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Unveiling hidden migration and mobility patterns in climate stressed regions: A longitudinal study of six million anonymous mobile phone users in Bangladesh

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ABSTRACT

Climate change is likely to drive migration from environmentally stressed areas. However quantifying short and long-term movements across large areas is challenging due to difficulties in the collection of highly spatially and temporally resolved human mobility data. In this study we use two datasets of individual mobility trajectories from six million de-identified mobile phone users in Bangladesh over three months and two years respectively. Using data collected during Cyclone Mahasen, which struck Bangladesh in May 2013, we show first how analyses based on mobile network data can describe important short-term features (hours–weeks) of human mobility during and after extreme weather events, which are extremely hard to quantify using standard survey based research. We then demonstrate how mobile data for the first time allow us to study the relationship between fundamental parameters of migration patterns on a national scale. We concurrently quantify incidence, direction, duration and seasonality of migration episodes in Bangladesh. While we show that changes in the incidence of migration episodes are highly correlated with changes in the duration of migration episodes, the correlation between in- and out-migration between areas is unexpectedly weak. The methodological framework described here provides an important addition to current methods in studies of human migration and climate change.

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1. Introduction

Where climate change renders places less habitable and productive, vulnerable populations often migrate (Black et al., 2011; McLeman and Smit, 2006). It is critical to develop methods for quantifying and modeling migration as a behavioral response to climate-related weather extremes (Palmer and Smith, 2014). However, this research is hampered by methodological difficulties in data collection, difficulties in attributing individual migration events to climate change, and by the large number of contextual factors found to influence migration (Feng et al., 2010; Henry et al., 2004; Mueller et al., 2014). Currently, representative household surveys form the basis of the knowledge on climate-induced migration (Black et al., 2013; Bohra-Mishra et al., 2014; Gemenne, 2011; Gray and Mueller, 2012). While household surveys are likely to remain the methodological cornerstone of efforts to quantify the sizes and causal mechanism behind climate-induced migration patterns, they carry several limitations.

First, migration trajectories resulting from climate-related impacts are highly complex and dynamic (Castles et al., 2005;

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Kniveton et al., 2012) and frequently include repeated movements across short distances (Tacoli, 2009). Analysis of such trajectories therefore requires detailed mobility data over a range of temporal and spatial scales, which is often not collected, analysed or reported in traditional survey based research studies (Bohra-Mishra et al., 2014; Findley, 1994). Secondly, household surveys are vulnerable to recall and interviewer bias, especially when multiple trips by several family members are to be recorded (Wesolowski et al., 2013; Wesolowski et al., 2012). Third, logistical difficulties of data collection mean that longitudinal household surveys are not always performed at the same time at each follow-up round, which may bias results when significant seasonality exists in migration patterns (Adger et al., 2002; Gray and Mueller, 2012; Henry et al., 2004; Raleigh and Kniveton, 2012; Saldaña-Zorrilla and Sandberg, 2009; Smith and McCarty, 1996). Fourth, due to the sudden and unanticipated nature of most climatic events, high-quality survey data on resulting migration patterns is extremely difficult to collect, especially when migrating households are spread across large areas (Fussell et al., 2014).

To adequately understand and quantify the interplay between extreme weather events, changing habitability and migration, it would be ideal to supplement traditional survey-based methodologies with analysis of longitudinal, high-resolution, individual-level mobility data, covering both local and national scales (Palmer and Smith, 2014). One data source that potentially can fulfill these requirements, while circumventing the above limitations, is mobile network operator call detail records (CDRs). CDR data comes in an industry standard format, which contains for each of the mobile network operator's subscribers, the location of the closest mobile phone tower at the time of each call, text message or data download. The data is routinely collected and stored by mobile network operators (see Section 2, S1). Previous studies have used CDR data for quantifying population mobility patterns to understand the spread of infectious disease (Bengtsson et al., 2015; Tatem and Smith, 2010; Wesolowski et al., 2012), infer regular internal migration patterns (Blumenstock, 2012), and to predict population movements (Deville et al., 2014; Lu et al., 2012, 2013).

Difficulties in quantification and prediction of migration as an adaptive response to climate change are especially pertinent in countries like Bangladesh, where climate resilience is a major concern due to cyclone vulnerability combined with sea-level rise that is occurring faster than global averages, exposing roughly 11 thousand km^2 of land and 20.5 million people to inundation risk by 2050, based on the IPCC AR4 medium scenario (Karim and Mimura, 2008). Usage of mobile phones in Bangladesh is increasing rapidly. Between 2011 and 2014, the proportion of households with at least one mobile phone rose from 78% to 89%, with much of that growth concentrated among rural households (S1) (National Institute of Population Research and Training (NIPORT), 2015).

To assess how mobile network data can augment our understanding of migration during and after extreme weather events across a wide range of temporal and spatial scales, we analysed two de-identified datasets from the largest mobile network operator in Bangladesh, Grameenphone (GP). Analyses were done both on the environmentally stressed areas in the Southern delta region of Bangladesh before and after Cyclone Mahasen, as well as on long-term national level migration patterns. The first dataset (D1) covers 1 April–30 June 2013, the period before and after Cyclone Mahasen, which struck Bangladesh on 16 May 2013 (see Section 2 and S1). The data includes, for each call, the position of the mobile phone tower closest to the caller for all 5.1 million GP phones in Barisal division and Chittagong district, the primary impact zones of Cyclone Mahasen (Fig. S2b). The second dataset (D2) covers a simple random sample of 1 million mobile phones drawn from the entire national set of mobile phones in the GP network. This dataset spans almost two years (1 January 2012–30 November 2013) and includes, for each calendar month, the location of each mobile phone's most frequently used tower that month (S1).

2. Data and methods

Each time a subscriber makes a phone call with his or her mobile phone, a call detail record (CDR) is generated in the system of the telecom operator. A CDR includes a timestamp of the call, the mobile phone number and the mobile tower used to route the call. This data can be used to analyse how phones move between towers

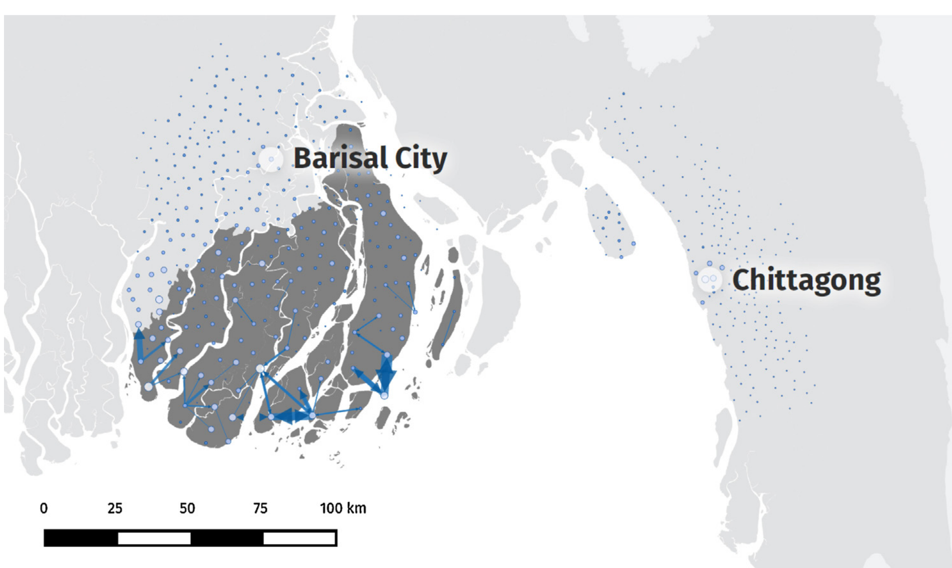

Fig. 1. High-risk mobility of mobile phone users during cyclone landfall and passing (00:00–06:00 a.m., 16 May). The dark grey area indicates the most affected areas (REACH Initiative, 2013). The thickness of each link represents the number of moving SIM cards, and the size of each node is proportional to the number of incoming subscribers to the node (max/min flow: 510/59 moves). Links encode movement that is greater than 10 km and by 50 or more subscribers (see Section 2 and S3). The map shows movements of phone users over distances of more than 20 km, from the Southwestern coast of Barisal toward the interior, as well as a pronounced southward flow within the island of Bhola in Southeastern Barisal. At this time, all people in the area should have taken shelter.

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