CDMX
2023

Modeling the health impacts of time-varying climate factors: heat and mortality

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(special thanks to Prof. Brisa Sanchez)

DREXEL UNIVERSITY
Urban Health Collaborative
Dornsife School of Public Health

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Introduction

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1. Common challenges in climate and health research
   - Example: Heat and mortality

2. Distributed lag non-linear models (DLNM)

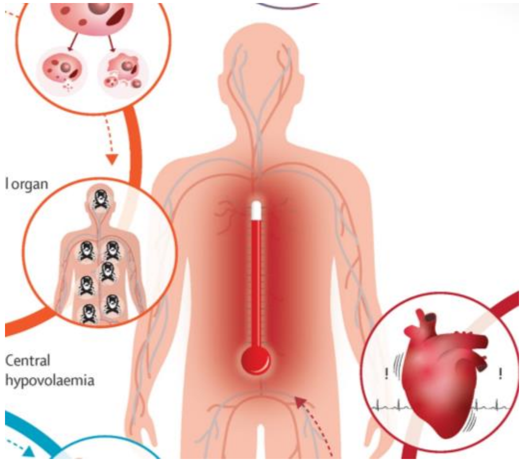
3. Demonstration: MS85, heat and mortality

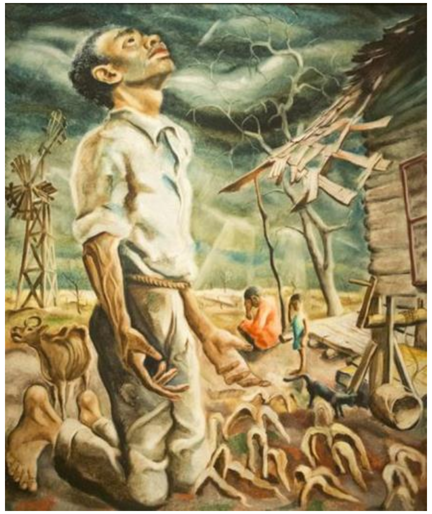
4. Resources

Climate and health: common challenges

CDMX 2023

1. Effects not always immediate
   - Time-scale: ???





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Climate and health: complex associations

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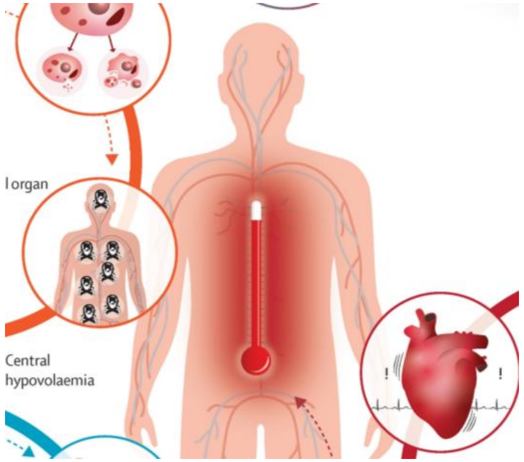
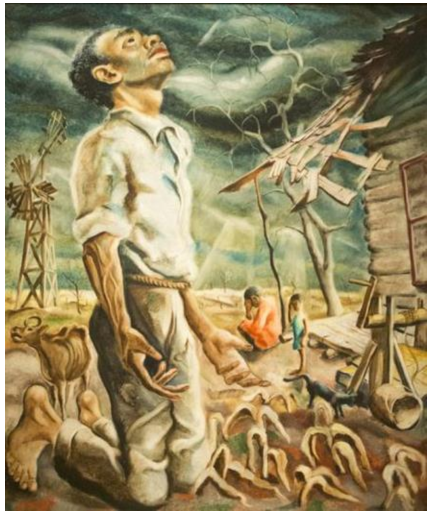
1. Effects not always immediate
   - Time-scale: ???

2. Weather vs. climate?





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Climate and health: complex associations

1. Effects not always immediate
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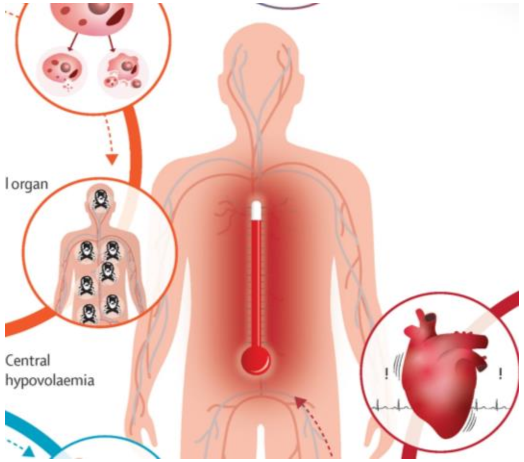
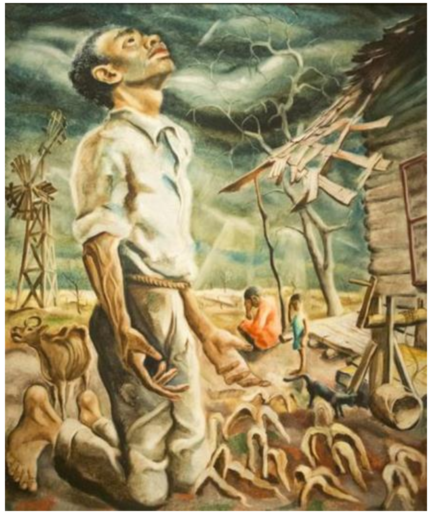
2. Weather vs. climate?

3. Dramatic differences in exposure profiles by area





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Climate and health: complex associations

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1. Effects not always immediate
   - Time-scale: ???

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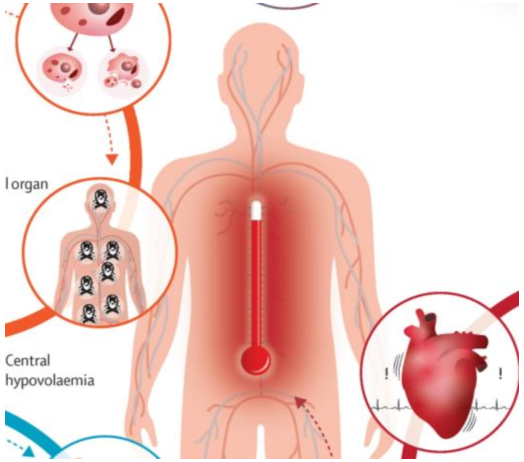
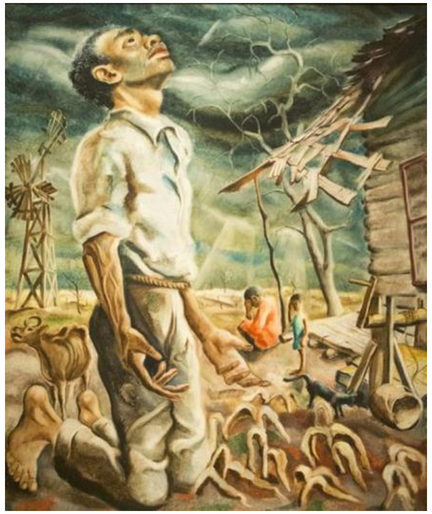
3. Dramatic differences in exposure profiles by area

4. Wide range of presentation and outcomes (direct and indirect)





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Climate and health: complex associations

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1. Effects not always immediate
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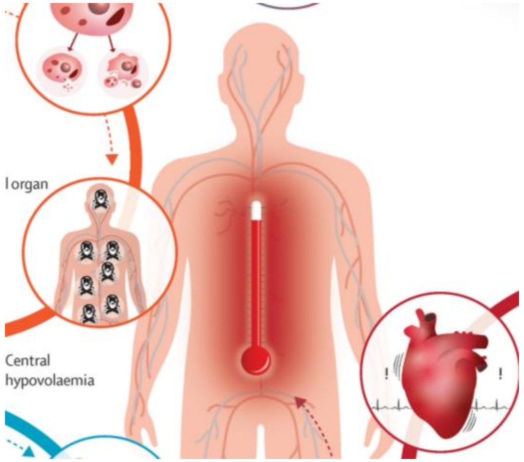
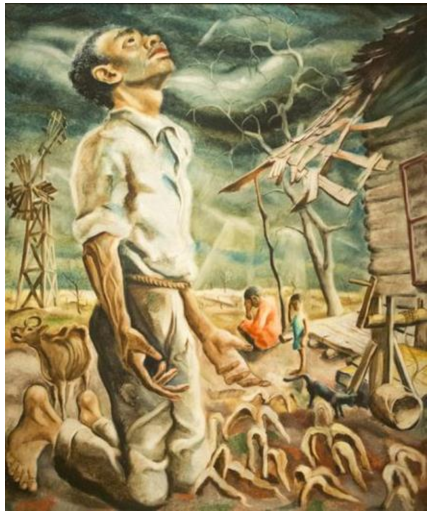
3. Dramatic differences in exposure profiles by area

4. Wide range of presentation and outcomes (direct and indirect)

5. Exposure added to underlying vulnerabilities





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Heat: growing challenge to urban health

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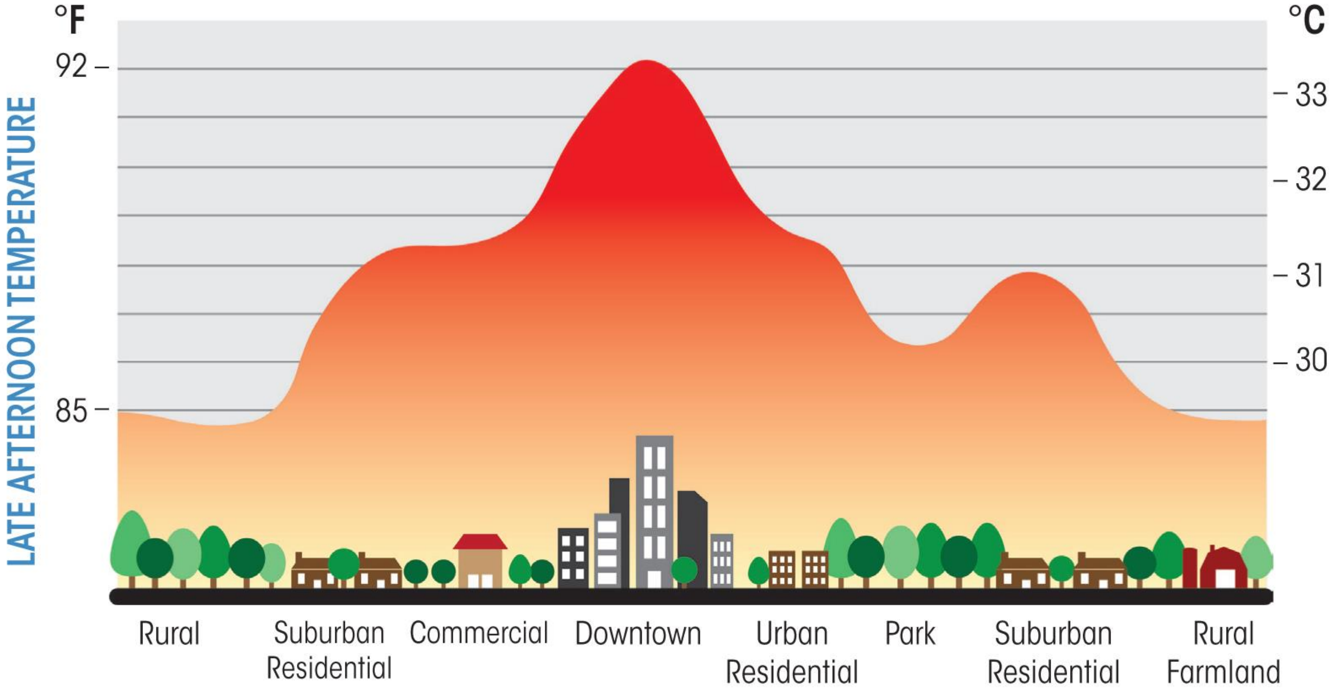

Urban heat island effect

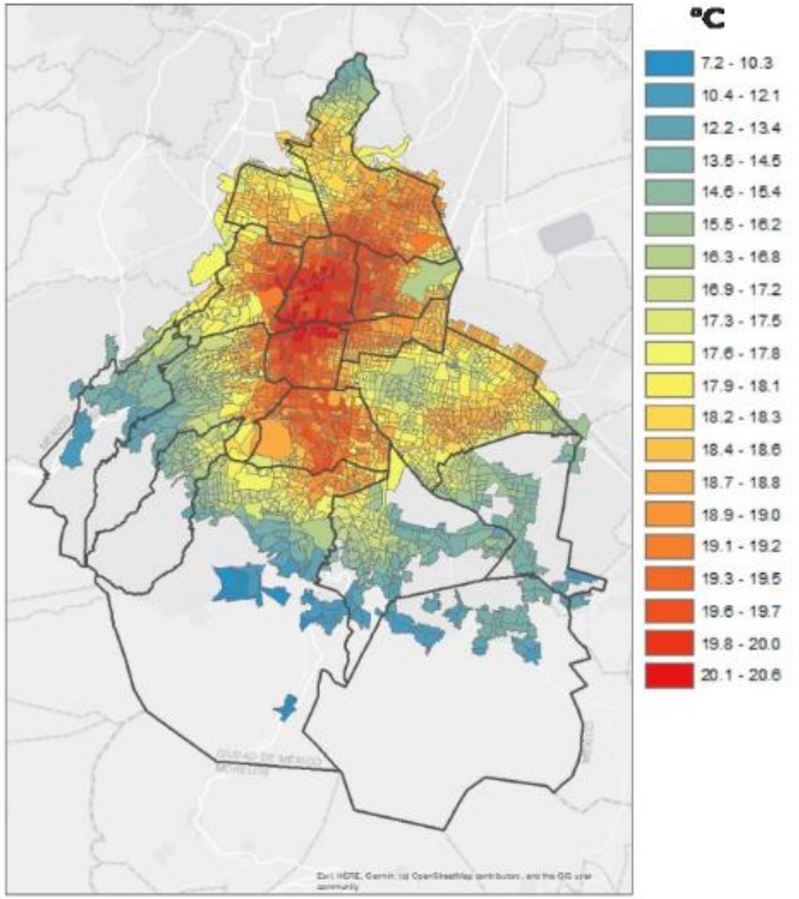

Figura 7. Mapa de temperaturas superficiales nocturnas

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Heat effects the body systemically

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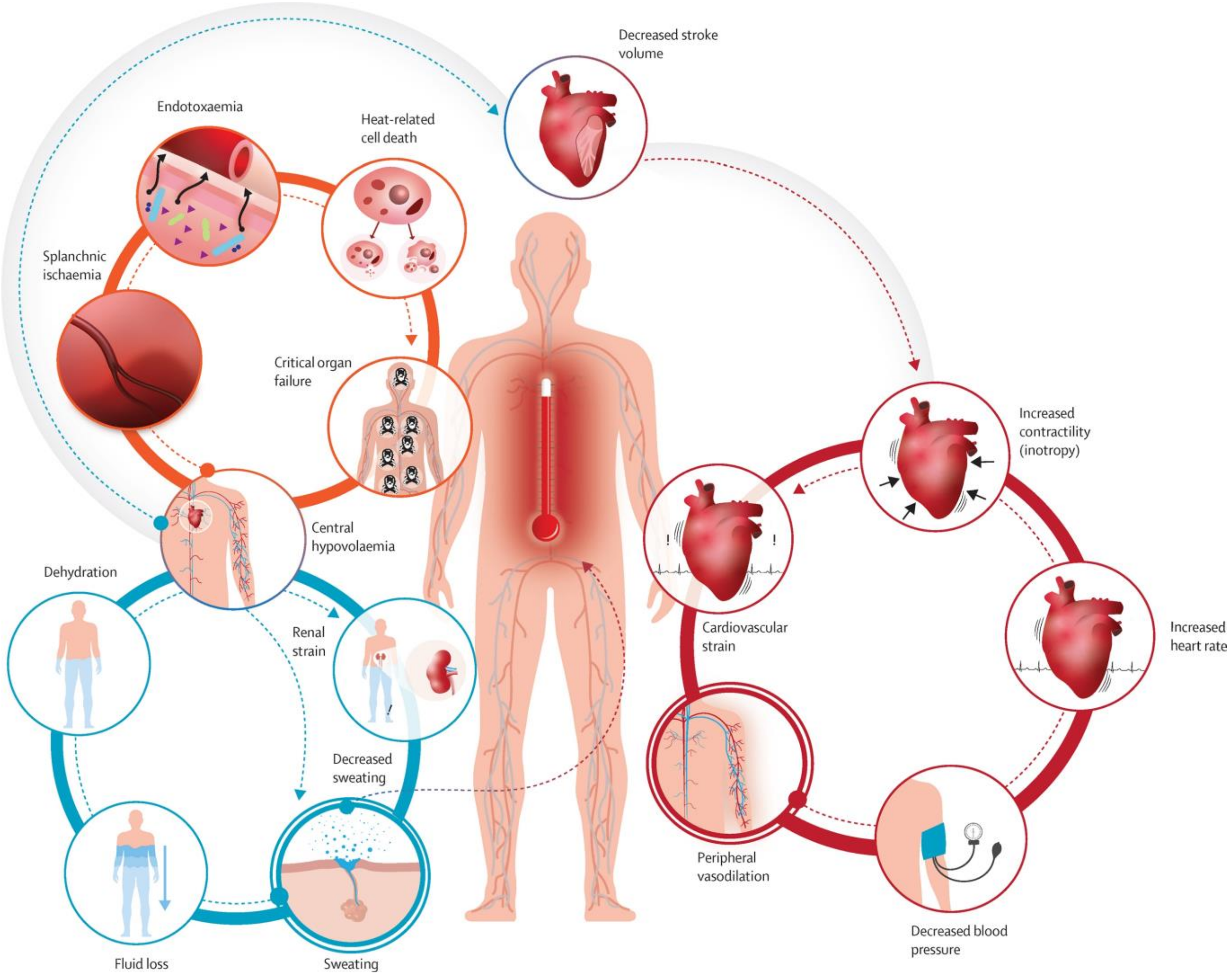
- Dehydration
  - Renal strain
- Cardiovascular strain
  - Vasodilation
  - Decreased blood pressure
  - Increased heart rate
- Cell death
  - Organ failure
- Others….

(Distinct health impacts from cold)



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Ebi et al, Lancet, 2021

Temperature and health: common challenges

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1. Effects not always immediate
   - up to 21 days after exposure
2. Weather vs. climate
   - Setting up analysis for policy impact
3. Dramatic differences in exposure by area
   - Climate (between city)
   - Urban heat island (within city)
4. Wide range of presentation and outcomes
   - All-cause mortality, CV, respiratory, homicide, drowning, etc.
5. Exposure added to underlying vulnerabilities
   - <u>Age</u>
   - SES: occupation, air conditioning, etc
   - Underlying disease
   - (mixed findings about gender and correlation with age)

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Miguel Castillo

Addressing non-linear exposure-health lags: distributed lag non-linear models

Challenge: physiological lag between exposure and outcome

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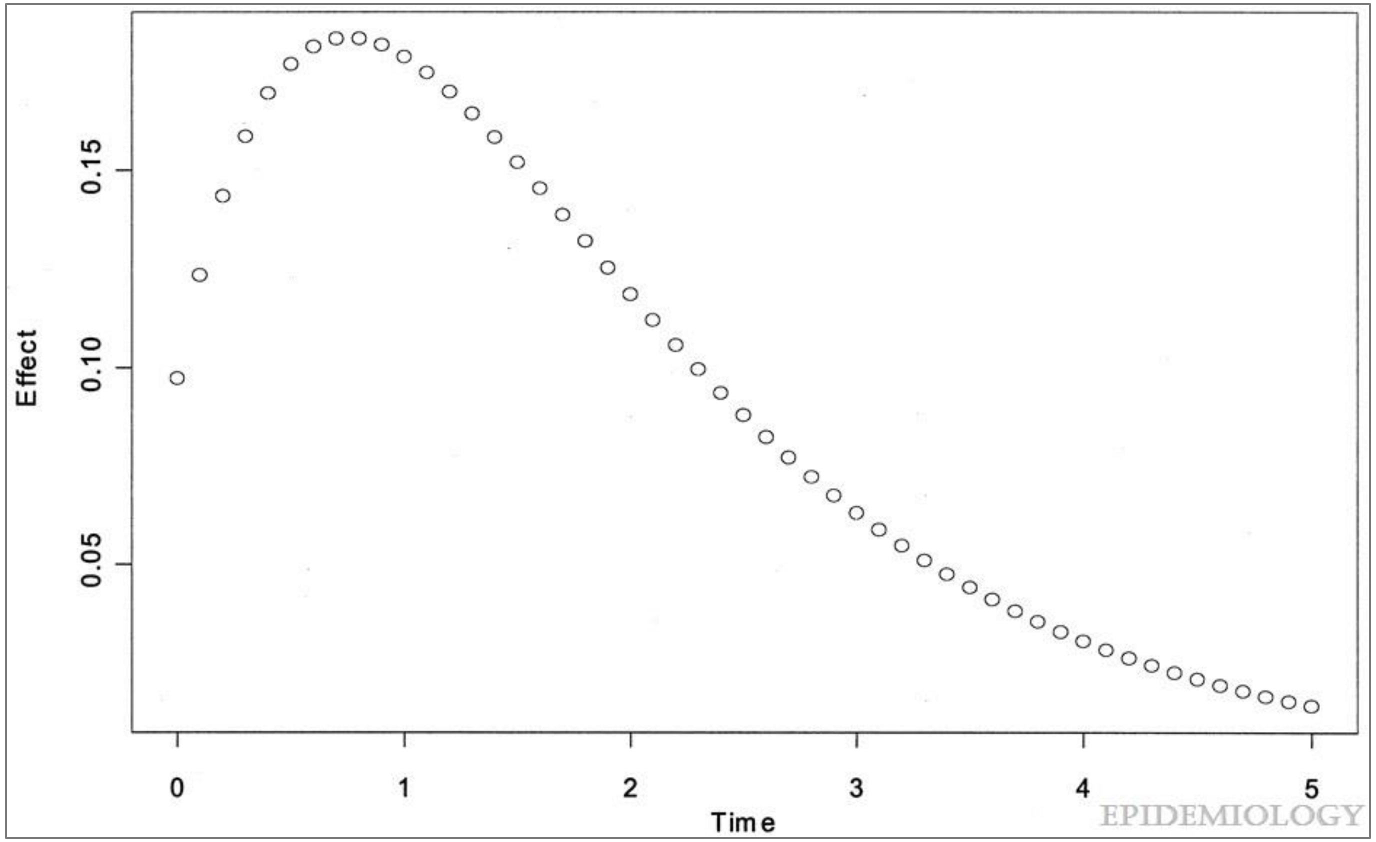
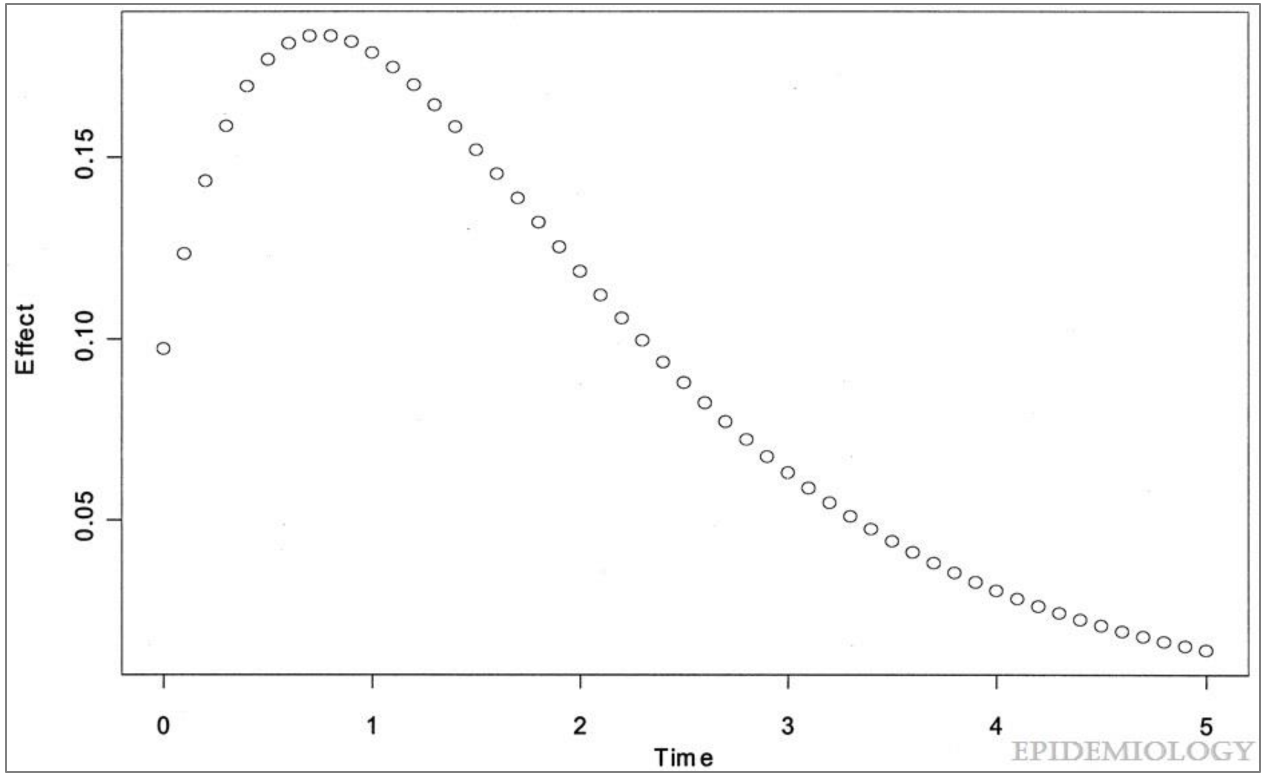
What we might hypothesize for

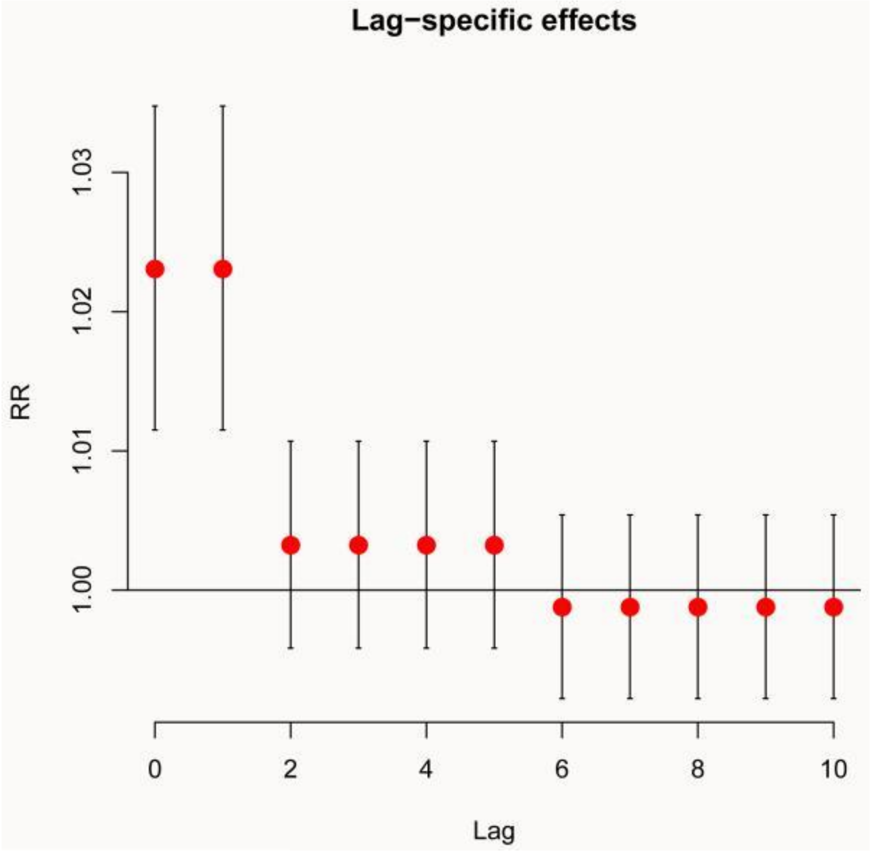
heat and mortality



Schwartz J, Epidemiology 11(3):320-326, 2000.

Common approaches have limitations



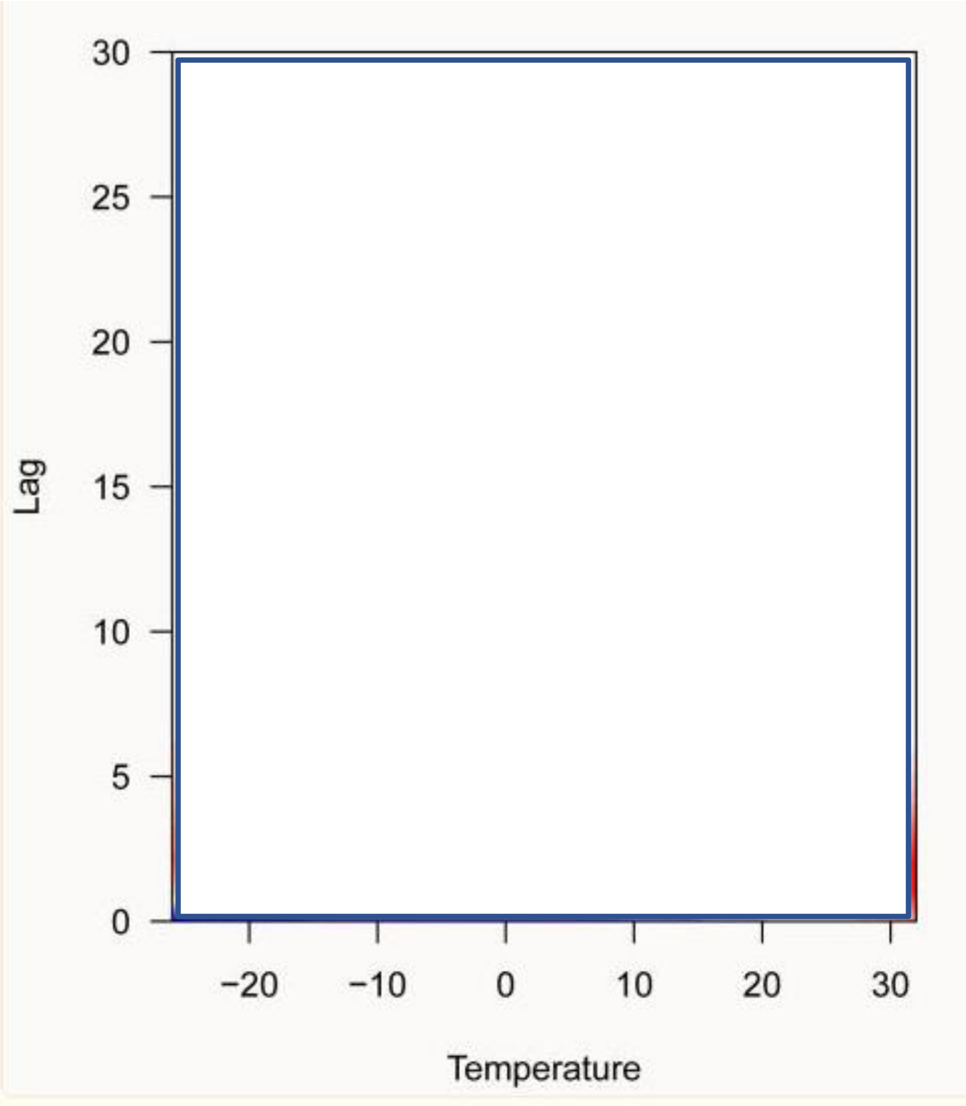


Schwartz J, Epidemiology, 2000, 11(3):320-326.
Gasparinni A, J Stat Softw. 2011; 43(8): 1–20.

Example: lagged exposure to heat

Two-dimensions:

- Temperature
- temporal lag



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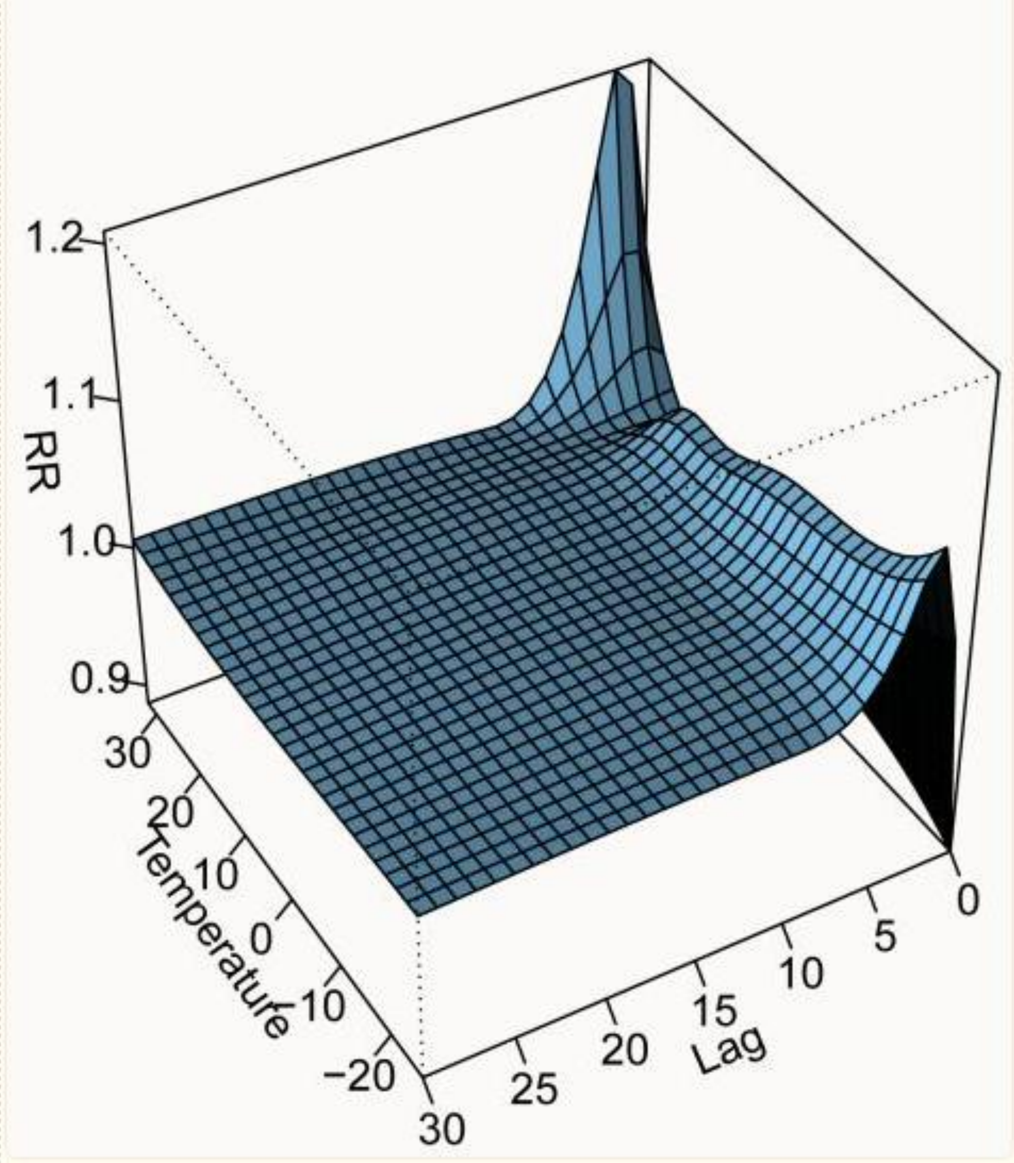
Gasparinni A, J Stat Softw. 2011; 43(8): 1–20.

Example: lagged exposure to heat

Three dimensions, all non-linear:

- Temperature
- temporal lag
- Relative risk



Gasparinni A, J Stat Softw. 2011; 43(8): 1–20.

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Example: lagged exposure to heat

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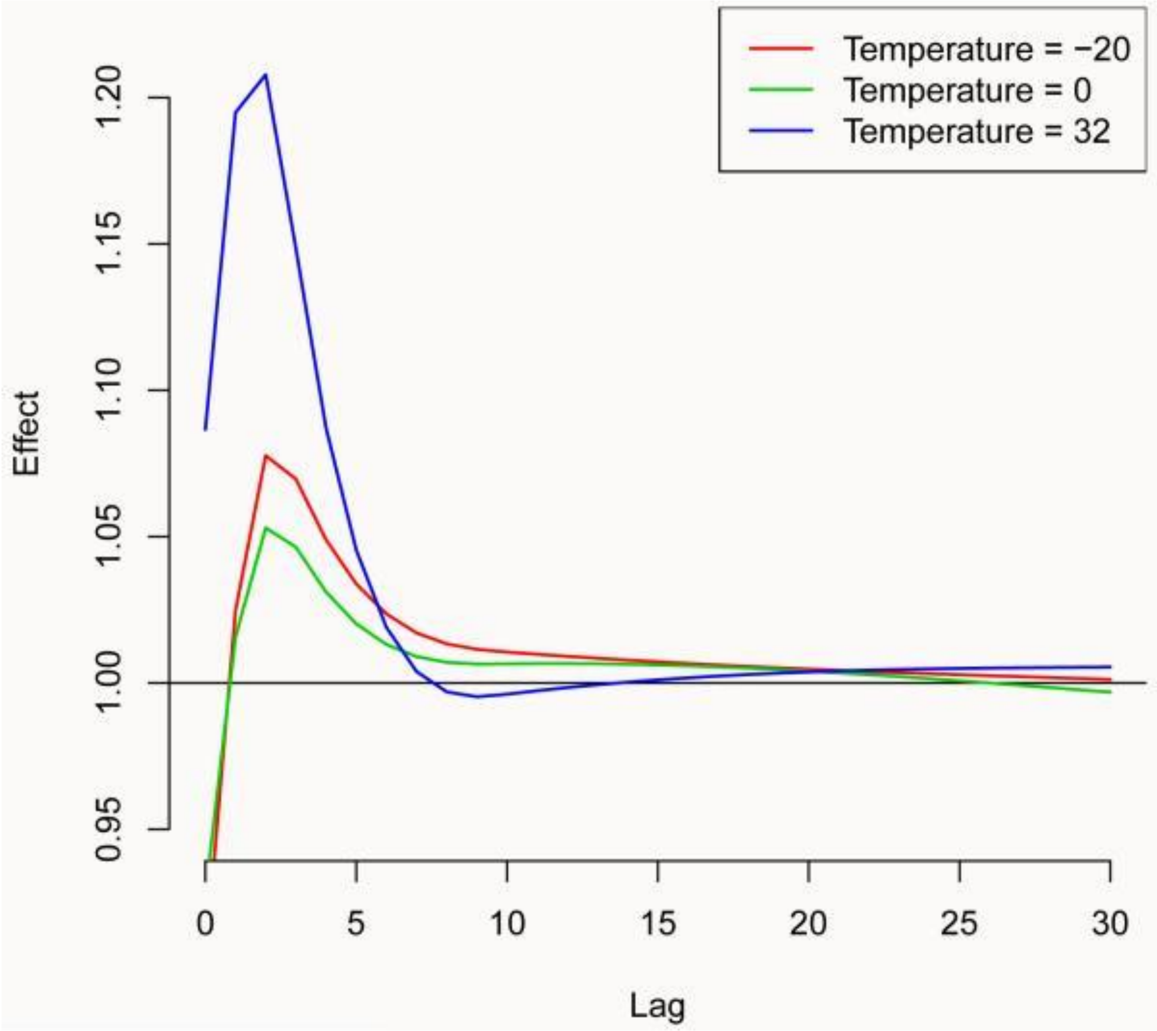
Associations of lag and RR

- Non-linear
- Vary by temperature

Need to model joint effect of 1) temperature and 2) lag



Gasparinni A, J Stat Softw. 2011; 43(8): 1–20.

Distributed lag non-linear models

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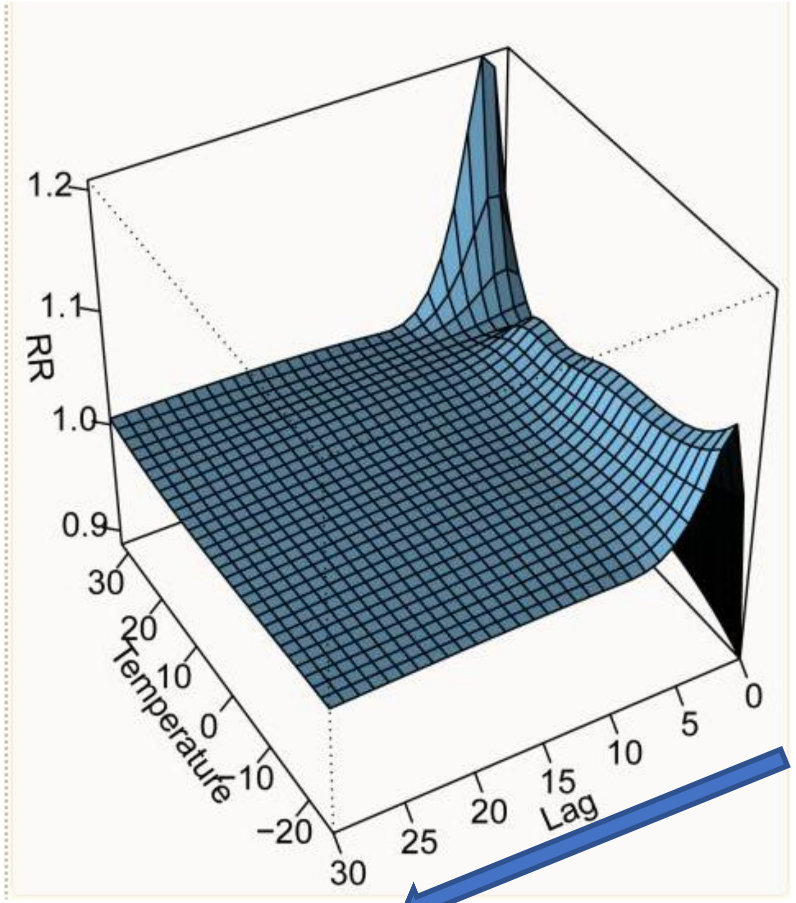
- Start with: joint distribution of relative risk across lags and temperature
- "Sum" relative risk (RR) across all lags
  - While accounting for uncertainty
- Cumulative RR across all lags
- Efficient way to model non-linear effects and uncertainty separately across
  - Lags
  - Temperature

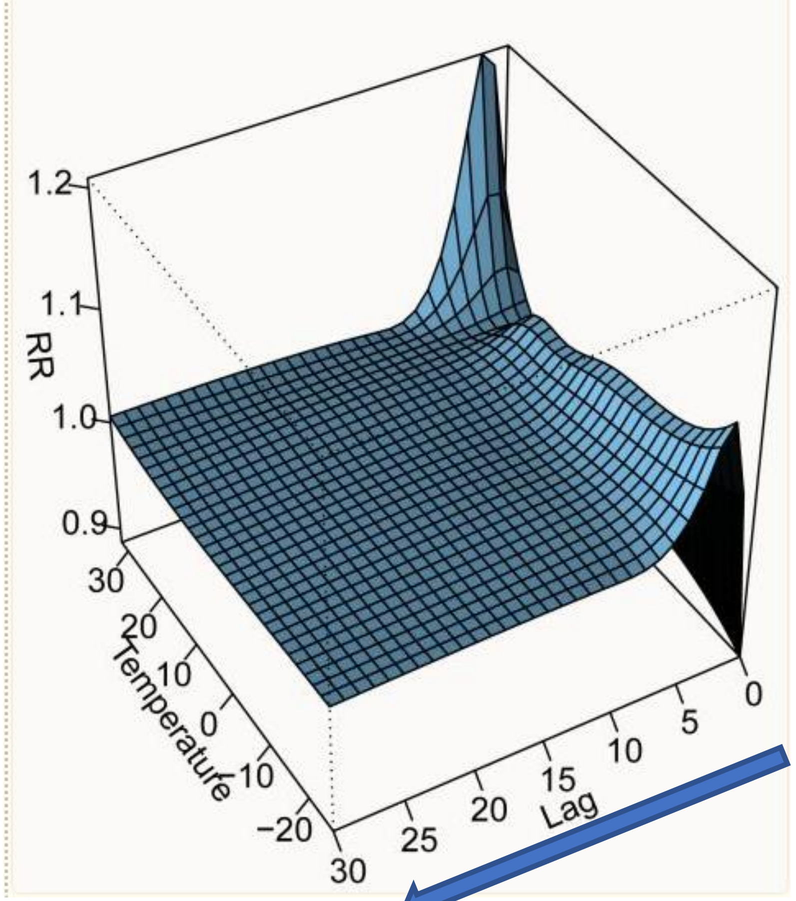


👀

Distributed lag non-linear models

- Reduces a dimension by collapsing lags into cumulative risk across lag period, for each temperature
  - Makes possible to do meta-analysis of outputs

- Can be applied to a variety of models
  - Case-crossover
  - Conditional Poisson
  - GEE, GLM, GAM families



Example analysis: MS85

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ARTICLES

https://doi.org/10.1038/s41591-022-01872-6

nature medicine

Check for updates

OPEN

City-level impact of extreme temperatures and mortality in Latin America

Josiah L. Kephart[1] ✉, Brisa N. Sánchez[2], Jeffrey Moore[2], Leah H. Schinasi[1,3], Maryia Bakhtsiyarava[4], Yang Ju[5], Nelson Gouveia[6], Waleska T. Caiaffa[7], Iryna Dronova[8], Saravanan Arunachalam[9], Ana V. Diez Roux[1,2,10] and Daniel A. Rodríguez[4,10]

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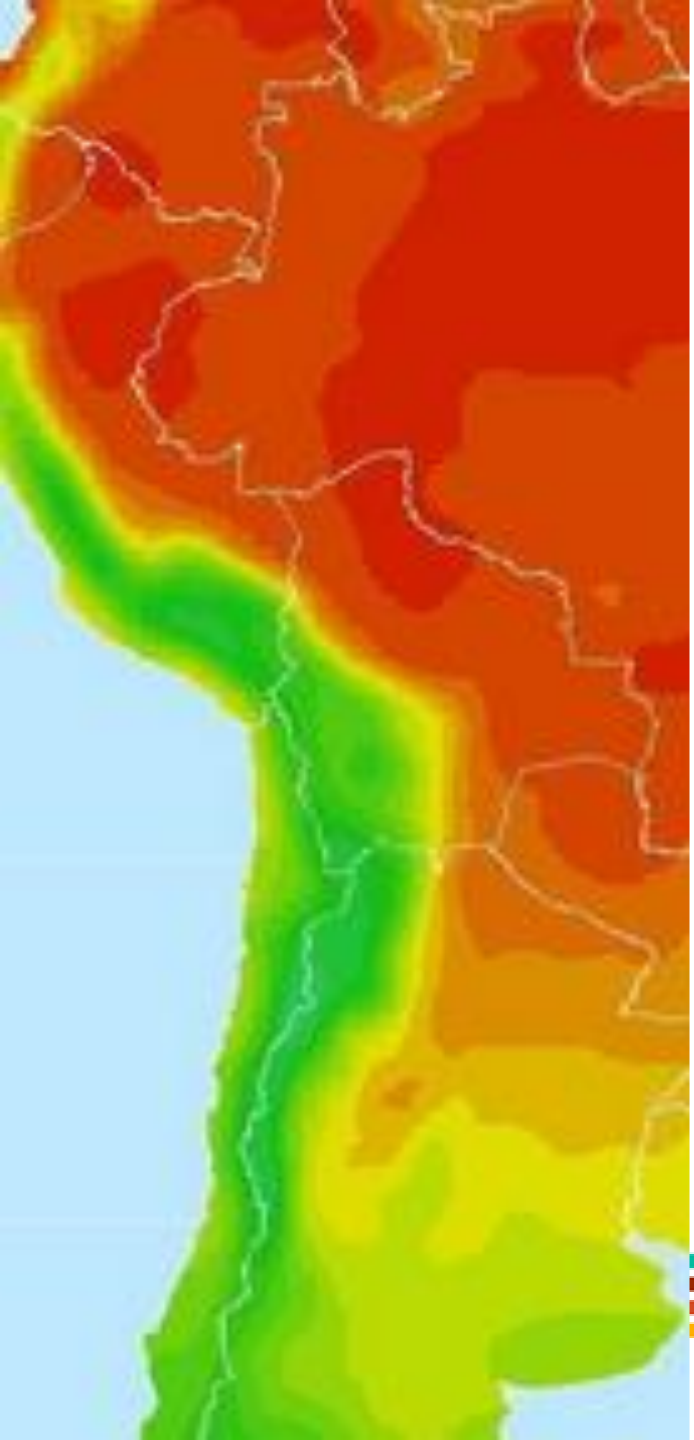

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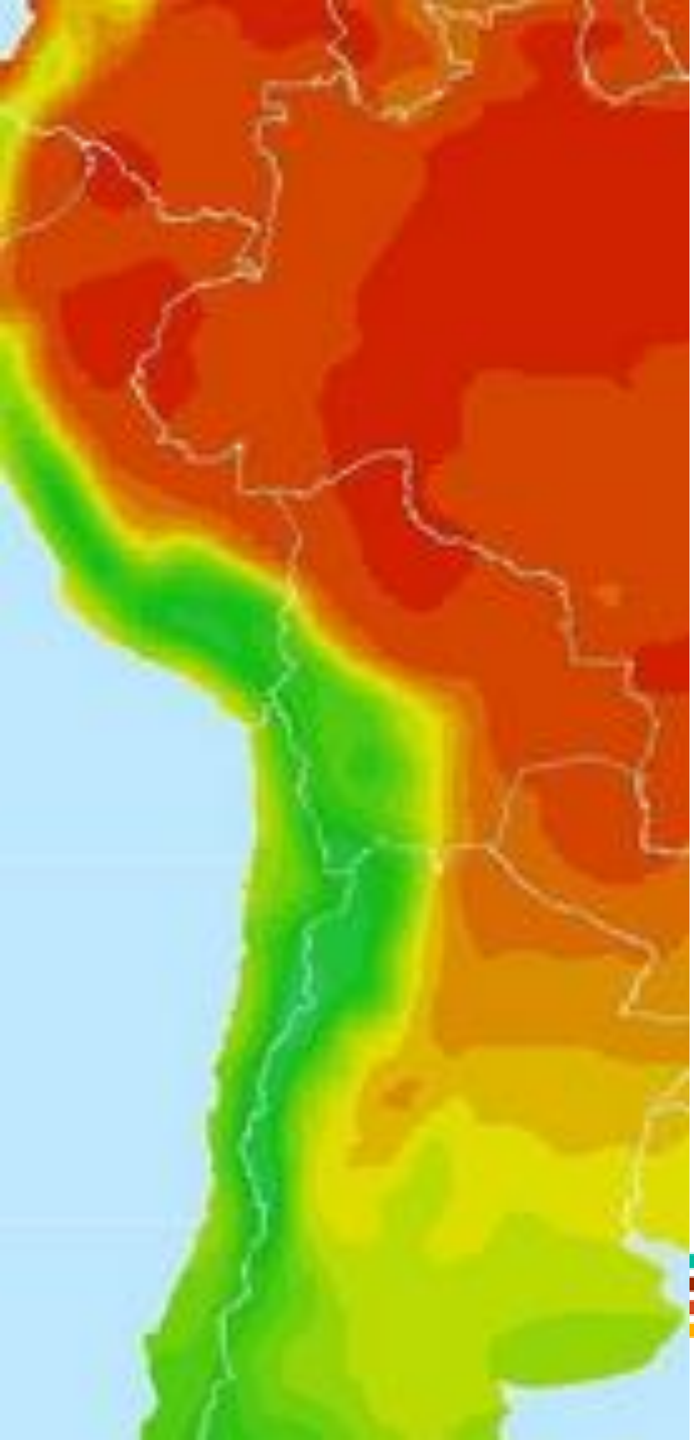
Aims

1) What is the relationship between **ambient temperature and all-cause mortality**?

2) Does this relationship vary by **age**?

3) Does this relationship vary by **cause of death**?
   - -Cardiovascular
   - -Respiratory Diseases (non-communicable)
   - -Respiratory Infections

Kephart et al, Nature Medicine, 2022



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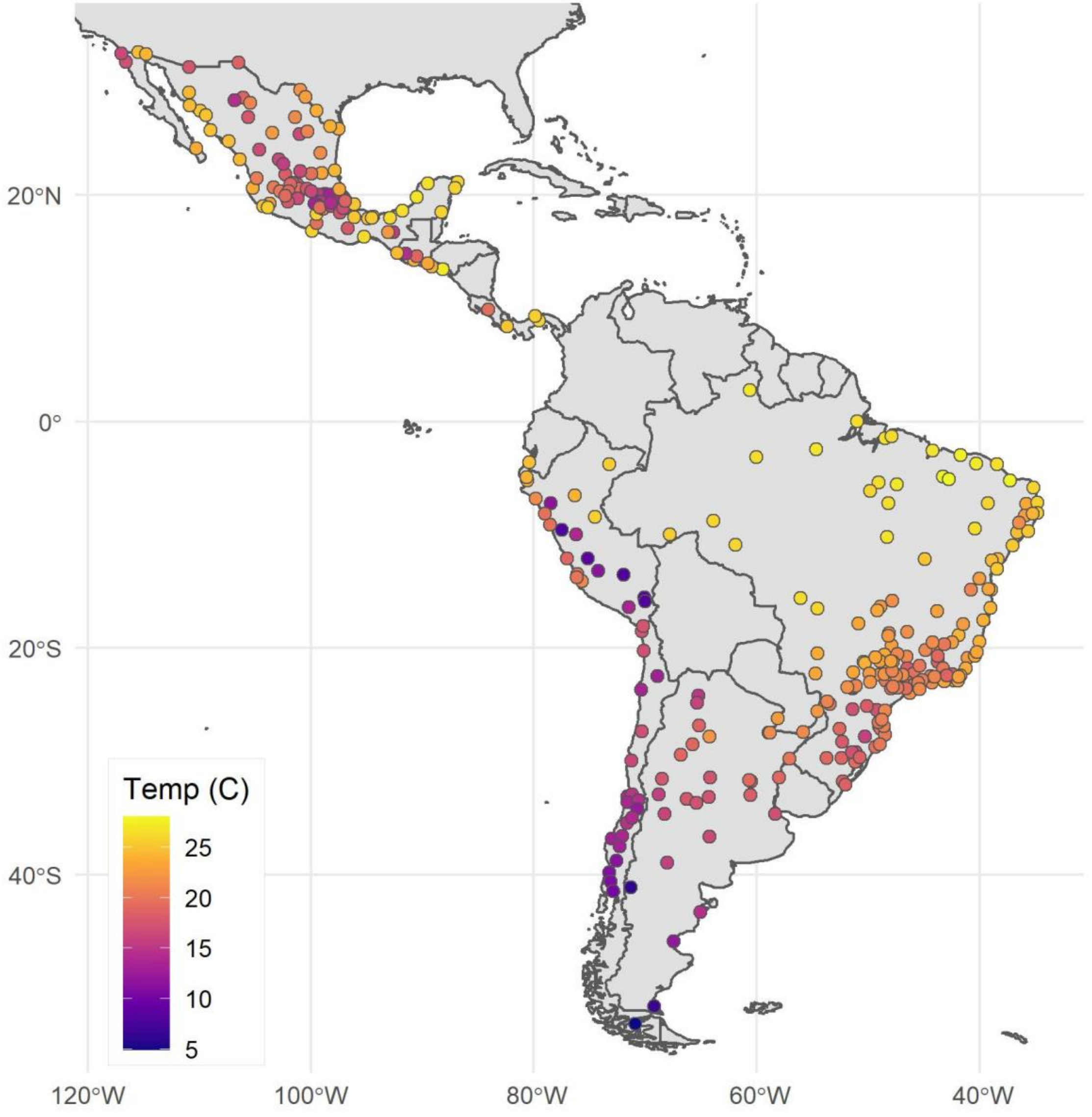
Study setting

- 326 cities from SALURBAL project
  - Argentina, Brazil, Chile, Costa Rica, El Salvador, Guatemala, México, Panama, Peru
  - >230 million residents
- Exposure: Temperature
  - ERA5-Land, ~9km horizontal grid resolution
  - <u>Population-weighted daily mean temperature</u>
- Outcome: Mortality
  - Individual-level, age and cause of death (ICD-10)
  - Aggregated to <u>city-level daily mortality counts</u>
  - 15 million + deaths
  - 2.9 billion person-years of risk

Kephart et al, Nature Medicine, 2022

Annual mean temperature in 326 study cities



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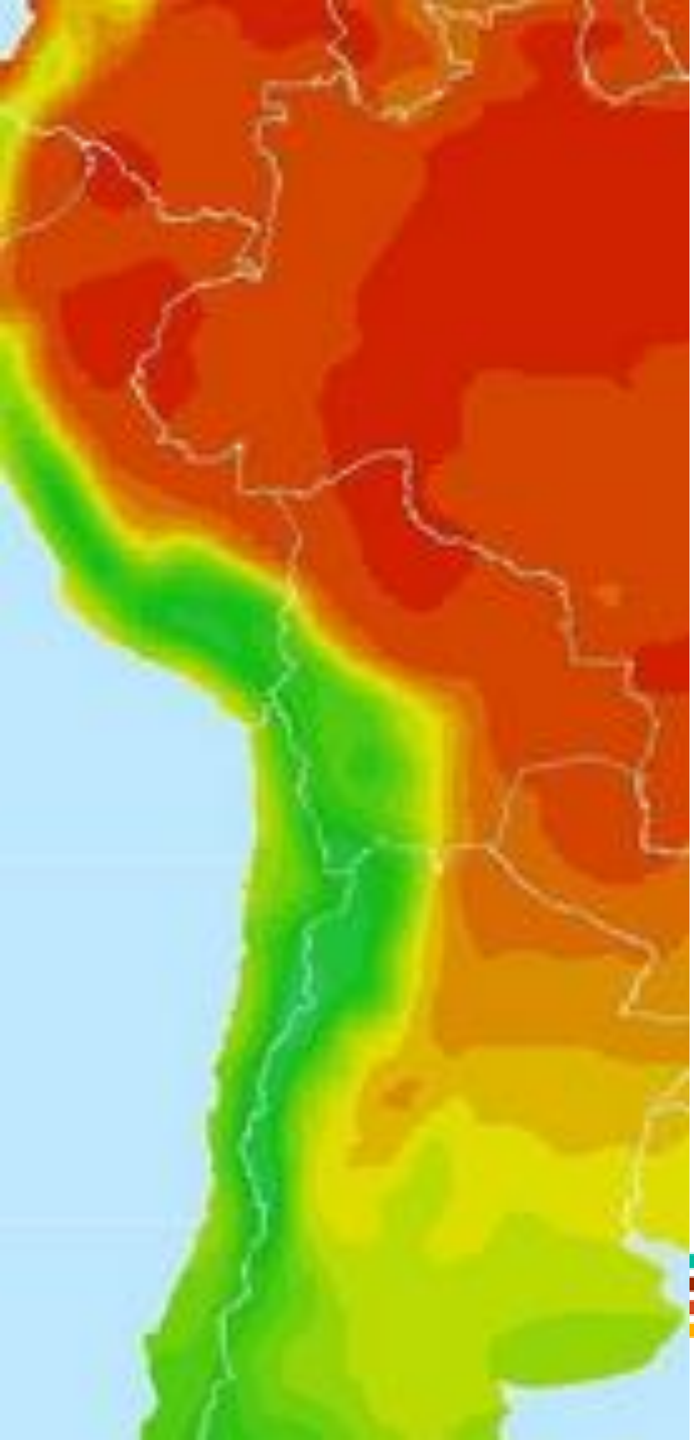
Kephart et al, Nature Medicine, 2022



Modelling approach: two phases

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- Phase 1: City-specific estimates
  - Distributed lag non-linear models
- Phase 2: Stabilizing/smooth city curves
  - Meta-analysis of Phase 1 outputs

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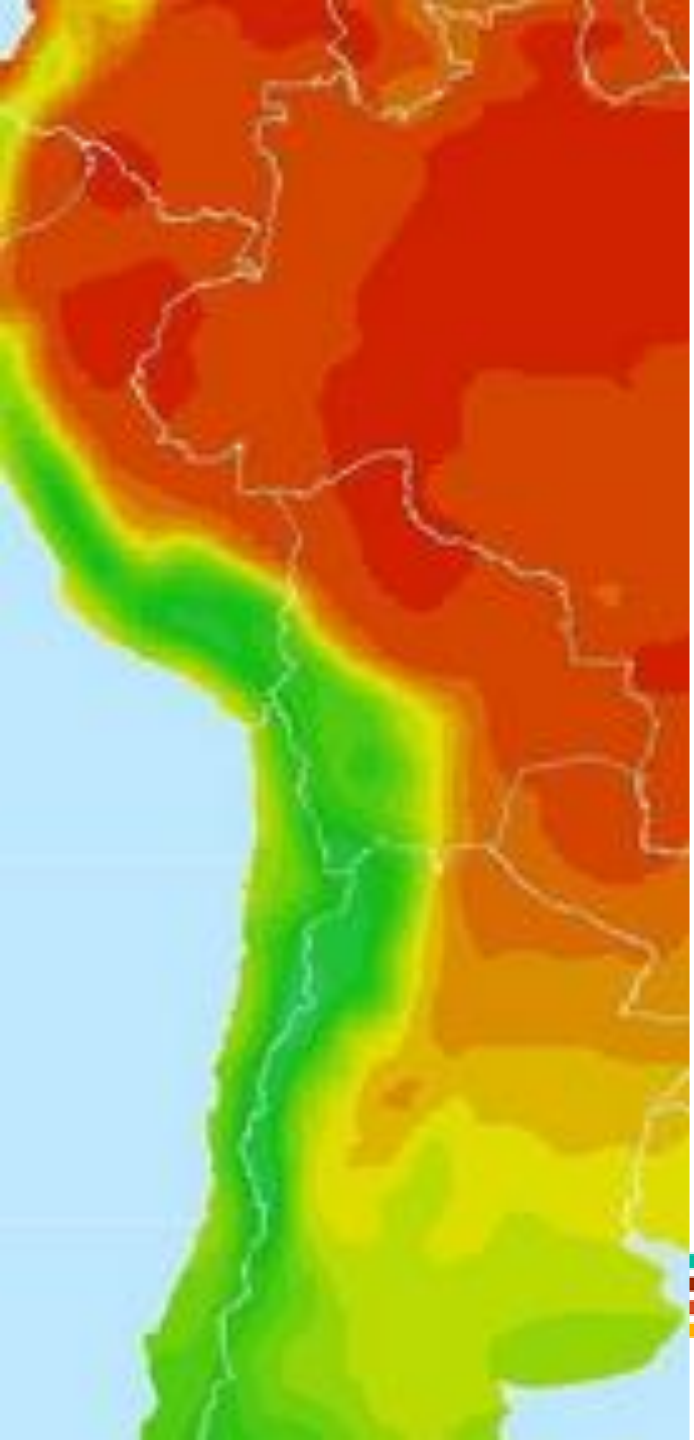
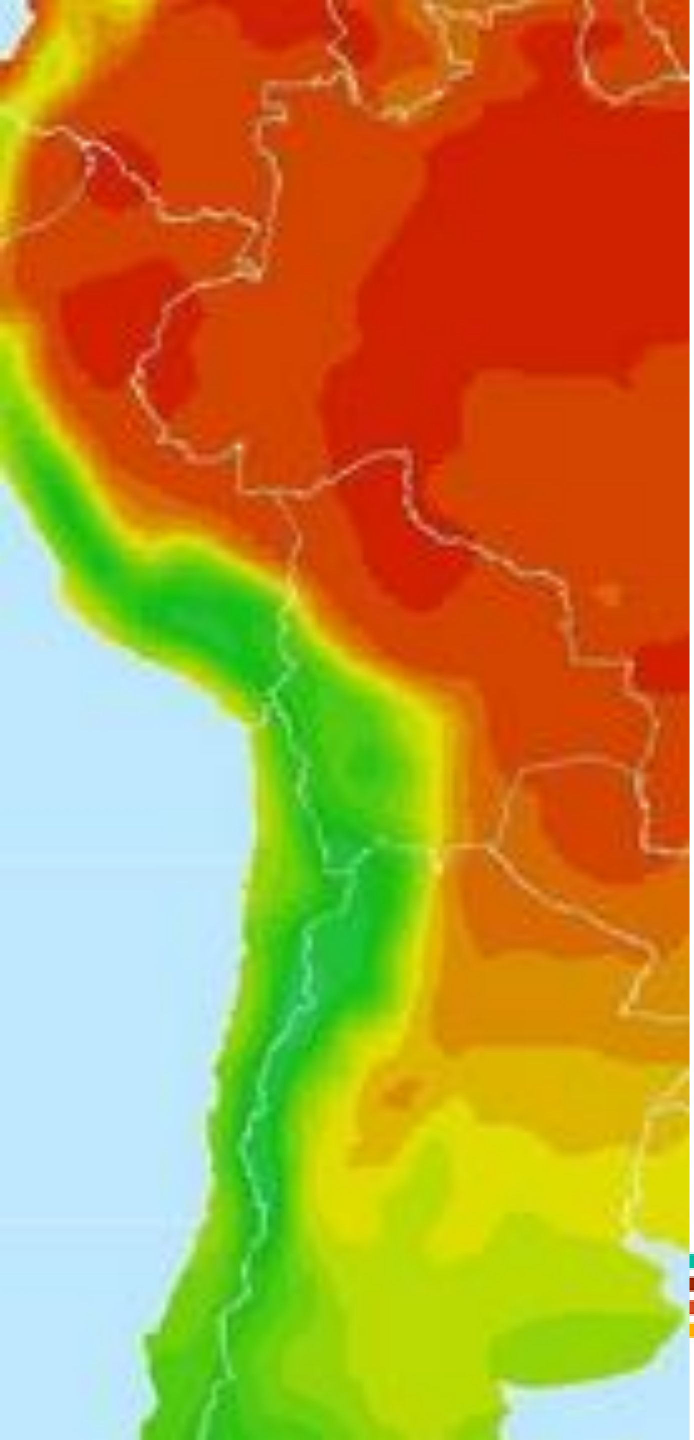
Kephart et al, Nature Medicine, 2022



Phase 1: City-specific estimates

1. Create time series
   - Daily city mean temperature
   - Daily city-wide death count
     - Aggregated by age and cause

Kephart et al, Nature Medicine, 2022



Phase 1: City-specific estimates

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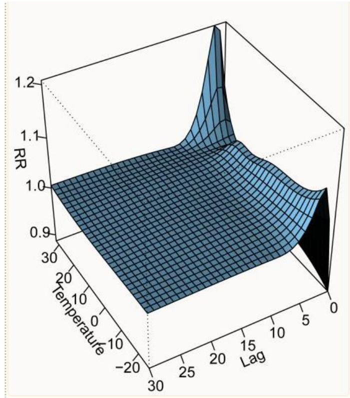
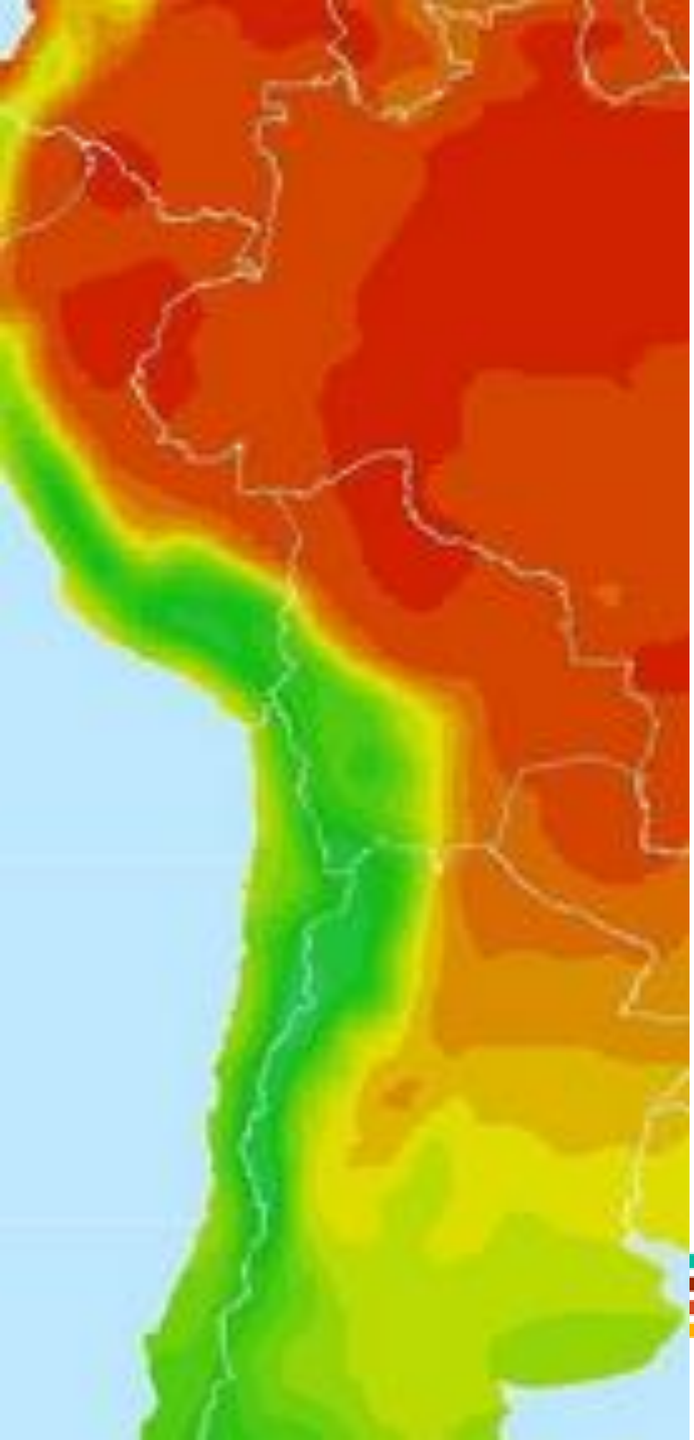
1. Create time series
2. Conditional Poisson models
   - Distributed lag (0-21 days)
     - Cumulative effect over lag period
   - Nonlinear temperature-mortality
     - Natural cubic spline
     - Knots
       - 10, 75, 90 percentiles
       - min, max
   - Log(annual city population) as offset



Kephart et al, Nature Medicine, 2022



Phase 1: City-specific estimates

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1. Create time series
2. Conditional Poisson models
   - Distributed lag (0-21 days)
   - Nonlinear
   - Log(annual city population) as offset
   - Temporal/seasonal adjustment
     - Day of week
     - Calendar month
     - Year
     - Goal: impacts of short-term temperature variability

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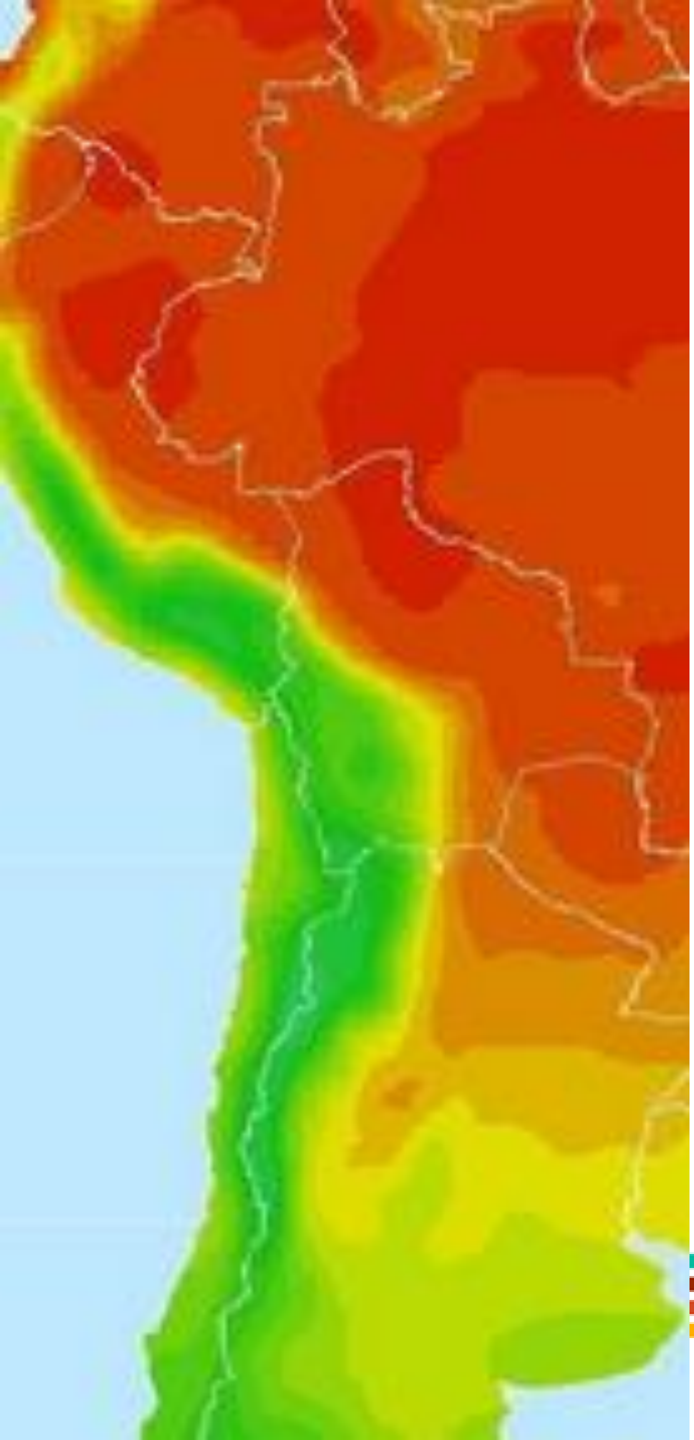
Kephart et al, Nature Medicine, 2022



Phase 2:
Stabilize city-specific estimates

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- Stabilize/smooth city-specific curves
  - Small N of daily deaths in many cities
  - Random effects meta-analysis
    - Dependent variables
      - Spline coefficients (N=4) of temp-mortality association
    - Meta-predictors
      - City temp: median, range
      - Country
    - Best Linear Unbiased Prediction (BLUP)
      - Balances raw city-curve with pooled curve

Kephart et al, Nature Medicine, 2022

City-specific temperature-mortality curves

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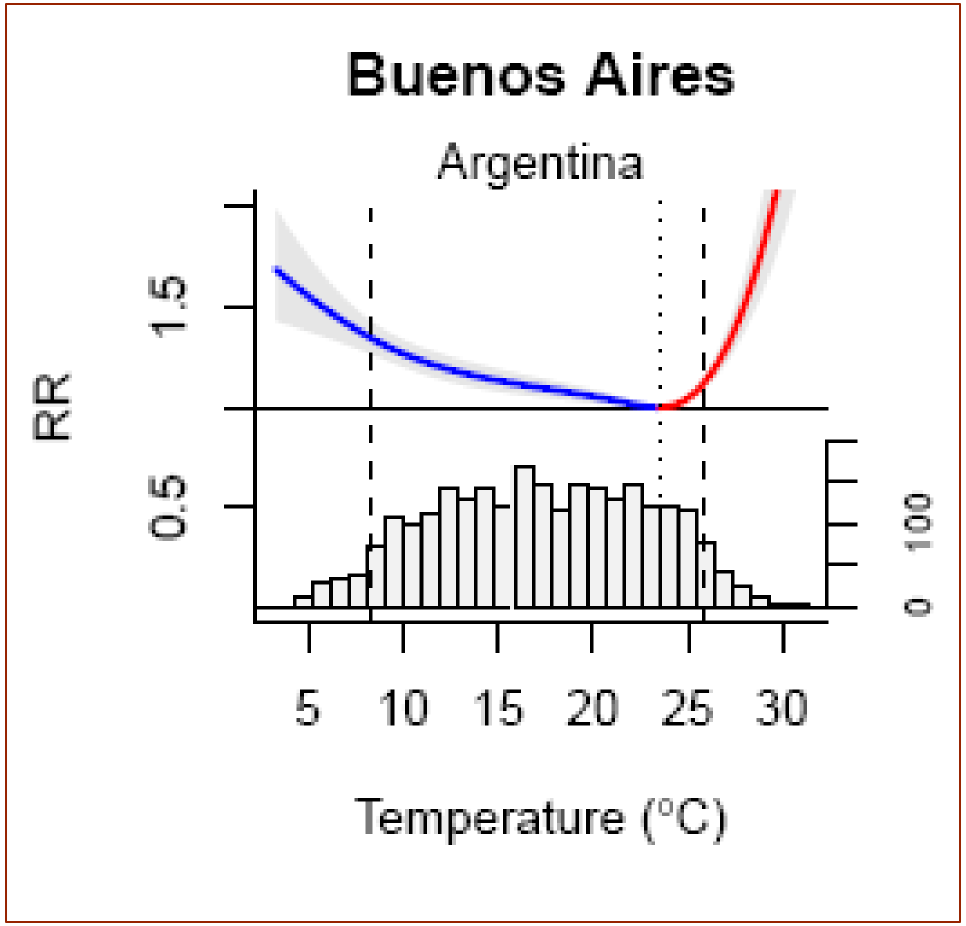

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Kephart et al, Nature Medicine, 2022

For each city: distribution of daily temperatures

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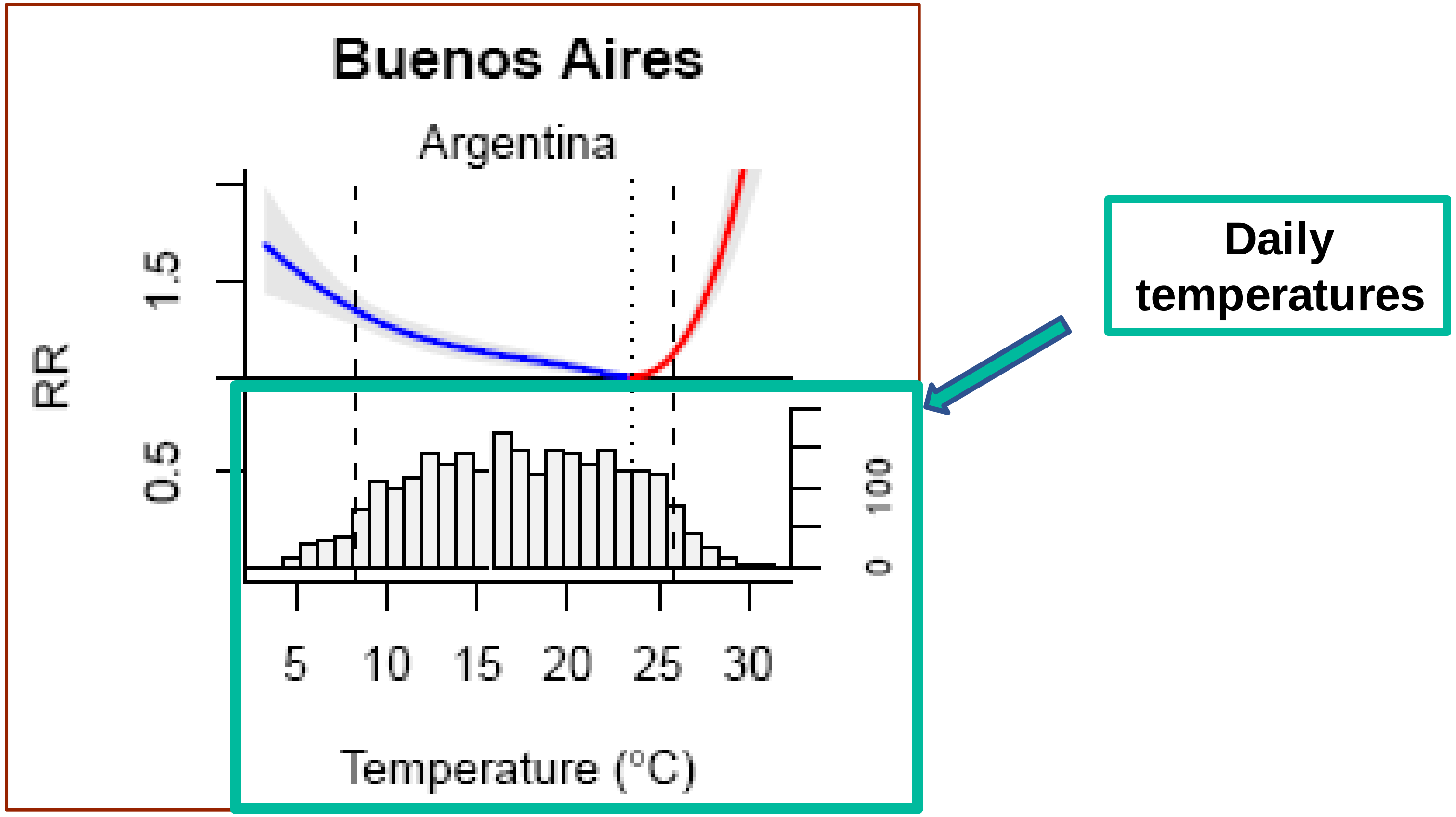

Kephart et al, Nature Medicine, 2022

For each city: defining optimal temperature

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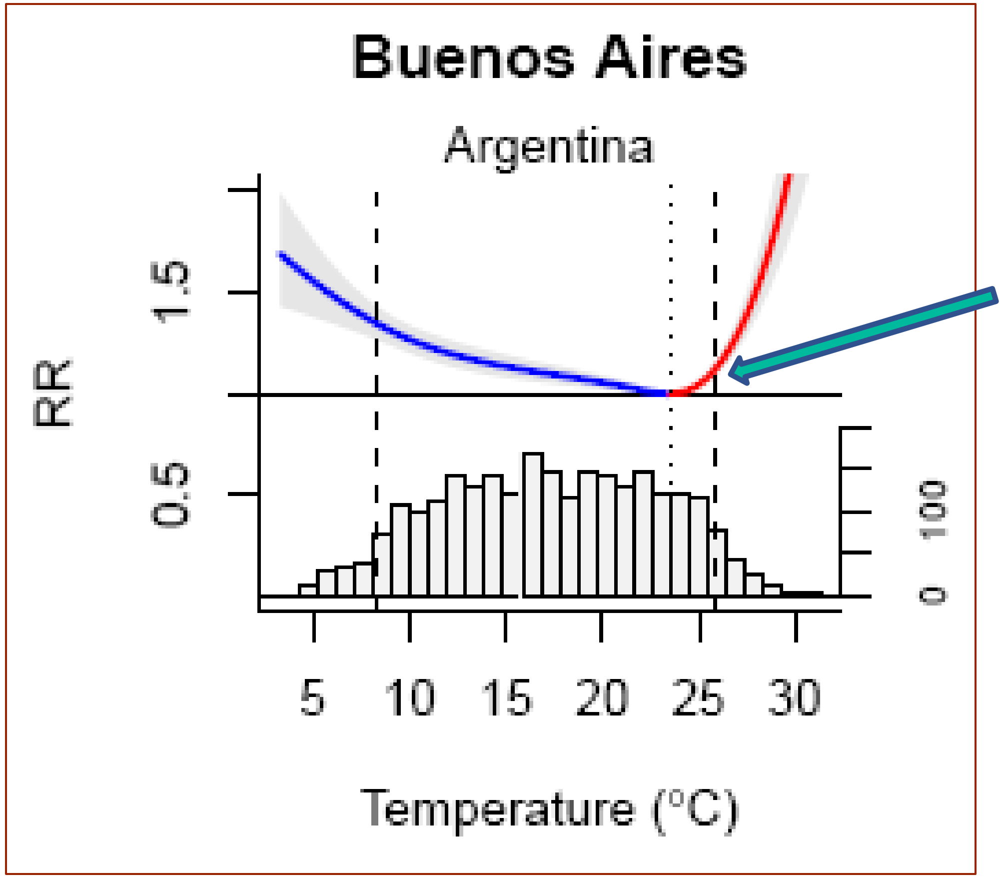
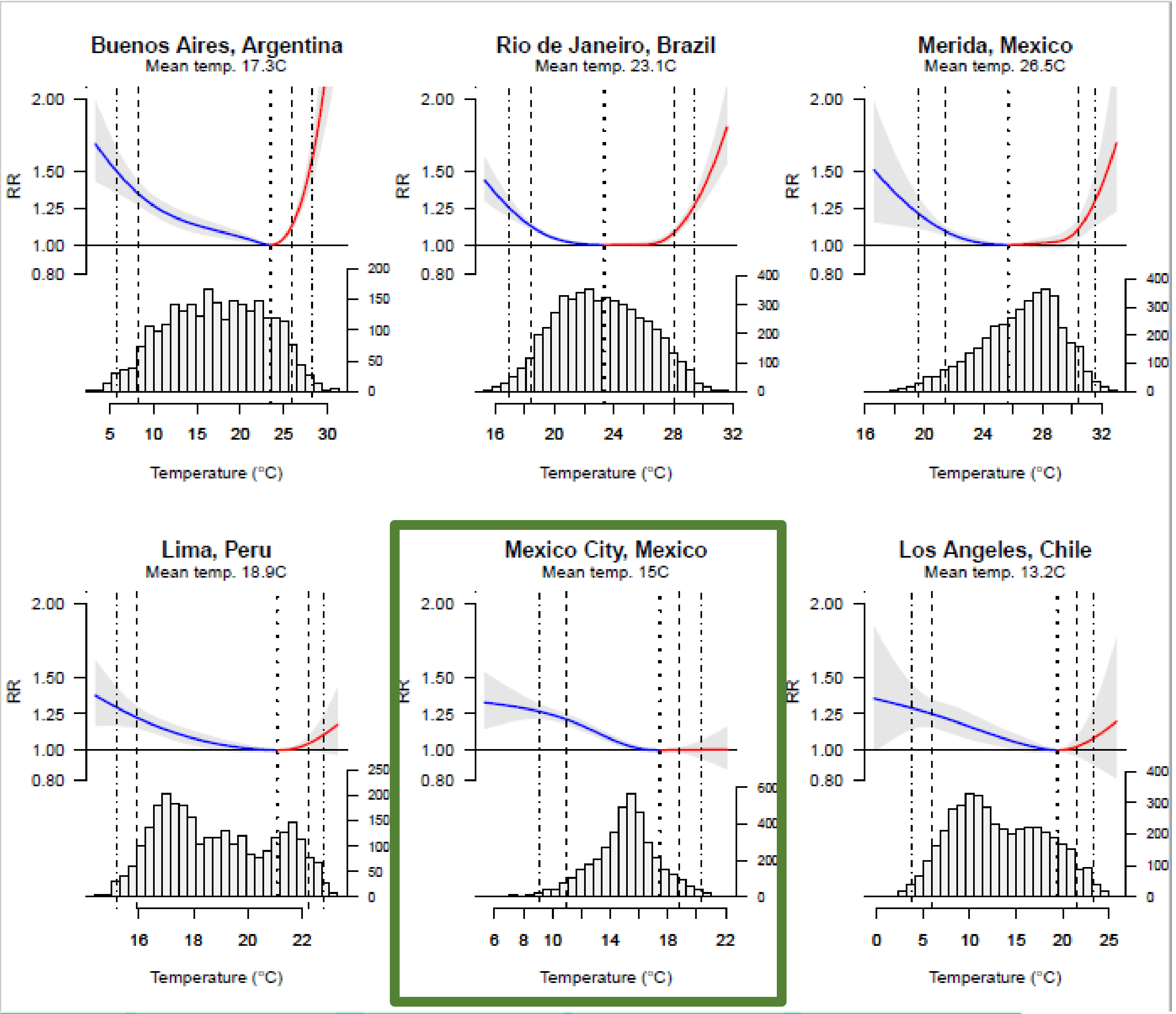


Optimal temperature

Kephart et al, Nature Medicine, 2022

For each city: temperature-mortality curve



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Wide variation between cities:

- Temp. range
- Temp. variability
- Temp.-mortality curve

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Kephart et al, Nature Medicine, 2022

For each city: temperature-mortality burden

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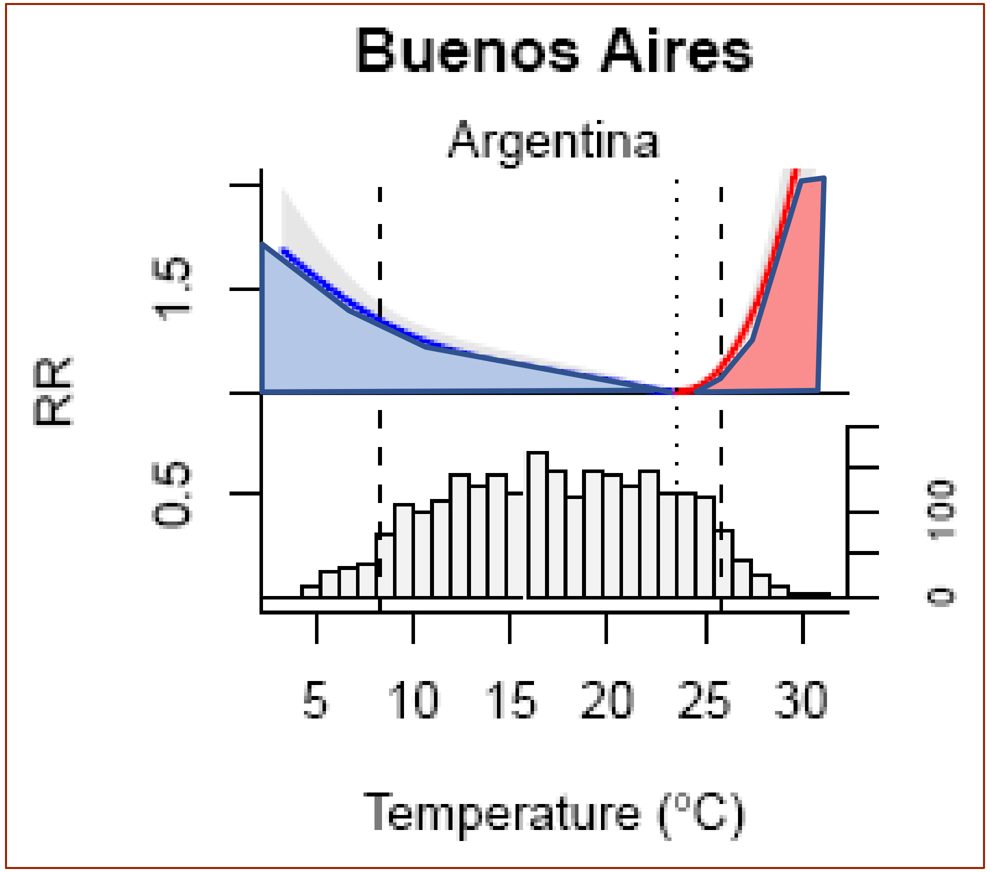
1. Excess death fraction

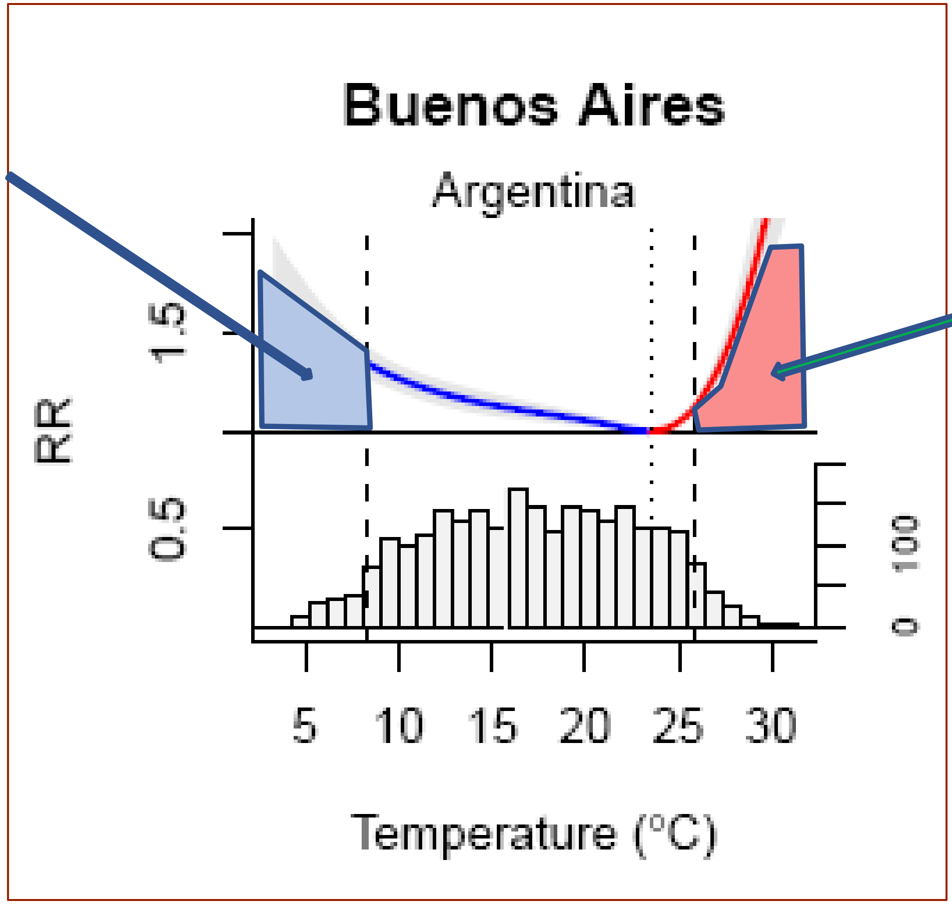
- % of total deaths explainable by ambient temperature
- Also known as “attributable fraction”



Kephart et al, Nature Medicine, 2022

Option: limiting to "extreme" temperatures

Cumulative risk of extreme cold (< 5th percentile)



Cumulative risk of extreme heat (> 95th percentile)

Kephart et al, Nature Medicine, 2022

Methods: Outputs

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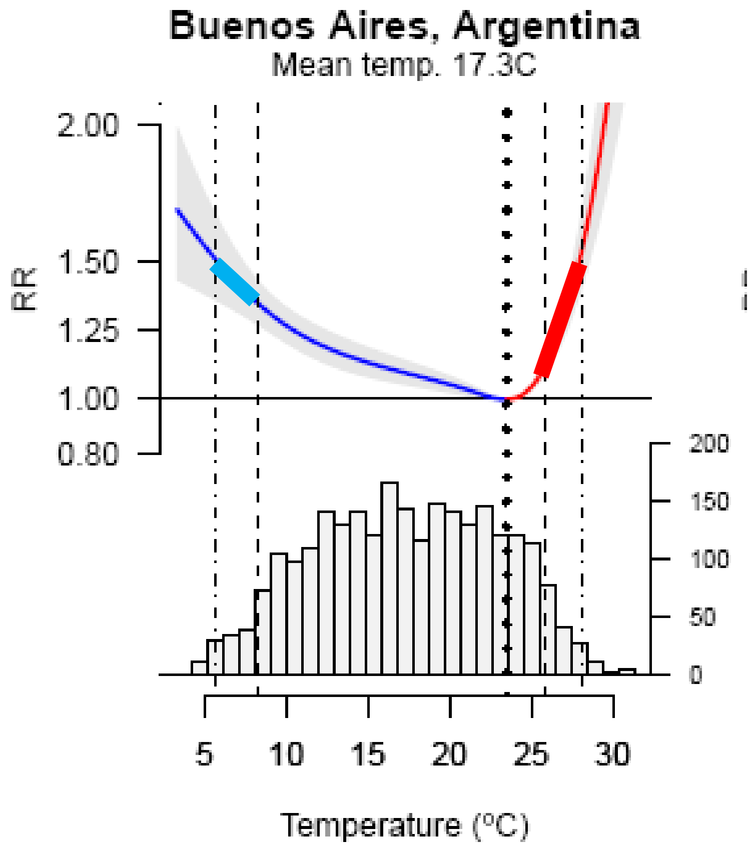
1) Excess death fraction
2) Change in **relative risk per 1°C change** under extreme temperatures
   - Change in RR / change in degrees,
   - Extreme heat
     - P95 vs. P99
   - Extreme cold
     - P5 vs. P1



Kephart et al, Nature Medicine, 2022

Combine city outputs into overall effects

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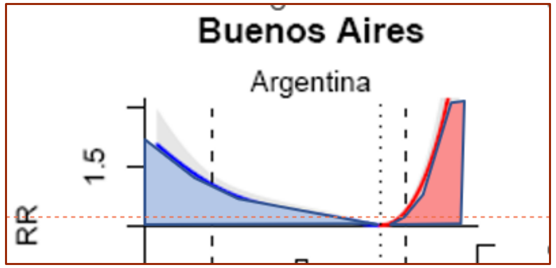
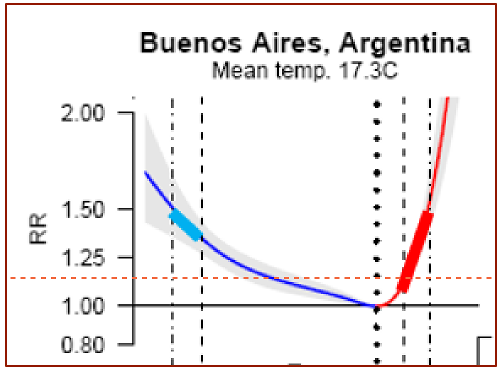
1. Excess death fraction
   - Sum deaths across cities
     - Heat (> optimal temp.)
     - Cold (< optimal temp.)
     - Extreme heat (> P95)
     - Extreme cold (< P5)



2. <u>Change in relative risk per 1°C change</u> under extreme temps
   - Meta-analysis of city effects
     - Extreme heat: P95 vs. P99
     - Extreme cold: P5 vs. P1



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Results: excess death fractions (%)

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Percent of total deaths explainable by ambient temperatures

	Heat*	
All	**0.67%**	(0.58% to 0.74%)
Age 65+	**0.81%**	(0.75% to 0.86%)
	Cold*	
All	**5.09%**	(4.64% to 5.47%)
Age 65+	**6.82%**	(6.41% to 7.18%)

*Cumulative effect of temperatures above/below the city-specific optimal temperature

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Kephart et al, Nature Medicine, 2022

Understanding heat vs. cold

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Percent of total deaths explainable by ambient temperatures (excess death fraction)

Heat*

All **0.67%** (0.58% to 0.74%)
Age 65+ **0.81%** (0.75% to 0.86%)

Cold*

All **5.09%** (4.64% to 5.47%)
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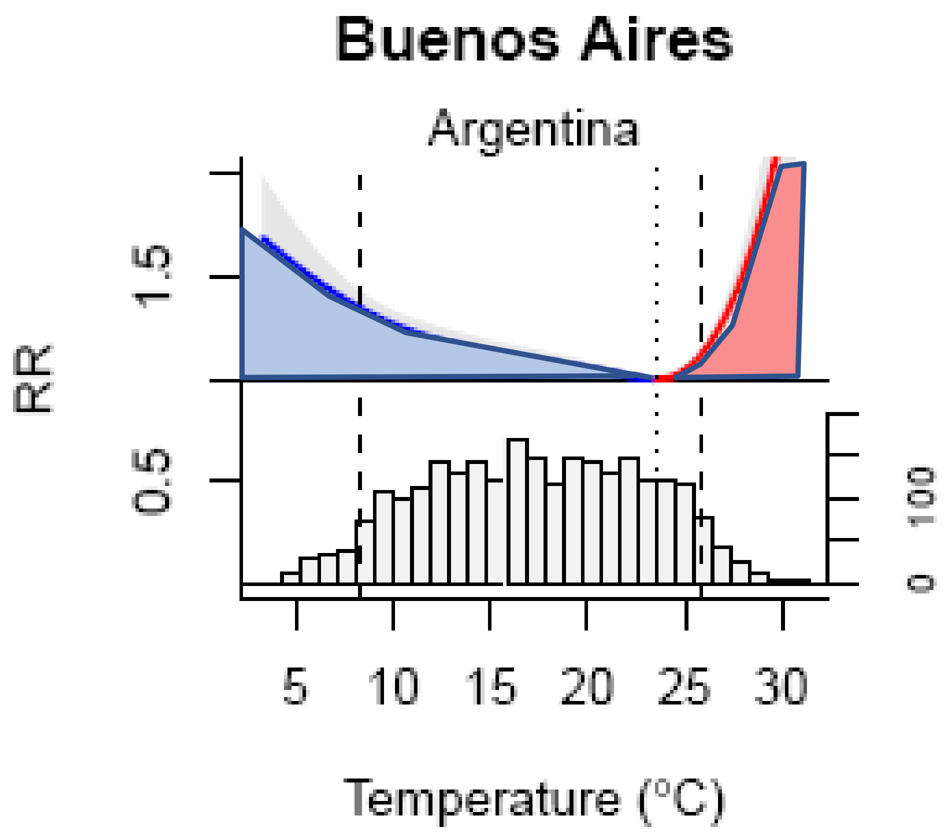

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Results: excess death fractions (%)

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	All Heat	Extreme Heat[2]	All Cold	Extreme Cold[3]
All Cause				
All Ages	**0.67% (0.58, 0.74)**	0.42% (0.38, 0.45)	**5.09% (4.64, 5.47)**	1.03% (0.99, 1.06)
Ages 65+	**0.81% (0.75, 0.86)**	0.55% (0.5, 0.59)	**6.82% (6.41, 7.18)**	1.36% (1.31, 1.39)
Cardiovascular				
All Ages	**0.69% (0.64, 0.74)**	0.38% (0.36, 0.4)	**8.43% (7.79, 9.01)**	1.52% (1.48, 1.55)
Ages 65+	0.75% (0.68, 0.82)	0.42% (0.38, 0.44)	9.35% (8.35, 10.13)	1.66% (1.59, 1.71)
Respiratory Disease				
All Ages	**1.1% (1.02, 1.18)**	0.54% (0.5, 0.57)	**9.62% (8.55, 10.39)**	1.58% (1.51, 1.63)
Ages 65+	1.28% (1.13, 1.4)	0.61% (0.55, 0.65)	9.31% (8.71, 9.78)	1.64% (1.56, 1.69)
Respiratory Infections				
All Ages	**1.56% (1.28, 1.81)**	0.81% (0.77, 0.84)	**10.53% (9.68, 11.2)**	1.92% (1.86, 1.97)
Ages 65+	1.84% (1.67, 1.95)	0.98% (0.92, 1.02)	11.79% (10.3, 12.8)	2.01% (1.9, 2.07)

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Kephart et al, Nature Medicine, 2022

Change in relative risk of mortality per 1°C increase above 95th percentile daily temperature

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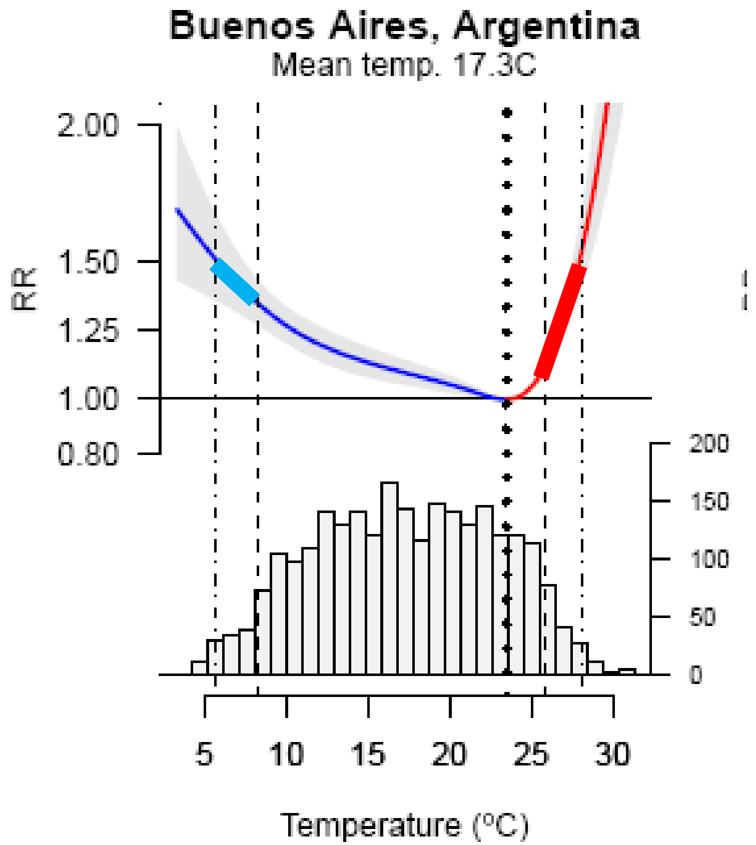


RR per degree hotter than 95% percentile

5.7% (4.6 to 6.7)

RR per degree colder than 5th percentile

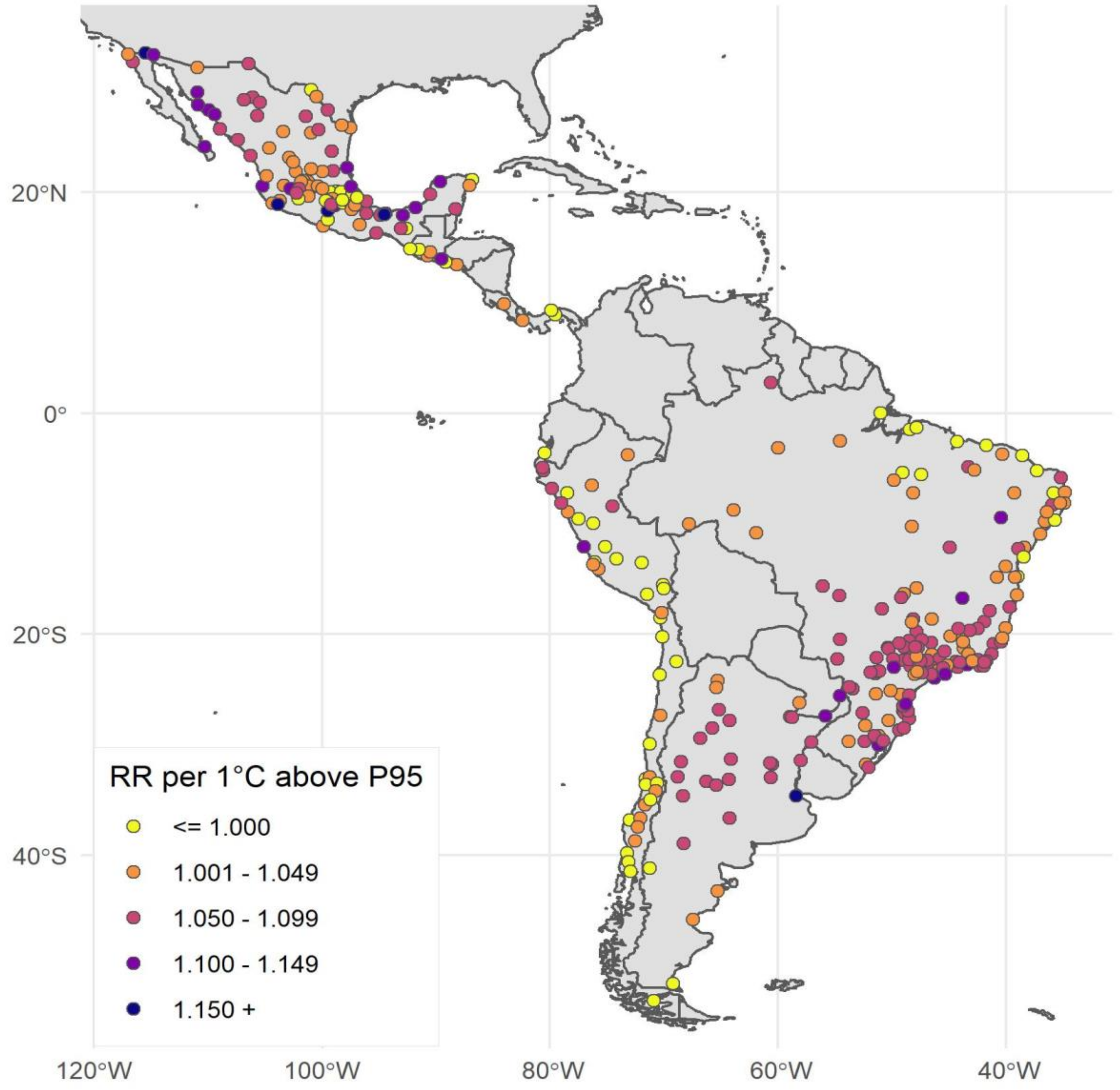
3.4% (2.8 to 4.0)

SALURBAL Urban Health in Latin America

Kephart et al, Nature Medicine, 2022

CDMX 2023

Change in relative risk of mortality per 1°C increase while under extreme heat



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Kephart et al, Nature Medicine, 2022

CDMX
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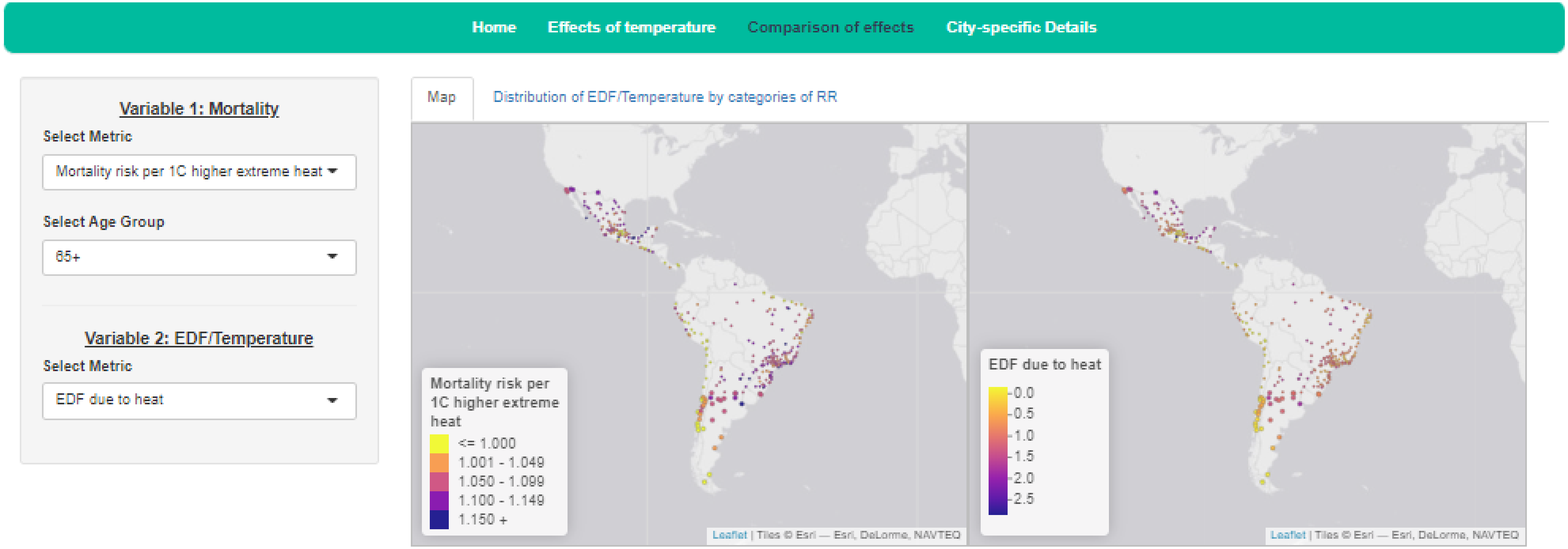
Interactive app for city-specific findings



drexel-uhc.shinyapps.io/MS85/

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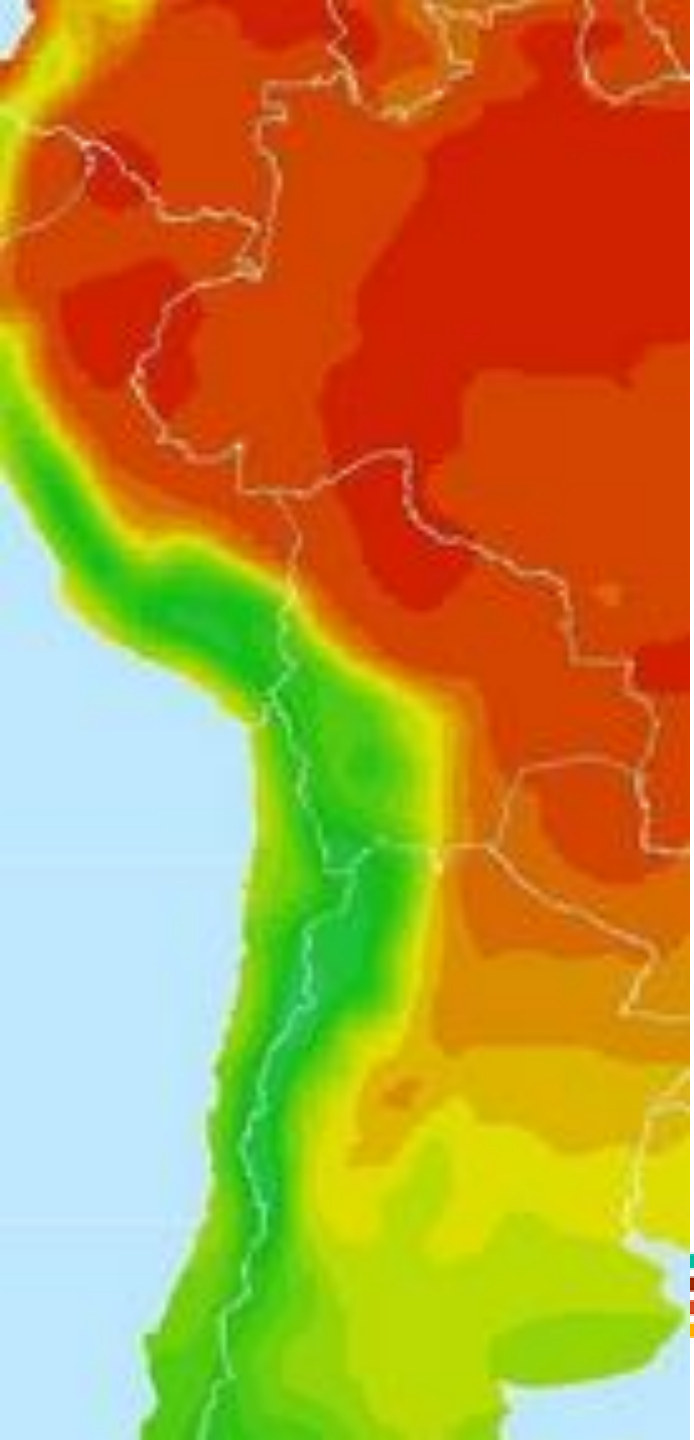


Summary of MS85 findings

CDMX 2023

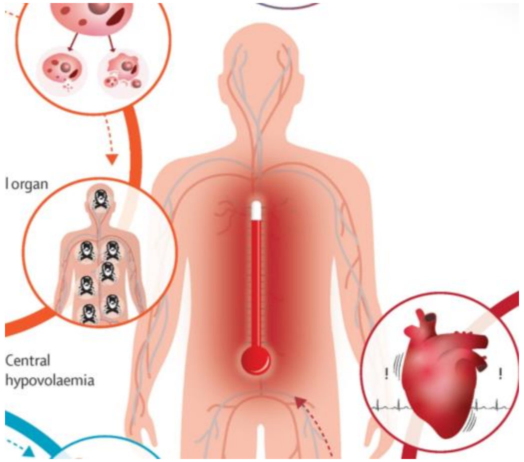
- Ambient temperature is a major driver of mortality in Latin American cities
- Older individuals are especially vulnerable
- **Small** increases in extreme heat temperature → **steep** increases in mortality
- Marginal increases in extreme heat will likely have a substantial impact on mortality, particularly among older individuals.
- Impact of temperatures on mortality varies spatially, local understanding is critical for effective mitigation planning

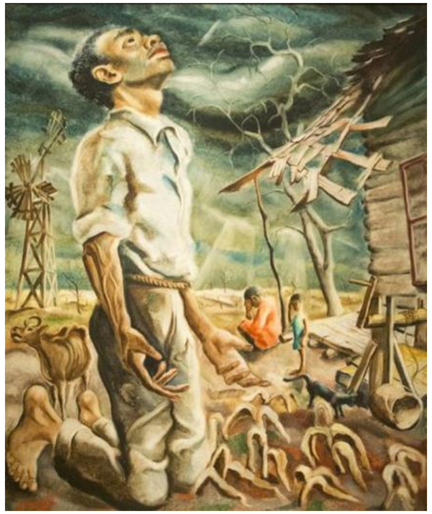
Kephart et al, Nature Medicine, 2022

Dealing with analytical challenges

CDMX 2023

1. Effects not always immediate
   - Distributed lags
2. Weather vs climate
   - Adjusted extensively to focus on short-term variation only
3. Differential exposure by area
   - City-level associations pooled via meta-analysis
4. Wide range of presentation and outcomes
   - All and cause-specific death
5. Exposure added to underlying vulnerabilities
   - Stratify by age & cause of death





Wikimedia commons. Joseph Vorst.

When to use distributed lag non-linear models

CDMX 2023

- Benefits
  - Allow for cumulative effects across lags
  - Capture effects at lags where effect may not be statistically significant
  - Reduce dimensions, allowing standard meta-analysis techniques (city -> overall)
  - R packages available

- Challenges
  - More complex than common methods
  - Computationally intense

- BEST FOR: exposures with unknown lagged effects that are unlikely to be linear

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Resources

- *Distributed Lag Linear and Non-Linear Models in R: The Package dlnm:* https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3191524/

- Stabilizing curves via meta-analysis https://doi.org/10.1186/1471-2288-13-1

- Two-stage analyses (combine city estimates via meta-analysis) https://doi.org/10.1002/sim.5471 https://doi.org/10.1016/S0140-6736(14)62114-0

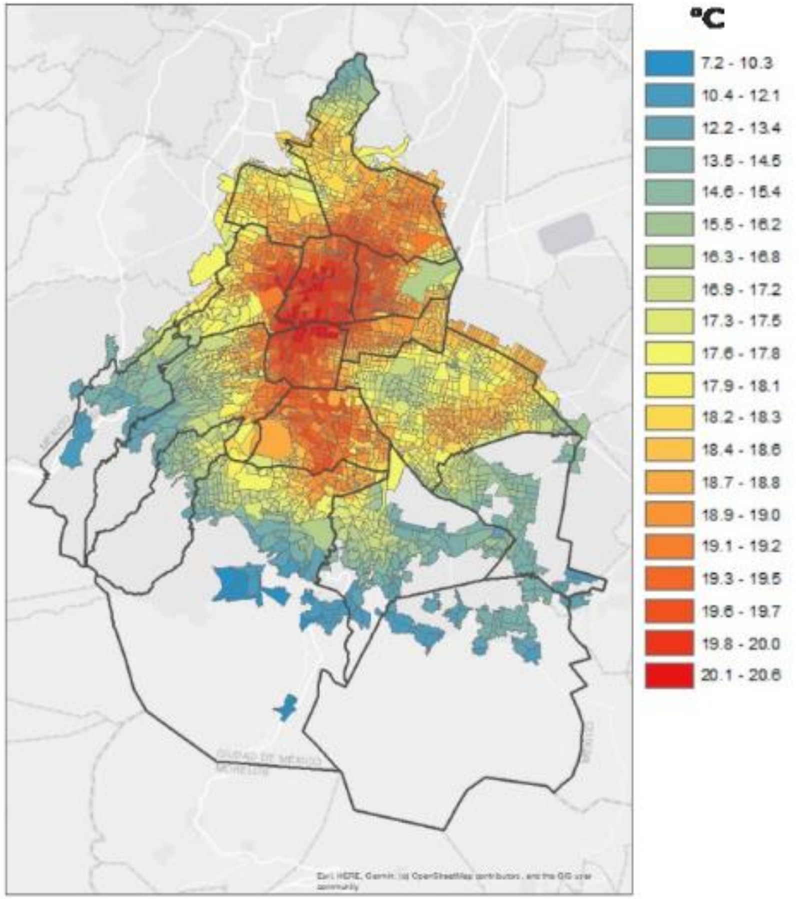

Figura 7. Mapa de temperaturas superficiales nocturnas

Within-city disparities in climate risks: floods

(MS218: work in progress)

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SALURBAL Flood Project Aims

- **MS218**
  - **Aim 1:** Characterize differential exposure to floods by social factors and features of the urban environment
    - Cumulative exposure, cross-sectional
  - **Aim 2:** Examine excess all-cause and cause-specific mortality due to exposure to floods

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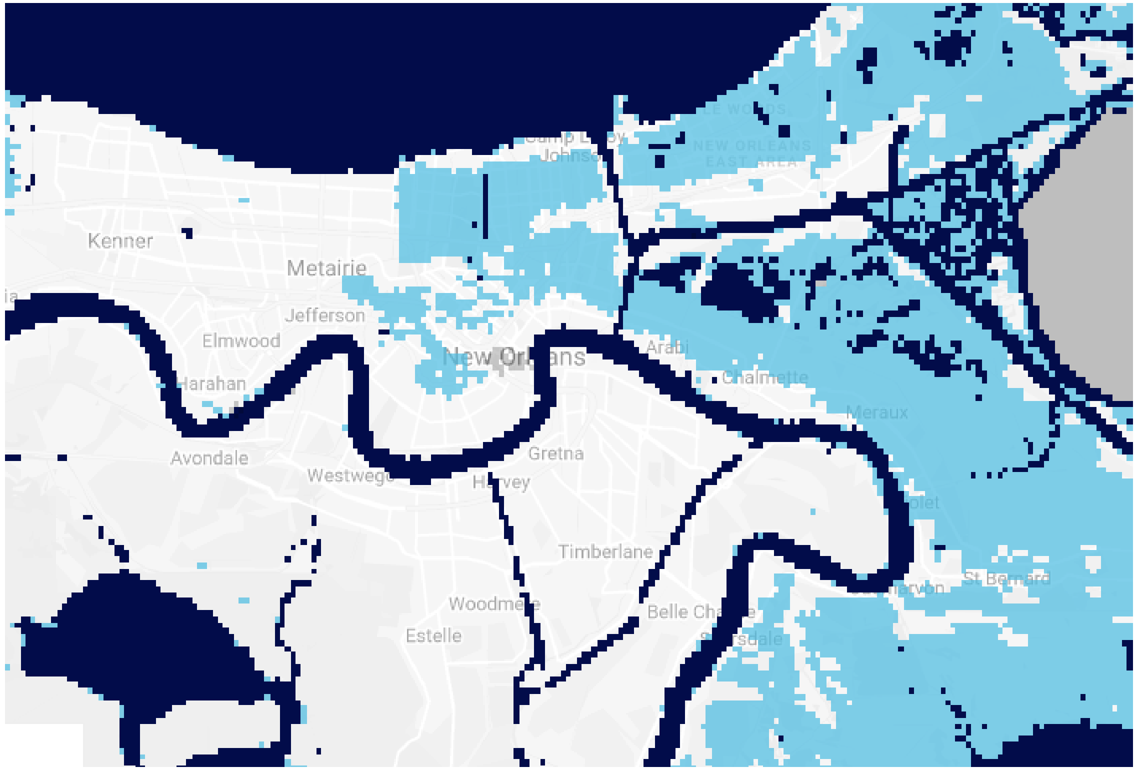
Global Flood Database

- 2000-2018
- 918 global flood events
- 250m x 250m resolution (L3!)
- Metrics
  - Maximum water extant beyond standing water extant (requires high confidence)
  - Flood duration in days
  - Dates



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Global Flood Database

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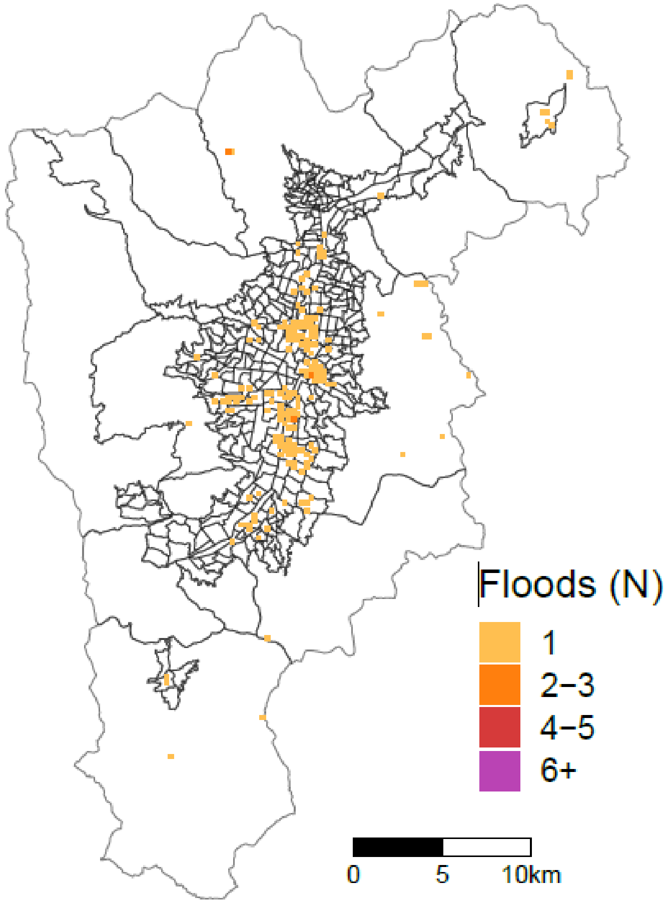

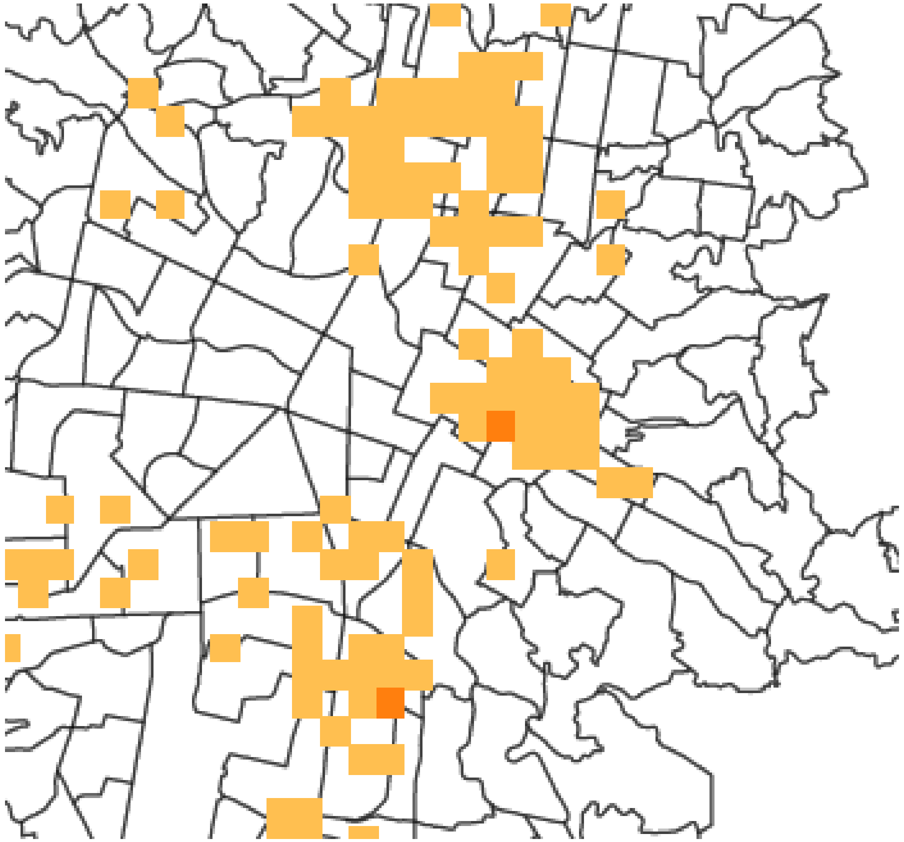

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Approach

1. Link flood raster data to SALURBAL L3’s
   1. (process 918 global raster files using JavaScript)

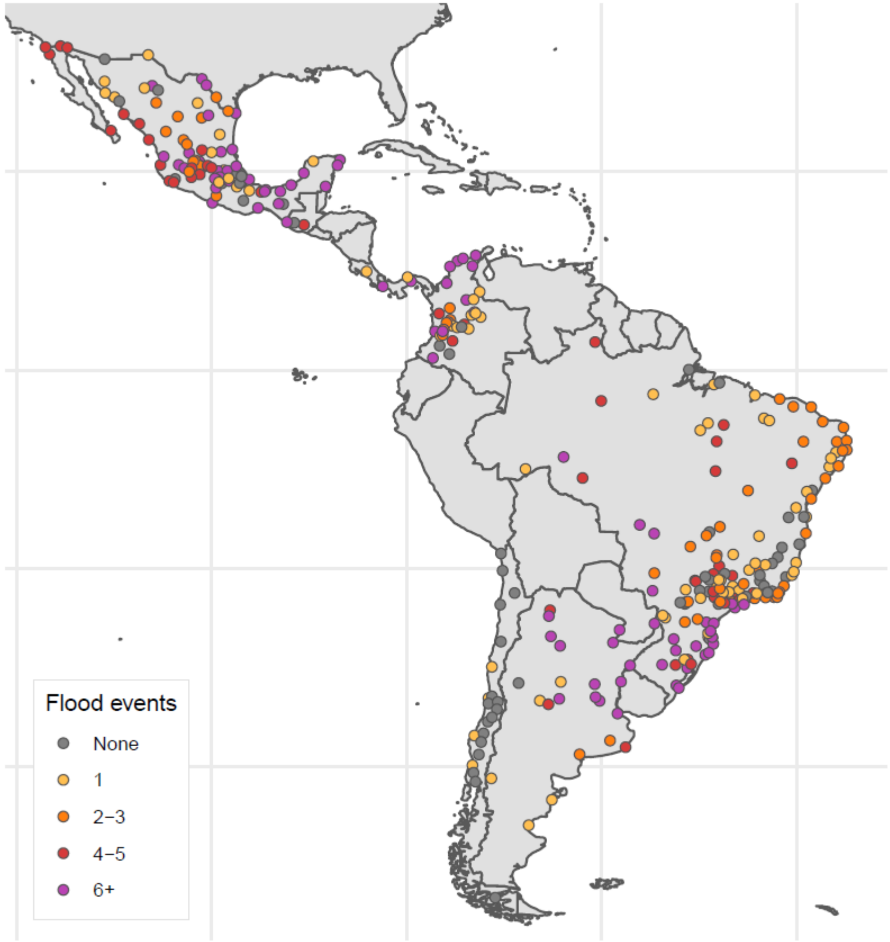
2. Merge with SALURBAL BEC and SEC L3 data

3. Describe disparities in flood exposure by education
   - Slope Index of Inequality (in progress)

4. Describe associations with urban environment

Study neighborhoods

- 47,187 neighborhoods
- 326 cities
- 8 countries
  - AR, BR, CL, CO, CR, GT, MX, PA
- 235.9 million people



	Total, neighborhoods	Study Population (millions)	% of study population living in flood-prone neighborhoods
Overall	47,187	235.9	15.9%
By educational attainment			
1st quintile (lowest)	9,428	102.6	**22.2 %**
2nd	9,439	46.1	18.3 %
3rd	9,444	33.8	9.4 %
4th	9,439	31.8	7.0 %
5th quintile (highest)	9,437	21.6	**4.3 %**

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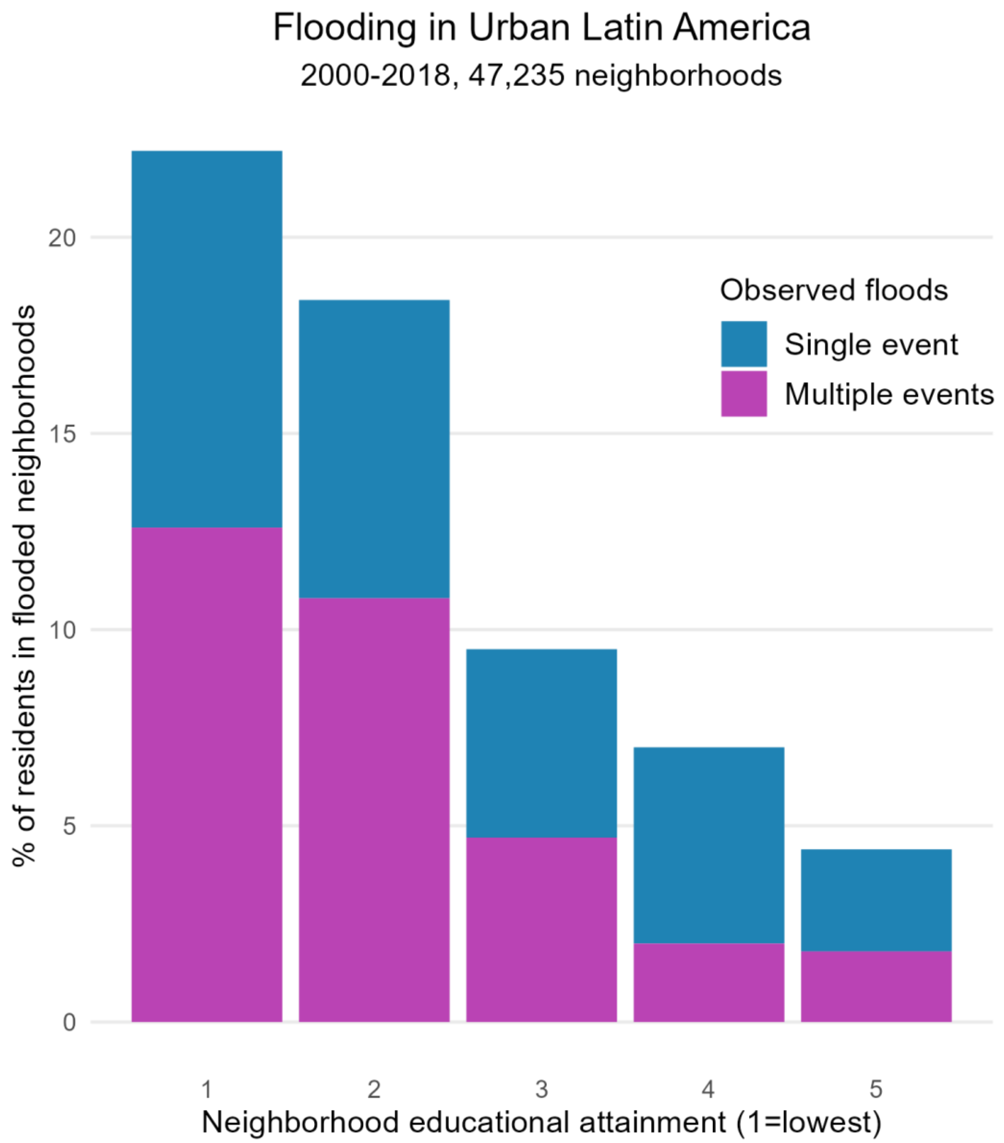
Major educational disparities in neighborhood exposure to flooding



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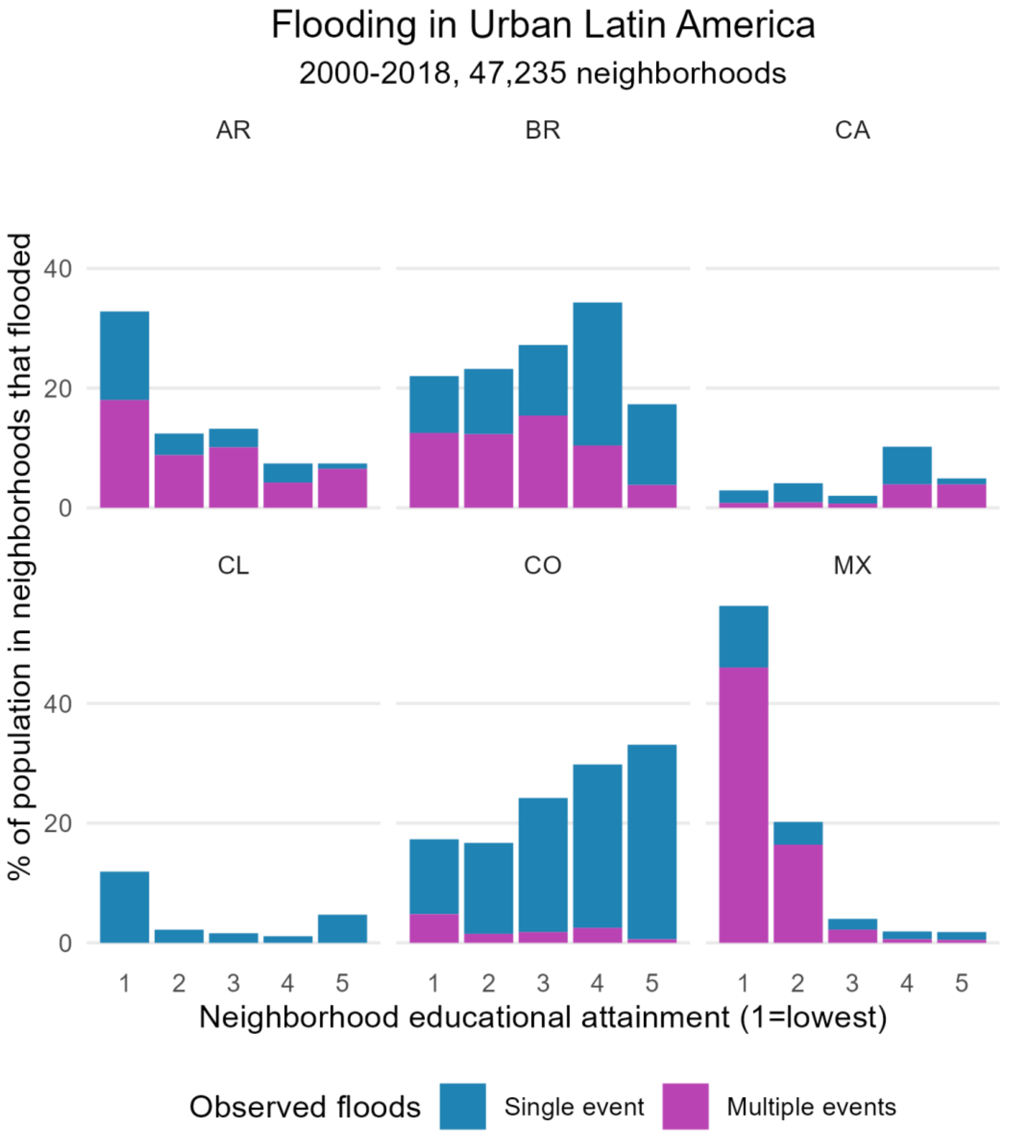
Variation within countries, but disparity consistent for multiple floods



Associations with urban environment

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Table 3. Odds ratio of neighborhood flooding associated with a one-unit z-score increase in neighborhood- and city-lev

		Univariable		Multivariable	
		Estimate	95% CI	Estimate	95% CI
Neighborhood-Level	Population density*	**0.17**	0.15, 0.20	**0.42**	0.36, 0.49
	Education	**0.66**	0.63, 0.69	**0.79**	0.74, 0.84
	Intersection density	**0.40**	0.36, 0.45	**0.80**	0.73, 0.87
	Greenness	**2.02**	2.02, 2.02	**1.57**	1.44, 1.70
	Distance from city center	**1.52**	1.46, 1.59	**1.20**	1.13, 1.26
	Coastal (<1 km)	**48.7**	39.9, 59.4	**67.91**	54.74, 84.26
	Altitude	**1.00**	0.99, 1.00	1.00	1.00, 1.00
	Slope	**1.02**	1.00, 1.03	**0.93**	0.91, 0.95

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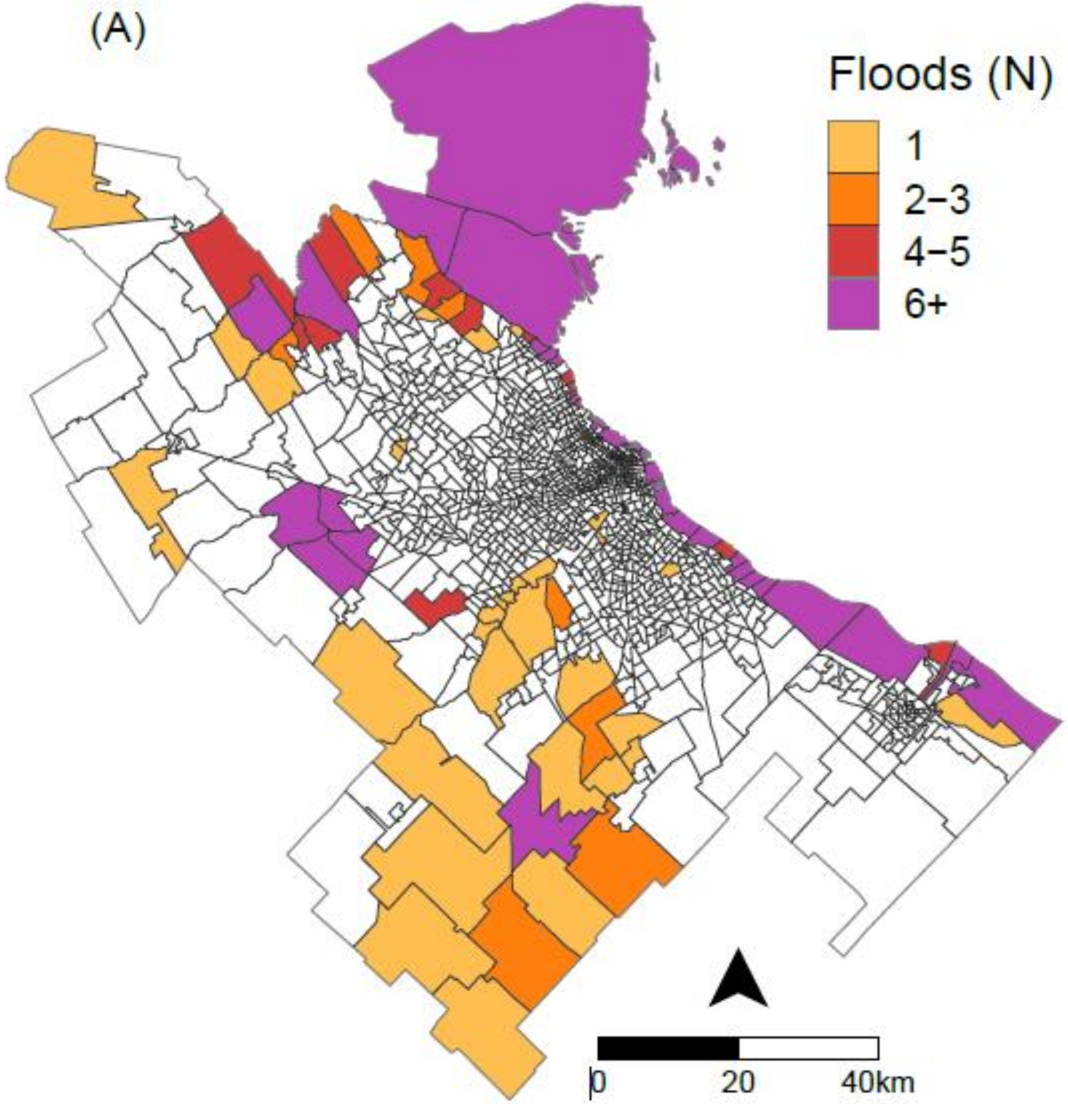
		Univariable		Multivariable	
		Estimate	95% CI	Estimate	95% CI
City-level	Population size	0.94	0.81, 1.09	1.13	0.95, 1.34
	Population density	0.85	0.66, 1.10	0.85	0.66, 1.09
	Education	1.04	0.76, 1.41	1.08	0.80, 1.48
	Intersection density	0.85	0.72, 1.00	0.84	0.69, 1.02
	Greenness/vegetation	**1.42**	1.42, 1.42	1.14	0.89, 1.45
	GDP - SEI	**1.21**	1.02, 1.44	1.08	0.92, 1.27
	Climate				
	Temperate	Ref	Ref	Ref	Ref
	Arid	0.69	0.39, 1.22	0.82	0.43, 1.56
	Tropical	**1.65**	1.10, 2.46	1.09	0.72, 1.63

Summary of associations with urban environment

- Neighborhoods features associated with flooding
  - Coastal***
  - Lower density (population and intersection)
  - Lower education
  - More green
  - Further from city center
  - Flatter slope
- City features
  - No associations with city features



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In summary

- Lowest education neighborhoods were **<u>5x more likely</u>** to experience flooding than highest education neighborhoods
- Coastal neighborhoods and peripheral n'hoods with lower density and more green experienced more flooding

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Next up: health analyses