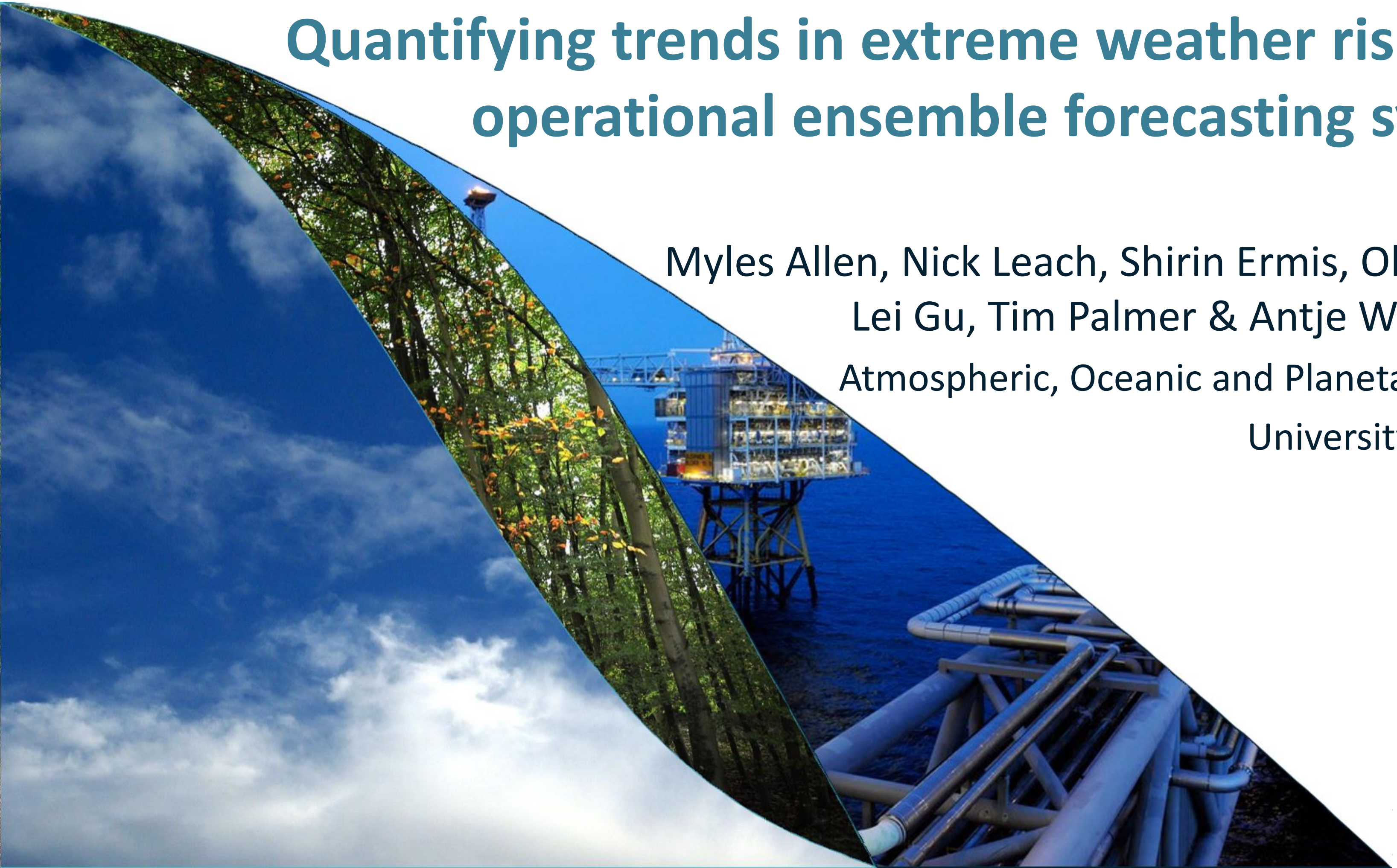
Quantifying trends in extreme weather risk using operational ensemble forecasting systems

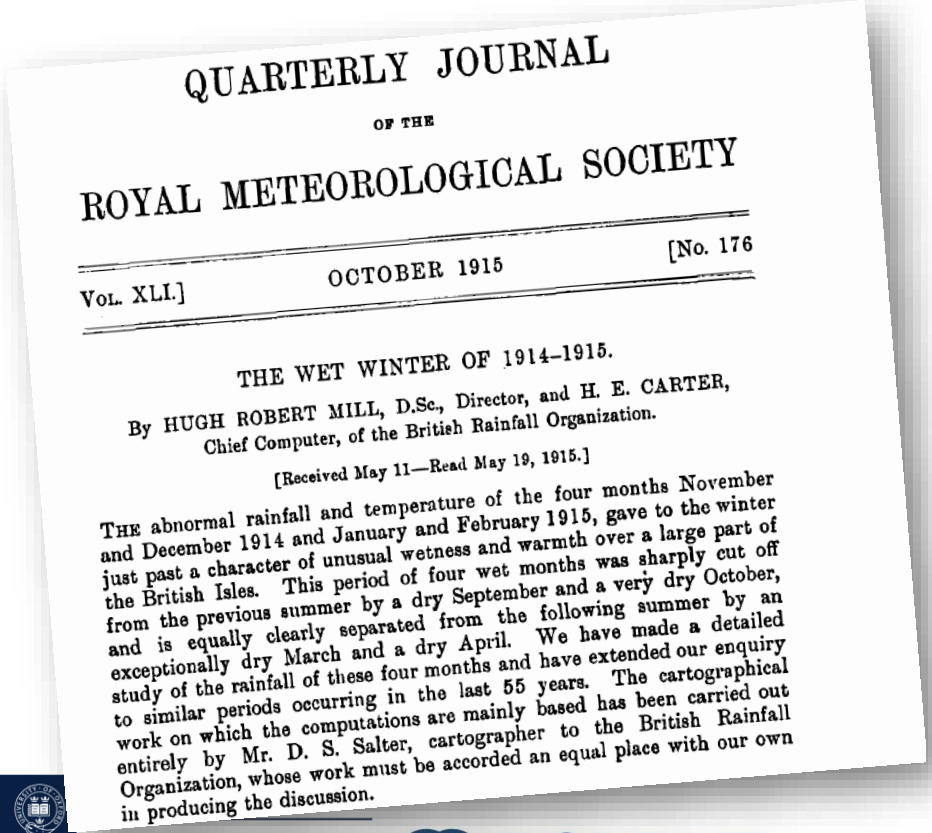
Myles Allen, Nick Leach, Shirin Ermis, Olivia Ayim, Lei Gu, Tim Palmer & Antje Weisheimer

Atmospheric, Oceanic and Planetary Physics

University of Oxford



People have always been interested in extreme event attribution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THE WET WINTER OF 1914–1915.

By HUGH ROBERT MILL, D.Sc., Director, and H. E. CARTER, Chief Computer, of the British Rainfall Organization.

[Received May 11—Read May 19, 1915.]

The abnormal rainfall and temperature of the four months November and December 1914 and January and February 1915, gave to the winter just past a character of unusual wetness and warmth over a large part of the British Isles. This period of four wet months was sharply cut off from the previous summer by a dry September and a very dry October, and is equally clearly separated from the following summer by an exceptionally dry March and a dry April. We have made a detailed study of the rainfall of these four months and have extended our enquiry to similar periods occurring in the last 55 years. The cartographical work on which the computations are mainly based has been carried out entirely by Mr. D. S. Salter, cartographer to the British Rainfall Organization, whose work must be accorded an equal place with our own in producing the discussion.

"An explanation which has been most readily accepted by the general public, and has even found favour among a few meteorologists, is that the heavy artillery firing in France and in Flanders is the primary cause of the unusual wetness of the past winter."

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Attribution in a chaotic or random process

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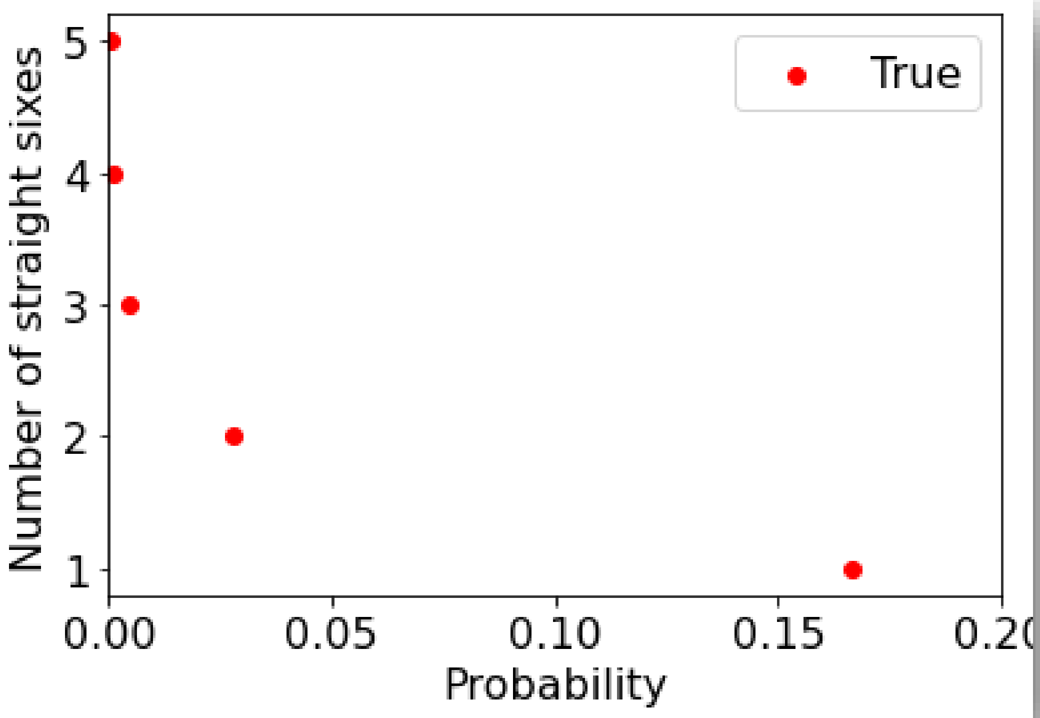

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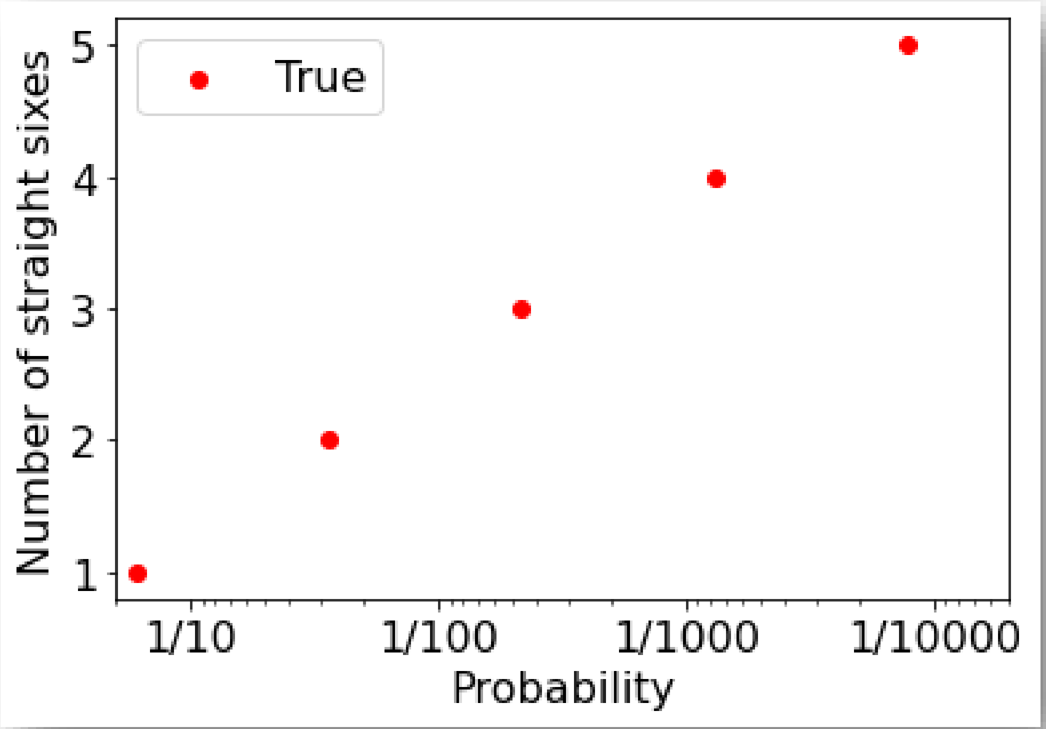
Attribution in a chaotic or random process



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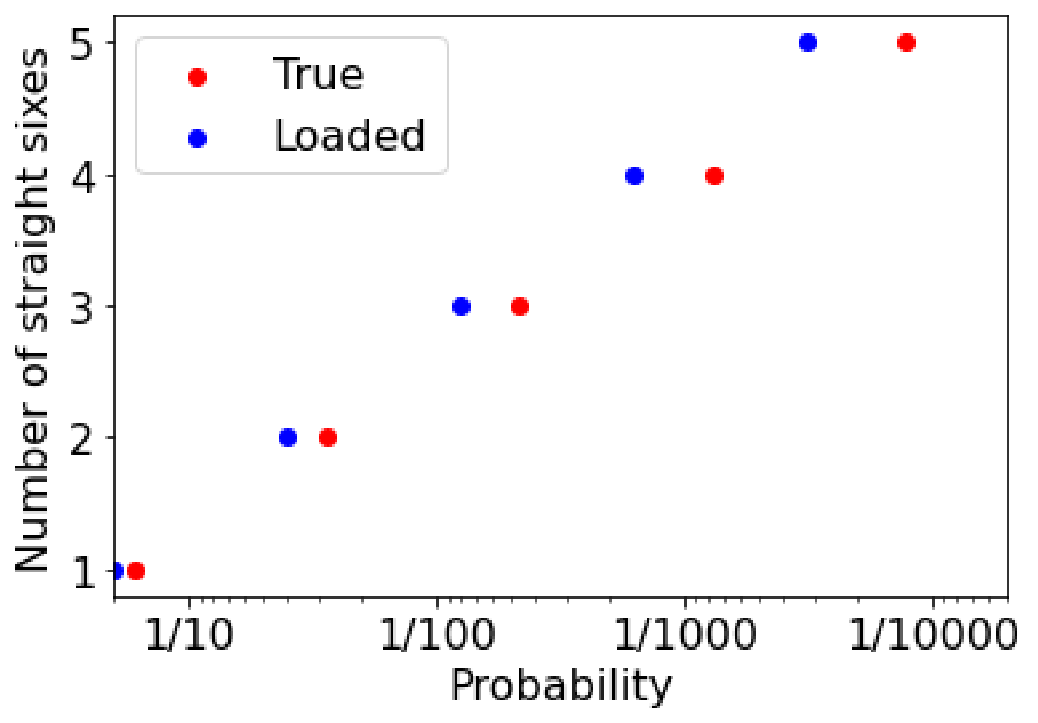
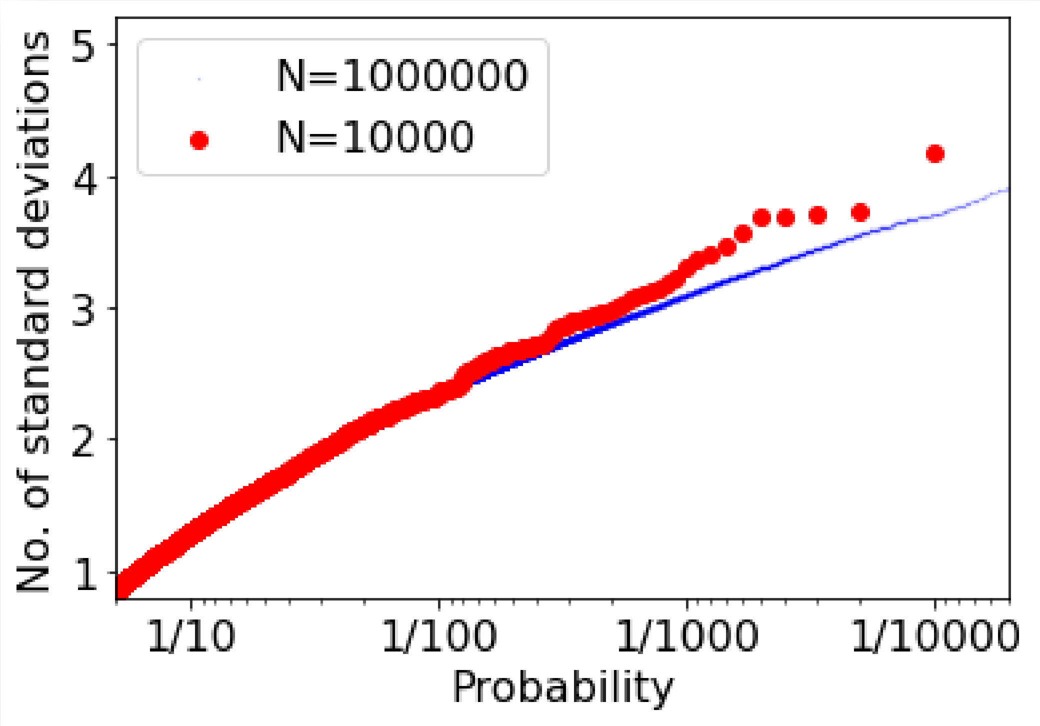
Attribution in a chaotic or random process

Changing return times



Return times for a Gaussian process



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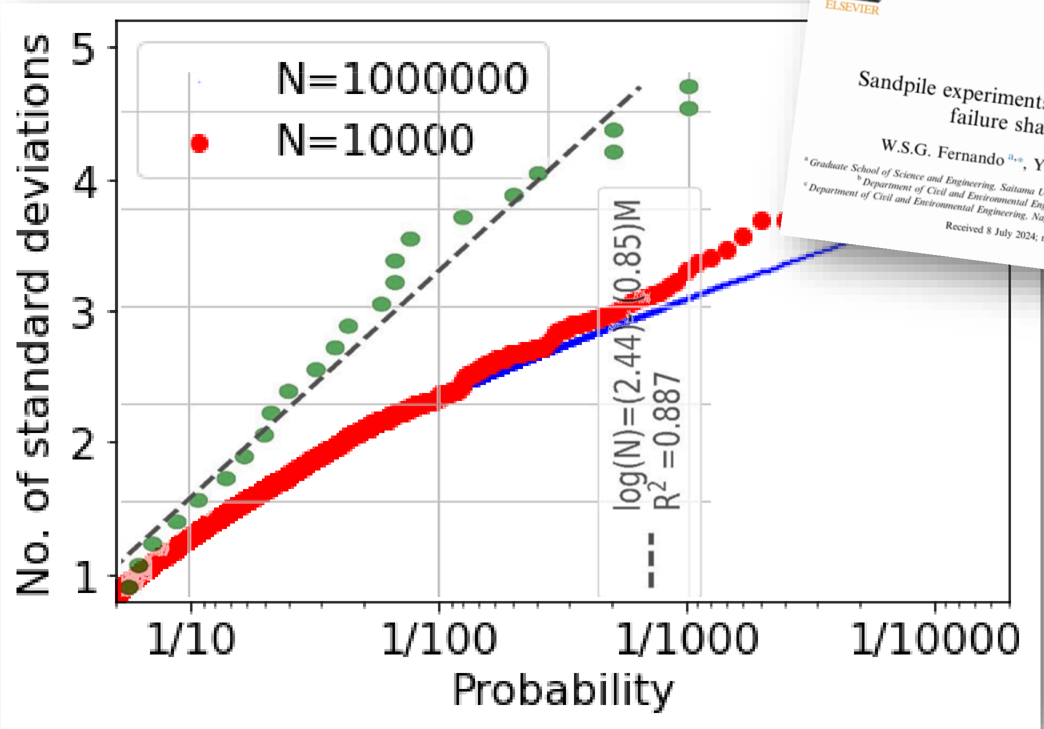
Return times for a more interesting process

Video by Sergei Klishin

Return times for a Gaussian process vs. sandpile

"Gutenberg-Richter slope":

expressed as a probability-ratio per unit increase in magnitude



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Sandpile experiments and statistical analysis for slope failure, failure shape, and frequency distribution

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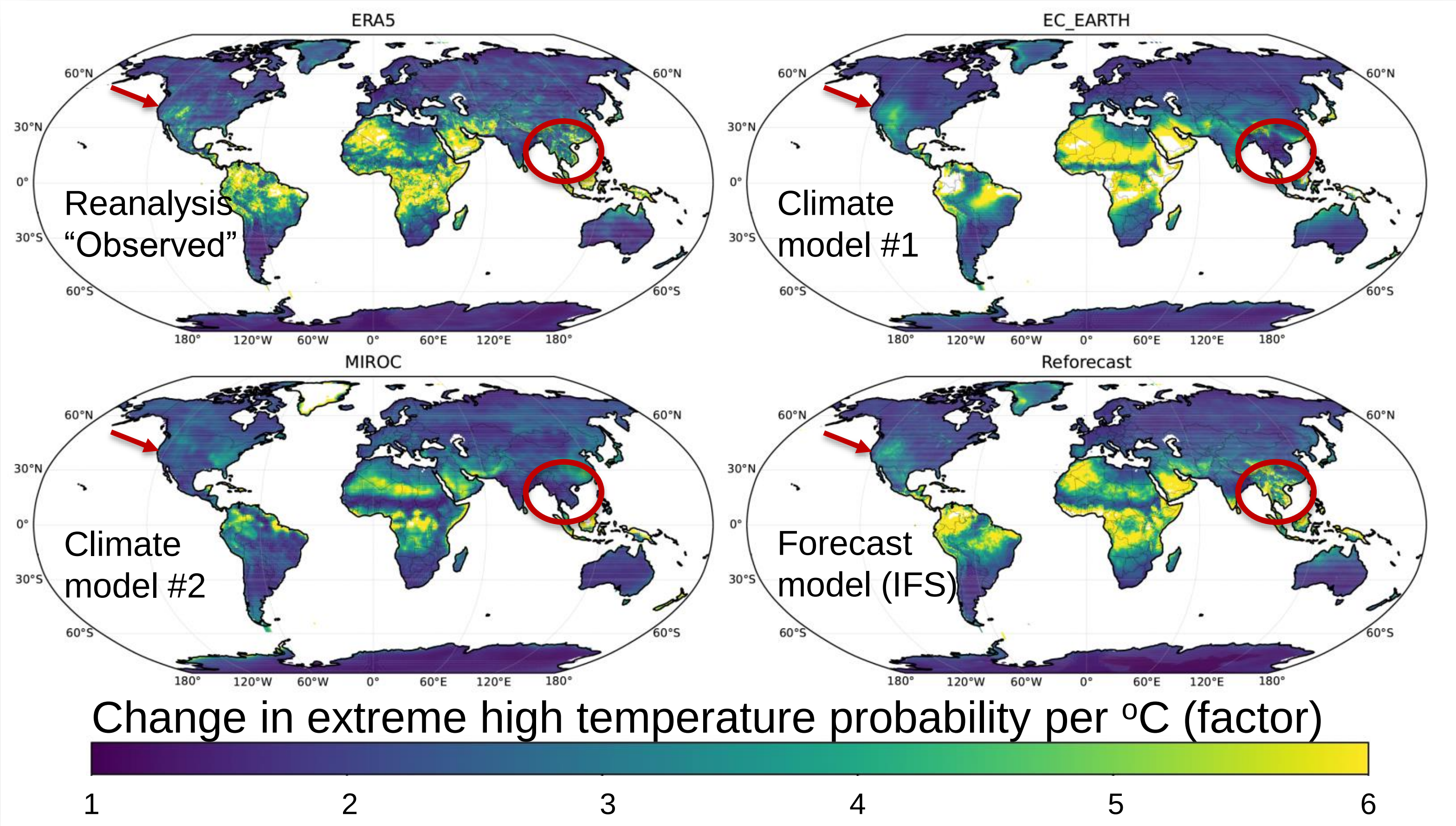
Chaos makes the attribution question challenging

- Extreme events may be more frequent than you would expect from a simple random process (sandpile example).
- External drivers of climate change can affect *both*
  - The **magnitude** of an event, assuming it happens anyway.
  - The **probability** of a similar event happening at all.
- Predicting the impact of external drivers on probabilities requires accurate simulation of the Gutenberg-Richter slope:
  - Relevant physics realistically simulated.

Modelled Gutenberg-Richter slopes



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The June 2021 heatwave in the Pacific Northwest

Lytton, British Columbia, 2021

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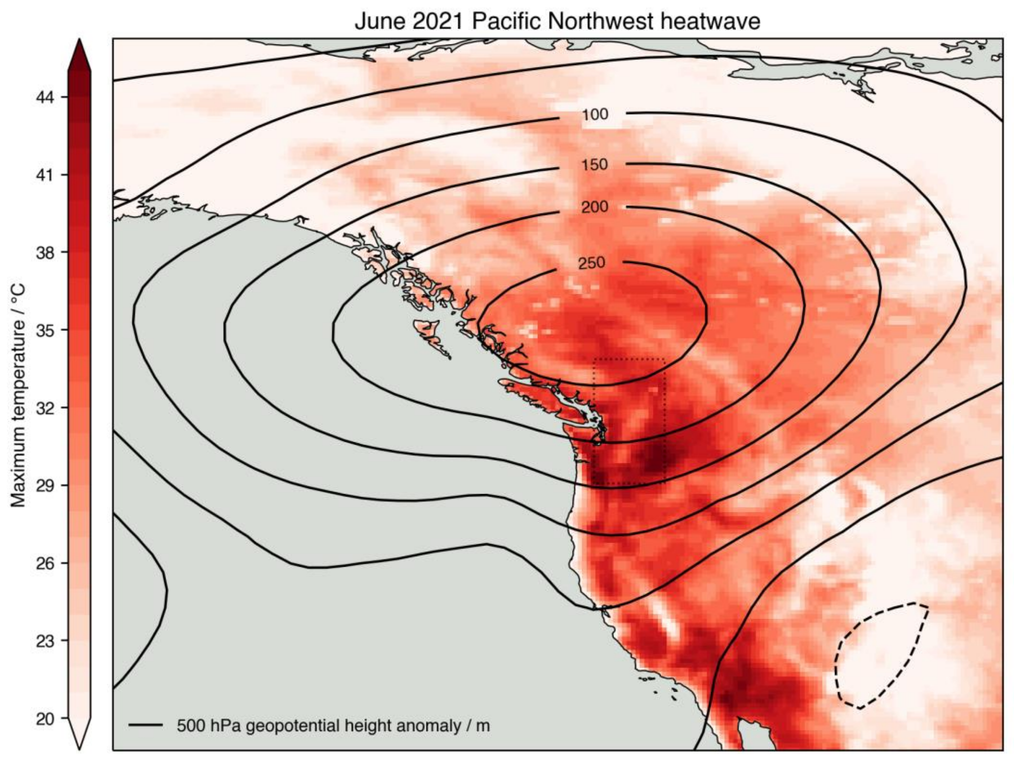
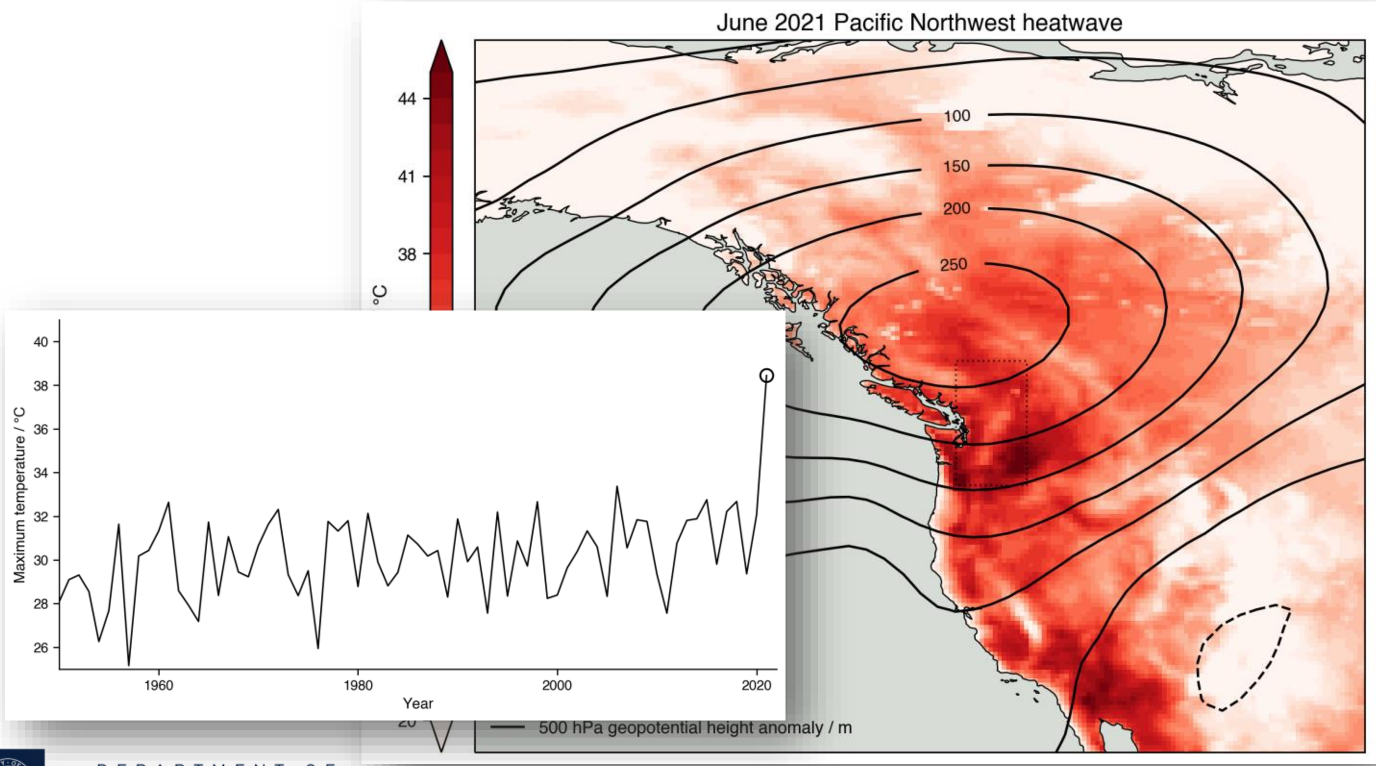
The June 2021 heatwave in the Pacific Northwest



Apparently unprecedented: so empirical G-R slopes irrelevant



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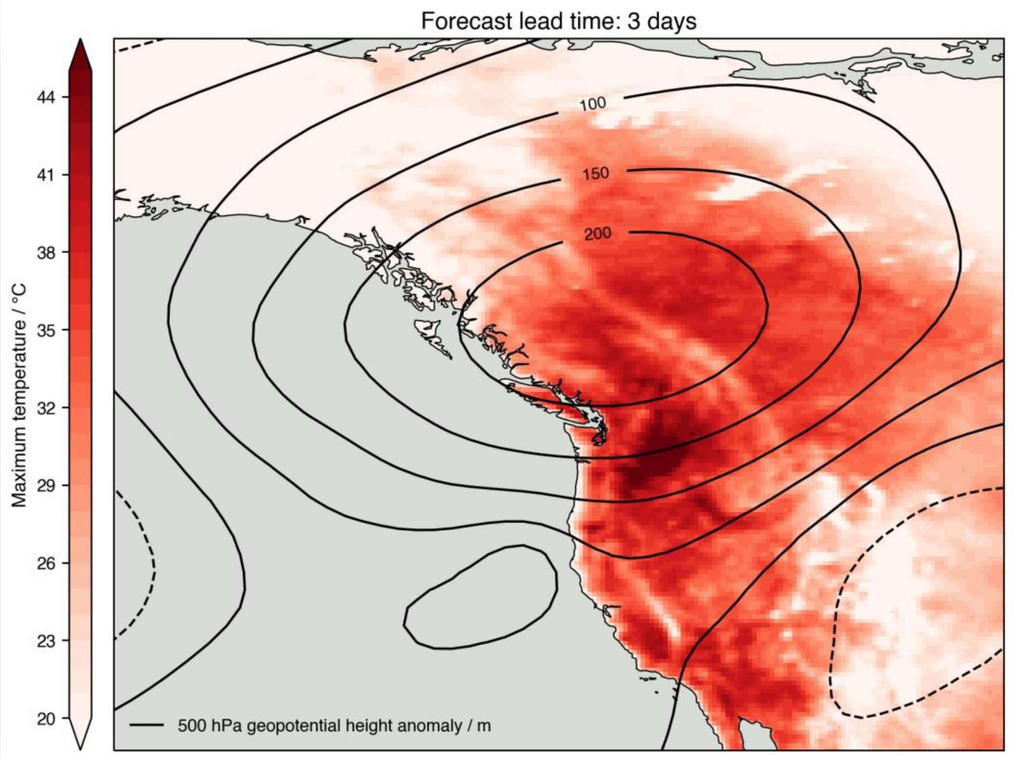
But remarkably well forecast: 3 days out



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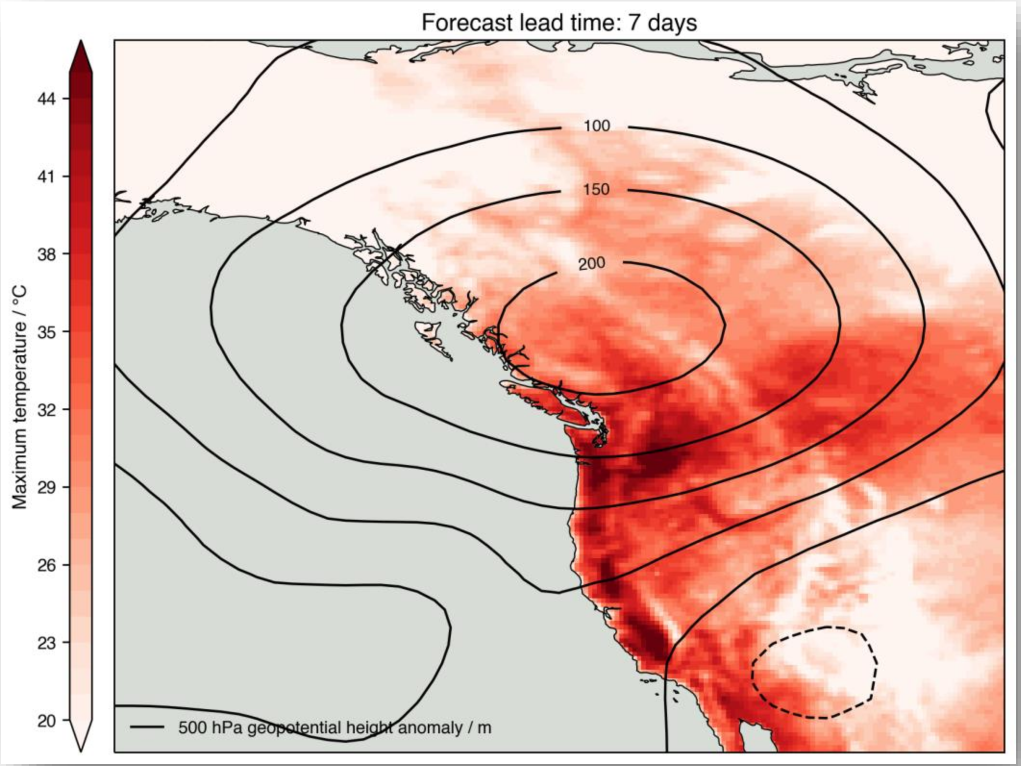
But remarkably well forecast: 7 days out



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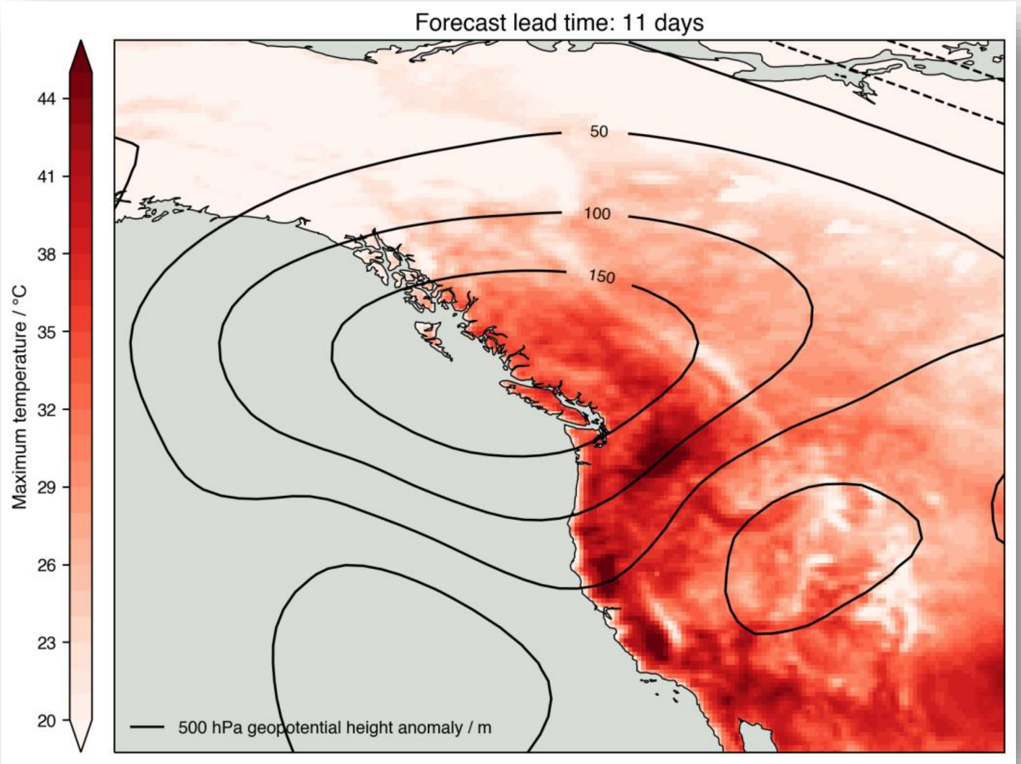
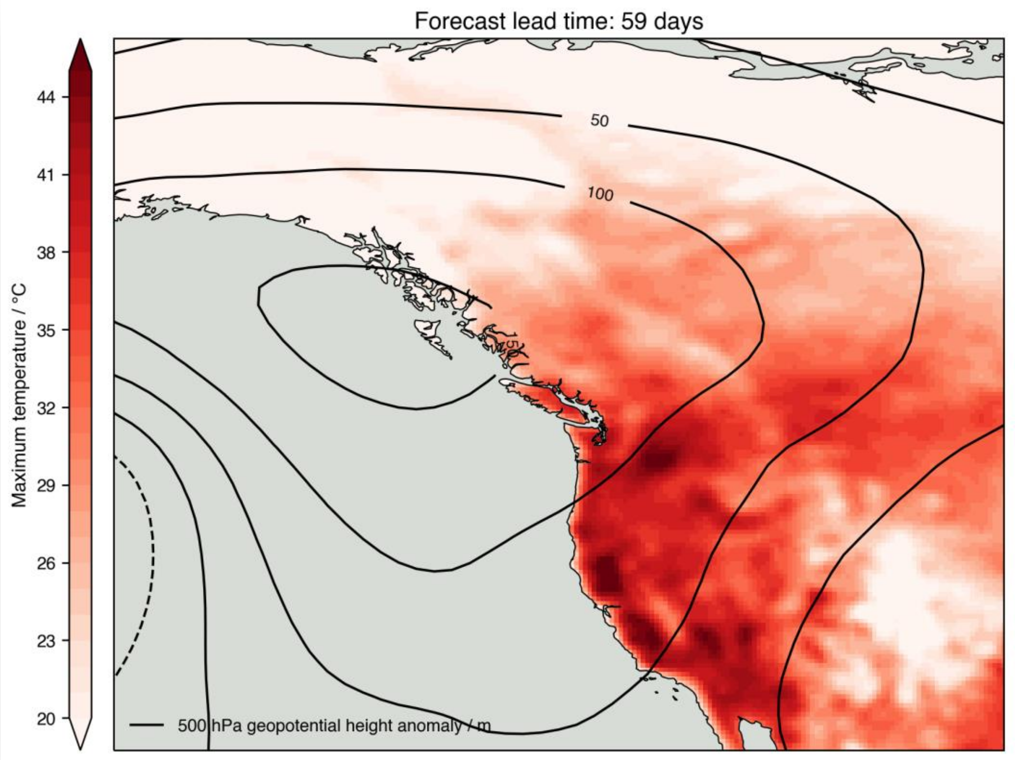
But remarkably well forecast: 11 days out



But remarkably well forecast: 2 months out



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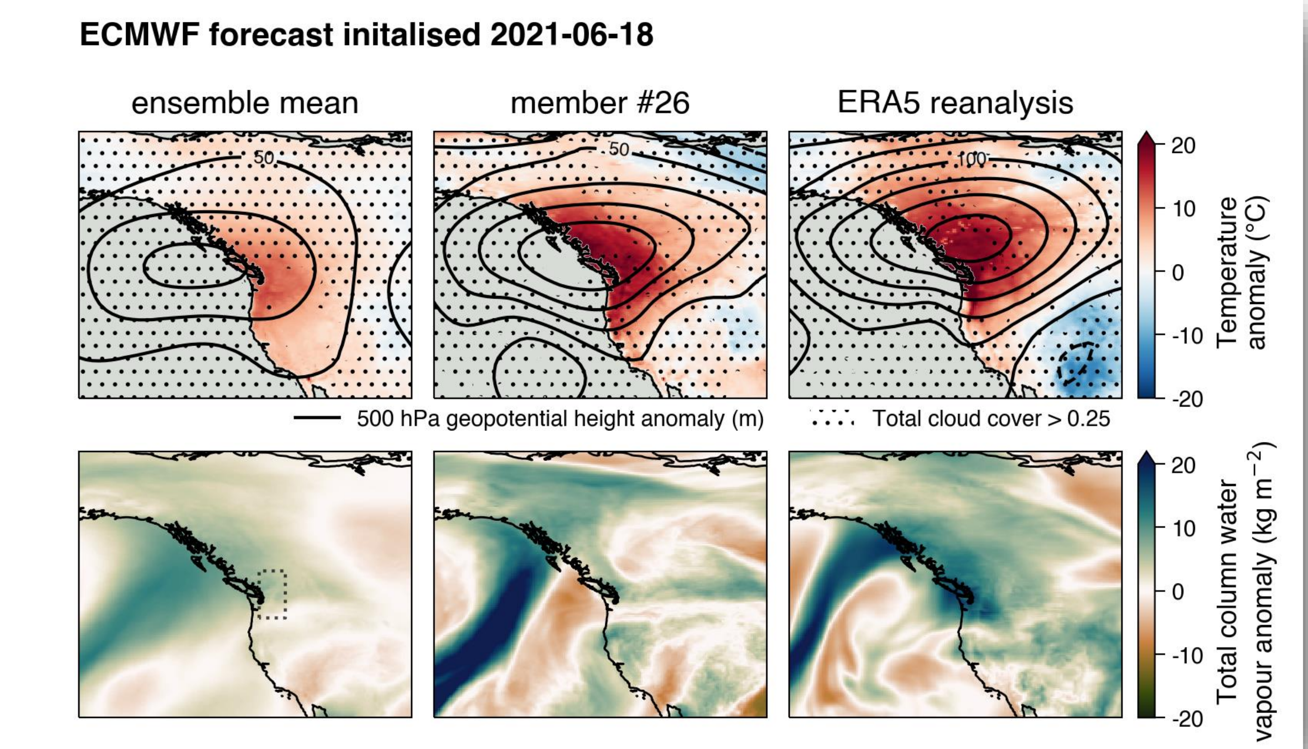
Does the model capture the essential physics of what actually occurred?



Note: the test is **can** the model reproduce the event, not **will**… The event may be intrinsically unpredictable.

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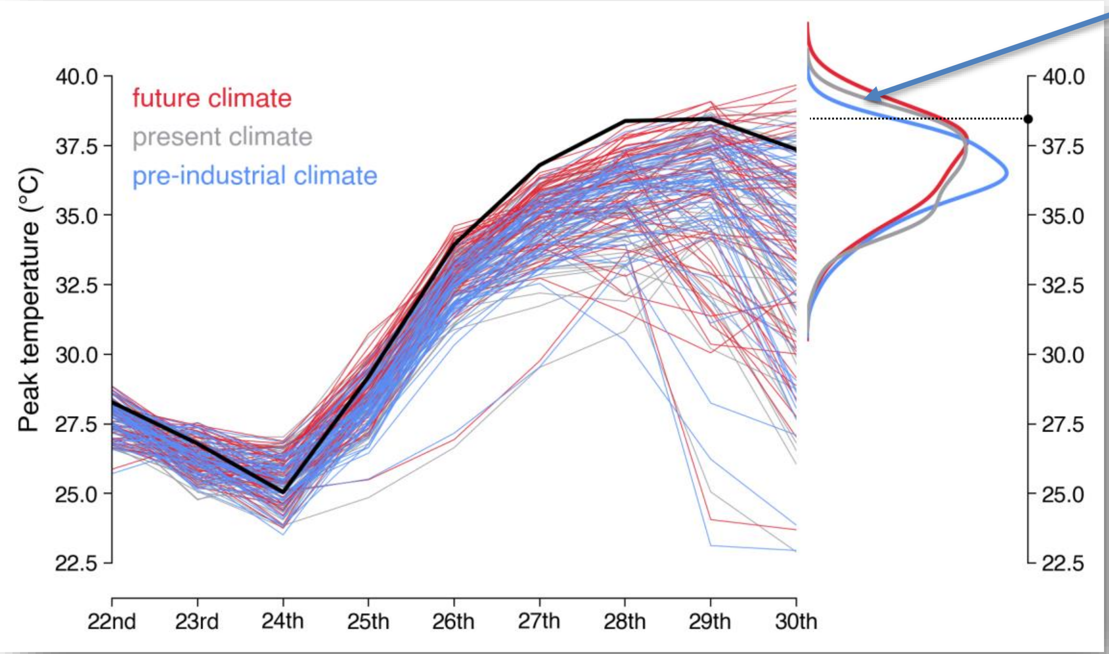
Forecast-based attribution with the operational medium-range and seasonal IFS (Leach et al, 2024)

- Reset CO_2 concentrations & modify initial conditions to subtract full 3-D pattern of ocean surface and sub-surface warming since 1900: "pre-industrial climate"
- Modify ocean salinities to conserve stability
- Rerun the 50-member ensemble forecast at increasing lead times to explore impact on forecast probability of event
- Repeat increasing CO_2 and adding pattern of warming to check linearity of response: "future climate"

Impact of warming on probability of heatwave

8-fold increase in probability for a 1.2^{o}C rise in global temperature



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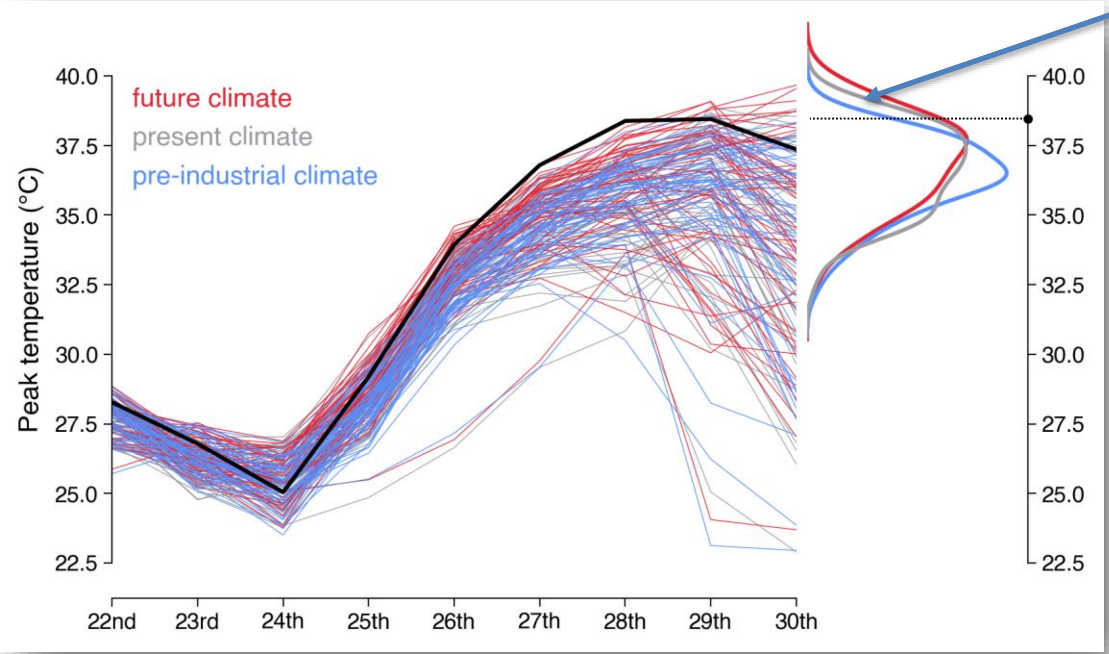
Impact of warming on probability of heatwave

Probability doubling every 20 years



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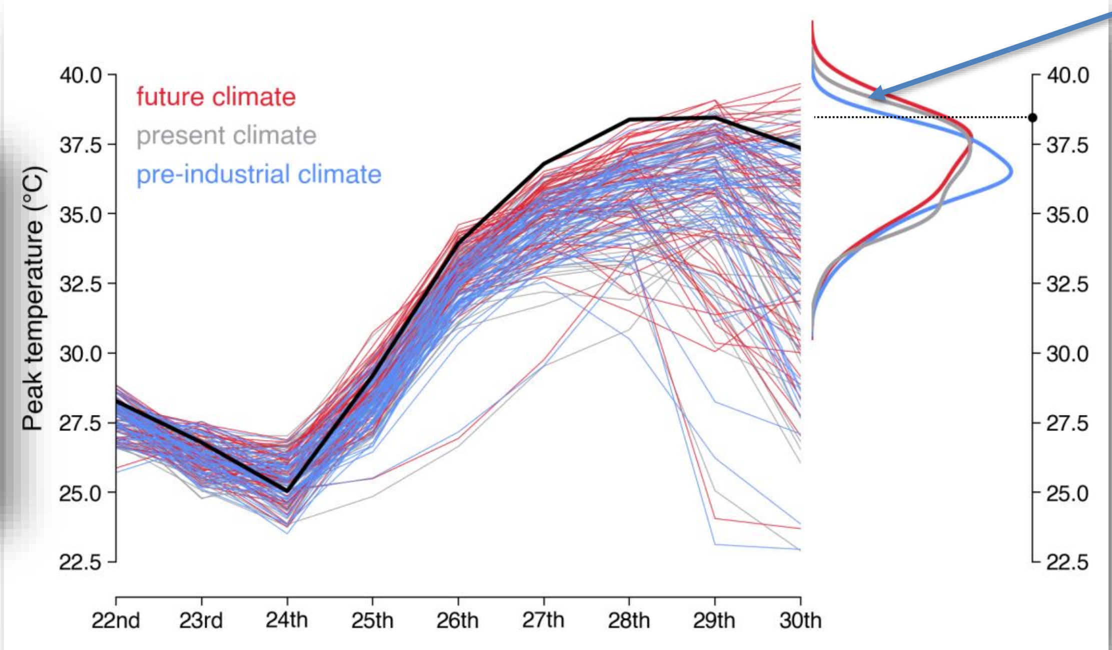
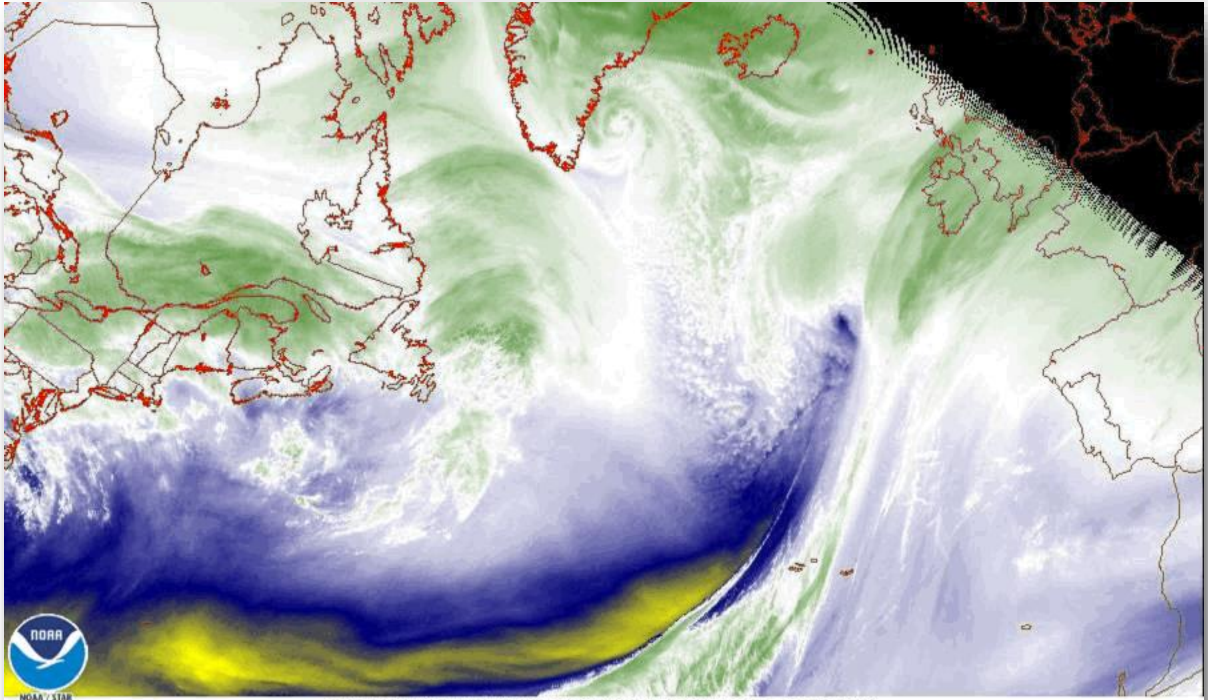
Impact of warming on probability of heatwave

Not "virtually impossible without climate change"

Leach et al, 2024



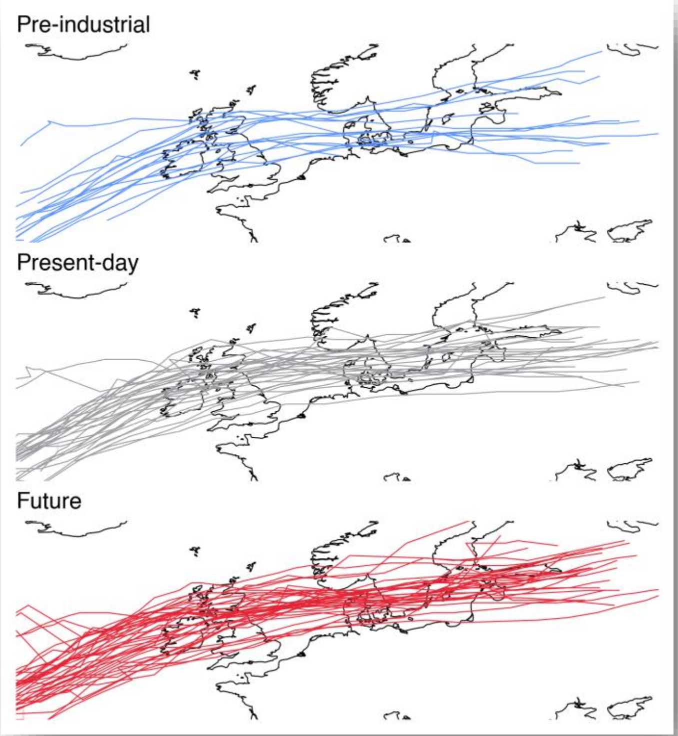
A more dynamical example: Storm Eunice, 17-19 February 2022

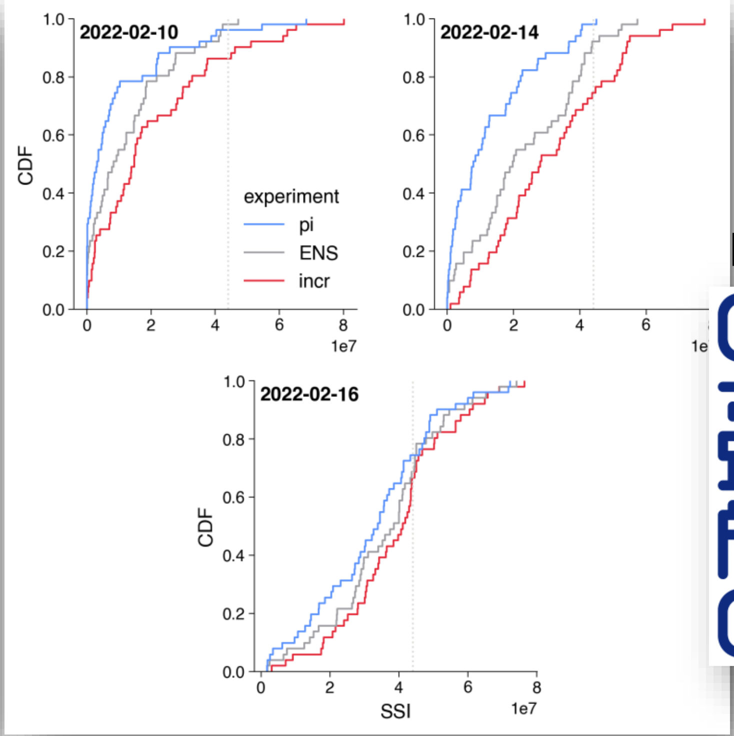


17 Feb 2022 15:50Z NESDIS/STAR GOES-East Band 09

€3.4 Billion loss across UK & northern Europe

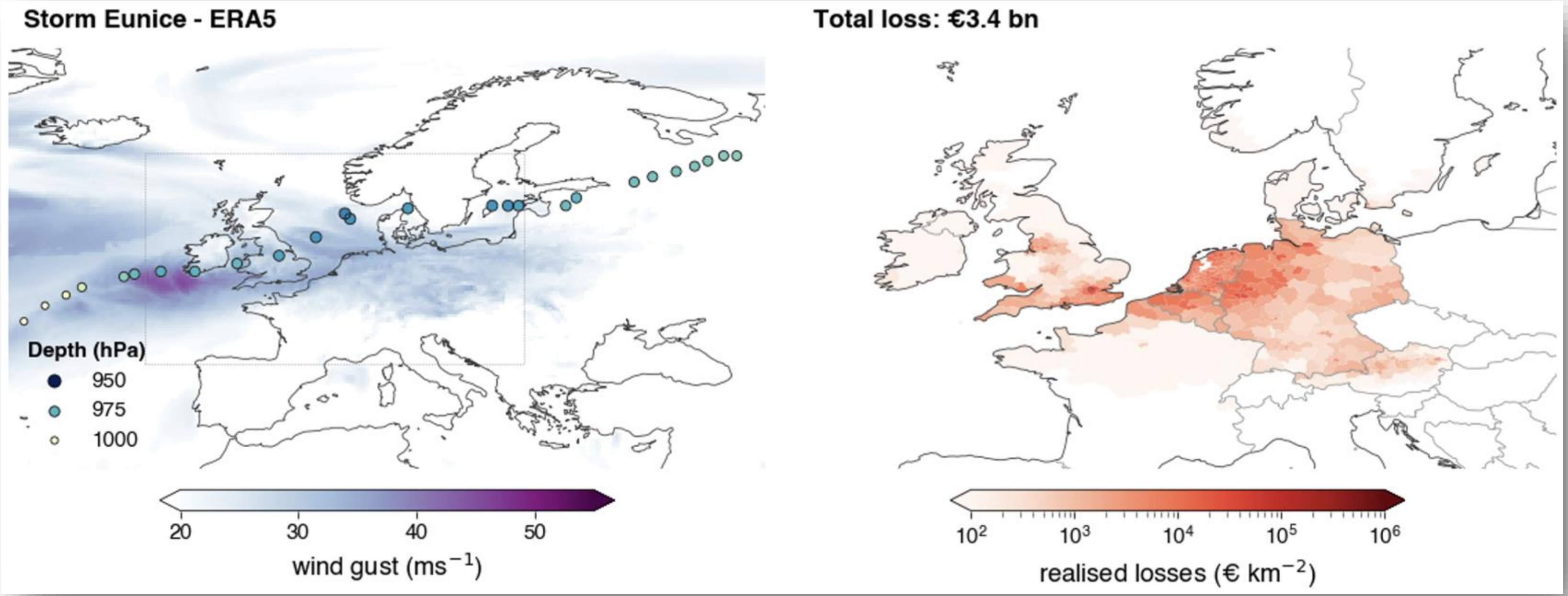
Impact of anthropogenic climate change on ensemble forecasts of Storm Eunice at 8, 4 & 2-day leads





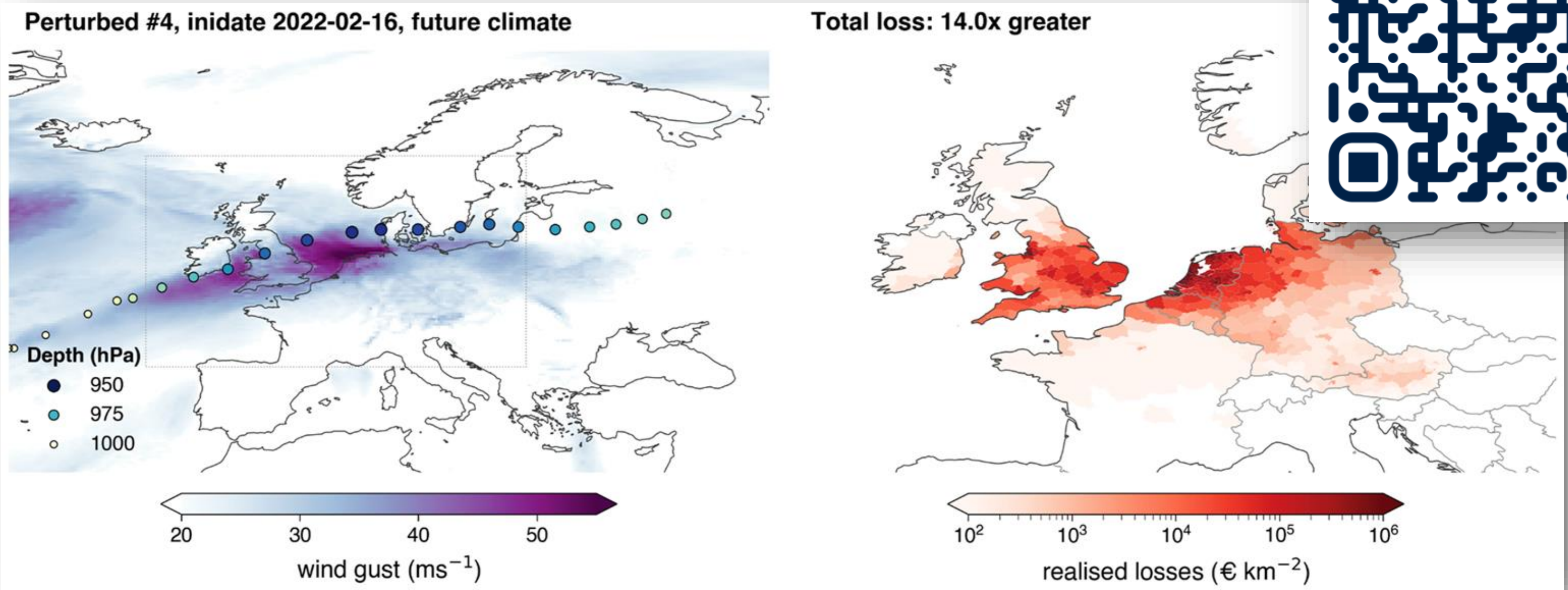
Ermis et al, 2024

Storm Eunice in future?



Leach et al, 2025

Storm Eunice in future?



Challenges for forecast-based attribution of trends in event probabilities

- Aim: quantify rates of change of probability of similar extreme events in a free-running and reliable model.
  - Reliable sensitivities of extreme probabilities require accurate return-time slopes, which require realistic high-resolution models.
  - Compromise on model for an adequate ensemble size.
  - Compromise on ensemble size for a reliable model.
  - Waste resources on “mindless” high-resolution ensembles.
- Use perturbed ensemble forecasts at progressively longer lead times to look for convergence of results.

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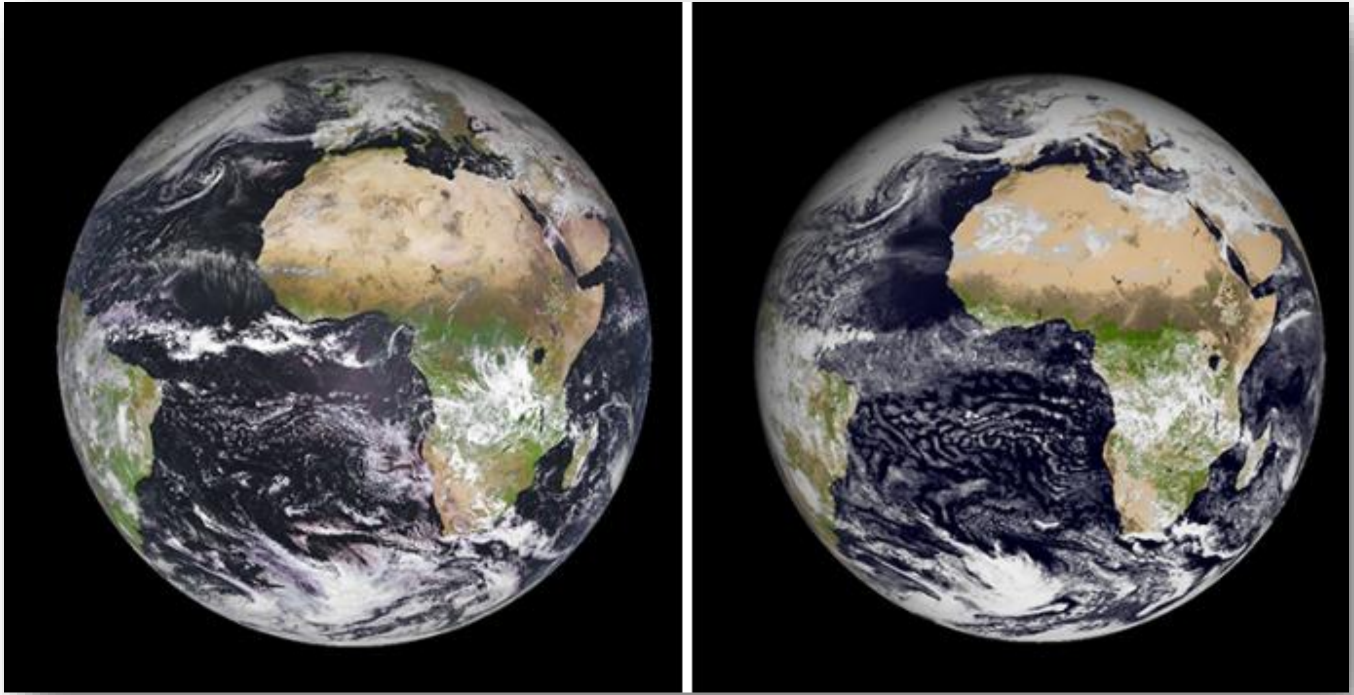
Reliable attribution of trends in extreme weather: a flagship application of digital twin Earths



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