

The importance of foundations

Nancy Reid
University of Toronto

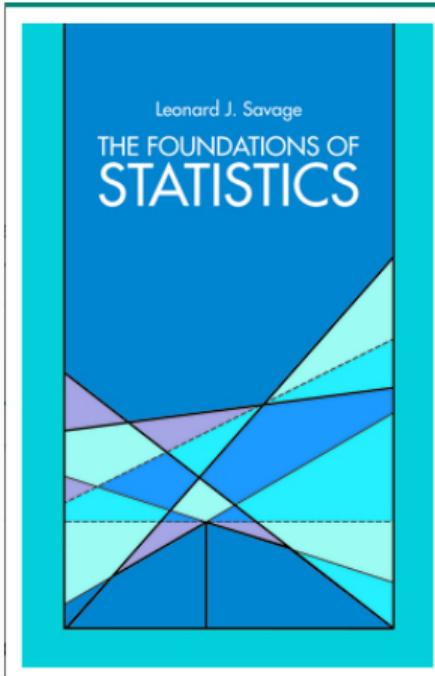
June 8 2023



Introduction

What are the foundations of statistics?

Savage 1954



It is unanimously agreed that statistics depends somehow on probability. But, as to what probability is and how it is connected with statistics, there has seldom been such complete disagreement and breakdown of communication since the Tower of Babel. Doubtless, much of the disagreement is merely terminological and would disappear under sufficiently sharp analysis.

- Statistics needs a healthy interplay between theory and applications
- theory meaning **foundations**, rather than theoretical analysis of specific techniques
- must be continually tested against new applications
- “the practical application of general theorems is a different art from their establishment by mathematical proof”

Fisher 1958 SMRW



International Statistical Review

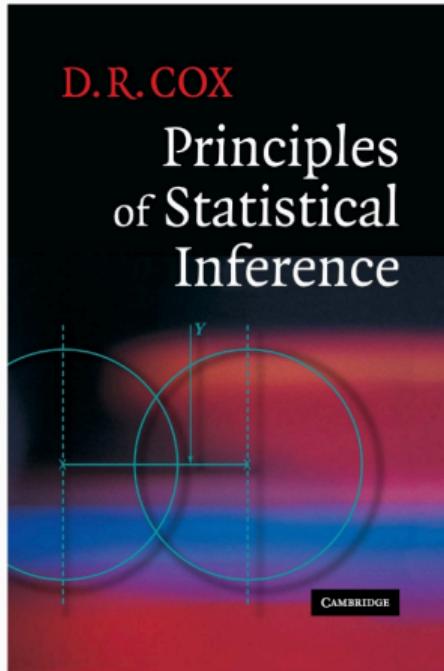
International Statistical Review (2015), 83, 2, 293–308 doi:10.1111/insr.12067

On Some Principles of Statistical Inference

Nancy Reid¹ and David R. Cox²

... What are the foundations of statistics?

- probability, analysis, applied mathematics modelling
- Bayes, Neyman, Fisher approaches to inference
- nature of uncertainty epistemic, empirical
- nature of induction belief functions, inferential models
- **interpretation of p -values, confidence regions, credibility intervals, likelihood ratios**
- role of sufficiency, ancillarity, conditioning, asymptotic theory
- sparsity, causality, assumption-free/lean inference, stability, prediction, decisions

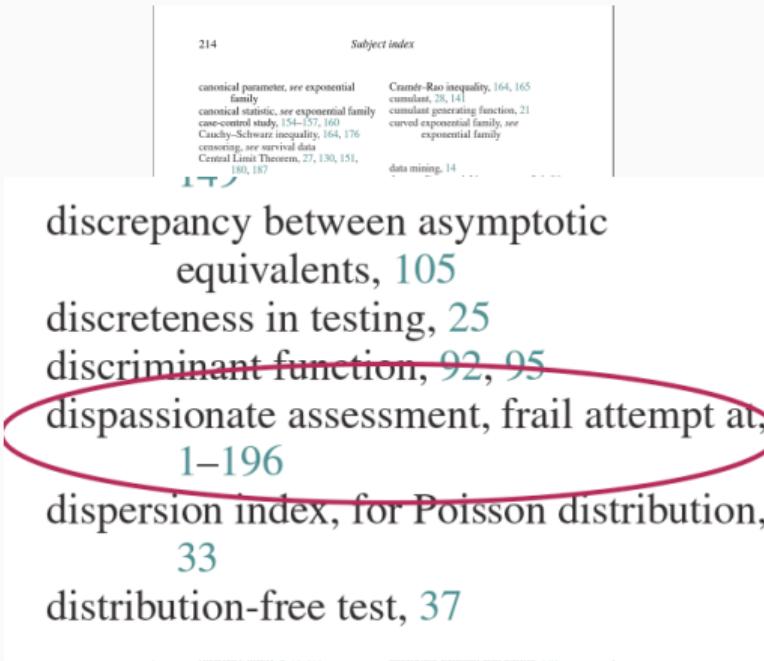


*I'm fairly cautious about the impact of the book in that it really is **very cryptic indeed on key issues** but we will see. In particular **quite apart from the Bayesian stuff** I have essentially discarded (**not rejected**) the Neyman-Pearson machinery in favour of Fisher's original approach and **I am sure this is the right route.***

Thanks to AWF Edwards

... What are the foundations of statistics?

Cox 2006



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“dispassionate assessment, frail attempt at, 1–196”

What use are foundations?

- provide a rigorous basis for the development of techniques
- provide a common language for particular classes of problems
- help to clarify the nature of uncertainty in scientific conclusions
- highlight aspects of data analysis which are likely to raise difficult issues
- suggest strategies for tackling highly complex problems
- avoid ‘re-inventing the wheel’ for each new application

Applications

Climate Change Made East Africa's Drought 100 Times as Likely, Study Says

The findings starkly show the misery that the burning of fossil fuels, mostly by rich countries, inflicts on societies that emit almost nothing by comparison.



NY Times, April 27



JSM August 2023

A water well near the town of Kelofo in Ethiopia, one of the nations hit hardest by the

Human-induced climate change increased drought severity in Horn of Africa

World Weather Attribution, April 27

1. Joyce Kimutai, *Kenya Meteorological Department, Nairobi, Kenya*
2. Clair Barnes, *Grantham Institute, Imperial College London, UK*
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8. Gerbrand Koren, *Copernicus Institute of Sustainable Development, Utrecht University, Utrecht, the Netherlands*
9. Gabriel Vecchi, *Department of Geosciences, Princeton University, Princeton, NJ 08544, USA, High Meadows Environmental Institute, Princeton University, Princeton, NJ 08544, USA*
10. Wenchang Yang, *Department of Geosciences, Princeton University, Princeton, NJ 08544, USA*
11. Sihan Li, *Department of Geography, University of Sheffield*
12. Maja Vahlberg, *Red Cross Red Crescent Climate Centre, The Hague, the Netherlands*
13. Roop Singh, *Red Cross Red Crescent Climate Centre, The Hague, the Netherlands*
14. Dorothy Heinrich, *Red Cross Red Crescent Climate Centre, The Hague, the Netherlands*
15. Carolina Margidian Pereira, *Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, Enschede, the Netherlands; Red Cross Red Crescent Climate Centre, The Hague, the Netherlands*
16. Julie Arrighi, *Red Cross Red Crescent Climate Centre, The Hague, the Netherlands; Global Disaster Preparedness Center, Washington DC, USA; University of Twente, The Netherlands*
17. Lisa Thalheimer, *United Nations University, Institute for Environment and Human Security, Bonn, Germany*
18. Cheikh Kane, *Red Cross Red Crescent Climate Centre, The Hague, the Netherlands; Institut de Recherche pour le Développement, U01000/99AA01, Marseille, France*
19. Friederike E. L Otto, *Grantham Institute, Imperial College London, UK*

Main findings

Applications

Example 2



HEALTH AND SCIENCE

Ivermectin — a drug once touted as a Covid treatment by conservatives — doesn't improve recovery much, clinical trial finds

PUBLISHED MON, OCT 24 2022 3:27 PM EDT | UPDATED TUE, OCT 25 2022 3:49 PM EDT



Applications

Example 2



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The Washington Post

Democracy Dies in Darkness

BUSINESS

Female scientists don't get the credit they deserve. A study proves it.

By Julianne McShane
June 22, 2022 at 11:00 a.m. EDT



Washington Post illustration

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Women are credited less in science than men

[Matthew B. Ross](#), [Britta M. Glennon](#), [Raviv Murciano-Goroff](#), [Enrico G. Berkes](#), [Bruce A. Weinberg](#) &
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[Nature](#) **608**, 135–145 (2022) | [Cite this article](#)

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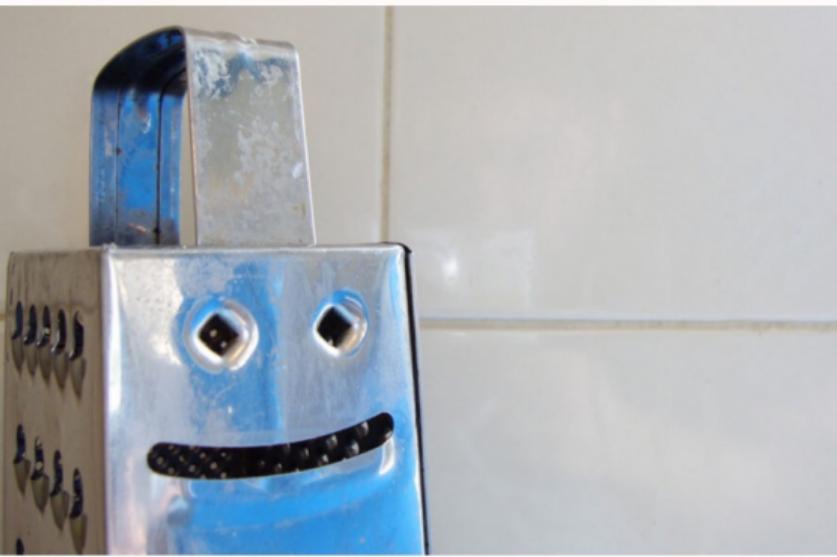
Abstract

There is a well-documented gap between the observed number of works produced by women and by men in science, with clear consequences for the retention and promotion of women¹. The gap might be a result of productivity differences^{2,3,4,5}, or it might be owing to women's contributions not being acknowledged^{6,7}. Here we find that at least part of this gap is the result of unacknowledged contributions: women in research teams are significantly less likely than men to be credited with authorship. The findings are consistent across three very

NEWS NEUROSCIENCE

Americans tend to assume imaginary faces are male

Why people perceive faces in inanimate objects as male by default is still unclear



*People often see imaginary faces in everyday objects, such as this smiling face in a cheese grater. These faces were more often seen as male than female by U.S. adults in a new survey.

*PAUL DAVID GALVIN/MOMENT/GETTY IMAGES PLUS

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Institution: TORONTO

Keyword, A

PNAS

Proceedings of the National Academy of Sciences of the United States of America

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RESEARCH ARTICLE

Illusory faces are more likely to be perceived as male than female

Susan G. Wardle, Sanika Paranjape, Jessica Taubert, and Chris I. Baker
+ See all authors and affiliations

^aPeople often see imaginary faces in everyday objects, such as this smiling face in a cheese grater. These faces were more often seen as male than as new survey.

Linking theory with practice

1. **Drought** Climate change attribution
climate models, subgroup analyses, predictions
2. **Covid** Treatment with Ivermectin
randomized trial, proportional hazards regression, Bayes/frequentist
3. **Women** Co-authorship and gender
linear regression, binary outcome, confounding
4. **Faces** Human perception
sign test, regression, computational modelling

Applications

Drought



Science

NEWS

Deadly African drought not possible without climate change, study finds



Warming climate made long rains twice as likely to underdeliver, World Weather Attribution calculates

Thomson Reuters · Posted: Apr 27, 2023 8:43 AM EDT | Last Updated: April 27

Climate Change Made East Africa's Drought 100 Times as Likely, Study Says

The findings starkly show the misery that the burning of fossil fuels, mostly by rich countries, inflicts on societies that emit almost nothing by comparison.



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News | Drought

Global warming made Horn of Africa drought possible: WWA study

World Weather Attribution scientists say rising greenhouse gas emissions made the nearly 3-year drought at least 100 times more

likely.



A water well near the town of Kelafu in Ethiopia, one of the nations hit hardest by the drought. Eduardo Soteras/Agence France-Presse — Getty Images

Human-induced climate change increased drought severity in Horn of Africa

[Link](#)

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- observational data, 3 sources
 1. global daily rainfall & temperature
 2. daily rainfall
 3. monthly rainfall

$0.5^\circ \times 0.5^\circ$, 1979 –
infra-red, “SoA”, 1981 –
1981–2014
- 4-year smoothed mean surface temperature proxy for anthropogenic climate change
- climate modelling data, 4 sources
 1. combine 12 global and 8 climate models: resolution 0.44°
 2. combine 5 global and 4 climate models: resolution 0.22°
 3. atmosphere-ocean coupled GCMs (two)
 4. sea-surface temperature forced ensemble, high resolution

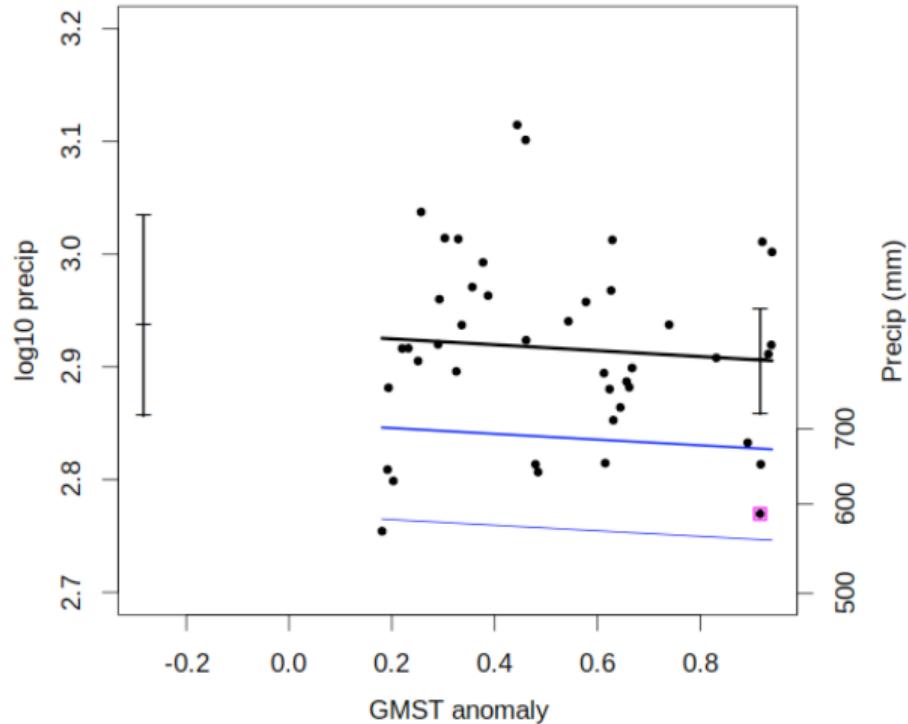
29 sims
10 sims
10/3 simulations
11 simulations
- thanks to Whitney Huang for many clarifications



- response is \log_{10} (monthly rainfall) in 2021 and 2022
and $\log_{10}(\text{PET})$ – potential evapotranspiration
 - covariates are global temperature anomaly, and ENSO index
El Nino-Southern Oscillation
 - “As a measure of anthropogenic climate change we use smoothed GMST”
Global Mean Surface Temperature
 - “Methods for observational and model analysis ... and synthesis are used according to the World Weather Attribution Protocol”
Philip et al. 2020
-
1. trend using observational data
 2. find climate models consistent with 1.
 3. compare predictions from 1. and 2.
 4. synthesize results in 3. to provide conclusions

The results

Kimutai et al. 2023



- rainfall decreasing with increasing temperature but not much
- 2022 rainfall is about a 1 in 20 year event
- 2022 drought about **2 times** more likely under climate change
- uncertainty 0.1 – 360

Climate Change Made East Africa's Drought 100 Times as Likely, Study Says

The findings starkly show the misery that the burning of fossil fuels, mostly by rich countries, inflicts on societies that emit almost nothing by comparison.

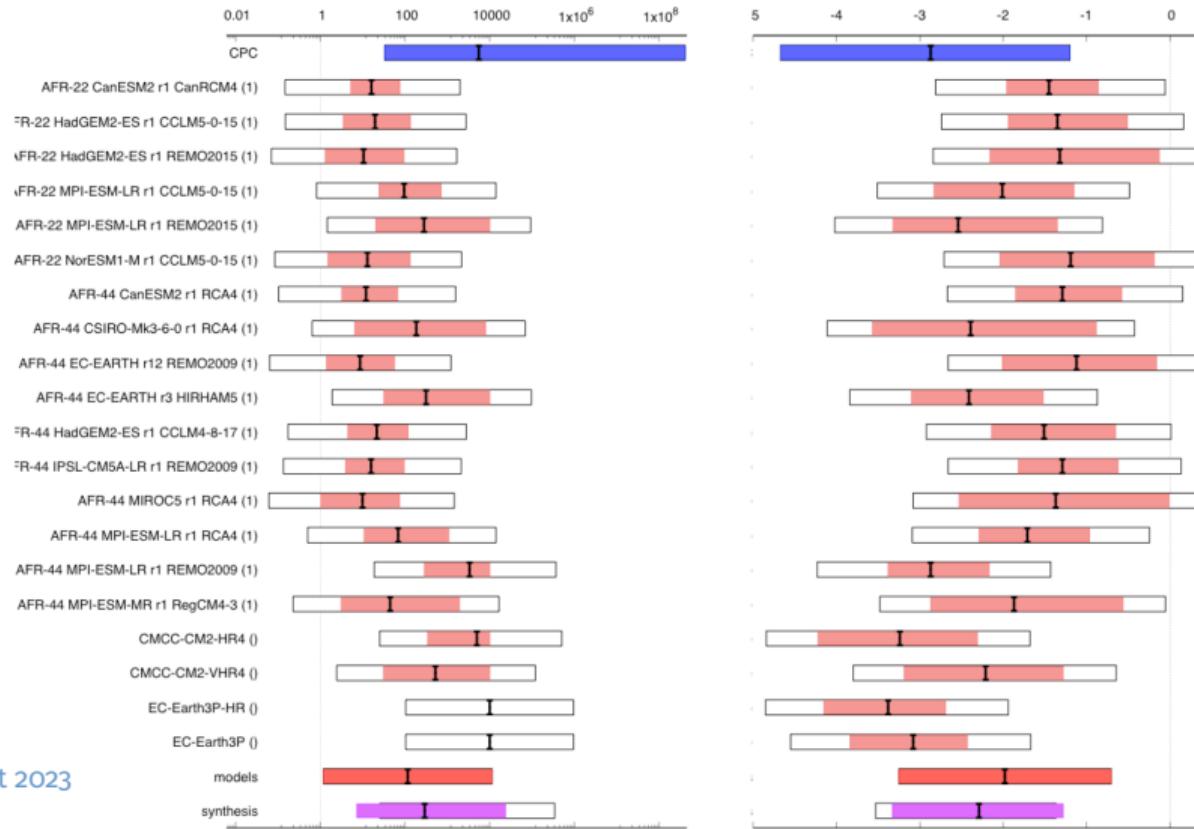


- change the response to SPEI rainfall adjusted for evaporation
- 2022 drought now **5500** times more likely uncertainty 32 to 4×10^8
- consider 'long rains' and 'short rains' separately MAM, OND
- combine model simulation results with observational data

Combining climate simulations and data

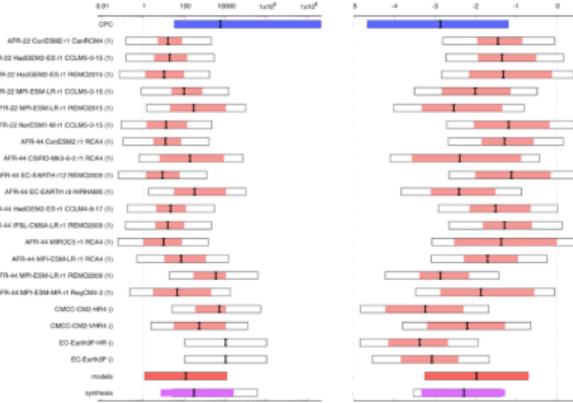
Kimutai et al. 2023

(a) Probability Ratio (*left*) and Intensity change (*right*) for current vs. 1.2degC cooler climates

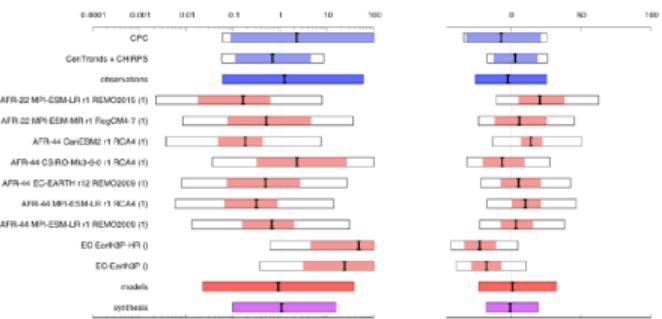


precipitation
adjusted
for evaporation

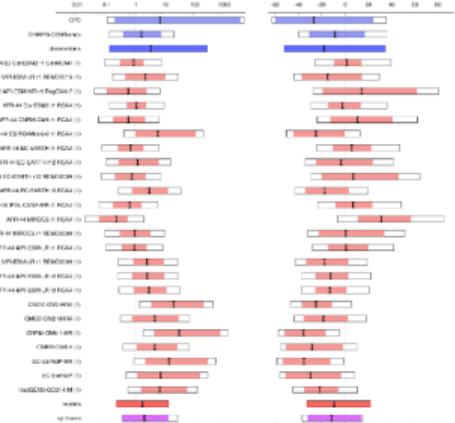
(a) Probability Ratio (left) and Intensity change (right) for current vs. 1.2degC cooler climates



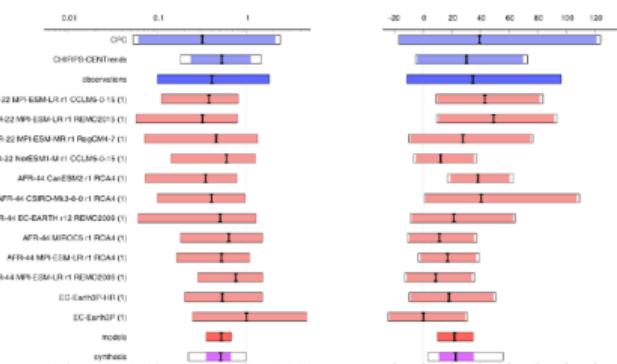
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(a) Probability Ratio (left) and Intensity change (right) for current vs. 1.2degC cooler climates



forest plots

- extrapolation beyond observations
extreme value modelling

Stein Statist. Sci. 2019

- assigning uncertainty to combined results
sources of uncertainty

Senn 2020

- ratios of estimated probabilities
nearly unbounded confidence intervals

CH 1974

- “the whole real line as a confidence interval
does not mean that a vacuous statement is being made”

- joint modelling of precipitation and evapotranspiration
tail copula modelling

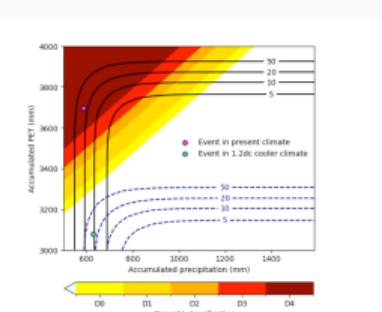


Figure 3: Joint distribution of 24-months precip and PET with corresponding SPEI drought classification (GPC dataset). The solid contours indicate return periods under the joint distribution in the current climate, while the dashed contours indicate the same return periods in a 1.2°C cooler climate. The shaded contours represent

Aside: joint modelling

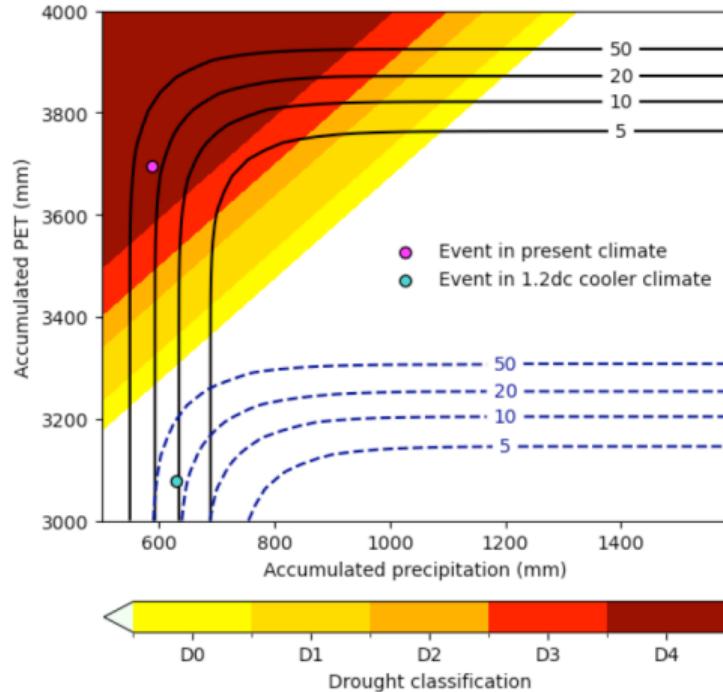


Figure 3: Joint distribution of 24-month precip and PET with corresponding SPEI drought classification (CPC dataset). The solid contours indicate return periods under the joint distribution in the current climate, while the dashed contours indicate the same return periods in a 1.2°C cooler climate. The shaded contours represent different levels of drought severity. The magenta point indicates the 2022 drought event in the current climate.

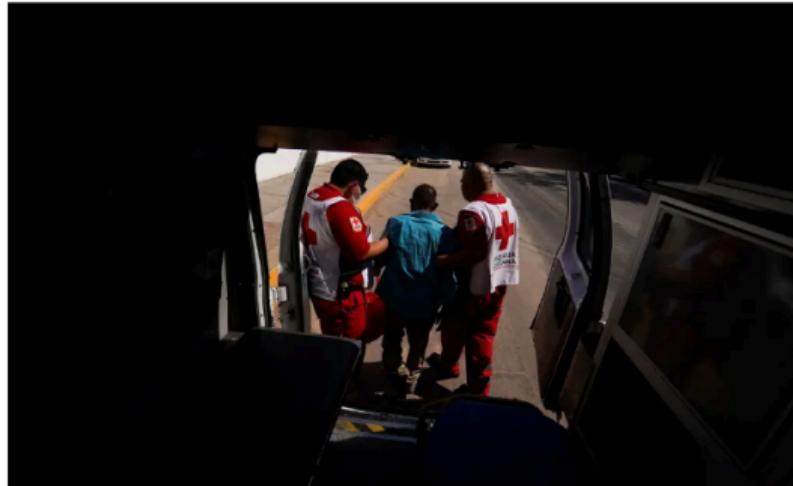
Some July Heat: ‘Virtually Impossible’ Without Climate Change, Analysis Finds

The latest study from World Weather Attribution scientists predicts that extreme heat waves will return more frequently.

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73



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Medicine

Covid



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HEALTH AND SCIENCE

Ivermectin — a drug once touted as a Covid treatment by conservatives — doesn't improve recovery much, clinical trial finds

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JAMA | Original Investigation

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Therapeutic Interventions and Vaccines (ACTIV-6) Study Group and Investigators

- randomized controlled trial
- platform trial of 6 potential treatments multicenter
- analysis of each treatment uses the same placebo group
- 817 patients in treatment arm; 774 in control arm
- primary outcome: time to recovery
- explanatory variables: **treatment**, age, sex, prior symptoms, calendar time, vaccination status, geographic region, center, baseline severity and others

- Bayesian proportional hazards model

$$\lambda(t; x) = \lambda_0(t) \exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_p x_p)$$

- some covariates fit with splines e.g. age
- underlying hazard modelled parametrically e.g. Weibull, or splines
- prior distributions:
 - for parameters of hazard function
 - for coefficients for explanatory variables $\beta_0, \beta_2, \dots, \beta_p$
 - for β_1 – treatment skeptical, noninformative, none
- likelihood \times prior \rightarrow posterior \rightarrow marginal posterior for β_1 or $\exp(\beta_1)$

Key Points

Question Does ivermectin, 400 µg/kg, daily for 3 days, compared with placebo, shorten symptom duration among adult (≥ 30 years) outpatients in the US with symptomatic mild to moderate COVID-19?

Findings In this double-blinded, randomized, placebo-controlled platform trial conducted in the US during a period of Delta and Omicron variant predominance, and that included 1591 adult outpatients with COVID-19, the posterior probability of improvement in time to recovery in those treated with ivermectin vs placebo had a hazard ratio of 1.07, with a posterior probability of benefit of .91. This did not meet the prespecified threshold of posterior probability greater than .95.

Meaning These findings do not support the use of ivermectin in outpatients with mild to moderate COVID-19.

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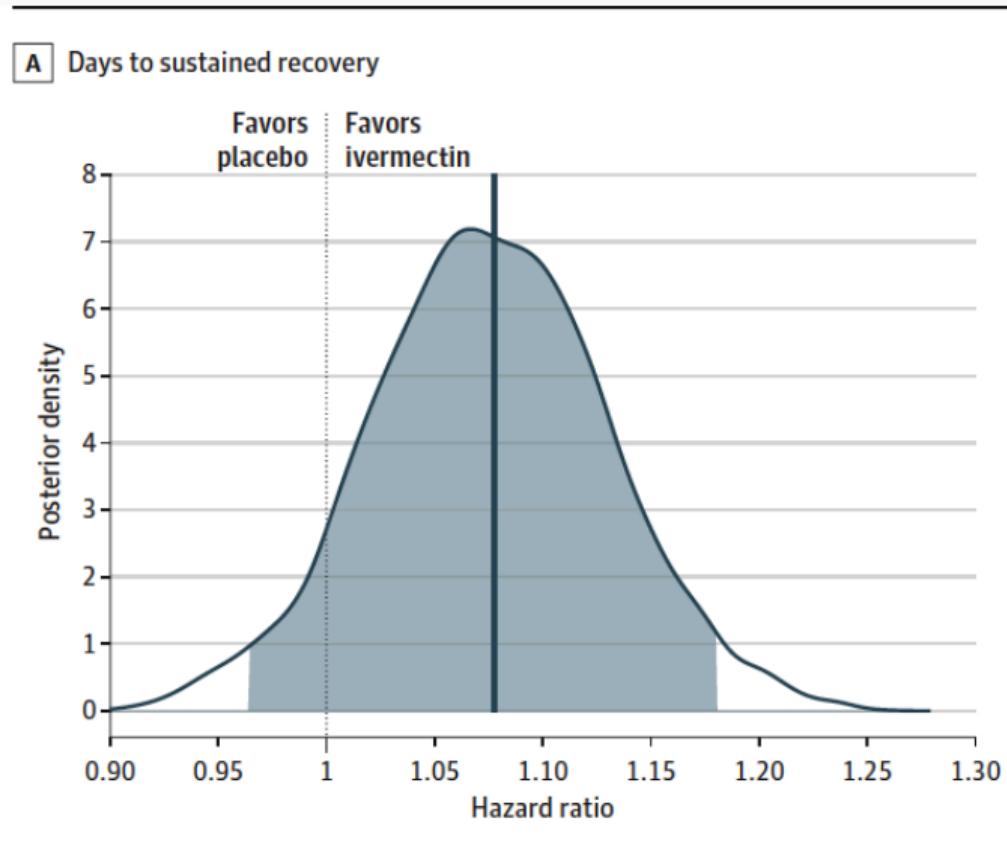
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Meaning These findings do not support the use of ivermectin in outpatients with mild to moderate COVID-19.

“Among outpatients with mild to moderate COVID-19, treatment with ivermectin, compared with placebo, did not significantly improve time to recovery.”

Hazard ratio estimated at 1.07, with posterior probability that $HR > 1 = 0.91$

“This did not meet the prespecified threshold of posterior probability greater than 0.95”



The theory: modelling and conditional inference

- Cox 1972: On regression models and life tables
- sets out proportional hazards regression and non-proportional

$$\lambda(t; x) = \lambda_0(t) \exp(x^T \beta)$$

- proposes analysis via **partial likelihood** eliminates hazard function
- uses point process modelling + conditional inference

- full likelihood function $L(\beta, \lambda) \propto \prod_{j=1}^n \{\lambda_0(t_j) \exp(x_j^T \beta)\}^{\delta_j} \exp\{-\exp(x_j^T \beta) \Lambda_0(t_j)\}$

- partial likelihood function $L_{part}(\beta) \propto \prod_{failures} \frac{\exp(x_j^T \beta)}{\sum_{k \in \mathcal{R}_j} \exp(x_k^T \beta)}$

The theory: Bayes and frequentist

Research Original Investigation

Effect of Ivermectin vs Placebo on Time to Sustained Recovery in Outpatients With Mild to Moderate COVID-19

Table 2. Primary and Secondary Outcomes

	Group, No. (%)		Adjusted estimate (95% CrI) ^a	Posterior P value (efficacy)
No.	Ivermectin	Placebo		
Primary end point, time to recovery ^b				
Skeptical prior (primary analysis)			HR, 1.07 (0.96 to 1.17)	.91
Noninformative prior (sensitivity analysis)			HR, 1.09 (0.97 to 1.22)	.93
No prior (sensitivity analysis)			HR, 1.09 (0.98 to 1.22) ^c	

Skeptical prior	1.07	(0.96 – 1.17)	0.91
Noninformative prior	1.09	(0.97 – 1.22)	0.93
No prior	1.09	(0.98 – 1.22)	

The theory: Bayes and frequentist

- both methods often lead to the same conclusions but not always
- Wasserman 2015; 2022
 - Stein 1959
 - Stone 1970
 - Robins and Ritov 1997
 - ...
- the nature of the conclusions is different
 - probability representing degree of uncertainty
 - probability representing long-run frequency

epistemic
aleatory
- calibration of Bayesian inference assesses the first on the basis of the second

Cox 1958, BFF

Applications

Women

The Washington Post

Democracy Dies in Darkness

BUSINESS

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Washington Post illustration

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Abstract

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Abstract

- “finding ‘what isn’t there’ from ‘what is there’ is a fundamental problem in statistics”
- analytic data
 - 118 campuses send de-identified data to U Michigan
 - + survey + qualitative analysis
 - tracks spending on personnel for each research project
 - payroll, all funding sources
 - 57 campuses with complete data 2013–2016
 - identify **teams**: PI, faculty, PDF, PhD, UGrad, Research Staff
 - identify **publications**: Web of Science
 - identify **gender**, job titles, scientific fields, patents, ...
- 9800 teams with 129,000 team members
- 39,000 articles; 18m ‘potential authorships’; 367,000 actual authorships
 - scientific articles

- **response** attribution rate = $\frac{\# \text{ actual authorships}}{\# \text{ potential authorships}} = \text{pr(attribution)}$
- **covariates** date of publication, number of days worked in the team, calendar time, position in the team, team's PI
- **model**
$$P(\text{ named }) = \beta_0 + \beta_1 \text{woman} + \beta^T \text{ covariates} + \text{ error}$$

Empirical strategy

The empirical approach was to estimate linear regressions using a model of the form

$$\begin{aligned} P[\text{named}_{i,t,e,l}] & \dots \\ & = \beta_0 + \beta_1 \text{woman}_{i,e} + X_{i,e} + M_{i,t} + O_{i,e} + \text{Team}_{i,l} + \mu_{i,t,e,l} \end{aligned} \tag{1}$$

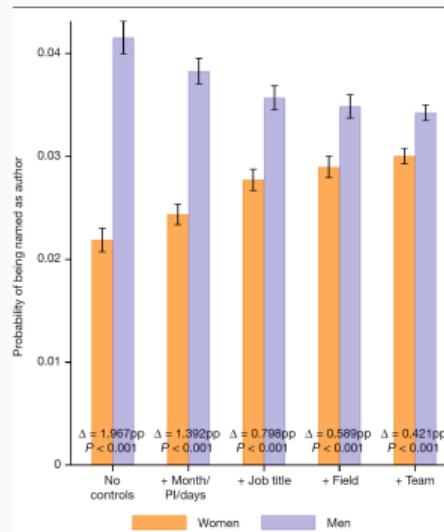
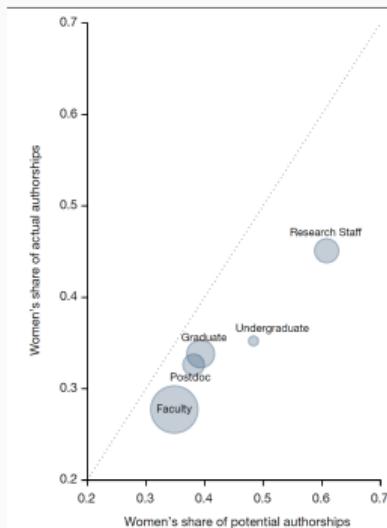
overall attribution rate 3.1%;

attribution rate for men 4.23%; attribution rate for women 2.12%

includes patents

difference smaller when covariates included

but still statistically significant



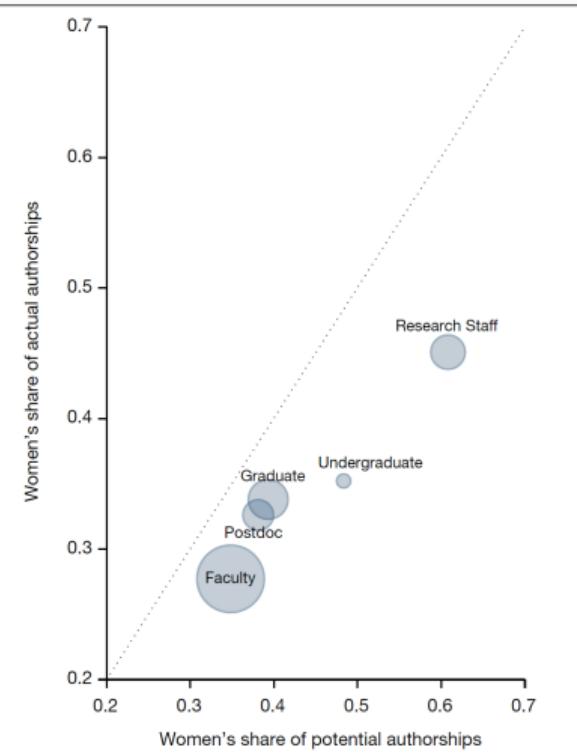


Figure 1

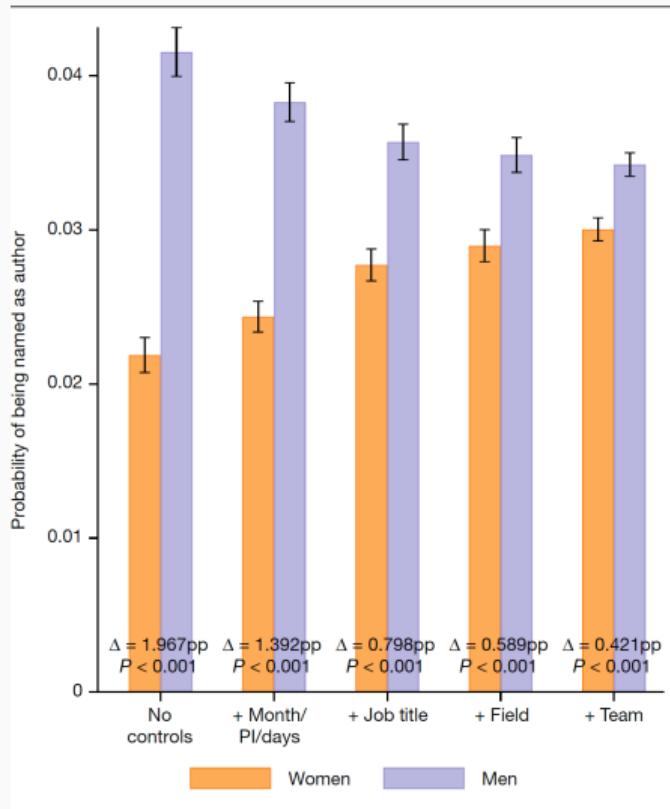
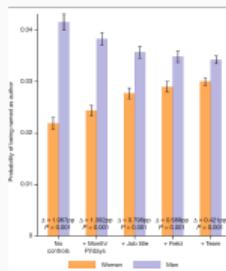


Figure 2

- linear regression with response a proportion
- logistic function is pretty linear for $p \in (0.2, 0.8)$ but these p 's $\in (0.01, 0.04)$
- there's a paper for that!
On the linear in probability model for binary data Battey, Cox & Jackson 2019
- possibly more concerning: what is the unit of observation? calculation of standard errors
- conditional inference



relevant subsets; adequate variability

Applications

Fun

NEWS NEUROSCIENCE

Americans tend to assume imaginary faces are male

Why people perceive faces in inanimate objects as male by default is still unclear



Institution: TORONTO

Keyword, A

PNAS

Proceedings of the National Academy of Sciences of the United States of America

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RESEARCH ARTICLE

Illusory faces are more likely to be perceived as male than female

Susan G. Wardle, Sanika Paranjape, Jessica Taubert, and Chris I. Baker
+ See all authors and affiliations

*People often see imaginary faces in everyday objects, such as this smiling face in a cheese grater. These faces were more often seen as male than as new survey.

PAUL DAVID GALVIN/MOMENT/GETTY IMAGES PLUS

PNAS

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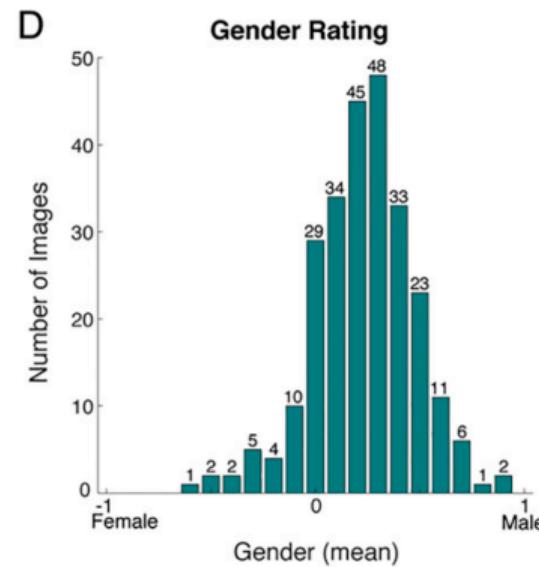
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ARTI

... The source

Wardle et al. PNAS 2021





Will AI really change everything? Not likely

Although tools like ChatGPT can astonish us with their output, they are not operating anywhere near human intelligence

JOSEPH WILSON

OPINION

PhD candidate in linguistic anthropology at the University of Toronto

Do you have AI fatigue yet? Not a day goes by without breathless commentary on the increasing power of artificial-intelligence models. A deluge of new apps and services promises to disrupt everything from health care to law to education. "The future is here," we are told. "Are you ready?"

The answer is no. Not if we are

blindly optimistic, claiming that AI will magically solve everything from climate change to the opioid crisis, or they are darkly dystopian, warning us that AI could escape its silicon chains and destroy humanity.

Even when AI developers themselves "warn" people of the existential threats AI could pose, as they did in an open letter recently calling for a pause in development, it functions as a marketing campaign. The tech companies are essentially congratulating each other for creating something too good. Google's chief executive, Sundar Pichai, has called AI, without irony, a technology "more profound than fire or electricity."

The public doesn't know what to believe and they're worried. A newly released poll conducted by Innovative Research Group for the 2023 Provocation Ideas Festival shows that 47 per cent of Canadians are more concerned than excited about the increased

"future-proof your career" or "become AI literate."

The reality is that most of what we read about AI is hype. In the near term, this new crop of AI tools will probably give us slightly better-written spam in our inboxes and reams of crappy, machine-generated websites. Real, life-saving applications are indeed possible in fields such as health care and agriculture, but they'll be hard to spot amid all the junk. Although tools such as ChatGPT and Midjourney are fun to play with and can astonish us with their output, they are not operating anywhere near human intelligence. They are essentially performing a clever parlour trick.

The reason we are astonished by their output is because, as a species, we're gullible. We tend to read human characteristics into any pattern that even mildly resembles a human. We see faces in electrical sockets and spot human silhouettes in evening shadows. We feel bad for a discarded

heightened empathy is one of the ways technology companies have captured the public's attention in recent months. OpenAI launched ChatGPT (which generates text) and DALL-E (which generates images) online and for free so the public could play around with them. It let the public work itself into a frenzy as they identified characteristics in the programs that were previously thought to be exclusively human: reason, humour, emotion, creativity. But generative AI can do none of these things. It has the form of human expression but no content.

The technology that runs under the hood of these tools is not fundamentally new. The mathematical models have changed in recent years, and new chips are making computation cheaper and more efficient, but ChatGPT only functions like a powerful autocomplete feature. Trained on an enormous amount of data, the model predicts which words

sky-high, further concentrating capital and technological know-how in the hands of very few billionaires. As such, the field of AI is desperately in need of regulation. This is necessary not because tech companies might unleash a mathematical model that will suddenly become conscious and take over the world, but for the very real, boring reasons that have always existed: so they don't take advantage of poorly paid temp workers, or refuse calls to be transparent with their algorithms, or flood social media with misinformation, or violate copyright laws by scraping the web for data without the permission of its owners. Sadly, these are things that Big Tech is already doing, and governments have been slow to act.

Fear, as populist politicians and headline writers know well, is best evoked by appealing to the unknown. Whether it's the fear of AI-gone-rogue or the fear of falling behind in the race to the future, in the fight to take

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Back to Foundations

Linking theory with practice

1. **Drought** Climate change attribution
climate models, subgroup analyses, predictions
2. **Covid** Treatment with Ivermectin
randomized trial, proportional hazards regression, Bayes/frequentist
3. **Women** Co-authorship and gender
linear regression, binary outcome, confounding
4. **Faces** Human perception
sign test, regression, computational modelling

What did I learn

- statistical “workflows” seem to be emerging in different disciplines
 - Drought – “A Protocol for probabilistic extreme event attribution analysis ”
Philip et al 2020, *Adv. Stat. Clim. Met. Ocean*
 - “Writing statistical methods for ecologists”
Davis & Kay 2023, *Ecosphere*
- tutorial-type articles in scientific journals
 - *Annals of Thoracic Surgery* – the statistician’s page
 - *J Am Medical Association* – Guide to Statistics and Methods
 - *Nature Methods* – Points of Significance
- “open data” observed in the breach
 - Drought – “Almost all the data are available via the KNMI Climate Explorer”
 - Women – “datasets ... are available at the Virtual Data Enclave Repository”
 - Covid – “... the data will be made publicly available”
- Communication

June 5, 2023



SmartBrief

Your World of Science News

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Study predicts extreme precipitation to increase by 52%

Precipitation events that deliver heavy rainfall or melted snowfall in one day are predicted to increase 52% in the Northeast by the end of the century, according to a study in Climatic Change. There will be a large increase in the number of days with extreme rain or snow, researchers predict, and a smaller increase in the amount of precipitation during each event, with extreme precipitation expected to happen mostly in winter and spring.

Full Story: New Hampshire Public Radio (6/5)



Human Cell Atlas project reveals new information about cellular function

Researchers working on the Human Cell Atlas project are learning more about how the placenta, immune system, brain, lungs and other organs function, and they have discovered thousands of new types of cells using single-cell genomics and advanced computational technology. The researchers have discovered how placental cells interact and function, identified a previously unknown lung cell type involved in cystic fibrosis, and identified two sets of nasal cells SARS-CoV-2 uses to infect people.

Full Story: The Guardian (London) (6/3)



US life expectancy has been declining for decades

A report in the American Journal of Public Health found US life expectancy has been steadily declining since the 1950s, and the COVID-19 pandemic further widened the gap between the US and other high-income nations, as the US recorded more deaths from the

“US Life expectancy has been declining for decades”

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Abstract

Objectives. To document the evolution of the US life expectancy disadvantage and regional variation across the US states.

Methods. I obtained life expectancy estimates in 2022 from the United Nations, the Human Mortality Database, and the US Mortality Database, and calculated changes in growth rates, US global position (rank), and state-level trends.

Results. Increases in US life expectancy slowed from 1950 to 1954 (0.21 years/annum) and 1955 to 1973 (0.10 years/annum), accelerated from 1974 to 1982 (0.34 years/annum), and progressively deteriorated from 1983 to 2009 (0.15 years/annum), 2010 to 2019 (0.06 years/annum), and 2020 to 2021 (-0.97 years/annum). Other countries experienced faster growth in each phase except 1974 to 1982. During 1933 to 2021, 56 countries on 6 continents surpassed US life expectancy. Growth in US life expectancy was slowest in Midwest and South Central states.

Conclusions. The US life expectancy disadvantage began in the 1950s and has steadily worsened over the past 4 decades. Dozens of globally diverse countries have outperformed the United States. Causal factors appear to have been concentrated in the Midwest and South.

June 5, 2023



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In mice

and in cells

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- probability, analysis, applied mathematics modelling
- Bayes, Neyman, Fisher approaches to inference
- nature of uncertainty epistemic, empirical
- nature of induction belief functions, inferential models
- interpretation of *p*-values, confidence regions, credibility intervals, likelihood ratios
- role of sufficiency, ancillarity, conditioning, asymptotic theory
- sparsity, causality, assumption-free/lean inference, stability, prediction

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