SALURBAL Climate and Urban Health workshop

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Part 1. Introduction to historical and projected temperature data

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Historical temperature data: Input

- ERA5-Land reanalysis dataset
- Produced by the European Centre for Medium-Range Weather Forecasts
- Combines weather data from stations with model data

Mean 2m temperature for February 2019 from ERA5-Land
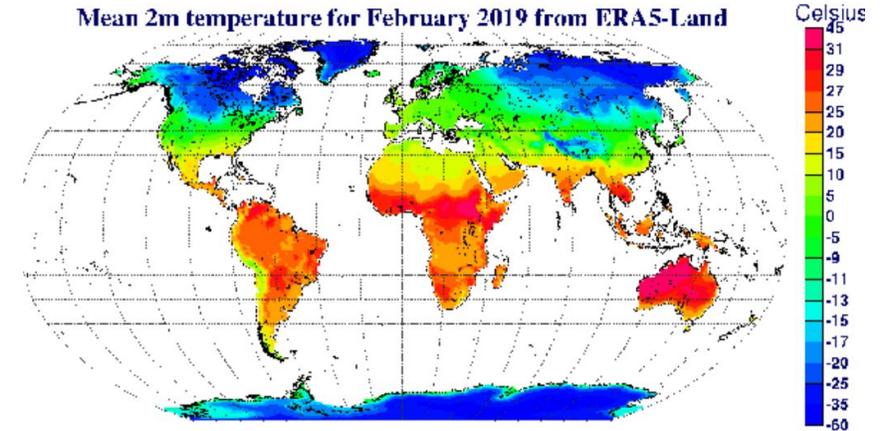
Data type	Gridded
Coverage	Global
Spatial resolution	9x9 km
Vertical coverage	2 meters above surface level
Temporal range	1950 to present
Temporal resolution	Hourly

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# Historical temperature data: Processing for SALURBAL cities

1. Imputation for coastal cities

2. Population-weighting of the data

3. Derivation of temperature time series for SALURBAL geographies

Temp. Pisco, Peru
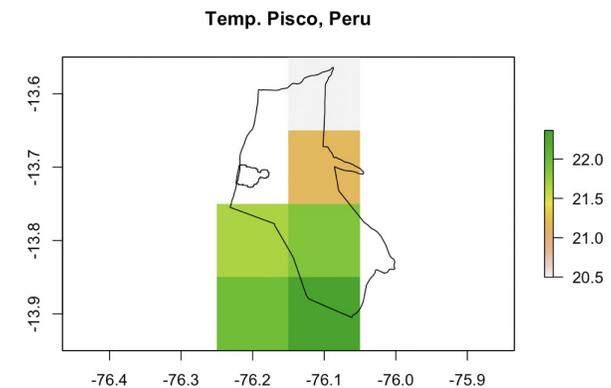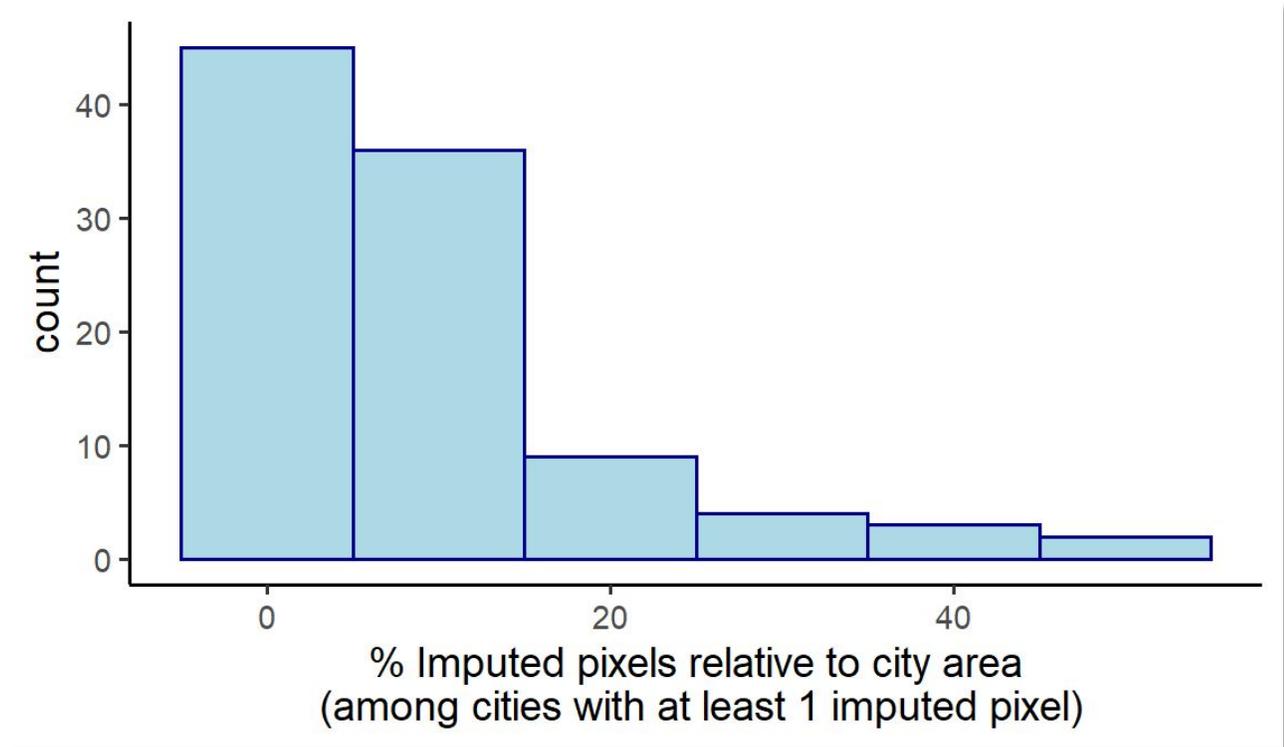
Processing step 1: Imputation

- Problem: ERA5-Land neglects pixels with more than 50% water => missing data in 98 coastal cities

- Solution: Impute missing pixels

- Procedure:

  - Fit a random forest regression for every spatial unit and every day of form
    $$ERA5\text{-}Land = f(X) + \epsilon, \text{ where}$$

  - X is a vector of ERA5 temperature (with no missing pixels) and terrain features such as absolute and relative elevation and aspect

Pisco, Peru

t, °C
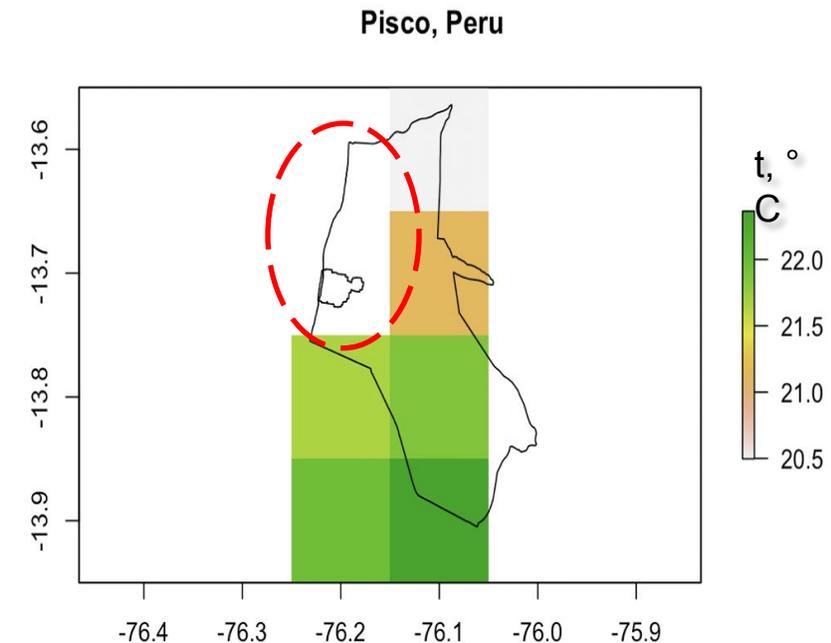
Processing step 1: Imputation

- 98 cities affected

- On average, 10% of city area was affected across cities affected by imputation

- Compared imputed data to weather data from stations

Processing step 2: Population weighting

- Weigh imputed temperature data by the spatial population distribution to improve the accuracy of temperature exposure

- Population weights from the WorldPop project (100 m grid cells with estimated populations counts for 2010)
  - For Panama and Peru used Global Urban Footprint

Argentina population 2010
Estimated total number of people per grid-cell at a resolution of (3 arc seconds approximately 100m at the equator)

High

Low

1000 km
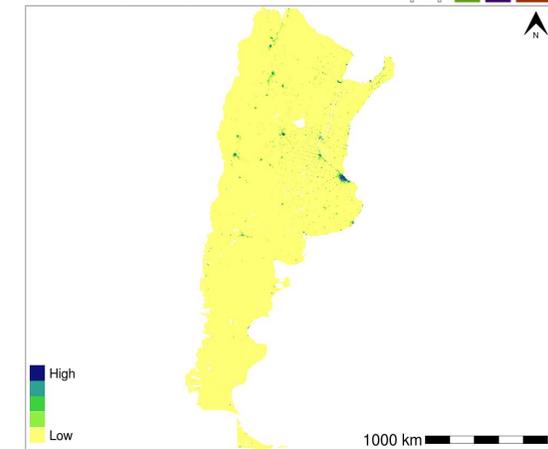
WorldPop (www.worldpop.org – School of Geography and Environmental Science, University of Southampton; Department of Geography and Geosciences, University of Louisville; Département de Géographie, Université de Namur) and Center for International Earth Science Information Network (CIESIN), Columbia University (2018). Global High Resolution Population Denominators Project – Funded by the Bill and Melinda Gates Foundation (OPP1134076). https://dx.doi.org/10.5258/SOTON/WP00645

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Processing step 3: Extract temperature time series for SALURBAL spatial units

- Using imputed and population-weighted data, extracted daily mean temperature for every day during 1996-2015 for L2, L1AD and L1UX as an average of ERA5-Land pixel values across each spatial unit

- Population-weighted and unweighted time series available

- Final dataset:

L1Name	Country	date	ADtemp_pw	ADtemp_x
Bahia Blanca	Argentina	1996-01-01	28.02	27.74
Bahia Blanca	Argentina	1996-01-02	26.82	26.68
Bahia Blanca	Argentina	1996-01-03	23.34	23.06

Measuring temperature exposure from ERA5-Land

- Advantages of ERA5-Land (and other reanalysis datasets)
  - High spatial resolution (9x9 km in ERA5-Land)
  - Global coverage and high temporal frequency
  - Temporal and spatial completeness (although need to be careful with coasts) even in areas with sparse weather data
  - Widely used in ecological, hydrological, and epi research globally
  - Similar temperature-mortality curves from ERA5-Land and weather stations (Mistry et al. 2022)

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Measuring temperature exposure from ERA5-Land

- Challenges/Things to keep in mind
  - Quality of reanalysis data is as good as input (weather data + computer weather model)
    - Fewer station observations as we go back in time
    - Simplified representation of the real world in the computer model
  - Spatial representation of actual exposure measures
    - Temperature from a 9x9 km grid vs. a point measurement (weather stations)
    - Temperature values from the reanalysis are representative of the entire environment within the 9x9 km grid as opposed to one single point
  - May underestimate extremely high temperatures in tropical regions
    - Possible underestimation of heat-related mortality (Mistry et al. 2022)

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Future temperature for SALURBAL

- Need future temperature for predicting future burden of temperature-related mortality
- SALURBAL's colleagues at UNC downscaled and bias-corrected a general circulation model to produce estimates of future daily temperature for SALURBAL cities
- Considered 2 scenarios of greenhouse gas concentration trajectories
  - RCP2.6 – Very stringent; requires that CO2 emissions start declining by 2020 and reach zero by 2100.
  - RCP8.5 – Based on assumptions of increasing concentrations of CO2; is in line with the current trajectory of emissions
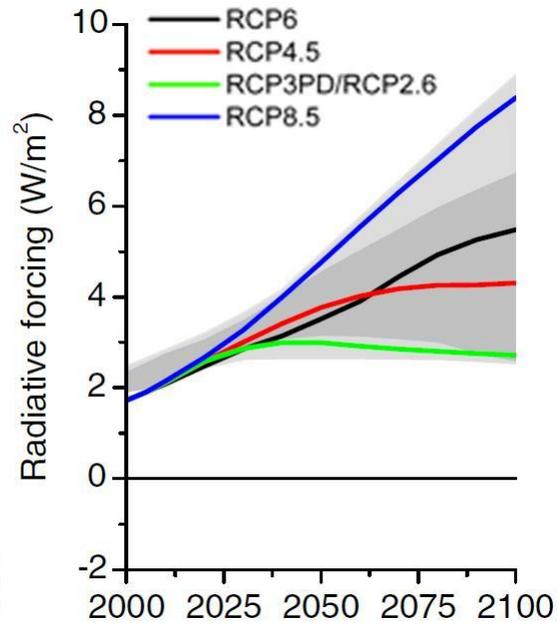
WRF downscaling and bias-correction

Data from MPI
For HIST, RCP26 and RCP85

Weather Research and
Forecasting (WRF) model

HIST
CAM and SAM
domains
1995-2005

RCP26
CAM and SAM
domains
2044-2054

RCP85
CAM and SAM
domains
2044-2054

At 12 km horizontal
resolution

van Vuuren et al (2011)

- Applied a trend preserving bias correction developed by Hempel et al. 2013
- CAM - Central America
- SAM - South America
- HIST - Historical
- Hourly outputs are stored

Slide courtesy of Ramarao Mandavilli

Final projected temperature product

|	
Variables	Daily min temperature*
	Daily max temperature*
	Daily mean temperature*
Scenarios	Historical (1996-2005); RCP2.6 (2045-2054); RCP8.5 (2045-2054)
Spatial resolution	9x9 km grids (matching ERA5-Land resolution)
Temporal resolution	Daily

* Available as population-weighted and unweighted

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Slide courtesy of Ramarao Mandavilli

Analysis examples

Examples of using city level heat-mortality outputs to examine modifying factors including

City-level socioeconomic and
demographic factors (MS135)

City-level greenspace
(MS121)
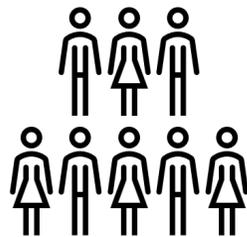
Maryia Bakhtsiyarava, Leah H. Schinasi, Brisa N. Sánchez, Iryna Dronova, Josiah L.
Kephart, Yang Ju, Nelson Gouveia, Waleska Teixeira Caiaffa, Marie S. O'Neill, Goro
Yamada, Sarav Arunachalam, Ana V. Diez-Roux, Daniel A. Rodríguez

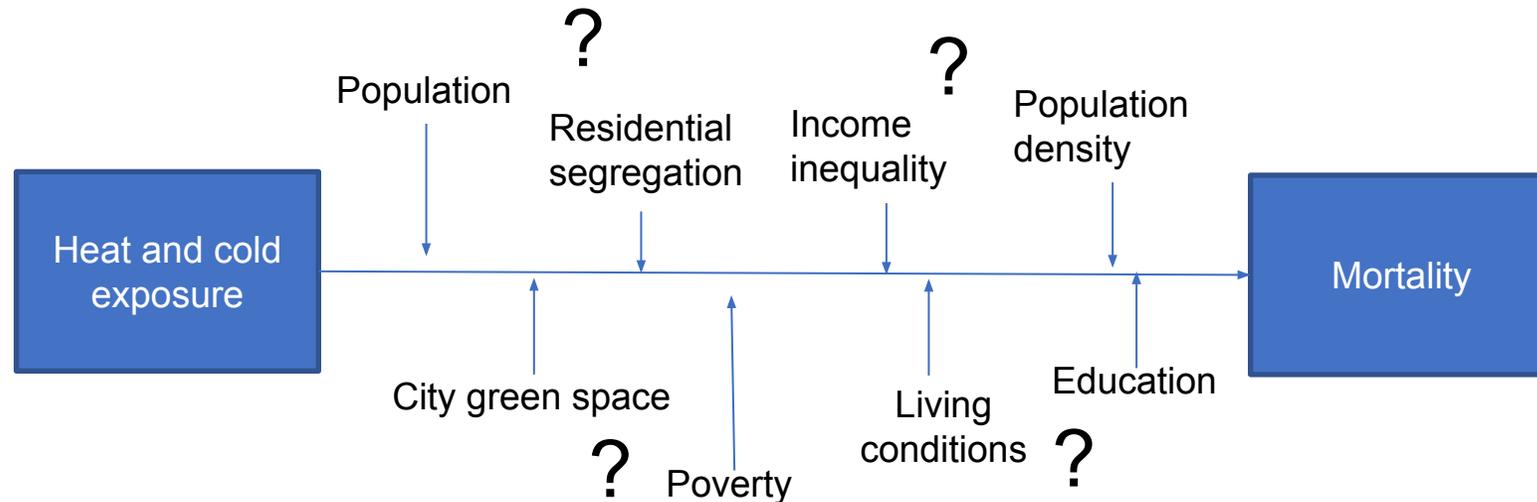Leah H Schinasi, Maryia Bakhtsiyarava, Brisa N. Sánchez, Josiah L. Kephart, Yang Ju,
Sarav Arunachalam, Nelson Gouveia, Waleska Teixeira Caiaffa, Marie S. O'Neill, Iryna
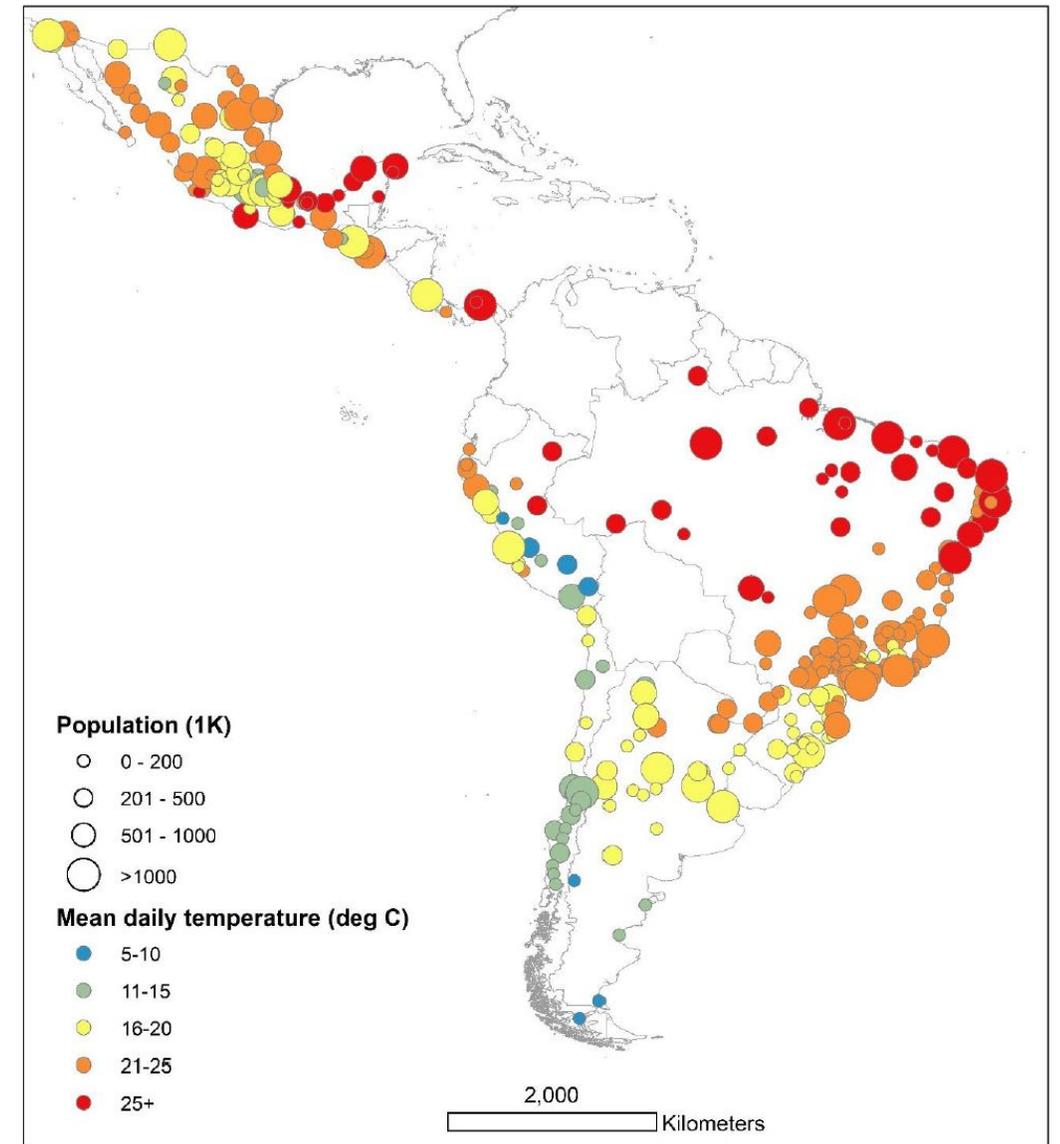Dronova, Ana V. Diez Roux, Daniel A. Rodríguez

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Vulnerability to non-optimal temperatures

Vulnerability = f(Exposure, Physiological Sensitivity, Adaptive Capacity)

Analysis Example 1. Modification of temperature-related mortality by city-level socioeconomic and demographic factors: Data

- 325 cities from Argentina, Brazil, Chile, Costa Rica, El Salvador, Guatemala, Mexico, Panama, and Peru

- Daily all-cause all-age mortality counts for 2002-2015 for 325 cities

- Daily city temperature data from ERA5-Land

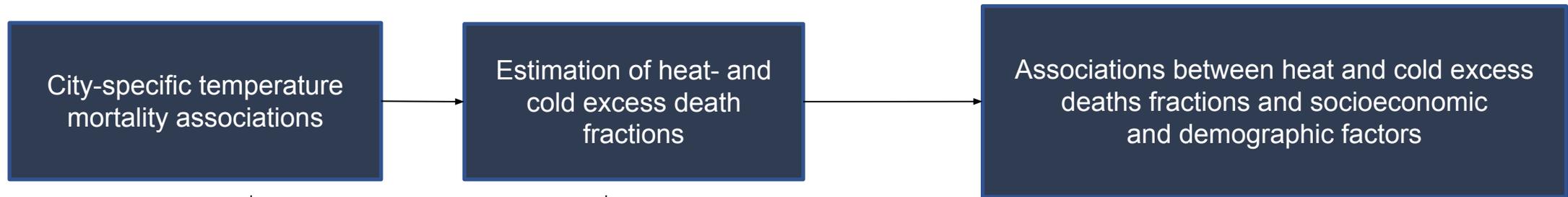- City-level census and survey variables

Population (1K)
- ○ 0 - 200
- ○ 201 - 500
- ○ 501 - 1000
- ○ >1000

Mean daily temperature (deg C)
- ● 5-10
- ● 11-15
- ● 16-20
- ● 21-25
- ● 25+

2,000 Kilometers

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Modification of temperature-related mortality by city-level socioeconomic and demographic factors: Data

Variable	N cities	Mean	SD
Daily temperature (°C)	325	20.45	4.38
Annual temperature range (°C)	325	14.98	6.73
Minimum Mortality Temperature (°C)	325	23.15	3.22
Total deaths	325	47,262	137,317
Socioeconomic and demographic effect modifiers			
Population (1K)	325	778	2,060
Population density per km^2	325	6,884	2,783
Population >65 years (%)	325	6.70	1.83
Built-up area (%)	325	59.09	6.85
Age-standardized mortality rate per 100,000 residents	325	551.89	119.54
Living conditions score:	325	0.01	1.76
Households with piped water inside the dwelling (%)	325	87.47	13.14
Overcrowding: households with more than 3 people per room (%)	325	5.96	4.78
15-17 yo attending school (%)	325	79.38	8.17
Secondary education (%)	325	38.70	9.40
Poverty (%)	319	30.62	15.80
Gini index of income inequality	296	0.50	0.08
Segregation (based on isolation index)	303	0.29	0.16

Modification of temperature-related mortality by city-level socioeconomic and demographic factors: Methods

City-specific temperature mortality associations

→

Estimation of heat- and cold excess death fractions

→

Associations between heat and cold excess deaths fractions and socioeconomic and demographic factors

Kephart et al. (MS85)

- Random effects meta-regressions to evaluate associations between heat and cold excess mortality fractions and each effect modifier
- Socioeconomic and demographic effect modifiers modeled as 3-level categorical variables split at tertile cutoffs (e.g., low, medium, high)
- Meta-regressions adjusted for indicators for countries, average daily temp, temperature range, and climate zone

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Modification of tempearature-related mortality by city-level socioeconomic and demographic factors: Methods

- Additional effect modification analyses
  - Mortality attributable to extreme heat and extreme cold
  - Temperature-related mortality for those 65 and older
  - CVD mortality
  - Cities stratified climate zones (arid, tropical, temperate)

Results

Cold EDF (%)　　　　　　Heat EDF (%)

Population, medium
Population, high

Population density, medium
Population density, high

Built-up area (%), medium
Built-up area (%), high

Age-standardized mortality rate, medium
Age-standardized mortality rate, high

Living conditions score, medium
Living conditions score, low

Secondary education (%), medium
Secondary education (%), high

Poverty (%), medium
Poverty (%), high

Gini index, medium inequality
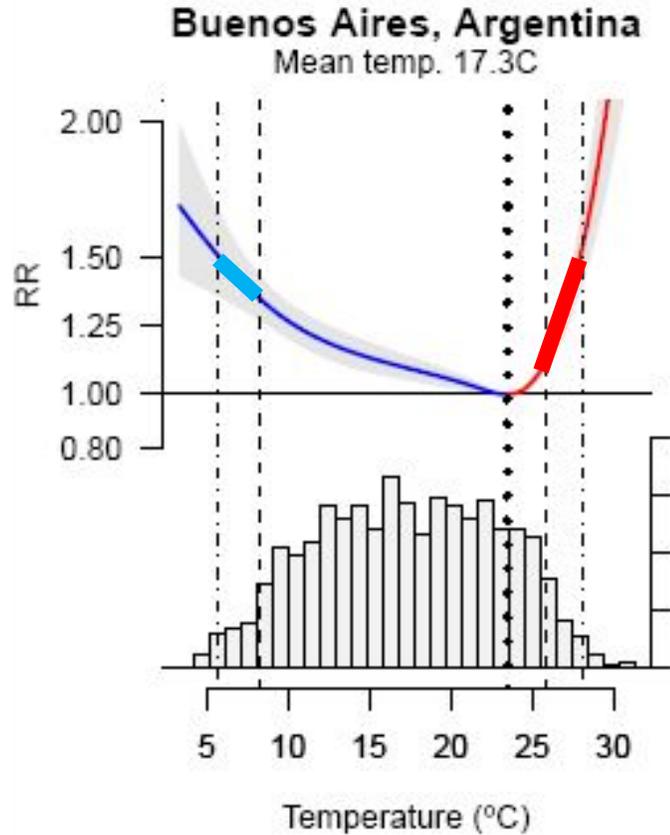Gini index, high inequality

Segregation, medium
Segregation, high

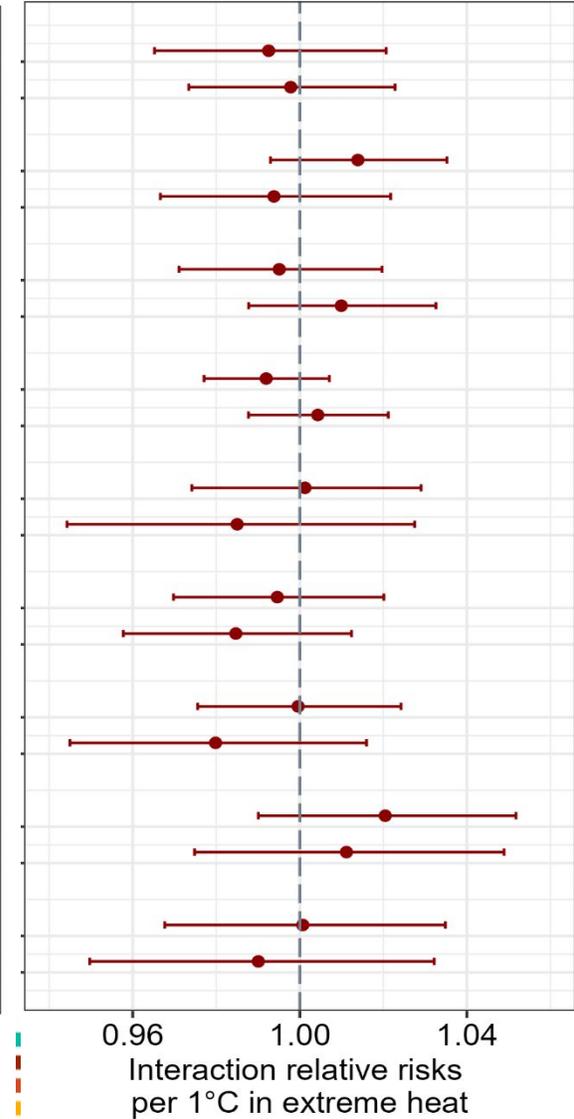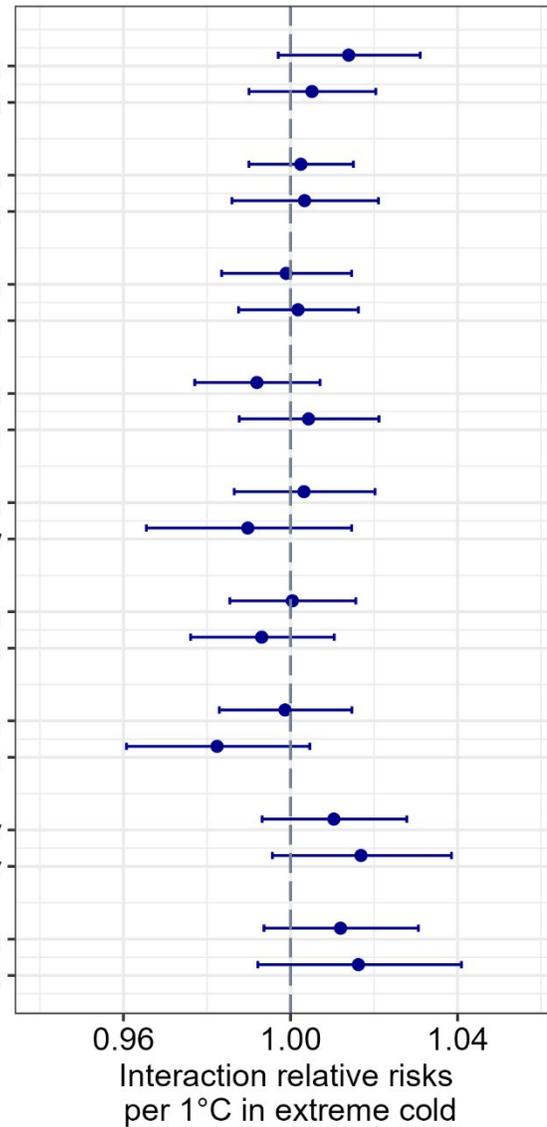Percentage-point difference in EDF　　Percentage-point difference in EDF

Results

Buenos Aires, Argentina
Mean temp. 17.3C

Kephart et al. 2022

Population, medium
Population, high

lation density, medium
opulation density, high

t-up area (%), medium
Built-up area (%), high

mortality rate, medium
zed mortality rate, high

nditions score, medium
g conditions score, low

education (%), medium
ary education (%), high

Poverty (%), medium
Poverty (%), high

dex, medium inequality
i index, high inequality

Segregation, medium
Segregation, high

Interaction relative risks
per 1°C in extreme cold

Interaction relative risks
per 1°C in extreme heat

Results summary

- Limited effect modification of cold-related mortality by city-level demographic and socioeconomic characteristics

- Several unexpected associations for heat-related mortality

  - Cities with high levels of poverty and income inequality experience smaller heat EDFs compared to cities with little poverty and income inequality

- Higher poverty and higher segregation were associated with higher cold-related mortality among those 65 and older

- Little evidence of effect modification for CVD mortality and by climate zones

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Analysis Example 2. Modification of heat-related mortality by city-level greenspace
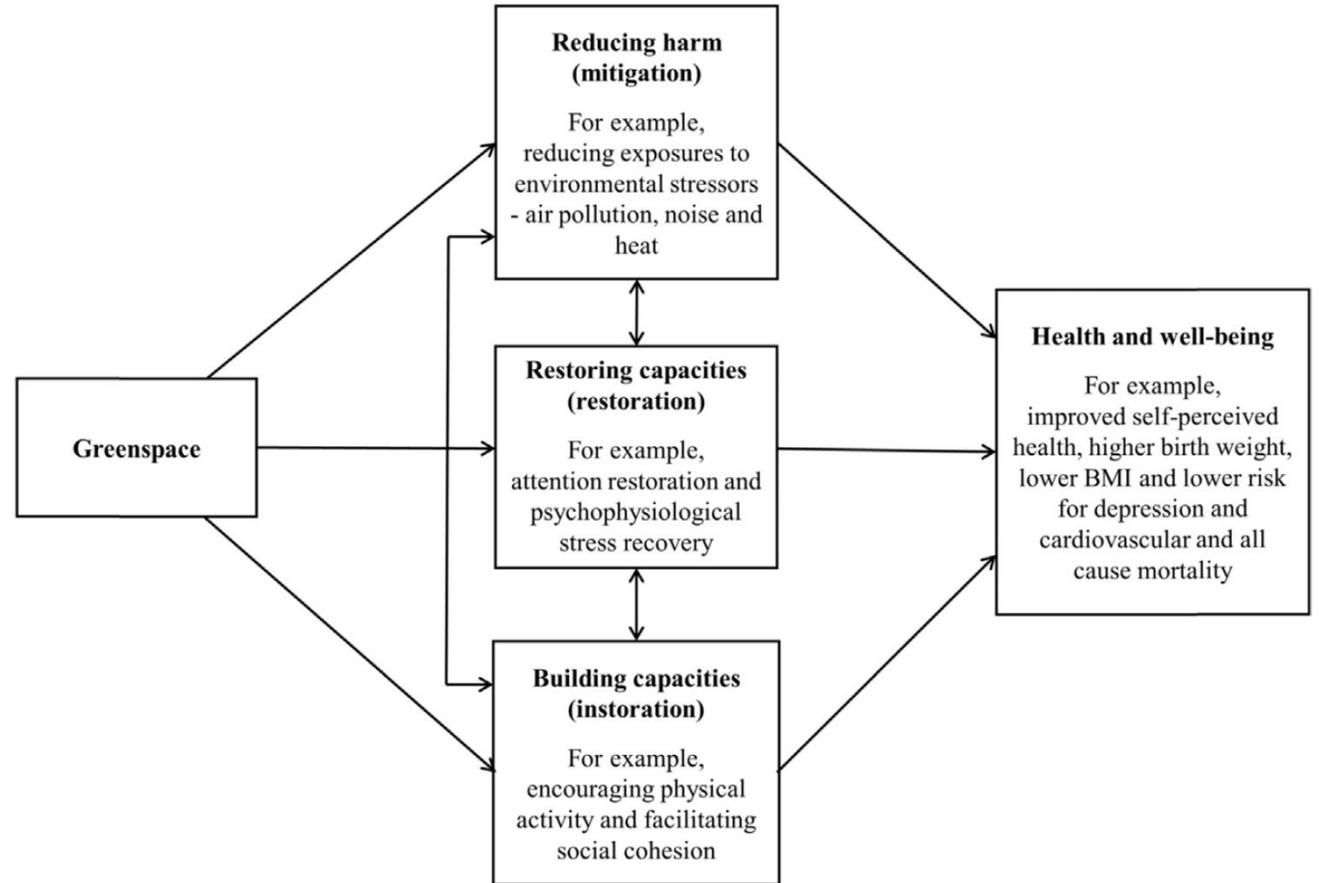
Markevych et al. 2017

Modification of heat-related mortality by city greenspace: Data

- 323 cities from Argentina, Brazil, Chile, Costa Rica, El Salvador, Guatemala, Mexico, Panama, and Peru

- Daily all-cause mortality counts for 2002-2015 for 325 cities

- Daily city temperature data from ERA5-Land

- Normalized Difference Vegetation Index from the MODIS instrument of Terra Satellite
  - 250 meters, every 16 days

- Greenspace map from Sentinel-2 images
  - 10 meter spatial resolution, resampled to 30 meters to streamline computation

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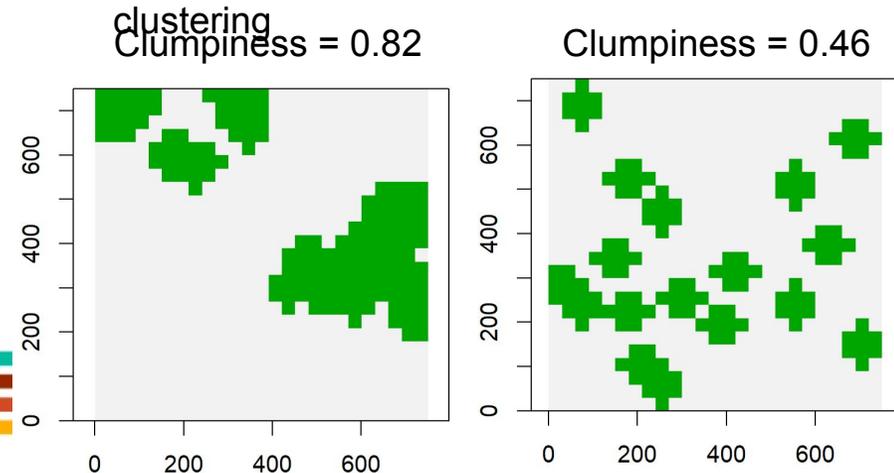
Measures of greenness

Amount: Area-level greenness

- City-level NDVI

  - Measures the amount and intensity of vegetation

  - Computed annual max NDVI for every pixel within city

  - Obtained the median of the annual maximum NDVI value to capture peak vegetation growth

  - Higher values mean more abundant and verdant vegetation
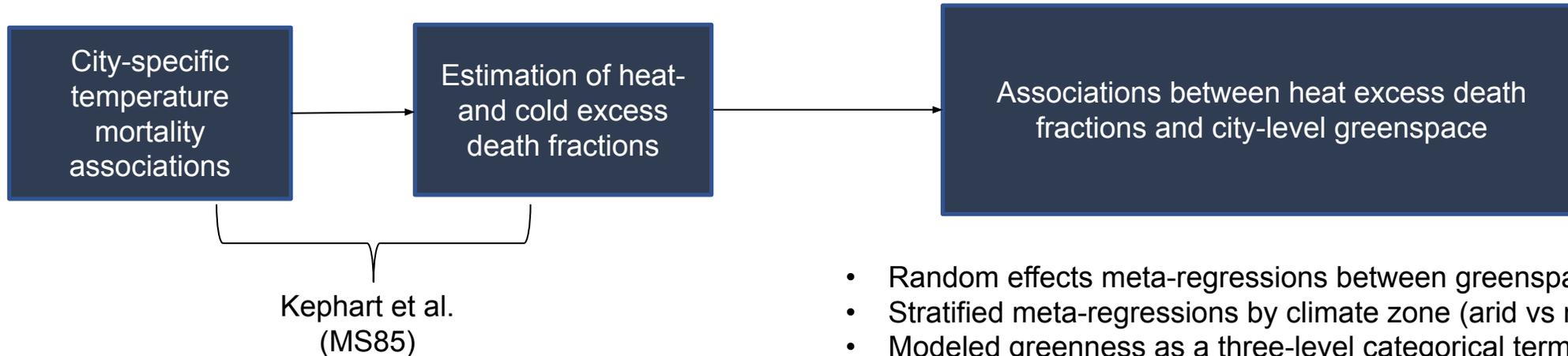
Spatial configuration: Clustering

- City-level greenspace clustering

  - Based on a landscape ecology measure called clumpiness index, which captures the extent of aggregation of greenspace across a landscape

  - Ranges from -1 to 1; -1 = maximum disaggregation, 0 = random distribution, and 1 = maximum clustering

Clumpiness = 0.82   Clumpiness = 0.46

Modification of heat-related mortality by city greenspace: Methods

City-specific temperature mortality associations

Estimation of heat- and cold excess death fractions

Kephart et al. (MS85)

Associations between heat excess death fractions and city-level greenspace

- Random effects meta-regressions between greenspace and heat EDFs
- Stratified meta-regressions by climate zone (arid vs non-arid)
- Modeled greenness as a three-level categorical term, with categories based on tertiles of the climate-zone (arid vs. non-arid) specific distribution.
- Meta-regressions adjusted for city PM2.5 concentration, social environment index and country
- Estimated effect modification of the association between heat-mortality and greenness by greenspace clustering by including an interaction term between a 3-level categorical NDVI variable and a dichotomous clustering variable (split at the median)

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Results

Random effects meta-regression estimates (Betas) and 95% Confidence Intervals (CI) of association between NDVI and heat-excess death fractions, stratified by climate zones[1]						
	Arid cities (N=79)			Non-arid cities (N=244)		
Greenness (NDVI)	Beta	95% CI	AIC	Beta	95% CI	AIC
Moderate	-0.43	-1.28, 0.42	281.1	0.21	-0.42, 0.85	947.8
High	-0.61	-1.61, 0.38		-0.17	-0.81, 0.47	

[1]The reference category is cities in the lowest tertile of the climate-zone specific distribution of greenness, as measured by NDVI. Moderate and high levels of greenness refer to the second and third tertiles of the climate zone specific distribution of greenness, measured by the NDVI. The results were derived from random effects meta-regressions that adjusted for particulate matter, social environment index, country group, and green space clustering.
Models were run separately for arid and non-arid climate zone cities.

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Greenness and clustering interaction: Results

Modification of random effects meta-regression estimates (Betas) and 95% Confidence Intervals (CI) of associations between NDVI and heat excess death fractions by level of clustering, stratified by climate zone[1]							
	Low Green Space Clustering			High Green Space Clustering			
Greenness (NDVI)	Beta	95% CI		Beta	95% CI		AIC	P for LRT[2]
Arid cities (N=79)							
Moderate	-0.66	-1.86	0.54	-0.26	-1.35	0.83	279.8	0.07
High	-1.27	-2.51	-0.02	0.06	-1.21	1.33		
Non-arid cities (N=244)							
Moderate	0.22	-0.65	1.09	0.16	-0.67	0.99	950.3	0.48
High	0.00	-0.81	0.81	-0.35	-1.20	0.50		

[1]The reference category is cities in the lowest tertile of the climate-zone specific distribution of greenness, as measured by NDVI. Moderate and high levels of greenness refer to the second and third tertiles of the climate zone specific distribution of greenness, measured by the NDVI. The results were derived from random effects meta-regressions that were adjusted for particulate matter, social environment index, country group, and a measure of green space clustering. Models were run separately for arid and non-arid climate zones. Effect modification by green space clustering was assessed by including an interaction term between the three-level categorical greenness variable (NDVI) and a term representing clustering, dichotomized at the median of the climate-zone specific distribution.

[2]The p-value for a likelihood ratio test (LRT) derives from a two-degree of freedom chi-square distributed test of improvement in model fit following inclusion of an interaction term between the three-level NDVI term and the two-level clustering term.

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Conclusions

- Higher city-level greenness is associated with modest protection against heat-related deaths in arid cities, and especially in cities with distributed rather than clustered greenspace.

- Vegetation in hot and dry climates has greater cooling capacity compared to humid climate zones (Zhou et al. 2017).

- Less clustered greenspace may be more protective against heat-related mortality

  - Consistent with some but not all exposure studies

  - E.g., a study from Phoenix, Arizona, showed that higher greenspace clustering was associated with enhanced cooling at a highly localized level, whereas less clustered greenspace had greater regional cooling effects (Zhang et al. 2017)

  - The implications of configuration for cooling may depend on spatial scale

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Lessons learned from effect modification analyses

Strengths

- Fill a geographical gap in research on temperature-related mortality and its effect modification outside of the Global North countries

- Better understanding of the magnitude and effect modifiers of cold/heat-related mortality in tropical and arid regions that have different temperature and climate regimes

- Large, representative sample of LAC

- High spatial and temporal resolution of exposure metrics (temperature, greenspace)

- Comprehensive greenspace metrics

- Robust statistical methods

Challenges

- City-level analyses mask a lot of heterogeneity in temp-mortality

- No data on proximity of greenspace to people's residences

- Did not account for within-city differences in temperature/greenspace

- Smaller geographical scale for effect modification analyses can help explain unexpected associations

- Did not consider thermal comfort

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Thank you!