

# **Joint-Outcome Expert Prediction Markets for Climate Risks**

Conditional Forecasting with the LMSR

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Acknowledgment: this presentation is based on



- ▶ Roulston, Kaivanto: “Joint-outcome prediction markets for climate risks”, under review
- ▶ Roulston, Kaivanto: “Can expert prediction markets forecast climate-related risks? Probabilistic calibration and information-add”, under review
- ▶ Roulston, Day, Kaplan, Kaivanto: “Prediction-market innovations can improve climate-risk forecasts”, *Nature Climate Change* 2022

▶ <https://www.crucialab.net/>





- ▶ Multiplicity of methodological & procedural choice – **abundance of**
  - ▶ Berg, Köbel, Rigobon, “Aggregate Confusion: The Divergence of ESG Ratings”, *RoF* 2022
  - ▶ Menkveld et al., “Nonstandard Errors”, *JoF* 2024
  - ▶ Sognnaes et al., “A multi-model analysis of long-term emissions and warming implications of current mitigation efforts”, *NCC* 2021
  - ▶ ‘single dataset, many researcher’ studies in psychology, economics, statistics, neuroscience, ...
- ▶ Incentives – **adverse**
- ▶ Multi-disciplinary problem – **need a level playing field and mechanism for integrating**
- ▶ Circularity problem – **unconditional forecasts unhelpful for policy making**
- ▶ Data gaps – **still substantial**



Two methods for eliciting and aggregating (expert or non-expert) beliefs about climate-related variables:

1. When verifiable outcome will (eventually) be realized:

‘Subsidized’ LMSR prediction markets

2. Outcome of interest not ultimately verifiable, but is subjective::

Bayesian Truth Serum + Surprisingly Common Criterion



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## Motivation recap

- LMSRs solve the challenges

## LMSR algorithmic market maker

- Trading environment

- Logarithmic Market Scoring Rule (LMSR)

## Quality of forecasts

- Calibration

- Information-add

## Joint-Outcome Markets

- Design challenge

  - Outcome space

- Results

## Conclusions



- ▶ Incentives – Participants rewarded in proportion of the information they impound into the market; ‘incentive-compatible mechanism’
- ▶ Multiplicity of methodological choice – Participation invited from users of different approaches, different models
- ▶ Multi-disciplinary problem – Participation invited also from country specialists in politics, energy policy, economics, ...
- ▶ Circularity problem – Resolved with joint-outcome markets, giving *conditional* forecasts

Pre-funded expert prediction markets, with algorithmic market maker

Specifically: joint-outcome markets, e.g. temp anomaly x CO<sub>2</sub> concentration



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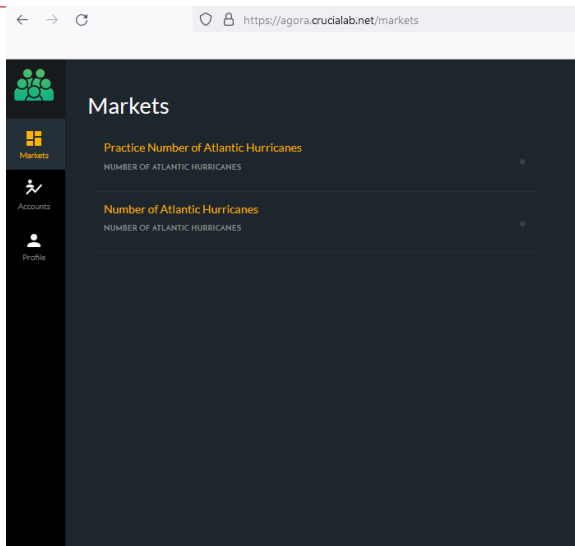
## Conclusions





- ▶ rather than open 'pay to play' (!), participation by invitation only, and each market is pre-funded with an endowment of real fiat
- ▶ each participant endowed with on-platform credits
- ▶ optionally: participant endowment transferable between markets
- ▶ when market closes, each contract for the realised outcome becomes worth 1 credit; all others become worthless  
i.e. Arrow securities
- ▶ credits can be redeemed at a pre-defined exchange rate  
(e.g. 1 on-platform credit = £1) from the pre-funded payout pool
- ▶ participants can sell their contracts early; there is no need to hold to maturity

# Trading environment: interface



## Trading environment: defining a contract on outcome '8'



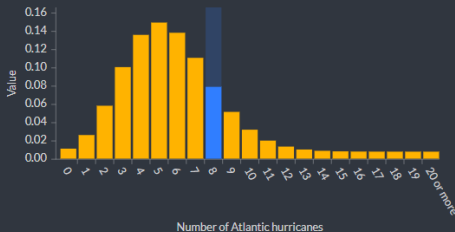
### Number of Atlantic Hurricanes

STATUS

Open

AVAILABLE CREDITS

1000.000



Create a contract by selecting the desired outcomes on the graph, then enter a name for the contract and click 'Create'.

Name: 8

Create

Cancel

# Trading environment: order for 100 contracts



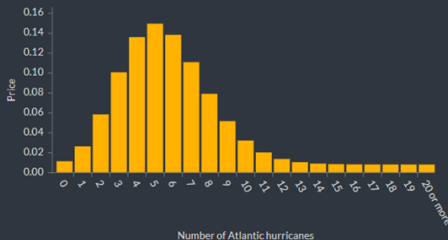
## Number of Atlantic Hurricanes

STATUS

Open

AVAILABLE CREDITS

1000.000



Contract	Price	Quantity	Order	Action	Inst. Value	Liq. Value
8	0.079	100	100	BUY 100 @ 0.081	0.000	0.000
Total:					0.000	0.000

+ Create a new contract

## Trading environment: contract on '9 or more'



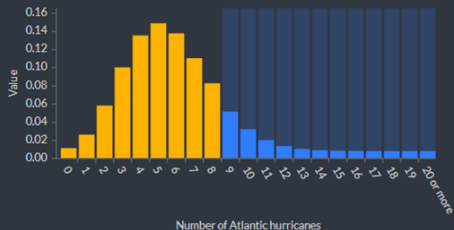
### Number of Atlantic Hurricanes

STATUS

Open

AVAILABLE CREDITS

991.895



Create a contract by selecting the desired outcomes on the graph, then enter a name for the contract and click 'Create'.

Name: 9 or more hurricanes

Create

Cancel

## Active Markets

CRUCIAL's inaugural market is live



# CAHM24

CRUCIAL Atlantic Hurricane Market 2024 (CAHM24) launched on Dec 11, 2023, and will run until the end of the 2024 Atlantic hurricane season. This market is to predict the number of Atlantic hurricanes that occur during the 2024 Atlantic hurricane season.

# Live market: CAHM24 price-probabilities



## CAHM24 price-probabilities

outcome	price	date (d.m.y)
0	0.004	11.04.2024
1	0.009	
2	0.026	
3	0.045	
4	0.047	
5	0.052	
6	0.048	
7	0.065	
8	0.091	
9	0.112	
10	0.13	
11	0.132	
12	0.113	
13	0.061	
14	0.025	
15	0.016	
16	0.009	
17	0.005	
18	0.004	
19	0.003	
>=20	0.003	



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- ▶ Cost function  $C(\mathbf{q}) = b \log \left( \sum_{i=1}^m e^{q_i/b} \right)$ 
  - ▶  $q_i$  the mm's exposure to outcome  $i$
  - ▶  $m$  the number of outcomes
  - ▶  $b$  the *liquidity parameter* determines the mm's maximum net loss
- ▶ prevailing (marginal) price of each outcome  $j$ :  $p_j = \frac{\partial C}{\partial q_j} = \frac{e^{q_j/b}}{\sum_{i=1}^m e^{q_i/b}}$
- ▶ n.b. prices are normalised, hence can be directly interpreted as *probabilities*
- ▶ asking price for order that changes mm's exposure from  $q_i$  to  $q_i + w_i$ :  
 $C(\mathbf{q} + \mathbf{w}) - C(\mathbf{q})$
- ▶ the reward participants receive is linear in the logarithmic scoring rule



- ▶ the LMSR mm is designed to lose money in return for information; there is no bid-ask spread, neither is there a trading commission
- ▶ it is a “strictly proper scoring rule”, hence incentive compatible
- ▶ under the LMSR, the mm’s maximum payout is bounded from above by  $b \log m$
- ▶ hence real-money market/experiments can be run, with non-negligible fiat incentives, with mathematical certainty of staying within *ex ante* budgetary limits



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## 24 markets successfully run with platform



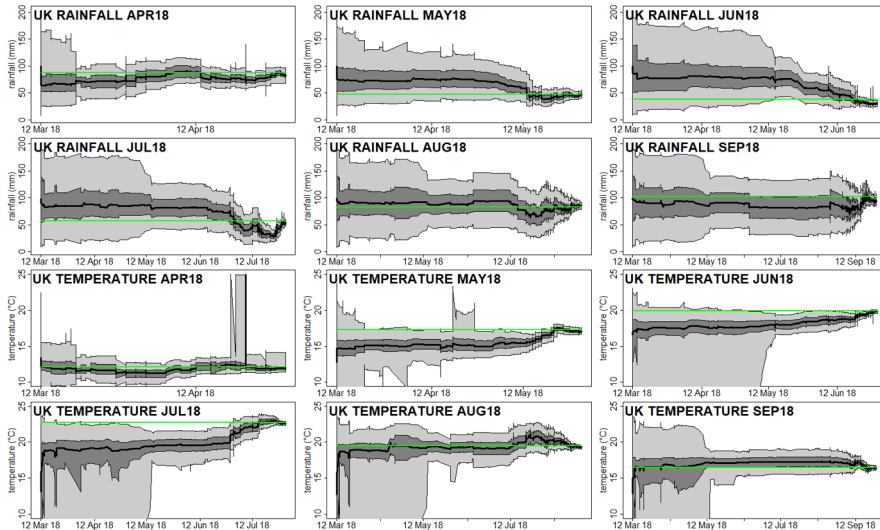
PREDICTED VARIABLE	PERIOD	OPENING DATE	MAX. HORIZON (months)	TRADES
UK total rainfall	APR 2018	MAR 12 2018	2	2202
UK total rainfall	MAY 2018	MAR 12 2018	3	2529
UK total rainfall	JUN 2018	MAR 12 2018	4	1474
UK total rainfall	JUL 2018	MAR 12 2018	5	1189
UK total rainfall	AUG 2018	MAR 12 2018	6	1793
UK total rainfall	SEPT 2018	MAR 12 2018	7	14120
UK av. daily max temp	APR 2018	MAR 12 2018	2	2202
UK av. daily max temp	MAY 2018	MAR 12 2018	3	2529
UK av. daily max temp	JUN 2018	MAR 12 2018	4	1474
UK av. daily max temp.	JUL 2018	MAR 12 2018	5	1189
UK av. daily max temp.	AUG 2018	MAR 12 2018	6	1793
UK av. daily max temp.	SEPT 2018	MAR 12 2018	7	14120
NINO3.4SSTA	JUL 2019	APR 3 2019	4	385
NINO3.4SSTA	AUG 2019	APR 3 2019	5	84
NINO3.4SSTA	SEP 2019	APR 3 2019	6	93
NINO3.4SSTA	OCT 2019	APR 3 2019	7	96
NINO3.4SSTA	NOV 2019	APR 3 2019	8	78
NINO3.4SSTA	DEC 2019	APR 3 2019	9	131
NINO3.4SSTA	JAN 2020	APR 3 2019	10	205
NINO3.4SSTA	FEB 2020	APR 3 2019	11	180
NINO3.4SSTA	MAR 2020	APR 3 2019	12	296
Atlantic hurricanes	JUN-NOV 2020	AUG 14 2020	3	594
US hurricane landfalls	JUN-NOV 2020	AUG 14 2020	3	501
UK wheat yield	2020/21 season	FEB 1 2021	11	183



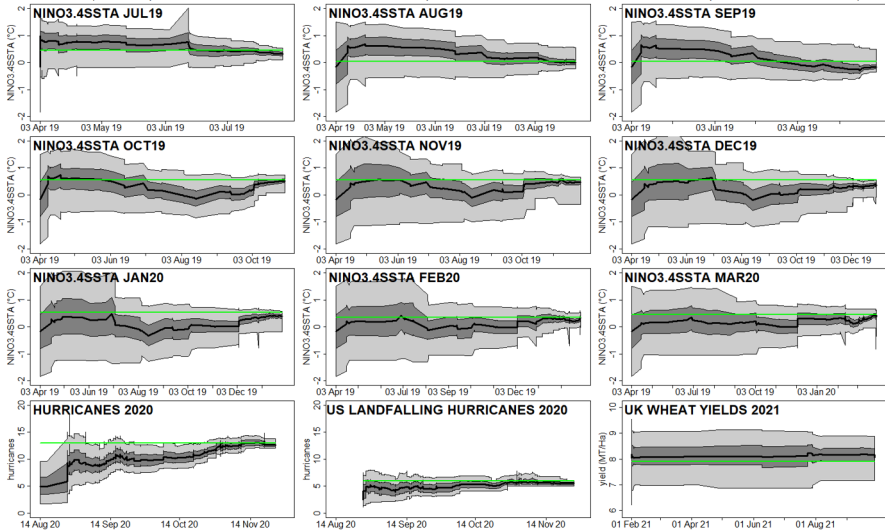
overleaf:

The evolution of the price distributions throughout each of the 24 markets. The black line represents the median of the implied probability distributions while the gray envelopes represent the 50% and 90% intervals. The green line is the outcome that was ultimately observed.

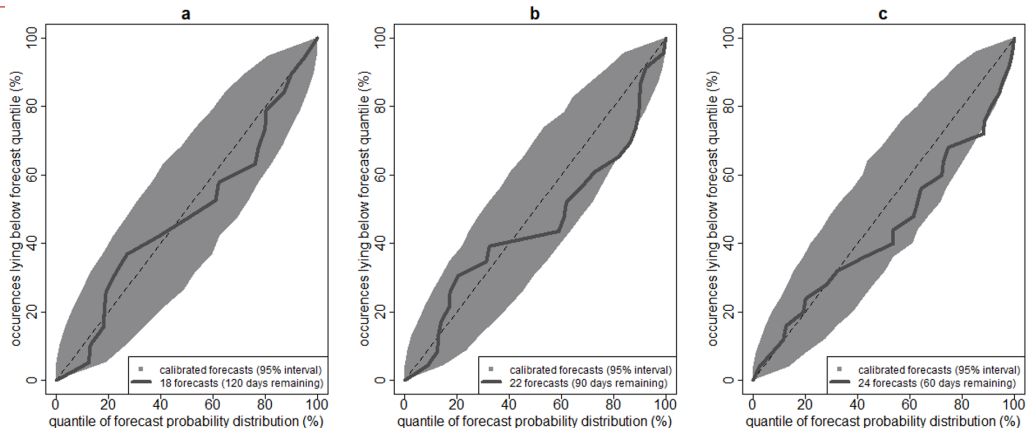
# 12 markets' price distribution plots



# Remaining 12 markets' price distribution plots



## Calibration plots



Reliability Q-Q curves for the 24 markets. Panels show the reliability of the forecasts at lead times of 120, 90, and 60 days. Gray envelopes represent reliability curves for perfectly reliable forecasts constructed by drawing synthetic verifications from the probability distributions implied by market prices. 95% of the reliability curves for these perfect forecasts lie within the envelope.





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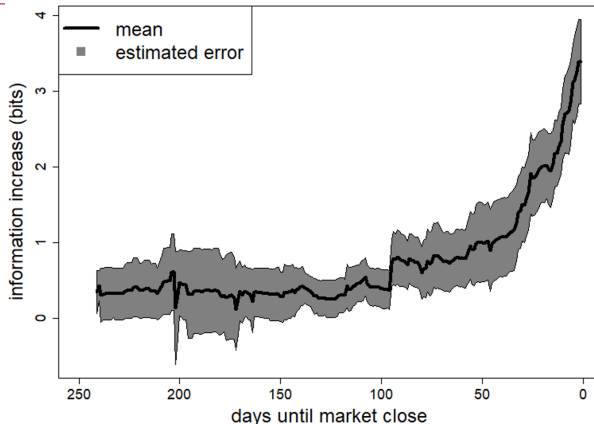
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## Information added over climatological means (bits)



The mean relative information of the probability forecasts generated by the prediction markets. The forecasts were benchmarked against a climatological distribution estimated from historical observations of the variable being predicted. The error was estimated by bootstrap resampling of the forecast categories (UK temperature, UK rainfall, NINO3.4 SST, hurricanes, and UK wheat yield)



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- ▶ We increase the number of partitions by more than an order of magnitude
  - ▶ The Gates-Hillman Prediction Market (CMU) outcome space had 365 partitions
- ▶ We are the first to construct and demonstrate the viability of the joint-outcome (two-dimensional) PM
  - ▶ This solves the circularity problem
- ▶ *Can subjects engage with the complexity – the 2D structure and large number of partitions – to effectively express and aggregate their views?*



- ▶ 6 markets for UK: April, May, June, July, August, September 2018
- ▶ all markets opened 12 March 2018
- ▶ outcome: **monthly average daily high temperature** x **monthly total rainfall**
- ▶ temperature partition: 0.2C intervals between 0C and 25C; open intervals above & below
- ▶ rainfall partition: 5mm intervals between 0mm and 200mm, with open interval above
- ▶  $127 \times 41 = 5,207$  mutually exclusive and comprehensively exhaustive outcomes
- ▶ this fine partition of the outcome space can create a liquidity problem; *but* LMSR solves!
- ▶ participants can specify any combination of partitions (outcomes) as a 'contract'
- ▶ each claim on the partition containing the realised outcome becomes worth 1 credit; all others become worthless



- ▶ 28 teams from British universities (expertise in meteorology, climate science, statistics, machine learning, economics)
- ▶ each team endowed with 1000 on-platform credits
- ▶ total incentive pool £55,000
  - ▶ 1<sup>st</sup>-place credit tally awarded £10,000
  - ▶ 2<sup>nd</sup>-place credit tally awarded £9,000
  - ▶ ...
  - ▶ 10<sup>th</sup>-place credit tally awarded £1,000
- ▶ gradual decline with placing intended to offset distortion introduced by tournament element



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Fig 1: Prices in the market for U.K. average daily high temperature and total monthly rainfall for July 2018 on 15 May 2018

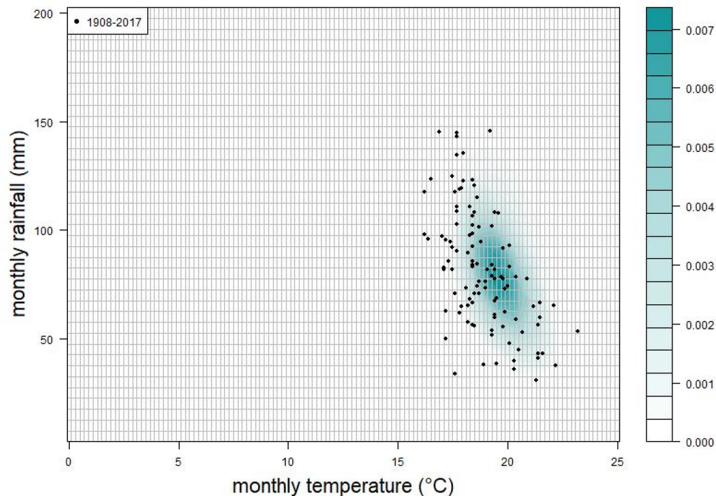




Fig 2: Daily number of trades and volume for each of the monthly markets

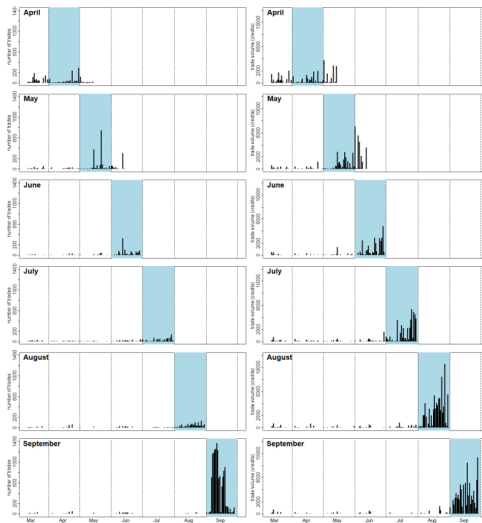


Fig 3: Evolution of marginal price distributions for UK average daily high temperature and monthly rainfall, April to Sept 2018

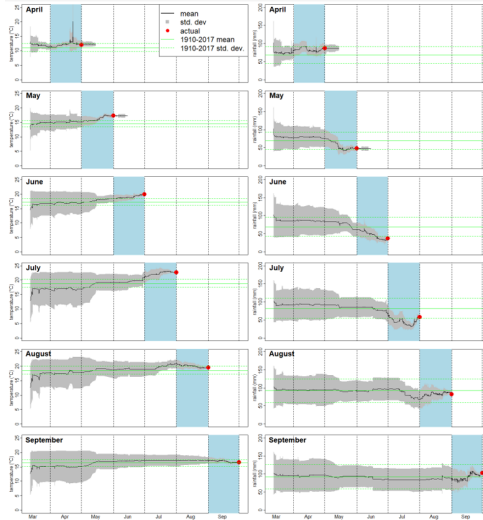


Fig 4: Animation of prices in the market for U.K. average daily high temperature and total monthly rainfall for June 2018



<https://www.crucialab.net/media/June2018.gif>



- ▶ British university participants quickly adapted to prediction markets as a mechanism through which to contribute their expertise
- ▶ a number of teams made use of the API, and adopted specialised division of labour
- ▶ conditional forecasting via joint-outcome markets proved viable, even with large, fine-grained outcome spaces
- ▶ LMSR prediction markets a potential laboratory for *Experimental Sustainable Finance*



Thank you!

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