CLIMATE ADAPTATION
RESEARCH SYMPOSIUM

MEASURING & REDUCING SOCIETAL IMPACTS

Heat Vulnerability Affecting Workers, Healthcare, and Neighborhoods

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The session will begin shortly.

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Juliana Helo
Universidad de los Andes

Andrew Ireland
Monash University

Jake Dialesandro
UC Davis

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UCLA Luskin Center for Innovation

Juliana Helo

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Temperature and Morbidity in Colombia

Temperature and Morbidity in Colombia

Juliana Helo Sarmiento
Universidad de los Andes

September 9, 2021

Motivation

- Changing climate has spurred an interest in quantifying the economic damages of this environmental risk (Dell et al., 2013)
- Cost associated to human health have been of particular interest
- Effort to quantify costs of climate change in terms of mortality risk based on empirically founded estimates of the relationship between short-term variations in temperature and mortality
  - Deschênes and Moretti (2009), Deschênes and Greenstone (2011), Carleton et al. (2018), Cohen and Dechezlepretre (2018), Burgess et al. (2011), Heutel et al. (2017), Deschênes (2014)
- Instances of extreme heat and cold increase mortality, close to zero-effects at mild temperatures.

But death is an extreme outcome, and we know much less about the effect of temperature shocks on morbidity

- Ignoring morbidity outcomes might underestimate the costs of climate change
- Miss the direct burden that climate change might impose on the health systems
- Understanding temperature-morbidity relationship might shed light on adaptation opportunities
- Access to health care could serve as a mediating factor between climate change and mortality

What do we know about the effect of temperature on morbidity outcomes?

- ER and hospitalizations increase after exposure to extreme heat and cold. (White (2017), Karlsson and Ziebarth (2016), Green et al. (2010))
  - External factors, cardiovascular illness, and diabetes.
- Fetal exposure to extreme heat affect health outcomes at birth (Kim et al. (2019), Kuehn and McCormick (2017))

Most of the evidence from developed countries located in temperate region (e.g. few states in the U.S, Europe (Germany, and some cities))

There are reasons to suspect that health responses in countries located in tropical and temperate regions differ

- On average lower income countries and weak health systems
- Populations are exposed to narrower ranges of temperature - no seasonality in temperature Temperature
- Relevant causes of death and morbidity - infectious diseases documented to react to temperature Causes

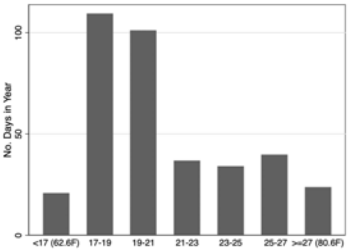
This paper explores the response of health services usage to temperature changes in Colombia

- Uses the universe of services provided by the health system (administrative data) in Colombia combined with fine scale weather data
- Hospitalization rates monotonically increase in the narrow/mild temperature range observed in Colombia.
  - Effects have been found at extremes
- Hospitalizations due to infectious diseases and maternal/pregnancy related care mainly explain these results.
  - These results have not been extensively documented in the literature

Temperature Data

- Reanalysis data from ERA-Interim produced by European Centre for Medium Range Weather Forecasts (ECMWF)
- Observational data and forecast models to produce a balanced panel on a $0.125^\circ \times 0.125^\circ$ grid level.
- Average daily temperature across four readings reported per day
- Aggregate at municipality level to construct a discrete version of the annual distributions of temperature
- Municipalities smallest administrative unit ≈ 1100

Annual Distribution of Daily Average Temperature



Classify temperature in seven categories.
Each bar represents the number of days per year the average person experiences in each temperature category.
17-19°C ≈ 62.6-66.2°F
25-27°C ≈ 77-80.6°F

- Empirical specification uses annual distribution of temperature
- Capture the non-linearity of the temperature-morbidity relationship (*a la* Deschênes and Greenstone (2011))

Colombian Morbidity Data

- Universe of health services from SISPRO system compiled by the Ministry of Health and Social Protection from 2009 - 2016
  - 4 outcomes (Consultations, Procedures, **Hospitalizations** and ER visits)
- Each type of service is classified by diagnosis according to the International Statistical Classification of Diseases and Related Health Problems by the World Health Organization (ICD-10 WHO)
- Aggregate at year-municipality level the total number of cases reported
- Balanced panel with approximately 8,000 observations

Empirical Strategy

$$MR_{iy} = \sum_{j=1}^{6} \beta_j BinTemp_{jiy} + \sum_{k=1}^{9} \gamma_k BinPrec_{kiy}$$
$$+ \eta_i + \nu_{dy} + \varepsilon_{iy}$$

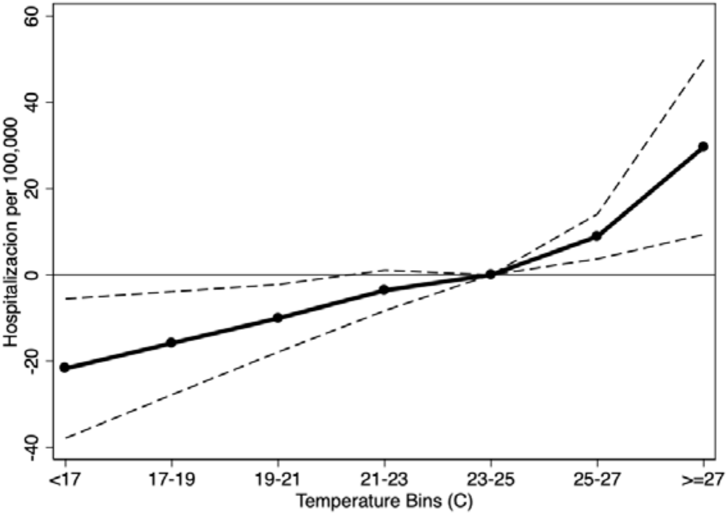
- MR: Morbidity rate per 100,000 inhabitants (Hospitalization Rate)
- i: Municipality and y: Year
- Seven 2°C bins ($T = 6$)
- Lowest includes everything less than 17°C (62.6°F)
- Highest includes everything above 27°C (80.6°F)
- Reference Bin 23-25°C (73.4-77°F)
- One additional day in temperature bin j changes annual morbidity by β_j per 100,000 inhabitants relative to the impact of 1 day in the 23-25°C (71.6-75.2°F) reference bin.

Empirical Strategy (Cont)

$$MR_{iy} = \sum_{j=1}^{6} \beta_j BinTemp_{jiy} + \sum_{k=1}^{9} \gamma_k BinPrec_{kiy}$$
$$+ \eta_i + \nu_{dy} + \varepsilon_{iy}$$

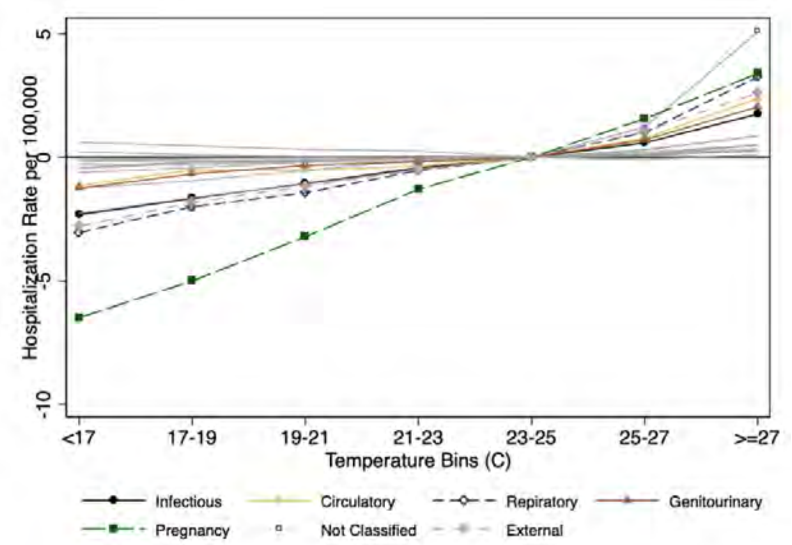
- $BinPrec_{kiy}$: Precipitation distribution in each municipality
- η_i: Municipality fixed effect
- ν_{dy}: Department (State)-Year fixed effect
- Standard errors are clustered at municipality level

Hospitalization rate increases in temperature



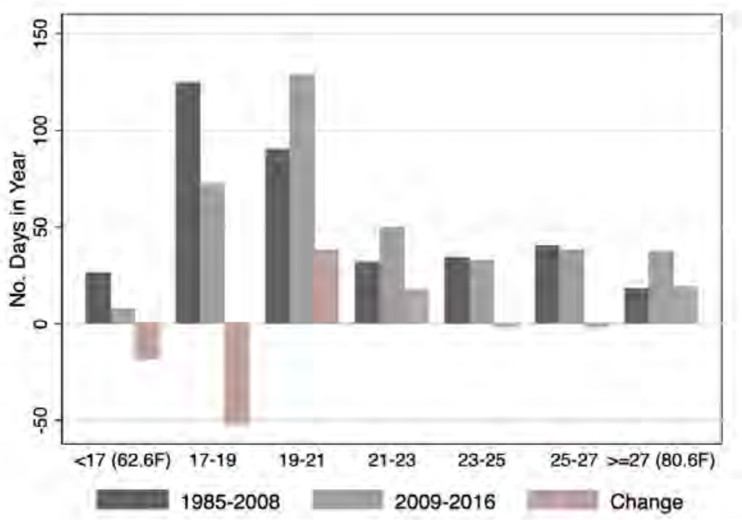
Exchanging a day in the reference bin $23-25^{\circ}$C for a day above 27°C increases hospitalization by 29.6 per 100,000 (0.86% of the average annual hospitalization rate).

Infectious diseases and maternal care mainly explain increases in hospitalization rates (relative to averages)



Costs and Implications for Climate Change

Historical change in Colombia's temperature distribution



A shift in the temperature distribution similar to what has been observed historically results in 1161.3 hospitalizations per 100,000 per year (33.6% of average annual rate)

- Assuming no further adaptation measures and the most conservative estimates.

$$\Delta HospitalizationRate = \sum_{j=1}^{6} \hat{\beta}_j \times \Delta DaysBinTemp_j$$

- Results suggest important increases in demand for services if temperatures continue to rise, but health systems could help mitigate the adverse effects of climate change

This paper advances our understanding of the temperature-health relationship in a tropical developing country

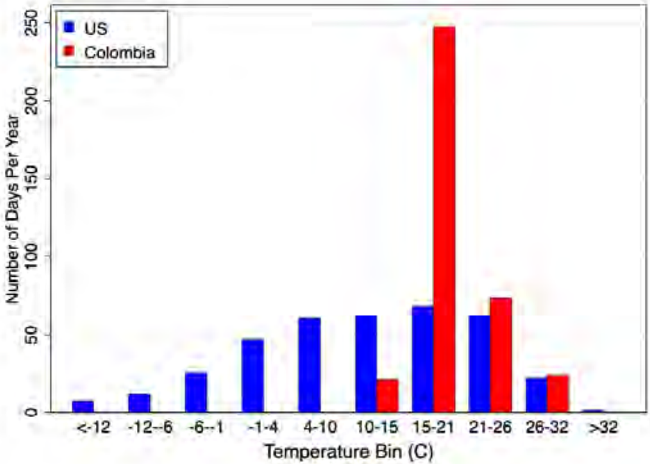
- Even small variations in ‘mild’ temperatures affect morbidity
- Infectious, and maternal health are important in explaining heat-related health complications
- Health systems might play a significant role in reducing the impacts of climate change
  - I’m exploring this hypothesis further.

Thank you.

Juliana Helo Sarmiento - j.helo@uniandes.edu.co

Populations are exposed to narrower ranges of temperature

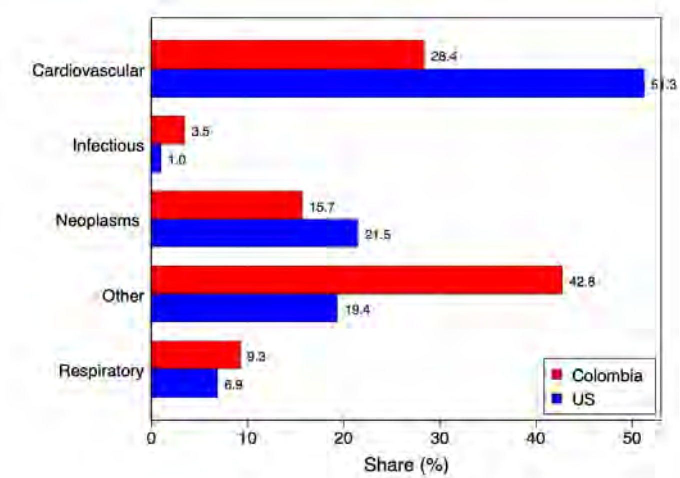
Return



- Estimates from U.S would predict close to zero effects at temperature in Colombia
- Evidence of de-adaptation to infrequent experienced events Heutel et al. (2017), Deschênes (2014)

Relevant Causes of Death

Return



- Even small variations in temperature are shown to increase disease prevalence
- Hii et al. (2009) show that dengue incidence increased succeeding higher temperatures Singapore.

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Heat and Workers' Safety: Heterogeneity Among Workers, Workplaces and Accident Types Over Time

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Heat and Workers' Safety

Heterogeneity Among Workers, Workplaces and Accident Types Over Time

Andrew Ireland

Co-authors: Prof. David Johnston, Dr. Rachel Knott

9th September 2021

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Motivation – Heat and Workers' Safety

Occupational Health is Costly

- Each year in Australia almost 1% of workers suffer a serious accident while working[1].
- Annually, work-related injury and disease costs the Australian economy AU$61.8 billion, representing 4.1% of GDP[2].

We expect that heat may adversely affect workers' safety because:

- Extreme heat can make dissipation of heat more difficult leading to dehydration and heat stoke.
- Laboratory experiments have shown high temperatures can reduce concentration and psychomotor performance[3], which may cause additional accidents.

Global temperatures have increased and will continue to rise

- Adverse safety impacts of heat may increase as workers are increasingly exposed to heat in their workplace.

[1] (Safe Work Australia, 2021) [2] (Safe Work Australia, 2015) [3] (Seppanen et al., 2006)

Related Literature – Heat and Workers' Safety

1. **Dillender, M. (2021).** ***Climate Change and Occupational Health: Are There Limits to Our Ability to Adapt?*** **Journal of Human Resources, 56, 184-224.**
   - Higher temperatures to significantly increase workplace accidents, particularly in warmer climates suggesting limits on adaptation.
2. **Page, L., & Sheppard, S. (2019).** ***Heat Stress: Ambient Temperature and Workplace Accidents in the US.***
   - The adverse effects of heat also extend to industries seemingly not sensitive to weather, such as retail, hospitality and education, albeit to a lesser extent than primarily outdoor-based industries.
3. **Park, J.R., Pankratz, N., & Behrer, P.A. (2021).** ***Temperature, Workplace Safety, and Labor Market Inequality.***
   - The types of claims occurring more frequently due to heat are not limited to heat stress (e.g. falls)
   - Low-income workers are disproportionately affected, suggesting that heat may exacerbate inequality.

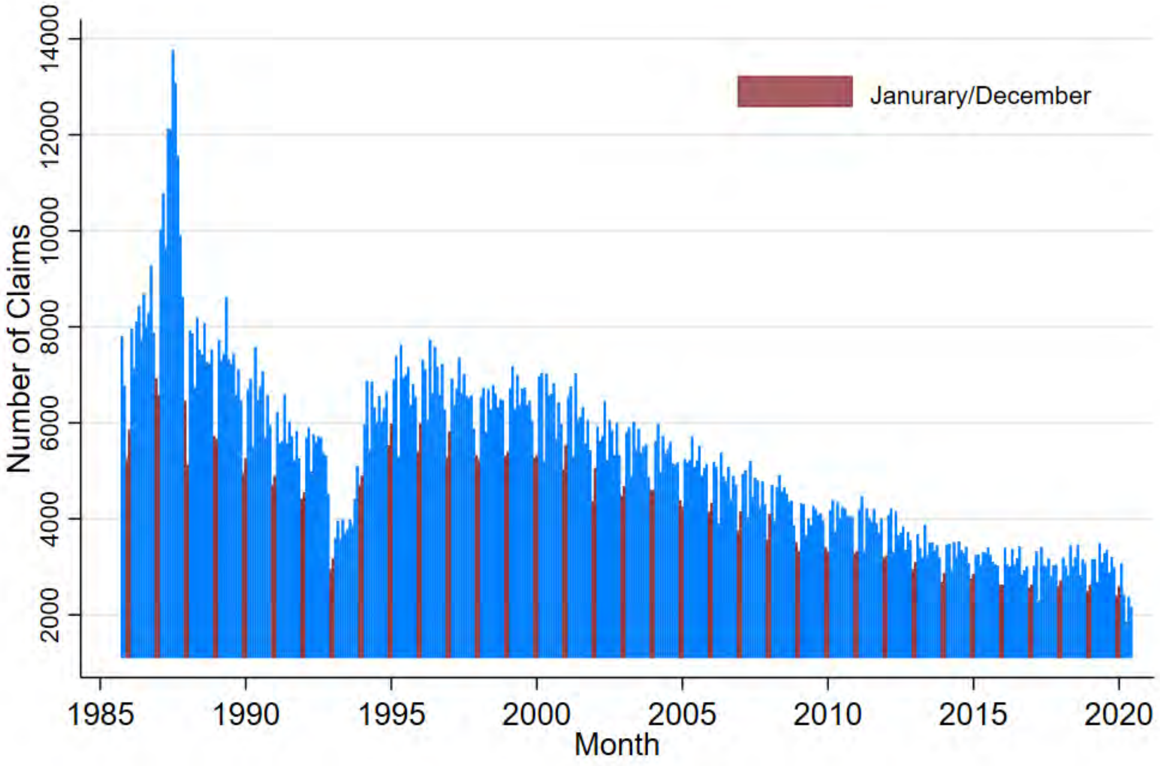
Contributions

1. First comprehensive study outside the US. Victoria has mandatory workers' compensation scheme, which is not the case for much of the US.
2. Investigate the impact of heat over time using a 35-year analysis period.
3. The data contains the date of affliction (pervious studies use dates related to when the claim was reported).
4. We show the effects of heat by age, gender, income and industry within the same occupation group.
5. Heterogeneity in the effect of heat on different accident and injury types to give insight mechanisms driving the temperature-safety relationship.

35 Years of Mandatory Workers Compensation in Victoria

- Employers in Victoria pay a premium to cover costs of injuries at work.
- Claims can be a weekly payment for time away from work and/or treatment expenses.
- Approximately 85% of the labor force are covered (sole traders, federal government employees and a list of approved self-insured companies are exempt).
- The scheme has changed over time, however, relatively few major changes in the past 20 years.
- On average, there were 209 claims per day in Victoria (0.54 per postal area) during the analysis period*.

Number of Occupational Health Claims in Victoria by Month of Affliction



*Based on weekdays and postal areas with at least one claim in the month

Data – 2 million claims over 35 years (1985-2020)

Claim:
- Date and postcode of affliction (used to match climatic variables)
- Accident type (e.g. falls, hitting object)
- Accident cause (e.g. powered equipment, materials/substances)
- Nature of affliction (e.g. fracture, burn)
- Bodily location recorded (e.g. lower limb, trunk)

Claimant:
- Age
- Gender
- Pre-injury income of claimant
- Occupation
- Employment type (full-time/part-time/apprentice)

Employer:
- Industry
- Employer size

Method

- We model the number of claims in each postal area (*p*) for each day (*t*) as a **Poisson-**distributed random variable in the following form:

$$E\left[claims_{pt}\middle|X\right] = \exp\left(\beta * maxtemp_{pt} + \phi_{pt} + \gamma * X_{pt}\right)$$

- ϕ_{pt}: Time and region fixed-effects
  - **Month-year-postal area fixed-effects** to account for time-specific characteristics that remain constant across locations and to control for unobserved regional characteristics that remain constant over time.
- X_{pt}: Other control variables
  - **Day of week fixed-effects**
  - **Precipitation (mm)**
  - Air pollution (PM2.5)
- Robust standard errors clustered at the postcode level (postcode being the level at which the treatment is assigned).
- Sample is restricted to weekdays and postal areas with at least one claim each month

Results – Main Effect

Estimated Effect of Maximum Temperature on Occupational Health Claims

	(1) Year-Month FE + Postal Area FE	(2) Year-Month-Postal Area FE	(3) Year-Month-Postal Area FE + Rain	(4) Year-Month-Postal Area FE + Rain + Pollution
Coefficient *(semi-elasticity)*	0.22*	0.22*	0.24*	0.20*
	(0.026)	(0.019)	(0.020)	(0.021)
Average Marginal Effect	0.00118*	0.00121*	0.00128*	0.00106*
(daily claims per Postal Area)	(0.014)	(0.010)	(0.011)	(0.011)
Day of Week	✓	✓	✓	✓
Postal Area FE	✓	×	×	×
Year-Month FE	✓	×	×	×
Postal Area*Year-Month FE	×	✓	✓	✓
Precipitation (mm)	×	×	✓	✓
Air Pollution (PM2.5)	×	×	×	✓
Claims Postal Area/Day	0.54	0.54	0.54	0.54
Claims Victoria/Day	209	209	209	209
N (Postcode-Day)	3,533,474	3,533,474	3,533,474	3,533,474

Notes: * $p < 0.01$

Each additional 1°C in daily maximum temperature results in 0.24% increase in claims (or 0.5 additional claims in Victoria).

Results – Occupation (before and after 2000)

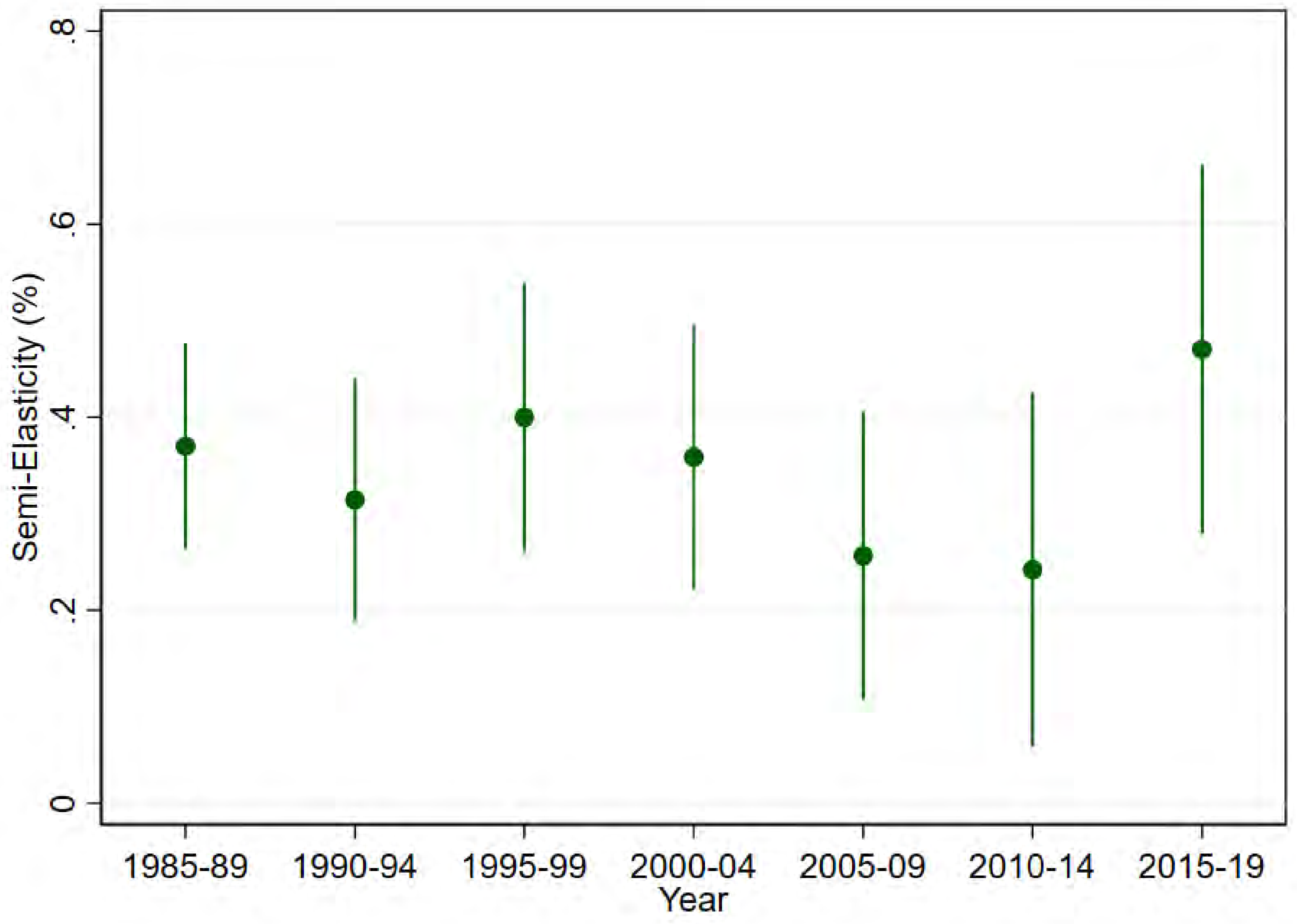
Maximum Temperature Estimates by Occupation Over Time, Semi-Elasticity (%)

Occupation	**1985-1999**	**2000-2020**	**All Years**
Tradespersons and related workers	0.38* (0.051)	0.36* (0.057)	0.38* (0.042)
Laborers and related workers	0.34* (0.042)	0.31* (0.053)	0.33* (0.033)
Production and transport workers	0.16* (0.066)	0.16 (0.062)	0.16* (0.045)
Clerical, sales and service workers	0.13 (0.106)	0.08 (0.058)	0.11 (0.060)
Professionals & associate professionals	0.09 (0.071)	0.11 (0.066)	0.10 (0.046)
Managers and administrators	0.25 (0.156)	-0.11 (0.144)	0.06 (0.110)
All Occupations	0.27* (0.027)	0.20* (0.026)	0.24* (0.020)

* $p < 0.01$

- The effect of heat is concentrated on tradespersons, labourers and related workers.
- The impact of heat has reduced over time, although not evenly across occupations

Results – Effect over time



Notes: *Laborers and Tradespersons, 95% confidence intervals*

- Heat has adversely impacted workers' safety throughout the analysis period.
- The years since 2015 have the largest effect.

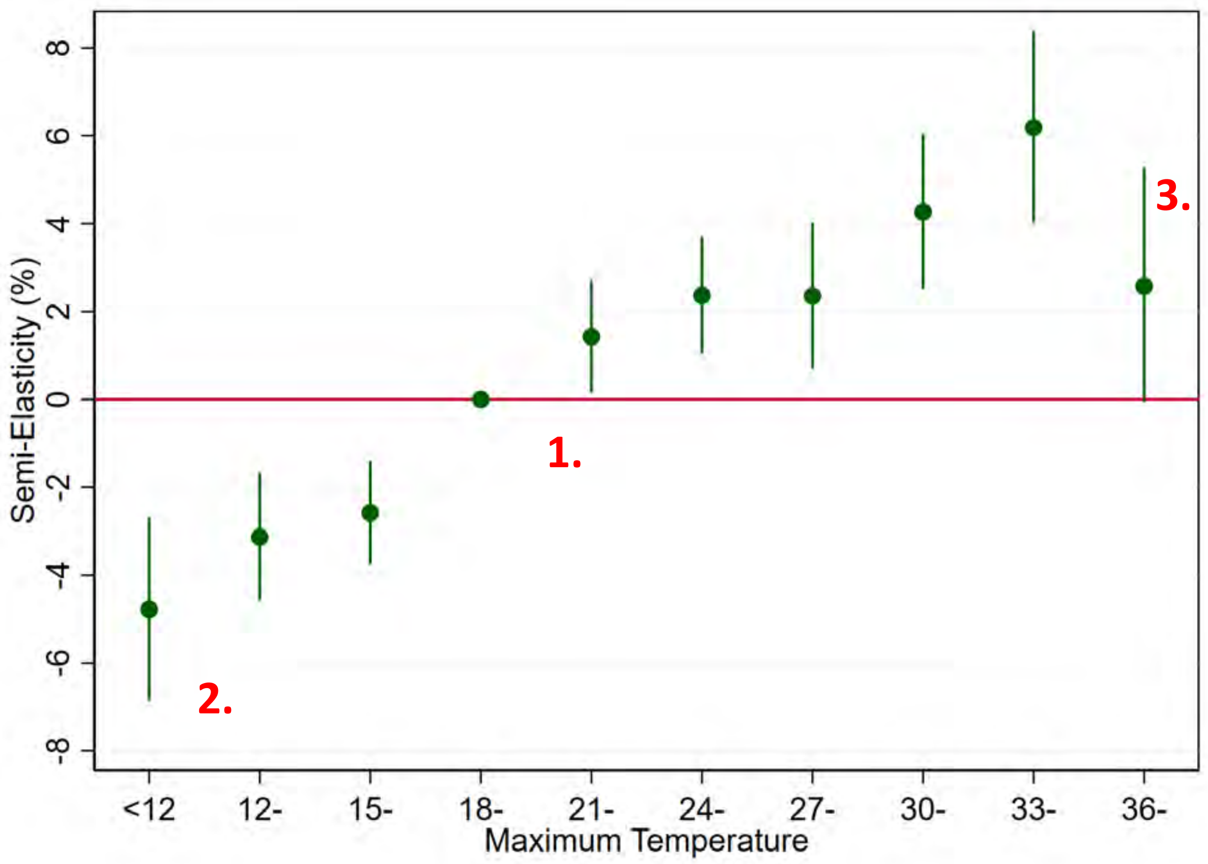
Results – Linear approximation is suitable

Using 3°C bins for maximum temperature:

1. Overall shape of the temperature-claims relationship is approximately linear
2. We don't observe any increase in accidents in cold temperatures.
3. The estimate for extreme high temperatures above 36°C is lower than for days 33-36°C

The estimates are a "residual risk" after accounting of all of the ways workers respond to temperature. E.g. changing work hours, wearing different clothing, taking additional breaks, not working when temperatures exceed a threshold etc.…

Effect of Maximum Temperature on Occupational Health Claims for High Risk Workers



Notes: *Laborers and Tradespersons, 2000-2020 * p <0.01*

Results - Industry

Maximum Temperature Estimates by Industry, Semi-Elasticity(%)

Industry	**Laborers and Tradespersons**	**All Occupations**
Agriculture, Forestry and Fishing	0.72* (0.238)	0.63* (0.205)
Construction	0.49* (0.089)	0.43* (0.077)
Manufacturing	0.30* (0.075)	0.23* (0.063)
Other Industry	0.27* (0.069)	0.14* (0.035)
All industries	0.34* (0.038)	0.20* (0.026)

Notes: *2000-2020 * p <0.01*

- Some of the difference in effect between industries is diminished when looking within manual workers.
- Agriculture, Forestry & Fishing and Construction have a higher effect for heat than other industries, even within laborers and tradespersons.
  - Greater proportion of time outdoors
  - Compositional difference in the kinds of laborers and tradespersons in each industry.

Results – Vulnerable Workers

- Overall, the effect of heat is larger for males…

Maximum Temperature Estimates by Worker Characteristic, Semi-Elasticity(%)

	All Claims	**Laborers and Tradespersons in Agriculture**	**Laborers and Tradespersons in Construction**
Sex			
Male	0.27* (0.032)		
Female	0.06 (0.049)		
Age			
Age 18-35, %			
Age 36-50, %			
Age 51-64, %			
Wage			
Low wage			
Middle wage			
High wage			
Employer Size			
Small employer			
Medium employer			
Large employer			
All Claims	0.20* (0.020)		

*Notes: 2005-2020 * p <0.01. "Agriculture" refers to Agriculture, Forestry and Fishing.*

Results – Vulnerable Workers

- Overall, the effect of heat is larger for males…
  …However, this is driven by compositional differences in occupation and industry

Maximum Temperature Estimates by Worker Characteristic, Semi-Elasticity(%)

	All Claims	**Laborers and Tradespersons in Agriculture**	**Laborers and Tradespersons in Construction**
Sex			
Male	0.27* (0.032)	0.62* (0.239)	0.42* (0.077)
Female	0.06 (0.049)	0.64 (0.409)	0.87 (0.507)
Age			
Age 18-35, %			
Age 36-50, %			
Age 51-64, %			
Wage			
Low wage			
Middle wage			
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Employer Size			
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*Notes: 2005-2020 * p <0.01. "Agriculture" refers to Agriculture, Forestry and Fishing.*

Results – Vulnerable Workers

- Overall, the effect of heat is larger for males… …However, this is driven by compositional differences in occupation and industry
- We find largest effects for younger (18-35) and older (51-64) workers. Agricultural workers over 50 may be particularly at risk.

Maximum Temperature Estimates by Worker Characteristic, Semi-Elasticity(%)

	All Claims	Laborers and Tradespersons in Agriculture	Laborers and Tradespersons in Construction
Sex			
Male	0.27* (0.032)	0.62* (0.239)	0.42* (0.077)
Female	0.06 (0.049)	0.64 (0.409)	0.87 (0.507)
Age			
Age 18-35, %	0.25* (0.040)	0.42 (0.324)	0.55* (0.114)
Age 36-50, %	0.16* (0.045)	0.48 (0.336)	0.27 (0.141)
Age 51-64, %	0.20* (0.053)	1.48* (0.382)	0.44 (0.176)
Wage			
Low wage			
Middle wage			
High wage			
Employer Size			
Small employer			
Medium employer			
Large employer			
All Claims	0.20* (0.026)	0.72* (0.238)	0.49* (0.089)

*Notes: 2003-2020 * p <0.01. "Agriculture" refers to Agriculture, Forestry and Fishing.*

Results – Vulnerable Workers

- Overall, the effect of heat is larger for males… …However, this is driven by compositional differences in occupation and industry
- We find largest effects for younger (18-35) and older (51-64) workers. Agricultural workers over 50 may be particularly at risk.
- Middle wage workers have the largest effect overall, however, within construction and agriculture, high wage workers are most impacted by heat.

Maximum Temperature Estimates by Worker Characteristic, Semi-Elasticity(%)

	All Claims	Laborers and Tradespersons in Agriculture	Laborers and Tradespersons in Construction
Sex			
Male	0.27* (0.032)	0.62* (0.239)	0.42* (0.077)
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Age 51-64, %	0.20* (0.053)	1.48* (0.382)	0.44 (0.176)
Wage			
Low wage	0.12 (0.068)	-0.25 (0.410)	0.42 (0.188)
Middle wage	0.19* (0.056)	0.60 (0.459)	0.30 (0.179)
High wage	0.12 (0.069)	1.12 (0.442)	0.61* (0.200)
Employer Size			
Small employer			
Medium employer			
Large employer			
All Claims	0.20* (0.026)	0.72* (0.238)	0.49* (0.089)

*Notes: 2003-2020 * p <0.01. "Agriculture" refers to Agriculture, Forestry and Fishing.*

Results – Vulnerable Workers

- Overall, the effect of heat is larger for males… …However, this is driven by compositional differences in occupation and industry
- We find largest effects for younger (18-35) and older (51-64) workers. Agricultural workers over 50 may be particularly at risk.
- Middle wage workers have the largest effect overall, however, within construction and agriculture, high wage workers are most impacted by heat.
- In Construction, employees at small and medium worksites are more sensitive to heat than those at a large site.

Maximum Temperature Estimates by Worker Characteristic, Semi-Elasticity(%)

	All Claims	Laborers and Tradespersons in Agriculture	Laborers and Tradespersons in Construction
Sex			
Male	0.27* (0.032)	0.62* (0.239)	0.42* (0.077)
Female	0.06 (0.049)	0.64 (0.409)	0.87 (0.507)
Age			
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Wage			
Low wage	0.12 (0.068)	-0.25 (0.410)	0.42 (0.188)
Middle wage	0.19* (0.056)	0.60 (0.459)	0.30 (0.179)
High wage	0.12 (0.069)	1.12 (0.442)	0.61* (0.200)
Employer Size			
Small employer	0.22* (0.059)	0.50 (0.272)	0.41* (0.130)
Medium employer	0.25* (0.043)	0.38 (0.333)	0.54* (0.125)
Large employer	0.13* (0.049)	1.79 (1.640)	0.13 (0.197)
All Claims	0.20* (0.026)	0.72* (0.238)	0.49* (0.089)

*Notes: 2003-2020 * p <0.01. "Agriculture" refers to Agriculture, Forestry and Fishing.*

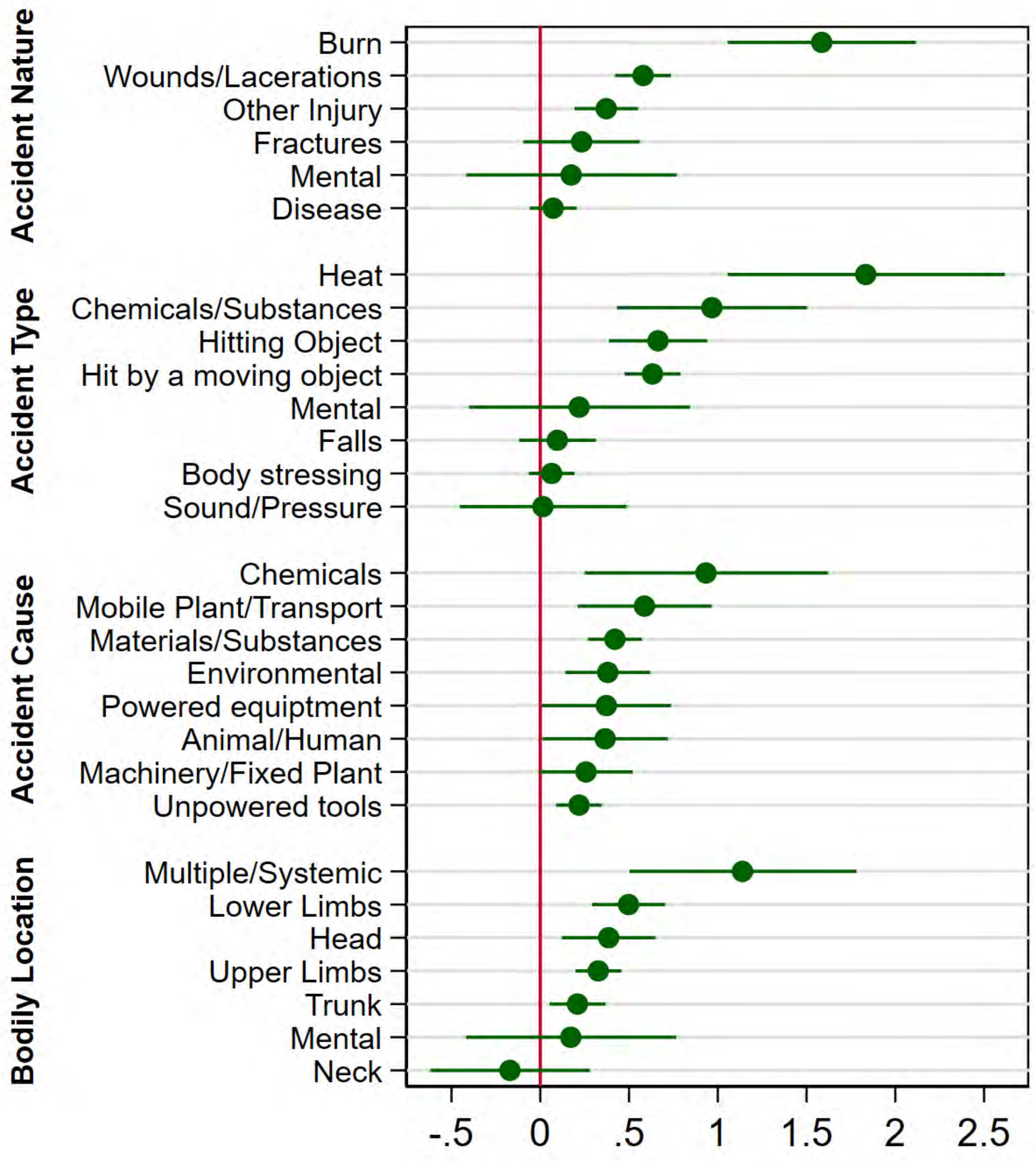
Results – Accident Type

Heat directly creates additional hazards

- Large effects for accidents related to environmental agencies such as chemicals, or touching hot surfaces.

"Biological" effects are not limited to heat stoke

- Accidents seemingly unrelated to heat (e.g. hitting objects and being hit by moving objects) are also significant.
- Reduced concentration and psychomotor performance as a possible cause.



Notes: *Laborers and Tradespersons, 2000-2020. 95% confidence intervals*

Next Steps

1. Employer heterogeneity: Can heat be managed by good risk management? Do firms learn over time?

2. Cost of heat related accidents

Conclusion – Policy Implications

- Heat has a significant adverse impact on workers safety in Victoria – consistent with studies from the US.
- The effects is particularly large for laborers and tradespersons in Agriculture and Construction – workers with fewer viable options for adaptation are vulnerable to climate change.
- Heat remains a significant threat throughout the 35 years.
- Males bear the majority of the heat-related injury burden, however, gender is not an independent risk factor (i.e. males are not at greater risk than peers in the same occupation).
- Contrary to previous work, we do not find low-income workers to be at greater risk.
- The "biological" impacts of heat are not limited to heat stress and dehydration. Heat increases various types and accidents and injuries affecting virtually all parts of the body, perhaps due to reduced concentration.
- High temperatures directly create environmental hazards such as hot surfaces, volatile chemicals and fire. Effective heat policy should these hazards, in addition to workers' physiological needs.

Acknowledgements

Co-authors: Prof. David Johnston, Dr. Rachel Knott

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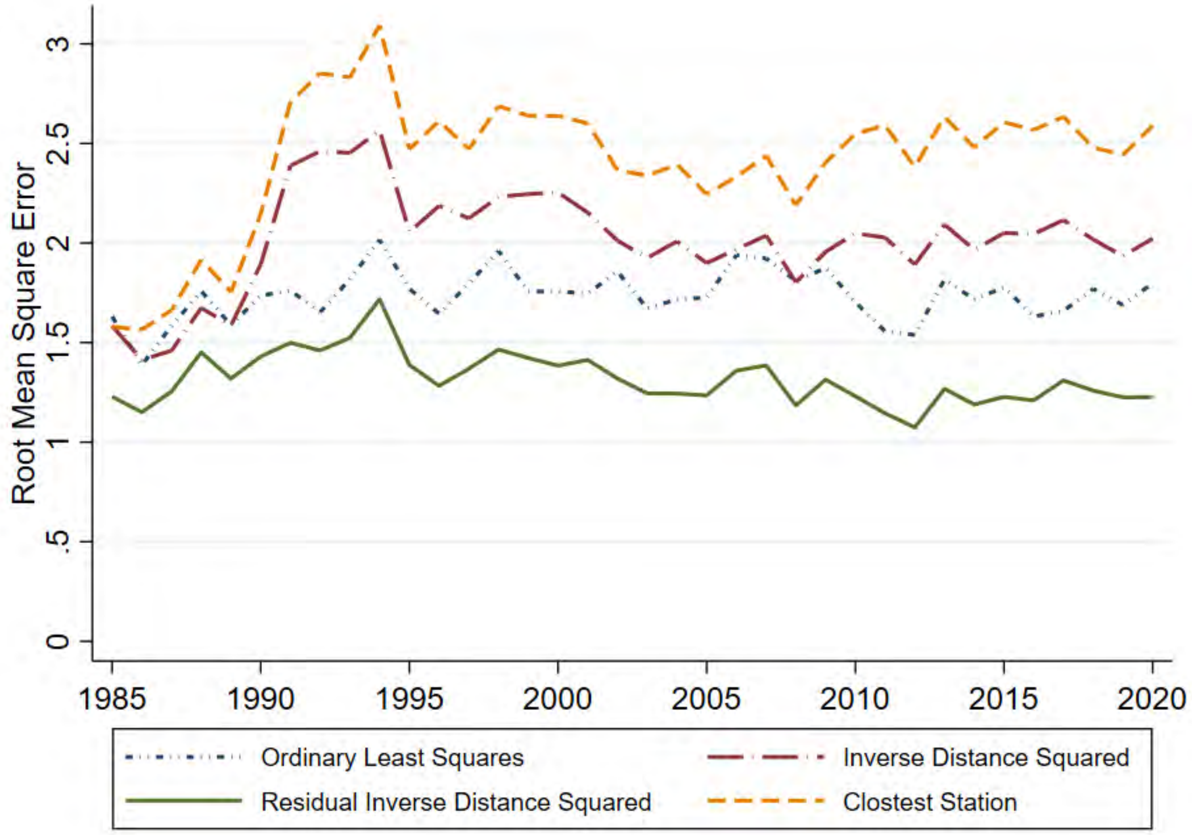
Appendix 1. Measurement of Temperature

- Cross-validation revealed that Residual Inverse Distance Squared as the method with least measurement error.

- Including elevation and distance to coast is important for Victoria.

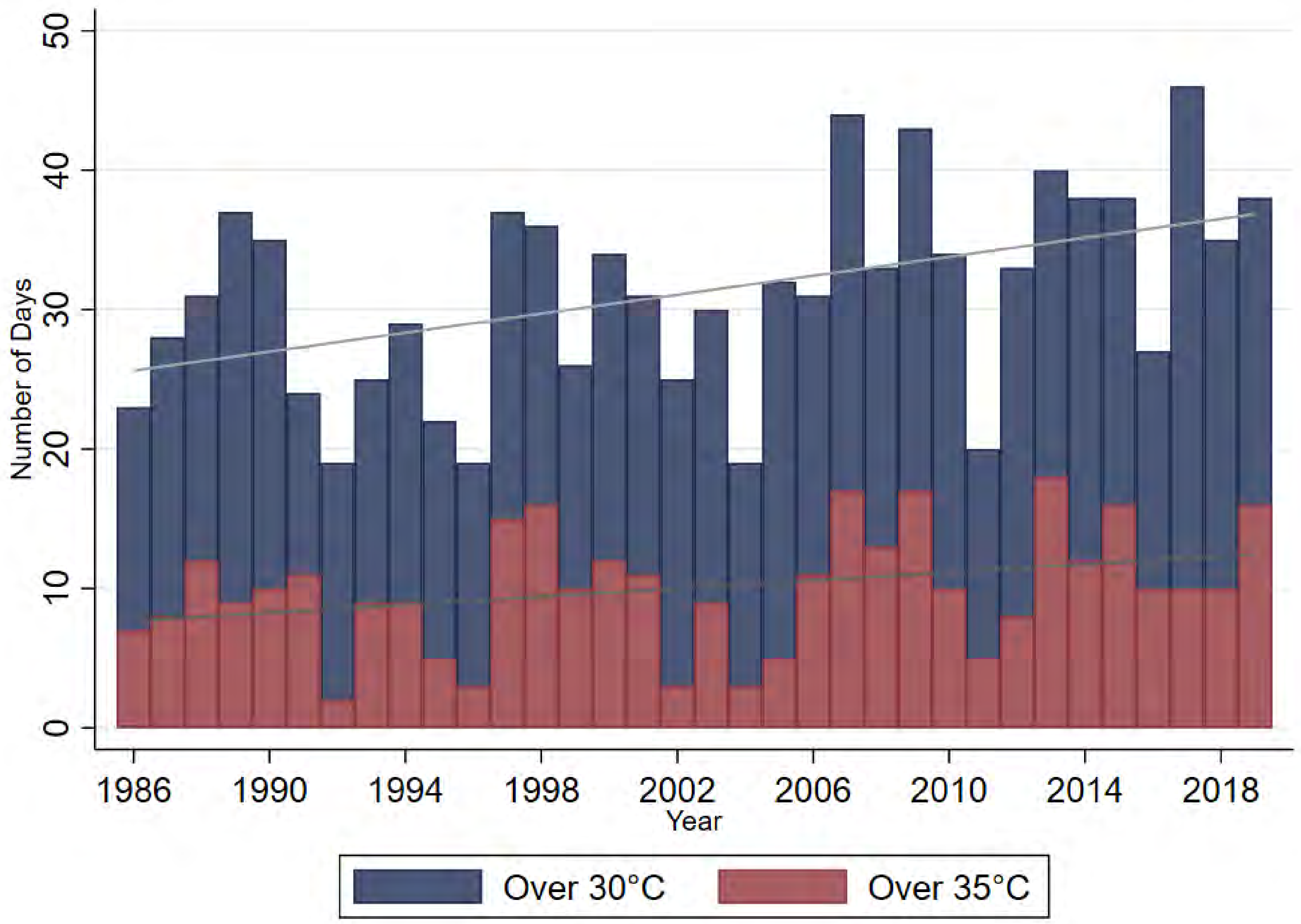
- However, our main results are not materially affected by choice of interpolation method. The majority of claims are in Metropolitan Melbourne, which has a high density of weather stations.

Figure A1. Comparison of Spatial Interpolation Methods over Time



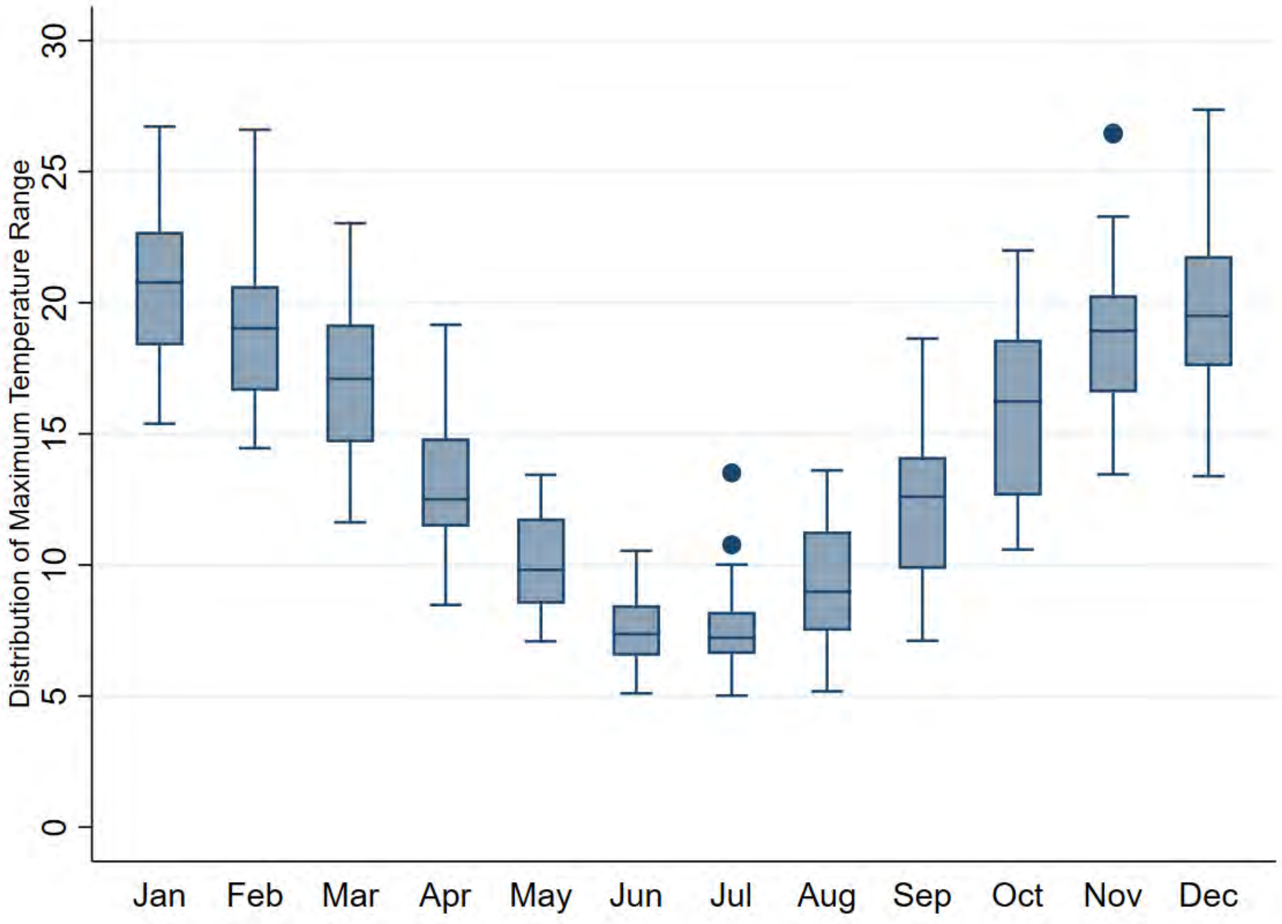
Appendix 2. Hot days in Melbourne

Figure A2. Number of Hot days in Melbourne by Year



Appendix 3. Temperature Variation

Figure A3. Range of Maximum Temperature in Melbourne by Month



***Notes:** "Range" represents the difference between the highest and lowest daily maximum temperature in a month. Boxplots show the distribution of the range between 1985-2020.*

Jake Dialesandro

Ph.D. Candidate, UC Davis

Reducing Thermal Inequity: Identifying Vulnerable Neighborhoods and Heat Mitigation Potential for Urban Cooling in Two California Cities

Reducing thermal inequity: Identifying vulnerable neighborhoods and heat mitigation potential for urban cooling in two California cities.

Jake Dialesandro,
Dr. Noli Brazil[1]
Dr. Stephen Wheeler[1]
Dr. Helen Dahlke[1]

[1] University of California Davis

Introduction

- Urban heat islands exacerbated by climate change has led to increased exposure to heat
- The burden of the excess heat is not equitable amongst populations
- The perils of excess urban heat including increased energy use, morbidity and mortality disproportionately impact certain groups
- Cities often lack the resources to implement heat mitigation strategies region wide

Project Objectives

- Map surface heat for day and night in large cities in the San Joaquin Valley
- Develop exposure and vulnerability indices at the block group level and identify highest vulnerable neighborhoods
- Benchmark relationship between urban heat and biophysical and social demographic variables
- Use InVEST urban cooling model to model cooling potential of planning interventions involving increasing tree canopy and surface albedo

Study Regions: Fresno and Bakersfield

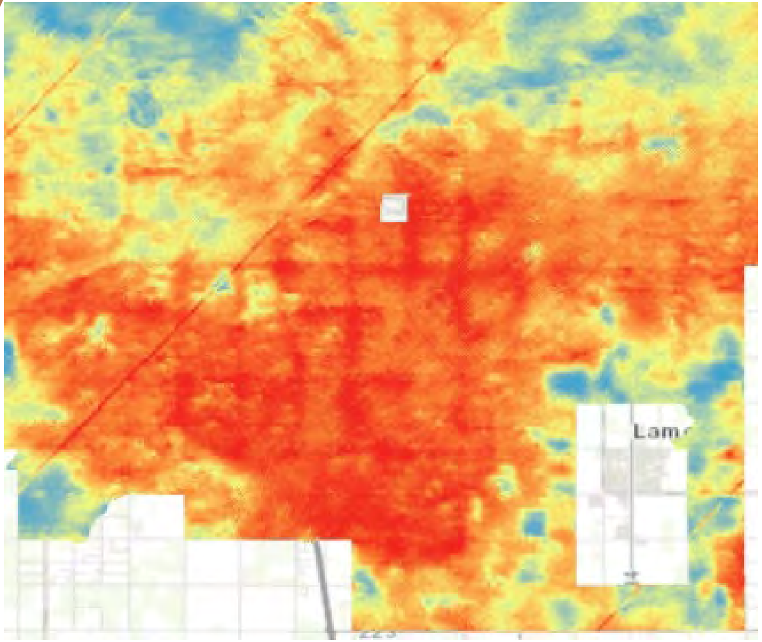
City	Population	Mean summer High	Annual Precipitation (mm)	% Impervious Surface	% Tree Canopy
Bakersfield	384,000	35.6° C (96° F)	185	56%	13%
Fresno	542,000	35 ° C (95° F)	320	44%	7%

Image credit:
ABC30 &
Community
Solutions

Data and Methodology

Landsat 8 OLI/TIRS and ISS ECOSTRESS

- LST
- Albedo
- Evapotranspiration

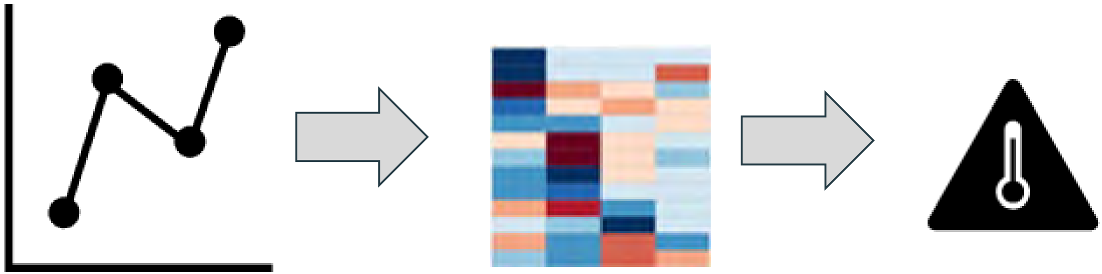


- Mapping heat footprint
- Thermal magnitude variable in InVEST Model

Data and Methodology

American Community Survey (2015-2019)

- Variables on race, income, education, and language
- Inputs for development of vulnerability assessment (PCA)



Data and Methodology

California Forest Observatory

MRLC

Ancillary Data

- 10 Meter tree canopy data (California Forest Observatory)
- Land Use/Land Cover (NLCD)
- Impervious Surface Fraction (NLCD)

Applications:

- InVEST Urban cooling inputs
- Statistical analysis of vulnerability

InVest Urban Cooling Model

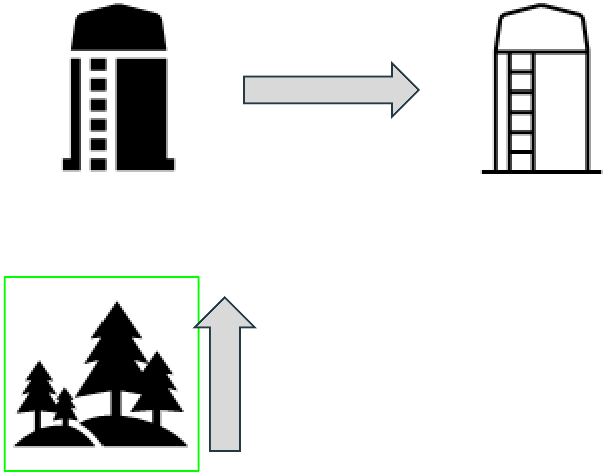
- Albedo
- Shade
- Evapotranspiration
- Rural Reference Temperature (Daytime)
- Urban Heat Island Magnitude (Daytime)

- Building Intensity
- Rural Reference Temperature (Nighttime)
- Urban Heat Island Magnitude (Nighttime)

InVEST Urban Cooling Model

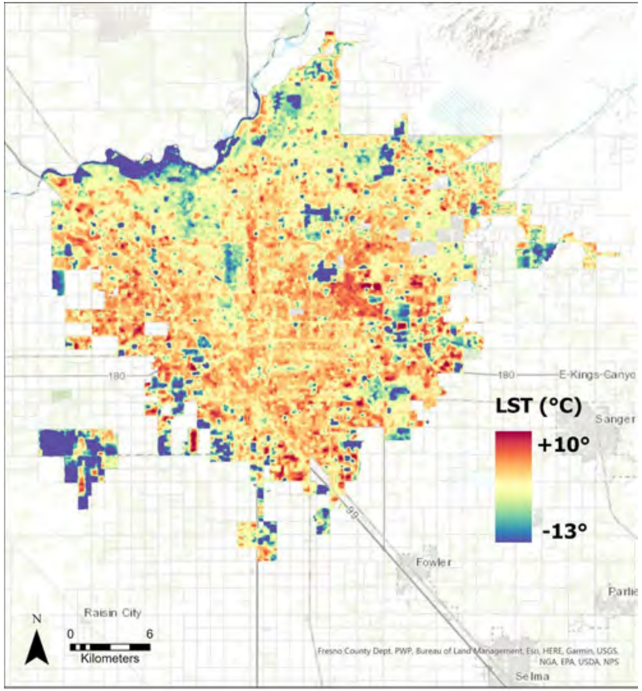
Planning Intervention Scenarios:

- 10 and 25% Tree Canopy Increase
- 10 and 25% Albedo increase on buildings
- Combined 10% albedo increase and 25% Tree canopy increase

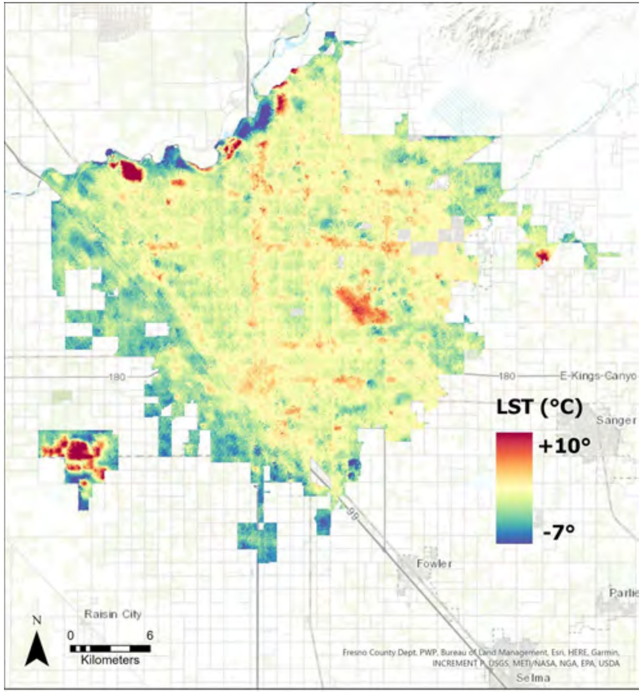


Results

Day and Night Urban Heat Footprints

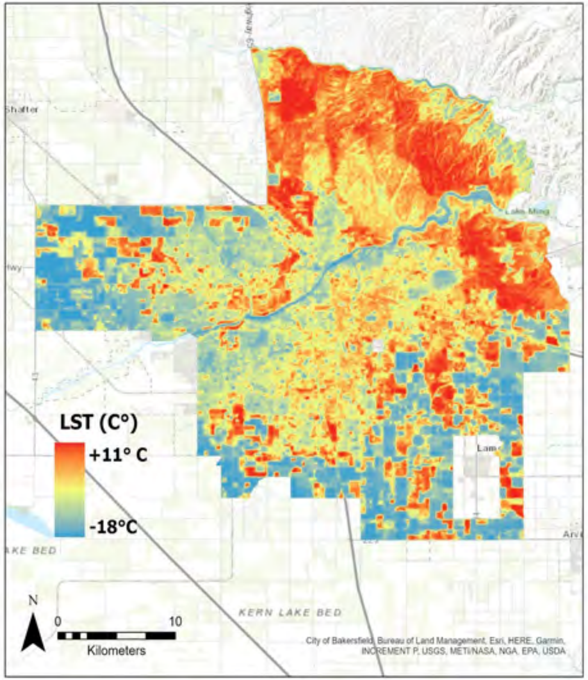


Fresno (Day)

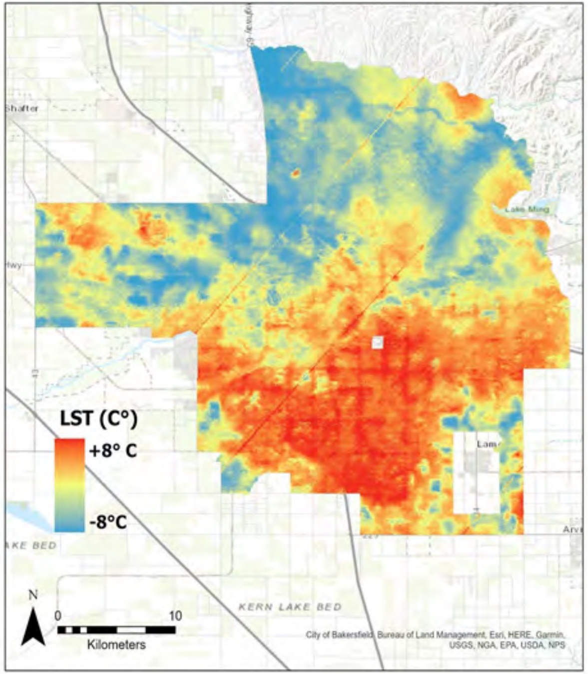


Fresno (Night)

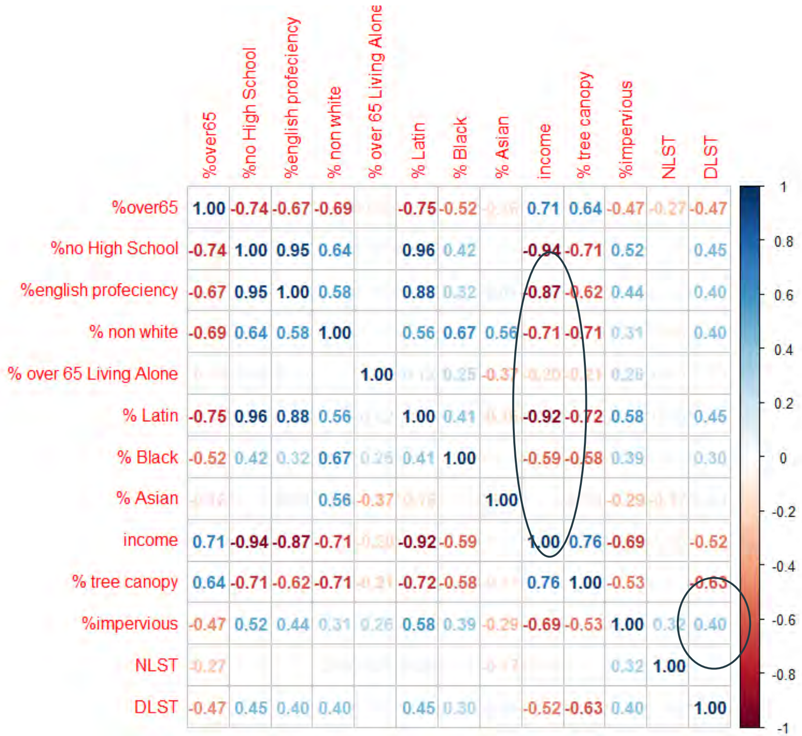
Day and Night Urban Heat Footprints



Bakersfield (Day)

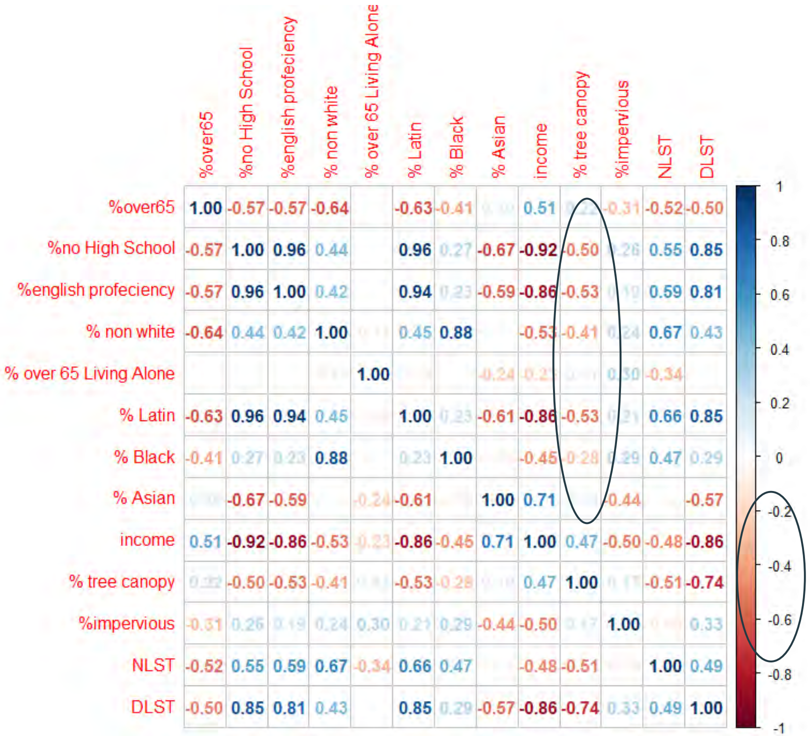


Bakersfield (Night)



Fresno

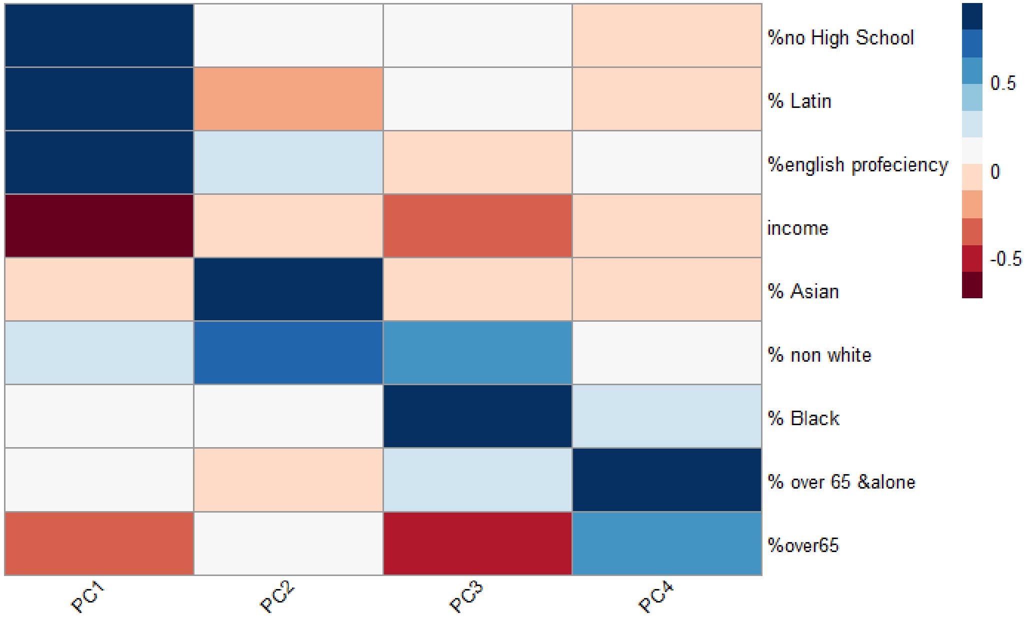
- Income and tree canopy strongest correlation with temperature
- Latinx strong inverse relationship
- Income very strong inverse relationship with % over 25 with no high school education, % limited english language proficiency, nonwhite populations



Bakersfield

- Income, asian population, and tree canopy strongest correlation with temperature
- Latinx strong inverse relationship
- Income again very strong inverse relationship with % over 25 with no high school education, % limited english language proficiency, nonwhite populations

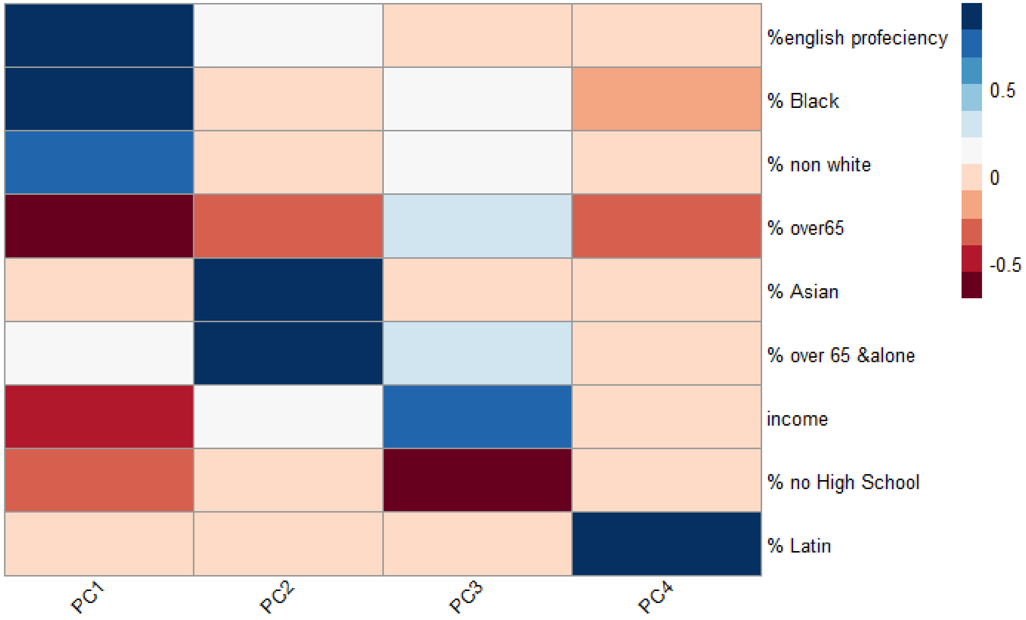
Vulnerability Indice



Fresno

- 4 PCA explaining 85% of the variance in dataset
- % over 25 with no high school diploma, %latinx, %english language proficiency, income strongest predictors

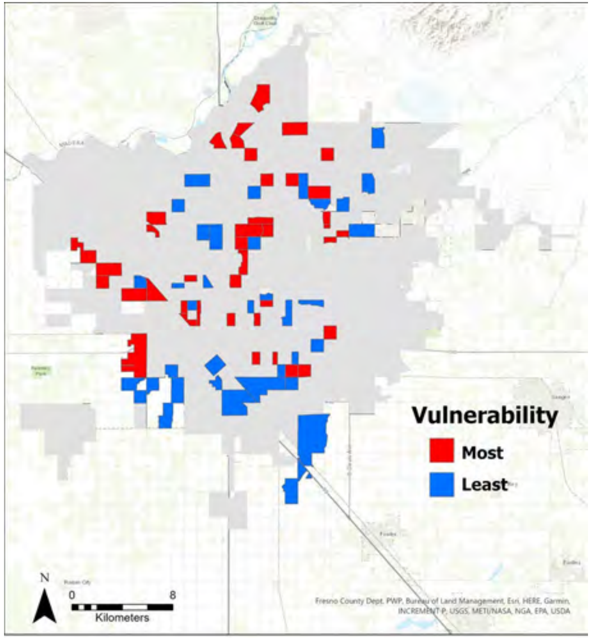
Vulnerability Indice



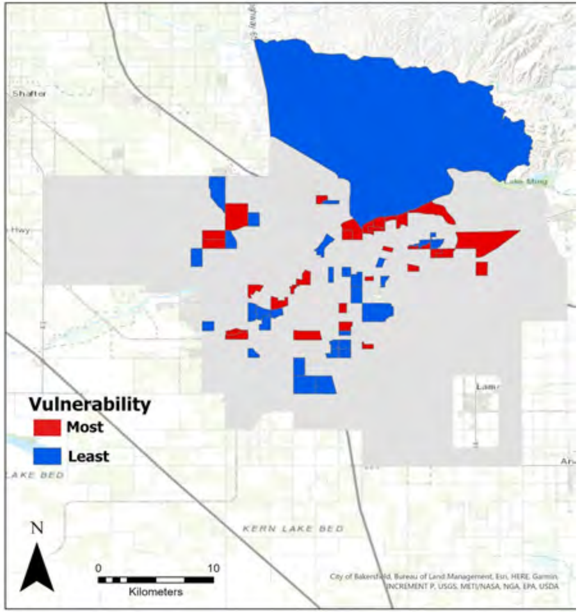
Bakersfield

- 4 PCA explaining 87% of the variance in dataset
- Race, age, %english language proficiency, strongest loadings

Vulnerability Indice



Fresno



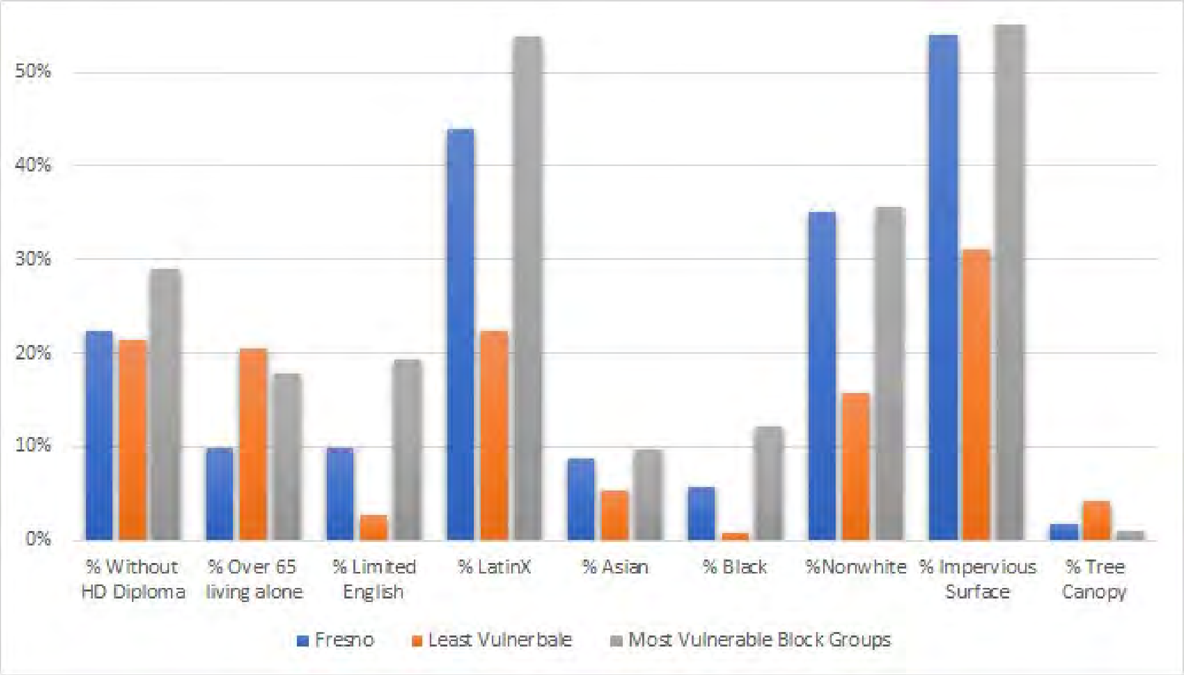
Bakersfield

Varying demographics amongst neighborhoods

- Vulnerability analysis shows that neighborhoods vary dramatically in biophysical and social characteristics
- Tree canopy far lower in vulnerable neighborhoods, and impervious surface far higher
- Income far higher (50% greater) in low vulnerability vs high vulnerability

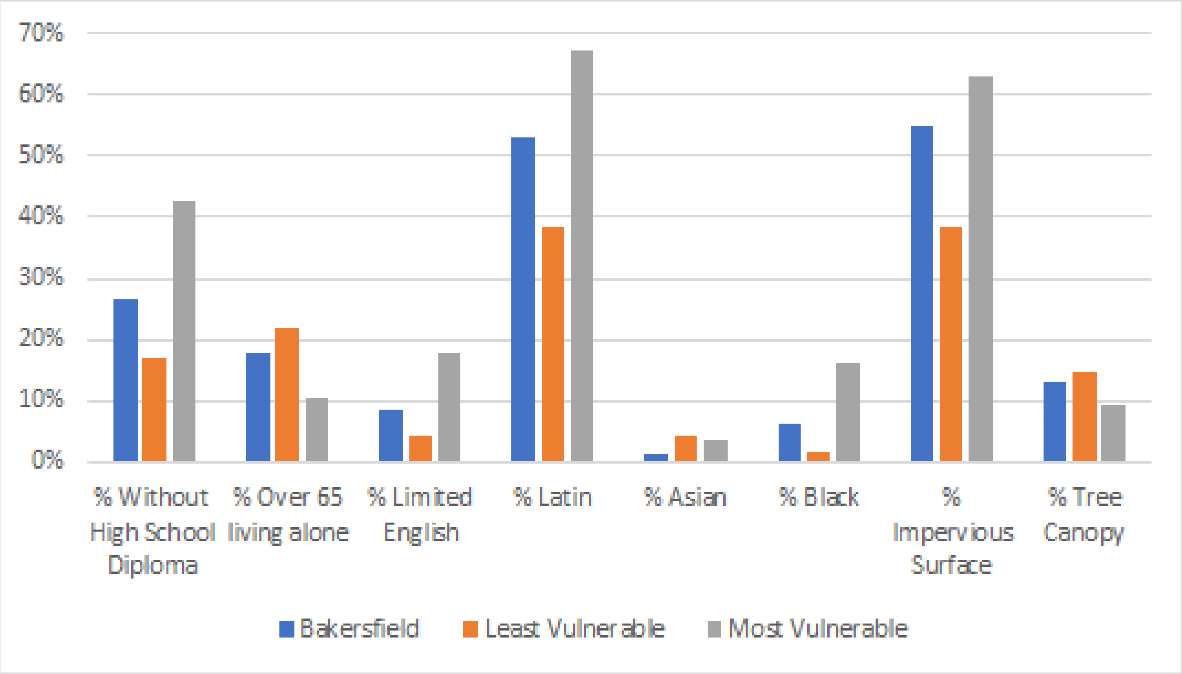
Fresno

- Vulnerable neighborhoods 4° C warmer in daytime than least vulnerable neighborhoods
- Income $22,000 lower than region city average ($30,000 vs $52,000)



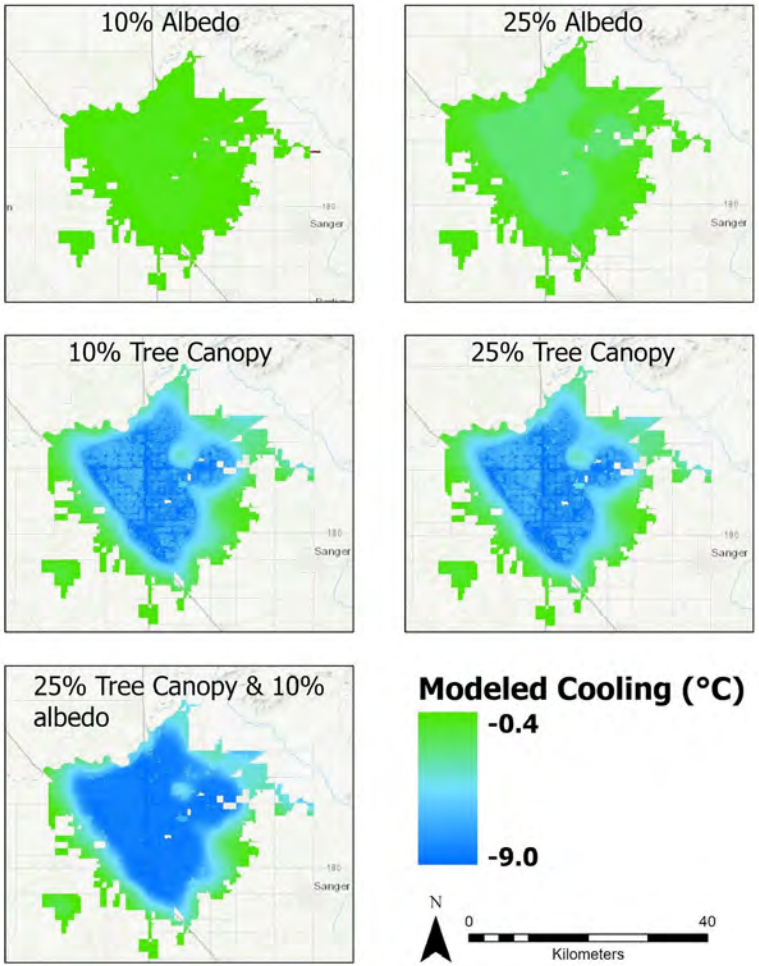
Bakersfield

- Vulnerable neighborhoods 3.2° C warmer than least vulnerable
- Similar income disparity
- Consistent pattern with racial demographics as Fresno

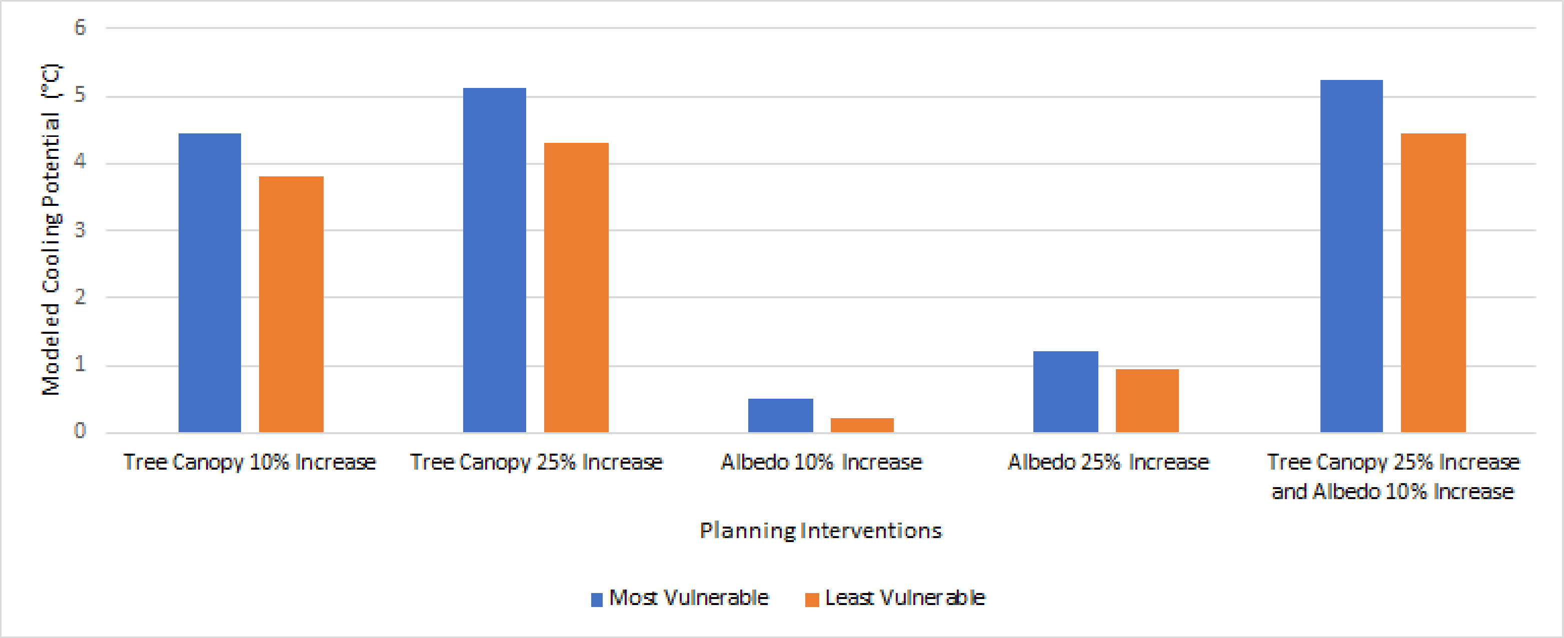


InVest Urban Cooling Model

- Tree Canopy much stronger cooling impact
- Albedo less than 2° C in most cases
- Combined albedo and tree canopy very similar to a single 25% increase in tree canopy
- Higher vulnerable neighborhoods had stronger cooling impacts



Cooling Impact by Neighborhood

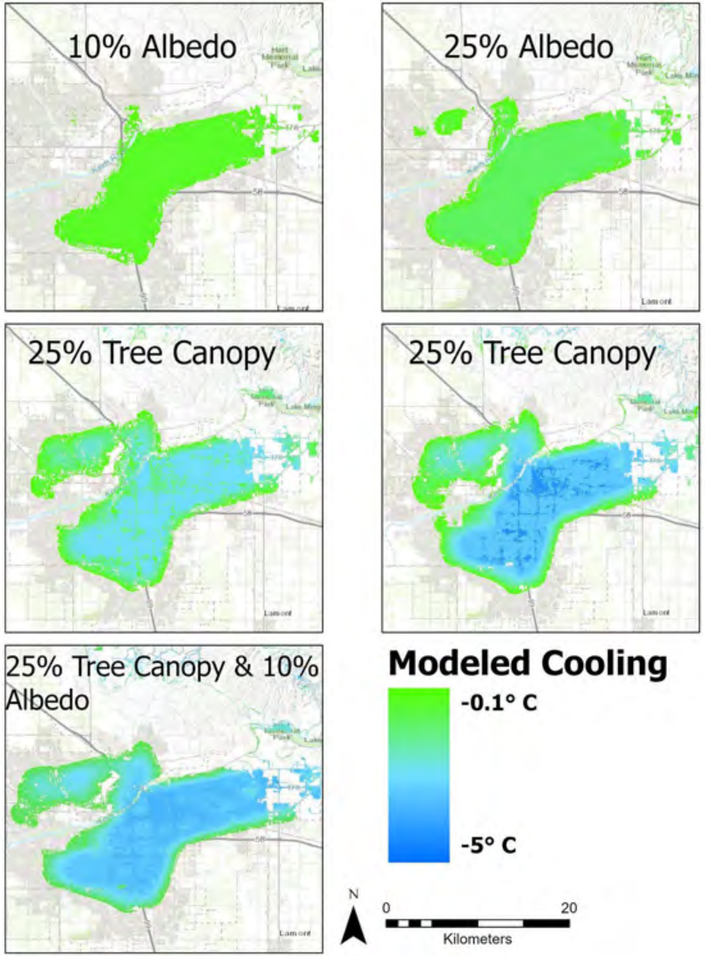


- Tree Inequity: Fig Garden (image left) has >35% tree canopy already, also low vulnerability scores #4 out of 419 Fresno block groups
- 50% lower modeled cooling from 10 and 25% tree canopy increases

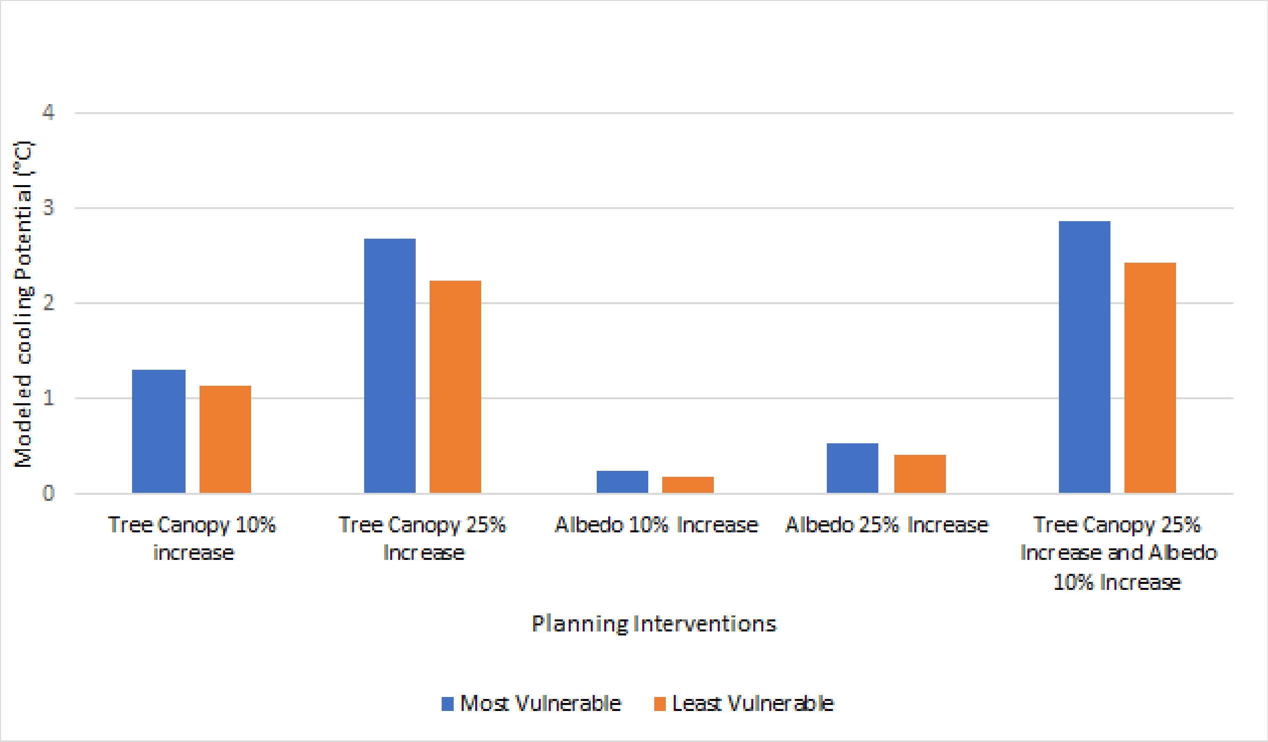
Image credit: Fresno Bee

InVest Urban Cooling Model

- Tree Canopy cooling much stronger than albedo
- Cooling less than Fresno from tree canopy increase
- Less spillover cooling from tree canopy increase



Cooling Impact by Neighborhood



Conclusion

- Temperatures vary for both cities by 15-30 °C for both day and night
- Vulnerability analysis shows education, ethnicity, and language proficiency substantially correlated to heat vulnerability
- 10 and 25% increase in built form albedo led to up to 2°C cooling while tree canopy increase led to 4-6° C cooling
- Neighborhoods with higher vulnerability benefited more from modeled planning interventions, could be prioritized communities

Future Work

- Inputs in InVEST Urban Cooling Model enhanced
    - More precise LULC and higher resolution
- Model cooling potential for vulnerable neighborhoods only
- Include survey data, CDC health data, and mobile data to get more precise readings on experienced temperature of residents

Acknowledgements & Thank you!

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- The Luskin Center for Innovation at UCLA
- My advisors at UC Davis:
    - Dr. Stephen Wheeler
    - Dr. Noli Brazil
    - Dr. Helen Dahkle

Appendix

Fresno Land Cover Cooling

Neighborhood Type	Temp °C	Tree Canopy 10% Increase, °C	Tree Canopy 25% Increase, °C	Albedo 10% Increase, °C	Albedo 25% Increase, °C	Tree Canopy 25% Increase & albedo 10% Increase, °C	Cooling Capacity
Developed Open Space	41.2	-3.23	-3.51	-0.29	-0.68	-3.59	0.20
Developed Low Intensity	42.7	-3.71	-4.17	-0.46	-0.88	-4.56	0.21
Developed Medium Intensity	43.5	-3.94	-4.44	-0.51	-0.94	-4.56	0.20
Developed High Intensity	44.3	-4.13	-4.64	-0.51	-0.96	-4.76	0.16
Most Vulnerable	43.0	-4.44	-5.13	-0.49	-1.21	-5.25	0.22
Least Vulnerable	36.5	-3.81	-4.31	-0.23	-0.94	-4.44	0.19

Bakersfield Land Cover Cooling

Neighborhood Type	Temp. °C	Tree Canopy 10% Increase, °C	Tree Canopy 25% Increase, °F	Albedo 10% Increase, °C	Albedo 25% Increase, °C	Tree Canopy 25% Increase & albedo 10% Increase, °C	Cooling Capacity
Developed Open Space	38.3	-0.84	-1.41	0.00	0.00	-2.42	0.12
Developed Low Intensity	40.6	-1.11	-1.71	0.00	-0.07	-2.34	0.14
Developed Medium Intensity	43.0	-1.36	-2.08	-0.23	-0.39	-2.75	0.14
Developed High Intensity	43.8	-1.14	-2.68	-0.27	-0.44	-2.69	0.11
Most Vulnerable	45.0	-1.31	-2.69	-0.24	-0.54	-2.88	0.16
Least Vulnerable	42.8	-1.15	-2.25	-0.19	-0.43	-2.44	0.14

Up next – 10:15-11:45am PT

SESSION 6.1

Emerging Research on Financial Adaptations to Climate Impacts

SESSION 6.2

Wading into the Economic Impacts of Climate Change on Water

SESSION 6.3

Equitable Adaptation to Climate-Related Flood Risks: Part 2

Thanks for tuning in!