CAUSAL PREDICTION AND ATTRIBUTION OF EXTREME WEATHER EVENTS

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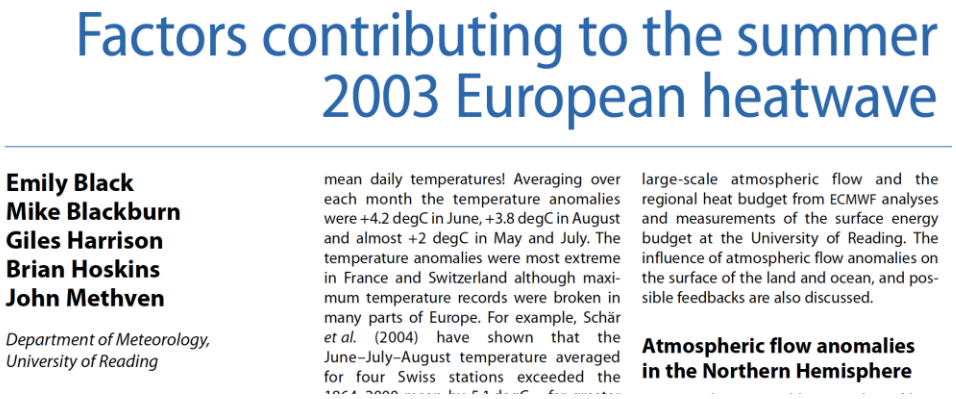
A study in contrasts

- Black et al. (2004) explored in detail the various causal factors behind the 2003 European heatwave: persistent anticylone, SST anomalies, drying of land surface, surface fluxes....
  - "*It is not known at this time why the large-scale circulation had the character it did*."
- Stott et al. (2004) ignored all those factors and targeted a much weaker, coarse-grained 'event' of only 1.6°C above the mean, to avoid 'selection bias'
- Black et al. is certainly highly cited, but Stott et al. has become the dominant paradigm



Factors contributing to the summer 2003 European heatwave

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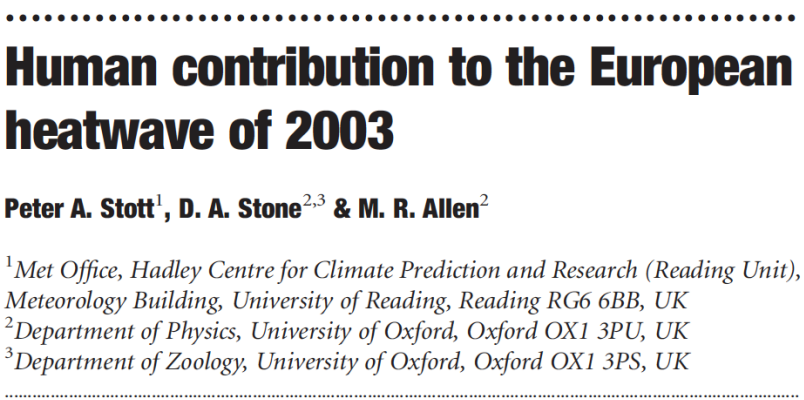
mean daily temperatures! Averaging over each month the temperature anomalies were +4.2 degC in June, +3.8 degC in August and almost +2 degC in May and July. The temperature anomalies were most extreme in France and Switzerland although maximum temperature records were broken in many parts of Europe. For example, Schär *et al.* (2004) have shown that the June–July–August temperature averaged for four Swiss stations exceeded the

large-scale atmospheric flow and the regional heat budget from ECMWF analyses and measurements of the surface energy budget at the University of Reading. The influence of atmospheric flow anomalies on the surface of the land and ocean, and possible feedbacks are also discussed.

Atmospheric flow anomalies in the Northern Hemisphere

Weather (2004)



Human contribution to the European heatwave of 2003

Peter A. Stott[1], D. A. Stone[2,3] & M. R. Allen[2]

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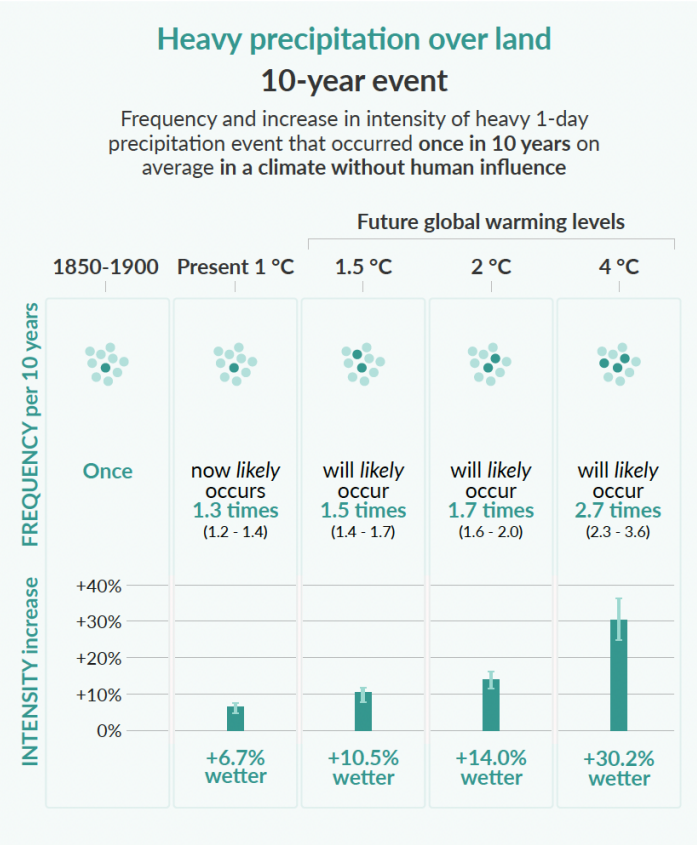
Nature (2004)

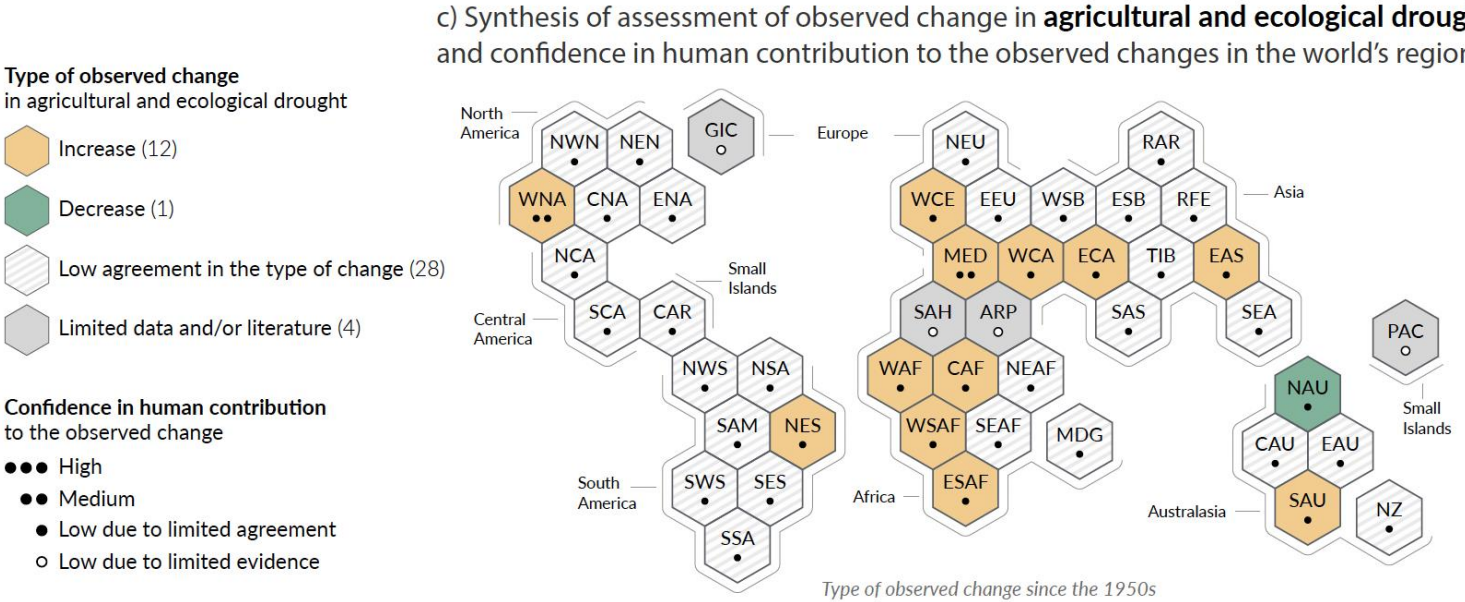
- Climate scientists like to describe changes in extreme events **probabilistically**, which requires **aggregation**



IPCC AR6 WGI SPM (2021)

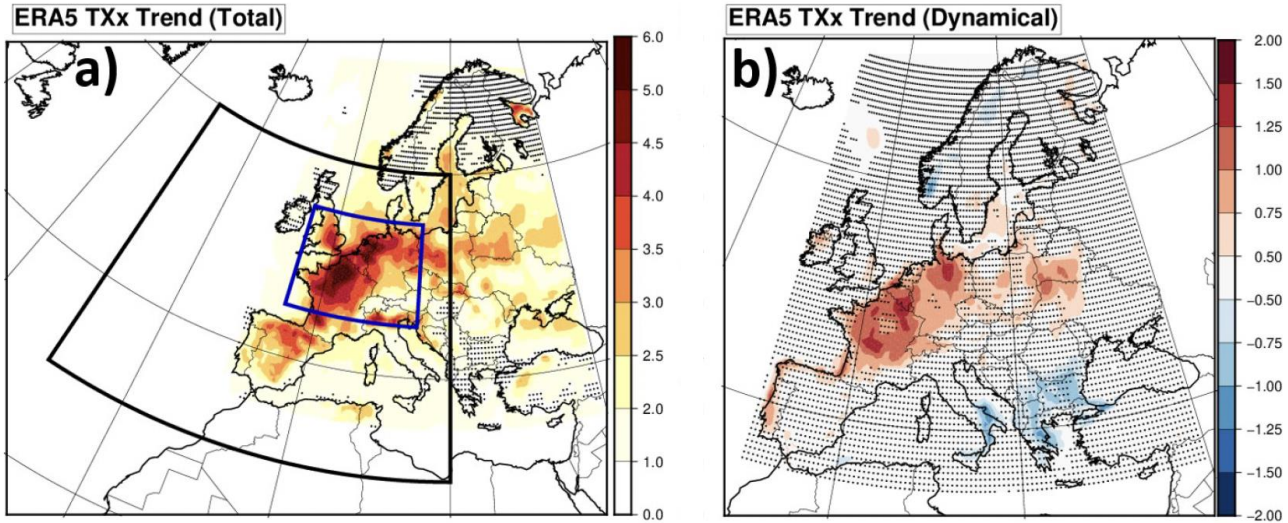
- Here the aggregation is over the **entire land surface** and **all kinds of heavy precipitation events**
  - Does this make any sense?
- Note that the increased intensity simply follows Clausius-Clapeyron scaling
  - This is informative, but it is really only a prior
- A factor that increases risk across a (statistical) population, while of relevance for anybody interested in effects on entire populations, **cannot be reliably applied to individuals within that population,** because **the real world is not iid** (e.g. Bueno de Mesquita & Fowler 2021 *Thinking Clearly with Data*)
- This is very well understood in other disciplines; **so why is it not understood within climate science?**

- 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**
  - Yet there can be a **wealth of climate information** when it is expressed **in conditional form** (see Chapter 10 of the IPCC AR6 WGI report)
  - Using IPCC regions can **obliterate important details** (Mindlin et al. 2023 J. Clim.)



SPM of IPCC AR6 WGI report (2021)

- And how about cases where, even if the sign is correct**, the observed trends lie outside of what the climate models seem capable of producing**?
  - In France, the summer maximum of daily maximum temperature has been increasing since 1950 up to five times faster than the global mean temperature
    - About 1/3 of this is due to dynamical trends which are not present in any model



Units: °C per °C of global mean warming

Vautard et al. (2023 Nature Comm.)

- Maybe the models underestimate variability and the observed dynamical trend will reverse
- Or maybe the dynamical trend is forced and the models are missing it
- Both represent plausible causal explanations

- 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**

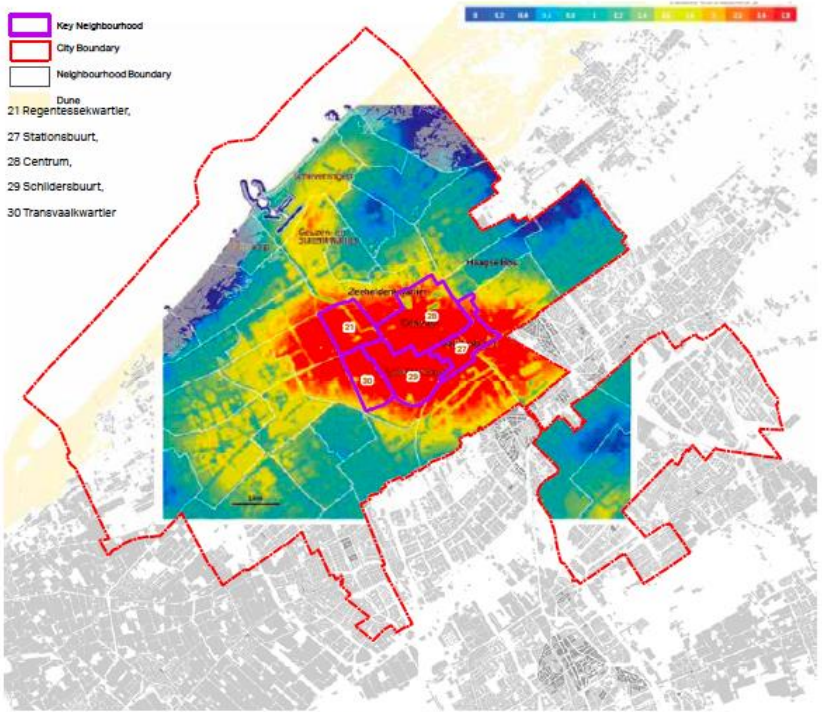


Figure 2–8: The urban heat island effect in The Hague – increased heat will affect more vulnerable neighbourhoods in The Hague

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)

There is no such thing as a "natural" disaster

- Representing the socio-economic situation and the managed environment at a local scale is crucial, as **there are always multiple causal factors**

- **We need a forensic approach**, not a yes/no attribution to climate change
- Moreover, the socio-economic situation and the managed environment are precisely the causal factors that are to be addressed through adaptation measures!

Libya flooding of 2023
Karim Sahib—AFP/Getty Images

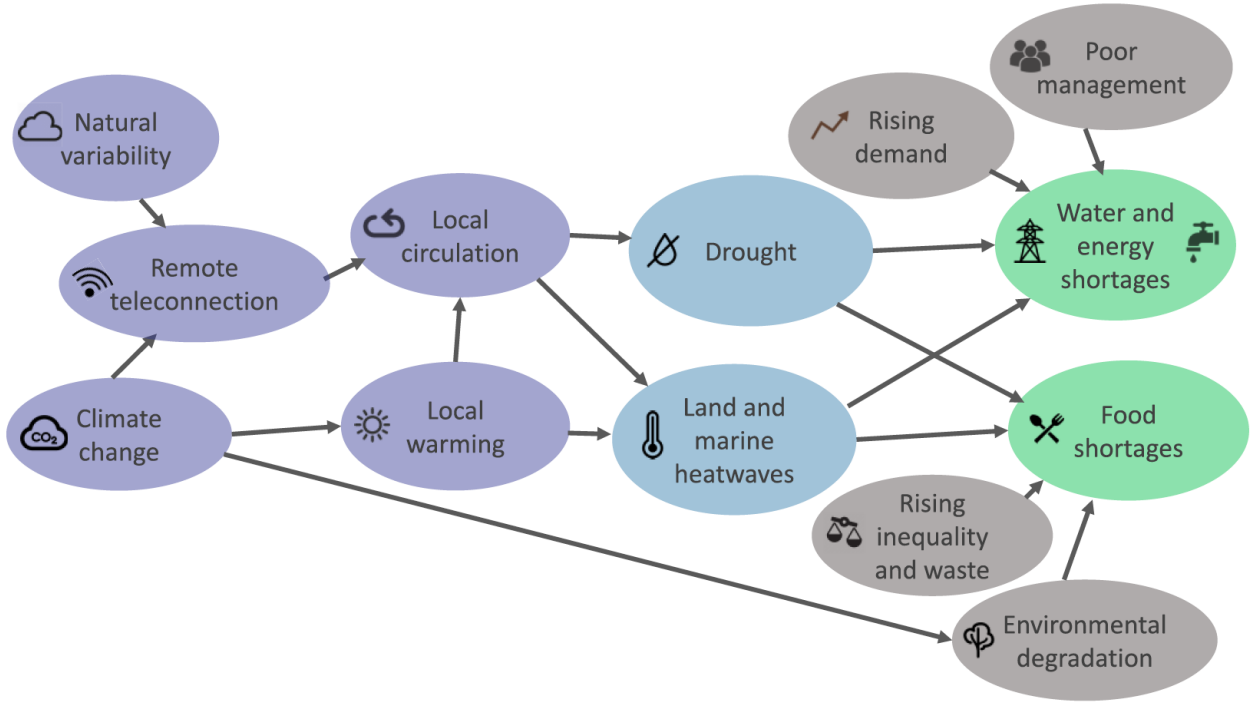
There is no such thing as a "natural" disaster

TABLE 10.1
Comparative Analysis of Four Famines

Which famine?	*Was there a food availability collapse?*	*Which occupation group provided the largest number of famine victims?*	*Did that group suffer substantial endowment loss?*	*Did that group suffer exchange entitlement shifts?*	*Did that group suffer direct entitlement failure?*	*Did that group suffer trade entitlement failure?*	*What was the general economist climate*
Bengal famine 1943	No	Rural labour	No	Yes	No	Yes	Boom
Ethiopian famine (Wollo) 1973	No	Farmer	A little, Yes	Yes	Yes	No	Slump
Ethiopian famine (Harerghe) 1974	Yes	Pastoralist	Yes	Yes	Yes	Yes	Slump
Bangladesh famine 1974	No	Rural labour	Earlier, yes	Yes	No	Yes	Mixed

Amartya Sen (1981 *Poverty and Famines*)

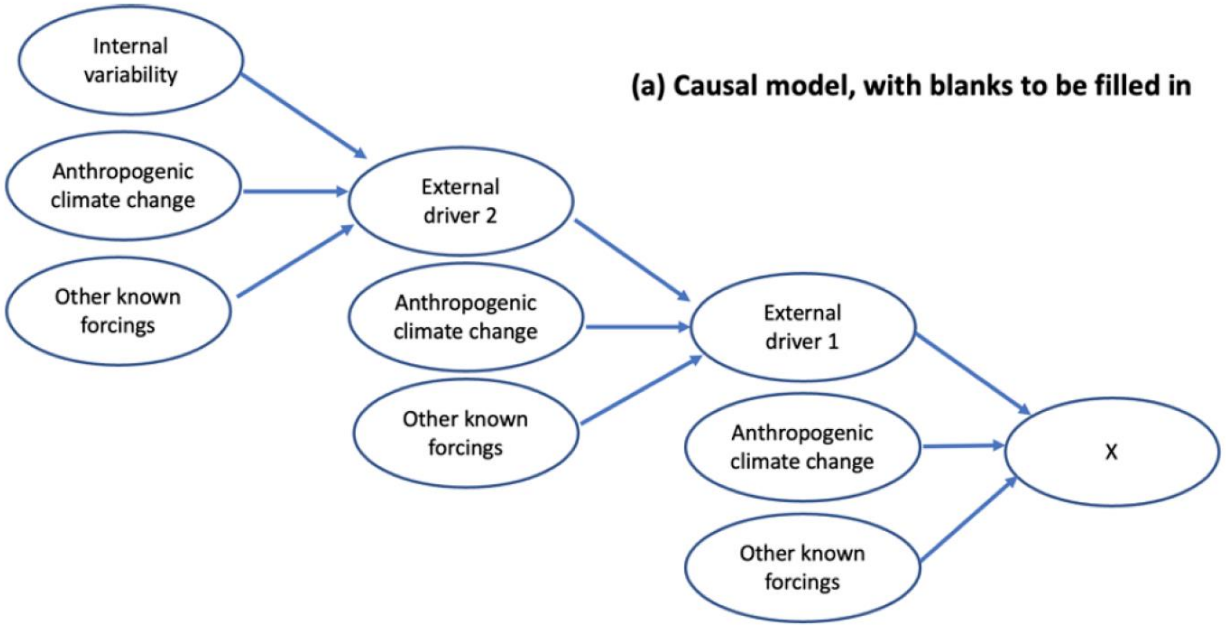
- The relevant causal factors and their connections to impacts can be represented in a **causal network,** which can be used to define **storylines** (Shepherd 2019 Proc. Roy. Soc. A)
  - Provides a powerful alternative to traditional (unconditional) attribution when uncertainties are high (Lloyd & Shepherd 2023 Env. Res. Clim.)



Example of the crisis across the food-water-energy nexus in SE Brazil from the failure of the 2013/14 monsoon

Rodrigues & Shepherd (2022 PNAS Nexus)

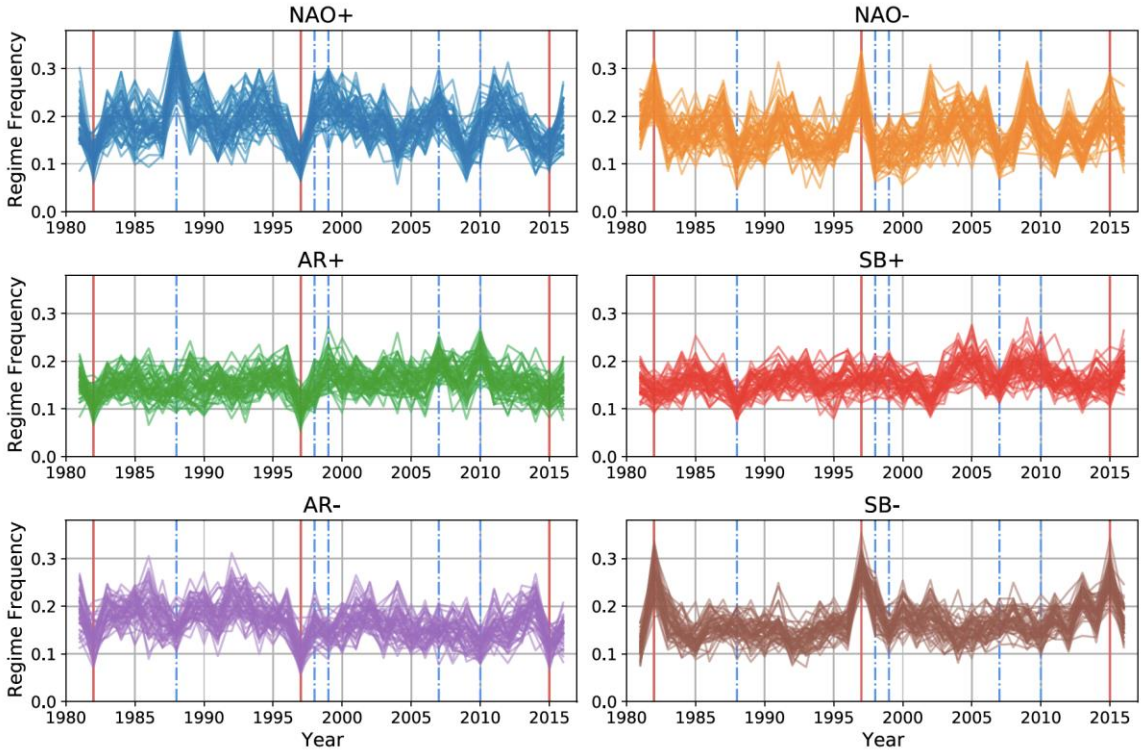
- The storyline approach can be seen as **conditional** attribution, where some of the causal elements are internal to the climate system (known as an "external driver" of the effect in question), and their attribution to climate change is left open
- Fully consistent with the IPCC Detection & Attribution Guidance Paper (2010), but traditionally, climate-change scientists have only considered **unconditional** attribution



Yet conditional attribution is standard practice in other aspects of climate science, e.g. seasonal prediction

Lloyd & Shepherd (2023 Env. Res. Clim.)

- The idea behind a causal network is to **use all available physical information in the estimation of a signal** (whether for prediction or for attribution)
  - This example uses **Bayes theorem** together with daily transition probabilities between North Atlantic/European wintertime circulation regimes to boost the signal

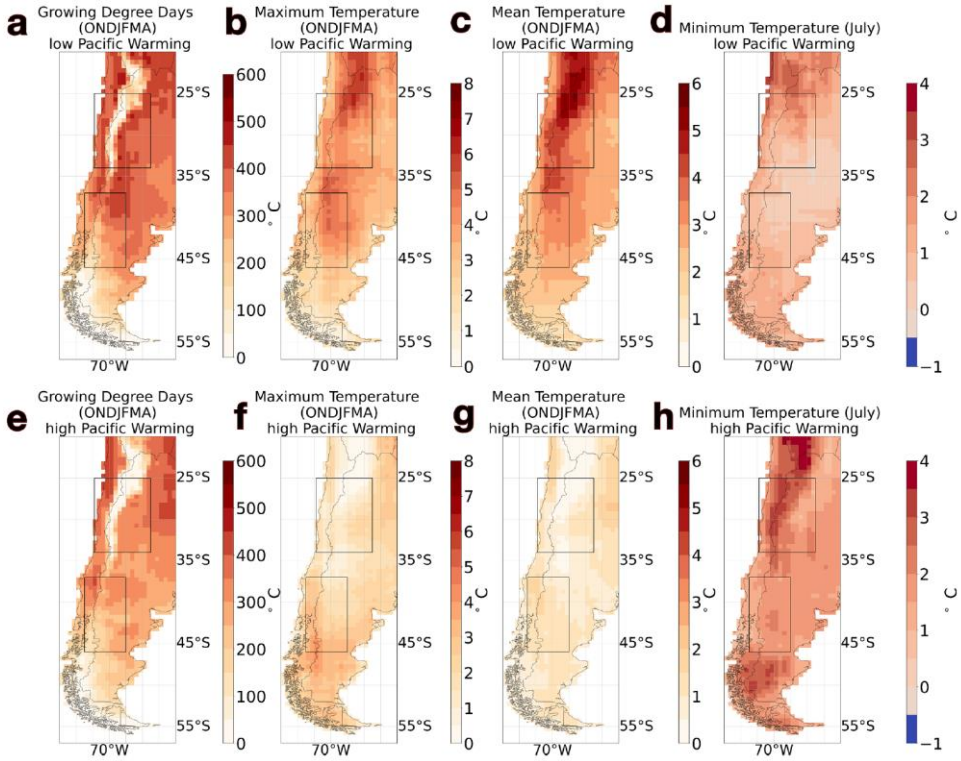


Vertical red lines = El Niño
Dashed blue lines = La Niña

Note that **a strong response to ENSO can be detected even from relatively small forecast ensembles** (here 10-member subsets from ECMWF SEAS5)

Falkena et al. (2023 J. Clim.)

- The idea behind physical climate storylines is **to provide a self-consistent representation of correlated aspects of physical climate risk, i.e. of compound risk**
  - This example computes Climatic-Impact Drivers relevant to the viticulture sector in South America, under **two extreme storylines encompassing the full seasonal cycle**



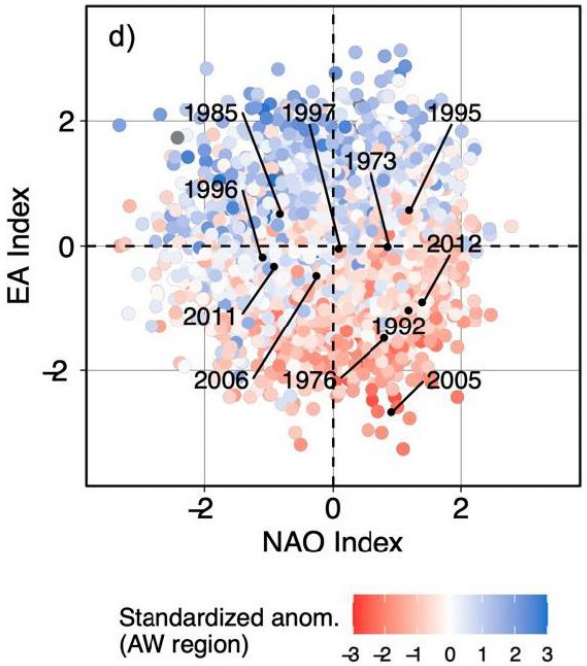
"low Pacific warming" means
- low central and East Pacific warming
- weakened SPV (but strengthened in MA)
- high upper-tropospheric tropical warming

"high Pacific warming" means
- high central and East Pacific warming
- strengthened SPV (but weakened in MA)
- low upper-tropospheric tropical warming

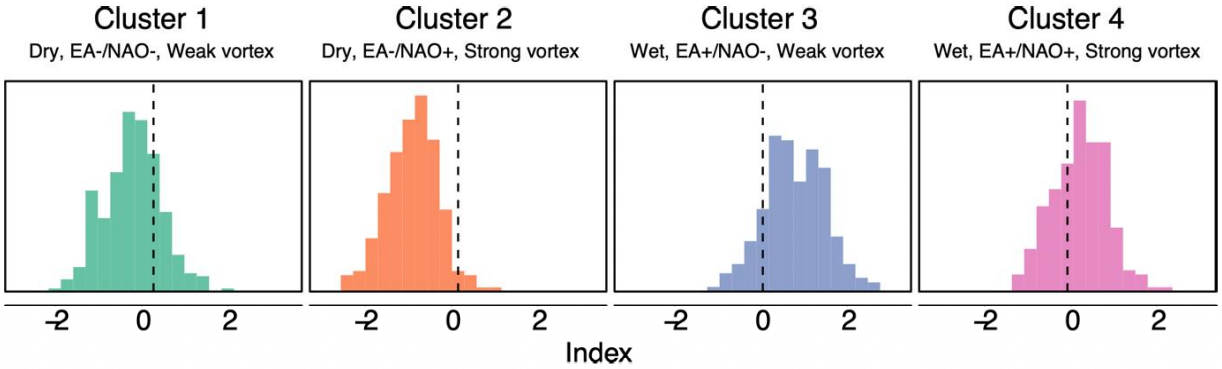
Mindlin et al. (2024 Climate Services)

- Storylines constructed from seasonal hindcast ensembles can be used to **supplement seasonal outlooks during ongoing droughts**

Winter precipitation anomalies for East Anglia region (colour: SEAS5 hindcasts)

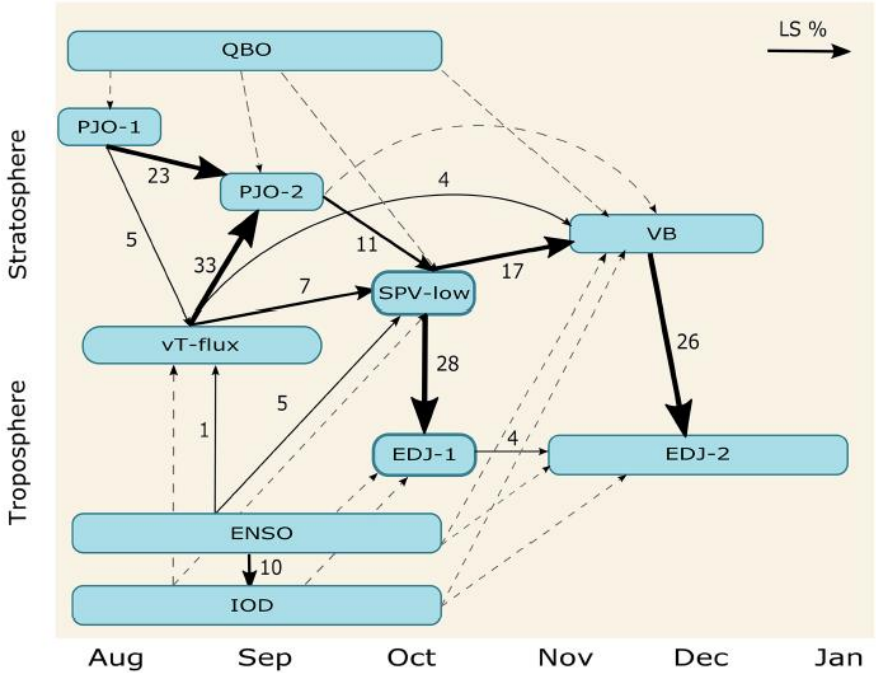


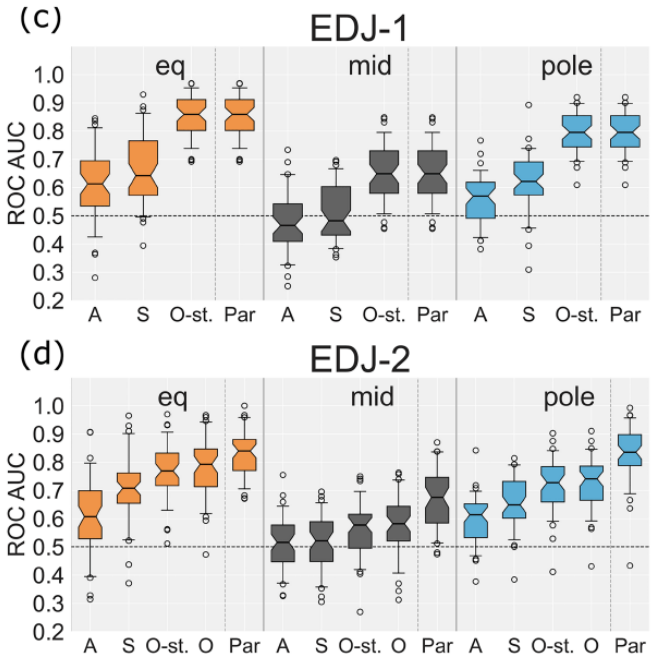
- In this study, which was performed in the summer of 2022 during drought conditions in southern England, storylines were constructed to examine how the drought might unfold over the coming winter, spring and summer, to inform planning by Anglian Water



Chan et al. (2024 NHESS)

- **Probabilistic causal networks** provide a way of quantifying the predictability of a target variable arising from known physical drivers, and its **dynamical updating**
  - This example is for the poleward (EDJ-1) and equatorward (EDJ-2) seasonal shifts of the Southern Hemisphere eddy-driven jet, using ECMWF System 4





Saggioro, Shepherd & Knight (2024 J. Clim.)

Frequently Asked Questions

- **What about probabilities?**
  - It's better science to acknowledge that some uncertainties are epistemic than to provide a sense of 'false precision' (Parker & Risbey 2015 Phil. Trans. A)
  - If you wish to treat CMIP multi-model ensembles as probability distributions, that is your right
  - Causal networks can provide a link between storylines and probabilities
- **Aren't storylines too subjective?**
  - If the price of 'objectivity' is to bury the subjectivity in procedural protocols, then that is not a price worth paying; it's better to be transparent
- **Aren't the number of storylines unlimited?**
  - A focus on decision relevance can narrow the possibilities dramatically
- **How do you determine what is physically plausible?**
  - This must be a process of co-development with the user

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
  - The historical record can be supplemented with **storylines of extreme variability** selected from large model ensembles such as seasonal hindcasts
- We need to explore storylines of climate risk, combining the best information from all sources — **interpreted not as a prediction but as representing plausible outcomes**