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# Mapping the Global Concerns of Sea Level Rise on Twitter - A Multimodal Framing Perspective for Urban Sensing

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## Summary

Sea level rise (SLR) is a global concern under climate change. Understanding how SLR is discussed, depicted, and framed helps urban management and public governance make more informed decisions towards climate actions and communicate more effectively. A multimodal dataset of tweets containing visuals and texts is collected, mapped, and analysed with multimodal topic modelling. It shows that SLR discussion mainly concentrates on coastal cities from the West and that complex themes are brought to the spotlight, including but not limited to risks, actions, and doubtful objections. The framework can be extended for other climate impacts, informative for climate-responsive urban management.

**KEYWORDS:** Spatial Mapping; Multimodal Topic Modelling; Urban Planning and Management; Climate Change; Public Administration and Policy

## 1 Introduction

Sea level rise (SLR), as a major climate change impact, has been a crucial concern in urban management and governance in recent decades, triggering debates in online public arenas, such as forums, social media, streaming platforms, etc. (Pearce et al. 2014; Farrell 2016; Stede and Patz 2021). Especially within online debates, texts and visuals are equally important, containing complementary and conflicting messages (Gommeh, Dijstelbloem, and Metze 2021; Rabello et al. 2022). The multimodal pairs formed with visuals and texts can frame debates from different perspectives, i.e., leading the discussion by focusing on a selected fragment of reality (Entman 1993; Dewulf and Bouwen 2012; Metze 2020; Rojas-Padilla, Metze, and Termeer 2022; Rojas-Padilla, Metze, and Dewulf 2024). The visual and textual framing can create different storylines for interpreting a policy issue (Metze and Dodge 2016; Efrat 2023; Rojas-Padilla, Metze, and Dewulf 2024), influ-

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ential for decision-making processes during urban planning and management. In the literature, frames are predominantly induced with only textual information in the discourse, either manually or with the help of topic-modelling algorithms such as latent Dirichlet allocation (LDA) (Dewulf 2013; Benites-Lazaro, Giatti, and Giarolla 2018; Dahal, Kumar, and Z. Li 2019; Eck, Mulder, and Dewulf 2020). Current advances in multimodal machine learning allow viewing visuals and texts holistically within their semantic contexts in a uniform high-dimensional vector space, where multimodal topics containing both visual and textual semantics can be derived (Grootendorst 2022; Radford et al. 2021; Song et al. 2022). This paper presents an exploratory analysis of mapping the spatiotemporal patterns and deriving multimodal frames from tweets at a global scale concerning SLR. By evaluating the multimodal topics obtained with BERTopic, the major global concerns of SLR can be revealed, effectively functioning as an inclusive urban sensing tool that takes inputs from a broad public (Liu et al. 2015; Gilardi et al. 2022).

## 2 Methodology

### 2.1 Data

A multimodal English dataset concerning SLR with all available tweets containing relevant keywords was collected using Twitter API v2. 1,821,333 tweets were collected from 729,364 unique users between 2012 and 2023, among which 164,939 tweets are truly multimodal, i.e., containing one of 10,925 unique images. For all collected tweets, the following information is typically available: the original textual content in English, the optional visual content if any being attached, the timestamp, the pseudonymized user ID, and the optional geo-location if provided. Since only a few tweets are geo-referenced when posted (13,162 tweets, 0.7%), the user-reported locations were also consulted from their pseudonymized profiles, making up a larger proportion (1,386,887 tweets, 76.1%).

### 2.2 Geocoding of Posts

The geotags of tweets and the user-reported locations both are named-based (i.e., only as a verbal description without any geographical coordinates) and vary at different scales, from micro-level POI and neighbourhood to meso-level town and city to macro-level province and country. A workflow of geo-coding and reverse geo-coding (Bai, Nourian, et al. 2024) was applied for both types of locations, using Python libraries Shapely, GeoPy, Country Info, and Wikipedia API, after which all locations were mapped to the city level. The tweets were aggregated and counted in each city, which was later mapped with Python libraries GeoPandas and Contextily. Specifically, the tweets containing multimodal information were counted and mapped separately in addition to all collected tweets, resulting in two global maps of cities emerging in SLR Twitter discussions.

### 2.3 Multimodal Topic Modelling

For pragmatic reasons, a subset of 10,925 multimodal tweets containing unique images was kept to induce the frames being used in the debate. A 512-dimensional embedding for each multimodal tweet was computed by averaging the respective 512-dimensional embedding of the text and the visual using the clip-ViT-B-32 model (Radford et al. 2021). The embeddings were fed to the modular

pipeline of BERTopic to get the multimodal topics represented by key visuals, keywords extracted with both class-based TF-IDF and KeyBERT (Grootendorst 2020), and relevant documents. The authors then manually checked all the obtained multimodal topics that were not considered noise to make sense of their themes and the probable stance (whether they are mainstream or sceptical) the tweets demonstrate. In parallel, the topics were also grouped into meta-topics by the types and subtypes of the key visuals. The types-subtypes-themes structure of topics was formulated as a graph, which was further visualized using Gephi (Bastian, Heymann, and Jacomy 2009).

### 3 Results

#### 3.1 Spatial Distribution of Discussions

Figure 1 maps the global spatial distribution of tweets related to SLR at the city levels. The

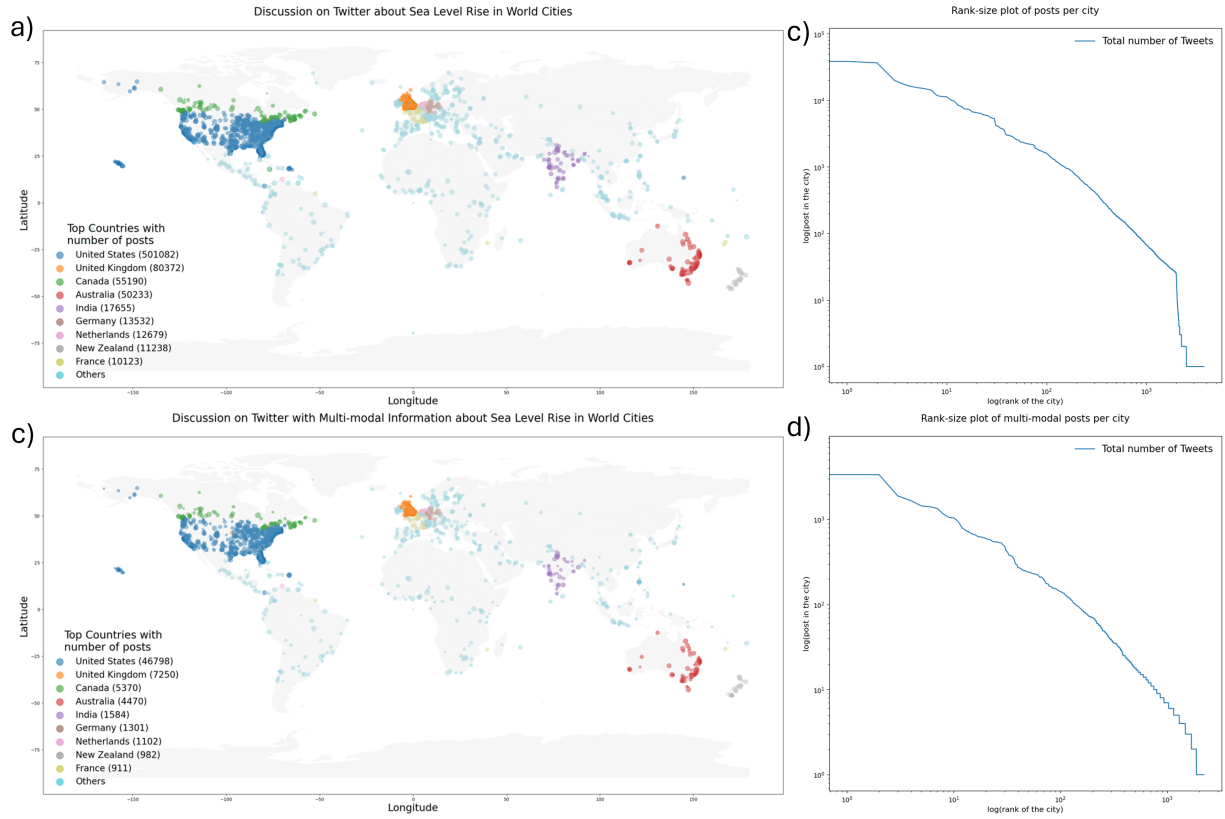


Figure 1: The global trend of discussions concerning sea level rise on Twitter on city level. a) Map of all tweets collected; b) the rank-size plot of all posting cities; c) map of multimodal tweets that contain images; d) the rank-size plot of posting cities of multimodal tweets. The top 10 countries are respectively coloured, while the numbers of tweets in each country are aggregated and counted.

entire dataset and the multimodal subset show a consistent pattern, where the multimodal tweets in each country are always roughly one-tenth of the text-only ones. The top posting countries are consistently the US, the UK, Canada, Australia, and India, dominantly from the West. City-wise, the posts are mostly from the coastal areas, reflecting the most vulnerable locations under global sea level rise. The rank-size plots at the logarithm scale roughly demonstrate a linear scaling pattern. Note the Twitter dataset is largely biased with its usage globally, possibly downplaying the contribution of East Asian countries.

### 3.2 Topics in Sea Level Rise Discussion

Among the 10,925 multimodal tweets, 7486 (68.5%) are not considered as noise by BERTopic model, i.e., can be clustered into a meaningful topic. Initially, 104 multimodal topics emerged, which are

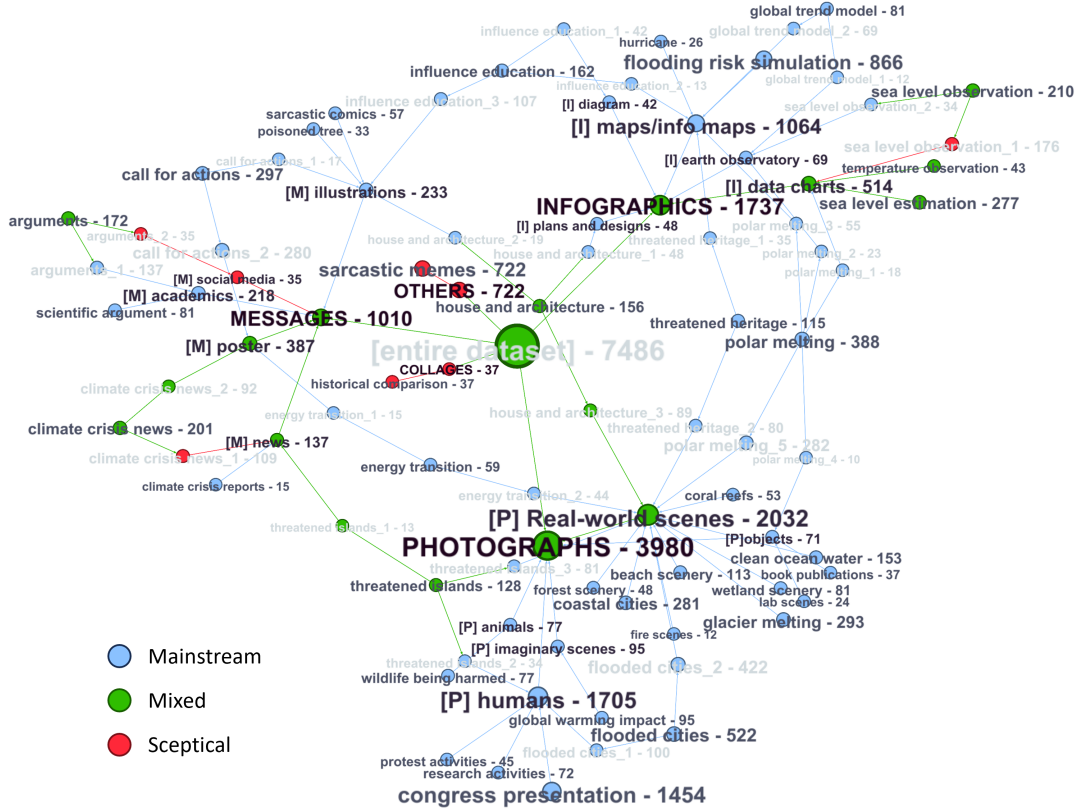


Figure 2: The meta-topics concerning sea level rise deduced from the multimodal topics and their respective counts of unique multimodal tweets. Each node represents a meta-topic in one of three levels, i.e., general types of visuals (in capital letters) - subtypes of visuals (starting with a code within brackets) - and specific themes of multimodal tweets (lowercase phrases). The nodes are coloured with the dominant provisional stances the tweets possess in each meta-topic.

further grouped respectively into 55 themes (e.g., melting glaciers, threatened heritage), 15 subtypes (e.g., real-world scenes, data charts), and 5 main types (photographs, infographics, messages, collages, and others) as meta-topics. Some themes may be present multiple times with different subtypes of visuals. For example, the theme of “threatened islands” can be demonstrated with photographs depicting real-world scenes, showing humans, or with news reports. After aggregating the repeated themes, 38 still remain. The semantic network of the meta-topics is visualized in Figure 2. The themes cover areas of climate impacts, risks, actions, and doubts about the existence of SLR. By preliminary checking on the representative documents and keywords, potential stances can be estimated for each theme and higher-level meta-topics. Most themes are anticipated with a mainstream view, whereas themes that show sea level observation data and historical comparison of photographs, and those that share social media screenshots and sarcastic memes are more controversial. These themes with different subtypes and types of visuals can be effectively considered the multimodal frames being used during online debates on SLR.



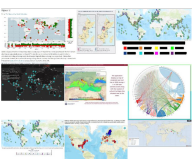
| Representative Visuals  | Representative Textual Documents  | Keywords based on C-TF-IDF   | Keywords based on KeyBERT  | Count Unique Multimodal Tweets | Type – Subtype – Theme of the Topic                                    | Provisional Stance |
|---|---|--|--|--------------------------------|--|--------------------|
|   | RT @USER : It's hard to be optimistic about the world's prospects as the effects of human-induced climate changed become ever more stark . In this case , researchers at Kiel University argue that all but 2 of the 49 world heritage sites in the Med basin are at risk . HTTPURL HTTPURL   | heritage sites<br>Venice<br>Heritage Sites<br>world heritage<br>world heritage sites<br>sites threatened sea<br>heritage sites threatened<br>sites threatened mediterranean        | landsubsidence unesco venice<br>sites threatened sea<br>risk sea level<br>mediterranean danger flood<br>sites mediterranean<br>endangered sea<br>canals venice<br>heritage sites threatened<br>laterrabruca course sea<br>seawater stain marks           | 54                             | PHOTOGRAPH<br>-<br>[P] Real-world Scenes<br>-<br>threatened heritage_1 | mainstream         |
|  | RT @USER : 4 million year old geologic evidence in a Malloccan cave gives #USF scientists new insights into past sea levels . Discover how their research has significant implications for understanding & predicting the pace of sea level rise amid a warming climate . HTTPURL HTTPURL     | cave<br>headed httpurl<br>malloccan cave<br>Malloccan<br>malloccan holds<br>cave malloccan<br>cave malloccan holds<br>chilling prediction<br>16 meters<br>malloccan holds chilling | sea levels discover<br>insights past sea<br>chilling prediction sea<br>ice earth lose<br>rise malloccan cave<br>scientists new insights<br>still likely rise<br>spanish caves httpurl<br>scientists discover clues<br>discover clues ancient             | 13                             | PHOTOGRAPH<br>-<br>[P] Real-world Scenes<br>-<br>threatened heritage_1 | mainstream         |
|  | RT @USER : Discover our new app that displays sea level height during a 1 in 100 year extreme event including projected sea level rise for the year 2050 . A simple risk index is used to determine the impact of coastal flooding on World Heritage Sites . Launch the app : HTTPURL HTTPURL | rt user mapped<br>user mapped<br>heritage sites<br>world heritage sites<br>world heritage<br>user mapped mediterranean<br>per country<br>pmsl<br>Mapped<br>mapped mediterranean    | shoreline change trends<br>impact coastal flooding<br>sea level fluctuations<br>sites risk sea<br>rise year 2050<br>risk climate impacts<br>hold warming sea<br>mapped mediterranean world<br>httpurl tanzania worldenvironmentday<br>httpurl shorebirds | 35                             | INFOGRAPHICS<br>-<br>[I] maps/info-maps<br>-<br>threatened heritage_2  | mainstream         |

Figure 3: Examples of topics under the theme of “threatened heritage”. The first five columns are generated with the BERTopic library, showing the representative visuals, documents, and keywords of the topic, as well as the tweets count. The last two columns are manually labelled by the authors.

As an example specifically interesting for urban management and planning, Figure 3 demonstrates three initial topics identified by BERTopic under the later aggregated theme of “threatened heritage”. The first two topics use real-world photographs to demonstrate the values, beauty, risks, and vulnerability of various heritage sites, represented mainly by Venice and Malloccan caves. On the other hand, the last topic uses info-maps to monitor the threats and impact of coastal heritage sites globally, as a means to draw attention. Both strategies can call upon the empathy of communities

who care about heritage in the climate debates, passing the message through.

## 4 Discussion and Conclusions

This paper presents an explorative study of a global Twitter dataset about sea level rise. Using geocoding and multimodal topic modelling, it maps the spatial distribution of discussions and summarizes the key multimodal topics within the debates. Multimodal frames can be inferred from the hierarchical structure of the meta-topics, highlighting certain aspects of fragmented reality that reach the concerns of various users (Efrat 2023; Rojas-Padilla, Metze, and Dewulf 2024). It has been argued previously that climate change adaptation can be framed as a tame techno-scientific problem or a wicked sociopolitical governance problem in the policy debates (Dewulf 2013). Both frames can be observed from the multimodal themes in this study. However, thorough manual efforts are still needed with expert knowledge to transform the topics and themes into frames that are informative for urban management and governance.

Modules in the workflow can still be improved in future studies. Only a subset of unique visuals entered the analysis. However, the same visuals can be paired with various texts, potentially changing the meaning of the multimodal message. The meta-topics can be treated as pseudo-labels to train models to analyse the entire dataset with semi-supervised classification (Zhou and M. Li 2010). Furthermore, the textual and visual embeddings are simply averaged in BERTopic, which can be replaced with more nuanced fusion strategies using more specified climate-aware embeddings (Song et al. 2022; Bai, Silva Torres, et al. 2024). Lastly, potential stances are only anticipated from examples. Trained classification models on climate change stances (Bai, Silva Torres, et al. 2024) can be later applied to verify the initial estimations and draw more concrete conclusions on the dynamic associations between the frames and stances.

Still, the methods proposed in this study can also be applied to other urban management and governance issues that relate to the Sustainable Development Goals of the United Nations, such as heritage conservation, water management, and climate change in general.

## 5 Acknowledgements

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## Biographies

Nan Bai is Assistant Professor in section Heritage & Architecture at Delft University and Technology. With a multi-disciplinary background, Nan always has a broad interest in the application of data science, artificial intelligence, and computational social science in the historic urban settings, especially the perceptions reflected in social media.

Art Dewulf obtained a PhD in Organisational Psychology and is Personal Professor of “Sense-making and decision-making in policy processes” at the Public Administration and Policy Group (Wageningen University). He studies complex problems of natural resource governance with a focus on interactive processes of sensemaking and decision-making in water and climate governance.