

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



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## 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
- 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.



Yeah...I  
can't go

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



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nature

# It's time to talk about ditching statistical significance

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

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- 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

JUDEA PEARL  
WINNER OF THE TURING AWARD  
AND DANA MACKENZIE

# THE BOOK OF WHY



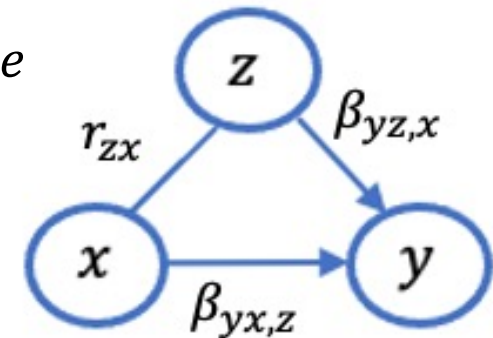
THE NEW SCIENCE  
OF CAUSE AND EFFECT

- **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  $z$

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

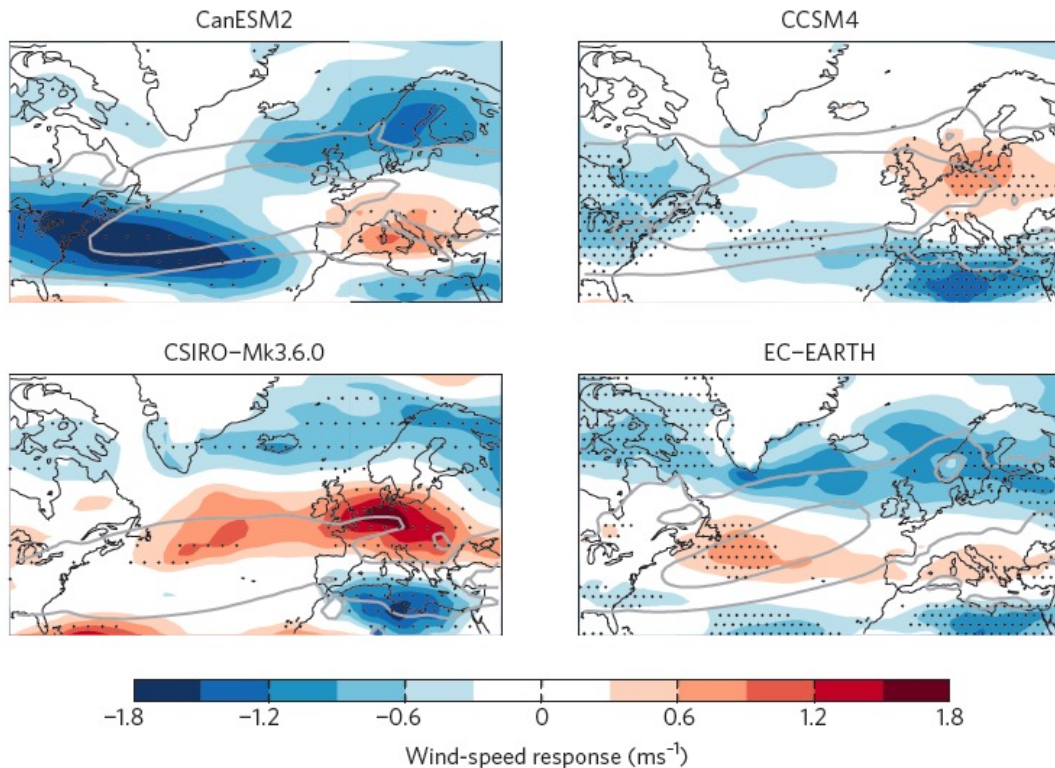
$$\Rightarrow r_{yx} = \underbrace{\beta_{yx,z}}_{\text{Direct}} + \underbrace{\beta_{yz,x}r_{zx}}_{\text{Indirect}}$$

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



Kretschmer et al.  
(BAMS, in press)

- *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!



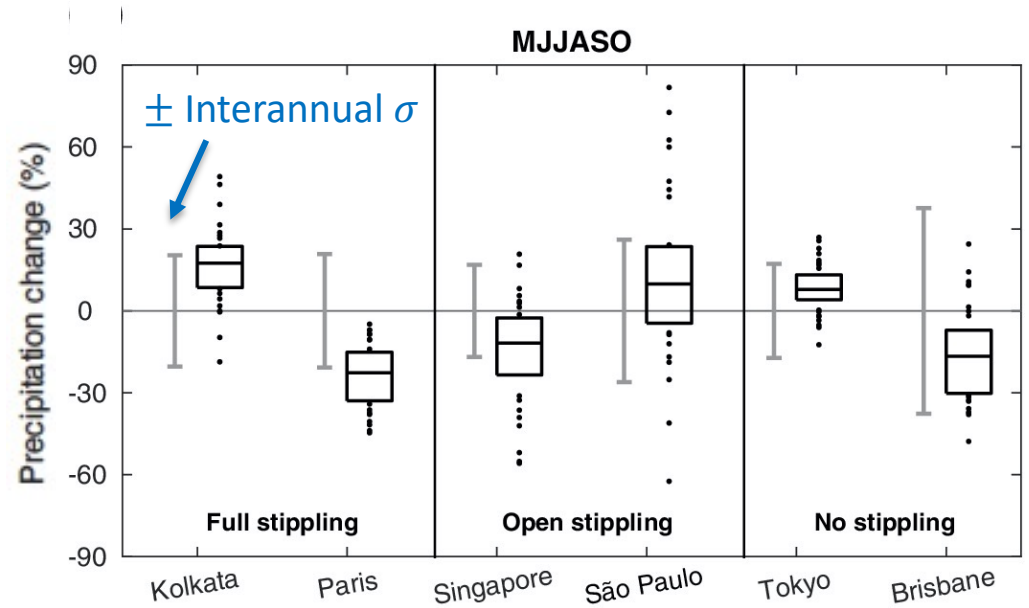
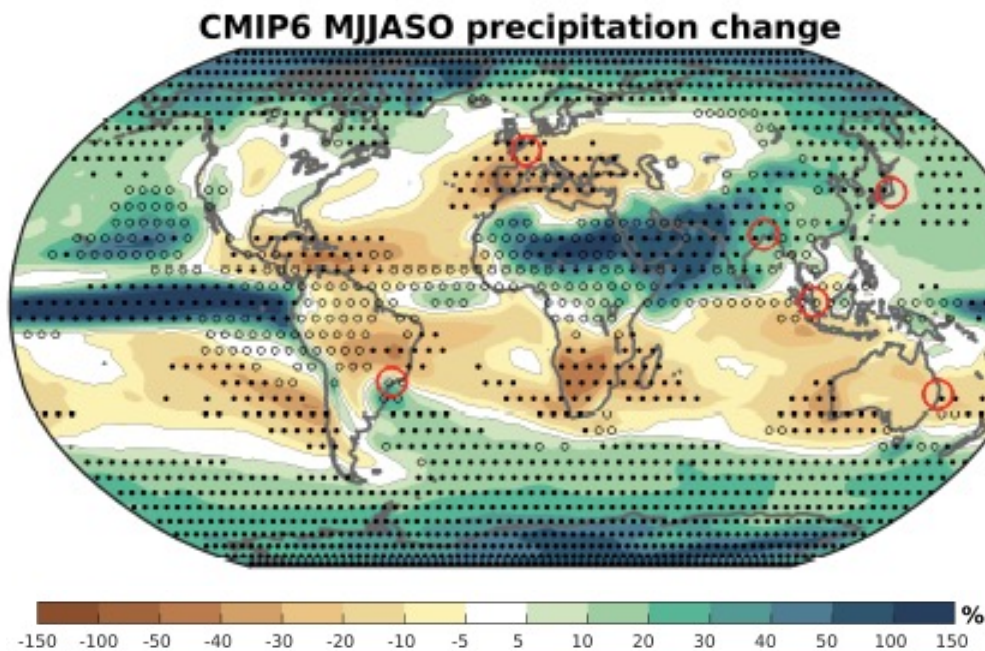
Wintertime lower tropospheric zonal wind speed climatology (contours) and end-of-century response to RCP 8.5 (shading)

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 (and are we really sure about South Asia?)

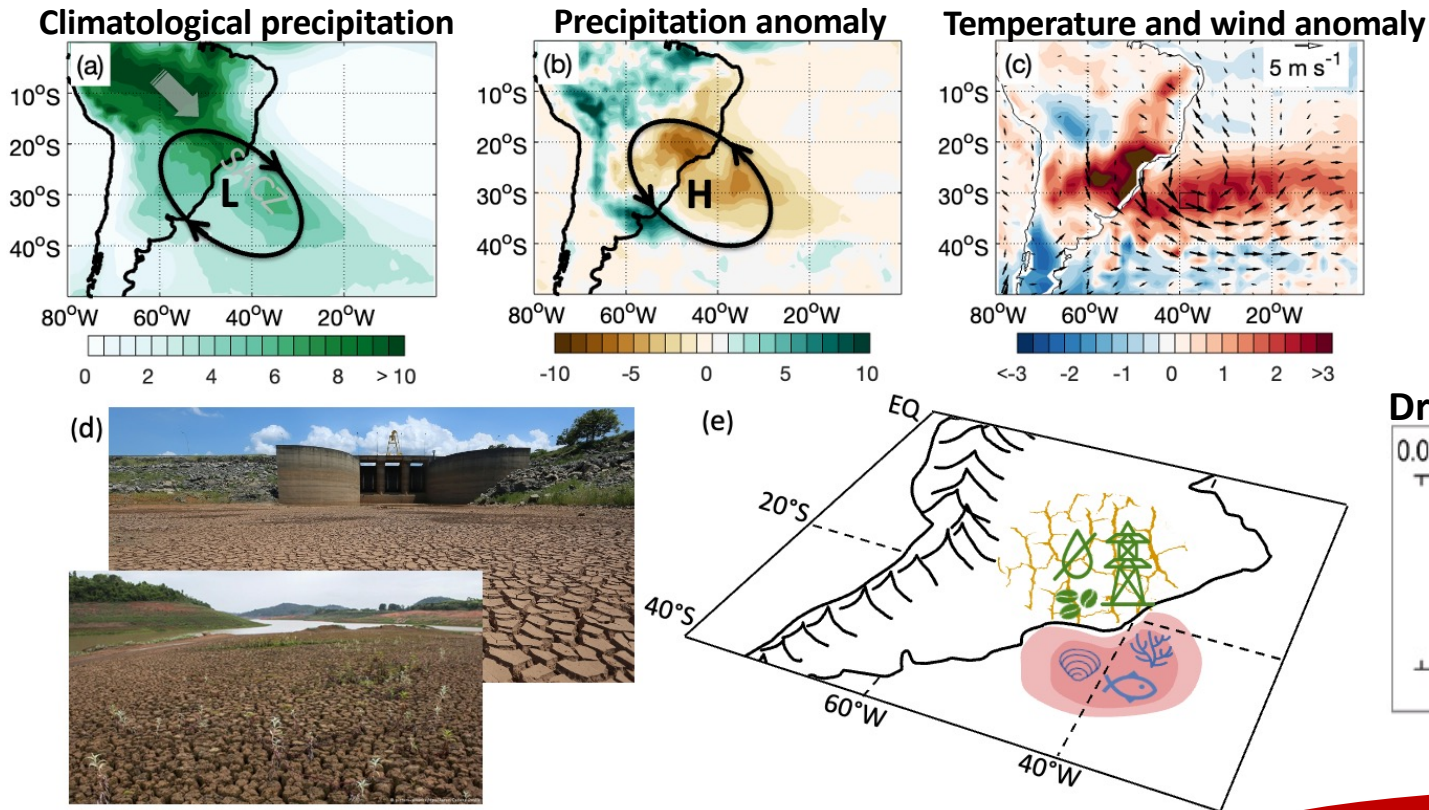
Changes over 21<sup>st</sup> century under RCP8.5



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

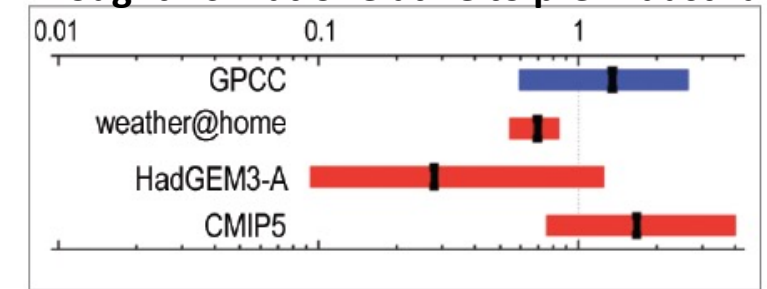
## Example: a compound extreme event in southeast Brazil

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



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

### Drought risk ratio relative to pre-industrial



Martins et al. (2017 BAMS)

Rodrigues & Shepherd (submitted)

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



Wilby & Dessai (2010 Weather)

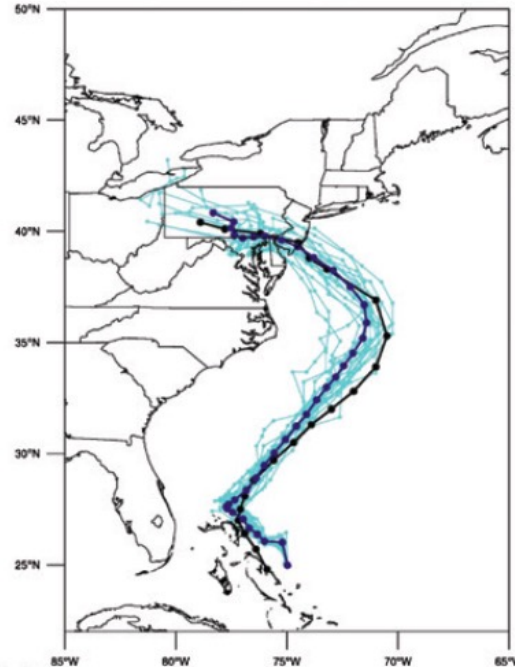
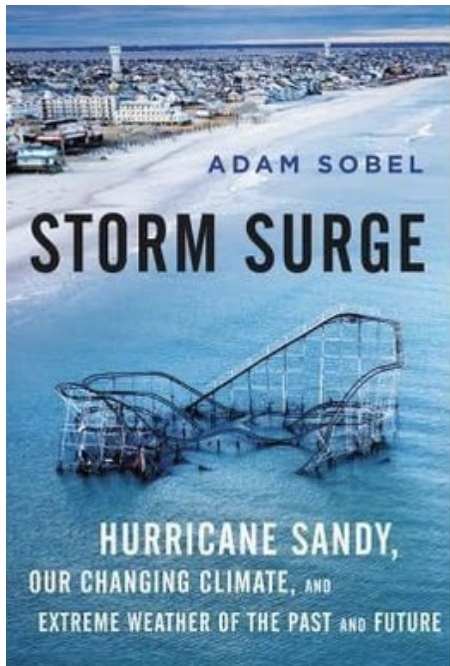
- Even when aggregation is reliable, **it is not informative about individual cases**
  - A famous example (Bortkiewicz 1898)



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



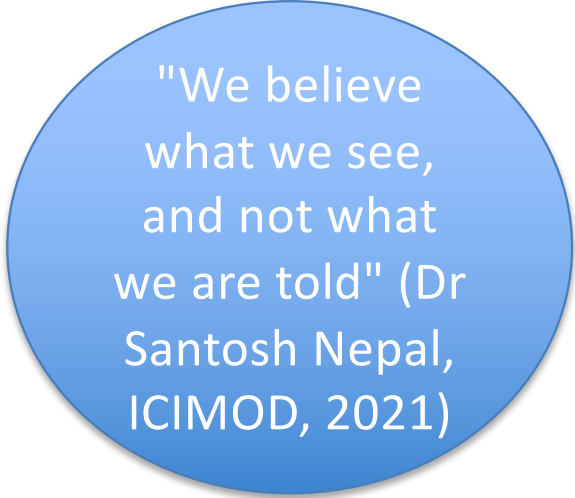
- **Hurricane Sandy (2012)** was unusual in its rapid westward steering and its merger with an extratropical storm, **both the result of a strongly deformed jet stream**
  - US weather forecasters didn't even have a protocol for handling such an event
  - It seems almost meaningless to ask if such a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



"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**

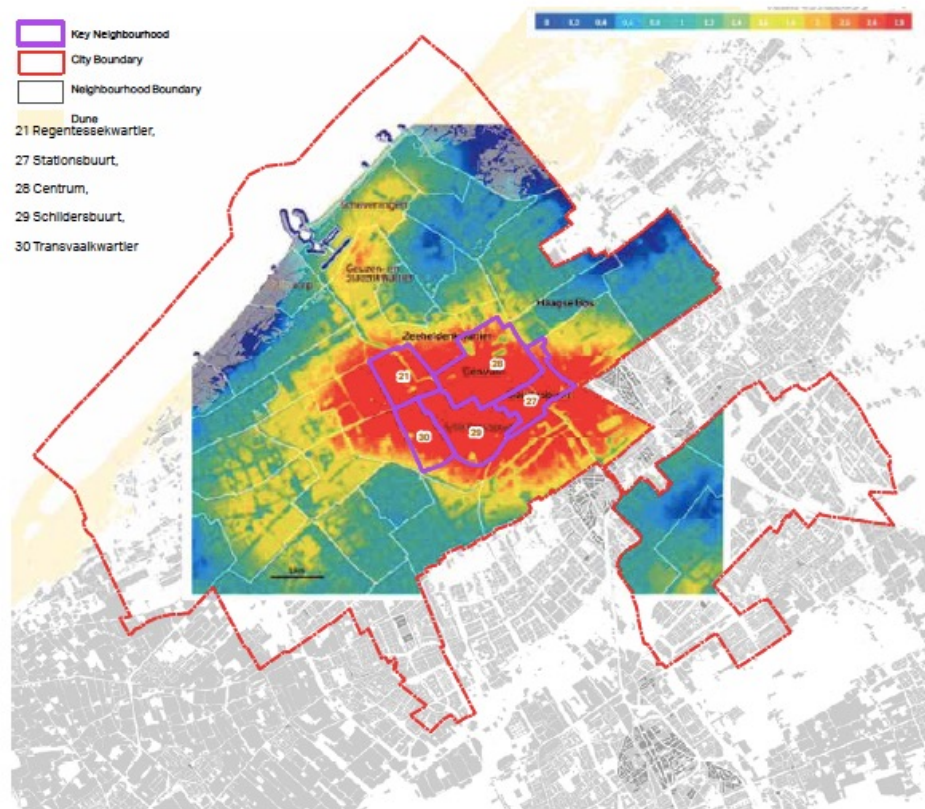


Figure 2-8: The urban heat island effect in The Hague – increased heat will affect more vulnerable neighbourhoods in The Hague

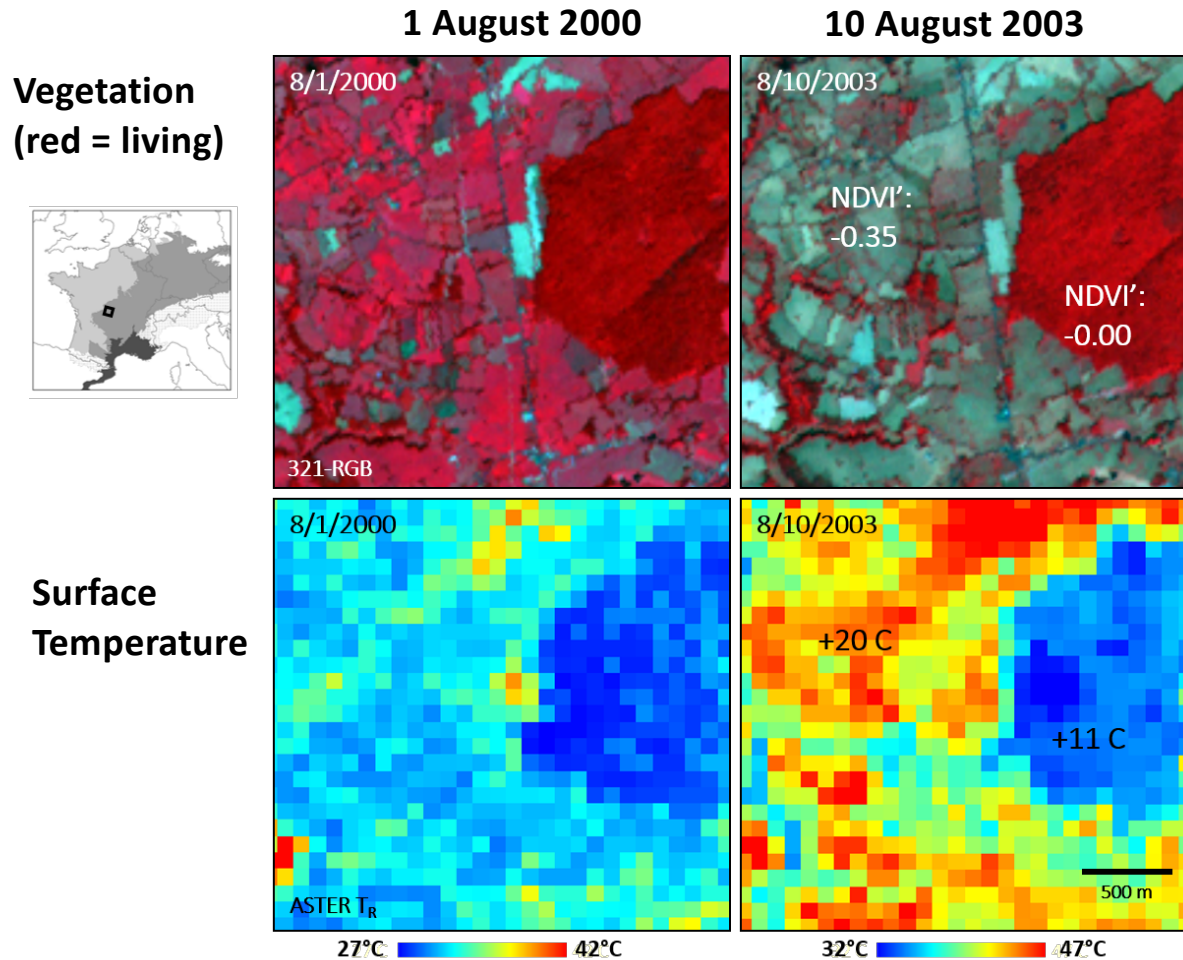
Urban heat island effect in The Hague, based on a recent heat wave

Not surprisingly, the poor neighbourhoods were disproportionately affected

From The Hague Resilience Assessment (January 2018)



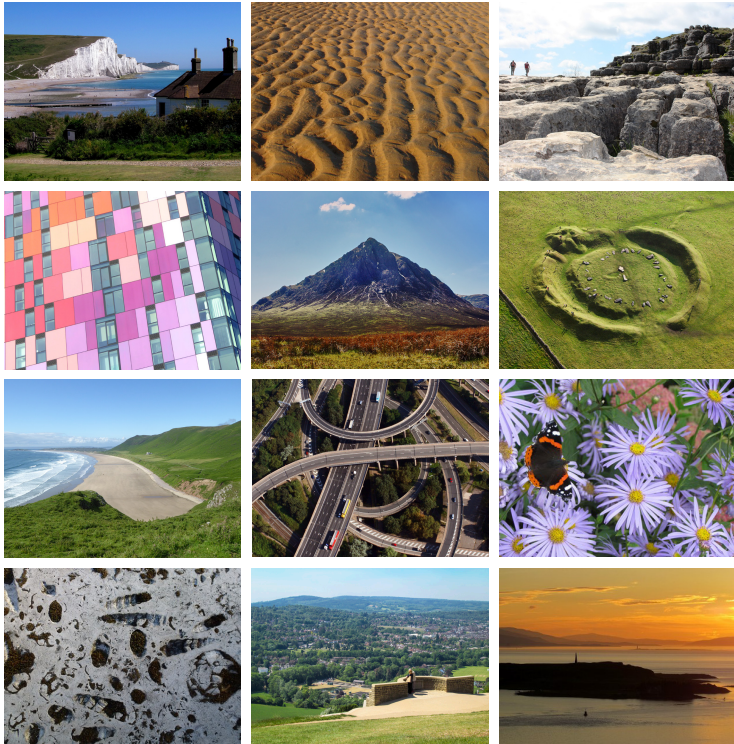
- **We actually have a huge amount of climate information, even at the local scale,** from both observations and modelling — it's just that the information is **conditional**



- 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.)

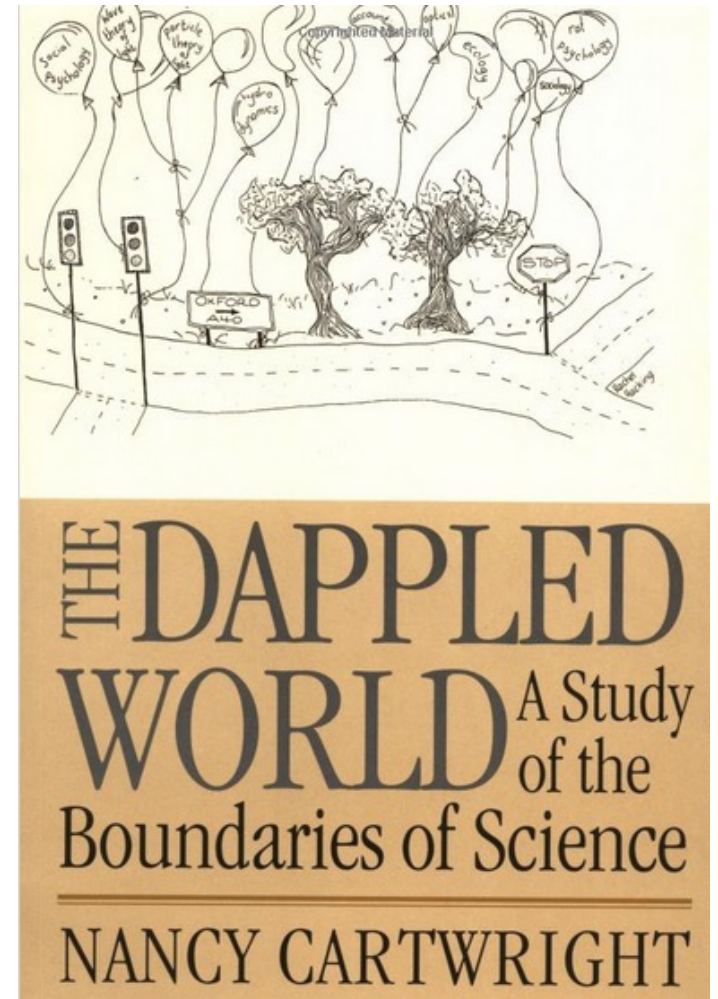
## EVERY LANDSCAPE HAS A STORY TO TELL



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

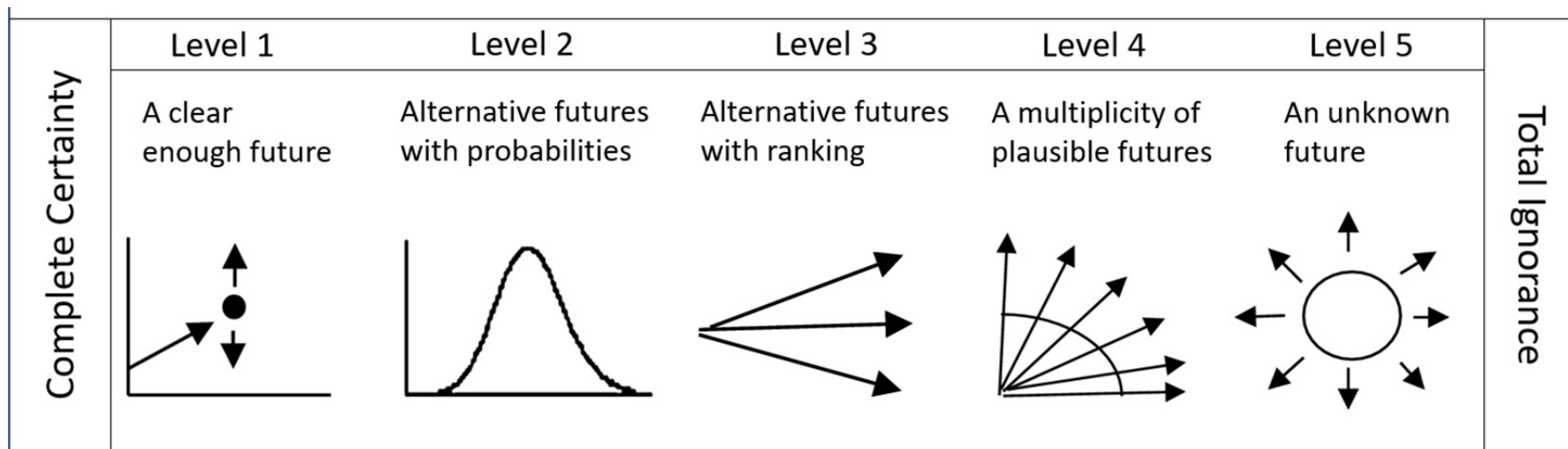
[www.discoveringbritain.org](http://www.discoveringbritain.org)

- 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)

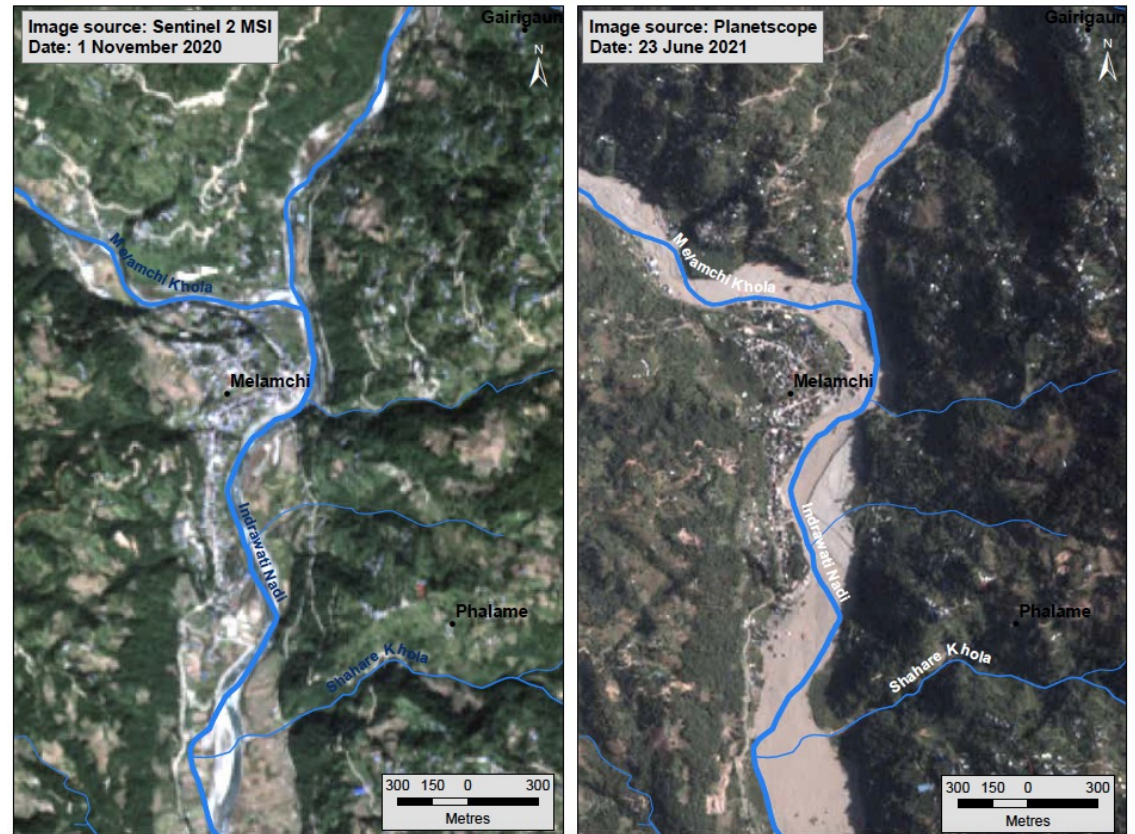


## Narrative in science

“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)

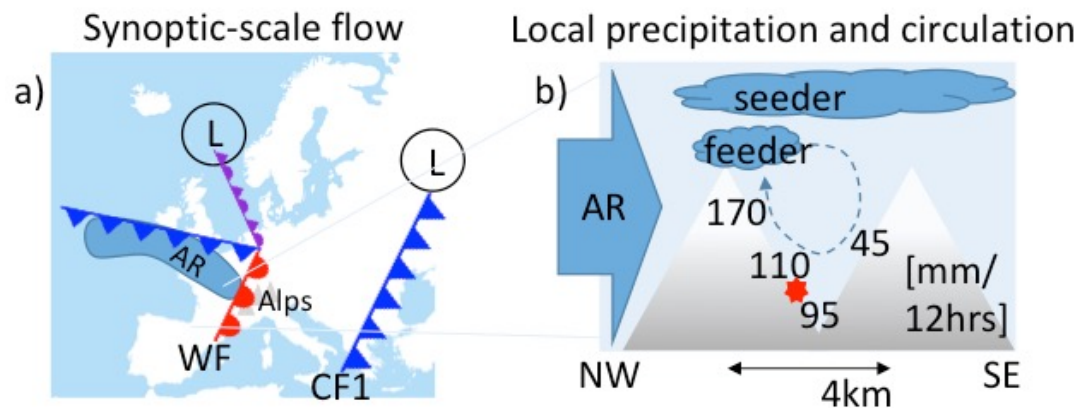
- So why not climate scientists too? (see Shepherd & Lloyd 2021 Climatic Change)



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

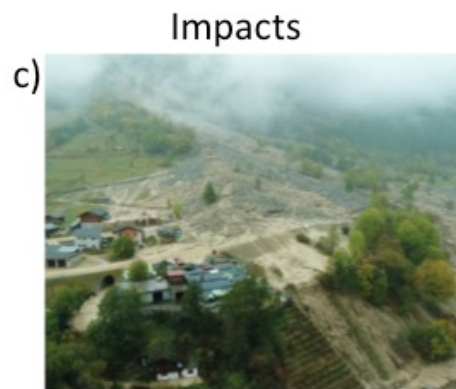
- **Storylines:** physically-based unfoldings of past climate or weather events, or of plausible future events or pathways (Shepherd et al. 2018 Climatic Change)
  - Definition now incorporated in IPCC Glossary (see also Box 10.2 of AR6 WGI report)
  - An **unforecasted rain-on-snow event in the Swiss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

Providing a physical basis for partitioning uncertainty



Exploring the boundaries of plausibility

Improving risk awareness

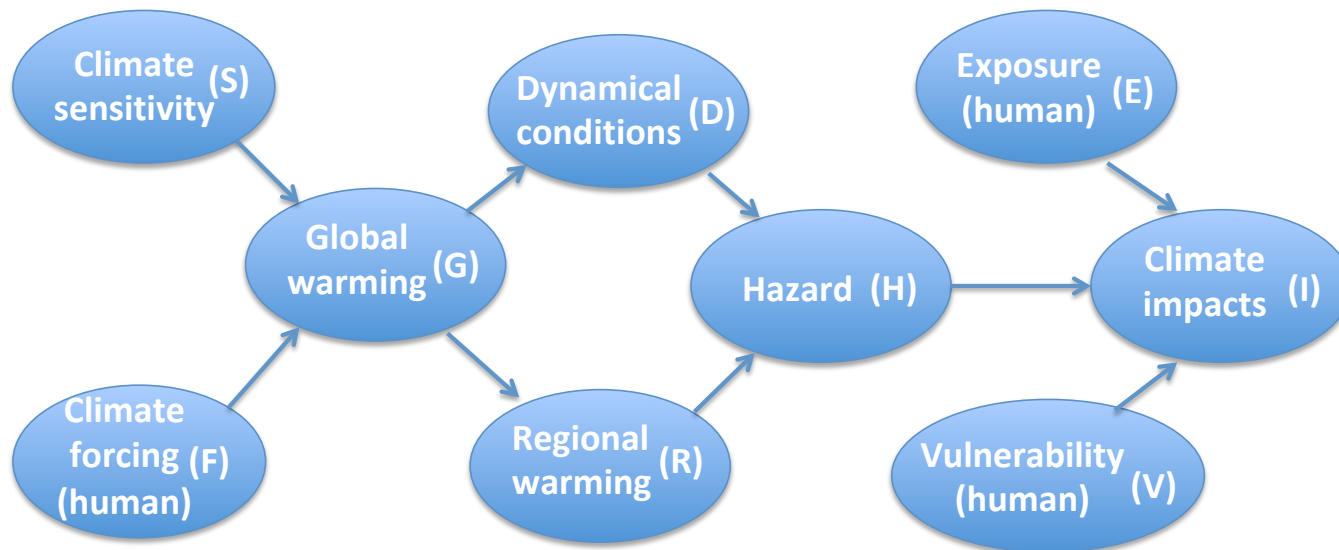


Strengthening decision-making

Shepherd et al. (2018 Climatic Change)



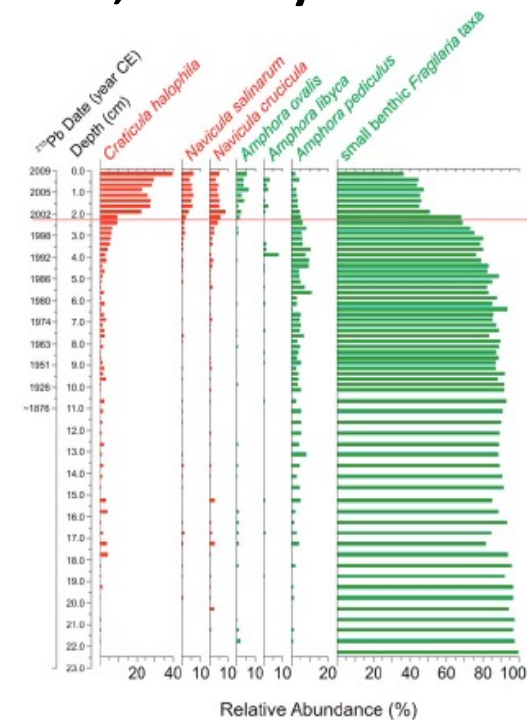
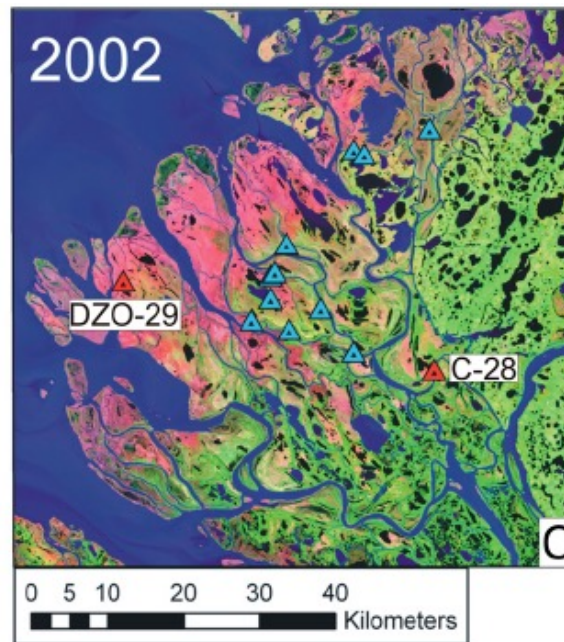
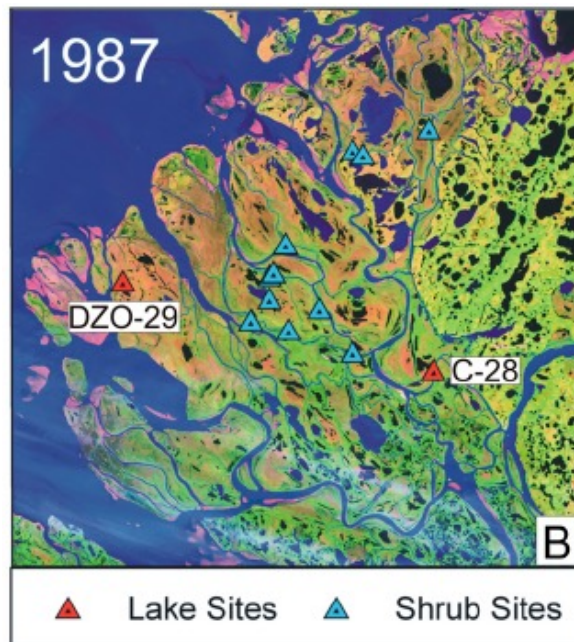
- **Storylines** are a way of navigating the cascade of uncertainty
  - **Causal networks** provide a means for representing **conditional** information
  - Storylines can be seen as **instantiations** of a causal network, by conditioning on one or more nodes: e.g. global warming levels and dynamical 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)

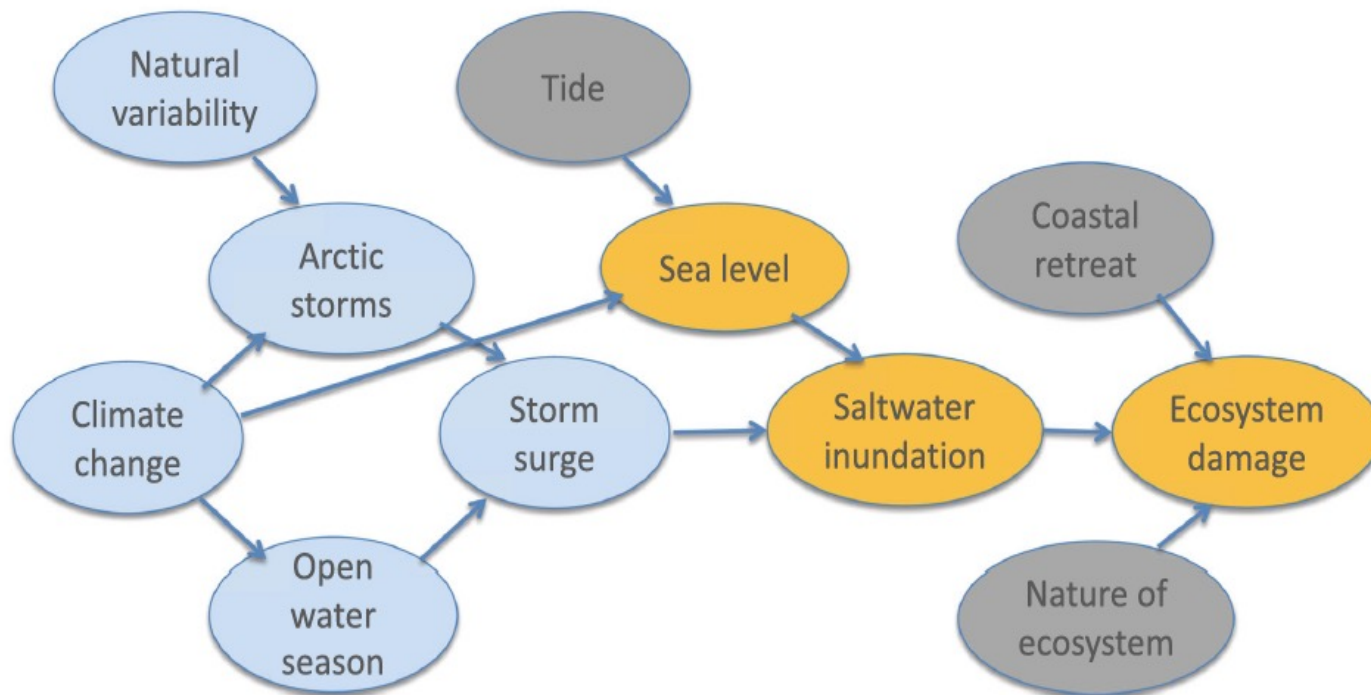
- **Example: Arctic ecosystem collapse**

- 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

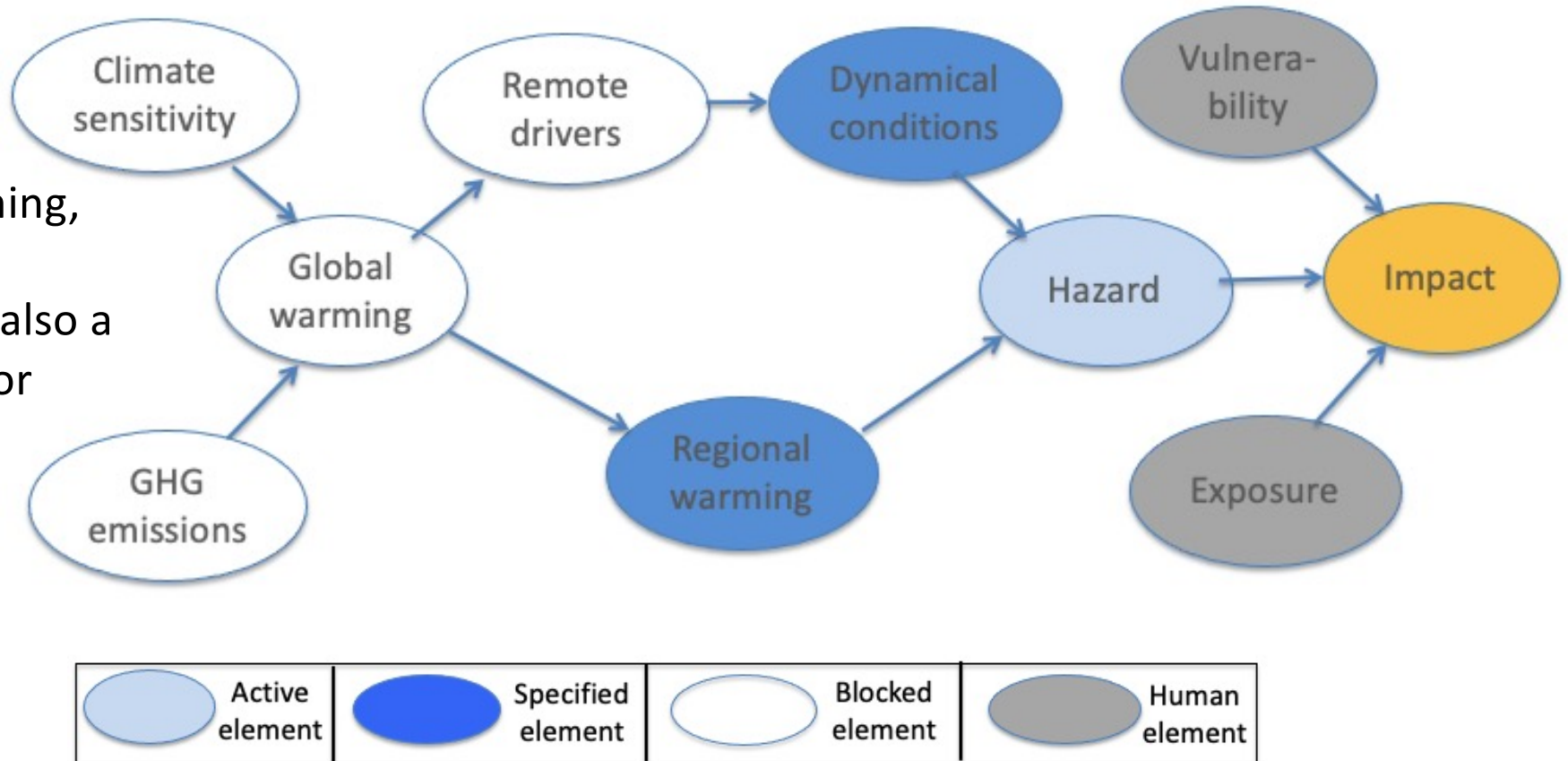
"We get no evidence for a hypothesis by merely working out its consequences and showing that they agree with some observations, because it may happen that a wide range of other hypotheses would agree with those observations equally well. To get evidence for it we must also examine its various contradictories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

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



## An event storyline

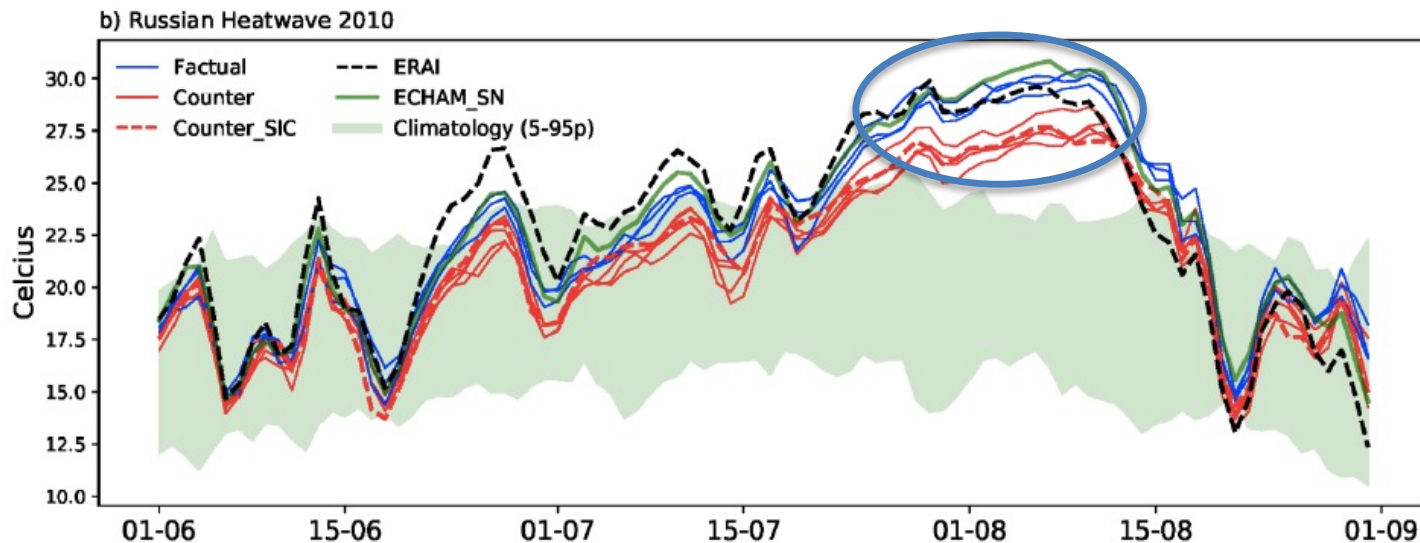
In this framing, the human element is also a causal factor (decision context)



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)
- Allows use of weather-resolving atmospheric models; physically self-consistent
  - Here the dynamical conditions are imposed through global spectral nudging

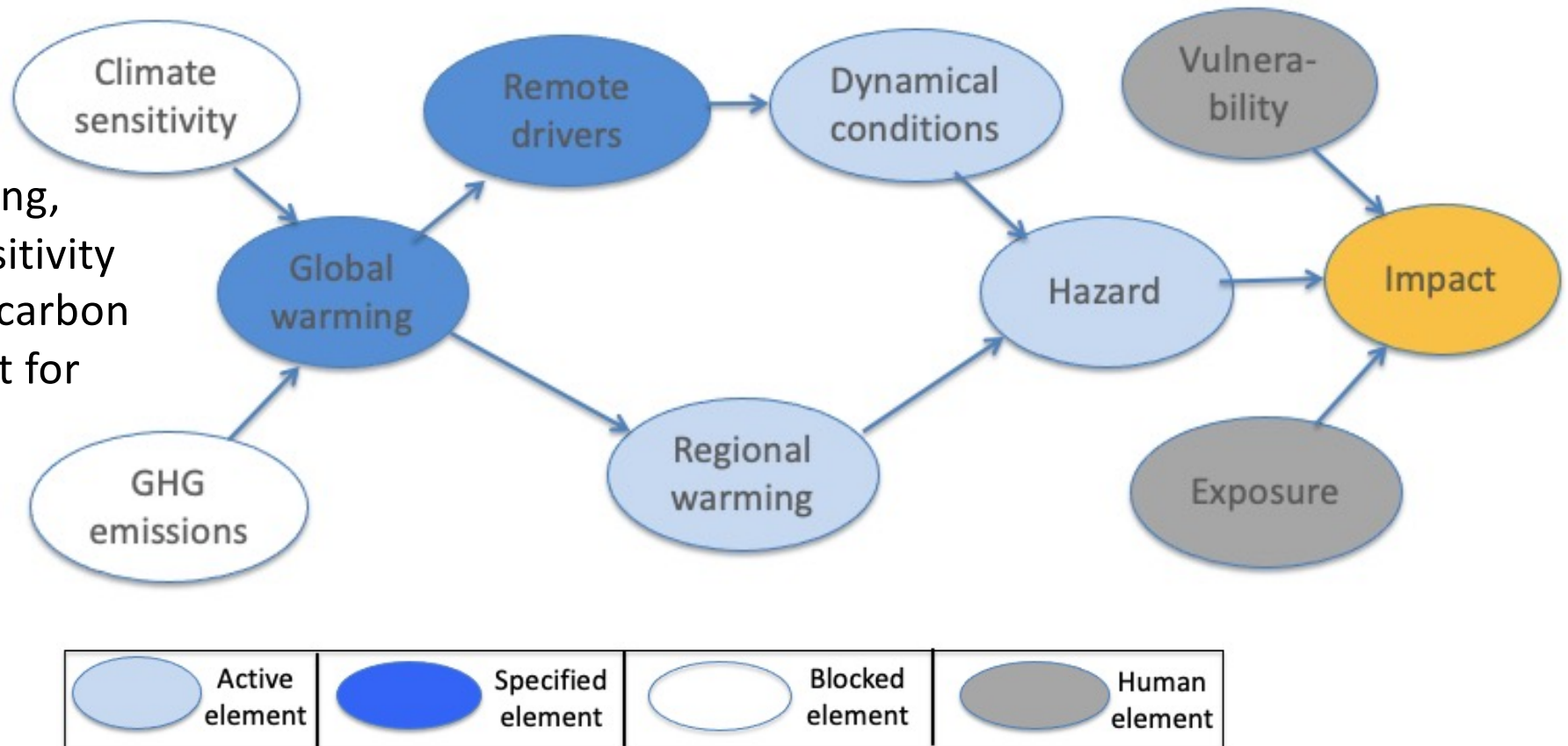


Very high signal-to-noise ratio achieved in both space and time

van Garderen, Feser & Shepherd (2021 NHESS)

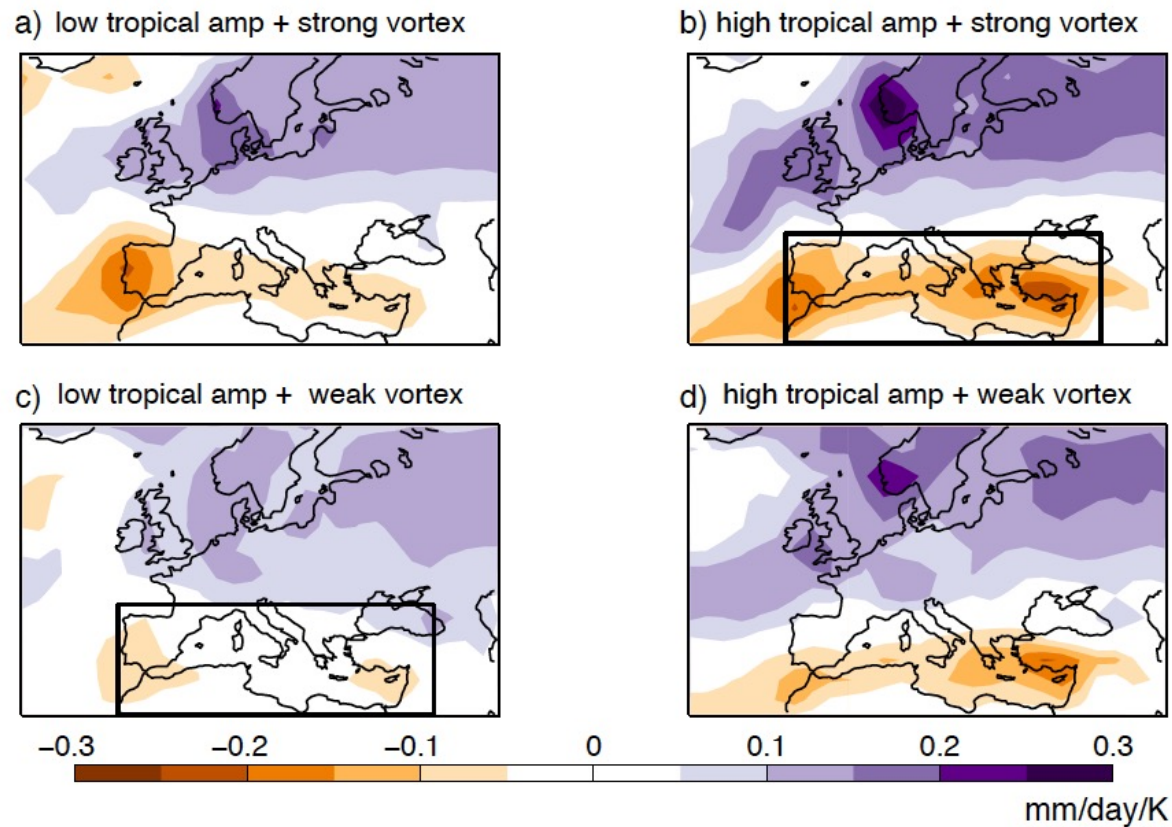
## A dynamical (circulation drivers) storyline of regional climate change

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

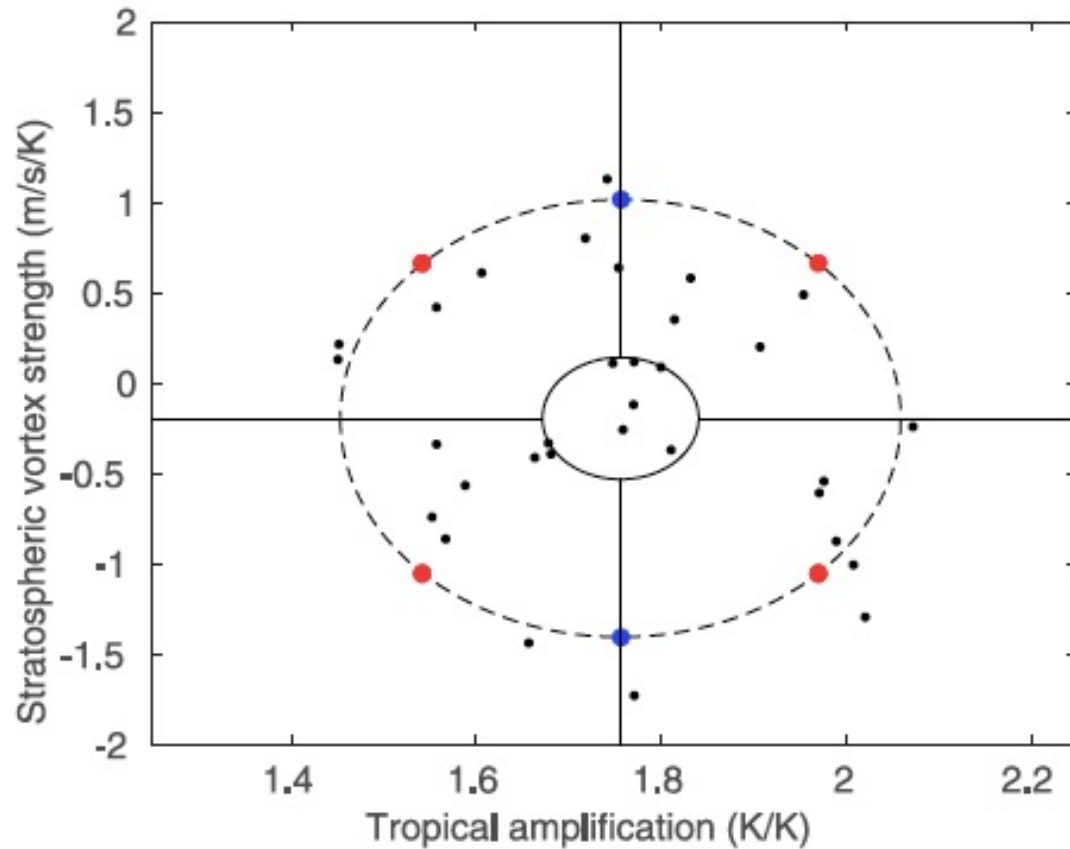
- **Example of dynamical storylines: four storylines of future cold-season Mediterranean drying (a major climate vulnerability for southern Europe)**
  - So far as we know, any one of these could be true



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.)



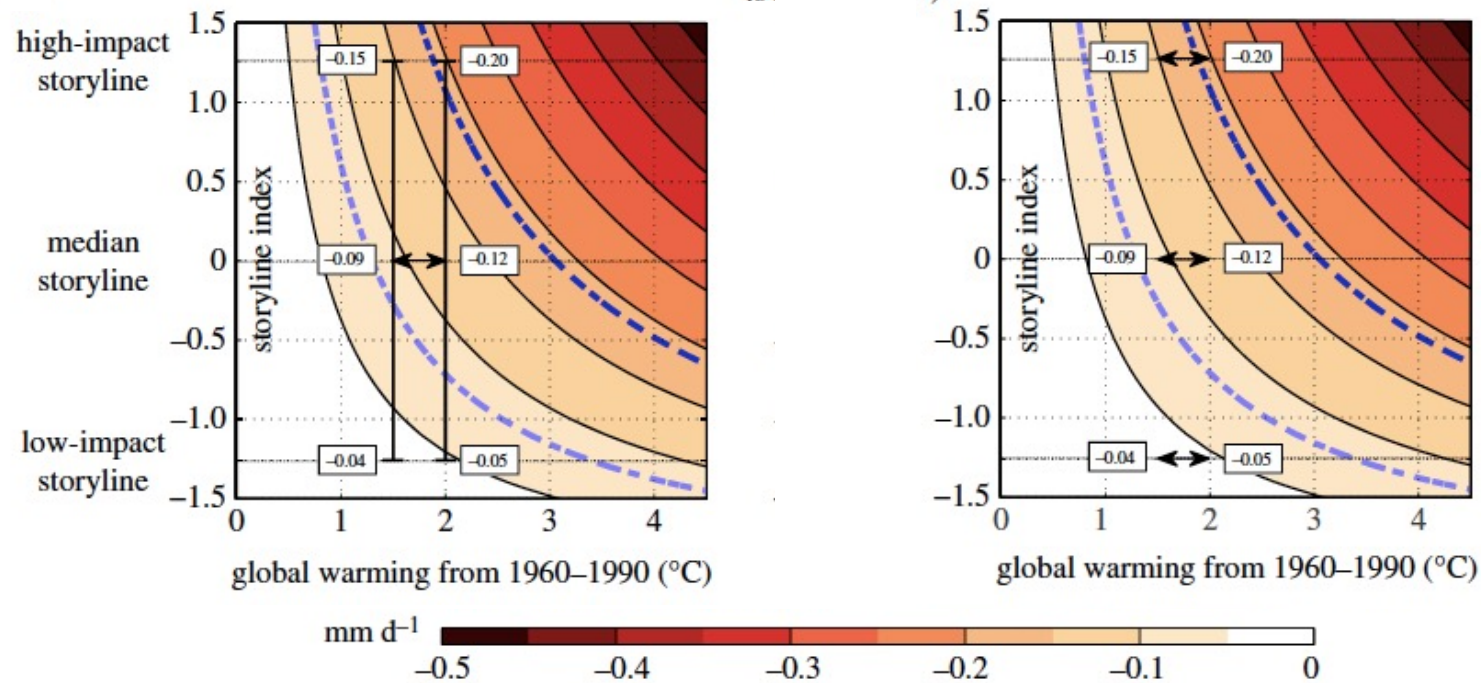
## Sensitivity of cold-season Mediterranean drying to global warming level

*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:*

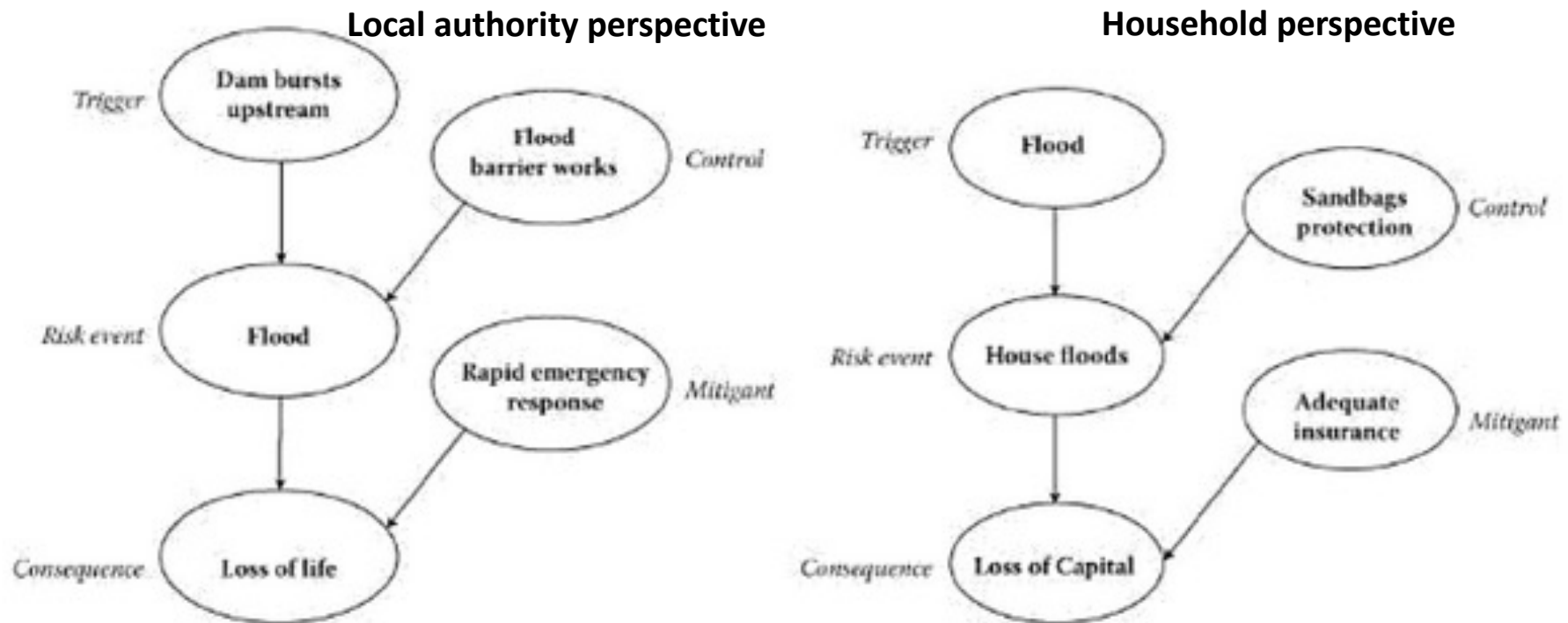
- 0.15 vs 0.20 mm/day for high-impact storyline
- 0.03 vs 0.05 mm/day for low-impact storyline
- Distinguishable for any storyline



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

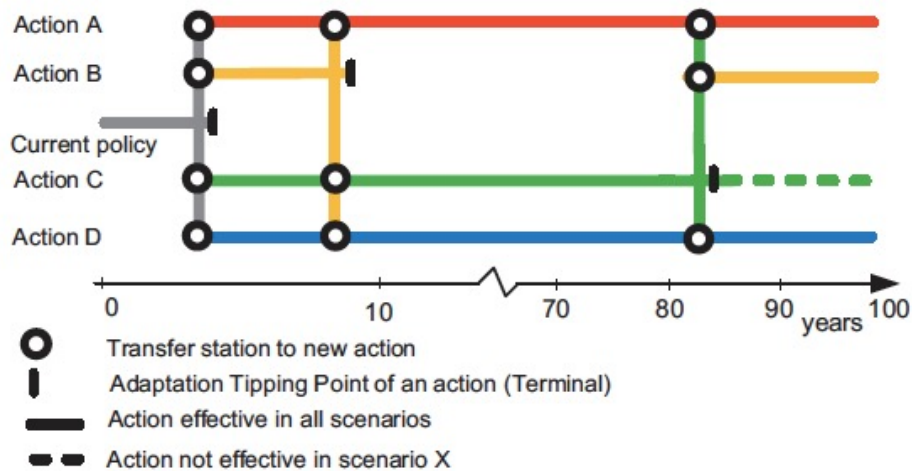
Zappa & Shepherd (2017 J. Clim.)

- **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



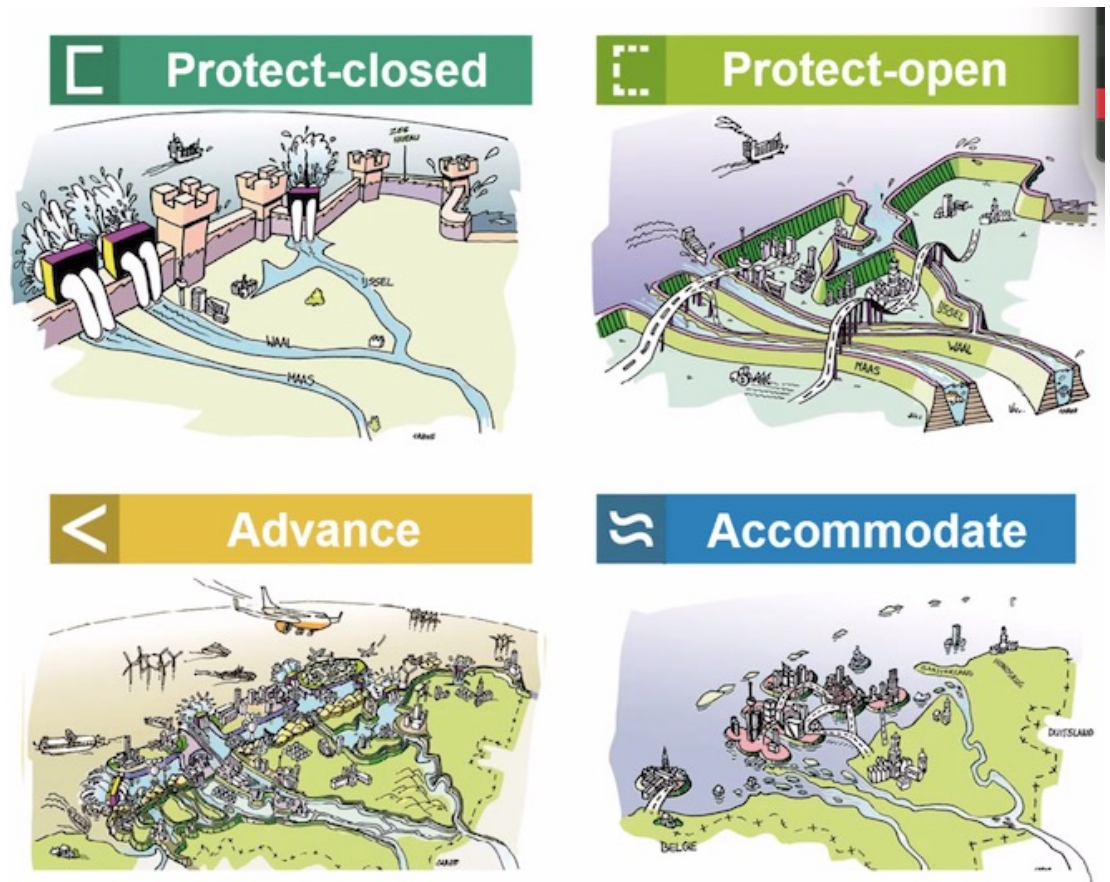
Fenton & Neil, *Risk Assessment and Decision Analysis with Bayesian Networks* (2019)

- 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)

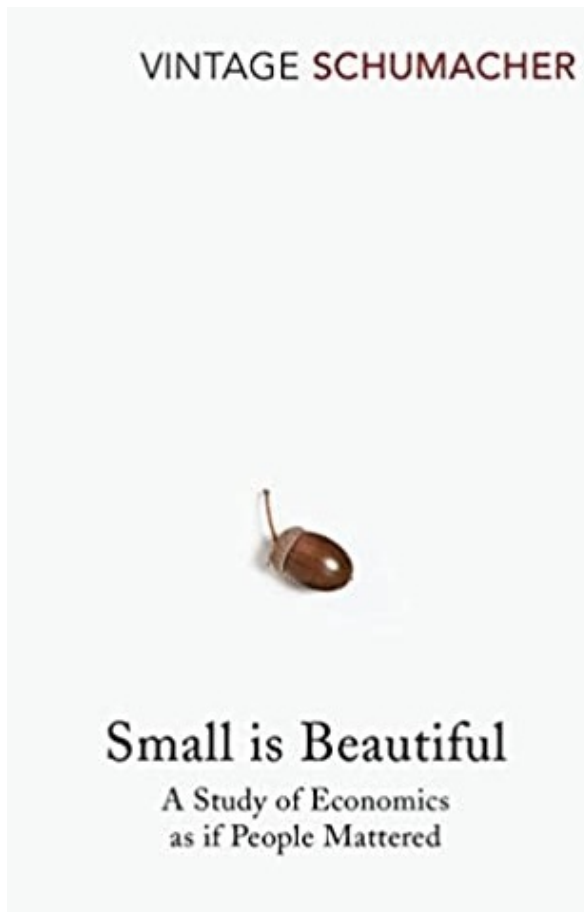
- Imagining the long-term future (here for sea-level rise in Holland) helps map out the various options and their socio-economic implications



Delta Commission report (2019)

## Inverting the construction of climate information

- “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)
- The challenge is to make it intelligible, and keep it simple:
  - “When a thing is intelligible you have a sense of participation; when a thing is unintelligible you have a sense of estrangement”
  - “It is rather more difficult to recapture directness and simplicity than to advance in the direction of ever more sophistication and complexity”



See further discussion in Rodrigues & Shepherd (submitted)



## 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**