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CrisisReady's novel framework for transdisciplinary translation: Case-studies in wildfire and hurricane response

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ABSTRACT

Extreme weather events including wildfires and hurricanes are becoming increasingly hazardous due to climate change, and often result in transient or permanent population displacements. Disaster-related disruptions in infrastructure, workforce, wages, and social networks can combine with population displacements to result in interruptions in health care access and prolonged impacts on morbidity and mortality. The data needed to make health systems and emergency management approaches more resilient to these hazards, and more responsive to the needs of affected populations, are sequestered in silos across private corporations and public agencies. In two case studies, we describe how our research team at CrisisReady negotiated access to privately held and novel data sources like anonymized geolocation data from cell-phones, while striking a balance between data security and public health utility. We describe how our analytic tools are embedded into disaster response workflows by co-developing our research questions and outputs with responders and policy-makers. ReadyMapper, an interactive data visualization tool to track population mobility, infrastructure damage, and health system capacity, in near real-time, was deployed during wildfires in California and during the Hurricane Ida response in Louisiana. The Data-Methods-Translational framework we have developed is scalable and relies on sharing science and co-creating products with policy makers and response agencies to ensure real-world applicability. These attributes make the framework particularly useful for formulating evidence-based approaches to protect human health through climate change adaptation.

Introduction

Climate change is a complex public health threat that calls for collaborative approaches to adaptation [1]. Populations face escalating frequency and intensity of flooding, heat, drought, and wildfires due to the effects of climate change; these hazards disproportionately affect the socioeconomically and medically disadvantaged [2,3]. Climate-related hazards will be a feature of life in many locations for the foreseeable future [4], and must be addressed alongside climate adaptation efforts.

Climate-influenced disasters including hurricanes, floods, heatwaves and wildfires present a variety of challenges for emergency planners and health systems. Acute impacts like damage to shelter, to critical utilities like power and water, and to transportation networks, result in health care disruption. Forced displacement (which may be transient or permanent) and loss of livelihoods and social networks all contribute to prolonged impacts on morbidity and mortality [5,6]. Technical and operational expertise that could improve emergency response systems to pre-empt and plan for protecting the medically vulnerable and displaced population, to minimize health care interruptions is limited and often least available in communities that are most at risk [7].

In this paper, we present a framework we have developed and deployed that scales much needed scientific expertise to provide policy makers and emergency responders with timely tools for data-driven decision making. We describe our framework using two case-studies from the wildfires in California, and from hurricane Ida, respectively, where we deployed an interactive data visualization platform, ReadyMapper, to successfully help local communities

Human Mobility Data and Climate-Related Disasters: Applications to California Wildfires and Hurricane Ida

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Table 1
Data in context — Examples of existing human mobility data sources and tools.

Organization	Data source	Data accessibility	Uses	Limitations
MapBox	Smartphone Mapping Apps (proprietary)	Private; access via negotiated use for specific pre-approved purposes	Compare relative activity levels in specified zones across time and space	Cannot provide information on where a population of interest originated or went; limited to smartphone users
Meta	Facebook App use	Private; limited access via portal can be negotiated by researchers and non-profit organizations with Data for Good at Meta	Provides % change in population over time;provides information on large-scale population origin and destination	Resolution of population density change is limited to 800m to preserve anonymity; limited to smartphone users of the Facebook app with location services enabled
Spectus	Location Intelligence Service Provider	Secure Jupyter Notebook environments made available to researchers	Provides count of distinct devices for a short response time	Limited information on representativeness of the underlying population using these location services
Mobile Network Operators	Cell tower pings	Private; limited access can be negotiated with network operators or aggregator	Population density change and move	Privacy and responsible use constraints; limited to cell phone users
National Shelter System	Midnight census counts in emergency shelters	Live data is publicly available on a dashboard	Reports shelter utilization	Does not provide information on daytime or shelter-adjacent activity
Local Healthcare Systems	Emergency Department (ED) Arrivals / Cases	Proprietary; may be shared with state/federal agencies	Syndromic surveillance; assess surge / trough in ED use	Not widely accessible. Does not capture populations unable to access care.
US Dept of Health and Human Services EMPOWER	Medicare users of electricity-dependent durable medical equipment	Regionally aggregated data is publicly available. Identities available to EMS during disasters.	Assess regional levels of medical vulnerability.	Does not include patients who are not on Medicare.
Power outages	Customer level detection of power outage scraped from power utilities by PowerOutages.com	Available for purchase and access via API	Detect loss of electrical service at the county or municipal level for the purpose of understanding impact on infrastructure and vulnerable populations, particularly those with power-dependent medical equipment	Does not include site level outage detection

monitor near real-time population mobility in the context of health system preparedness. We describe how access to data needed during extreme weather events needs to be negotiated well in advance, how the scientific methods and analytic tools should be developed so they can be widely used and understood, and how pre-existing relationships with end-users are key. Our Data-Methods-Translational Framework lends itself to scaling the expertise need while preparing for climate adaptation globally.

The data-methods-translational readiness framework

The team at CrisisReady, a research-response collaboration between the Harvard Data Science Initiative and the humanitarian response organization, Direct Relief, comprises public health practitioners, data scientists, epidemiologists, medical personnel and humanitarian responders from both organizations. CrisisReady advances scalable expertise in data driven decision making during public health emergencies [8], with a specific focus on the use of novel, privately held data streams for rapid surveillance and response. Our approach has three components: Data Readiness, Methods Readiness, and Translational Readiness.

Data readiness

The data needed to address impacts of climate-related disasters on health includes information on human mobility, medical and social vulnerabilities, health system capacity, the electric grid and other infrastructure, and hazard data ranging from fire perimeters to flood inundation. Many of these data, such as mobility data or satellite imagery are owned by private corporations; other data such as contact and location information of patients with durable medical equipment (i.e., the EMPOWER database maintained by HHS) are available with federal agencies, but not readily available to local responders. In the absence of regulatory requirements to make such data readily available, the duration, resolution, and timeliness of data are often subject to the priorities of data brokers; real-time access to disparate data sources is impossible without months to years of negotiations and trust-building between scientists, technology companies, other data brokers, response agencies, and communities themselves [9]. The data supporting CrisisReady's situation reports and interactive visualization tools is imported from a variety of sources; some are free and publicly available; others are private and/or purchased (Table 1). Data procurement entails pre-negotiated data sharing agreements and use policies so that when disaster occurs, data pipelines are already in place. Datasets are seldom interoperable, standardized or ready-to-use; alignment requires substantial processing capacity, currently available only at select institutions globally. In a collaborative process that involves data scientists, lawyers, and public health practitioners, sensitive data are procured, stored, and aligned using resolutions and formats that protect privacy while retaining public health utility through differential privacy algorithms and strict ethical use policies [10].

Methods readiness

Many data sources require careful assessment before being used to guide decisions. Population mobility information from technology companies such as Mapbox, Cuebiq and Meta reflects the social, economic, and demographic characteristics of users of specific digital applications and mobile devices. These data have their own uncertainties, biases, and issues of representativeness; when combined, they warrant sophisticated methodological rigor and assessment for accuracy, interpretability, and utility [11]. We depend on multidisciplinary internal and external collaborations drawing on the expertise

of public health professionals, medical personnel, epidemiologists, data scientists, humanitarian responders, and graphic designers, and on the lived experience of responders and affected communities to address these issues and define what information products we produce, why, and for whom. Our needs assessment process, which informs development of methods, tools, and reports, includes qualitative surveys of key stakeholders including members of affected communities. Resolving methodological challenges with stakeholders before an event occurs allows us to identify and communicate limitations during a disaster.

Translational readiness

The concept of translational readiness encompasses the array of technical, logistical, social, and educational factors that make information operationally accessible, relevant, practical, and useful. Even if an analysis is sound and timely, there is often limited capacity in the field to receive, understand and act on information based on novel, unfamiliar data streams. Integrating end-users into the development process has helped our team develop analytic products that are valued by the intended audience and address real-world needs and limitations. This approach helps ensure that recipients are familiar with analytic products and provides a pathway to integration in decision-making. In some cases, this has meant iterative workshopping of data pipelines, analytical methods, and visualization tools with potential end-users to build familiarity and incorporate suggestions for improvement. In other cases, Translational Readiness has meant developing communities of practice with partners in academia, government, and response agencies through collaborative support agreements, workshops, and trainings which expand capacity. We have supported a variety of processes ranging from development of new analytic methodologies specific to relevant questions from organizational partners to integration of mobility data into national disaster risk reduction policies and strategies [12].

In practice, escalating climate hazards present unanticipated challenges. Communities that are likely to be most affected are less likely to have the technical capacity and resources to take full advantage of available data to support planning and decision making [7]. They are, however, likely to have the most acute awareness of their needs and capacities to respond, mitigate and adapt. The multi-stakeholder approach underpinning the Data-Methods-Translational Readiness framework we have developed since the start of the COVID-19 pandemic [13] and deployed in disasters around the world including hurricanes, volcanic eruptions, and wartime displacements provides a model for scaling scientific capacity while retaining local relevance. We describe here the application of the Framework to health system preparedness for wildfires in California and the response to Hurricane Ida.

Case study: mapping human mobility and health system capacity during wildfires in California

Climate change is contributing to escalating frequency and intensity of wildfires in California [14]. Warmer, drier, windier summertime conditions increase the risk of ignition and the scale of conflagration, while wet wintertime conditions contribute to increased fuel availability [14]. Recent fire seasons have witnessed mandatory evacuations as well as voluntary movements of thousands of people. Wildfire response has also included public safety power shutoffs and power outages imperiling electricity-dependent medical care. Power outages and evacuations result in disruptions to health care and other essential services. Public health systems in affected communities and those receiving evacuees have limited information on who is vulnerable, and who is moving, when, and where, impeding optimization of timely resource allocation including medical transport, shelter, and reinstitution of medical care.

Since 2019, our research team has worked with public health agencies at the local, county and state level in California, including with representatives of CCLHO, CPCA, CalEMSA, CalOES, county emergency response planners, and officials from the CDC, FEMA and HHS to identify information gaps which if addressed would help optimize medical resource allocation and planning. The result is ReadyMapper, a digital platform that allows multiple stakeholders to query information on population vulnerability, infrastructure functionality, healthcare capacity, and population mobility [15]. Platform outputs include interactive visualizations and customizable situation reports. Development of this tool has depended on a multidisciplinary application of our Data, Methods, and Translational Framework:

Data pipelines

Near-real time data on wildfire perimeters and inpatient bed utilization are obtained from CalFire and The US Department of Health and Human Services via pre-established data import systems. Static data on population characteristics, healthcare facilities, and geographic features are stored and updated periodically as new data sets become available. Proprietary mobile device application utilization data is obtained from Data for Good at Meta in an anonymized, aggregated format at an 800 m resolution, which is sufficient to guide deployment of assets during a crisis but preserves anonymity for individual device users. This is complemented by telemetry data from Mapbox at 100 m resolution which uses an index of rates of device mobility to depict spatial and temporal change in population movement. In each case, data procurement is pre-negotiated, and can be activated at the onset of a wildfire event.

Methods

Integration of widely varying data types requires that analytic approaches be developed prior to the onset of a wildfire. Seemingly straightforward data can be complex to utilize. Mapping healthcare facilities in California required multiple databases; state data [16] did not include federally facilities on military bases, while federal datasets [17] did not include some local facilities. Creation of a comprehensive healthcare facility map ultimately required input from data scientists, web designers, medical personnel, and local emergency managers. Mobility data requires additional analysis; utilization data from the Meta platform is processed to provide near-real-time information on changes in population density and movement relative to a 90-day baseline period preceding the event. The result is a percentage change in the population of device users present in a given 800m tile, and the z-score of that change, which can be displayed as a heat map or aggregated at the level of a city, town, or county. This information is then aligned with other data ranging from pre-event demographics of the affected population to driving times from key features such as healthcare facilities using pre-defined approaches that have been refined using both historical and real-time disaster data. Determining the representativeness of the mobility data in the affected communities is challenging and varies widely across urban and rural California.

Community engagement and feedback

The ReadyMapper tool, including its user interface and mapping symbology, has been co-developed with partners in emergency management, public health, and humanitarian response. Interviews with key informants in these fields helped delineate the data gaps, analysis gaps, and use cases that informed subsequent development of the tool. As development and testing progressed, potential end-users were engaged in a process of routine iterative feedback, in which health officers, emergency managers, and other professionals interacted with the tool and identified areas for

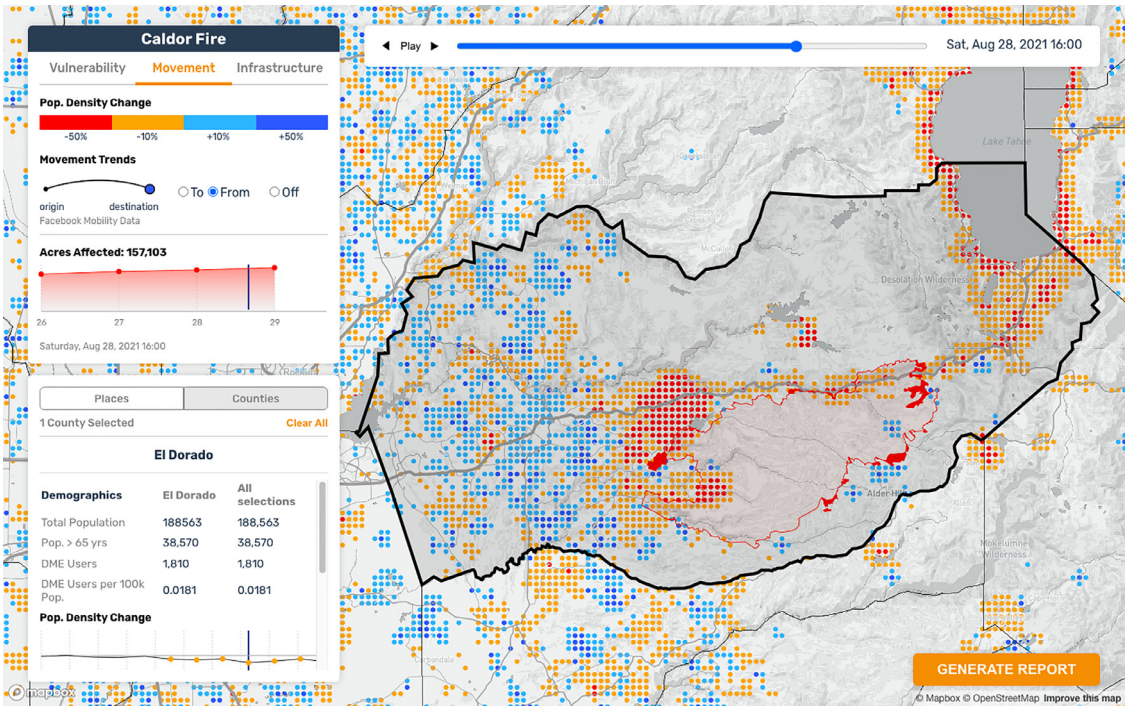

Fig. 1. Increases (blue) and decreases (orange/red) in population density during the Caldor Fire in El Dorado, CA as of August 21, 2021, inferred from aggregated device utilization data. The fire perimeter is visible as a red outline in the center of the image. The panel on the left, the time slider at the top, and the report generation button in the lower right provide a sampling of the tools available in the ReadyMapper platform. PDF Reports generated through the ReadyMapper platform contain an enhanced selection of statistics and data visualizations relative to default availability in the online interface, and can be customized to reflect the end-users' priorities. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

improvement, clarification, or modification. A launch event in August 2022 was held in Santa Barbara with state, county, private sector, and non-profit collaborators from across California; further refinement of the ReadyMapper tool to meet the needs of specific organizations is ongoing.

ReadyMapper now includes visualizations of baseline population vulnerability, healthcare and other infrastructure, and human mobility. The results can be viewed interactively, allowing users to tailor the visualization to their needs, or summarized in reports suitable for dissemination to decision makers (Fig. 1). Refinement continues as the ReadyMapper platform is adjusted to meet the needs of organizations responding to wildfires in California.

Case study: developing near-real-time situation reports for Hurricane Ida

Climate change is contributing to increasing hazards from Atlantic hurricanes, including escalating intensity, rainfall, risk of "stalling"

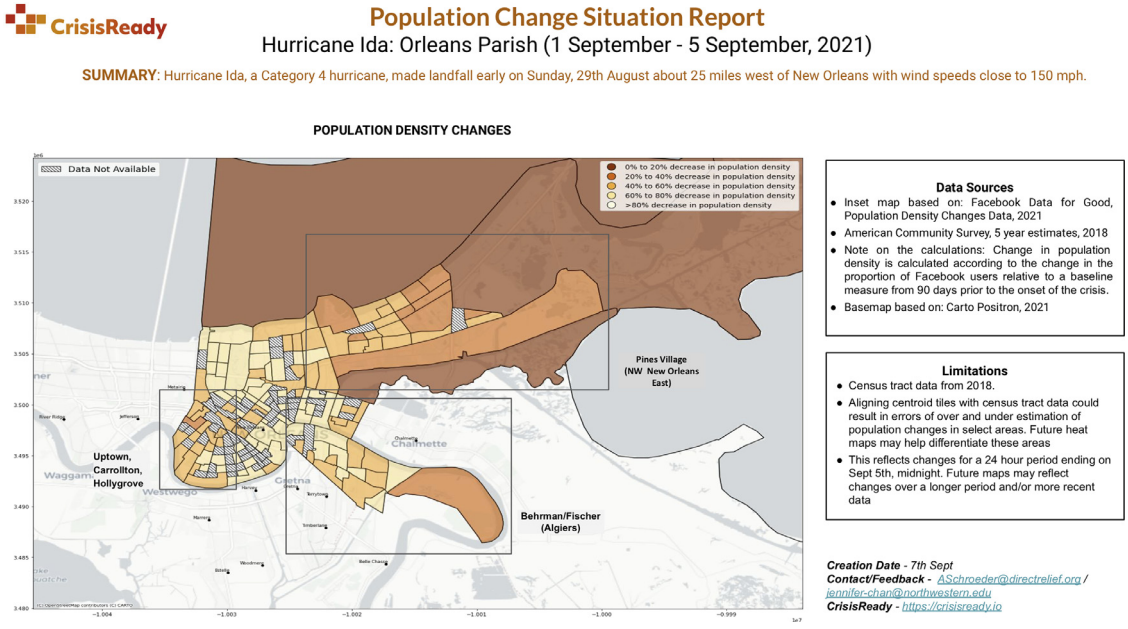

Fig. 2. A sample of a situation report describing population density changes in New Orleans following Hurricane Ida in early September 2021, as inferred from mobile application login data. Boxes on the right communicate dataset and methodological limitations, which are essential to consider when applying mobility results inferred from mobile devices to decision making during a disaster.

and rapid intensification, and storm surge hazards; in addition to direct injuries, hurricanes can cause substantial disruption, displacement, and resulting impacts on health and healthcare [18]. During Hurricane Ida's 2021 landfall in Louisiana, critical infrastructure such as roads, bridges and power lines were damaged, limiting accessibility of healthcare and threatening patients dependent upon electricity. Over 1 million customers were without power following the landfall, contributing to at least 10 deaths [19].

As the hurricane rapidly intensified, the Emergency Operations Center (EOC) in New Orleans was tasked with conducting post-storm evacuations. Traditional data sources such as 311 and 911 calls that the EOC monitors to understand the burden of risk to residents are usually biased in favor of wealthy census tracts that have well serviced digital infrastructure. The Office of Performance and Accountability (OPA) assisting the EOC reached out to CrisisReady to provide reports on the extent of sheltering within the Parish, using mobility data to supplement ongoing operations.

CririsReady adapted their efforts from an automated disaster situation report development process, which used pre-arranged data pipelines and methodology, to a bespoke effort which took into account the specific translational needs of the Office, including generating reports at the census tract level and using mobility data in conjunction with information on socioeconomic vulnerabilities. The CrisisReady team worked through several iterations to create PDF reports mapping three census tract clusters with high population proportions sheltering in place. The Office of Accountability and Performance asked for visualizations daily, and later requested more detailed data products that could be passed to in-house analytics teams to meet their evolving needs. Outputs included changes in mobility and baseline population information. Maps were complemented by information detailing data sources and limitations to help users understand data regency and underlying methodologies (Fig. 2). The outcome of this process was a set of plug-and-play modules and functions that could be adapted to the needs of the client and that clearly communicated known uncertainties regarding extrapolation of device mobility information to the entire population. This process allowed the Office to have reliable estimates on the extent of sheltering within the city on each day such that post-storm evacuations could be carried out if necessary.

Conclusion

Climate-related disasters such as wildfires and hurricanes present a mounting challenge for policymakers, planners, and responders. Multi-disciplinary, multi-institutional collaborations that engage impacted individuals and organizations as essential co-creators can support novel approaches to climate change adaptation that would be difficult to develop or implement in isolation. The Data-Methods-Translational Readiness approach applied to wildfires and hurricanes in these case studies can put useful analyses from novel data sets in the hands of those who need them to address the escalating health impacts of climate change, regardless of their current analytical and spatial technology capacities.

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Author Contributions

Andrew Schroeder – Writing – original draft, review & editing Caleb Dresser – Writing – original draft, review & editing Akash Yadav – Writing – original draft, methodology, visualization Jennifer Chan – Conceptualization, methodology Shenyue Jia – Visualization, methodology Caroline Buckee – Writing – review & editing, supervision Satchit Balsari – Writing – review & editing, supervision.

Author Agreement Statement

We the undersigned declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us. We understand that the Corresponding Author is the sole contact for the Editorial process. Dr. Balsari is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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