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Bingqing Xiong
City University of Hong Kong, bxiong2-c@my.cityu.edu.hk

Na Jiang
City University of Hong Kong, najiang3-c@my.cityu.edu.hk

Mengyao Fu
City University of Hong Kong, mengyaofu3-c@my.cityu.edu.hk

Jian Yao
China Unicom (Shanghai Branch), yaojian1@chinaunicom.cn

Chee-Wee Tan
Copenhagen Business School, ct.digi@cbs.dk

See next page for additional authors

Authors
Bingqing Xiong, Na Jiang, Mengyao Fu, Jian Yao, Chee-Wee Tan, Eric Lim, Weiquan Wang, and Jianfeng Gu

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Research-in-Progress

Bingqing Xiong
City University of Hong Kong
Hong Kong
bxiong2-c@my.cityu.edu.hk

Na Jiang
City University of Hong Kong
Hong Kong
najiang3-c@my.cityu.edu.hk

Mengyao Fu
City University of Hong Kong
Hong Kong
mengyaofu3-c@my.cityu.edu.hk

Jian Yao
China Unicom (Shanghai Branch)
China
yaojian1@chinaunicom.cn

Chee-Wee Tan
Copenhagen Business School
Denmark
ct.digi@cbs.dk

Eric Lim
UNSW Sydney
Australia
e.t.lim@unsw.edu.au

Weiquan Wang
City University of Hong Kong
Hong Kong
weiquan@cityu.edu.hk

Jianfeng Gu
China Unicom (Shanghai Branch)
China
gujf@chinaunicom.cn

Abstract

All Weather conditions affect human behaviors and the growing number of Mobile Weather Applications (MWAs) has amplified this effect. Yet, little is known about how human seek to actively control their behavior by appropriating mobile technology to anticipate changing weather conditions. Guided by Anticipatory Behavioral Control Theory (ABCT), this study endeavors to bride the abovementioned knowledge gap by investigating how the interface design and usage of MWAs would impact the relationship between abnormal weather conditions and users' movement patterns. From analyzing panel data collected on the hourly movement trajectories of over 1.95 million anonymous mobile phone users over a 2-month period, we strive to shed light on the moderating influence of content representation and usage intensity of MWAs on the relationship between weather conditions and human behaviors.

Keywords: Weather forecast, movement pattern, anticipatory behavioral control, mobile weather applications

Introduction

From a desire for intimacy in cold conditions (Hong and Sun 2012) to an increased urge to gamble when the sun is shining (Bassi et al. 2013), there is little doubt that weather has profound effects on humans. Indeed, past studies have linked weather conditions, in the likes of humidity, temperature, rain, and sunshine, to changes in individuals' criminal and suicidal tendencies (Cohn 2016), cognitive status (Keller et al. 2005), mood swings (Goetzmann et al. 2015), as well as investment and shopping behaviors (Busse et al. 2015; Li et al. 2017). Although this line of work has generated indisputable evidence attesting to the cognitive and behavioral impact of weather, it tends to treat humans as passive receipts who react in a reflexive fashion (cf. Goetzmann et al. 2015), an assumption which may not hold true with advances in mobile technology. Due to the permeation of mobile devices across every walk of life, individuals are now able to anticipate weather conditions by monitoring weather updates on

Mobile Weather Applications (MWAs). The ubiquitous nature of these applications implies that the effects of weather forecasts are rendered more salient in our daily lives (Hong and Tam 2006). According to a study from Online Publishing Association (OPA), checking weather forecasts is the number one regular activity on mobile phones[1]. By keeping abreast of weather forecasts through MWAs, individuals can adjust their movement patterns to accommodate changing weather conditions.

To this end, we construct a research model that posits individuals' usage patterns of MWAs as having a moderating influence on the relationship between weather conditions and human behavior. Specifically, our study is anchored on the Anticipatory Behavioral Control Theory (ABCT), which holds that behaviors are goal oriented rather than stimulus-driven and that human actions are almost always rooted in anticipation of the future (Hoffmann et al. 2007). Additionally, we also outline our plans for an empirical study to validate the hypothesized relationships in our research model.

Towards an Anticipatory Behavioral Control Model of the Effects of Weather Conditions on Human Behaviors

Weather affects humans both psychologically and physically. Persinger and Levesque (2016) discovered that weather accounts for over 40% of changes in mood. An upbeat mood induced by sunny weather can positively stimulate market index returns and stock valuation (Hirshleifer and Shumway 2003). Likewise, Busse et al. (2015) found that a larger number of convertible cars are purchased by consumers on sunny days with clear skies whereas Li et al. (2017) observed that mobile promotion effectiveness is highly dependent on weather conditions. Even though prior research has accumulated extensive knowledge on the effects of weather on humans, advances in mobile technology have challenged conventional wisdom by converting individuals from passive recipients to proactive agents who can exercise greater control over how they react to changing weather conditions. For this reason, this study draws on the ABCT to investigate the moderating impact of MWAs on the relationship between weather conditions and human behavior.

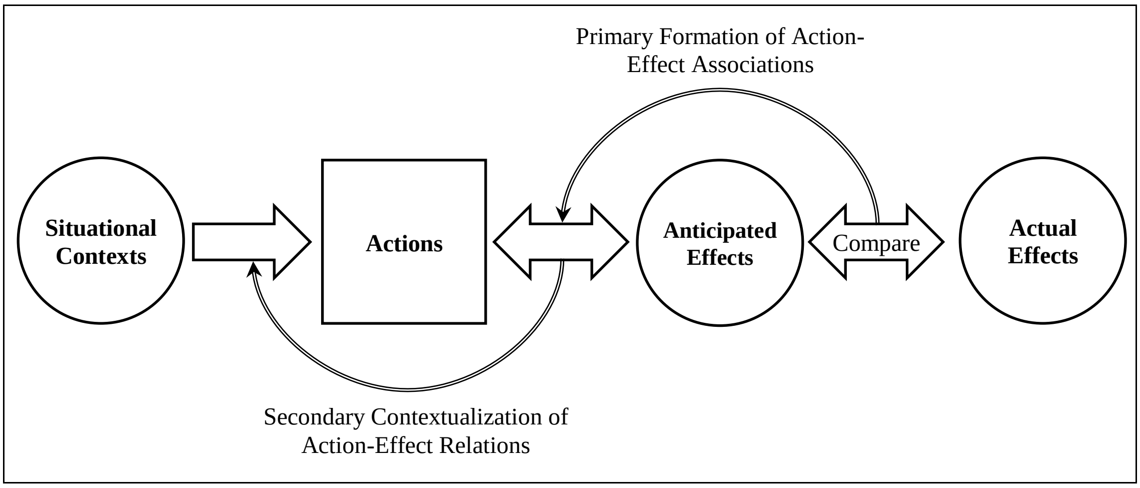

Figure 1. Anticipatory Behavioral Control Framework

McCulloch (1949) equate human brains with learning systems. As postulated by the ideomotor theory, humans' eventual selection of a course of action among a set of behavioral options is activated by the mere anticipation of the sensory experience resulting from the action (Wenke and Fischer 2013). From this premise, Hoffmann et al. (2007) proposed the ABCT to take into account the supremacy of action-effect learning and the conditionalization of action-effect relations to situational contexts (see Figure 1). The ABCT posits that behaviors, as opposed to being stimulus-driven, are purposeful and targeted so much so any ensuing action can be construed as a form of anticipation (Hoffmann et al. 2007). Four focal concepts are espoused by the ABCT, namely actions, effect anticipations, actual effects, and

[1] URL: http://www.huffingtonpost.com.au/entry/the-number-one-use-smartphone_n_1818632.

situational contexts. According to the ABCT, a course of action is pursued based on the anticipation that the execution of the action will bring about desired effects. Following which, the actual effects of performing the action are compared with anticipated effects and the strength of the corresponding action-effect relation is adjusted whenever necessary. There is also a secondary learning process as situational contexts are integrated. If the action-effect is contextualized, the stored context and present situation will be associated. Extrapolated to the context of our study, we submit that abnormal weather conditions represent a situational context in which the usage of MWAs and the way they are designed would modify the strength of association between the learning process and situational contexts. Figure 2 depicts our proposed research model.

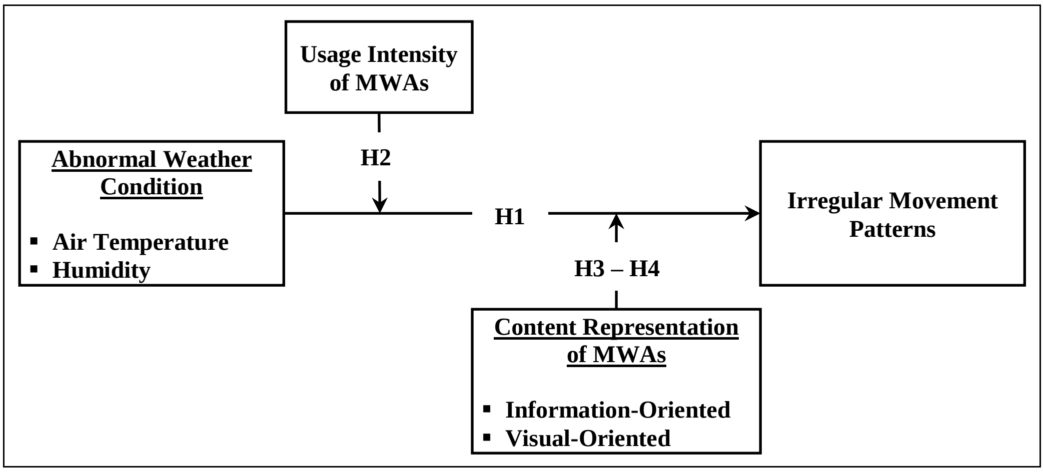

Figure 2. Anticipatory Behavioral Control Model of the Effects of Weather Conditions on Human Behaviors

Hypotheses Formulation

It is apparent that changing weather conditions govern human behaviors (Pieters and Zeelenberg 2005). As alleged by Efferson et al. (2016), individuals are more inclined to reduce outdoor activities and remain indoors during extremely high temperatures or rainy conditions due to previous experience with bad weather conditions. Conceivably, consistent with ABCT, weather conditions can be construed as contextual situations that confront humans and shape their assessment of action-effect relations by compelling individuals to continuously adapt their schedules to real-time weather conditions. For instance, in times of bad weather, commuters may head out for work earlier than usual in anticipation that it would take them much longer to arrive at the workplace. We therefore hypothesize that:

Hypothesis 1: Abnormal weather conditions positively influence the irregularity of movement patterns.

Adhering to theories of decision making, we argue that the usage intensity of MWAs mitigates the effects of weather conditions on human behaviors. Prior research has indicated that the availability of relevant information typically improves the accuracy of decisions (Porat and Haas 1969; Streufert 1973). Weather forecasts accessible from MWAs serves as a critical source of information for deriving anticipations and evaluating actions. In keeping with the ABCT, the more information one obtains from MWAs, the greater their anticipatory control over weather conditions. If the actual outcomes from proactive control behaviors conform to the anticipated ones, the corresponding action-effect relation will be strengthened (Hoffmann et al. 2007). Consequently, we hypothesize that the usage of MWAs could reinforce the action-effect relation and cause individuals to deviate more significantly from their usual movement patterns in response to changing weather conditions:

Hypothesis 2: Usage intensity of MWAs will reinforce the relationship between abnormal weather conditions and irregular movement patterns.

Yet, despite official meteorological data being reflective of weather condition, the informational representation of the same weather condition across MWAs could differ according to the amount, range, and type of content being represented. We hence expect the interface design of MWAs to have an impact on users' level of awareness and decision-making performance (SpeierMorris 2003). As contended by Hong et al. (2014), the way a piece of information is delivered will dictate the insights to be gleaned from the information and ultimately determine users' decisional patterns. In the same vein, MWAs aid users by reducing complex meteorological data into simpler and digestible forms. We therefore employ the term ***content representation*** to refer to the intermediate steps in MWAs for converting meteorological data into comprehensible formats (cf. Kim et al. 2016). Past studies have shown that data characteristics such as dimensionality, scale, and cardinality can drive decision making by varying the appropriateness of information presentation formats (Lurie and Mason 2007). Consequently, we build on prior research in information systems to accentuate two dimensions of content representation that are likely to be deterministic of users' subsequent behaviors: namely information- and visual-oriented representations (Lurie and Mason 2007).

Information-Oriented *Content* Representation: Information-oriented representation consists of contextual meta-information that is appended to data values (e.g., colors) for content differentiation purposes (Lurie 2004). One definitive aspect of information-oriented content representation is the level of 'vividness', which captures the extent to which weather forecasting constitutes the primary function of a MWA. It is common for MWAs to be inundated with other features (e.g., calendars), thereby distracting users from paying attention to weather forecasts. Information-oriented representation can thus draw users' attention to weather forecasts through contextual meta-information. We therefore hypothesize that the level vividness will strengthen the effects of abnormal weather conditions on irregular movement patterns by altering the saliency of weather forecasts relative to other information being presented in MWAs (cf. Hsee 1996):

Hypothesis 3: Information-oriented content representation of MWAs will strengthen the relationship between abnormal weather conditions and irregular movement patterns.

Visual-Oriented Content Representation: Visual-oriented representation is founded on task-related attributes, which include interactivity and depth of content representation. Interactivity is the extent to which users are able to interact with the content presented in MWAs. In the context of this study, the interactive content representation can, for instance, be accomplished through the provision of anthropomorphic characters that interact with users. Within extant literature, scholars have confirmed that interactivity can bring about effective delivery of available content by enticing users to bolster their involvement (Teo et al. 2003). Interactivity features often culminate in better alignment between digital environments and reality, thereby reducing users' learning curve (Teo et al. 2003). In other words, interactivity can strengthen the relationship between abnormal weather conditions and irregular movement patterns through more engaging representation of weather forecasts.

Apart from interactivity, the depth of content representation, which reflects the extent to which MWAs are able to portray meteorological data in high levels of granularity (e.g., per hour over a 24-hour period), is also likely to affect how weather forecasts are accessed and processed by users. For instance, MWAs, which provide scrollbars or zooming features enabling meteorological data to be viewed at varying levels of granularity, are probably better in catering to users' meets by permitting the latter to react dynamically to anticipated changes in weather conditions (cf. Dennis and Carte 1998). That is, the depth of content representation can bestow users with a better understanding of weather predictions, thereby strengthing the relationship between abnormal weather conditions and irregular movement patterns through better forecasting. We therefore hypothesize that:

Hypothesis 4: Visual-oriented content representation of MWAs will strengthen the relationship between abnormal weather conditions and irregular movement patterns.

Methodology

To validate our research model, we plan to conduct OLS regression analysis on a massive dataset containing application usage and locational data for more than 1.95 million anonymous mobile phone users, which is collected by Shanghai Unicom, one of China's biggest mobile operators (see Table 1).

Table 1. Description of Dataset

Dataset	Description
Set I: User Tag	Dataset I contains the following information for each of the 1,959,103 mobile phone users who appeared in Shanghai from April 1 to May 31, 2017: user ID, mobile terminal information, roaming behavior, consumption patterns, application usage (page view for 300 selected applications), number of visits to the site, including local and out-of-town users.
Set II: Location Record	Latitude and longitude information of the grid center points for each user in Dataset I over a 24 hours period, including the local and field. There should be 1464 location records for every user.
Set III: Meteorological Data	Publicly available historical meteorological data which had been recorded by Wunderground.com for every half an hour in Shanghai. Each meteorological record consists of weather conditions (i.e., sunny, cloudy, overcast, foggy, snowy, and rainy), temperature, and humidity.

Data Analysis

Independent Variables: For this study, the exogeneous variable is the weighted-average deviation from normal temperature and humidity in each hour, for Shanghai. Although there could be other key indicators (e.g., wind speed and air quality) of abnormal weather conditions, we do not take them into consideration at this time, but they will be incorporated into our data analysis in subsequent stages. Abnormal weather conditions refer to sharp changes in temperature and humidity (i.e., deviating from average temperatures and humidity in the same location over long periods). To illustrate, if 1 p.m. through 4 p.m. on Apr 1, 2017, are warm and sunny and at 5 p.m. it starts to rain, we deem it to be abnormal. Due to the granularity of our dataset (i.e., hourly records on location and weather condition), our study has an added advantage over prior research that predominantly concentrates on coarser-grained daily analysis.

The deviation of temperature from normal in moment *s* of day *d* is formulated as

$$T_{s,d} = (t_{s,d} - \alpha_m), \tag{1}$$

where $t_{s,d}$ is the temperature in moment *s* of day *d*, α_m is the long-run average for temperature in month *m*:

$$\alpha_m = \sum_{1}^{n_m} \left(\sum_{1}^{24} t_{s,d} \,/\, (n_m \cdot 24) \right), \tag{2}$$

and n_m refers to the total number of days in month *m*.

Similarly, the deviation of humidity from normal in moment s of day d is formulated as

$$H_{s,d} = (h_{s,d} - \beta_m), \tag{3}$$

where $h_{s,d}$ is the humidity in moment *s* of day *d*, β_m is the long-run average for humidity in month *m*:

$$\beta_m = \sum_{1}^{n_m} \left(\sum_{1}^{24} h_{s,d} \,/\, (n_m \cdot 24) \right), \tag{4}$$

and n_m refers to the total number of days in month *m*.

The second explanatory variable is the type of content representation in MWAs: information versus visual orientation. In our dataset, we have records on the usage patterns for 10 MWAs. The information- and visual-oriented content representations for each of the 10 MWAs will be coded via a Likert scale for comparison purposes. For instance, Mojitianqi is geared towards the visual-oriented representation, whereas, Oppo Weather may lean towards information-oriented representation.

Table 2. Application Usage Comparison

User Tag	Application Usage (Number of Page Views)									
	Weather	Transiting	2345tian qiwang	Oppo Weather	The Weather	Mojitianqi	Shishitianqi	China Weather	365 Calendar	Wannian li
X	0	0	0	0	0	8	0	0	0	0
Y	0	0	0	6	0	0	0	0	0	0
Z	0	0	0	20	0	0	0	0	0	0

The third explanatory variable is the usage intensity of MWAs. As depicted in Table 2, users Y and Z share the same affinity for weather applications, but with different numbers of page views.

Dependent Variable: In our study, location records are updated hourly, from April 1 to May 31 in 2017. There are 1,464 location records for every user and they are presented in 2-dimensional space, i.e., as (x, y) coordinates on a geographical map. We employ distance deviation to denote irregular movements of users. The deviation of location from average in moment *s* of day *d* is formulated as:

$$\text{Distance}_{s,d} = |(L_{s,d} - l_{s,m})|, \tag{5}$$

where $L_{s,d}$ is the location in moment *s* of day *d*, $l_{s,m}$ is the long-run average location for the same moment *s* in month *m*:

$$l_{s,m} = \left(\sum_{1}^{n_m} x_{s,d}/n_m , \sum_{1}^{n_m} y_{s,d}/n_m\right), \tag{6}$$

x, *y* refers to latitude and longitude respectively, and n_m refers to the total number of days in month *m*.

Projected Outcome: In Figure 3 and Table 3, we illustrate two discrete trajectories of user X that occur in the same time period across two separate days with normal and abnormal weather condition respectively. Distance deviation is measured as the deviation of user X at the moment *s* from the average trajectory during the same time period for the month of April.

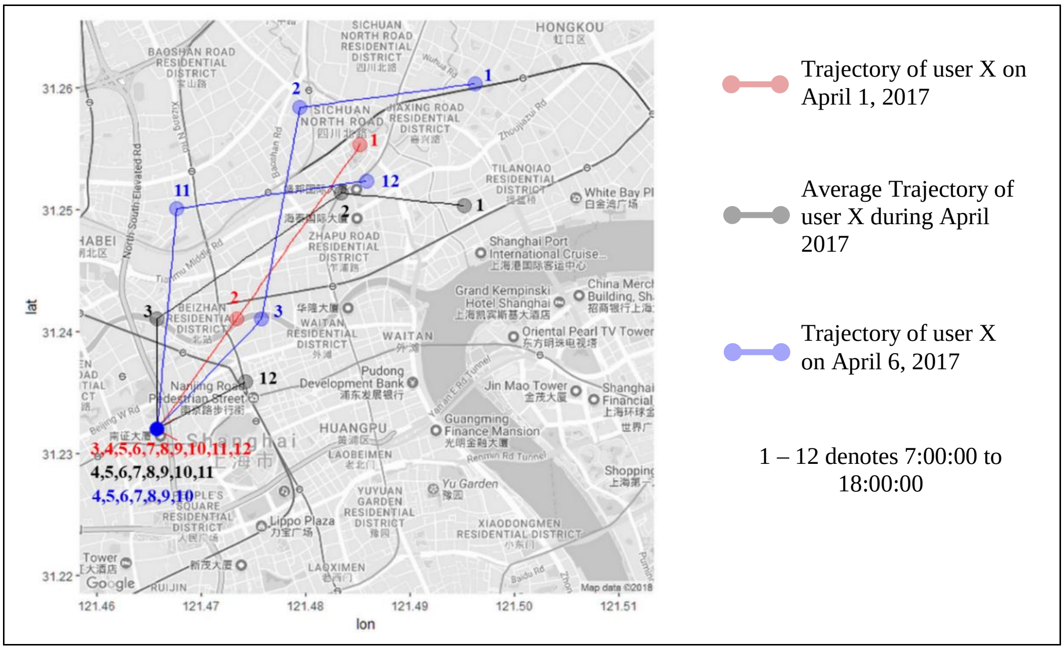

Figure 3. Movement Deviation of User X in Google Map

Further Analysis: We intend to continue to enhance this study in ruling out the effect of individual heterogeneity through a Difference in Difference (DID) test. It is possible that user with higher intention to forecast weather may have a higher usage intensity of MWAs. To check the robustness of our results to this potential bias, we will perform analyses of DID.

Table 3. Movement Deviation of User X

Moment [7 am – 16 pm]	1st April 2017			Average Trajectory		6th April 2017		
	Latitude (x)	Longitude (y)	Distance Deviation (m)	Latitude (x)	Longitude (y)	Latitude (x)	Longitude (y)	Distance Deviation (m)
7:00:00	31.25532	121.48521	1149.25	31.25032	121.49521	31.26032	121.49621	591.47
8:00:00	31.24105	121.47342	1263.13	31.25137	121.48342	31.25837	121.47942	602.54
9:00:00	31.23205	121.46578	521.80	31.24104	121.46578	31.24104	121.47578	1111.95
10:00:00	31.23205	121.46578	0.00	31.23205	121.46578	31.23205	121.46578	0.00
11:00:00	31.23205	121.46578	0.00	31.23205	121.46578	31.23205	121.46578	0.00
12:00:00	31.23205	121.46578	0.00	31.23205	121.46578	31.23205	121.46578	0.00
13:00:00	31.23205	121.46578	0.00	31.23205	121.46578	31.23205	121.46578	0.00
14:00:00	31.23205	121.46578	0.00	31.23205	121.46578	31.23205	121.46578	0.00
15:00:00	31.23205	121.46578	0.00	31.23205	121.46578	31.23205	121.46578	0.00
16:00:00	31.23205	121.46578	0.00	31.23205	121.46578	31.23205	121.46578	0.00
17:00:00	31.23205	121.46578	0.00	31.23205	121.46578	31.25007	121.46763	1065.99
18:00:00	31.23205	121.46578	966.23	31.23585	121.47424	31.25237	121.48579	1603.00

Expected Contributions to Theory and Practice

Past studies share a tendency to examine the effects of weather condition on human behaviors from a reactive angle. Departing from this premise, we contest that individuals, empowered by advances in mobile technologies, strive to exert control over changing weather conditions. Inspired by the ubiquity of mobile devices and the availability of MWAs, we draw on ABCT to tease out design and usage considerations of weather forecasting applications that would shape humans' reactions to changing weather conditions. We introduce interface design and usage intensity MWAs as moderating influences on the relationship between weather conditions and users' movement patterns. Furthermore, in contrast to contemporary studies which are predominantly grounded in coarser-grained weather conditions (e.g., sunny, rainy, or cloudy), we endeavor to validate the aforementioned hypothesized relationships at a higher level of granularity (i.e., hourly fluctuations in temperature, humidity, and location). In turn, this would yield invaluable insights that can be harnessed by developers to design content representations for displaying weather forecasting information in comprehensible and digestible formats.

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