DEVELOPMENT
DATA PARTNERSHIP

Heatwaves Data Collaborative

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Introduction

Heatwaves Data Collaborative Overview

The Heatwaves Data Collaborative will build the capacity of municipal governments to:

- Measure risk and occurrence of heatwaves;
- Identify and measure impacts of heatwaves; and
- Quantify potential efficacy of heatwave impact mitigation measures

by undertaking six **key activities**:

1 Problem Statement Formulation
Through stakeholder workshops, prepare problem statements (challenge, proposed solution, outputs, collaborators, key tasks).

2 Team Formation and Data Fellows
Form small, grant-funded teams from international organizations, companies, NGOs, and researchers.

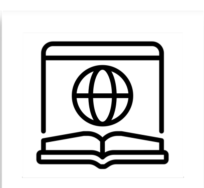
3 Foundational Open Datasets
Curate and document shared open datasets to be used by all problem statement teams.

4 Proprietary Datasets
Leverage existing and form new agreements to use proprietary datasets through the Development Data Partnership.

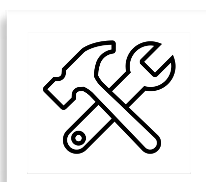
5 Data Goods
Produce fully replicable code and documentation, hosted on GitHub.

6 Capacity Building
Work with governments and NGOs to ensure widespread use of Data Goods for impact.

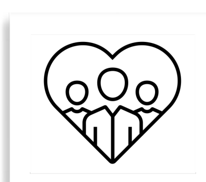
Through these activities, the Collaborative will produce three **outputs**:



Common datasets and definitions, used to support all program components



Reusable methodologies for:
- Identifying cities and populations at most risk of experiencing heatwaves
- Measuring the impacts of heatwaves across multiple sectors
- Measuring the marginal mitigation effect of investments in preventative measures.



Capacity building activities to ensure wide use of the methodologies and datasets.

Collaboration

The Heatwaves Data Collaborative enables teams across sectors and organizations to simultaneously focus on their areas of expertise, while collaborating through use of common frameworks and datasets, standards for production and review of reusable methods, and through regular check-ins to ensure the different work streams are aligned and build upon each other.

This collaboration is made possible through the **Global Data Facility** donor funding pooling mechanism and the existing legal and technical infrastructure underpinning the **Development Data Partnership**:

Legal Foundation
Template data license agreements and MOUs between international organizations and companies saves time and resources.

Data Marketplace
A shared proposal management portal facilitates seamless interactions between companies and international organizations.

Shared IT Architecture
Centralized IT architecture and processes for ingesting, storing, and pre-processing data, as well as for coding collaboration, lower costs and facilitate secure data use.

Data Goods
Shared code repositories and documentation for derived data products and algorithms broaden Partnership impact.

Data Governance
A strong data governance system guides best practices for responsible and ethical data use.

Fund Pooling
The Global Data Facility supports fund pooling and disbursement across different entities, supporting large-scale collaboration.

Through the **Partnership** Data Fellows program, third-party researchers can also leverage shared Partnership agreements, which currently include these **contributing members**:

Draft Problem Statements

Differentiating Heatwave Identification and Measurement by Sector

Leads: Sahiti Sarva, Data Scientist, Development Data Group; World Bank;
Benny Istanto, Geographer, Development Data Group; World Bank

CHALLENGE

While numerous studies indicate a rise in the number of heatwaves, different national meteorological offices and academic studies use their own definitions of a heatwave. Research suggests that adopting different definitions of heatwaves affects the subsequent measurement of heatwave impact across sectors such as human health, economy, education, and electricity. Additionally, the insights generated from these efforts would be incomparable across sectors and geographies.

Using a standard pool of definitions to identify heatwaves will enable comparable heatwave trends and impact analyses and support a much-needed collective,

PROPOSED SOLUTION

The team proposes the creation of a foundational dataset that identifies heatwaves based on a set of sector-specific definitions. The team will use suitability to measure impacts in health, energy, education and economy as the criteria to select heatwave definitions through literature reviews and interviews with experts. For each sector, the definitions will be differentiated based on the additional variables required to measure impact. Sector specific definitions will be differentiated based on the additional variables that will enable better measurement of sector specific impacts. For instance, having additional information about wind speed, tree cover and number of additional days of exposure becomes important when measuring impact on health. Furthermore, measuring minimum temperature in a day, especially in urban areas, is considered to display a better correlation with health impacts. On the other hand, cooling days and heating days which take an average of maximum and minimum temperature and relative humidity have been mentioned, according to literature, as a metric the energy sector can employ. Drawing these variables from the same foundational climactic dataset or comparable datasets will allow for any research built upon them to be comparable as well.

Once the definitions are identified, the team will identify open datasets (at the lowest possible granularity, currently at 25km resolution) and proprietary datasets (such as tomorrow.io) to apply these definitions for selected case cities. The results will be compared to identify the limitations and use cases of each dataset. Currently, the team is exploring the advantages of using GLDAS data to identify heatwaves using Wet-Bulb Global Temperature (WBGT), an index considered suitable to measure heatwave impacts in the health and economic sectors. Following this, heating and cooling days will be calculated to test its suitability to the energy sector.

This foundational dataset will enable sector-specific definitions to be applied using the same baseline climate and weather data. To ensure the robustness of these definitions to measure sector-specific impacts, the team will test their suitability by working with other teams working on measuring impact across different sectors for select case-cities. The insights will be used to document the advantages and disadvantages of each definition.

The intended purpose of this identified set of definitions is to create a common database that identifies heatwaves for each sector. This database will act as an input to other problem statements focusing on measuring impact and quantifying efficacy of mitigation measures. These definitions will also be used for near-time heatwave predictions.

EXPECTED OUTPUTS

Outputs	Type	Description
Sector-specific Heatwave Definitions	Open Data	Documented use cases for different heatwave definitions and their suitability to measure sector specific impacts
Foundational Heatwave Occurrence Dataset	Open Data	Dataset that identifies historic heatwaves based on sector specific definitions.
Micro-weather Datasets	Proprietary Data	Identified and documented proprietary datasets that can be used to measure heatwaves.
Methodology to Produce Historic Heatwave Dataset for Different Sectors	Code	Reproducible code, documentation, visualizations, and training materials to track heatwaves for the purpose of monitoring impacts across different sectors.
Methodology for Near-time Heatwave Prediction	Code	Reproducible code for near-time heatwave predictions, by sector.
Reports	Insights	The documentation reflecting on the applicability of the datasets, the assumptions made behind the creation of the dataset and their implications to the results will be made available as a report.

CONFIRMED AND SOUGHT COLLABORATORS

Type		Confirmed	Sought
	International Organizations	• Global Facility for Disaster Reduction and Recovery; World Bank • ESA: satellite imagery and remote sensing data	World Meteorological Organization
	Companies	• **Tomorrow.io**: providing temperature, humidity, and air quality index data, wind speed • **Earthmetry**: Electricity consumption data, water storage data, temperature, humidity, and air quality index in India • **Facebook**: Population data and climate opinion surveys	• **AWS** or **Microsoft** (Cloud compute credits) • **Google** (search trends) • **Fraym** (population sentiment data)
	Government Entities		**India Meteorological Department**: provision of urban meteorological data; review and test outputs from the statement.
	NGOs, Academia, Research Organizations	• **World Resources Institute** • **Mathematica:** heat stress modeling	
	Donor and Development Partners		Donor support for project

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Long-Range Forecasts of Heatwaves and Their Magnitudes

Leads: Eric Mackres, Data and Tools Manager, Urban Efficacy & Climate, World Resources Institute (WRI) Ross Center for Sustainable Cities; Ted Wong, Research and Project Associate, WRI Ross Center for Sustainable Cities

CHALLENGE

Global changes to climatic patterns of temperature and humidity will require many governments, private sector actors, and civil society organizations to make major changes to infrastructure, settlement patterns, and social safety nets. As major adaptation actions can take years for planning, financing, and implementation, it is important that decision makers have access to high-quality, forward-looking forecasts that predict heatwave magnitudes and probabilities at least five years into the future. Existing data resources rarely provide forward-looking forecasts at any sort of useful level of spatial resolution. When they do, they generally provide forecasts of directly simulated variables like maximum expected temperature, rather than metrics that are used for health and infrastructure planning. Without forecasts that are both sector-specific and sufficiently forward-looking, adaptation actors can struggle to make historical data and raw simulation outputs into insights and action.

PROPOSED SOLUTION

The World Resources Institute proposes collaborating with international organizations to create a data resource providing forecasts of probabilities and magnitudes of heatwaves, using sector-specific heatwave definitions as developed by the Heatwave Data Collaborative, for any inhabited location, for any year through 2100. The resource will take the form of data methods, reproducible code, interactive code notebooks, and map datasets. Also to be developed, as part of the Collaborative's Capacity Building efforts, is an interactive web application, on which users can choose locations, years, heatwave definitions, and GHG emission scenarios of interest, and be given maps, tables, and visualizations describing the probability profile of local heatwaves. The resource will also draw on the Heatwave Data Collaborative's research on heatwave impacts to translate forecasted heatwave magnitudes into forecasted impacts on infrastructure, economy, and public health. The outputs will be designed to maximize actionability: query results will be expressed as probabilities of specific threshold exceedances and of concrete impacts to different sectors.

This toolkit will give planners and policymakers tools they need to inform the design, funding, and implementation of heat adaptation strategies that work for their local communities. The outputs from this will also inform other Problem Statements working on short time scale forecasts. The code and documentation will be made available on GitHub to allow for further research to take place using the forecasted scenarios for a given sector.

Further Solution Details

Our method for estimating heatwave probabilities is based on a more general method for estimating climate-hazard indicator probabilities. (The general method is detailed in a forthcoming WRI Technical Note.) Given an indicator definition and a threshold indicator magnitude, we estimate the probability of threshold exceedance using a Bayesian estimator based on using the ERA5 Reanalysis historical dataset to derive a prior and NASA's NEX-GDDP-CMIP6 downscaled simulation outputs. The method is versatile enough to accommodate any indicator that can be calculated from daily temperature, precipitation, and humidity data. For heatwaves, it can accommodate definitions that involve consecutive runs of days exceeding a threshold, thresholds defined by local percentiles, and humid-heat definitions that combine temperature and humidity information. The source datasets allow for estimation of indicator probabilities for any year through 2100, using any of four IPCC emissions scenarios. The spatial resolution is approximately 25 km.

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EXPECTED OUTPUTS

Output	Type	Description
Raster Data Layers	Open data	Global maps of heatwave probabilities based on critical definitions and thresholds (e.g., probabilities of five-day heatwaves with lethal wet-bulb temperature (≥35°C)). Maps will be in GEOTIFF format.
Code	Code	Fully documented and reproducible code, hosted on a GitHub repository to support future improvements and collaboration.
Training Materials	Training materials	Sample curriculum materials for capacity building on using the code and accessing data
Interactive Tool (Dashboards and Visuals)	Tool	Functional interactive data tool which can be embedded in a larger tool or website, or else deployed as a stand-alone resource with its own URL. Backend deployment and frontend code.
Communication Materials	Communication materials	Blog post, slide deck, and promotional video providing overview of the tool's functions, uses, and early findings and insights.

CONFIRMED AND SOUGHT COLLABORATORS

Type		Confirmed	Sought
	International Organizations	• **World Bank**: Data Lab • **Pan-American Health Organization (PAHO)** climate and health team	
	Companies	**Google**: Data processing in Google Earth Engine	
	Government Entities	**WRI partner cities in Africa and India** (to be determined): Use-case development and user testing with Energy, water, transportation, and health infrastructure offices of cities	**NASA**: Development of NEX-GDDP-CMIP6, the primary source dataset
	NGOs, Academia, Research Organizations	• **World Resources Institute**: probabilistic methods, data science, data productization and user / use case identification • **Mathematica:** Dashboard to show projected sector-specific impact	**Arsht-Rockefeller Resilience Center / Extreme Heat Resilience Alliance**: use case development, productization for city heat officers
	Donor and Development Partners		

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Assessing Intra-Urban Heat Hazard Disparities

Leads: Eric Mackres, Data and Tools Manager, Urban Efficacy & Climate, World Resources Institute (WRI) Ross Center for Sustainable Cities; Nicholas Jones, Data Scientist, Global Facility for Disaster Reduction and Recovery (GFDRR) World Bank

CHALLENGE

Heatwaves can evoke thoughts of ice-cream and swimming pools, but they can also Heat hazard varies significantly within cities. Studies have found intra-urban area variations of 7 degrees Celsius (Yan et al. 2014) and higher. As a result, some populations and infrastructure are exposed to more hazard during heatwave than others. Understanding spatial variation of hazard is essential to understanding spatial and population variation of heat wave impacts. These variations are significant enough that some parts of a city may meet a definition of a heatwave while others do not. More importantly, these variations can inform priorities for heat wave response – helping to target distribution of resources to locations and populations with greatest heat exposure.

Spatial variation of heat hazard is correlated with urban form and surface characteristics (e.g. building materials, vegetation, tree cover) (Venter et al. 2020a; Yang et al. 2021), as well as social vulnerability (e.g., spatial segregation, race, income and other indicators of social marginalization) (Hsu et al. 2021; Hoffman et al. 2020). Data on spatial variation of hazard, along with information on population exposure, vulnerability and existing heat mitigating characteristics, can be used to select and target mitigation interventions.

Although a growing number of cities are acting to address urban heat, two key barriers impede action at the scale that the global heat-risk challenge calls for: (i) lack of spatially explicit data on heat exposure within cities; (ii) lack of awareness and engagement by local stakeholders. Fortunately, participatory approaches to mapping heat exposure have been proven to successfully address both gaps. Engaging citizens to map heat can generate scientifically valid datasets of value to heat action planning while generating awareness, civic engagement, and recognition of grass-roots perspectives on heat impacts.

The project partners have conducted successful pilot projects combining community-based data collection on heat with advanced modeling approaches. The current effort seeks to take these approaches to scale. Specifically, it will adopt a cohort-based approach to help at least 12 global cities engage their citizens on heat while generating the scientific evidence base to support investments and policy changes for a cooler city.

PROPOSED SOLUTION

We propose three components, each using different data sources and meeting different needs.

Open Cities Heat Watch. This activity will support at least 12 global cities to create scientific datasets on urban heat while engaging citizens and building civic awareness on the need for heat action. Candidate cities will be identified through an open Call for Participation issued through World Bank urban sector Task Teams and through WRI country offices. Requests for support will be prioritized based on need for urban heat action, implementation capacity of the local partner, and link to financing and policy reform. In each participating city, the partner entity (typically a local NGO or university in collaboration with city government) will be supported to mobilize volunteers and conduct a heat mapping campaign. Reference datasets, methodology, and sensor equipment for measuring point-in-time spatial variation will be provided together with training sessions and implementation support. : Mapping campaigns, engaging local stakeholders in data collection using mobile sensors on a single, peak heat day, can collect thousands of datapoints on heat indicators across a city. This point data can be translated into raster data to provide a medium-resolution hazard map for the city. GFDRR, NOAA, their partners and others have run these campaigns and analyses in several cities. This effort will support heat mapping in a methodology-agnostic approach considering the needs and priorities of local stakeholders. Data collection approaches supported will include vehicle traverses, use of stationary sensors (eg. Wet Bulb Globe Temperature monitors), citizen engagement on micro-level, site-specific causes of heat using FLIR cameras, and survey-based approaches. Additional open source method documentation, improved data management guidance and training will help to make these methods accessible and useful in more cities.

Methodology and reproducible code for measuring temporal trends in spatial variation: Ongoing monitoring of intra-city hazard variation can provide a time-series datasets for more nuance on temporal variation across the day and year (e.g., daytime vs nighttime heat, heat prevalence under varied meteorological conditions), can be used to track trends over a period of years, and eventually evaluate the impacts of heat mitigation measures. These measurements can also be associated with multiple heatwave definitions and events and be integrated into near-real-time response systems. For this approach the team will leverage remote sensing data calibrated to data from in-situ, ground-based weather sensors. These methods have been applied to single cities, but not yet deployed in replicable, scalable ways. We will emphasize developing a data pipeline to ease access to required datasets from multiple data partners, automated validation and cleaning of data and integrating multiple data types to produce analyses applicable in most cities globally. Relevant remote sensing datasets are mostly open source (e.g., Landsat, ECOSTRESS, geostationary meteorological satellites), but data from ground sensor networks is a mix of open source and proprietary data (e.g., Netatmo, Weather Underground, Tomorrow.io). The Development Data Partnership provides an important platform to facilitate collaboration with these proprietary data holders. This effort will process available remote and ground sensor data, develop time-series hazard raster datasets, and assess validity and statistical error of outputs for all major cities in at least two (2) low- and medium-income countries with the highest heat risk.

Piloting assessment methodologies for indoor heat stress. Heat stress is often experienced within buildings, but excessive heat exposure indoors has not been adequately measured or understood in most developing country settings. In Indonesia, the World Bank has supported the delivery of public housing initiatives in areas where the number of heatwave days if projected to double by 2050. However, there remains an evidence gap on indoor heat exposure both in housing units and in other key public facilities such as schools. Quantifying the level of heat exposure faced by residents of government-supported housing units and school children would build the business case for investing in building structures with improved insulation and passive cooling approaches. Measurement campaigns in US public housing demonstrate viable models. This activity will review indoor sensing equipment deployment models, engage local NGOs in Indonesia or 1-2 other selected countries on indoor heat stress monitoring, produce heat monitoring outputs, and present a scalable model for sensors and their deployment modality for use in other World Bank and WRI engagements.

Qualitative data collection from the pilots conducted across the case cities. The team will document the process of measuring air temperature, community engagement practices, identified best practices, pitfalls and lessons learned in each of the case cities. This will also allow for knowledge transfer to occur when scaling the methodology to new cities.

Further Solution Details

- NOAA Urban Heat Island Mapping Campaigns website
- Urban Heat in Johannesburg and Ekurhuleni: A meter-scale analysis and vulnerability assessment
- Venter et al. (2020b) "Hyperlocal mapping of urban air temperature using remote sensing and crowdsourced weather data"
- Open Cities Africa: under Component 1, the initiative proposes to extend the cohort-based, demand-driven implementation model used successfully in this GFDRR program to address the issue of heatwaves.

EXPECTED OUTPUTS

Output	Type	Description
Mobile sensor traces and heat readings	Open data & training materials	Participants in mapping campaigns will be trained and provided with sensors to collect heat indicators across selected cities.
Methods to translate mobile sensor traces to heat hazard maps	Code & training materials	Reproducible code, interactive code notebooks, and data methods for processing sensor data into point and raster datasets. Training materials for analysts to use data and code.
Heat hazard map based on mobile sensors for at least 12 cities	Datasets	Point and raster datasets for each city mapped through mobile sensor campaign
Stationary weather sensor readings	Open/ Proprietary data, code & training materials	Reproducible code, interactive code notebooks, and data methods to enable weather sensor readings to be accessed, cleaned and organized to be appropriate for use with remote sensing data for intra-urban heat mapping. Training materials for analysts to use data and code.
Methods using stationary sensor readings with remote sensing to create heat hazard maps	Code & training materials	Reproducible code, interactive code notebooks, and data methods to use remote sensing and ground sensor data to produce point and raster datasets on heat hazard.
Heat hazard map based on stationary sensors and remote sensing for major cities in 2+ countries	Datasets	Point and raster datasets for each city mapped using the remotes/stationary sensor methods
Intra-city heatwave impact estimates and forecasts based on hazard map(s) for 2+ cities	Insights	Hyperlocal estimates of heat wave impacts for each city with a intra-urban heat hazard map, based on literature and outputs from impact measurement problem teams. Forecasts of future impacts using forecasted city-scale heat hazard from other problems teams.

CONFIRMED AND SOUGHT COLLABORATORS

Type	Confirmed	Sought
International Organizations	**Global Facility for Disaster Reduction and Recovery (GFDRR)**: mobile heat mapping campaigns, data science and modeling expertise	
Companies		• **Tomorrow.io**: weather data • **Netatmo:** sensor network data • **Weather Underground**: weather station data • Cloud computing credits • **Fraym**
Government Entities		• **NOAA** Climate Program Office: mobile heat mapping campaigns • **NASA JPL**: experience with thermal sensor-based analyses with multiple satellites • **NASA-GMAO**: experience with satellite/ground sensor calibration for air quality mapping • **Global Heat Health Information Network**
NGOs, Academia, Research Organizations	World Resources Institute: data science, data productization and user / use case identification	• **Arsht-Rockefeller Resilience Center** / Extreme Heat Resilience Alliance • Jesus Lizana, U**niversity of Oxford**: weather station data aggregation • Zander Venter, **Norwegian Institute for Nature Researc**h: remote sensing data calibration with ground sensors
Donor and Development Partners		• GFDRR: 50% cost of ML specialists • Funding to support production of Data Goods, training materials, and community building activities

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Forecasting Heatwaves for Early Action

Leads: Vladimir Tsirkunov, Lead Specialist, Head of the GFDRR Hydromet Program, World Bank; David Rogers, Lead Meteorological Consultant, World Bank

CHALLENGE

Climate change attribution suggests that heatwaves will increase in severity and frequency due to global warming. Preventing harm to those at risk requires the ability to take early action, which depends on accurately forecasting and warning of the impact of heatwaves on people's health, energy supply and demand, food and water security, transportation and other urban infrastructures. A major challenge is transferring knowledge and knowhow from the more advanced forecasting centers to developing countries and implementing that knowledge to reduce risks. Creating impact-based forecasts and warnings for early action requires the meteorological forecasts to be combined with spatial and socio-economic data on vulnerability of people and assets. In this way warnings can be tailored to specific needs of individuals and economic sectors. Knowing what to do and when is critical to mitigating risks. Heatwaves also have a causal relationship with thunderstorms and flash floods. So, these additional threats must be considered in forecasting for early action.

PROPOSED SOLUTION

Heatwaves, like most meteorological hazards, are caused by the interaction of the land, air and ocean on a global scale. The chaotic nature of the atmosphere means that the system is inherently uncertain but reliable prediction is critical if society is to be able to anticipate a heatwave or other extreme weather event and take early action. This requires weather and climate models to be run as ensembles; that is, multiple times for a single forecast period to capture the range of possible forecasts due to small fluctuations in the initial state of the atmosphere at the beginning of the period and the uncertainty inherent in the computer models. Currently, 50-members (individual forecasts) is considered sufficient to provide a reliable global forecasting system by the European Centre for Medium Range Weather Forecasts (ECMWF). The resolution of the ECMWF operational ensemble prediction system (EPS) is expected to be about 9km by 2023.

Given that impacts are felt on much smaller scales and are influenced by the variations of the urban landscape, it is important to be able to downscale the model predictions to much finer resolution. This can be done using limited area models or increasingly through the application of machine learning and AI techniques. The ability of many developing countries to utilize the data from the advanced centers, such as ECMWF, is limited. Previous projects, however, have demonstrated, that twinning advanced meteorological services with a developing country enables them to access these data and use it effectively in their forecasting systems[1].

The critical element in the proposed solution is the availability of 1) remote and in situ observations of the urban environment (atmospheric temperature, humidity, wind, surface albedo) at high temporal and spatial resolution; 2) data on the vulnerability of infrastructure (homes, factories, transportation networks, urban and peri-urban agriculture, energy sources (supply and distribution networks); and data on the social determinants of vulnerability to heatwaves (poverty, ethnicity, age, gender, disability, access to air-conditioning, access to social services, etc.) and exposure (lack of access to air-conditioning, housing, etc.). Populations are differentially affected by heat based on geographical distribution. Higher tolerance exists in typically hot climates. Consequently, heat health warnings need to be carefully targeted – for example, tourists from higher latitudes visiting a tropical or subtropical country are likely to have a much lower tolerance for excess heat than the indigenous population.

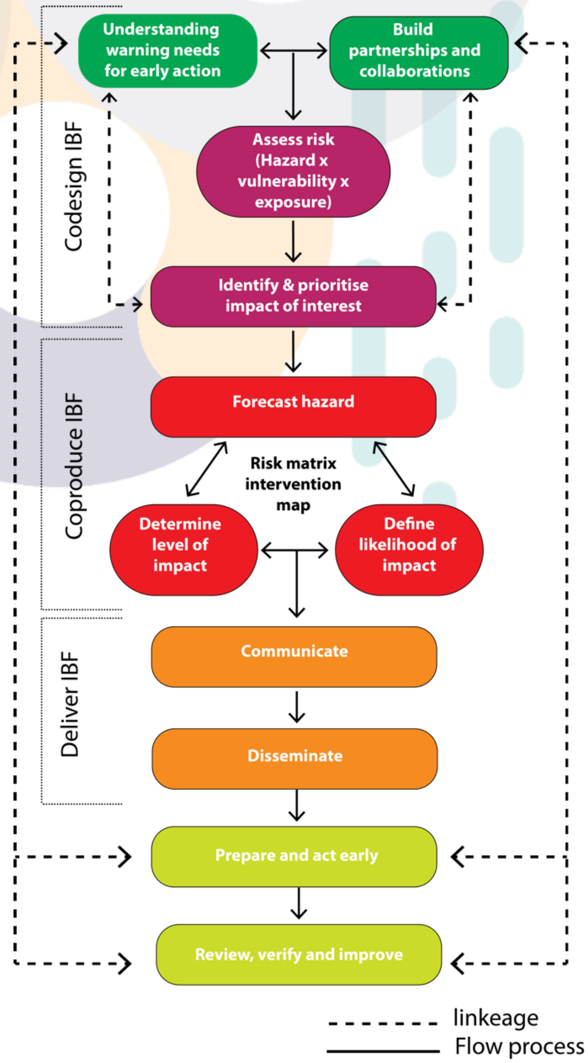

Figure 1 Methodological framework for heatwave forecast and warning (after Met Office and International federation of Red Cross and Red Crescent Societies)

By combining the heat, vulnerability and exposure data, impact-based forecasts and warnings can be created for hyperlocal scales enabling early action by individuals, civil society and officials. The steps for producing impact-based warnings for early action are known and can be readily applied (Figure 1).

The methodology would identify and help prioritize impacts of interest including heat health, energy supply and demand, food and water security, and transportation networks. Different messaging strategies will be used in the dissemination of communication to different sectors.

The same approach can also be applied to climate projections. In this application, the probability of heatwaves (intensity and frequency) combined with vulnerability and exposure data would identify heatwave impacts due to climate change and inform potential investments in mitigation efforts.

EXPECTED OUTPUTS

Output	Type	Description
Spatial and temporal Meteorological data	Open data	Timeseries of meteorological data gridded and scaled for each urban environment in a format that can be used to train AI tools and other applications.
Spatial and temporal Impact data	Open data	Timeseries of impacts, based on verified impact-based forecasts, gridded to each urban environment that can be used to improve impact-based forecasts and assess the ability of people and economic sectors to take early action.
Spatial and temporal Climate projections	Open data	Timeseries of climate projections scaled for each urban environment. Database on evolving risks due to climate change and potential interventions
Vulnerability and exposure maps	Open data	Vulnerability and exposure maps related to sectors of interest
In situ observational and forecast data	Proprietary data	Time series of meteorological observations for each urban environment based on access to all available in situ data from public and private sources with applicable data protocols applied
Tools to create impact-based forecasting	Code	Access to tools to create impact-based forecast and warnings; code to display information and enable data to be utilized by platforms such as Google.
Methodologies for ensemble prediction, and impact-based forecasts	Training materials	A collection of materials on key aspects of forecasting, warning and early action for heatwaves
Knowledge transfer to developing countries on the use of methodologies	Knowledge transfer	Transfer knowledge and know-how to developing countries on the use of ensemble prediction and impact-based forecast and warning systems to support early action and support planning to mitigate the impact of heatwaves through impact-based climate projections.

CONFIRMED AND SOUGHT COLLABORATORS

Type	Confirmed	Sought
International Organizations	**GFDRR Hydromet Program**, World Bank Group	**European Centre for Medium Range Forecasts (ECMWF)**: Source of Ensemble prediction systems' data
Companies	**Synoptic Data**, a Public Benefit Company: Observational data integration, quality control and dissemination **HMEI** (Hydromet Industry Association): In situ meteorological observations through a consortium of instrument manufacturers	**Tomorrow.io**: Microweather data
Government Entities	**UK Met Office**: Development of Impact-based forecasts for early action **Met Norway**: Application of Ensemble Prediction Systems	**India Meteorological Department**: Urban meteorological forecasting **Centre for Climate Research Singapore**: Transfer of knowledge on operational heatwave services
NGOs, Academia, Research Organizations	SEEDS India	**University of Oxford**: Development of AI tools for EPS downscaling and training in use of ensembles **Google.org**: access to real time, dynamic vulnerability and exposure data
Donor and Development Partners		Financial support for the challenge

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ADDITIONAL INFORMATION

#	Key Task	Description	Duration
1	Ensemble Prediction System (EPS)	Create and make available database of daily forecasts for regions of interest for re-analysis	1 month
2	Observations	Aggregate all available local observations	2 months
3	Vulnerability indices	Create a database of vulnerability and exposure data for sectors and communities of interest and develop heat-related vulnerability indices	3 months
4	Impact-based forecasting system	Create and test impact-based heatwave forecast and warning system and validate again known impacts	4 months
5	Ensemble Climate projections	Create a database of impact-based climate projections suitable for planning mitigation and adaptation investments	12 months
6	AI downscaling	Train an AI system to downscale EPS for regions of interest	6 months

* Some activities will be conducted in parallel.

Improve Climate Risk Literacy through Seamless Navigation of Information:

Weather Alerts, Seasonal Outlooks, and Climate Change Scales

Leads: C. MacKenzie Dove, Technical Climate Consultant, World Bank; Caspar Ammann, Climate Consultant, Climate Strategies Group and World Bank

CHALLENGE

There is an inherent, scientific separation of forecast strategies across timescales (weather, S2S, [decadal], climate change). However, for users / decision-makers / planners, that separation represents a challenge when the products are also disconnected and if each remains based on different language and guidance aimed at a distinct audience. Particularly in the development context, a better integration is critical in order to maximize investment outcomes and to work towards resilience to the mounting hazards and risks. In order to improve the literacy around the existing forecast products, and to enable a better integration of the information with risk understanding, translational tools should be in place that bring together the different products in a seamless way and guide the users to their meaning across timescales. This would strengthen risk management capacity, enable resilient planning, and thus bring out the full promise of the forecasts in the places where they are most needed.

PROPOSED SOLUTION

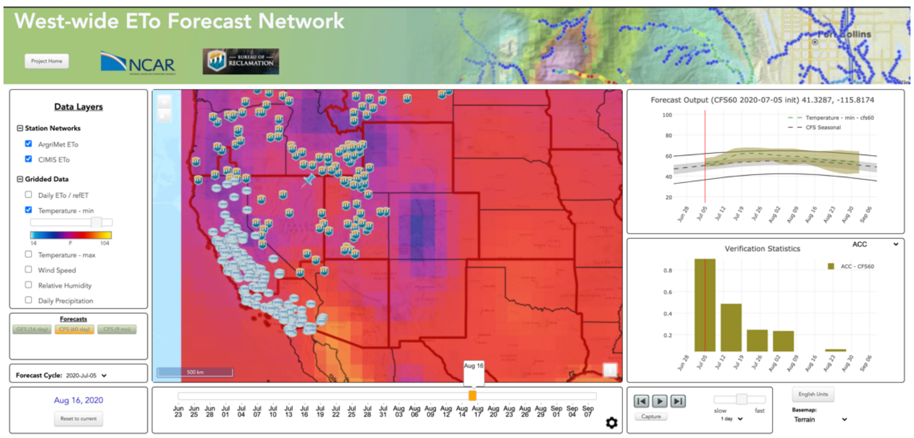
Develop specifically designed interfaces (flexible dashboards) that provide a variety of use-oriented visualization, simple narrative translations and syntheses of the real-time and most-updated forecast products with the aim of integration. This will enable Managing Heat Waves: Heat hazard potential needs to be recognized in the long-range forecasts; candidates of events need to be tracked and refined continuously into their potentially different manifestations; and concrete predictions with associated alerts and warnings need to be issued and updated; and ultimately, the monitoring is guiding responses as the hazards and impacts are unfolding in real time. Preparing for Future Heat Waves: Using the understanding of how current heat waves and heat hazards are impacting people, their activities, infrastructure and the environment, design outlooks for the upcoming seasons of likely occurrence in intensity, (duration) and frequency of heat waves and their expression across the socio-economic landscape. For the long-term planners, expand on the routinely (monthly) used seasonal approaches by using scenario development to explore the broader range of possible impacts under a changing climate to highlight the need for strategies to improve resilience and to properly manage them.

To allow for effective communication of results, and provide guidance around decision making in the face of uncertainty, sector specific impacts under different scenarios can be expanded upon to allow for users to see if the impact is contained within a sector or widespread across sectors.

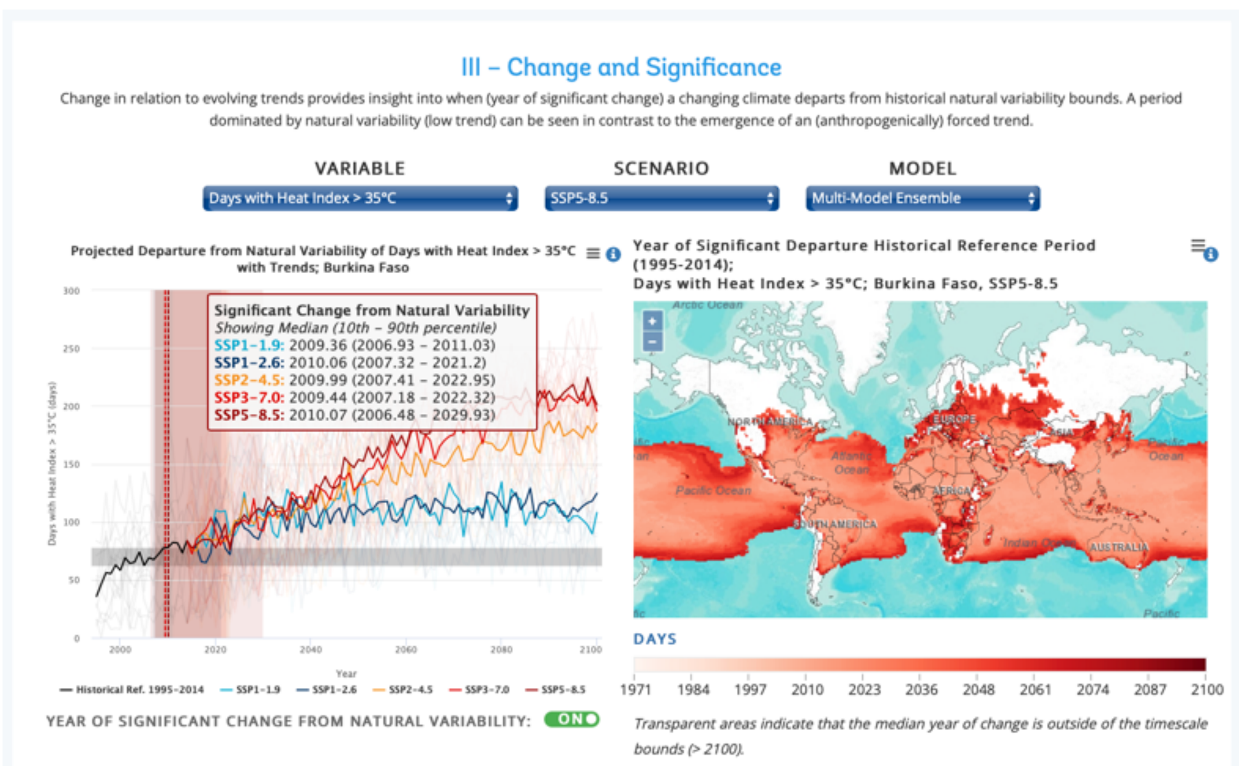
This will serve as a foundational dataset for additional sector specific research to measure impact and quantify mitigation measures that can be applied in urban areas.

Further Solution Details

Here is an example visualizations module -- developed for US Bureau of Reclamation: Operational Reference Evapotranspiration forecast with (much) higher than normal evaporative loss of moisture out of the ground for the upcoming 60 days paired with verification statistics to illustrate predictive skill.



And for Climate Trends and Variability in context of Climate Change, here are examples previously developed with World Bank Climate Change Knowledge Portal.



EXPECTED OUTPUTS

Output	Type	Description
Heatwave forecast methodology at different timescales	Code and documentation	Reproducible methodology for identifying ongoing (near-real-time), predicted (forecast), and anticipated heat waves (probabilistic forecast)
Web-based interactive dashboard for evolving heatwaves	Code for producing dashboards and implementation	Heat wave forecast dashboard with seamless integration from hours to months identifying ongoing (near-real-time), predicted (forecast), and anticipated heat waves (probabilistic forecast) using flexible visualizations, event classifications, and narrative descriptions.
Heatwave scenario testing methodology	Code and documentation	Reproducible code and methods for seasonal outlook and climate change projections and current climatological statistics (intensity, duration, frequency) of heat waves, the global context of variability in "mean", and trends using scenarios of future large scale climate change.
Web-based interactive dashboard for outlooks to heatwaves (seasonal context and climate change timescales)	Code for producing dashboards and implementation	Interactive Scenario Interface for seasonal outlook and climate change projections to illustrate current climatological statistics (intensity, duration, frequency) of heat waves, the global context of variability in "mean", and trends using scenarios of future large scale climate change using visualizations, statistics, ranges, extremes, narratives
Forecast Management Infrastructure	Code to create cloud service and implementation	Cloud-based forecast management with API for services. Base infrastructure can be built for one or two development use-cases but can be scaled to global reach.
Capacity Building	Training materials	Introduction to scientific concepts of the forecasts, the process of determining "skill", and translation of how to interpret and use while keeping cross-time-scale information perspective.

CONFIRMED AND SOUGHT COLLABORATORS

Type		Confirmed	Sought
	International Organizations	• The **World Bank**'s Climate Change Knowledge Portal	• International Committee of the Red Cross – on the ground
	Companies		• Amazon AWS • Microsoft Azure • Google • Applied Climatologists (Larry Kalkstein)
	Government Entities		• NOAA • ECMWF
	NGOs, Academia, Research Organizations		• National Center for Atmospheric Research • IRI-Columbia Univ.
	Donor and Development Partners		• Adrienne Arsht-Rockefeller Foundation - Resilience Center and their Extreme Heat Platform

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Supporting Inter-Comparable Work on Heat, Extreme Heat Conditions, and Extreme Heat Events through Provision of Robust, Systematic and Consistently Produced Climate Data Products

Leads: C. MacKenzie Dove, Technical Climate Consultant, World Bank; Megumi Sato, Task Team Leader for Climate Change Knowledge Portal (CCKP), World Bank

CHALLENGE

Policy makers and development practitioners require *operational* climate data products that are produced in a systematic manner enabling inter-comparable work across countries and sectors. While there are many 'climate data providers', the challenge has always been that these large data archives, system grids and downloadable data packages are inflexible and *primarily designed for the atmospheric modeling and scientific research communities* and not for the broader development community and/or non-scientific practitioners. Additional challenges emerge for development practitioners as users can encounter conflicting data processing methods, different data formats, differing ensemble criteria, different data resolutions, and different baselines, making data inconsistent, resulting in various data products that are non-comparable.

For a community to understand changing heat conditions and extreme heat event distributions within climate timescales, users need: (1) Consistently produced, inter-comparable data for all countries, and (2) An ability to understand comprehensive climate conditions, which may also be present when a 'heat event' occurs in order to appropriately assess comprehensive and compounding risks. We need to establish access to consistently processed, comparable data and products is essential for WBG Teams, Country Units and designated Sector Analysis when preforming climate impact modeling at country and sectoral levels, climate risk screening and analytical efforts at the project level or broader analytical efforts and inter-sectoral workstreams of corporate commitments. We also need to understand the potential for changing heat conditions and extreme heat events across climate timescales, should not be done in a 'vacuum,' as dangerous heat conditions often may occur in areas experiencing compounding risks from changing precipitation dynamics and/ or increasing aridity conditions. The ability to understand and more fully capture the compounding range of risks of for a specific time period or seasonal analysis is an essential part of understanding, preparing for and adapting to dangerous heat.

PROPOSED SOLUTION

As a WBG designated data climate service, CCKP is designed to enable users to define, understand, and then communicate impacts of climate, natural variability, and future climate changes across contexts. CCKP presents a user-centric platform built on a systematic data archive that provides *access to processed climate data across primary collections* that is robust, science-driven, and consistent, enabling inter-comparable work between sectors and across countries. The standardized approach within CCKP ensures a systematic and coherent approach to using and processing the best available climate change information, ensuring that users are provided with an appropriate, robust, trusted source of information that allows them to undertake climate change assessments and meet climate corporate commitments. Additionally, given the large data volumes and complexity of global climate model compilations, WBG Teams and indeed, many countries do not have the capability (technical, computational, scientific) to process the raw data, as such many countries are using CCKP data for national programming and analysis.
CCKP's systematic data archives and flexible architecture enables efficient management of large and complex data volumes and the ability to respond quickly for new product generation to meet expressed needs from WBG teams and collaborators. All CCKP data is freely and publicly available.

CCKP has a range of temperature and precipitation derived climate indicators currently available (many co-developed with WBG Sector teams to meet expressed needs), which can support users understand changing conditions across time, space and climate scenarios. New heat-orientated products continue to be produced, including:

- *Projected Heat Risk and Relentless Heat Conditions*: (reflected across both space and time) in relation to population densities, poverty scales and facility locations
- *Crop Suitability:* Presentation of potential for reduction/ expansion/ new emergence of designated crops suitability across space and time in relation to optimal and sub-optimal temperature and precipitation bounds
- *Disease Suitability based on thermalogical tolerance of species:* data presentation as fundamental niche for the reduction/ expansion of areas species could exist. (*under discussion)*
- *Extreme Heat Products*: Extreme Heat Events; event distributions; probability of heatwaves, across climate timescales
- CCKP is near complete with downscaling (0.25° x 0.25°) of existing CMIP6 Collection (all variables, global); this will also be publicly available.

CCKP's architecture and processing capabilities result in the ability to quickly produce new variables, such as threshold-based products, as required by teams and/ or collaborators. The opportunity to participate in the *Heatwave Data Collaborative* offers not only the opportunity for collaborators to benefit from the available climate data offerings, but also new opportunities for co-developed products to meet unique needs of the community.

Further Solution Details
https://climateknowledgeportal.worldbank.org/

EXPECTED OUTPUTS

Output	Type	Description
Examples of Existing CCKP Temperature-orientated products	CCKP climate variables derived from CMIP6	• Avg Mean Temp • Avg Max Temp • Avg Min Temp • Cold Spell Duration Index • Cooling Degree Days (ref 65F) • Heating Degree Days (ref 65F) • Maximum of Daily Max-Temperature • Minimum of Daily Minimum Temperature • Number of Frost Days (Tmin<0C) • Number of Days with Heat Index >35C • Number of Days with Heat Index >37C • Number of Days with Heat Index >39C • Number of Hot Days (Tmax>35C) • Number of Hot Days (Tmax>40C) • Number of Hot Days (Tmax>42C) • Number of Hot Days (Tmax>45C) • Number of Ice Days (Tmax<0C) • Number of Summer Days (Tmax>25C) • Number of Tropical Nights (Tmin>20C) • Number of Tropical Nights (Tmin>26C) • Warm Spell Duration Index
Soon-to-be-published Extreme Heat Risk Condition products	CCKP climate variables derived from CMIP6, categorization for defined 'national-scale risk'	• Number of Hot Days (Tmax>30C) • Number of Tropical Nights (Tmin>23C) • Number of Tropical Nights (Tmin>29C) • Number of Days with Heat Index >41C
Extreme Heat Event Products, Under Development	CCKP climate variables derived from CMIP6	• Extreme Heat Event: Future Return Periods, Future Annual Exceedance Probabilities • Probability of Experiencing a 'Heatwave'

CONFIRMED AND SOUGHT COLLABORATORS

Type	Confirmed	Sought
International Organizations	World Bank: Climate Change Group- Global Unit; Development Data Group; Data Lab Numerous data platforms throughout the WBG have integrated CCKP data as the ‘foundational climate data’ in sector platforms analytical tools IMF, IFC, MDBs, USAID, FAO currently using CCKP data in internal analysis and risk assessments ESA	Staff support and existing linkages to corporate commitments Ongoing discussion, scaled collaboration with Development Data Group
Companies	Sistema	Current collaboration on product development; ongoing contract with Sistema
Government Entities	NHMS’ and National Climate Directorates are using CCKP data as supplement to national centers; support climate programing use	
NGOs, Academia, Research Organizations		
Donor and Development Partners	Climate Support Facility Trust Fund	CCKP primary funding support

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Assessing Heatwave Impact on Human Well-Being

Leads: Julie Rozenberg, Senior Economist, Sustainable Development Practice Group, World Bank; Mariana Conte Grand, Climate Change Senior Economist, Sustainable Development Practice Group, World Bank

CHALLENGE

Although there is no consensus on a single definition of human well-being, it is broadly acknowledged that well-being embodies physical health and relates to how people feel. Climate change impacts both dimensions, but the latter has been much less studied. The IPCC and the WHO recently highlighted that, because rapidly increasing climate change is a threat to psychosocial well-being, it should be considered in climate policies. In parallel, a WHO survey found that only 9 out of 95 countries have included psychological dimensions in their national health and climate change plans. As more extreme heat is expected for the future, a more complete understanding of the relationship between ambient temperature and expressed sentiment is important to help countries undertake appropriate actions to cope with aggression and conflicts that can derive from peoples' unease when facing extreme heat.

In general, heat-related psychological distress (i.e., anxiety, depression, as well as derived aggression) are difficult to assess using conventional administrative data, while survey data take time and are costly. This may explain why research usually focuses more on violence once it occurs in the physical space (e.g., several forms of crimes or suicides).

PROPOSED SOLUTION

The team proposes to capture the relationship between heat extremes and people's mood by looking at social media contents. Specifically, we aim to use geolocated tweets within major Latin American metropolitan areas. We would employ natural language processing algorithms to translate tweets to three quantitative indicators: sentiments, profanities, and racist slurs. We plan to use existing dictionaries, e.g., Hedonometer, and develop new ones as needed. We would then analyze their relationship with daily temperature (while controlling by other weather factors and other possible confounders).

We would also like to look at online search behavior. The terms that people search in Google the days with high temperature can indicate changes in their emotional state, their consumption decisions, or the adoption of mitigation behavior. Complementarily, we would consider analyzing data regarding human mobility (e.g. Google´s Community Mobility Reports) to learn about time use during times of extreme heat since it may give clues about averting heat practices.

The team intends to focus the analysis on Latin American countries (LAC) because it encompasses a vast area of the world, with very diverse climate, and is made up largely of countries that are generally middle income. Even if there are differences among countries, the region has a relatively high happiness index despite its GDP per capita level, inequality rates, and weak political institutions. However, climate change could affect that subjective well-being. There are very few studies analyzing the link between climate and social media expression, none covers Spanish or Portuguese-speaking countries, and their sample size is usually small.

Digital media give more people the tools to record and share their experiences of conflict. Climate change may encourage violence in digital media, and by directly examining individuals' reactions to heat, precautionary actions could be put into place, and physical violence and conflicts may be prevented.

It is noted that validation will be important for these analyses, to remove the influence of time trends and potentially confounding factors (e.g., concurrent events such as political unrest or sporting events that could lead to frustrations that are expressed using similar key words).

Further Solution Details

- Hedonometer dictionaries
- Association Between Expressed Sentiments In Tweets And Temperature: Evidence For A Latin American Country (D. Aromí, M. Conte Grand and M. Rabassa)
- Reference Paper: The Economic Consequences of Increasing Sleep Among the Urban Poor

EXPECTED OUTPUTS

Output	Type	Description
Literature review of the relationship between heatwaves and social media expressions and Google searches and mobility	Document	Summary of the literature (number of publications, by type, method use, source, country covered, etc.), which will additionally cover how to handle potential biases in social media data analytics.
Geolocated tweets organized per metropolitan area in LAC.	Code and data	Database with geolocated tweets.
Construction of Dictionaries in Spanish and Portuguese	Code and data	Profanities and racist slurs dictionaries in Spanish and Portuguese, adapted to specific language usage of the different countries.
Estimates of temperature-sentiment relationship	Code and document	Econometric analysis with results tested for the whole region and by countries.
Google search intensity per topic per heat day.	Code and data	Systematization of the typical searches associated to heat to capture plans people elaborate to avert its effect.
Google´s Community Mobility Reports for cities selected per heat day	Code and data	Systematization of the mobility associated to the days of heat to capture actual behavior people undertake to avoid heat (for example, travel to the mountains).
Policy recommendations	Document	Repository of policy alternative to adapt to consequences that can follow from psychosocial stress observed in social media due to heat, and observed changes in behavior as derived from Google searches and people’s mobility.

CONFIRMED AND SOUGHT COLLABORATORS

Following are confirmed and sought partners and resources for this

Type		Confirmed	Sought
	International Organizations	The **World Bank**'s Regional Direction for Latin America and the Caribbean, Sustainable Development Practice Group: Staff Time and Link to Existing Project	
	Companies		• **Twitter** (API) • **Google** (search trends) • **Fraym** (population sentiment data for LAC)
	Government Entities		
	NGOs, Academia, Research Organizations	• **Daniel Aromi**, researcher Universidad de Buenos Aires • **Mariano Rabassa**, researcher Universidad Católica Argentina	
	Donor and Development Partners		Donor support for project

CONTACTS

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ADDITIONAL INFORMATION

#	Key Task	Description	Duration
1	Collection of social media data	A large corpus of Tweets will be retrieved using an appropriate API and relevant search parameters.	5 months
2	Collection of weather data	Processing of daily satellite data from the ERA5 Reanalysis provided by the Copernicus Climate Change Service (C3S).	2 months
3	Collection Google searches and mobility data for days of extreme heat	Based on activity 2, process Google data to assess attempts and actual averting behavior during heatwaves	5 months
4	Data processing and analysis	Generation of indices and estimation of the daily impact of high temperature on expressed sentiments, aggression, and averting behaviors.	3 months
5	Report findings	Write a final report with the main findings and policy recommendations.	3 months

Creating Heat-Health Vulnerability Maps to Measure Impact of Heatwaves on Human Health

Leads: Tamer Rabie, Lead Health Specialist; Health, Nutrition and Population (HNP) Global Practice, World Bank; Stephen Dorey, Public Health Specialist, Health, Nutrition and Population (HNP) Global Practice, World Bank; Aakash Mohpal, Senior Economist, Health, Nutrition and Population (HNP) Global Practice, World Bank

CHALLENGE

Deaths related to heatwaves are often difficult to measure, especially in low-income countries given the complexity of the relationship between heat and human health. Outside of fatal impacts, excess heat also causes significant heat related morbidity from cardiovascular disease, acute renal failure, respiratory conditions, and other non-communicable diseases (NCDs). Additionally, health impacts resulting from a concurrent exposure to increased levels of air pollution have been shown to act synergistically such that co-exposure to heat and air pollution are worse than the sum of these individual exposures. Studies in high income countries such as the United States have shown the relationship between heatwaves and illnesses. However, these methodologies are often not replicated in lower income countries leaving them data poor and with an evidence gap and ill-equipped to measure and respond to impacts of increasing heatwave. Much of the burden of the health impacts from heat also occurs not on the hottest – but less frequent – days but on the less deadly but more frequent warm or hot days.

PROPOSED SOLUTION

The team proposes the use of nontraditional private sector data and combine it with additional publicly available health related datasets to map populations vulnerable to heat related illnesses during a heatwave. The study will also incorporate air quality standard data from ground monitoring stations. Movement maps will be created using GPS data and call records data from the private sector to map increased hospital visits during heatwave days. The movement maps will be overlaid with building stock maps to see where the emergency visits to hospitals are coming from – commercial buildings, residential buildings, or other areas. Finally, socio-demographic information will be added to this dataset to create heat-health vulnerability maps.

The study will compare findings on heatwave days, heatwave days with bad Air Quality and non-heatwave days. This would help identify the increase in emergency hospital visits due to a heatwave and the areas from which these emergency visits are occurring. Additionally, each of these will be tested against different definitions of a heatwave to identify the definition that best correlates with heat-related illness impact.

Generate knowledge will be used to generate practical and policy relevant recommendations developed in conjunction with policymakers and planners in priority countries – primarily those countries involved in the study. A further option which will be explored will be to use this information to catalyze the establishment of at least one climate and health observatory. As a consequence of prior discussions and interest in the regions it is anticipated that the Latin America and Caribbean Region (LCR) is likely to be the primary focus and with this in mind the study proposers have already had encouraging discussions with the Pan-American Health Organization (PAHO) who could be potential co-leads on this.

Further Solution Details

- Reference Paper for Considering Income as Part of the Analysis: Uncovering Socioeconomic Gaps in Mobility Reduction during the Covid-19 Pandemic Using Location Data

EXPECTED OUTPUTS

Output	Type	Description
Heat-health vulnerability maps	Code	Maps that identify areas where there were increased numbers of hospitals visits or other measures of increased healthcare utilization or mortality/ morbidity burdens.
Correlation between heatwaves and air quality	Code	Maps identifying the number of hospital visits due to co-exposure to heatwaves and bad air quality, and identifying areas where air quality is worse during a heatwave

CONFIRMED AND SOUGHT COLLABORATORS

Following are confirmed and sought partners and resources for this

	Type	Confirmed	Sought
	International Organizations	• The **World Bank**'s Health, Nutrition and Population team • **Pan-American Health Organization (PAHO)** climate and health team	
	Companies		• **Waze**: traffic and movement data • **Mapbox**: Movement data • **Outlogic**: GPS data • **Veraset**: GPS data
	Government Entities		• Peru • El Salvador • India • Pakistan • Djibouti
	NGOs, Academia, Research Organizations	• **Mathematica:** Replicating their existing methodology used to create ClimaWATCH in developing countries	London School of Hygiene and Tropical Medicine (LSHTM)
	Donor and Development Partners		

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- **Tamer Rabie,** World Bank: trabie@worldbank.org

ADDITIONAL INFORMATION

#	Key Task	Description	Duration
1	Data collation	Private and public data sets will be collated into an agreed platform, then cleaned ready for the next task.	1-3 months depending on scope
2	Data analysis	Agreed analyses will include applying potential definitions of heatwaves and performing appropriate statistical analyses. This task will also involve identifying a subset of heatwave definitions to go forward to the next stage. Note heatwave definitions may be flexible to allow inclusion of different absolute values for different contexts.	1-2 months
3	Add GIS	Analyzed data outcomes combined with GIS 'vector' data to provide GIS outputs in the form of maps and other data representation options. This second stages of analysis may then highlight insights not previously seen in task 2 and hence there would be the option to add further iterations of analysis and GIS application.	
4	Methodology capture	To provide a global public good from this work the process and learning derived from these stages will be captured and presented as a methodology for others to use to apply this work in other countries and contexts.	
5	Report writing	Information, maps and other infographic data outputs will be used to create a report(s) to facilitate communication and uptake of knowledge in particular by policymakers and health planners	
6	Dissemination and embedding of knowledge	The knowledge captured in the health-health mapping reports will support dissemination and communication efforts undertaken by the collaborator organizations making use of their networks. One particular option that will be explored will be support for uptake by newly established climate and health data platforms which may be developed through this and other relevant work.	

Heatwaves and Violence: A Case Study of El Salvador

Leads: Tamer Rabie, Lead Health Specialist; Health, Nutrition and Population (HNP) Global Practice, World Bank; Stephen Dorey, Public Health Specialist; Health, Nutrition and Population (HNP) Global Practice, World Bank; Aakash Mohpal, Senior Economist; Health, Nutrition and Population (HNP) Global Practice, World Bank

CHALLENGE

Heatwaves can evoke thoughts of ice-cream and swimming pools, but they can also make people angry, frustrated, and violent. Crimes against people peak in summer months (while property crimes peak in winter months).[1] Baseball pitchers hit batters more often on hot days[2] and higher ambient temperatures are correlated with subnational conflicts.[3] Machine learning models for predicting future violence are one potential tool to prevent incidents.[4] Predictive analytics can be leveraged by policymakers to prevent violence, and predictions of periods and episodes of violence can be incorporated in health system planning.

The Central American nation of El Salvador is highly prone to extreme heat hazard and has a strong history of subnational violence. Frequent gang wars have led El Salvador to claim the top spot globally in terms of murders per capita (61.7 per 100,000 people in 2017),[5] and the prevalence of gender-based violence (GBV) is also very high (third highest femicide rate in Latin America). Given the established links between heatwaves and violence, these social problems are likely to exacerbate in the future. The availability of more actionable evidence offers one way out. However, the paucity of reliable administrative data and costliness of survey data means that novel big data must be relied upon.

PROPOSED SOLUTION

To address the relationship between extreme heat events and violence, the team proposes to develop methods to estimate both variables. For violence, the team will examine social media data to identify incidences of violence in general, and GBV. These will be triangulated and cross validated with available data from traditional sources such as print media, GBV hotline, hospital records of violence and trauma. The team will employ natural language processing algorithms to translate tweets and social media posts to quantitative indicators for violence, alongside a probability of correct classification. Existing dictionaries will be used, and new ones will be developed as needed. The team will then analyze their relationship with daily temperature (while controlling by socioeconomic, political, and other confounding factors).

In addition, the team would analyze Google Trends data for people's online search behavior. The terms that people search in Google on the days with high temperature can indicate changes in their emotional state and their decisions. The team could also analyze data regarding human mobility (e.g., Google´s Community Mobility Reports) to learn about time use during times of extreme heat since it may give clues about averting heat practices. These complementary analyses will be aimed at identifying risk-reduction interventions best applicable to the El Salvadorian context.

The team intends to focus the analysis on El Salvador given the high prevalence of violence in the country as well as its heatwave risk hazard. Nevertheless, the results may be generalizable to other countries in the region that have similar socioeconomic and geographic characteristics. For example, the neighboring countries of the Honduras and Dominican Republic are the two countries that have higher rates of femicide than El Salvador. There are very few studies analyzing the link between climate and violence covering Latin American countries, and this work aims to help fulfil this evidence gap. Digital media give more people the tools to record and share their experiences of conflict and violence. Climate change may encourage more violence, and by directly examining individuals' reactions to heat, precautionary actions could be put into place, and physical violence and conflicts may be prevented.

Further Solution Details

- Hedonometer dictionaries: https://hedonometer.org/words/labMT-en-v1/

EXPECTED OUTPUTS

Output	Type	Description
Literature review of the relationship between heatwaves and violence, including GBV	Document	Summary of the literature (number of publications, by type, method use, source, country covered, etc.)
Geolocated tweets and social media posts organized per metropolitan area in LAC.	Code and data	Database with geolocated tweets and social media posts
Construction of Dictionaries in Spanish and Portuguese	Code and data	Violence episodes and their probabilities as identified from social media, triangulated, and cross-referenced from administrative data.
Estimates of temperature-violence relationship	Code and document	Econometric analysis with results tested for the whole region and by countries.
Policy recommendations	Document	Repository of policy alternative to adapt to consequences that can follow from psychosocial stress observed in social media due to heat and observed changes in behavior as derived from Google searches and people's mobility.

CONFIRMED AND SOUGHT COLLABORATORS

Following are confirmed and sought partners and resources for this

Type		Confirmed	Sought
	International Organizations	The World Bank's Regional Direction for Latin America and the Caribbean, Sustainable Development Practice Group: Staff Time and Link to Existing Project	
	Companies		• Twitter • Facebook • Google
	Government Entities	Ministry of Health, El Salvador	
	NGOs, Academia, Research Organizations		University of Bangor, Wales Brookings Institution Universidad de El Salvador
	Donor and Development Partners		Seeking donor support

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ADDITIONAL INFORMATION

#	Key Task	Description	Duration
1	Collection of social media data	A large corpus of Tweets and Facebook data will be retrieved using an appropriate API and relevant search parameters.	6 months
2	Collection of administrative data	Search and compilation of administrative data on violence in general and on GBV	2 months
2	Collection of weather data	Processing of daily satellite data from the ERA5 Reanalysis provided by the Copernicus Climate Change Service (C3S).	2 months
3	Collection Google searches and mobility data for days of extreme heat	Based on activity 2, process Google data to assess attempts and actual averting behavior during heatwaves	5 months
4	Data processing and analysis	Generation of indices and estimation of the daily impact of high temperature on the incidence of violence	3 months
5	Report findings	Write a final report with the main findings and policy recommendations.	3 months

Guiding Cool Infrastructure Planning to Mitigate Urban Heatwaves

Leads: Eric Mackres, Data and Tools Manager, Urban Efficiency & Climate, World Resources Institute (WRI) Ross Center for Sustainable Cities

CHALLENGE

From the slums of Dharavi, India to the suburbs of Lisbon, Portugal, unrelenting heat waves have surged in recent years. Climate forecasts indicate that this trend will only accelerate, causing devastating impacts on human health, the economy and social equity. Heat kills an average of 489,000 people globally annually (Zhao, Q. et al. 2021)—the single deadliest natural disaster in most years—and an additional 255,000 heat deaths are expected every year by 2050 (WHO 2014).

The choices we make on how we build our cities and other infrastructure can produce significant cooling--improving health, making cities more livable and equitable, saving energy, and saving lives. Infrastructure that cools cities—like solar reflective roofs, walls, and streets (ESMAP 2020, UNEP 2021), as a group referred to as "cool infrastructure"—is sorely under-utilized. By increasing reflectivity, cities can reduce air temperatures by 3 - 4°C or more (Ma et al. 2018; Santamouris 2014).

These passive cooling investments provide myriad benefits at net negative costs and without exacerbating climate change (as distinct from mechanized cooling interventions air conditioning). Cool infrastructure measures provide both climate mitigation and adaptation through the same low-cost actions.

While cool infrastructure has great potential, it's difficult for communities to plan, fund, deploy and track these solutions. Changes in urban surfaces are not being measured with methods that are repeatable, scalable, and broadly accepted, stifling finance of these solutions. Without these data and tools, adoption of cool infrastructure projects and policies will be too slow and costly to save lives.

PROPOSED SOLUTION

Building on our albedo and intra-urban heat hazard measurement work, we will develop a method to estimate the impact of cool infrastructure deployment on air temperature. This existence of this link has been established in general in the literature, but has not been parameterized for spatial modeling across a range of cool infrastructure strategies and urban geographies.

We will use a three-step approach to quantifying the impact. First, we will use data on the reflectivity of different materials as measured in laboratory settings. We will consider three types of cool infrastructure interventions as well as their combinations: roofs with reflective paint or membranes, walls with reflective paint or materials, and street surfaces with reflective materials or coatings. We will use these parameters to develop albedo measurements for a given set of cool infrastructure investments in an urban environment.

Second, we will take this analysis one step further and measure the impact of increased albedo on air temperature across cities. For the sample of cities identified in the first step, we assess the impact of changes in albedo on changes in air temperature, holding constant other changes in development and land use.

Third, we will combine these two measurement steps into a single approach that will allow us to input a cool infrastructure investment plan for a defined geography (e.g. paint 500m^2 of roof in a specific census tract with reflective paint) and receive back an estimate of the prospective reduction in surface air temperature. The tool will allow reliable comparison among plans and across geographic locations.

Further Solution Details

Resources from earlier iterations of WRI's approach to this topic:

- WRI Urban Heat Mitigation Github Repo
- WRI Los Angeles Surface Reflectivity App

EXPECTED OUTPUTS

Output	Type	Description
Surface reflectivity maps for 10 cities experiencing extreme heat risk	Open data layer	Open raster data layer available for download and visualized on a simple dashboard from each city in the study.
Method for scaling this work to other cities not included in the project	Code & training materials	Reproducible code, interactive code notebooks, and data methods for processing sensor data into raster datasets. Training materials for analysts to use data and code.
Temperature maps showing the impact of investments in cool infrastructure	Open data layer	Open raster data layer available for download and visualized on a simple dashboard from each city in the study.
Method for estimating the impact of cool infrastructure investment on experienced air temperature	Code & training materials	Reproducible code, interactive code notebooks, and data methods for processing sensor data into raster datasets. Training materials for analysts to use data and code.
Dashboard that helps planners model scenarios for cool infrastructure investment and the impact on experience air temperature	Dashboard, Code, Open Data & Insights	A simple dashboard (e.g. using Shiny or Streamlit) that allows users to provide a file with a cool infrastructure plan (e.g. paint 100 roofs in a neighborhood with reflective paint) and receive back and estimate We will also provide users with the reproducible code to adapt the dashboard for their own needs.

CONFIRMED AND SOUGHT COLLABORATORS

Following are confirmed and sought partners and resources for this Data

Type		Confirmed	Sought
	International Organizations		• World Bank's Global Facility for Disaster Reduction and Recovery team.
	Companies		• Maxar imagery • Planet imagery
	Government Entities	• Cities working with WRI's Ross Center for Sustainable Cities	
	NGOs, Academia, Research Organizations		• Adrienne Arsht-Rockefeller Foundation Resilience Center • Reflective Earth • Smart Surfaces Coalition
	Donor and Development Partners	• Foundational WRI work on this topic has been funded by Reflective Earth • Funding for related activities in the U.S. has been secured through the Smart Surfaces Coalition	• We seek funding to scale this work globally

CONTACTS

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Linking Urban Green Space to Heatwave Impact Mitigation

Leads: Brilé Anderson, Environmental Economist, Sahel and West Africa Club (OECD), Nicholas Jones, Data Scientist, GFDRR, World Bank; Eric Mackres, Data and Tools Manager, Urban Efficacy & Climate,WRI

Community members plant trees in Sierra Leone under the "Freetown the Treetown" campaign. **Photo credit: David Alieu**

CHALLENGE

As African cities urbanize, there is intense pressure on green spaces, including trees and greenspace, which deliver indispensable ecosystem services from sequestering carbon, disaster risk reduction from heavy rainfalls and floods, maintaining biodiversity, mitigating air and noise pollution, and critically, reducing impacts of heatwaves. Therefore, targeting the restoration of trees – in specific areas – can help communities cope with ongoing and future effects of climate change and heatwaves, along with improving the well-being of residents. This challenge seeks to develop a replicable methodology for establishing baseline information for planning and financing of urban greening initiatives, as well as baseline green space data for African cities.

PROPOSED SOLUTION

The team proposes to use the latest machine learning techniques and remote sensing data to create detailed maps of tree cover in African cities and generate ancillary indicators for green space contributions towards mitigating extreme temperatures.

Pilot work by the Global Facility for Disaster Reduction and Recovery (GFDRR) and World Bank Urban and Disaster Risk Management Africa team has produced high-resolution maps of tree canopy in Dar Es Salaam and Freetown using machine learning and training data created by local youth. The World Resources Institute has developed a global, medium-resolution tree cover model and dataset that is relevant to many urban applications. These tree canopy maps provide a baseline to plan and monitor urban greening initiatives. This challenge seeks to expand these approaches by working with external collaborators on creating urban tree canopy maps with remote sensing data and machine learning techniques, as well as generating accompanying indicators on the potential impact of these green spaces on mitigating extreme temperatures.

The project will provide the first comprehensive mapping and assessment of urban tree canopy to inform greening initiatives in African cities. The maps will be made publicly accessible online via an open data portal. They will be used to inform policy dialogue with the OECD and World Bank investment financing.

EXPECTED OUTPUTS

Output	Type	Description
Foundational Datasets	Data and Documentation	Remote sensing images (Sentinel-1 & 2, Maxar, Planet), methods for access through cloud catalogs or APIs, and, if needed, procedures to obtain permissions for access.
Code for Identifying Urban Greenspace and Accompanying Indicators	Code and Documentation	Reproducible code, interactive code notebooks, and data methods for efficiently producing urban greenspace maps in Africa and generating statistics. For example: https://github.com/datapartnership/mobilkit
Derived Urban Greenspace Maps for 40 African Cities	Dataset	High resolution tree maps in cities made available online (via the OECD GeoFragilities platform and World Bank Development Data Hub)
Global 10-meter resolution tree cover map	Dataset	WRI's medium-resolution, open source tree cover data product [Trees in Mosaic Landscapes]() (currently available for 2020 for all of Africa) is improved and made available through additional distribution channels and used as a source for indicators.
Report based on indicators generated from global and African city maps	Indicators and report	Assessment of tree cover related disparities between and within cities, including disaggregation by land cover / land use and socio-economic characteristics and estimates of heat wave mitigation impacts
Training Materials	Training Materials	Training materials distributed by participating international organizations to incentivize and support urban planning departments to quantify urban greenspace and generate heatwave impact mitigation measures.
Tree-Mapping Hackathon and Implemented Data Goods Repository	Community Building	Invite activist and urban planner data scientists from cities across different continents to contribute towards a global tree mapping hackathon, using datasets and methodologies provided through the Collaborative to contribute towards a shared repository of urban greenspace and heatwave impact mitigation datasets and indicators.

CONFIRMED AND SOUGHT COLLABORATORS

Following are confirmed and sought partners and resources for this Data

Type	Confirmed	Sought
International Organizations	• Global Facility for Disaster Reduction and Recovery (World Bank) • Sahel and West Africa Club (OECD) • European Space Agency	
Companies		• Remote Sensing Data Provider (e.g., Maxar, Planet) • Facebook Spatial Computing Team (technical mentorship) • Compute Credits • Data Engineering Resources • Hosting Support (e.g., AWS, MS Planetary Computer) for Shared Results Repository.
Government Entities	• Freetown City Council (Sierra Leone)	• City government of Kinshasa, Democratic Republic of Congo
NGOs, Academia, Research Organizations	• World Resources Institute • Resilience Academy (Tanzania) • Sokoine University of Agriculture (Tanzania)	• Swiss Federal Institute of Technology in Zurich (ETH Zurich) • For testing method in South Asia, The Nature Conservancy India
Donor and Development Partners	• GFDRR: 50% cost of ML specialists	• Funding to support production of Data Goods, training materials, and community building activities

CONTACTS

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Using Solar Energy to Build Heatwave-Resilient Energy Systems

Leads: P Bhanumati, Senior Economist, Statistics Department, IMF

CHALLENGE

The household sector accounts for a significant share of primary energy use. As the world seeks to significantly reduce greenhouse gas emissions by 2030 and eliminates net greenhouse gas emissions by 2050, households will need to transition away from their use of fossil fuels. The transition to renewable energy sources will require significant investment by governments and households alike over the next several years. Governments will need to incentivize households to reduce their carbon footprint from their consumption of transportation and housing services. Households, on their part, must make these investment decisions in times of highly volatile energy prices. Currently, there is a lack of indicators that c**onsider households income inequality** in tracking household progress towards reducing their carbon footprints and the barriers to the progress in terms of households' affordability of transition to renewable energy sources.

On the other hand, it is essential to look at building adaptive capacity, especially for the household sector, in the face of increased frequency of extreme events like heatwaves. **Warmer temperatures increase households' electricity reliability and affect many aspects of the energy system, including production, transmission, and demand.** In addition, they can reduce the thermal efficiency of power production, which makes it difficult for power plants to comply with environmental regulations regarding the temperature of their cooling water and could lead to plant shutdowns. Examples are available of governments on pursuing energy efficiency to reduce demand on the electricity grid, especially during heat waves. A recent case of California handling the energy crisis during a heatwave is an example of how **governments can plan to enhance the adaptive power capacity by going the solar way**.[1] As an added benefit, the increase in solar radiation due to heat waves has boosted the solar energy output in many countries, with Germany recording the highest solar power output. It is, however, important that technologies are developed to make solar panels as relevant for the extreme weather conditions likely to exist in the region.

The need of the hour is **to build data systems that can inform on the progress and barriers for the transition towards heatwave-resilient energy systems.**

PROPOSED SOLUTION

To assist local, state, and federal governments to better understand households' adaptive capacity to handle heat waves using solar energy, the team proposes to develop two household renewable energy serviceability indexes. One index will represent the percentage of dwellings in a certain spatial grid provided with rooftop solar panels given the solar resources available[2]. Current research indicates a negative correlation between relative income levels and solar panel adoption.[3] Based on census data and general information on the investment cost of rooftop solar panels,[4] a second index reflects on a grid basis the (average) solar panels investments to income ratios given the risk of heatwaves in the region. This index may indicate those areas where household income levels are obstructing solar panel investment without government support. Both indexes can be used by local, state, and federal governments to develop **geographically targeted policies** to assist households in making the necessary behavioral changes required to reduce their carbon footprints, while also adapting for the heatwave-ridden future. The geographic scope of the analysis will be contingent on resources provided for this work.

In coordination with other efforts under the Heatwaves Data Collaborative, the team will also develop a methodology to determine the extent to which increased reliance on solar energy in a given area may mitigate pressures on the electricity grid during a heatwave.

1. https://www.forbes.com/sites/energyinnovation/2022/09/19/how-clean-energy-kept-californias-lights-on-during-a-historically-extreme-heat-wave/?sh=3ad4c7e146bb
2. Global Solar Atlas 2.0: Technical Report (English). Energy Sector Management Assistance Program Washington, D.C.: World Bank Group. http://documents.worldbank.org/curated/en/529431592893043403/Global-Solar-Atlas-2-0-Technical-Report
3. Sunter, D.A., Castellanos, S. & Kammen, D.M. Disparities in rooftop photovoltaics deployment in the United States by race and ethnicity. Nat Sustain 2, 71–76 (2019). https://doi.org/10.1038/s41893-018-0204-z
4. https://sites.energycenter.org/solar/homeowners/cost

EXPECTED OUTPUTS

Output	Type	Description
Key indicators		
Solar panel density	Open Dataset	Percentage of dwellings in a pre-defined spatial grid (e.g., H3) provided with rooftop solar panels.
Solar investment to income ratio	Open Dataset	The projected required investment in solar panels given the solar resources and the heatwave risk profile divided by the average (or median) income of households in a certain grid.
Derived indicators, Analyses and Training		
Renewable energy potential	Dataset	The amount of renewable energy production (in kilowatts per time unit) by full adoption, given the current solar panel density and solar resources in a certain grid. This analysis would require additional data on household energy consumption and renewable energy generation (in quantities).
Income effects of solar energy adoption (longer term)	Dataset	(non)renewable energy cost related to the average or median income in a grid. This analysis would require additionally data on household energy consumption and renewable energy generation (in money terms).
Training materials	Training Materials	Training agenda, slides, and script for use in disseminating methods. Materials to be posted on the Development Data Partnership website.

CONFIRMED AND SOUGHT COLLABORATORS

Following are confirmed and sought partners and resources for this Data

Type		Confirmed	Sought
	International Organizations	• The IMF Fiscal Affairs Department to assist in the development of a clean energy pricing model.	
	Companies	• Mapillary: street view imagery to model building energy requirements and clean energy production.	• Google: Provide clean energy potential and energy requirements, data science services, etc.; Expand on the heatwave forecasting to derive the risk profiles for each grid.; Compile weather data to build and provide country's risk profile. • SpaceKnow: To provide data on energy requirements. • Microsoft: Provide cloud services and data science services. • Data on evolution of cost of solar panels, complete investment required to set up a solar panel equipment+ implementation. • GroundTruth Ground truth data. • Survey companies such as Premise to complement data on income and affordability of solar panels. • Tomorrow.io: Weather data (historic and forecasting) to build and provide a country's risk profile.

Type	Confirmed	Sought
Government Entities		• Census of household income, energy usage, household address. • National statistical offices (NSOs) from selected pilot countries with existing solar capacity (e.g., Australia, China, Germany, South Africa, U.S.) • Electric Utilities in pilot countries to understand program feasibility vis-a-vis local regulations.
NGOs, Academia, Research Organizations		Researchers associated with J-PAL may be interested in testing multiple interventions to encourage adoption of rooftop solar. See for instance, ongoing work of Teevrat Garg (UC San Diego) in a city in south India (Bangalore).
Donor and Development Partners		*Donor support requested*

CONTACTS

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ADDITIONAL INFORMATION

#	Key Task	Description
1	Acquire and process data	Acquire, store, pre-process, and document challenge data, including transportation emissions, building footprints, photovoltaic power potential, household income by census tract, household photovoltaic power production, clean energy production, clean energy prices.
2	Set up collaborative coding environment	Facilitate legal and technical requirements to facilitate code collaboration
3	Build model and assemble indicators	Coordinate collaborators to build, test, and validate a household clean energy expenditure model.
4	Test model and seek feedback.	Coordinate model and dataset peer review; finalize model documentation and post it on shared code repository.
5	Disseminate indicators on various platforms and update on an annual basis	Work with various dissemination platforms to share indicators and disseminate data and metadata (e.g., IMF (International Monetary Fund) Climate Indicators Dashboard, EIE (Environmental Insights Explorer), Climate Trace...)
6	Prepare and disseminate training materials	Design training curriculum (handouts, slides, script, code, sample dataset) and disseminate through the Development Data Partnership.

White Roofs for Safer Schools: Should We Paint all Classroom Roofs White to Improve Learning?

Leads: Edward Anderson, Team Lead Digital Earth Partnership in GFDRR, World Bank; Jamie Proctor, Tanzania Country Lead for EdTech Hub

CHALLENGE

A growing literature base has been developed from Global North contexts, showing a clear link between classroom temperature and student learning outcomes. However, very little evidence shows how this impact translates to low- and middle-income countries (LMICs), where average classroom temperatures are often high.

Research in 2022 by the EdTech Hub shows that classroom temperatures in Tanzania are high and that a white-paint-cool-roof intervention would help mitigate these high temperatures. The study reviewed classroom policy in Tanzania, established links between temperature and learning, and assessed temperature retrofit options. Empirical evidence of temperatures inside classrooms in Dar Es Salaam suggests that the temperature often exceeds 40°C. Literature searches indicate that this is the first-time classroom air temperatures have been recorded and published for East Africa.

A further experiment involved using a low-cost retrofit intervention to reduce temperature – by painting the classroom roof blue or white over eight days. Results showed that the White Paint Intervention (WPI) reduced the temperature by around 3.7°C over the course of the school day and up to a maximum of 5°C. The White Paint Intervention was roughly twice as effective as Blue Paint Intervention at reducing interior air temperatures. The WPI results were then modelled to estimate the classroom temperature reduction over a year, based on the assumed 3.5°C reduction. Using estimates from the existing literature, the learning impact of the intervention was calculated. The results suggest that using the White Paint Intervention can improve learning by 7.1%, which translates to an estimated 3.2 Learning Adjusted Years of Schooling (LAYS) per classroom per year, at a cost-effectiveness of 5.3 LAYS per USD100.

This challenge aims to develop a methodology for measuring and ranking the potential efficacy of heatwave / heat stress mitigation in schools using White Paint Intervention to model expected costs and benefits in terms of Learning-Adjusted Years of Schooling (LAYS) metric. The WPI is expected to also include climate co-benefits for child health (reduced heat stress) as well as climate change mitigation (reduced energy need for cooling).

PROPOSED SOLUTION

So far, pioneering groundwork has been done by EdTech Hub in Tanzania to demonstrate the mitigation efficacy of White Paint Intervention (WPI) on School Heat stress in terms of indoor classroom air temperature reductions. These temperature reductions are in turn correlated with learning outcomes. The challenge lies in scaling up the datasets to apply this analysis to a larger set of schools and categorizing the most promising school roofs for WPI. In Tanzania alone there are over 20,000 primary school buildings and over 5000 secondary school buildings without local air temperature data.

The proposed solution aims to collect satellite-based data for the entire school buildings portfolio in Tanzania to include roof temperatures, ground surface temperatures, and building and roof typologies and roof conditions.

An appropriate set of ground truth data are to be collected to support the training of a predictive model that can estimate: i) classroom volumes; ii) classroom building roof type; iii) Classroom air temperatures; iv) Potential WPI cooling benefits; v) Modelled LAYS benefits; vi) Expected WPI costs.

EXPECTED OUTPUTS

- **Open Data.** School locations, aggregated examination results, building and roof classification schemas, classified roof typologies, modeled and actual indoor air temperatures.
- **Proprietary Data.** High resolution imagery (satellite or drone) is required to classify school building roofs. A range of sources are expected. Commercial imagery may be purchased but the underlying imagery is likely restricted in it redistribution – but the right to distribute derived products with an open license is preferred. Existing proprietary imagery such as google earth may potentially be used for feature extraction or validation.
- **Code.** GIS analysis of roof types. AI classifier for classroom volumes, classroom roof types and condition, indoor air temperature prediction.
- Datasets and Insights. Examples of Data Good implementation for specific countries and time periods, posted on GitHub.
- **Training Materials.** Hands-on curriculum materials for capacity building and guiding university students in Resilience Academy on building the component image classifiers and using the WPI ranking tool.
- **Global Report** presenting the evidence and advocating for WPI interventions in heat stress affected schools.
- **Tanzania Report** estimating specific costs and benefit for UK AID and Tanzania Ministry of Education

EXPECTED OUTPUTS

Output	Type	Description
School Roofs in Tanzania	Database of approximately 20,000 school roof shapes, locations and material type and color	Modelled estimates of roof shape, size, material, colour, in GIS database (Shape files) with attributed estimated by AI or derived from ground truth.
School Indoor Air Temperatures	Database of max classroom air temperatures by school building	Modelled estimated of indoor air temperatures for school buildings derived from model using satellite roof temperature measurement, extern air temperature estimate, and sample of indoor classroom temperature measurements.
In Situ Classroom temperatures	Time series data of air temperature readings for selected school	Collected during the summer months by local digitization campaign to capture max indoor air temperatures.
Assessment of White Paint Intervention Heat stress reduction and education outcome benefits	GIS Map of school locations color coded according to ranking	An online map with data layers showing school locations, estimated heat stress levels, cost of WPI, benefits of WPI in terms of heat stress reduction/ cooling, Rank as $/degree temperature reduction and rank $/LAYS.

For further solution details:

- Proctor, J. Research paper (2022), EdTech Hub, “Should we paint all classroom roofs white to improve learning in Tanzania?” Online at: https://docs.edtechhub.org/lib/Z8B66R9X
- Fab Inc (led by Paul Atherton)
- Laterite (led by Dimitri Stoelinga and Ravina Pattni)
- Open Development & Education (ODE) (led by Taskeen Adam and Bjoern Hassler)
- The ESMAP Primer for Cool Cities summary of good practice initiatives on cool roofs/white roofs that have been initiated by the Global Cool Cities Alliance. GCCA

CONFIRMED AND SOUGHT COLLABORATORS

Type		Confirmed	Sought
	International Organizations	**World Bank's** Digital Earth Partnership: Staff Time and Link to Existing Project	**World Bank's** GFDRR Safer Schools Program and Education GP WFP
	Companies	**Laterite:** in -situ measurement of classroom experience data (including temperature) **Open Development & Education (ODE):** Trialling roof painting and other temperature reduction activities in Tanzania	**Satellite Data provision: space based surface temperatures at school locations** **Satellite Data: Optical high resolution imagery of classroom buildings for roof classification** **Observational Data**
	Government Entities	Government of Tanzania has an existing MoU with EdTech Hub and Education sector program with FCDO/UKAID	**Tanzania Ministry of Education:** School Locations and examinations results data **Tanzania Meteorological Agency**
	NGOs, Academia, Research Organizations	**EdTech Hub:** project management, coordination and research provided by four staff. **University of Dar es Salaam:** research support and provision of students on industrial placement to support data collection and manual labelling **Fab Data IO:** Analysis of temperature data with school examination	**Resilience Academy Tanzania:** support to conduct in-situ data collection and training dataset curation and labelling – financing of $100,000 needed to deploy 250 students for 10 weeks digitization campaign. Global Cool Cities Alliance, GCCA **J-PAL** for an impact evaluation that measures relative cost effectiveness as well as the short and long-term impact on student health and learning outcomes.
	Donor and Development Partners	**UK AID:** $280,000 financing of Tanzania based research and education data analysis and advice provided by Senior Education and Climate Adviser	Seeking financial support for the scale up data acquisition, analysis and global research

CONTACTS

For further information about this challenge, contact:

- **Edward Anderson,** eanderson1@worldbank.org

Greening of Informal Settlements: A Guidebook and Cost-Benefit Assessment Methodology

Leads: Nicholas Jones, Data Scientist, Global Facility for Disaster Reduction and Recovery (GFDRR) World Bank

CHALLENGE

Many cities show a marked disparity in vegetation cover and heat stress between rich and poor neighborhoods. In African cities such as Johannesburg, informal settlements have vegetation cover of less than 15% floor area, compared to 40-65% in many prosperous residential suburbs. Taking the example of South African cities, tree planting initiatives (such as those undertaken ahead of the 2010 World Cup) have helped redress the historical gap in urban vegetation known locally as ‘green apartheid’. However, a marked gap remains. A recent Urban Heat Assessment study found that townships such as Soweto and Alexandra may see 100 or more hot nights per year by 2050 compared to just 40 in leafy residential suburbs. In response, municipal governments are seeking to increase tree cover in informal settlements – a measure that is expected to help reduce health and economic impacts of future heatwaves.

Just like Johannesburg, many developing cities face marked disparities between green cover in informal settlements compared with more prosperous neighborhoods, while also sharing the need for tools and resources to advance greening of such areas. Greening of informal settlements faces challenges of limited space, a harsh physical environment limiting species choices, threats to tree survival, and need for community buy-in. Advantages of expanding green assets outweigh costs, but city leaders and citizens’ associations often lack hard evidence on costs & benefits and on effective operating models.

PROPOSED SOLUTION

This engagement will develop a Resource Kit on urban greening on informal settlements and marginalized urban communities based on pilot activities to be conducted in the cities of Johannesburg and Ekurhuleni. It will comprise three activities:

1. Guidebook: Urban greening diagnostics. Using South African cities as a pilot case, this activity will develop and test a methodology to develop locally-specific Greening Action Plans on greening of informal settlements. The diagnostic is expected to include sections on: (i) institutional setting and community engagement; (ii) baseline mapping of green assets; (iii) success and risk factors for plant survival; (iv) table of suitable species and their needs/characteristics; (v) operating model for establishment; (vi) operating model for tree care and maintenance; (vi) unit cost estimates (capital and recurring).

2. Methodology: Quantifying heat stress reduction benefits. Building on recent work, this activity will quantify benefits of a package of urban greening measures in Johannesburg and/or Ekurhuleni, demonstrating a methodology that can be replicated in other cities. The proposed approach is to identify a 'business-as-usual' case (no greening intervention) and an 'intervention' case (planting of green assets). A participatory web-mapping tool will be developed for definition of the intervention case. Extending previous work on high-resolution urban climate modeling, a suite of climate indicators will be produced for each case. The indicators will include mean temperatures, number of heatwave days per year, and number of hot nights per year. This will be done for future climate scenarios (eg. 'optimistic' scenario SSP1-1.7 and 'pessimistic' scenario SSP3-7.0). This pilot expects to demonstrate heat stress reduction benefits from the urban greening measures.

3. Greening Action Plan (first pilot). A first Greening Action Plan will be developed for a local area agreed with the municipal government utilizing the methodologies described above. This costed set of interventions will be submitted for financing consideration from climate finance sources.

Further Solution Details

This work will build upon a 2-year engagement with the Cities of Johannesburg and Ekurhuleni in South Africa as described in the following documents:

- Urban heat in Johannesburg and Ekurhuleni, South Africa: A meter-scale assessment and vulnerability analysis (paper published in Urban Climate journal).
- Beating the Heat in South African Cities (World Bank blog).
- South Africans making heat maps of their cities (video)

The focus on greening of under-resourced communities was specifically identified in a workshop with the cities. The City Resilience Program is active in cities worldwide that face similar challenges with greening of dense and marginalized urban neighborhoods; this work therefore presents high impact and scalability potential by addressing key barriers to heat stress reduction in vulnerable urban communities.

EXPECTED OUTPUTS

Output	Type	Description
Guidebook: Urban Greening Diagnostics	Knowledge product	A guidebook for community associations, city leaders and urban specialists with a clear conceptual framework, curated best-practice examples, and step-by-step guidance on creating local Greening Action Plans in informal settlements and marginalized urban areas.
Methodology	Code and documentation	Code for calculating urban green space impact scnearios.
Web tool	Code for and implementation	Code for creating an online web tool for creating urban green scenarios as open geospatial datasets as an input for climate modeling and implementation. Or (subject to feasibility checks): A web tool for rapid estimates of urban greening impacts on local heat stress.
Methodology paper	Knowledge product	A scientific paper documenting the climate modeling approach used to evaluate 'business-as-usual' vs. 'urban greening' scenarios.

CONFIRMED AND SOUGHT COLLABORATORS

Following are confirmed and sought partners and resources for this Data

Type		Confirmed	Sought
	International Organizations	• Digital Earth Partnership (GFDRR) • City Resilience Program (GFDRR)	• ESA GDA Knowledge Hub
	Companies	• VITO (climate modeling expertise)	
	Government Entities	• City of Johannesburg Metropolitan Municipality • City of Ekurhuleni Metropolitan Municipality	
	NGOs, Academia, Research Organizations	• PlanAct (expertise in community engagement in informal settlements)	• Johannesburg Botanical Garden (expertise in tree species suitability assessment)
	Donor and Development Partners	• Digital Earth Partnership (GFDRR) • City Resilience Program (GFDRR)	

CONTACTS

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Quantifying the Impact of Climate Investment Opportunities in South Asia's Cooling Sector

Leads: Mehul Jain, Climate Change Specialist, South Asia Disaster Risk Management and Climate Change Unit, World Bank
Asmita Tiwari, Senior Urban and Disaster Risk Management Specialist, South Asia Disaster Risk Management and Climate Change Unit, World Bank

CHALLENGE

Severe heatwaves, responsible for thousands of deaths across South Asia over the last few decades, are increasing with alarming frequency. This spring, triple-digit (Fahrenheit) temperatures scorched India and Pakistan, while Bangladesh and Sri Lanka sweltered under unusually high heat. A recent study shows that the recent heatwave across India and Pakistan was 30 times more likely compared to a century ago. In India, the heat wave in April 2022 brought the country to a standstill, with temperatures in the capital, New Delhi, topping 46°C, highest recorded. Climate models have projected that change in temperature by the end of the 21st century relative to 1901–1960 could be as high as 5°C in India, where projected temperatures could exceed the survivability threshold at a few locations. Warming trends, population growth and rapid urbanization require urgent attention to cooling strategies that will not only save lives but safeguard hard-fought gains in poverty reduction and economic growth.

Cooling has become a development challenge that is not only an immediate threat to the economy of the SAR countries but is jeopardizing the health and livelihoods of many, particularly in the urban areas owing to the severe impacts of the urban heat island (UHI) effects. The current and projected cooling access gap can impede achievement of the developmental and climate goals. For example, lost labor from rising heat and humidity could put up to 4.5 percent of India's GDP – approximately US $150 – 250 billion – at risk by the end of this decade. Pakistan and Bangladesh could suffer losses of up to 5% of their GDP. Pakistan, still reeling from a deadly flood season, is expected to lose more than 5.5 percent of working hours in 2030 from excessive heat which will exacerbate migration.

PROPOSED SOLUTION

Countries across South Asia are showing an unprecedented increase in the demand for cooling across sectors, including thermal comfort in buildings. In recent years, cooling as a core element of its development strategy has become an urgent priority for the Government of India. In 2019, India became one of the first countries in the world to launch a comprehensive cooling action plan, the India Cooling Action Plan (ICAP), an ambitious response to address the country's cooling needs while reducing climate impacts. In June 2022, Bangladesh published its own National Cooling Plan while Pakistan recently announced it will adopt one by 2026. For a region that could face the worst effects of future heatwaves, South Asia now is at a crossroads.

It is critical to develop actionable roadmaps to implement the action plans aimed at providing thermal comfort for all, particularly in the urban areas in the region. Data-driven active and passive cooling solutions need to be integrated in the construction practices and urban planning that allow a sustainable development pathway for the rapidly urbanizing areas. While the actions undertaken thus far present a promising picture, there are significant challenges to realize the cooling goals to face the heat stress. These includes lack of data to assess and identify the gaps, priority actions and strategic investments across the cooling sectors. Additionally, there is a need to fill the data gaps to be able to accurately assess the benefits incurred through the investments and initiatives.

In case of India, the team has already developed an actionable roadmap, prioritizing eight key intervention areas where with the help of concessional finance, the market for cooling and cooling related efficient, affordable, scalable technologies can be created. Through this intervention, the team will work towards identifying the impact of an investment.

Availability of granular data is a critical element in the two-pronged approach to strengthen and assess the climate and development efficacy of actions in the urban cooling sector particularly considering its multisectoral nature.

The key components of data assessment outputs would include the quantification of benefits incurred per dollar spent and the associated development and climate co-benefits generated through the measures.

Further Solution Details
Relevant background documents:

- Ahmedabad Heat Action Plan
- India Cooling Action Plan
- Climate Investment Opportunities in India's Cooling Sector

EXPECTED OUTPUTS

Output	Type	Description
Narrowed Scope of Cooling Measure Interventions	Literature Review	Identify cooling investments that have demonstrated the most promise in South Asian countries, and for each, breakdown approximate investment costs and expected impacts.
Relative Costs and Impacts of Cooling Measures	Dataset	Prepare comparable datasets on cooling intervention measures, their costs, and relative impacts. Will include clearly documented assumptions and limitations of the dataset.
Method for Urban Benefit-Cost Anlaysis of Cooling Measures	Methodology	Develop method a city can use to prepare a benefit-cost of different cooling interventions in the short-, mid-, and long-term, with a focus on Sout Asian cities.

CONFIRMED AND SOUGHT COLLABORATORS

Following are confirmed and sought partners and resources for this Data

Type	Confirmed	Sought
International Organizations	South Asia Urban Resilience Team; World Bank	• ESMAP team, World Bank
Companies		• Facebook (Replicating methodology for Electricity Grid Maps) • Earthmetry (electricity consumption data for India)
Government Entities		
NGOs, Academia, Research Organizations		
Donor and Development Partners		

CONTACTS

For further information about this challenge, contact:

- **Mehul Jain:** mjain4@worldbank.org
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Heatwave Alert and Two-Way Learning for Highly Adaptive People

A heatwave early warning system, pathways for learning, and amplified voices for people living in slums

Leads: Jean-Louis Ecochard, Global Head of Innovation; NetHope

CHALLENGE

According to the United Nations, one billion people live in slums. It is predicted that by 2030, 1 in 4 people on the planet will live in slums. As defined by UN-Habitat, a slum is a run-down area of a city characterized by substandard housing, squalor, and lacking in tenure security. There are 5.7 million people living in the 5 largest slums (Orangi Town in Karachi, Pakistan: 2,400,000, Neza, Mexico: 1,200,000, Dharavi in Mumbai, India: 1,000,000, Kibera in Nairobi, Kenya: 700,000, Khayelitsha in Cape Town, South Africa: 400,000). SDG 11 report that "Empirical analysis shows that a 1 per cent increase in urban population growth will increase the incidence of slums by 2.3 per cent and 5.3 per cent in Africa and Asia, respectively." and concludes that "To achieve the Sustainable Development Goals, the world's 1 billion slum dwellers must be given the support they need to lift themselves out of poverty and live free from exclusion and inequality."

For people living in slums, a tiny change in living conditions, such as a heatwave, results in exceedingly high negative impact to their already vulnerable economies and health conditions. Rising temperature represent deadly threats to slum dwellers. Although slum dwellers are highly adaptive people, they need know when heatwaves are coming and how to respond to them.

PROPOSED SOLUTION

The proposed Heatwave Alert and Two-Way Learning for Highly Adaptive People aims to minimize the health and economic impact of heatwaves on people living in slums by giving them early warning systems, learning pathways for adaptation and resilience, and a mean to be heard and inform policy makers on their lived experiences.
In alignment with the Principles for Digital Development Principles, solutions will be co-designed with slum dwellers, for them, merging their lived experiences with the expertise of the tech sector.

The work will be led by the NetHope network of nonprofits and the communities they serve, NetHope tech partners, and national and local governments, in coordination with an international development organization partner (tbd).

The early warning system will leverage current solutions produced through other streams of activities in the Heatwaves Data Collaborative and adapt these information streams by co-creating solutions fit for the lives and context of people living in slums.

EXPECTED OUTPUTS

The proposed Heatwave Alert and Two-Way Learning for Highly Adaptive People has four principal outputs:

Convening a Community of Interest: Convening of NGOs, governments, tech companies and slum communities about heatwave early warning, pathways for learning and amplified voices.

Early Warning System: A method to provide early warning of heatwaves to slum communities. This will likely consist of code that will take existing heatwave alert data streams and adapt them to the context of slum dwellers.

Learning Pathways for Adaptation and Resilience: A toolkit of optional action on heatwave adaptation and resilience that is adapted to local communities of slum dwellers and designed to enable full self-determination. This will consist of a series of training modules to create capacity building capabilities and optionality of actions by slum dwelling communities, all based on the outputs of the Heatwaves Data Collaborative.

Amplified Voices: A platform to record and amplify the voices of slum dwellers. This will consist of a process to record voices and videos of slum people by local NGOs and post them onto a publicly available sharing platform (TBD).
Further Solution Details

- Humanitarian Principles: The four guiding principles are Humanity, Neutrality, Impartiality and Independence.
- Principles for Digital Development.
- AI and Ethics.
- Sphere humanitarian standards

CONFIRMED AND SOUGHT COLLABORATORS

Type	Confirmed	Sought
International Organizations	Time and Link to Existing Project **UNICEF** program focused in urban slums **UN Habitat** slum upgrading programme	The World Bank's Urban and Rural Development Global Practice: Staff
Companies	**Avanade:** Ideation, design thinking **Microsoft:** Solutions & Data integration, and climate adaptation and resilience **Salesforce:** Climate adaptation and resilience	Firm that specializes in A/B testing in public warning systems, such as: GMMB.
Government Entities	Governments of India, Kenya, Mexico, Pakistan, and South Africa, including local governments for the towns of Cape Town, Karachi, Mumbai, and Neza.	Seeking support
NGOs, Academia, Research Organizations	**NetHope** and its network of more than 60 international humanitarian nonprofits working in 190 countries	Confirmed
Donor and Development Partners	**Skoll Foundation** (Slum Dwellers International) **Bill and Melinda Gates Foundation** **Hope Foundation** **Seed Foundation** **EXO Foundation**	Seeking support

CONTACTS

For further information about this challenge, contact:

- **Jean-Louis Ecochard:** jean-louis.ecochard@nethope.org

Annex 1
Collaborators

Advisory Group

Advisory Group	Bio
Alex Chunet Representative to the World Bank, European Space Agency	Alex Chunet is the European Space Agency Representative to the World Bank and supports the coordination of activities implemented under the ESA-World Bank partnership and in particular the ESA GDA programme. He previously worked for the World Bank from 2017 to 2020 as a geospatial data scientist and contributed to the deployment of earth observation technologies and their application and adoption within World Bank operations and analytical pieces. Subsequently, he also led the development of the first geospatial strategy of the Agence Française de Développement (AFD) from 2020 to 2021.
Aparna Keshaviah Principal Researcher, Mathematica	Aparna Keshaviah has two decades of experience bringing advanced analytics and innovative data sources to clarify urgent public health questions. Keshaviah's recent research focuses on the intersection of population health and environmental health. She designed and developed Mathematica's ClimaWATCH tool, which helps communities assess climate-related vulnerability by providing a framework to explore how heat waves have affected health and magnified inequity. She has also directed environmental justice projects aimed at helping clinicians, patients, and communities recognize and address the adverse health issues associated with environmental exposures. Her research has been widely published in leading journals such as the New England Journal of Medicine, JAMA Psychiatry, and Environmental Health Perspectives. She is a 2006–2007 Fulbright fellow and holds a master's degree in biostatistics from the Harvard School of Public Health.
Aparna Krishnan Project Director, J-PAL South Asia	Aparna Krishnan is a Project Director, J-PAL South Asia and leads a portfolio aimed at strengthening the use of administrative data for evidence-informed policy making under the global Innovations in Data and Experiments for Action (IDEA) initiative at J-PAL. In her role, she engages extensively with state and national government partners, technology and data experts, researchers and international organizations in India and internationally to establish new research and policy partnerships that leverage existing and new forms of data for impact evaluations. She has a Masters in International Policy from the University of California, San Diego and a Masters in Economics from Gokhale Institute, India.

Advisory Group	Bio
Daron Bedrosyan Energy Specialist, World Bank	Daron Bedrosyan is an energy specialist in the World Bank's Energy Sector Management Assistance Program (ESMAP). His work focuses on the Regulatory Indicators for Sustainable Energy Index in the ESMAP Energy Analytics Hub and technical assistance funding for Coal Transition and innovative solar projects. He is a graduate of Queen's University and the University of Toronto's Munk School of Global Affairs.
David Rogers President, Health and Climate Foundation (HCF)	Dr. Rogers is President of the Health and Climate Foundation (HCF), an international non-profit organization dedicated to finding solutions to climate related health problems and supporting partnerships between health and climate practitioners. Prior to founding HCF, Dr. Rogers held various appointments in government, the private sector and academia. These include Chief Executive of the UK Met Office; Vice President, Science Applications International Corporation; Director of the Office of Weather and Air Quality at the US National Oceanic and Atmospheric Administration; Director of Physical Oceanography at Scripps Institution of Oceanography, and Associate Director of the California Space Institute, University of California, San Diego, USA. Currently, Dr. Rogers is a senior advisor to the World Bank.
Katie McWilliams Geographer, World Bank	Katie McWilliams is a geographer with the World Bank Group, where she incorporates geospatial data and analytical insights into development projects. Her work encompasses a variety of sectors, from climate change to urban development to transportation. She holds an MA in Geography from George Washington University and a BS in Meteorology from Ball State University.

Problem Statement Authors

Each of the authors contributed to problem statements in the following categories:

R Measuring Risk and Occurrence of Heatwaves
I Measuring Heatwave Impacts across Sectors
M Quantifying Efficacy of Mitigation Measure
C Capacity Building

Author	Problem Statements	Organizations
Aakash Mohpal	I2, I3	Senior Economist, **Health, Nutrition and Population (HNP) Global Practice, World Bank**
Asmita Tiwari	M6	Senior Urban and Disaster Risk Management Specialist, **South Asia Disaster Risk Management and Climate Change Unit, World Bank**
Benny Istanto	R1	Geographer, **Development Data Group; World Bank**
Brilé Anderson	M2	Environmental Economist, **Sahel and West Africa Club, OECD**
C. MacKenzie Dove	R5, R6	Technical Climate Consultant, **Climate Change Knowledge Portal (CCKP), World Bank**
Caspar Ammann	R5	Climate Consultant, Climate Strategies Group and **Climate Change Knowledge Portal (CCKP), World Bank**
David Rogers	R4	Lead Meteorological Consultant, **GFDRR**, World Bank
Edward Anderson	M4	Team Lead Digital Earth Partnership in **GFDRR**, World Bank
Eric Mackres	R2, R3, M1, M2	Data and Tools Manager, Urban Efficacy & Climate, **World Resources Institute** (WRI) Ross Center for Sustainable Cities
Jamie Proctor	M4	Tanzania Country Lead for **EdTech Hub**
Jean-Louis Ecochard	C1	Global Head of Innovation; **NetHope**

Author	Problem Statements	Organizations
Julie Rozenberg	I1	Senior Economist, **Sustainable Development Practice Group, World Bank**
Mariana Conte Grand	I1	Climate Change Senior Economist, **Sustainable Development Practice Group, World Bank**
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Mehul Jain	M6	Climate Change Specialist, **South Asia Disaster Risk Management and Climate Change Unit, World Bank**
Nicholas Jones	I2, M2, M5	Data Scientist, **Global Facility for Disaster Reduction and Recovery (GFDRR)** World Bank
P Bhanumati	M3	Senior Economist, Statistics Department, **IMF**
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Stephen Dorie	I2	Public Health Specialist, **Health, Nutrition and Population (HNP) Global Practice, World Bank**
Tamer Rabie	I3	Lead Health Specialist; **Health, Nutrition and Population (HNP) Global Practice, World Bank**
Ted Wong	R2	Research and Project Associate, **WRI Ross Center for Sustainable Cities**
Vladimir Tsirkunov	R4	Lead Specialist, Head of the **GFDRR Hydromet Program**, World Bank

Annex 2
Concept Note

CONCEPT NOTE

Heatwave Data Collaborative

Identifying and Mitigating Urgent Health and Socio-Economic Impacts of Urban Heatwaves

The Challenge

An increasing occurrence of heatwaves could impact the progress made in at least ten of the 17 sustainable development goals (SDGs).[1,2] In 2022 alone, extreme heat was speculated to cause reduced crop yields in India,[3] hydropower shortages in China,[4] increased flooding in Pakistan,[5,6] and the highest excess mortality during heat periods observed in the UK since 2004.[7] However, even within the same country, these impacts are not felt by every person and every sector equally. Heatwaves are a critical, global phenomenon that must be addressed collectively and with urgency.

The Solution

The proposed Heatwaves Data Collaborative would knit together disparate efforts by international organizations, private firms, and academia to develop common datasets and methodologies for identifying and mitigating the urgent socio-economic impacts of heatwaves.

The Collaborative would be led by the Development Data Partnership, a consortium of international organizations and private companies, supporting advancement of the SDGs through data sharing and data science collaboration. Funding would be pooled through the Global Data Facility.

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1 Perkins-Kirkpatrick, S. E., & Lewis, S. C. (2020). Increasing trends in regional heatwaves. *Nature communications*, *11*(1), 1-8.

2 Appendix 1: Impact of heatwaves on progress made towards SDGs

3 Beillard J. Mariano., 2022 India - Extreme Temperatures Scorch Indian Wheat Production. [online] Global Agriculture Information Network. Available at: https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=India%20-%20Extreme%20Temperatures%20Scorch%20Indian%20Wheat%20Production_New%20Delhi_India_IN2022-0045.pdf

4 Le Page, M. (2022, August 23). China's worst heatwave. *New Scientist*. https://www.newscientist.com/article/2334921-heatwave-in-china-is-the-most-severe-ever-recorded-in-the-world/

5 Mallapaty, S. (2022). Why are Pakistan's floods so extreme this year?. *Nature*.

6 Zachariah, M., Arulalan, T., AchutaRao, K., Saeed, F., Jha, R., Dhasmana, M. K., ... & Philip, S. (2022). Climate Change made devastating early heat in India and Pakistan 30 times more likely. *World Weather Attribution*.

6 UK Health Security Agency. (2022, October 7). UKHSA and ONS release estimates of excess deaths during summer of 2022 [Press release]. https://www.gov.uk/government/news/ukhsa-and-ons-release-estimates-of-excess-deaths-during-summer-of-2022

Heatwave Data Collaborative Objectives

To help governments identify and mitigate the impact of heatwaves, the Collaborative will focus on building the capacity of international organizations, government, and civil society to:

- Measure Risk and Occurrence of Heatwaves
- Identify and Measure Impacts of Heatwaves
- Quantify Potential Efficacy of Heatwave Impact Mitigation Measures

Specifically:

1. **Measure Risk and Occurrence of Heatwaves**
   Currently, there is no internationally accepted methodology to define or assess impacts from heatwaves. In absence of a standard, meteorological departments and researchers use their own datasets and definitions to identify heatwave occurrence. Further, these definitions often do not differentiate between thresholds necessary to understand impacts on people versus agricultural yields.

   Through the Heatwaves Data Collaborative, participants will identify and test which collection of definitions can be meaningfully applied to derive socio-economic and health impact analytics and, with those definitions, prepare and document the foundational datasets and code needed to analyze past heatwaves, identify cities at most risk of heatwave impacts, and trigger warnings for current heatwaves.

2. **Identify and Measure Impacts of Heatwaves**
   Participants will prepare methodologies and datasets that international organizations, governments, and civil society can use to monitor the impacts of heatwaves.

   For the purpose of this very first global data collaborative, the scope of the challenge will be drawn around urban areas, where the impacts of heatwaves are acute and vulnerable populations most concentrated. But subsequent efforts can focus on agriculture and food security, which would involve different datasets, methods, and actors.

   When a heatwave alert is triggered for a given urban area (“heatwave zone”), practitioners can use the code and methods produced through the Collaborative to estimate potential short and mid-term impacts on energy, health, education, and economy. For each subsequent day of the heatwave, local actors can re-run the analyses to update expected impacts and their likelihood, which would in turn be used to inform rational decisions on mitigation measures.

For example:

a. Energy. A direct impact of heatwaves is a surge in peak electricity consumption, especially on the hottest days.[8] Once a heatwave alert is triggered, a local government could use the Collaborative data and code outputs to estimate the potential increased stress on the electricity grid, with increasing probabilities assumed for each additional day the heatwave endures. With this information, governments can take preventative measures, such as encouraging reverse work schedules for select sectors or communicating upcoming energy rate adjustments to flatten demand. In absence of a heatwave, the model could be similarly used for preventative planning.

b. Health. Empirical studies have established a causal link between heatwaves and heat-related illness and death amongst vulnerable populations.[9,10] Other studies have linked heatwave occurrence to increased malaria risk,[11] increased hospital visits,[12] changes in mental health,[13] and increase in morbidity due to co-exposure to heat and air pollution.[14] The Collaborative will pool together select health linkages into a cohesive framework for assessing population health risks as a heatwave occurs, as well as how these risks evolve as a heatwave persists. With this information, governments can take a range of mitigation measures, from provision of cooling stations, adding temporary staffing to health facilities, and issuing public service announcements, to targeting provision of anti-malarial provisions.

c. Economy and Economic Wellbeing Heatwaves have been linked to reduced labor productivity (e.g., construction and agriculture),[15] and, anecdotally, shutting down of energy-intensive industries (e.g., server

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[8] Hatvani-Kovacs, Gertrud, Martin Belusko, John Pockett, and John Boland. "Assessment of heatwave impacts." *Procedia Engineering* 169 (2016): 316-323.

[9] Keshaviah, A. *ClimaWATCH* (No. 278e61c636af4f179b54d5171f886bca). Mathematica Policy Research.

[10] Romanello, M., Di Napoli, C., Drummond, P., Green, C., Kennard, H., Lampard, P., ... & Costello, A. (2022). The 2022 report of the Lancet Countdown on health and climate change: health at the mercy of fossil fuels. *The Lancet*.

[11] Zermoglio, F., Ryan, S. J., & Swaim, M. (2019). Shifting burdens: malaria risk in a hotter Africa. *Technical report, USAID*.

[12] Schramm, P. J., Vaidyanathan, A., Radhakrishnan, L., Gates, A., Hartnett, K., & Breysse, P. (2021). Heat-related emergency department visits during the northwestern heat wave—United States, June 2021. *Morbidity and Mortality Weekly Report*, *70*(29), 1020.

[13] Thompson, R., Hornigold, R., Page, L., & Waite, T. (2018). Associations between high ambient temperatures and heat waves with mental health outcomes: a systematic review. *Public health*, *161*, 171-191.

[14] Rahman, M. M., McConnell, R., Schlaerth, H., Ko, J., Silva, S., Lurmann, F. W., ... & Garcia, E. (2022). The effects of coexposure to extremes of heat and particulate air pollution on mortality in California: implications for climate change. *American Journal of Respiratory and Critical Care Medicine*, *206*(9), 1117-1127.

[15] Chavaillaz, Y., Roy, P., Partanen, A. I., Da Silva, L., Bresson, É., Mengis, N., ... & Matthews, H. D. (2019). Exposure to excessive heat and impacts on labour productivity linked to cumulative CO2 emissions. *Scientific reports*, *9*(1), 1-11.

farms).[16,17] Through the Collaborative, using historical data, likelihoods and further verification will be assigned to these possible occurrences, so that governments can make more informed decisions about mitigation and prevention measures.

d. Education. Some local governments are likely to close schools in times of extreme heat (e.g., in Ahmedabad's Heat Action Plan).[18] Once a heatwave is triggered, local governments could use the Collaborative outputs to provide advance warnings to schools about probability of the need for closure and trigger an alternative system, providing space for lessons to occur in temporary air-conditioned facilities.

In many cases, methodologies for these analytics have already been developed – the challenge is to make these analytical methods readily accessible to practitioners (e.g., as reproducible code, instead of a paper), leveraging common data sets and standards, and ensuring all results are comparable with each other and across time.

3. **Quantify Potential Efficacy of Heatwave Impact Mitigation Measures**
Finally, using information derived from the previous two tasks, Collaborative participants will identify and quantify the potential efficacy of heatwave impact mitigation measures. For example, based on prior research, the Collaborative may explore:

    a. What would be the return on investment in terms of extreme heat mitigation with expansion of urban greenspace?
    b. What is the market potential for residential and commercial solar panels in a metropolitan area, and by how much would a 5% increase in solar power utilization reduce grid load during a heatwave?
    c. By how much (in terms of number of days) can we improve early heatwave detection through crowdsourced data collection?
    d. What is the impact of installing targeted, efficient space cooling solutions to the electricity grid of a city?
    e. By exploring real-time surveillance using health service data, is it possible to design and trial an early warning system for health outcomes?

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[16] Hui, M. (2022, August 23). China's factories are shutting down again—but not because of COVID. Weforum. https://www.weforum.org/agenda/2022/08/china-factories-drought-electricity-climate-change/

[17] Roth, E. (2022, July 19). 'Google Cloud and Oracle Servers suffer cooling breakdowns during UK heatwave'. The Verge. https://www.theverge.com/2022/7/19/23270581/google-cloud-oracle-servers-outage-uk-cooling-failure

[18] National Research Development Corporation (2019) Ahmedabad Heat Action Plan. https://www.nrdc.org/sites/default/files/ahmedabad-heat-action-plan-2018.pdf

Key Activities

The Heatwave Data Collaborative will achieve these three capacity building objectives:

- Measure Risk and Occurrence of Heatwaves
- Identify and Measure Impacts of Heatwaves
- Quantify Potential Efficacy of Heatwave Impact Mitigation Measures

By undertaking six Key Activities:

1 Problem Statement Formulation
Through stakeholder workshops, prepare problem statements (challenge, proposed solution, outputs, collaborators, key tasks).

2 Team Formation and Data Fellows
Form small, grant-funded teams from Data and Development Partners, and via the Data Fellows program, NGOs and researchers.

3 Foundational Open Datasets
Curate and document shared open datasets to be used by all problem statement teams.

4 Proprietary Datasets
Leverage existing and form new agreements to use proprietary datasets and make available through the Partnership.

5 Data Goods
Produce fully replicable code and documentation, hosted on GitHub.

6 Capacity Building
Work with governments and NGOs to ensure widespread use of Data Goods for impact.

Through these activities, the Collaborative will produce:

- Common datasets and definitions
- Methodologies for identifying heatwaves and cities at most risk of experiencing heatwaves, measuring the impacts of heatwaves across multiple sectors, and for measuring the marginal mitigation effect of investments in preventative measures.
- Capacity building and outreach to ensure wide use of the methodologies and datasets.

The following sections describe these activities in greater detail.

1. **Problem Statement Formulation**
   Individual problem statements will be formulated as mechanisms to secure collaborators and resources for each aspect of the heatwave challenge, described in the previous section:

   a. Identify Global Occurrence of Heatwaves
   b. Identify and Measure the Impacts of Heatwaves
      a. Energy
      b. Health
      c. Economy and Economic Wellbeing
      d. Education
   c. Quantify Potential Efficacy of Heatwave Impact Mitigation Measures

   Each statement includes:

   a. Type (Definitions, Impacts, Preventative Measures)
   b. Sectors (Health, Energy, Economy and Economic Wellbeing, Education, Other)
   c. Challenge Summary
   d. Proposed Solution
   e. Indicative Outputs
   f. Confirmed and Sought Collaborators:
      a. International organizations
      b. Companies
      c. Government entities
      d. NGOs, academia, research organizations
      e. Donor partners
   g. Supported SDGs
   h. Other Inputs (indicative tasks, literature review summary, etc.)

   Here is a link to sample statements for discussion: https://datapartnership.org/heatwaves.

   In December 2022, the Partnership will convene a workshop with interested donors and collaborators to solicit inputs on sample problem statements, with particular focus on solutions, indicative outputs, and collaborators, as well as ideas for additional problem statements that could be added.

2. **Foundational Datasets: Open Data**
   For each problem statement, the Partnership will coordinate with membership and third parties to source “foundational datasets” – curated links to open data that are annotated per a common schema and accompanied by methods for data

bias and quality assessment. A light form of versioning monitoring would also be implemented.

Most Development Data Partnership international organization members coordinate statistical and data work and maintain several macro, financial, geospatial, and development topic databases. As the creators and curators of thousands of datasets available to civil society and governments, members are well positioned to identify, improve meta-data for, and in some cases, create new open data products that are needed to inform the Heatwaves Data Collaborative analytical work.

3. **Foundational Datasets: Private Data Partnerships**
   In addition to these open foundational datasets, the Development Data Partnership will facilitate licensed access to private sector data that can be used to generate new kinds of insights and global data products.

   The Development Data Partnership seamlessly links private sector data resources to international organizations for development of the needed solutions, through the following five pillars:

   a. <u>Legal Foundation</u>. Template data license agreements and MOUs between international organizations saves time and resources.
   b. <u>Data Marketplace</u>. A web-based proposal management portal facilitates seamless interactions between Data and Development Partners.
   c. <u>Shared Secure IT Architecture</u>. Centralized IT architecture and processes for ingesting, storing, and pre-processing data, as well as for coding collaboration, lower costs and facilitate secure data use.
   d. <u>Data Goods</u>. Accessible code repositories for derived data products and algorithms broaden Partnership impact.
   e. <u>Data Governance</u>. A robust data governance system guides best practices for responsible and ethical data use.

   The Development Data Partnership will leverage existing and sign new pro-bono data license agreements with firms -- e.g., weather companies, remote sensing firms, IoT companies, and financial transaction firms -- to establish a corpus of timely and granular data that could be used to inform immediate impacts of a heatwave. These datasets would be preprocessed, documented, and hosted on the Partnership IT infrastructure and made available to participating data scientists through the Partnership's legal framework.

4. **Problem Statement Teams and Data Fellows**
   Facilitating access to shared public and private sector data is only the first step. Equally important is understanding how (and whether) these data can be used to make meaningful policy and investment decisions.

To produce the three Heatwave Data Collaborative outputs – methods and data for: identifying heatwaves, identifying and measuring their impact, and for identifying and quantifying preventative mitigation measures -- the Partnership will oversee the formation of small, grant-funded teams to address selected problem statements.

Team members will be sourced from:

a. Development Data Partnership member organization staff (as of time of writing: the World Bank, IMF, IDB, CAF, UNDP, EBRD, ADB, and OECD);
b. Development Data Partnership member tech company staff (as of time of writing, 27 companies, including LinkedIn, Twitter, Meta, Microsoft, Mapbox, and others); and
c. Civil society by invitation and/or application through the **Data Fellows Program.** The Development Data Partnership Data Fellows program, piloted through the generous support of the Rockefeller Foundation, facilitates the legal and technical mechanisms needed to provide civil society access to Development Data Partnership and World Bank data resources, supporting experimentation and development of the scalable solutions needed to solve SDG challenges.

Team formation and coordination would be managed and monitored through the Development Data Partnership. Each team will receive specific guidance on their challenge, the available public and private datasets that are at their disposal, documentation on the standard project templates for code sharing and dissemination, and a handbook. Teams will also receive advisory on available cloud computing resources provided through the Partnership's membership.

5. Data Goods and Governance

Regardless of which problem statement a team is assigned to, all will be expected to produce Data Goods that include:

a. <u>Open Data.</u> Complete data documentation, open license details, and links to hosting platforms.
b. <u>Proprietary Data</u>. Complete data documentation, licensing information, and guidance for procurement / access.
c. <u>Code</u>. fully documented and reproducible code, hosted on a GitHub repository to support future improvements and collaboration.
d. <u>Code and Data Examples</u>. Examples of Data Good implementation for specific countries and time periods, posted on GitHub.
e. <u>Training Materials</u>. Sample hands-on curriculum materials for capacity building.

Critical to the success of the Heatwaves Data Collaborative – and what sets this program apart from others – is the focus on **ensuring all outputs across the**

different work steams are replicable, updatable, and statistically comparable with each other. These outcomes are achieved leveraging the existing data governance of the Development Data Partnership and the following team activity requirements:

a. All analytical work leverages the shared Foundational Datasets. If a new dataset is used, it must be appropriately documented, made accessible, and added to the Foundational Datasets catalogue.
b. All teams work with the Partnership-provided code and documentation repository template. GitHub, the world's largest open-source code repository, will be the final home for all outputs, ensuring code, data information, and user-friendly web-based documentation are accessible to all stakeholders, and to facilitate continued updating and collaboration after the project is complete.
c. Teams participate in monthly virtual check-ins to share progress, receive ideas and feedback, identify areas of overlap, and receive general encouragement from each other.
d. As the deadline nears for completion of the first round of outputs, the Partnership will convene an independent peer-review committee to review initial outputs and identify critical areas that may require further support or re-working.
e. Draft final outputs will be demonstrated at a workshop for feedback from stakeholders and all Collaborative members prior to completion.

6. **Capacity Building**
Upon finalization of the Data Goods for each Problem Statement, the Collaborative will support a series of communications and capacity building activities to ensure widescale uptake and sustainability of the Collaborative outputs, long after the program ends. For example, depending on the Problem Statement, activities may include:

a. Translation of Data Goods materials into select languages;
b. A training kit for use by staff from international development organizations or dedicated training hubs to train project counterparts on implementation of the Data Goods, prepared in collaboration with the World Bank's new NLP4Dev Program – a ML-based system for making complex datasets more findable.
c. A global hack-a-thon, inviting coders to use the Data Goods materials to replicate statistics for their own regions, contributing towards a global repository;
d. An instructional kit for developers, for use in creating new consulting services or software products with the Data Goods; and/or
e. An on-line course.

Program Management

The Development Data Partnership is a collaboration between international organizations and companies, created to facilitate the use of private sector data in international development. The Partnership -- founded by the World Bank, IMF, Inter-American Development Bank, UNDP, and OECD – enables practitioners from eight international organizations to tap into its nearly 30 pro-bono data license agreements with companies like Meta, LinkedIn, Mapbox, and Tomorrow.io. With the frequent and granular data produced by these companies, practitioners can pilot new data science methods to solve development challenges. The Partnership oversees a complete legal, IT, and governance infrastructure to efficiently link data to projects and provides support for data science collaboration across sectoral and institutional boundaries. As of time of writing, the Partnership includes eight international organizations and 27 data partners and supports more than 250 projects covering 13 SDGs.

The Global Data Facility is a World Bank-managed Trust Fund that enables scaled improvements of and strengthened human capacity for data collection, data management, data governance, data analysis, data sharing, and data use and reuse for transformational social and economic development. The Facility serves as a global funding and action coordination mechanism for a spectrum of partners, practitioners, and country clients to work together to solve the world's most pressing SDG challenges.

Program Concept Design Process

This concept note is a living document, regularly commented upon and improved by a growing cadre of collaborators from international organizations, firms, research organizations and academia, donors, and other stakeholders. If you have read this far, we hope you will share your advisory and guidance with the team through this note.

Here is our concept design work plan:

1. **Week 1 (week of November 7, 2022)**
    a. Circulate Concept Note draft for comment
    b. Start identifying and setting up meetings with potential collaborators for:
        i. Advisory group
        ii. Candidate problem statement leads and collaborators covering key topics: heatwave definitions, impacts (energy, economy, education, and health), and preventative measures
        iii. Candidate collaborative component leads (problem statement formulation, foundational datasets, private data partnerships, data fellows, data goods, and capacity building activities)
        iv. Interested foundations and donors
    c. Prepare model Problem Statement as an example for circulation

2. **Week 2-3 (weeks of November 14 and 21)**
    a. Meet with potential collaborators to:
        i. Improve concept note contents and refine activities
        ii. Further expand / refine founding collaborator pool and their roles
        iii. Identify problem statement leads
    b. Coordinate preparation of a few draft problem statements
    c. Set up meetings with Data Partners, to solicit inputs on concept note and draft problem statements.
    d. Confirm December workshop date with stakeholders and donors

3. **Week 4 (week of November 27)**
    a. Meet with Data Partners to confirm interest and potential contributions towards selected topics

4. **Week 5 (week of December 5)**
    a. Finalize draft documents and prepare presentations for Workshop

5. **Week 6 (week of December 12): Heatwaves Data Collaborative workshop**

Impact of Heatwaves on Progress Made towards SDGs

Heatwaves could impact the progress made in the following SDGs

- **SDG 2: Zero Hunger** – Heatwaves have been linked to lower agricultural yields resulting in an increase in malnourishment and food shortages. [19,20]

- **SDG 3: Good health and well-being** – The relationship between heatwaves and mortality and other heat-related illnesses is well established. [21, 22]

- **SDG 4: Quality Education** – There is considerable amount of work in studying the relationship between cognitive function and rising temperatures. Studies have seen a reduced cognitive function in hot temperatures[23] and that learning is inhibited with increasing temperatures across the world.[24] Heatwaves, in the past, when extreme, have also caused the closure of schools, as was the case in Ahmedabad's Heat Action Plan. If done repeatedly, this could lead to a loss of quality education.

- **SDG 6: Clean Water and Sanitation** – Heatwaves could create both droughts and excess rainfall which leads to floods.[25] It was seen that the co-occurrence of heat and drought can tend to have a greater impact than each of them stand alone. [26] This, in turn, reduces access to clean drinking water.

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- **SDG 7: Affordable and Clean Energy** – Heatwaves cause an increase in peak electricity demand.[27] This changes the price of electricity or forces local governments to have power outages thereby reducing access to electricity.

- **SDG 8: Decent Work and Economic Growth** – Heatwaves result in a reduction of labor productivity, thus impacting the economic growth, especially of low-income countries where construction and agriculture sectors are a greater percentage of the GDP. [28]

- **SDG 9: Industry, Innovation and Infrastructure** – Any progress made towards SDG 9 by increasing road roads, pavements and built environment will in turn add to the urban heat island effect.[29]

- **SDG 10: Reduce inequalities** – While heatwaves impact cities more, even within cities, the socio-economically disadvantaged will face a greater impact due to a combination of location (they tend to live in areas with less green cover) and access to heat adaptations like air conditioning. [30] This exacerbates the existing inequalities.

- **SDG 11 and 13: Sustainable Cities and Communities and Climate Action** – Through heatwave impact mitigation measures such as urban greenspace expansion, we can build urban resilience to heatwaves, supporting sustainable cities.

- **SDG 14: Life Below Water** – Marine heatwaves have also increased in frequency over the past few years threatening global biodiversity. [31]

- **SDG 15: Life on Land** – It was seen in a study that heat stress negatively impact the welfare of livestock resulting in a reduction in production of milk and meat. [32]

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Annex 3

Advisory Group Comments on Draft Problem Statements

Heatwaves Data Collaborative: Advisory Group Comment Matrix

Directions

Thank you for agreeing to volunteer your exceedingly valuable time to join our advisory group! Over the past few weeks, we have received problem statements covering three aspects of the Heatwaves Challenge:

- Measure risk and occurrence of heatwaves;
- Identify and measure Impacts of heatwaves; and
- Quantify potential efficacy of heatwave impact mitigation measures.

These statements have been prepared by different teams across different sectors and organizations. Your role is to review these Problem Statements as a package and provide inputs on the following:

- General merit of the Problem Statement vis-a-vis the goals of the Collaborative;
- Opportunities to combine Problem Statements or separate one Problem Statement into smaller challenges; and/or
- Recommendations for datasets the teams may consider and potential collaborators (could be colleagues from your own organization).
- Bonus: Recommendations for additional topics that should be included.

Please find below comment matrices for your use. **Add your initials after each set of comments, please!**

Note: AK1 = Aparna Keshaviah (Mathematica); KM = Katie McWilliams (World Bank); AC = Alex Chunet (ESA); DR = David Rogers (GFDRR, World Bank); AK2 = Aparna Krishnan (IFMR, J-PAL); DB = Daron Bedrosyan (ESMAP, World Bank)

If you do not have time to review all statements, please select at least a few. There will be additional opportunities to provide your inputs. Thank you again.

#	Topic	Problem Statement	General Merit of the Problem Statement	Recommendations for Datasets, Papers, Resources, and/or Collaborators*
R1	Measure Risk and Occurrence	Differentiating Heatwave Identification and Measurement by Sector	AK1: The end-goal of the work is clear, but more thought is needed around the level of data granularity available to measure sector-specific impacts and the analytic approach, (e.g., how to disentangle the definition of a heat wave that was used to measure sector-specific impacts form the definitions that will be explored *de novo*). Also, consider if the focus is really on the definition of a heatwave, or if instead it's on identifying triggers for heat alerts, which can help provide early warnings to mitigate sector-specific impacts of extreme heat. KM: I'm intrigued by the idea of creating a definition based on sectors. Using meteorological thresholds is difficult because a heatwave in Norway, for instance, will have different thresholds than a heatwave in India. But it might be difficult to gather the necessary sector-related information, at the right resolution, across the globe. AC: Relevant Problem Statement. Agree with KM on the variation in thresholds depending on geographic location (and factors such as humidity). DR: Like all other inherently meteorological phenomena, the impact of heat depends on who and what is exposed and the level adaptation that has occurred in the past.	AK1: Kanti et al. 2022 compared various heat waves definitions and the burden of heat-related mortality in France and mention the use of an internationally generalizable definition that comes out of Australia. Also, Kalkstein et al. 1996 describe how other factors (such as cloud cover and wind speed) may important to consider (in addition to temperature & humidity). The company Fraym has data on health characteristics, food insecurity, etc. that may be useful. And if there is capacity to analyze mess meteorological data, consider the official datasets available from countries' meteorological departments on individual weather characteristics. Decomposing the WBGT into individual metrics will help identify definitions that are meaningful beyond a research context (e.g., useful to policy audiences). NASA SEDAC also has a good repository of satellite-derived global air pollution data. AC: It will be important to also take into account and factor for future datasets that are scheduled to be released. For example, the ESA LSTM mission will be a fundamental source new data source. DR: There are global data sets of all meteorological parameters. The ERA5 data set produced by the Copernicus Climate

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			Focusing on defining a “heatwave” rather than locally defined “excess heat” may prove misleading. It would also be important to consider sectoral *interdependencies* since one sector vulnerable to a hazard (in this case heat) may have a significant and often overlooked impact another. Another important factor is the cumulative effect of heatwaves. One single event may have minimal consequences, but several may have a cumulative impact. The period of exposure is also important. Hopefully these can be considered explicitly in the proposed work. I would caution against trying to create too rigid definitions that do not consider the hyperlocal context of the impact of excess heat.	Change Service (C3S) at ECMWF provides hourly estimates of meteorological variables from 1950 to the present. This can be used to determine the local sensitivity to excess heat based on past events. A similar analysis is required for R4 but there the focus is on specific urban environments.
R2	Measure Risk and Occurrence	Long Range Forecasts of Heatwaves and their Impact	AK1: Making forecasts and sector-specific impact estimates more accessible is valuable, but it’s not clear who the target audience is for this work. Consider the extent to which your audience is literate in statistical methods, and if not, the role of well-designed visualizations to communicate results plainly. KM: This problem statement could be a sub-component of R1, since it references using the sector-specific heatwave definition created by the Data Collaborative. While the forecasting of probabilities and magnitudes	AK1: Mathematica would be interested in working with this team to develop a community risk profile visualization that shows the projected magnitude of impacts of extreme heat in different sectors, providing a quick and digestible way to assess where the risks are highest and take planning and preparedness steps accordingly. Based on the solution we developed for the U.S. Agency for Healthcare Research and Quality’s “Visualization Resources of Community Health-Level Social Determinants of Health” Challenge, we can create a multi-dimensional fingerprint showing projected

#	Topic	Problem Statement	General Merit of the Problem Statement	Recommendations for Datasets, Papers, Resources, and/or Collaborators*
			of heatwaves is important, I actually think the key part of this problem statement is the forecasting of impacts on infrastructure, the economy, and public health. AC: Relevant Problem Statement. I also believe that it might be worth integrating it in R1 considering how closely those two are related. The work to assess impacts is very important and could feed a lot of existing endeavors and analytical work. DR: Impact-oriented climate forecasts at scale are critical. The available data is at 25 km resolution and may require further downscaling to analyze the impact of excess heat at urban scales. However, it isn't clear how the impacts will be projected on climate timescales. This requires a set of scenarios based on a plausible set of assumptions about changes in exposure and vulnerability. This would have merit for planning but projects to 2100 that are essentially based current social and economic vulnerabilities may not be relevant since early interventions will change future outcomes significantly. Focusing on shorter planning horizons may be more appropriate.	sector-specific impacts of extreme heat, for example. AC: same comment as above on LSTM DR: There is some overlap with R4 on longer time scales. If R4 focuses on reanalysis and short time scale forecasts of impacts to manage responses to heat. This can inform the longer-time scales proposed by R2 and can provide a baseline for impact-oriented climate projections.

#	Topic	Problem Statement	General Merit of the Problem Statement	Recommendations for Datasets, Papers, Resources, and/or Collaborators*
R3	Measure Risk and Occurrence	Assess ing Intra-urban Heat Hazard Disparities	AK1: The project will yield evidence that will help 12 global cities more accurately measure and risk and vulnerability to extreme heat, but a pathway to scaling this work is missing. If the quantitative mapping is coupled with qualitative data collection on process measures, to describe lessons learned and identify best practices and pitfalls (e.g., related to community engagement and mapping approaches), that could promote learning in other cities and facilitate scaling of the proposed approach. KM: The urban heat island effect is a well-document phenomenon, and with a majority of the world's population living in urban areas, this problem statement rightly addresses those challenges. The 12-city pilot program is a reasonable approach to gauge how easy/difficult it will be to collect the necessary hyper-local data, while also engaging with local stakeholders. I especially like the third proposed solution, which focuses on indoor heat stress as I believe that is an under-studied aspect of heat islands. But I would like to see information on how exactly this will be scaled for use in other cities. AC: very important problem statement which has a fundamental importance to inform spatial planning.	AK1: NASA SEDAC has satellite-derived data for multiple countries on air pollution, which is a relevant confounder / exacerbating factor to control for in your models. Also, the company FRAYM AC: following up on AK1's comment on the need to find avenues for scalibility, I believe that remote sensing offers great opportunities to scale up UHI related analytics. However, the reality is that the link between Land Surface Temperature and Air Temperature is still poorly understood, therefore, I think this activity could be used to advance knowledge on this front and try to produce a model that improves the prediction of air temperature based on land surface temperature data, and potentially even take into account building characteristics to predict indoor temperature. DR: There is overlap with R4 and both projects would benefit from further discussion. R4 would focus on South Asia and the opportunity to compare, and contrast would be helpful to address the upscaling issue.

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			DR: This is a very and useful effort. On the comments from other reviewers – We should be cautious about what can and cannot be universally applied at scale. While there will be some basic characteristics of the impact of heat that are transferable, we should also understand the unique nature of each built environment. The project should be able to do this.	
R4	Measure Risk and Occurrence	Forecasting Heatwaves for Early Action	AK1: There is some overlap between this project and R1. If these projects are kept separate, consider bringing more focus in this project to the communication and dissemination piece – e.g., testing out different messaging strategies to different groups to help develop tailored warnings. KM: I also see some overlap with R5- if the outputs here could be made available via a forecasting dashboard. DR: (author of R4) There are numerous overlaps (mostly complementary) between R4 and other initiatives. Note the expertise in R4 is operational forecasting for anticipatory action. Utilizing data to enable anticipatory action that mitigates the threat is the main output – avoiding morbidity and mortality, altering city management functions (e.g., heat shelters and possible financial transfers	AK1: This project is very similar in scope to work that Mathematica has done in the U.S. through our ClimaWATCH tool. DR: (as author of R4). The is to understand what anticipatory actions can be taken at the city level in response to hyperlocal forecasts of excess heat. AK1 suggestion would be helpful but would need to applicable at the block level within a city

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			to maintain shelters) and managing urban power distribution to ensure grid operations.	
R5	Measure Risk and Occurrence	Seamless Navigation of Information From Weather Alerts	AK1: The overall goal of the project is worthwhile, but the risk of information overload needs to be considered. Allowing users to quickly see how projections differ under various scenarios can clarify how much confidence exists around forecasted impacts, but it can also create confusion if not coupled with guidance around decision-making in the face of uncertainty. One option may be to include detailed sector-specific impacts (e.g. through activities in project R1) so that officials can see if impacts will be contained or widespread under various scenarios. KM: What is the geographic scope- will the forecasting datasets be global? Or will each country have an individual dashboard using more local forecasting datasets? The proposal also mentions linking with CCKP, so could be some overlap with R6. AC: Important activity for the dissemination of results. When I think about it, although maybe simplistic I see R6 as an activity helping with inputs, R2 as the activity about producing data layers, and R5 as the activity	AC: this activity could build on the upcoming GDA APP activity dedicated at elaborating a web-based analytics platform dedicated to specific sectors, such as UHI/heat stress DR: R4 would be interested in providing inputs to R5, particularly on real-time probabilistic (I think we define probabilistic in a different way) impact-based forecasts for anticipatory action. We would find the dashboard useful for operational decisions on time scales of 0-15 days for specific cities where the decision makers are the public, DRM, utilities and facilities managers.

#	Topic	Problem Statement	General Merit of the Problem Statement	Recommendations for Datasets, Papers, Resources, and/or Collaborators*
			feeding the front end so those three activities should be closely coordinated. DR: This project addresses a very important issue. Seamless forecasting across all time scales is a reality and the need to ensure that the decision making is equally aligned is critical. As a decision-making tool this would be very useful. What is not so obvious is who is the audience and how will they be engaged in the development?	
R6	Measure Risk and Occurrence	Supporting Inter-Comparable Work on Heat, Extreme Heat Conditions, and Extreme Heat Events Through Provision of Robust, Systematic and Consistently Produced Climate Data Products	AK1: This is well-considered project that seeks to produce climate data products that are comparable and systematic across various dimensions (geographies/sectors). It seems like the there is already a product in development, but that newer outputs will be added over time. In addition to create data sets, it would be great to see tools developed to visualize the data, which could help those users who are less quantitatively minded digest the data and patterns. KM: This could be an excellent addition to the CCKP, and ties in nicely with the existing site's scope and purpose. New datasets, visualizations, and (potentially) analyses would help keep the site relevant.	AK1: The type of multi-dimensional visualization we propose for R2 above could be useful here.

#	Topic	Problem Statement	General Merit of the Problem Statement	Recommendations for Datasets, Papers, Resources, and/or Collaborators*
			AC: I think this work is fundamental to ease the integration of Climate data and other related inputs for activities in the R2 activity. Therefore, both of those activities R6 and R2 should be coordinated closely. See comment above for coordination with R2, R5 and R6.	
I1	Measure Impact	Assessing Heatwave Impact on Human Well-Being: Monitoring Relationships between Temperature, Social Media Sentiment, and Behaviour in Latin America	AK1: This is a very interesting problem statement focused on an under-reported health outcome associated with extreme heat. Validation will be important for these types of analyses, to remove the influence of time trends and potentially confounding factors (e.g. concurrent events such as political unrest or sporting events that could lead to frustrations that are expressed using similar key words). KM: Interesting and unique approach to studying psychological effects of heat waves. Two questions: how to account for twitter reliability (given recent headlines and impending lack of content moderators) and how will heat extremes be defined- a heat extreme day in Rio will be very different than a heat extreme day in Quito, for example. AC: very interesting problem statement. Great to build on twitter data for sentimental analysis. There are potential linkages and synergies with the I3 activity.	AK1: The company Fraym has data on population sentiment (e.g., related to specific events or activities, political issues, etc) that may be useful to consider (at least to control for confounding). Latin America is a region where they actively produce data.

#	Topic	Problem Statement	General Merit of the Problem Statement	Recommendations for Datasets, Papers, Resources, and/or Collaborators*
			DR: Although this is focused on Latin America, it will be interesting to compare with studies in other regions. In South Asia, for example, and in Bangladesh in particular, perceptions of risk have highlighted the very high concern about heat (more than other hazards (e.g., floods). The concern is even more elevated among children. It would be good if I1 could document peoples' mood differentiated by age and gender. AK2: Leveraging social media for climate change impacts is novel, and there may be some interesting behavioral interventions to test for observed trends/patterns. See for example research on improving poor quality sleep (partly due to heat among other factors) on cognition, productivity and psychological well-being.	
I2	Measure Impact	Creating heat-health vulnerability maps to measure impact of heatwaves on human health in urban, rural and at the national level	AC: great to build on mobile phone data and related databases to analyze impact of heatwaves on public health. Curious to know whether the building classification will be extracted from an existing dataset (i.e. OSM but often incomplete) or built by analyzing commuting patterns. DR: This is a very important component of the overall heatwave initiative. Since interventions should dieback on vulnerability it would be very useful to engage with this activity to establish a vulnerability index for	AC: Here is a link to a paper I co-authored that uses mobile phone data to analyze impact of COVID19 across income levels (this might be of interest to the team if they want to integrate income level as a variable).

#	Topic	Problem Statement	General Merit of the Problem Statement	Recommendations for Datasets, Papers, Resources, and/or Collaborators*
			heat health and to track changes in that index in response to improved interventions. Past work in China, for example, showed that increase affluence resulting in access to air conditioning reduced morbidity and mortality in otherwise high-risk populations (elderly). In South Asia, passive interventions coupled with forecasts (R4) are intended to reduce exposure to excess heat and poor air quality. The proposed vulnerability maps or at least the methodology could be adopted beyond I2 geographical region of interest.	
I3	Measure Impact	Heatwaves and Violence - A Case Study of El Salvador	AC: interesting project that might benefit from coordinating efforts with I1 activity.	
M1	Quantify Efficacy of Mitigation Measures	Guiding Cool Infrastructure Planning to Mitigate Urban Heatwaves	AK1: This is a well thought-through problem statement with a clear approach to creating a dataset and utilizing it for a specific purpose. KM: Clearly defined problem and solution. Useful to build off similar methodology from a project in Los Angeles, and the outputs and results are scalable (although future users would need to acquire their own imagery to run the albedo analysis?) AK2: This solution aims to generate a big push investment into construction patterns and building materials for cooling. For the replicability and scalability of this work, it would be useful to plan for actual use cases	

#	Topic	Problem Statement	General Merit of the Problem Statement	Recommendations for Datasets, Papers, Resources, and/or Collaborators*
			that incentivize adoption of these technologies so that actual household constraints could be considered also. This would help link the scientific technology, associated data with real instances of adoption/ AC: Great problem statement, agree with comments above. This should definitely build on efforts of R3. DR: Ground level albedo is a necessary but not sufficient measure of the planetary albedo that contributes to the air temperature a street level. Cloud affects the planetary albedo directly and winds will mix the air and redistribute heat. Changing the albedo horizontally can enhance winds. Without getting into the science, I suggest that you consider how the urban boundary as whole is impacted by changes in surface reflectivity. You can potentially create more cooling but also more problems with air quality. I am not sure 2m resolution for albedo buys anything if you aren't considering the whole boundary layer.	
M2	Quantify Efficacy of Mitigation Measures	Linking Urban Greenspace to Heatwave Impact mitigation	AK1: This is an interesting solution that is being suggested! Understanding the temporality (e.g., is this a static product with indicators or a dynamic one) would be helpful.	AK1: The company Fraym has geospatial data in environmental and agricultural components that may be useful to help develop a panel dataset. Also, it may be useful to use nighttime light data (since most

#	Topic	Problem Statement	General Merit of the Problem Statement	Recommendations for Datasets, Papers, Resources, and/or Collaborators*
			KM: The benefit of this problem statement is that greenspace data is important to a wide variety of sectors, so any data generated from the work would be very useful. The proposal mentions creating 'accompanying indicators on the potential impact of these green spaces on mitigating extreme temperatures.' What exactly would those indicators be? AC: Great problem statement, quite complementary with M1. Mapping green spaces to assess there impact on UHI is fundamental DR: This would be very useful for interventions in many different geographical locations.	greenspaces are dark) as an alternative data layer that could support sensitivity or validation checks. KM: Green City Watch could be a useful partner, and have worked with the Bank before. DR: The Nature Conservancy in India would be a useful partner.
M3	Quantify Efficacy of Mitigation Measures	Using Solar Energy to Build Heatwave-Resilient Energy Systems	KM: An interesting problem statement which turns the negative aspects of a heatwave into a potential positive- utilizing the solar output occurring during a heatwave to help reduce energy demand therefore reliance on fossil fuels, which are partly the cause of climate change (and more heatwaves). However, what is the geographic scope of this statement? It says they will look at a 'certain spatial grid' and I'm curious if we're talking about city or country scale. (Anything larger would be ambitious, given the need to create a solar panel density indicator.)	

#	Topic	Problem Statement	General Merit of the Problem Statement	Recommendations for Datasets, Papers, Resources, and/or Collaborators*
			AK2: This is an important and interesting problem statement aimed at understanding household adaptive capacity to invest and use solar energy. It would be valuable to assess both the technical and infrastructure capacity as well as the behavioral aspects enabling /constraining adoption. Combined these could provide very useful insights to local and national solar policies of governments so that mitigation measures can be targeted well. It may also be useful to look at impact of rooftop solar on small businesses in terms of barriers to adoption and overcoming uncertain power supply and effects on productivity. AC: interesting problem statement. However, I don't see this as falling in the "Quantify efficacy of mitigation measures" but rather related to adaptation more than mitigation. This does not make it less relevant but we might need to think about where it would fit and in connection with which other activities. DR: In the long term as dependence on solar energy increases – managing demand and supply becomes critically dependent on energy for cooling and availability due to incoming shortwave radiation (which is highly depended on cloud cover).	AK2: Researchers associated with J-PAL would be understanding and interested in testing multiple interventions to encourage adoption of rooftop solar. See for instance, ongoing work of Teevrat Garg (UC San Diego) in a city in south India (Bangalore).

#	Topic	Problem Statement	General Merit of the Problem Statement	Recommendations for Datasets, Papers, Resources, and/or Collaborators*
			Consequently, modelling the actual energy availability from solar within the context of excess scenarios in urban settings would be very helpful for planning investments. DB: An important energy stakeholder other than air conditioning companies to add to the list that has been compiled in the Concept Note is electricity utilities. In many developing countries where vertically integrated utilities have a monopoly on generation, transmission and distribution of electricity, any solar rooftop installations should be approved/coordinated with the electric utilities. It is necessary for system planning of supply and demand. Utilities can also provide beneficial feedback on how heatwaves affect electricity blackouts.	
M4	Quantify Efficacy of Mitigation Measures	White Roofs for Safer Schools – Should we paint all classroom roofs white to improve learning	KM: Interesting plan to scale up existing work on how classroom heat negatively affects performance- a tailored proposal which isolates a very specific problem to be addressed. The proposal doesn't specifically mention heatwaves… but I assume that as heatwaves increase in duration and intensity, the problem in schools will be exacerbated. While this statement focuses on Tanzania, I do like the ability to utilize the outputs in other countries/regions.	

#	Topic	Problem Statement	General Merit of the Problem Statement	Recommendations for Datasets, Papers, Resources, and/or Collaborators*
			AK2: This is a very clearly laid out problem statement with a specific solution and detailed workplan. The measurements could also capture the effects of ambient temperature on teacher effectiveness, student cognition, physical and mental health. A rigorous impact evaluation would also help generate estimates of cost effectiveness which would help inform decisions and feasibility of scaling the approach in Tanzania and other similar environments (especially relative to other mitigation measures) AC: Great problem statement and clear implementation plan. This activity is crucial to promote scalability by better understanding the relationship between land surface temperature and air temperature, taking into account built up characteristics. DR: In contrast to my comments on M1, the direct benefit to temperature within a building makes this an important contribution to mitigating the impact of a heatwave. This is especially important where active cooling is not an option (most places). The idea might also apply "heat shelters" designed as spaces for the vulnerable to use	AK2: Researchers affiliated with J-PAL could help explore the potential for an impact evaluation that measures relative cost effectiveness as well as the short and long-term impact on student health and learning outcomes.

#	Topic	Problem Statement	General Merit of the Problem Statement	Recommendations for Datasets, Papers, Resources, and/or Collaborators*
			an intervention strategy to cope with excess heating in a housing community. DB: The ESMAP Primer for Cool Cities provides an excellent summary of good practice initiatives on cool roofs/white roofs that have been initiated by the Global Cool Cities Alliance. GCCA would be a well informed partner to work with on this.	
M5	Quantify Efficacy of Mitigation Measures	Greening of Informal Settlements - A guidebook and cost benefit assessment methodology	KM: Loosely related to M2, which also looks at greenspace. This proposal outlines a very specific problem- how greenspace can help mitigate heat effects in informal settlements. I appreciate that there is a clear plan to scale up- the toolkits, guidebook, and code would be replicable in other cities/countries after the pilot is complete. AC: great problem statement. Agree with KM on relation with M2. Guidebook component is very pertinent to encourage capacity and local ownership.	AC: guidebook, in addition to other capacity building material across all other activities could be hosted in the ESA GDA knowledge hub (which is an activity that will be kicked off in a few weeks)
M6	Quantify Efficacy of Mitigation Measures	Quantifying the Impact of Climate Investment Opportunities in South Asia's Cooling Sector	AK1: The target geographies that are the focus of this work are highly vulnerable, and it is becoming increasingly important to find sustainable adaptation measures. That said, the problem statement is very high-level and it's unclear how the outputs align with the solutions (e.g. how will data on the interventions be collected, and what is a successful outcome?). The team should consider narrowing their scope more to help	

#	Topic	Problem Statement	General Merit of the Problem Statement	Recommendations for Datasets, Papers, Resources, and/or Collaborators*
			identify what interventions will be considered, what will be analyzed, where it will be analyzed, and how they will be able to collect the data. Also think through who your target audience is. AC: This activity is broader than the others, I believe it could actually build on the outputs of the other more focused activities to then elaborate comprehensive action plans. DR: This is an opportunity to couple activities such as R4, which will provide the evidence based on reanalysis and benefit from the analytical work proposed here. R4 recommends working with this team to identify several cities (e.g., Dhaka, Chennai, Columbo) where we or collaborators have active programs).	
C1	Capacity Building	Heatwave Alert and Two-way Learning for Highly Adaptive People	AK1: It's great to see such an underrepresented and vulnerable population as the focus of this work. However, some of the expected outputs seem misaligned with the goals. For example, if slum communities lack access to weather apps or phones, why is programming code the main way that early warnings will be delivered (instead of qualitative messaging)? KM: Good focus on warning an overlooked and underserved section of urban population; slum dwellers. While the warning	AK1: The team should consider engaging with companies that work on communication and risk messaging, to do some A/B testing. One example is GMMB.

#	Topic	Problem Statement	General Merit of the Problem Statement	Recommendations for Datasets, Papers, Resources, and/or Collaborators*
			system is important, I believe the toolkit which helps with adaptation and resilience is key- warning slum dwellers a heatwave is impending is great, but helping to mitigate the effects is also important. Also, how exactly will the warning system work? What methods will be used to disseminate the information? DR: Impact-based forecasts and warnings for anticipatory action recognizes that the most vulnerable are usually the most marginalized. R4 proposes to focus on cities in South Asia and would be happy to work with C1 to ensure anticipatory action is possible in the cities where we would focus activities. Seed is also a potential partner in the R4 initiative and so there is a natural interface. We note that in many slum areas, fire also accompanies excess heat and efforts to reduce this risk without exacerbating the heat health issues are also needed. Since slum dwellers are generally responsible for their own home construction, the proposed tool kit will be a very useful tool to ensure that these communities do not inadvertently expose themselves to more harm. (The example of building back homes in Bangladesh made entirely of tin to prevent	

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			their destruction due to fire is creating a potential death trap due to excess heat) AK2: Adding to the above, this topic contributes to efforts to develop customized tech products and solutions for a largely under-represented (and under-researched) and vulnerable section of the population. However, it is not clear if there is also a plan to develop a product/solution for mitigation, or if it is only a platform to capture the effects of heatwaves. There could be interesting intersections with using social networks in slums to spread information on awareness as well as encourage adoption of measures.	

** Could be your own organization.*

Opportunities to Combine Problem Statements or Separate Statements into Smaller Challenges

Feel free to use problem statement numbers when suggesting combining statements, and **please don't forget to initial your comments.**

- AK1: Problem statements R1, R2, R4, and R5 all have a focus on fostering action through improved heat alerts or information integration. If the associations between extreme heat and sector-specific impacts identified in R1 could be viewed together in the dashboards built for R5, and the projects developed in R2, that could foster improved planning and action by government officials tasked with considering impacts across sectors. Further, the associations between extreme heat thresholds and multisectoral impacts, as identified in R1, could then be synthesized with social and infrastructural vulnerability factors in R4 to determine how risk alerts and messages should be targeted.

- AK1: There could be some synergies between projects R1 and R6, with the outputs of R6 feeding into R1 to develop a comparable and consistent metric for sector-specific thresholds.
- AK1: For the workshop, it may be useful to develop a conceptual map or Sankey diagram that shows relationships between these projects (i.e., how the outputs from one project would be used as inputs to another).
- AK1: There are possible synergies between M1 & M2 – there could be scope for the teams to develop a multi-dimensional resource, pool resources, or to learn from each other's methods.
- KM: I see similarities in R4, R5, and R6, all of which discuss forecasting and/or building dashboards. R4 and R5 deal with short-term, meteorological forecasting and R6 with long-term climatological forecasts. So R6 is a clear tie-in with the existing CCKP, while R4 and R5 could either be stand-alone or also joined with CCKP (depending on how large of a scope CCKP wants to have).
- KM: R2 mentions utilizing the definitions created by R1, so this could be a sub-component of R1.
- AC: I believe we could think about an R6-R2-R6 sequence as mentioned in my comments. Also, close link between M2 and M5 which are complementary with M1 in terms of sector. Apart, from this I agree with most comments above.

BONUS: Topics that Should be Added

What is missing? Tell us! And **please don't forget to initial your comments.**

- AK1: Two key topics are missing here. First, there is a need to quantify the multisectoral effects of extreme heat in a manner that clarifies the costs of climate inaction. A project that estimates the monetary impacts of extreme heat due to effects on health outcomes, labor productivity, crop yields, and economic measures could prompt more governments to act to mitigate these impacts. Such a project could yield online calculators to estimate the monetary implications of sector-specific impacts, so that global cities and countries can conduct their own calculations based on local or regional historic impacts (which other teams are working to estimate). Second, data and risk measures only useful to the extent that people can understand them. No project has a focus on improving risk messaging. Scientific communication around climate change has often fallen short, and more work is needed to understand what types of messages and delivery modes work best to increase people's risk awareness. Using mixed-methods approaches and A/B testing with different vulnerable groups (including the slum communities that are the focus of project C1) could inform the development of a guidance document or video for government officials.
- AK2: Some of the problem statements could explicitly include measurements on health and productivity outcomes. These could be added to problem statements such as the school roofs or alerts for slum dwellers. The problem statements focused on developing

simple technical solutions at the household level could also combine interventions and evaluations that address constraints to adoption. The impact of both heatwaves and proposed mitigation measures on health and learning outcomes and other socio-economic outcomes is important to inform policy goals or to nudge action (one of the stated goals of the collaborative). Similarly, insights on cost effectiveness, operational feasibility, adoption of measures will all provide useful information to guide policy and programmatic action especially in low resource settings

- AK2: Impact of heatwaves on labor productivity and gender is an important area that needs more research. Some indicative questions could include understanding which sectors/types of workers/tasks are more vulnerable to heatwaves; how do workers sort (across tasks, work locations, sectors) in the face of rising temperatures. What kinds of mitigation activities (through policies, contracts or physical conditions) have effects on improving labor productivity and welfare outcomes.
- AC: I would like to insist on three things. 1) Maybe we need to have a closer look at how different future datasets that are scheduled to be released (such as the ESA LSTM mission) could be used and might impact the analytics that can be produced; 2) we might want to have a more structured approach to the scalibity of those tools and bring a stronger focus on activities that will build on remote sensing data combined with ground truthing in order to produce highly scalabe models; 3) I feel that a higher number of capacity building components should be included in order to ensure the use and transfer to those tools to local institutions and stakeholders.
  In addition, it is important to think about synergies with the ESA GDA programme:
    - The services elaborated through each activity could be then integrated, hosted and ran on the GDA analytics platform so that they can easily be used by any stakeholder or counterpart
    - Capacity building content could be elaborated in collaboration with the ESA GDA knowledge hub which will be kicked off in a few weeks.