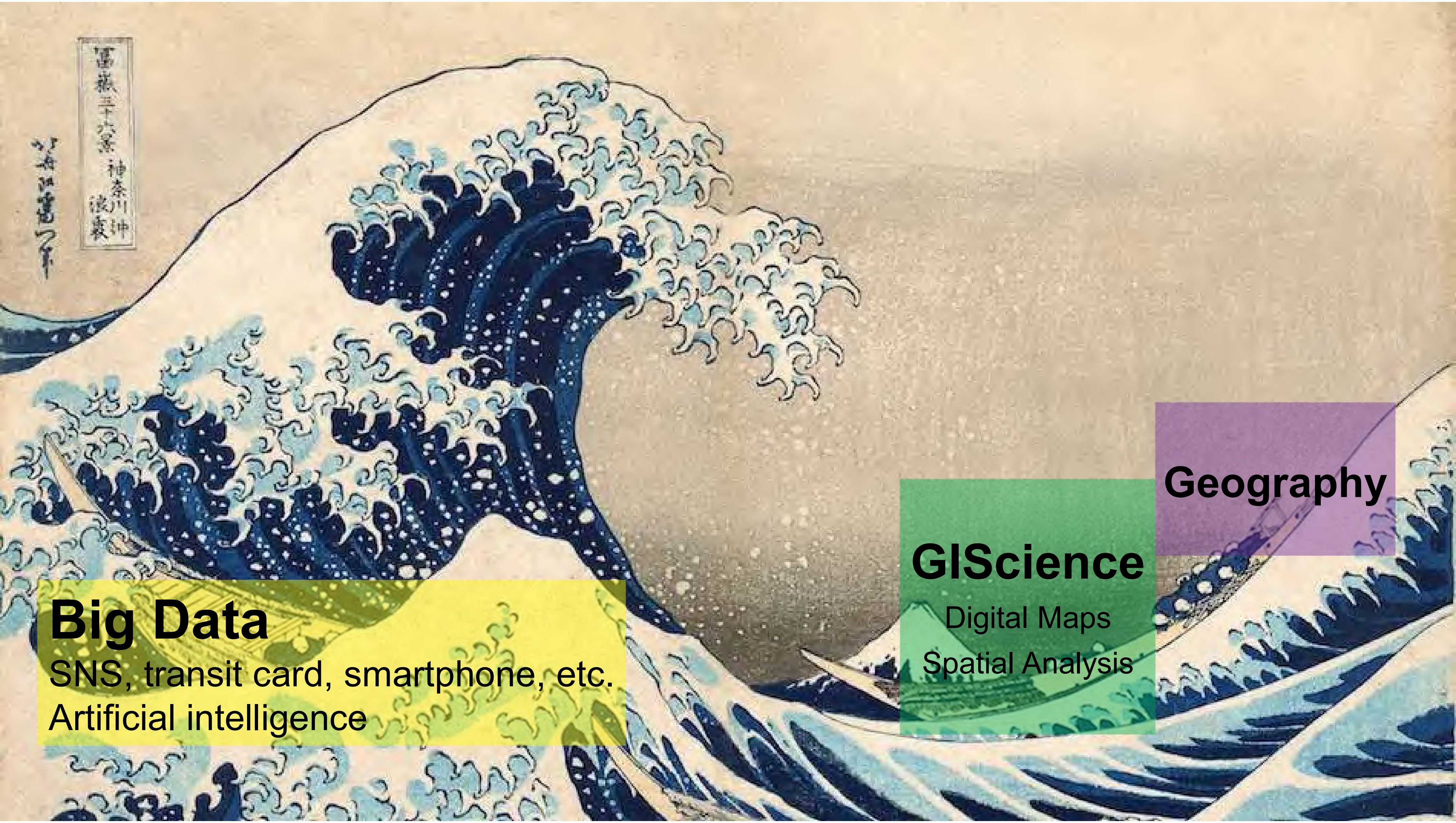
Northern Institute, CDU, 12 November 2025

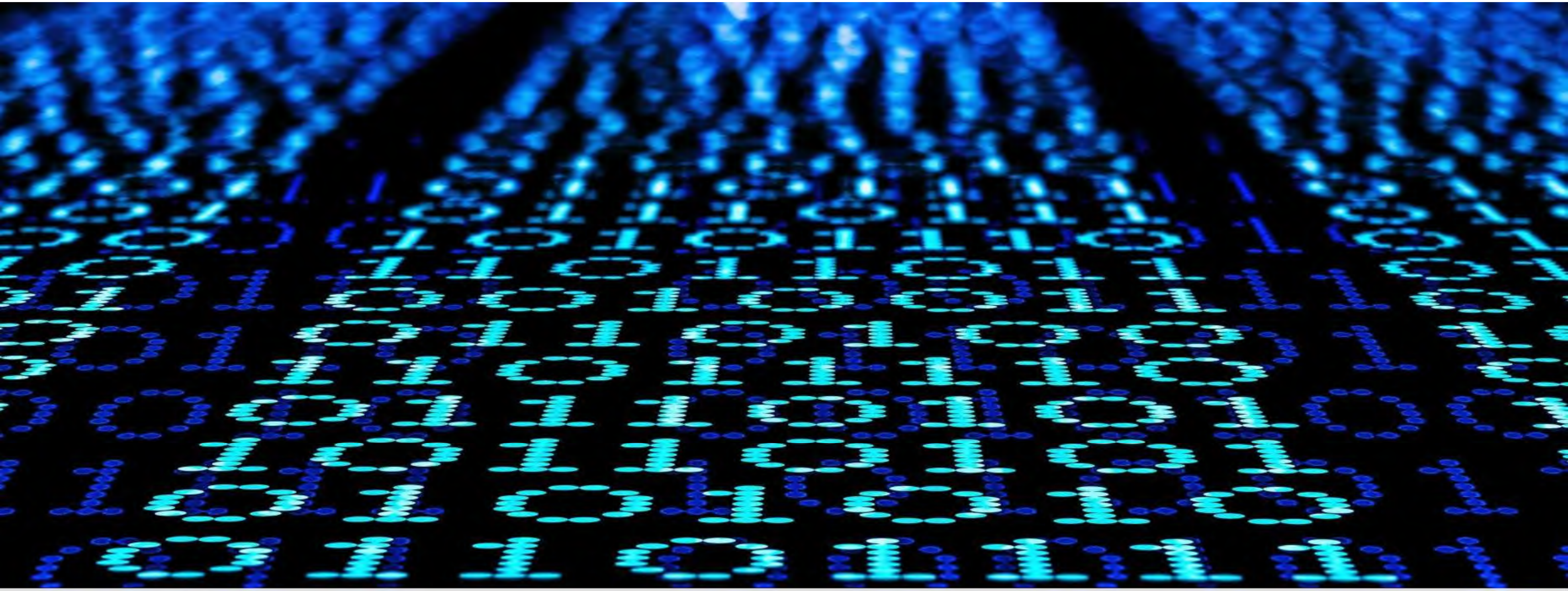
Mobile Phone Big Data and the COVID-19 pandemic: Progress Report

RITSUMEIKAN

Kazumasa HANAOKA
Ritsumeikan University, Japan

INTRODUCTION

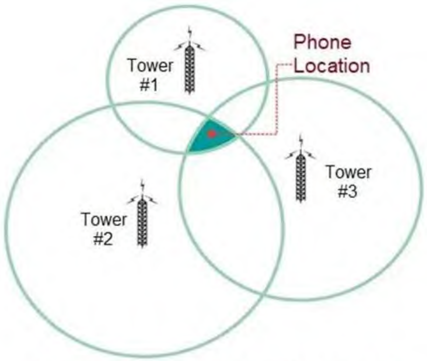

Geography
GIScience
Digital Maps
Spatial Analysis
Big Data
SNS, transit card, smartphone, etc.
Artificial intelligence



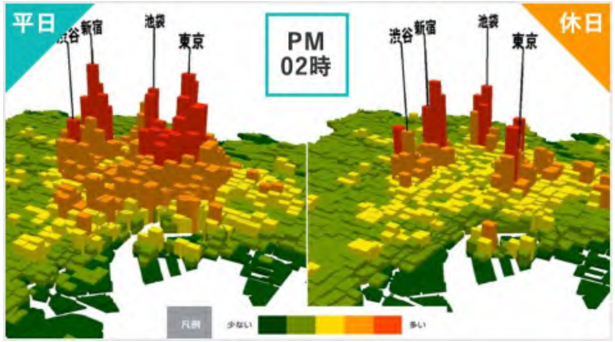
EMERGENCE OF BIG DATA IN THE 2010S

MOBILE PHONE DATA IN JAPAN

Two Types of Locational Data Collection:



Cellular Tower Triangulation Positioning



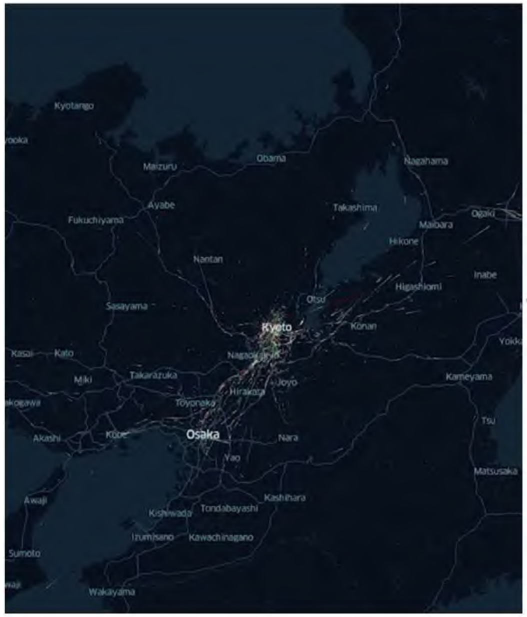
出典：https://mobaku.jp/service/jpn_distribution/

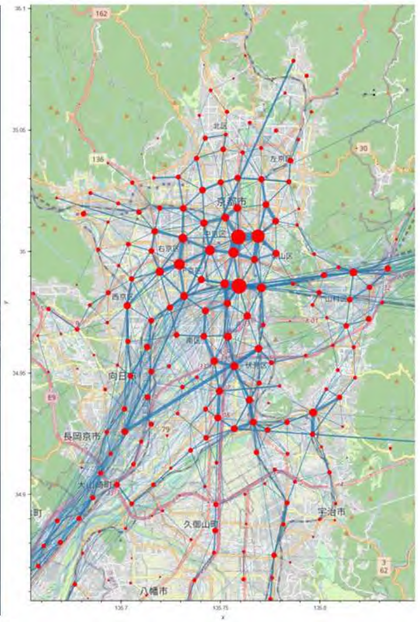
Cellular tower-based data

- Providers: Mobile carriers
- Data format: Grid cells (125 m, 250 m)
- Continuous recording and broad population coverage

App-based data (GPS and Wi-Fi network)

- Providers: Mobile carriers and app developers (e.g., KDDI, Agoop, Blogwatcher)
- Data format: Trajectories (x-y coordinates)
- Detailed trajectory data





TRAJECTORY DATASET (PROVIDER: AGOOP CORP)

Visualization of people's movement flows into and out of Kyoto City on 1 July 2020

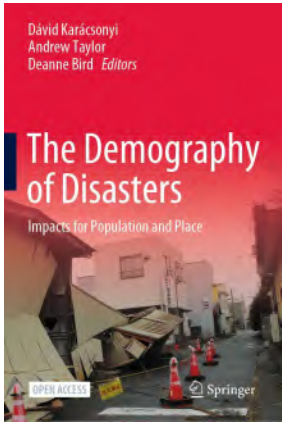
Kepler.gl(Developed by UBER)

DISASTER & BIGDATA

When unexpected events such as natural disasters or pandemics occur, big data derived from mobile phones is particularly useful for monitoring population movements in near real time.

For example,

Even five years after the Great East-Japan Earthquake in 2011, population recovery in Fukushima remained limited due to the nuclear power plant accident. The population distribution in Fukushima after the accident was observed using big data derived from mobile phones.



A free copy is available from https://link.springer.com/book/10.1007%2F978-3-030-49920-4

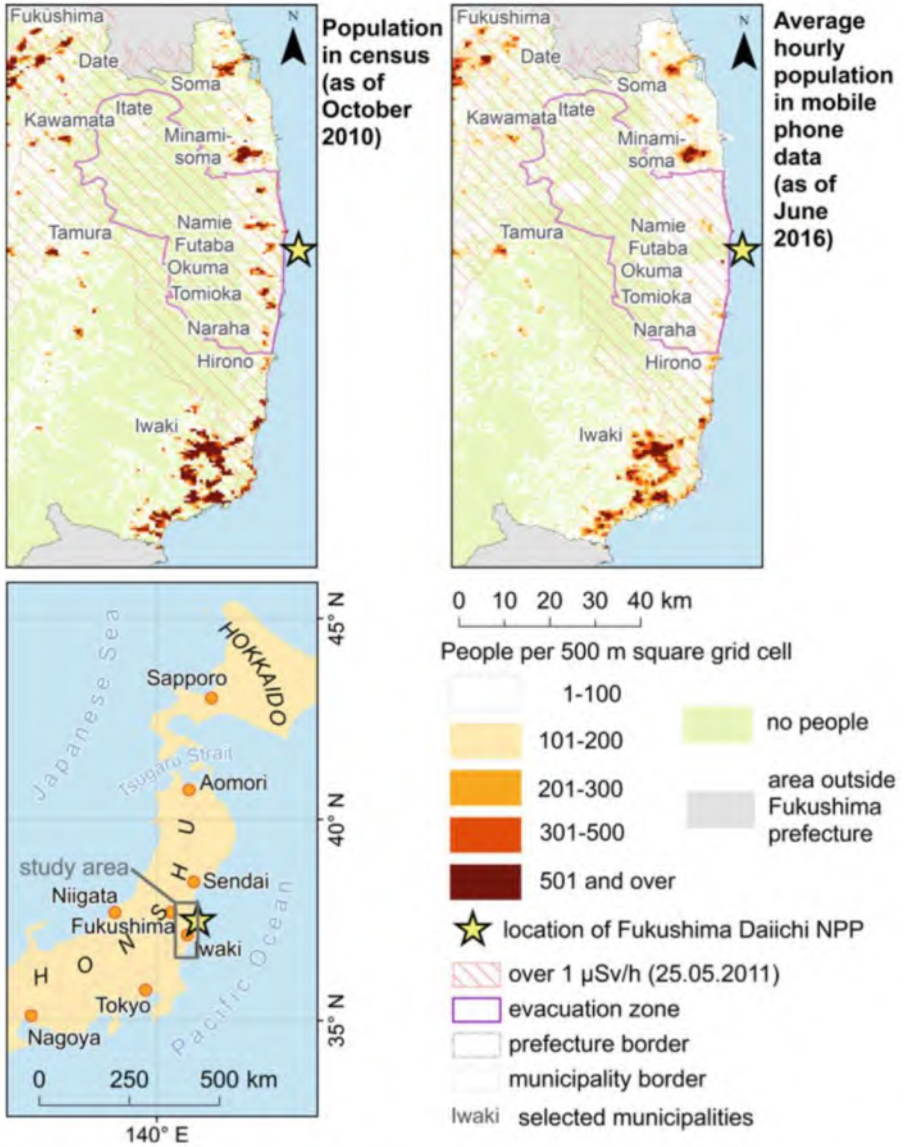
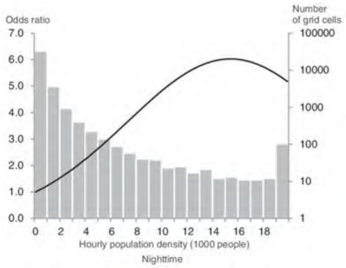
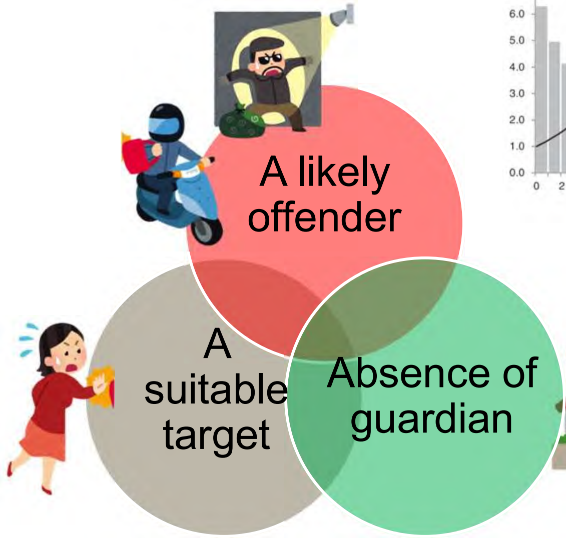


Fig. 2.7 Population distributions in census and mobile phone data (Author Hanaoka cartography by Hanaoka and Karácsonyi)

STREET CRIME & BIG DATA

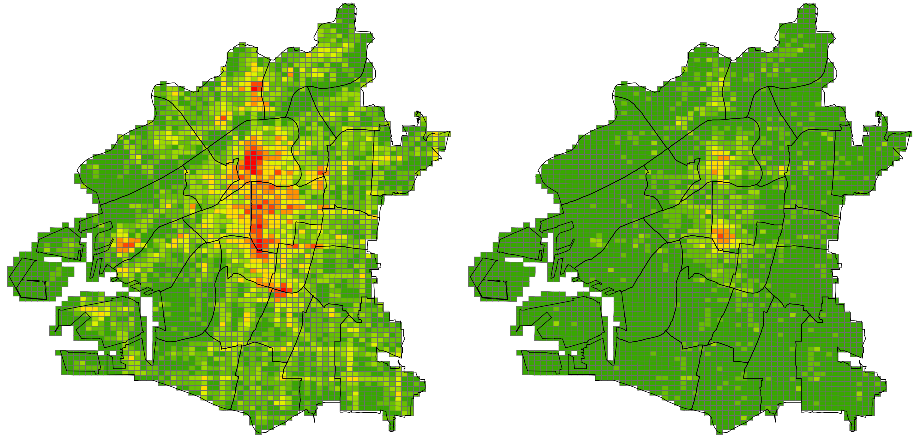
Natural surveillance by citizens can be quantified using hourly ambient population data derived from mobile phone big data. Our research demonstrates a quadratic relationship between ambient population and crime occurrence during nighttime (Hanaoka, 2018).



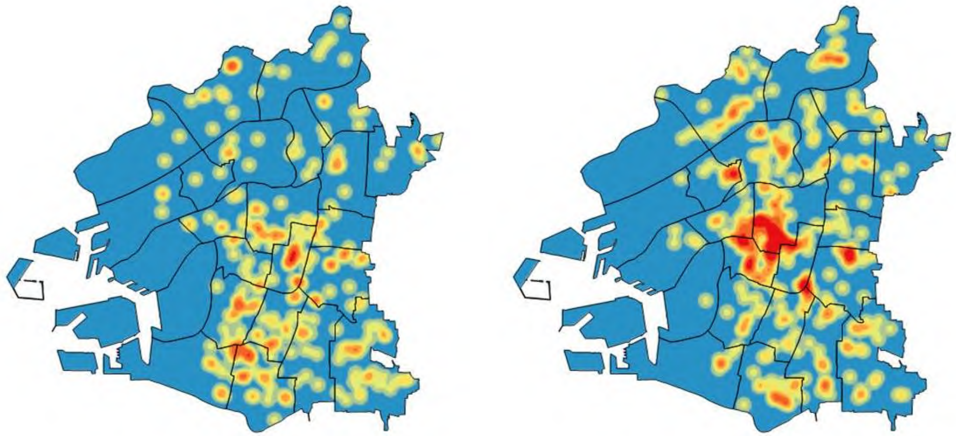


Routine Activity Theory

Daytime Nighttime

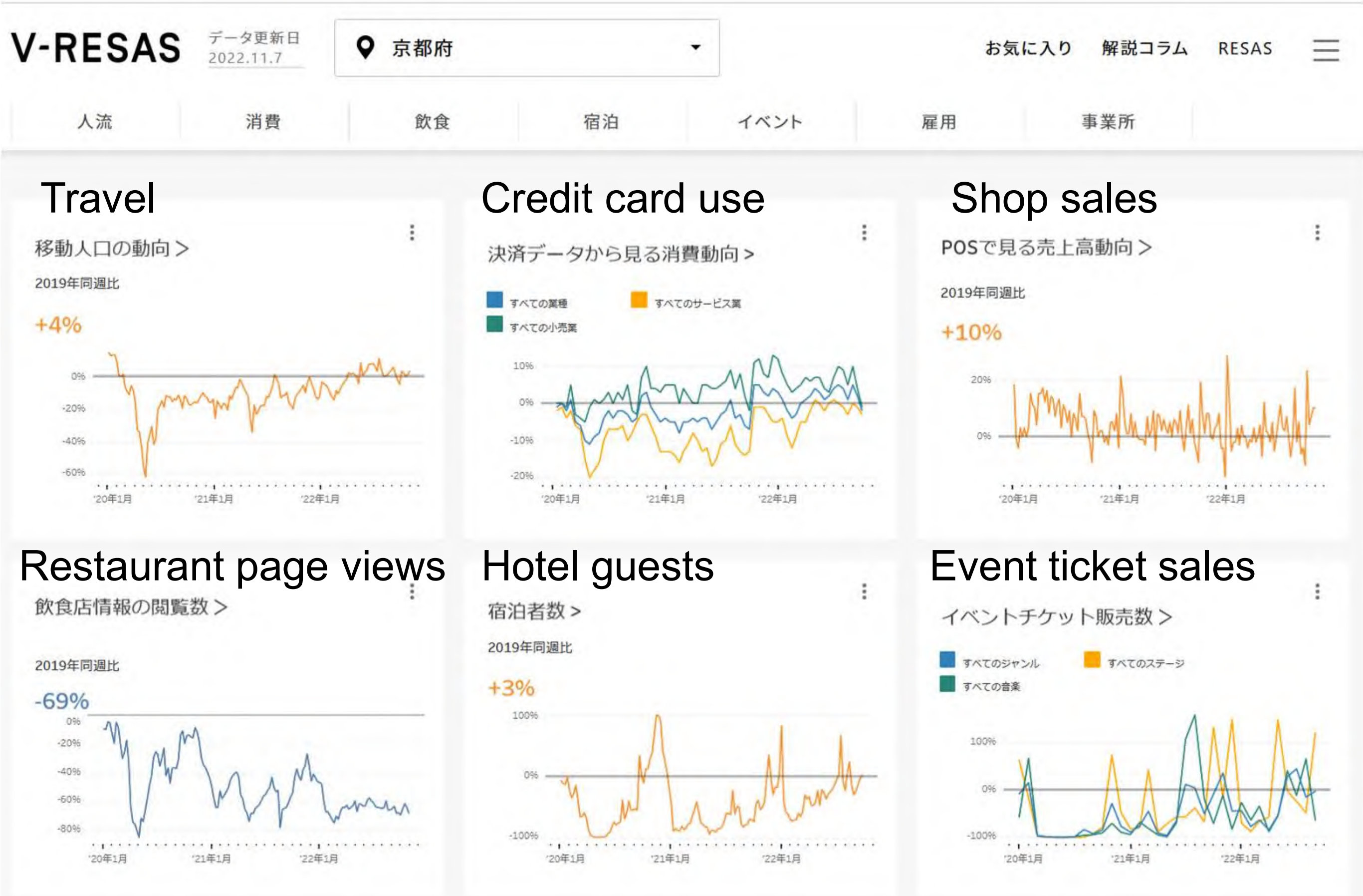


Ambient population



Snatch-and-run offense

INCREASED USE OF BIG DATA IN FIGHT AGAINST THE COVID-19 PANDEMIC



“V-RESAS” website was created by Japanese ministry

During the COVID-19 pandemic, the “going-out rate” in city centers, estimated from the locational data of mobile phone users, was frequently reported on television and in newspapers in Japan.

Government ministries in Japan have also been using big data to provide information on people’s movements and consumption patterns.

RELATED RESEARCHES

COVID-19 and people's movement

- In Tokyo, non-compulsory measures against the COVID-19 have sufficiently reduced people's inflow and decrease the effective reproduction number. (Yabe et al. ,2020) .
- In Osaka, compared to the pre-pandemic period, spatial extent of people's activities was reduced by half during the pandemic (Kato, 2021).

Social network and community detection

- Locations and call logs of mobile phone users were used to reconstruct interactions and functional areas among residents to study social and spatial segregation.
- Guo et al. (2018), Shi et al. (2015), Xu et al. (2021), Zhang et al. (2022)、Dannemann et al (2018)、Moya-Gomez, B. et al (2021)

→ The long-term behavioral changes during the pandemic period, as well as variations in the movement of people have not been fully explored **throughout the city**.

AIM OF THIS RESEARCH

This study aims to understand the spatio-temporal distribution of people in Kyoto City based on mobile phone location data. In particular, our analysis focuses on long-term changes and regional differences.

Study area: Kyoto City, Japan

- The population of the city is approximately 1.5 million.
- Kyoto City, the ancient capital of Japan, attracts both domestic and international tourists.

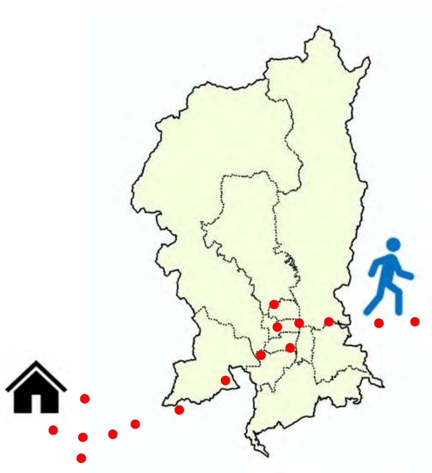
Study period: 24 months, from January 2019 to December 2020

MOBILE PHONE BIG DATA

We use locational data from mobile phone users collected through smartphone apps. The data was provided by Blogwatcher Ltd.

- It covers a 24-month period from January 2019 to December 2020.
- It includes trajectories of both Kyoto City residents and visitors.
- Home and workplace locations are estimated, but these locations were adjusted to the center of a grid cell to protect user privacy.

ProfilePassport



Kyoto City, Japan

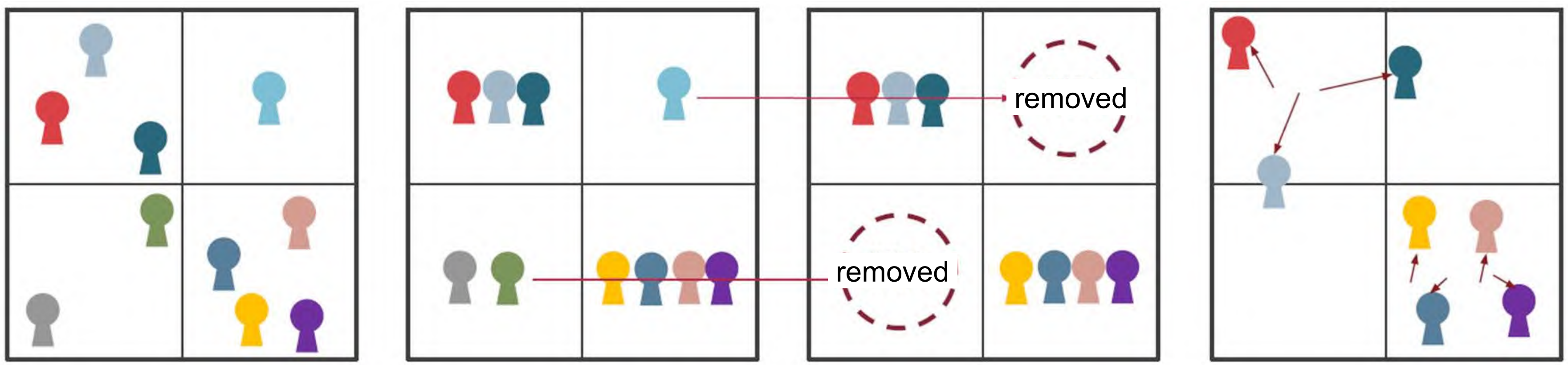
All trajectory records of people who entered or left Kyoto City at least once during a given month are available.

Descriptive statistics of the data (2 years)

✓ Total recorded points: 48.7 billion points
✓ Total unique ids(smartphones): 4.42 million
✓ Average (mode) interval time between two recorded points: 5-6 minutes

DATA MASKING FOR PRIVACY PROTECTION

Raw data → Dividing by grid cell → Removing small counts → Adding noises

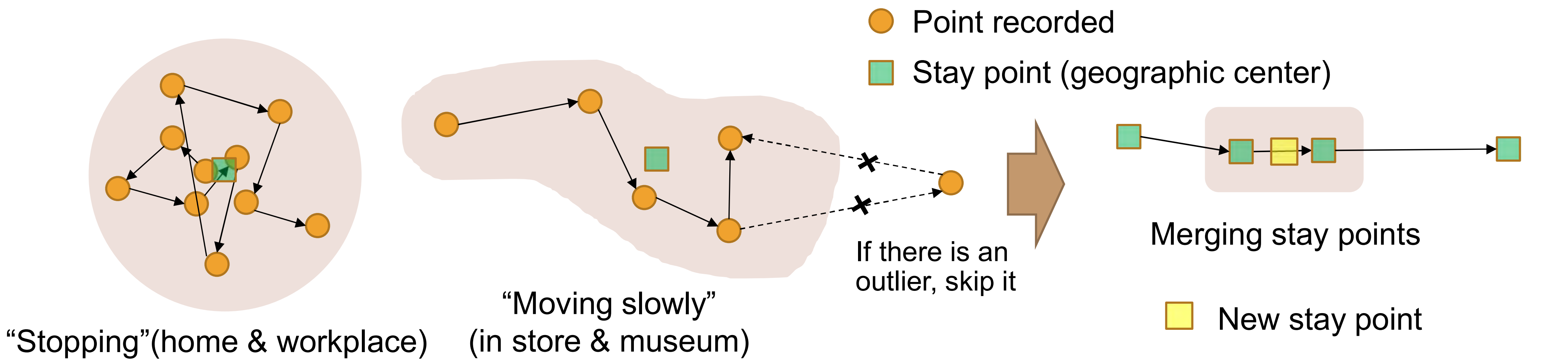


ESTIMATION OF STAY POINTS

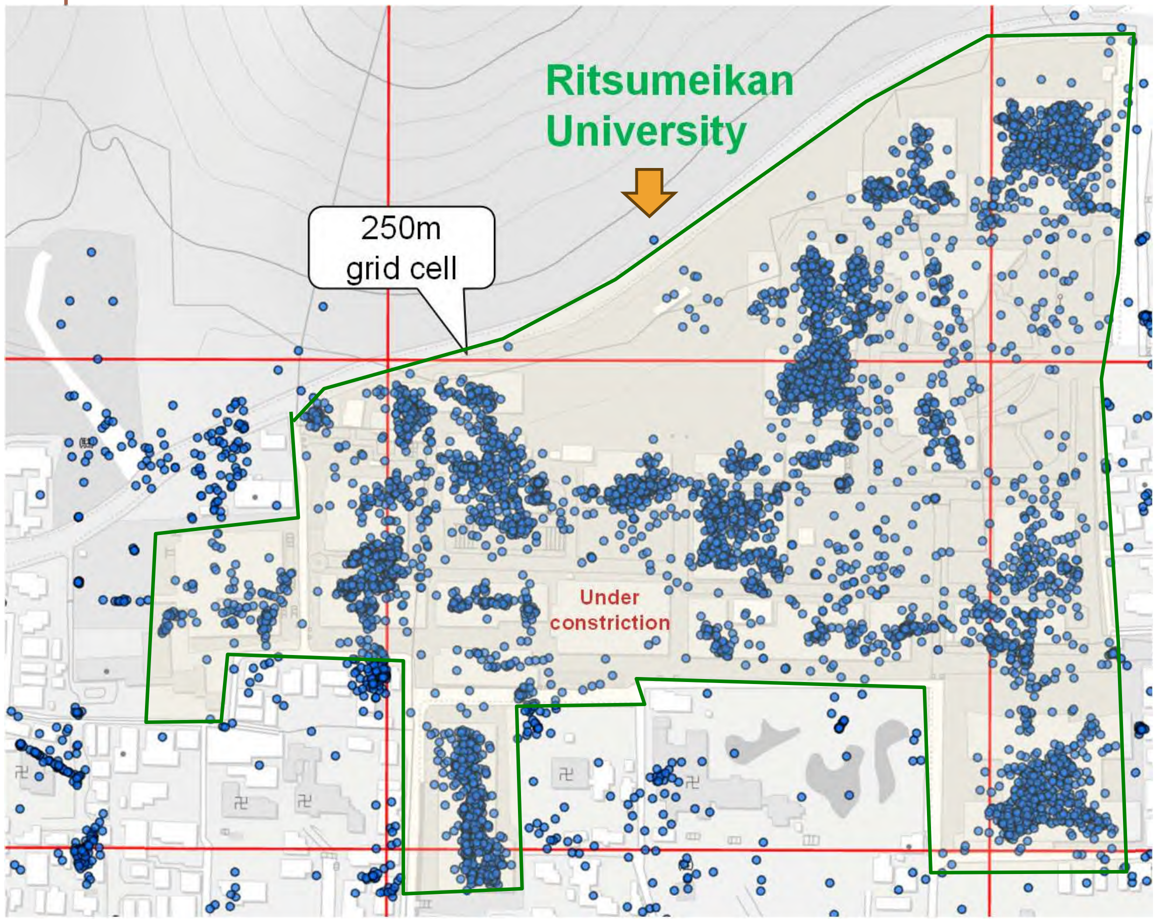
Types of stay points considered; “stopping” and “moving slowly”.

Points were considered ‘staying’ if the speed of travel between two consecutive points was less than 30m/min (normal walking speed for women in 60s: 72m/min) and the distance between them was less than 40m. We removed outliers caused by weak GPS signals.

Furthermore, if the interval between two consecutive stay points was less than 6 hours and the distance was less than 40m, they were merged as a single stay point. This procedure was performed twice.



RESULTS OF STAY POINT ESTIMATION

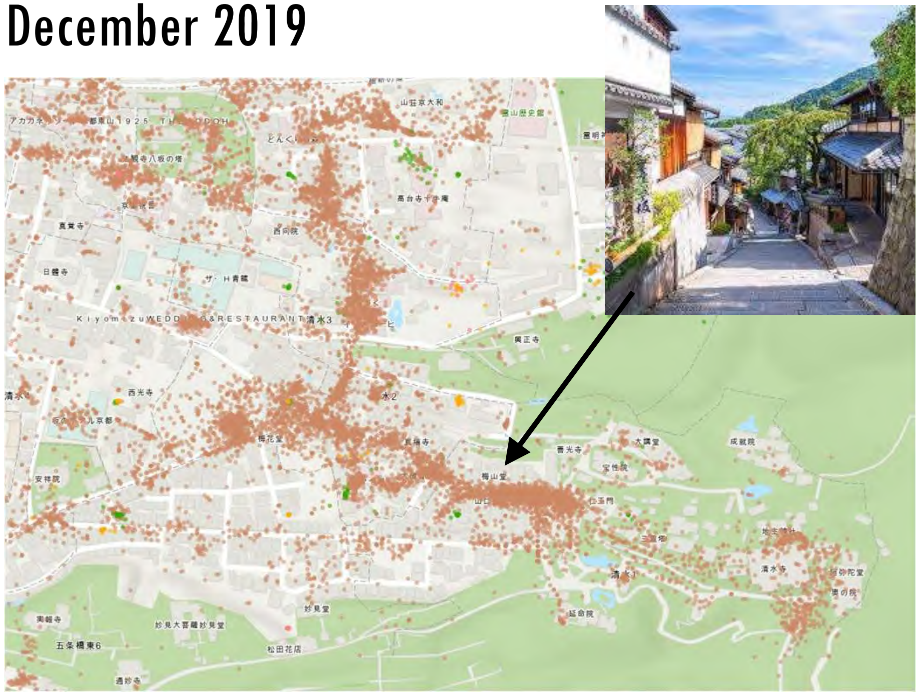


(Stay points outside home & workplace, May 2019)

1. We extracted 110 million points -where people stayed for more than10 minutes- from a total of 48.7 billion log points.
2. Time spent on weekdays and weekends was calculated using 250-m grid cells, distance bands from home, and other spatial units.

STAY POINT (10 MINS AND LONGER)

December 2019



Historical district (Streets and Temples)
in Kyoto

Railway Museum

Aquarium

Museum district (Umekoji District)
in Kyoto

RESULTS OF ANALYSIS

1. To what extent have Kyoto residents changed their activity spaces?
2. Where did Kyoto residents go on weekends within the city?
3. Where did residents of a particular neighborhood stay in the city?
4. Where are people from different regions likely to encounter each other?

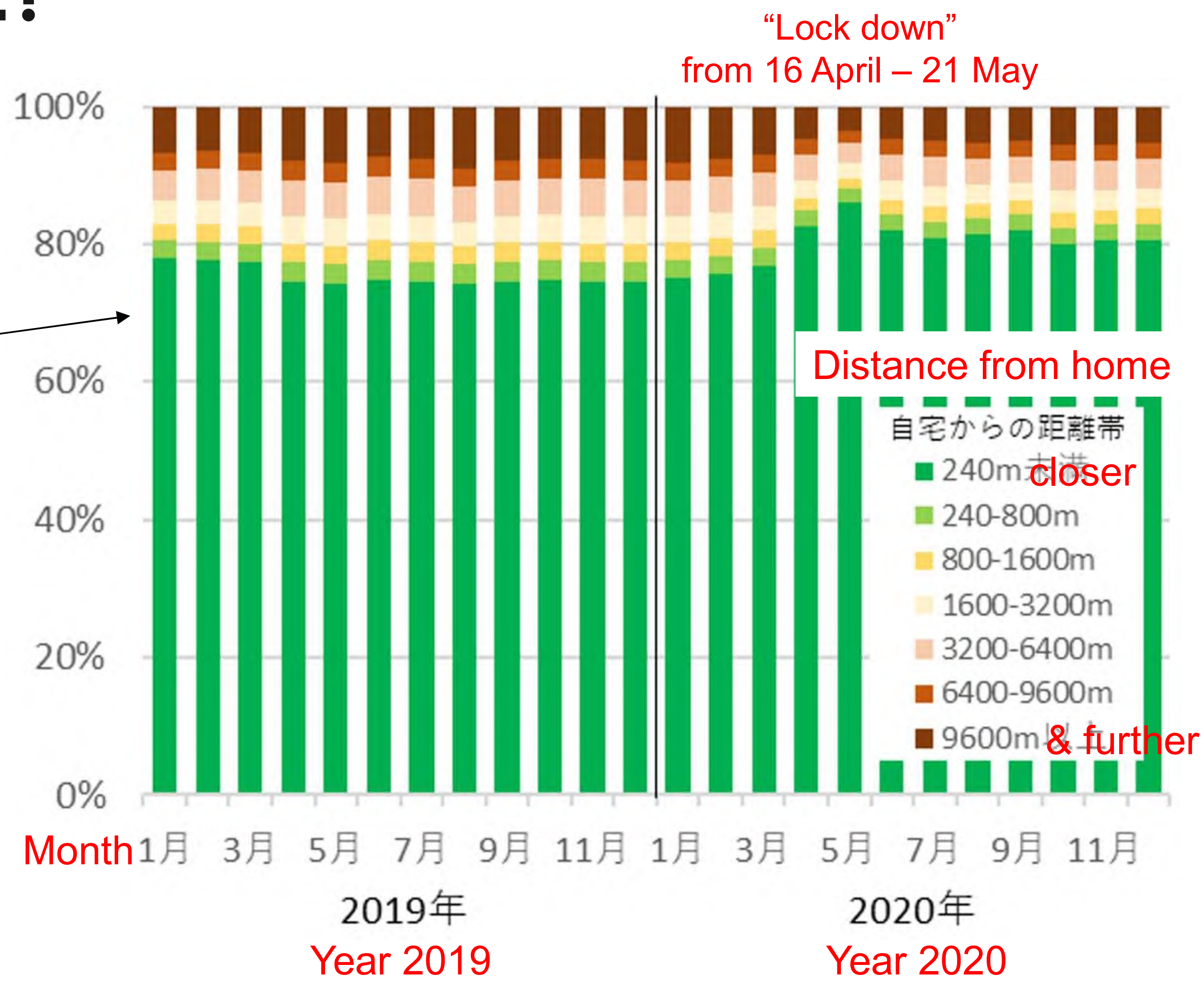
1. TO WHAT EXTENT KYOTO RESIDENTS HAVE CHANGED THEIR ACTIVITY SPACE?

This graph shows the percentage of time spent by distance band from home for 24 months.

The percentage of people staying closer than 240m from home (green bar) remained at just under 80% in 2019. However, **since April 2020, it has exceeded 80%.**

Even after the 'lockdown' ended in late May 2020, it remained around 5 points higher than before.

Note: This graph was derived from stay-point data, excluding time spent in transit.

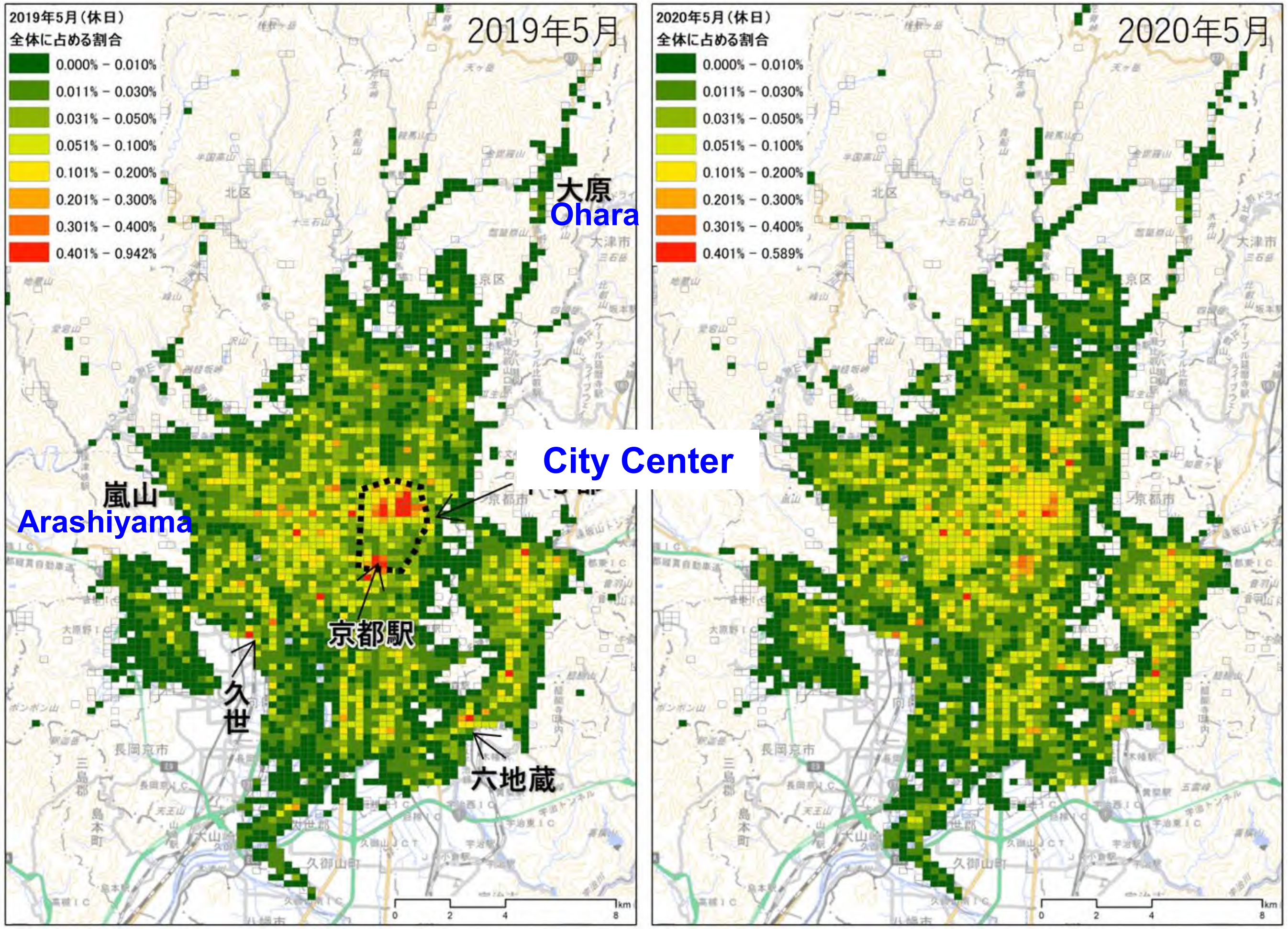


2. WHERE DID KYOTO RESIDENTS GO ON WEEKENDS IN THE CITY?

The total time spent by Kyoto residents outside their homes on weekends was tabulated by 250-m grid cells.

These maps clearly show that during the pandemic, residents avoided visiting the city center and stayed closer to their homes than before.

There are fewer red cells in the city center and more bright-green cells in the suburbs.



May 2019 (Weekends)

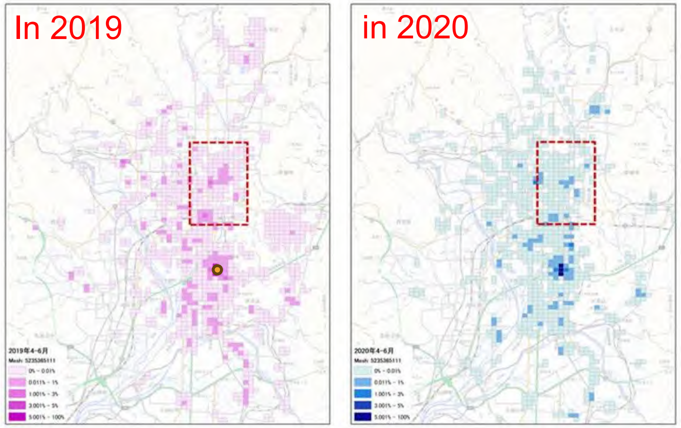
May 2020 (Weekends)

3. WHERE DID RESIDENTS OF A PARTICULAR NEIGHBORHOOD STAY IN THE CITY?

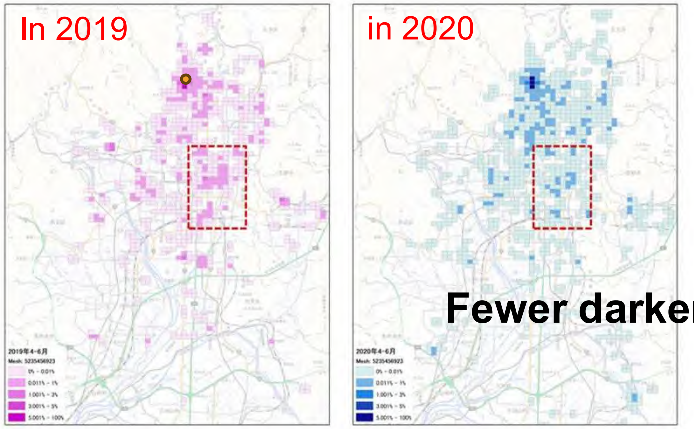
Three suburban neighborhoods were selected, and kernel densities of stay points were calculated for the three-month periods from April to June in 2019 and 2020, respectively.

Residents in these neighborhoods tended to stay close to home or visit places that were easily accessible by train or bus.

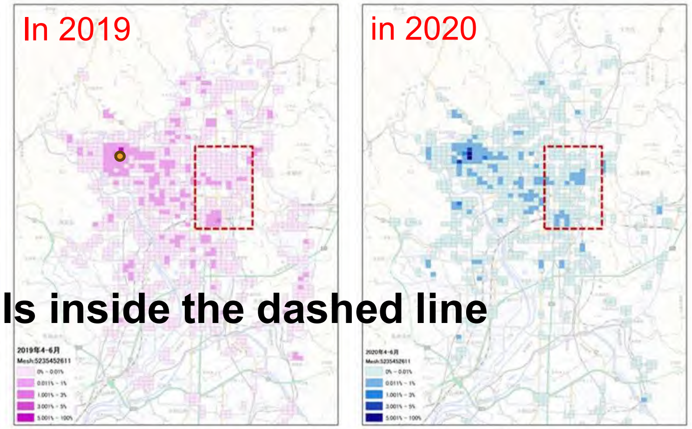
During the pandemic**, residents visited a wide range of areas but appeared to spend less time in the city center.** These results likely reflect the impact of shop closures and residents' attitudes toward social distancing.



Distribution of staying points of neighborhood A



Distribution of staying points of neighborhood B



Fewer darker cells inside the dashed line

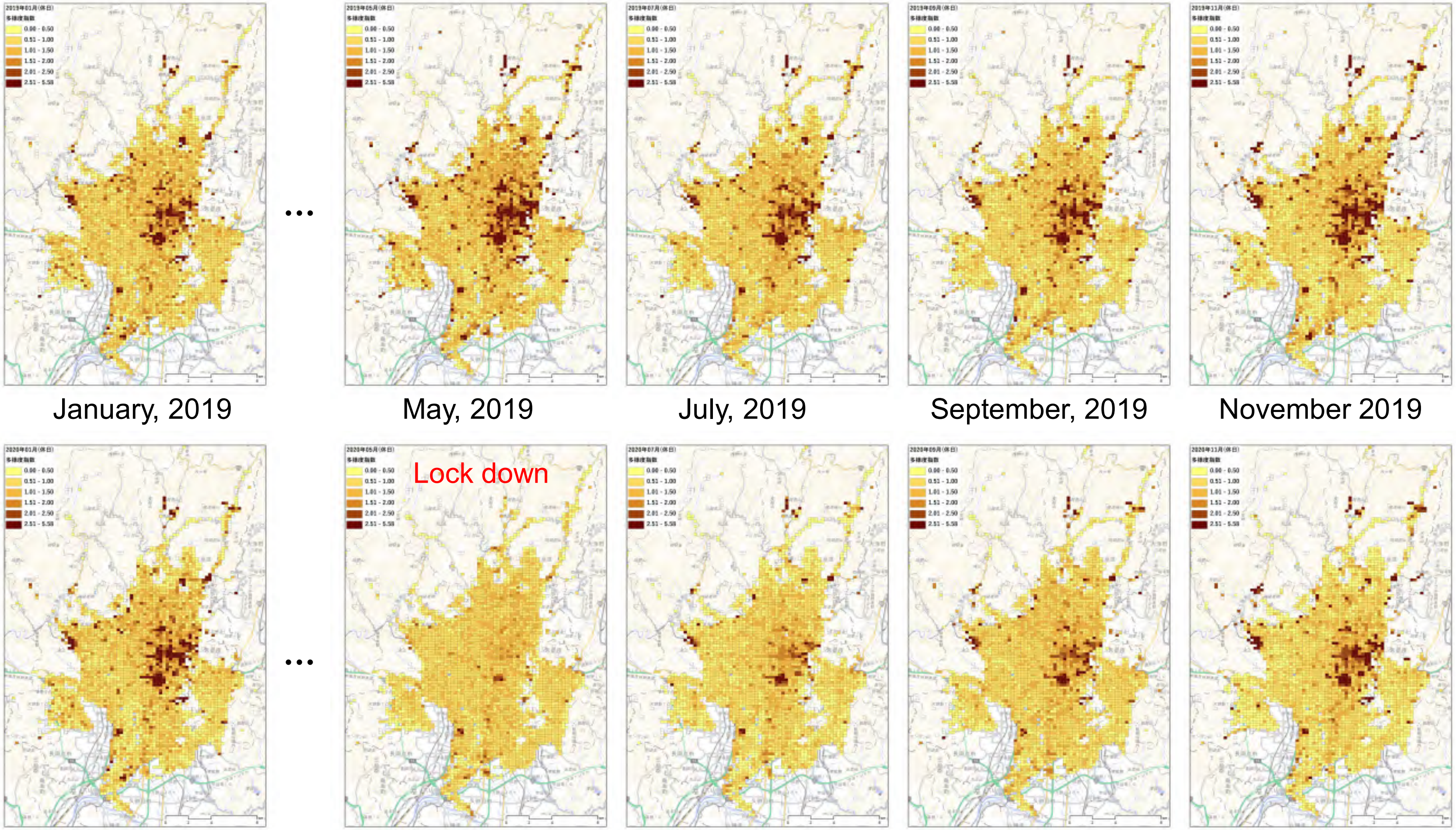
Distribution of staying points of neighborhood C

4. WHERE ARE PEOPLE FROM DIFFERENT REGIONS ARE LIKELY TO ENCOUNTER?

Origins of visitors (by prefecture) from Hokkaido to Okinawa prefecture and abroad (48 regions in total)

北海道	青森	・・・	・・・	・・・	・・・	滋賀	京都	大阪	・・・	・・・	・・・	・・・	沖縄	海外
0.01	0.05					0.18	0.25	0.20					0.03	0.01

$$Entropy = \sum p_i \log_2(1/p_i)$$



January, 2019 … May, 2019 | July, 2019 | September, 2019 | November 2019

January, 2020 … May, 2020 | July, 2020 | September, 2020 | November 2020

Diversity index (entropy bit)

- 0.00 - 0.50
- 0.51 - 1.00
- 1.01 - 1.50
- 1.51 - 2.00
- 2.01 - 2.50
- 2.51 - 5.58

Low All visitors come from the one region

High Visitors came from all 48 regions equally

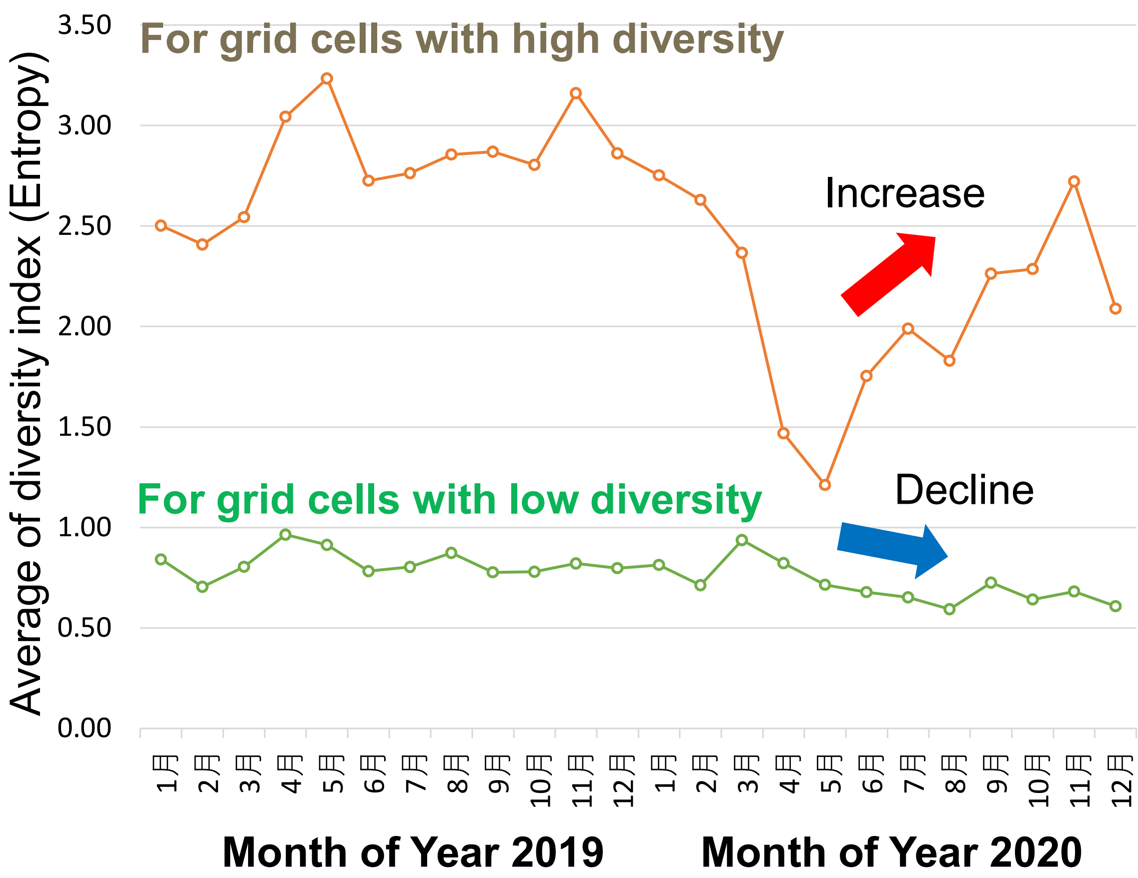
CHANGES IN DIVERSITY INDEX BY REGIONAL TYPE

To examine changes in the diversity index by region type, we classified regions into high- and low-diversity groups as of April 2019 (prior to COVID-19).

In regions with high diversity, the index declined significantly during the lockdown but rose again soon after it was lifted.

On the other hand, in regions with low diversity (mainly suburban areas), the index continued to decline gradually rather than increase.

These results suggest that after the lockdown was lifted, inflows returned to the city center and touristic sites, whereas in residential and neighborhood commercial areas in the suburbs, **residents continued to avoid meeting visitors (relatives and friends) from outside Kyoto City.**



SUMMARIES

1. During the pandemic, the percentage of "stay home" increased by more than 10 percentage points in May 2020 compared to the pre-pandemic period. Even after the state of emergency was lifted, it did not return to its previous level and remained approximately 5 percentage points higher.
2. During the pandemic, people moved widely across the city but tended to avoid the city center, where social distancing was difficult to maintain and many stores were closed following government requests.. These changes in people's mind and spatial behavior were revealed and visualized using big data from mobile phones.
3. Based on our long-term observation of people's movements, visitors from other regions disappeared during the pandemic. After the end of the emergency declaration, the number of visitors from various prefectures recovered rapidly in the city center and at touristic sites, but not in residential areas or neighborhood commercial areas.

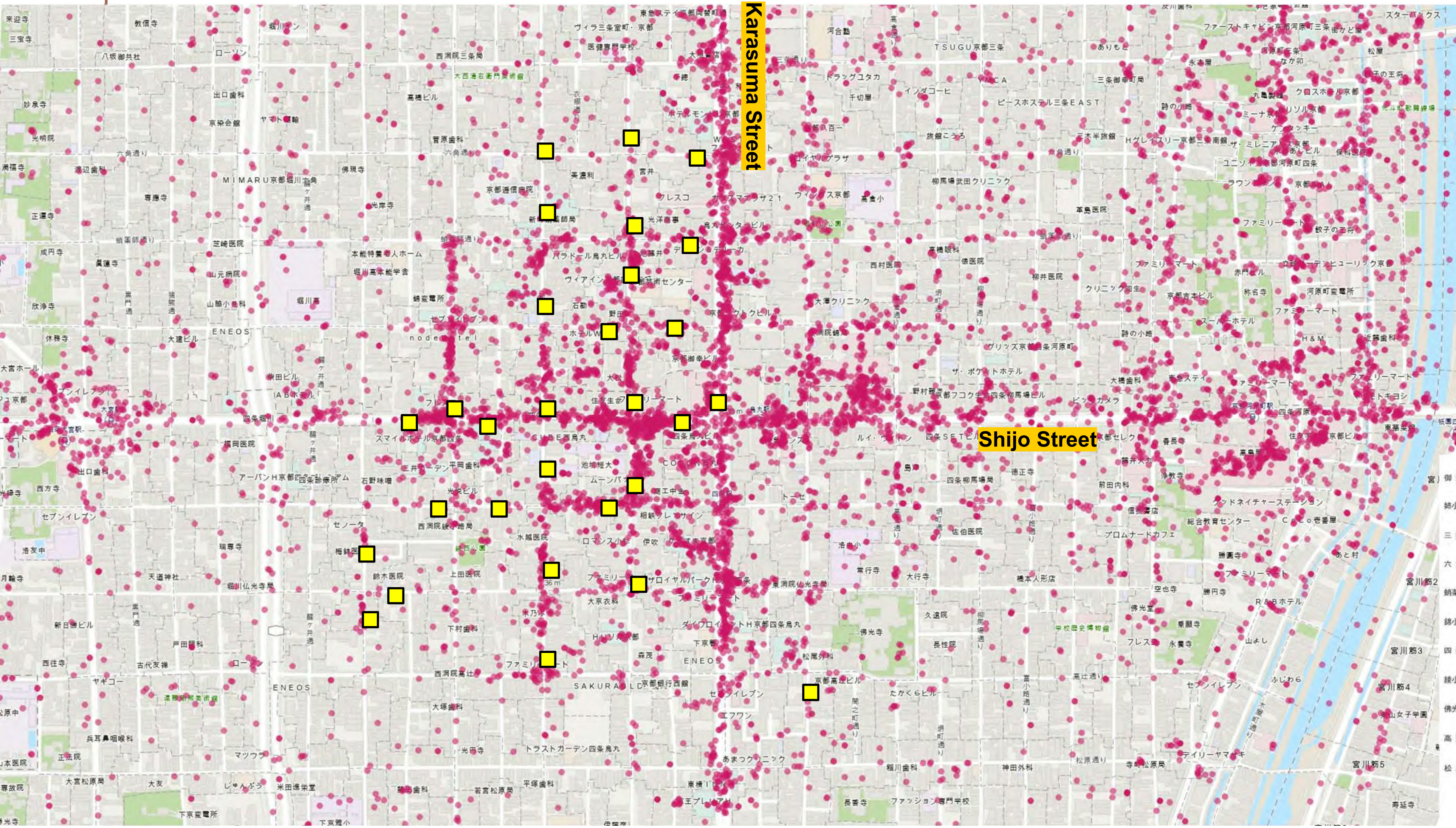
➡ In conclusion, mobile phone big data allow us to analyze long-term changes in people's movements at a very fine spatial and temporal scale. In the next step, we plan to extend our analysis using the datasets from 2021 and 2022.

FOR URBAN ANALYTICS

STAY POINT DISTRIBUTION DURING GION FESTIVAL IN KYOTO

16 JULY 2019 17:00 - 23:59

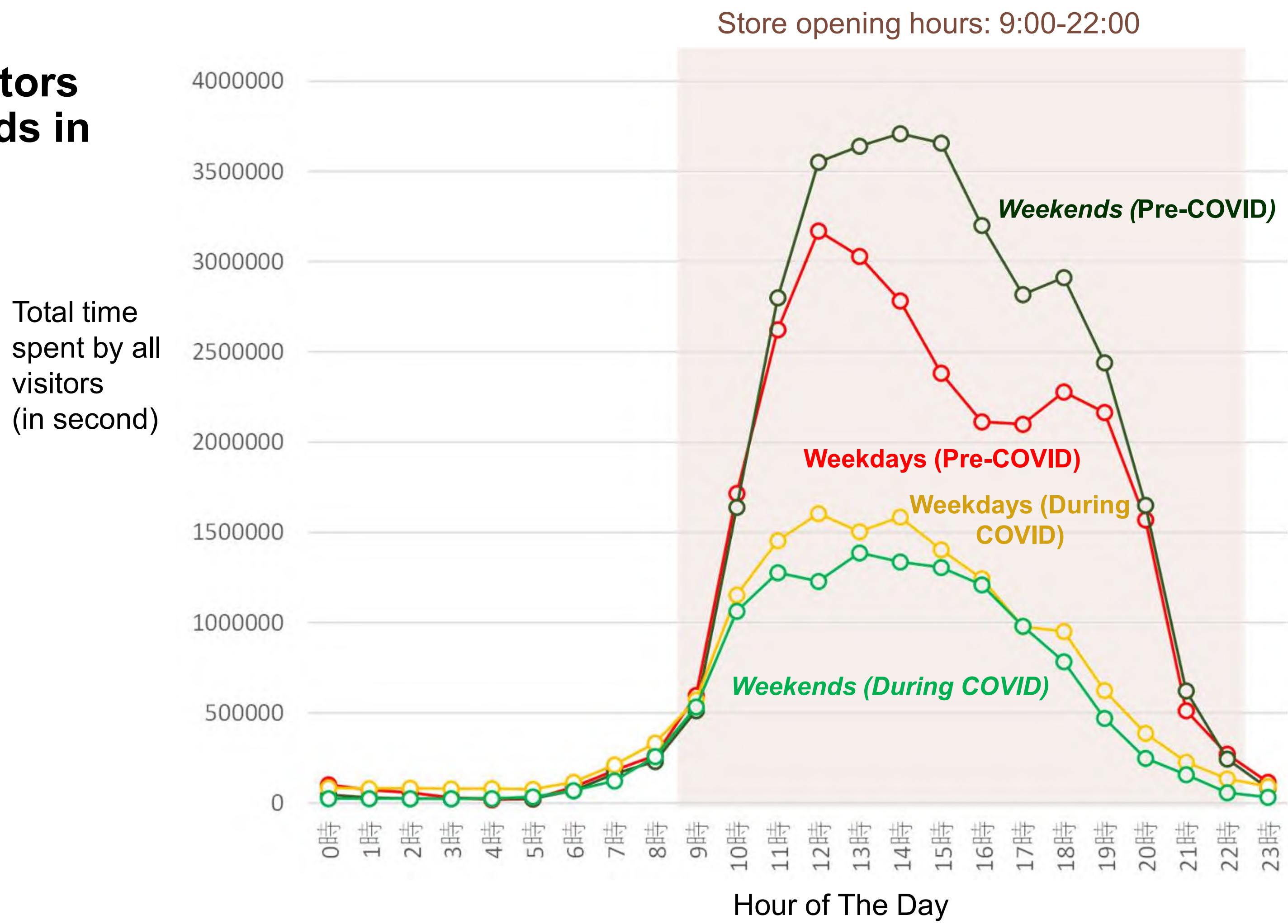
Float



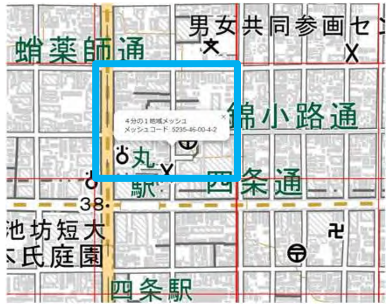
STAY POINTS INSIDE A LARGE SHOPPING MALL

TIME SERIES PROFILE OF VISITOR VOLUME

Total time spent by all visitors on weekdays and weekends in May 2019 and 2020



ELECTROCARDIOGRAM OF CITY CENTRE



Time spent by locational type (home, workplace, and other) and by hour

Line colour

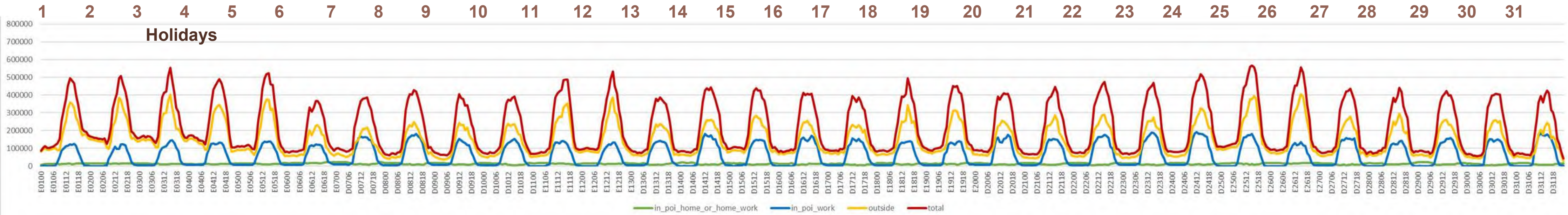
Red : Total time spent

Blue : Time spent at workplace

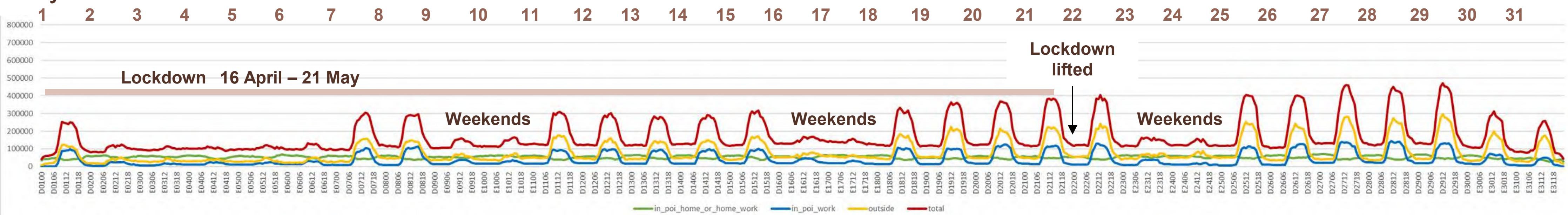
Green : Time spent at home

Orange : Time spent outside home and workplace

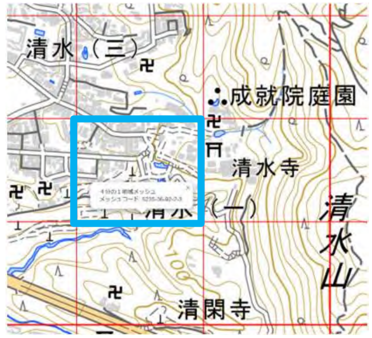
May 2019



May 2020



ELECTROCARDIOGRAM OF TOURISTIC AREA



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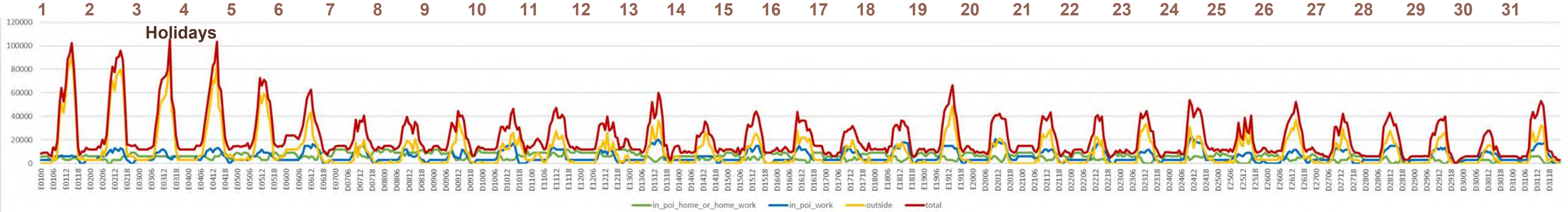
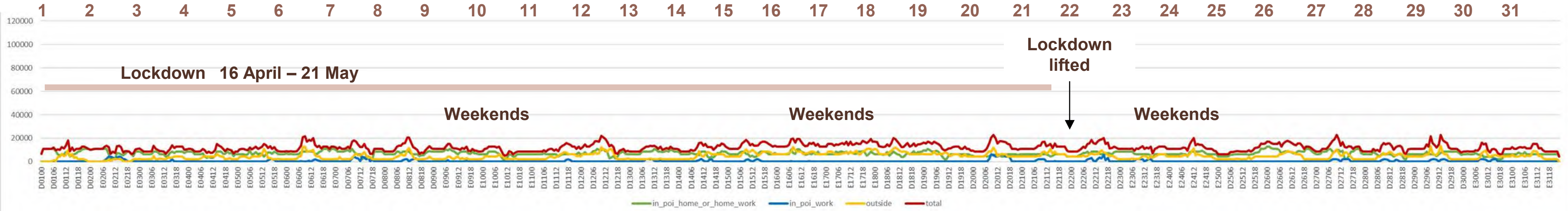


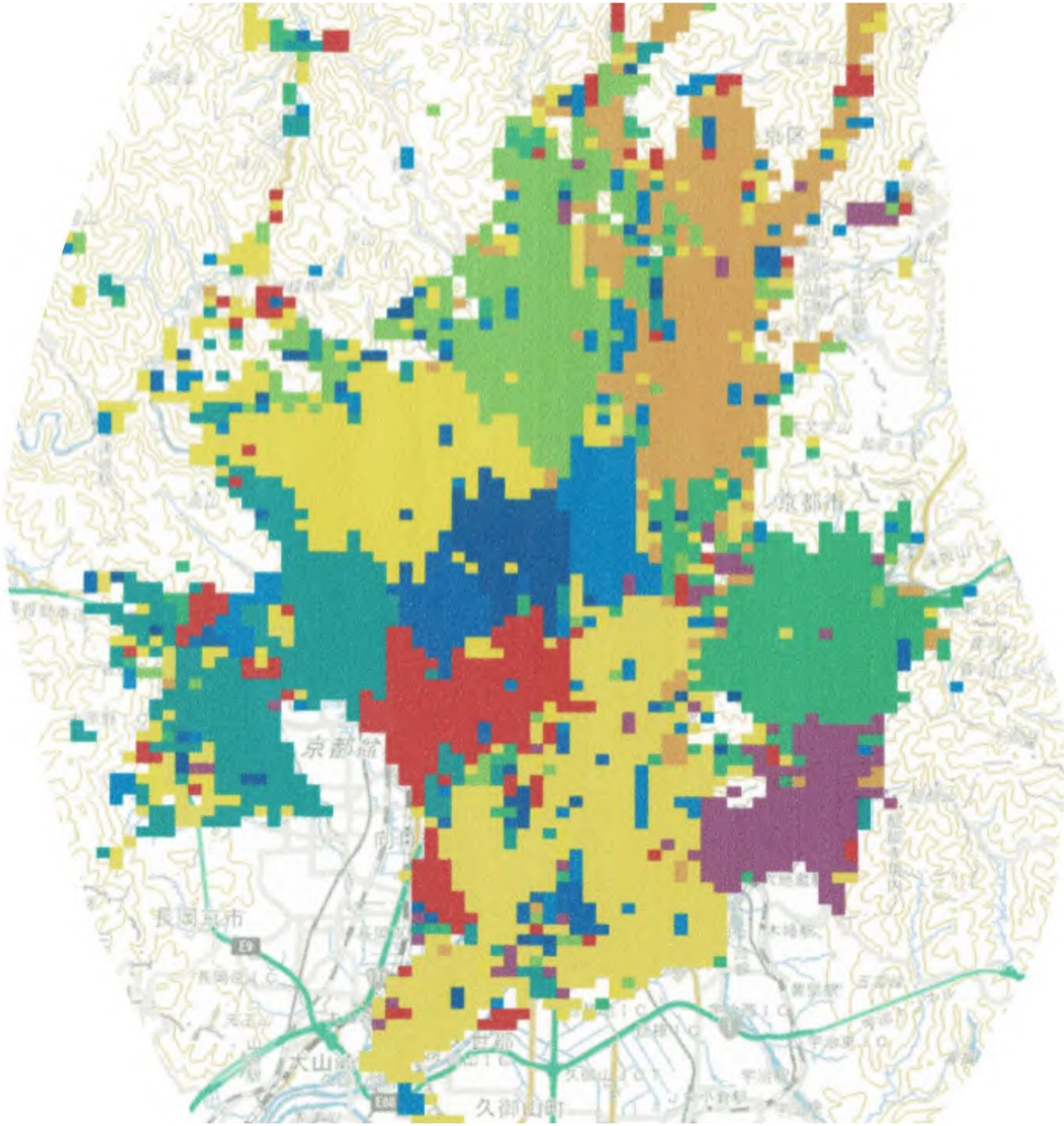
May 2020



TRIP-BASED TYPOLOGY OF NODAL REGIONS

Time spent outside home

Teodoro, D., Boris, S. G. and Horacio, S. (2018) The time geography of segregation during working hours, R. Soc. Open sci.5180749180749, http://doi.org/10.1098/rsos.180749



COLLABORATIVE RESEARCH WITH UNIVERSITY COLLEGE LONDON

A dashboard application to explore population distribution derived from GPS location data during the COVID-19 pandemic in Kyoto, Japan

James Todd [a,*], Keiji Yano [b], Kazumasa Hanaoka [b]

- From Geometry to Quality: A Combinatorial Framework for Pedestrian Route Choice.
- Stephen Law, Kimon Krenz, James Todd, Hanaoka Kazumasa, Yano Keiji

- How Well Do Shortest-Path Principles Predict Pedestrian Routes? A Longitudinal Benchmark with Large-Scale GPS Trajectories.
- Kimon Krenz, Stephen Law, James Todd, Hanaoka Kazumasa, Yano Keiji

ROUTE CHOICE IN KYOTO Yano-sensei, James Todd and Kimon Krenz

Using GPS Mobility data to compare actual route choice and different route choice strategy

real path
shortest metric path

People do not always choose the shortest path; instead, they often select routes that offer a more comfortable environment, such as greener surroundings. This project aims to understand route choice behavior and its determinants using mobile phone big data. First, we found that people tend not to choose the shortest path in areas with which they are unfamiliar. Second, the results suggest that environmental qualities add significant explanatory power: greener streets are associated with higher route selection probabilities—especially during the summer.

THANK YOU FOR LISTENING

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REFERENCE

Yabe, T., Tsubouchi, K., Fujiwara, N. et al. Non-compulsory measures sufficiently reduced human mobility in Tokyo during the COVID-19 epidemic. Sci Rep 10, 18053 (2020). https://doi.org/10.1038/s41598-020-75033-5

Kato, H.; Takizawa, A.; Matsushita, D. (2021) Impact of COVID-19 Pandemic on Home Range in a Suburban City in the Osaka Metropolitan Area. Sustainability , 13, 8974. https://doi.org/10.3390/su13168974

Kato H, Takizawa A (2022) Time series cross-correlation between home range and number of infected people during the COVID-19 pandemic in a suburban city. PLoS ONE 17(9): e0267335. https://doi.org/10.1371/journal.pone.0267335