causality in tort law (paraphrased here, from Lloyd & Shepherd 2021 Climatic Change):
  - First, an observed correlation or association must be shown between exposure to risk (or condition) and bad outcomes. The observed association must have an identified **causal explanation**, for which a responsible party should be held accountable.
  - Second, a **sufficiently complete list of possible explanations (or conditioning properties) for the bad outcomes must be enumerated**.
  - Third, **tests that could help discriminate between the different explanations should be considered or conducted**. It is recognized that in many cases, it is infeasible to perform direct tests.
  - Fourth, **all relevant information must be considered in drawing a conclusion about which explanation is more likely**. What constitutes relevant information for drawing a scientific conclusion is a matter of scientific judgement. One can look to consensus scientific committees for some guidance on this.

– Fifth, **it must be shown that the bad outcome is more probable with the accountable cause than without it** (i.e. the risk ratio is greater than one)

- For event attribution, the risk ratio is the Bayes factor, which factorizes as follows:

$$\frac{P_f(E,C)}{P_c(E,C)} = \frac{P_f(E \mid C)}{P_c(E \mid C)} \times \frac{P_f(C)}{P_c(C)} \quad \text{(NAS 2016)}$$

where *E* is the event, *C* is the atmospheric circulation situation conducive to the event, *f* is factual (with climate change), and *c* is counterfactual (without climate change)

– The first factor is the primary hypothesis (thermodynamic aspects of climate change)

– The second factor represents aspects of climate change not included in the primary hypothesis (specifically, changes in atmospheric circulation)

$$\frac{P_f(E,C)}{P_c(E,C)} = \frac{P_f(E \mid C)}{P_c(E \mid C)} \times \frac{P_f(C)}{P_c(C)}$$

- If the first factor is greater than unity, then in order for climate change to not increase the probability of the event, **one would need to be able to argue that the second factor was strong enough to overcome the first**
  - In general **this would seem to be a difficult case to make**, given the well-known uncertainties surrounding the dynamical response to climate change (Shepherd 2014 Nature Geosci.), and the lack of agreed-upon theories for that response
- In the absence of other knowledge, a Bayesian approach would introduce an uncertainty range in this quantity, which would be a uniform distribution centered about zero change
  - Contrary to some claims, the storyline approach is **not a biased estimator of risk**
  - **The standard of scientific accuracy in the tort law context is much lower ("the preponderance of evidence", i.e., more likely than not) than the usual standard**
- Thus, storyline event attribution is not a 'just so story'

nature

EDITORIAL · 20 MARCH 2019

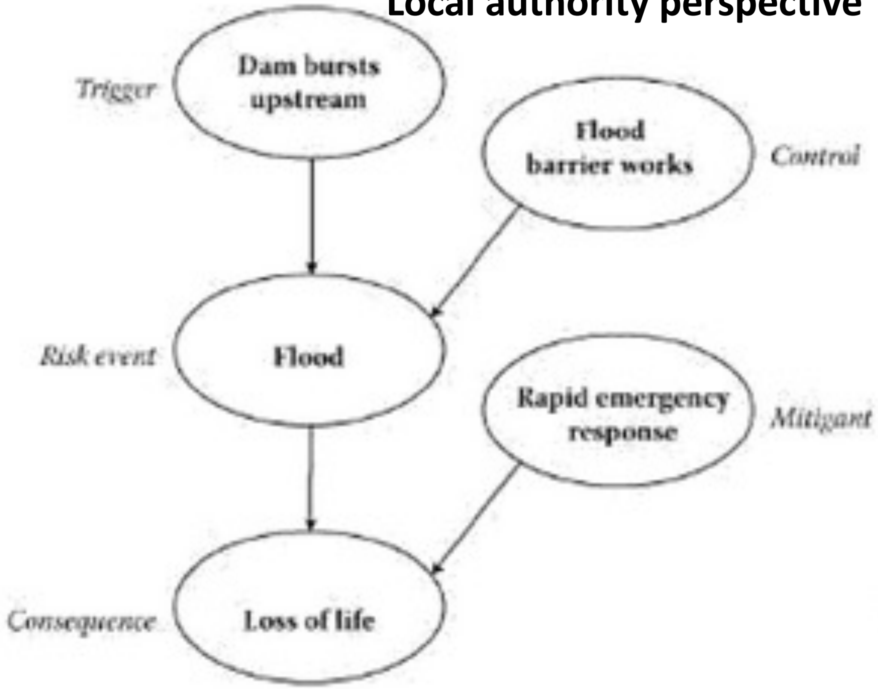
It's time to talk about ditching statistical significance

Looking beyond a much used and abused measure would make science harder, but better.

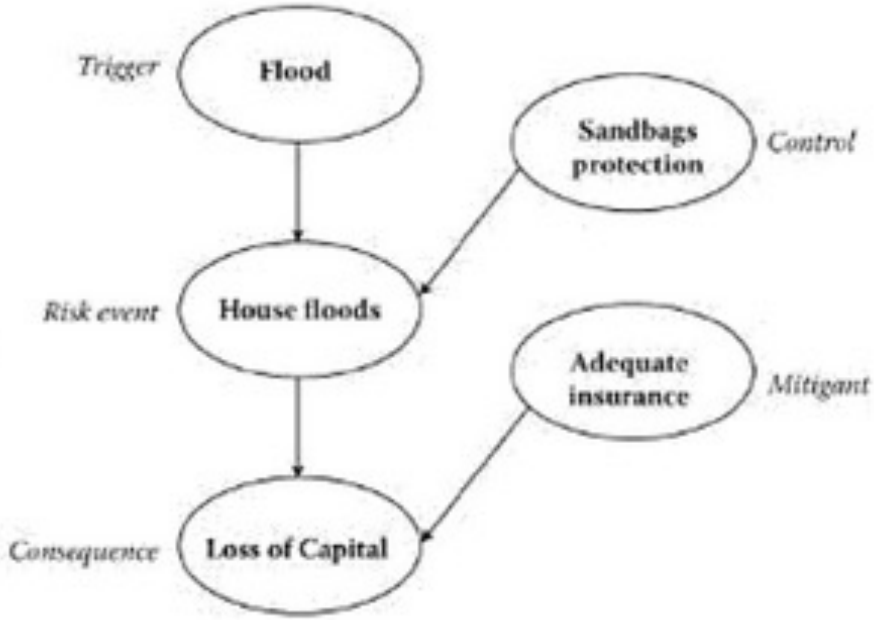
- Properly done, there is far more rigour in narrative/storyline reasoning!

- **Climate impacts are readily embedded within causal networks**, with separate consideration of exposure (via "control") and vulnerability (via "mitigant")
- The same event may represent different storylines, depending on the perspective

Local authority perspective

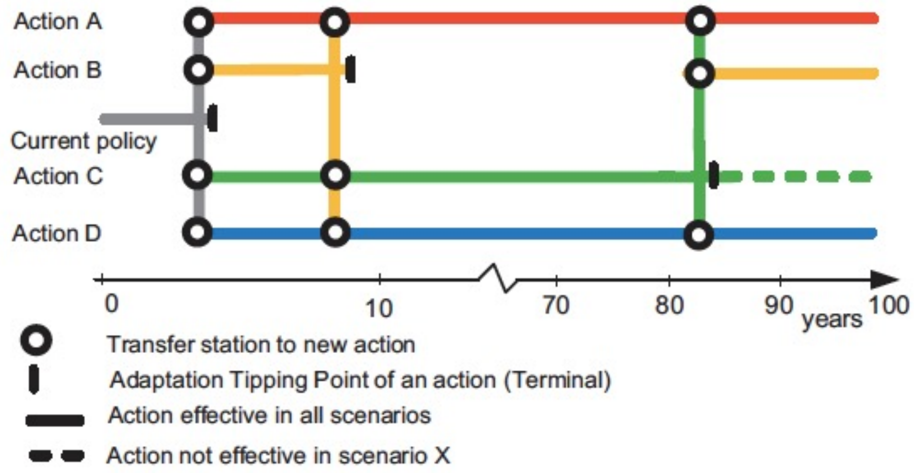


Household perspective



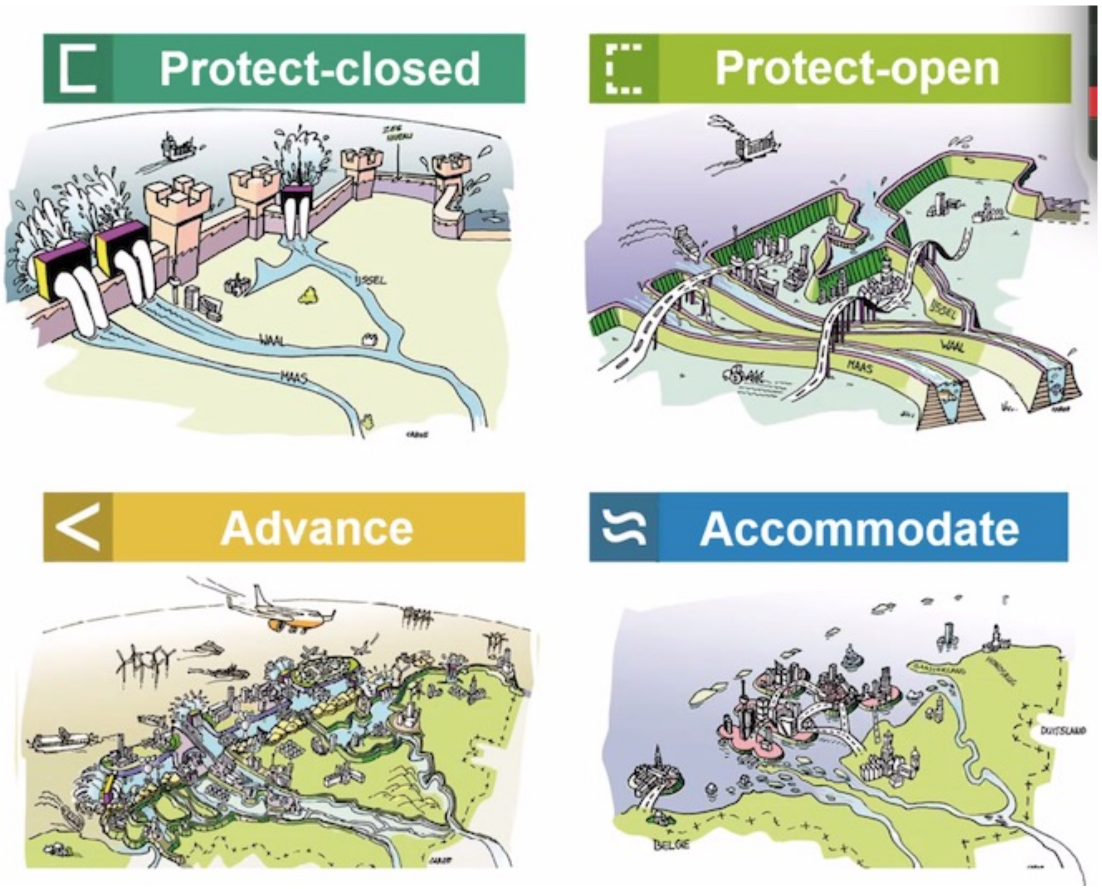
Fenton & Neil, *Risk Assessment and Decision Analysis with Bayesian Networks* (2019)

- The **Dynamic Adaptation Pathways** approach relates future scenarios to policy options, providing guidance on required decision points
- Here, Action B might be a local adaptation measure, C a regional infrastructure measure, and A and D major land use changes



Haasnoot et al. (2013 Glob. Env. Change)

- Imagining the long-term future (here for sea-level rise in Holland) helps map out the various options and their socio-economic implications



Delta Commission report (2019)

(E.F. Schumacher 1973)

Small is Beautiful

- How would climate-change science look if it was structured "as if people mattered"? (Rodrigues & Shepherd 2022 PNAS Nexus) It would involve:
- **Grappling with complexity** of local situations....

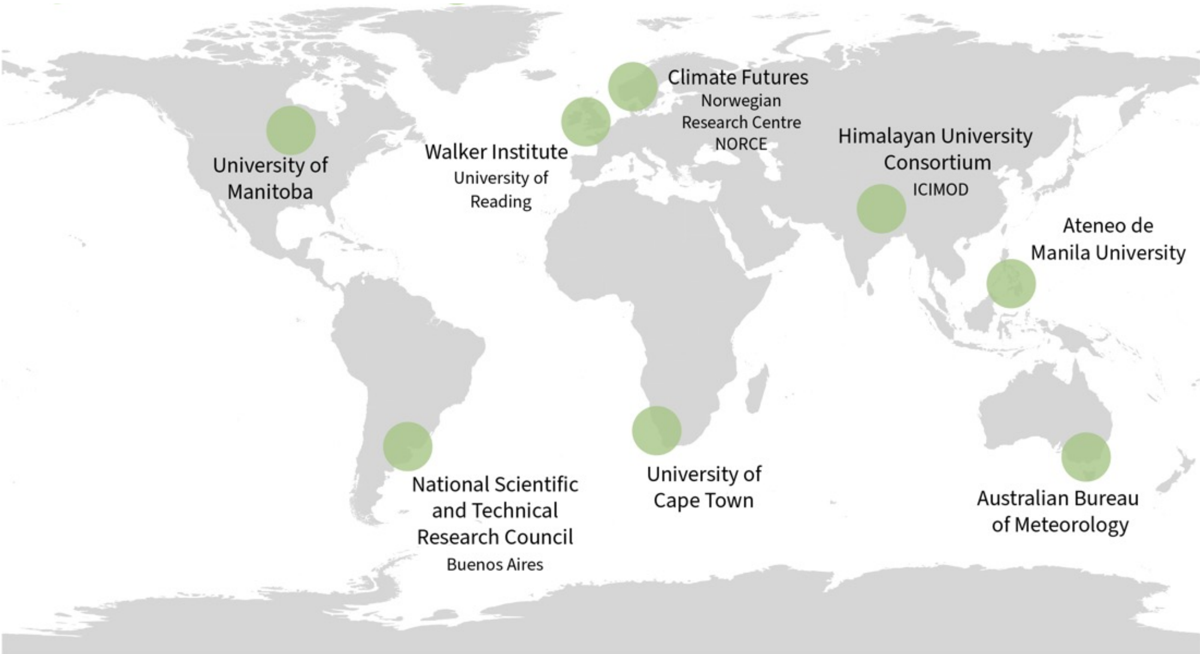
  ....by expressing climate knowledge in a conditional form → *conditional probabilities*
- **The importance of simplicity** when dealing with deep uncertainty....

  ....through the use of *physical climate storylines*
- **Empowering local communities** to make sense of their own situation....

  ....by developing ''intermediate technologies'' that build trust and transparency → *causal networks*

My Climate Risk

Network of regional hubs



Australian Bureau of Meteorology (Melbourne, Australia)	Sugata Narsey
Ateneo de Manila University (Manila, Philippines)	C. Kendra Gotangco Gonzales
Himalayan University Consortium (Kathmandu, Nepal)	Chi Huyen Truong (Shachi)
Climate Futures, NORCE (Bergen, Norway)	Erik Kolstad
National Scientific and Technical Research Council/CONICET (Buenos Aires, Argentina)	Anna Sörensson
University of Cape Town (Cape Town, South Africa)	Chris Jack
University of Manitoba (Winnipeg, Canada)	Julienne Stroeve Jennifer Lukovich
Walker Institute, University of Reading (Reading, UK)	Ros Cornforth

Concluding Remarks

- To address adaptation challenges, we need to navigate the **'cascade of uncertainty'** in climate projections, and connect to the decision space
  - The **societally relevant question** is not "What will happen?" but rather "What is the impact of particular actions under an uncertain regional climate change?"
- We need to find a scientific language for describing the **'plural, conditional'** state of knowledge that exists at regional and local scales, and **resist aggregation**
  - The **storyline approach** to regional climate information does exactly this (see Shepherd 2019 Proc. Roy. Soc. A)
- Linking to historical events, in their proper context, brings a **salience to the risk**; well understood psychologically
  - Storylines also provide a **built-in (not contrived) narrative**, hence an emotional element, which is essential for decision-making (Damasio 1994; Davies 2018)
- We need to explore storylines of climate risk, combining the best information from all sources — **interpreted not as a prediction but as representing plausible futures**