Temporal tile-maps for characterising the temporal occupancy of places: A seabird case study

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Summary

GPS is regularly used by movement ecologists to track animals, whose data are used to infer aspects of animals' behaviour and the factors that might drive this. Temporal signatures of the occupancy of places helps us understand animals' use of space, but this can hard to explore because of the complex spatiotemporal nature of the data. We present visual encodings and interactions designed to identify how temporal occupancy signatures of places vary spatially. These tile the space into grid squares, embedding temporal glyphs within. We apply these to GPS data from gull tracking and illustrate their use in movement ecology. The tool that implements this and data are available to download and use.

KEYWORDS: GPS tracking, temporal signatures, visualisation, movement ecology.

1 Introduction

GPS is used by ecologists to track animals to answer ecological questions about how the environment affects animals' behaviour (Nathan, 2008; Kranstauber et al., 2011). In Slingsby and van Loon (2016), we made the case that a useful preliminary step is to visually browse and explore these data interactively, prior the data being transformed and processed for more structured analysis. We proposed visual encodings and interactive techniques for doing this, available as a free downloadable tool at `http://gicentre.org/birdGPS/`. The tool takes unprocessed GPS data and produces linked space-time views that enable data to be explored in space and time (`https://vimeo.com/171595827`). Although we can interactively help identify the temporal signatures of places, it is difficult to identify temporal signatures where spatiotemporal properties of the data are complex.

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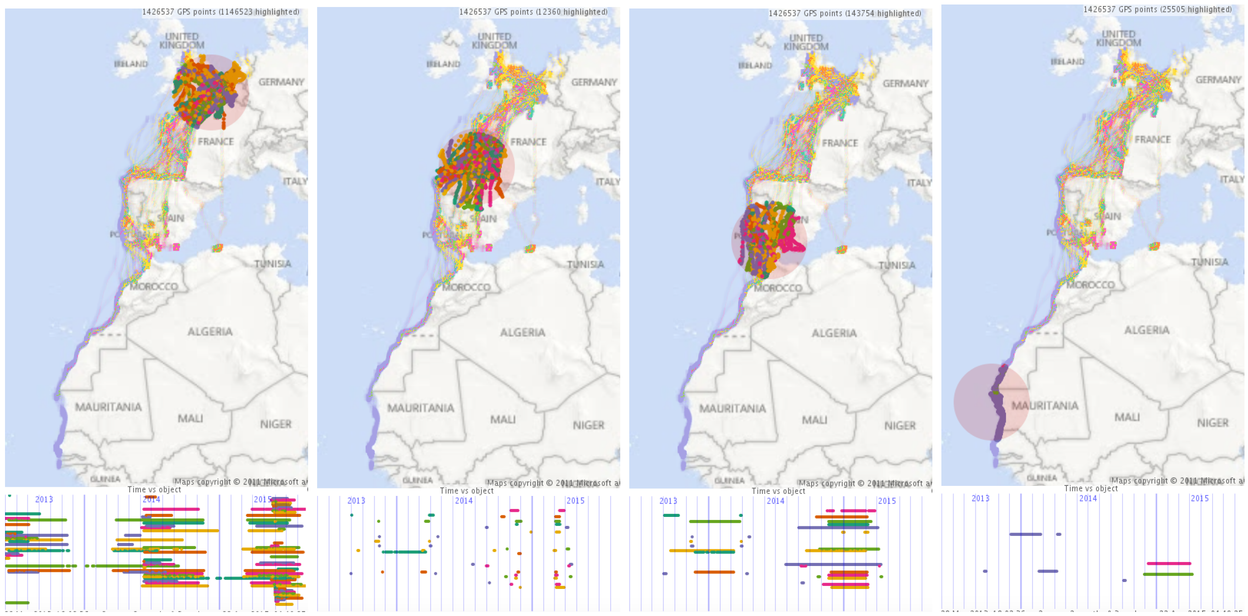

Figure 1: The interactively-linked space-time view shows the whereabouts of about 50 Lesser Black-Backed Gulls over a three-year period. The red circular area on the map interactively indicates the *times* at which they were there (from left to right in the timeline at the bottom) and *which individuals* (rows in the timeline). It indicates that the gulls migrate southwards for the winter (thicker vertical lines are the December-January boundaries). Gull data from `http://bit.ly/2j7uPlm` and maps from Microsoft Bing.

We extend this work, proposing new visual encodings and interactions for interactively identifying *places* of interest based on their temporal signatures of occupancy. We use a freely-available dataset of Black-Backed Gull and Herring Gull data from `http://bit.ly/2j7uPlm` as an example of a GPS-tracked animal whose temporal pattern of occupancy, implies behaviours of interest to bird movement ecologists. However, these techniques can be applied to any objects tracked by GPS where the temporal pattern of occupancy is of interest.

2 Interactive brushing space-time views

Clearly, maps of GPS positional data cannot easily show *when* those positions occurred and this of often importance. There are various options for depicting this. A good option is to have a view that only shows temporal aspects of the position, and through interactive *brushing*, these views are linked.

Fig. 1 shows how this works in BirdGpsExplorer (Slingsby and van Loon, 2016). The map (Fig. 1, top) shows *geographical* aspects of the positional data and the timeline (Fig. 1, bottom) shows *temporal aspects* of the positional data. By interactively moving a *brush* (temporary selection)

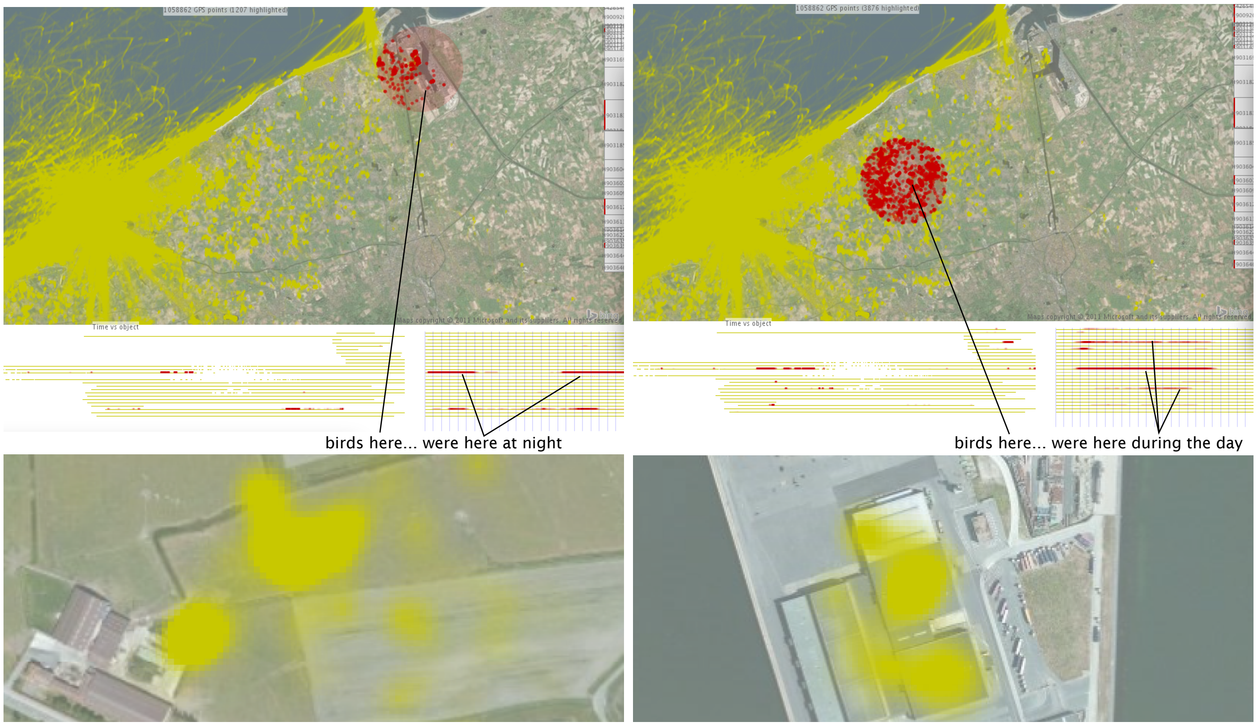

Figure 2: *Left:* brushed area has gulls in the daytime. *Right:* brushed area has birds at night. On each of the upper screenshots, the left (and wider) timeline as as in Fig. 1, and the right (and narrower timeline) is over a day, running from midnight to midnight where vertical lines are hours. Below, zoomed-in aerial imagery shows a grassy field where some of the gulls feed during the day and a rooftop where some of the gulls spend the night. Data from the same sources as in Fig. 1.

over the maps, only the corresponding points are shown in the timeline. This example confirms that these Lesser Black-Backed Gulls migrate southwards for the winter. Although it is easy to discover this for such a simple example, it can be extremely difficult to discover where there is more spatiotemporal subtlety.

From informally exploring Herring Gull data, we noticed that there are some areas are occupied by gulls during the day (Fig. 2, left) and other areas are occupied by gulls during the night (Fig. 2, right). In many cases, daytime areas are grassy fields that provide food and night time areas are roofs or the middle of small lakes that are safe places to sleep. However, serendipity has a big role in us identifying these areas through interactive brushing. We wanted a more systematic way to visually summarise temporal signatures of gull occupancy as these often indicate areas of significant to the animals being considered.

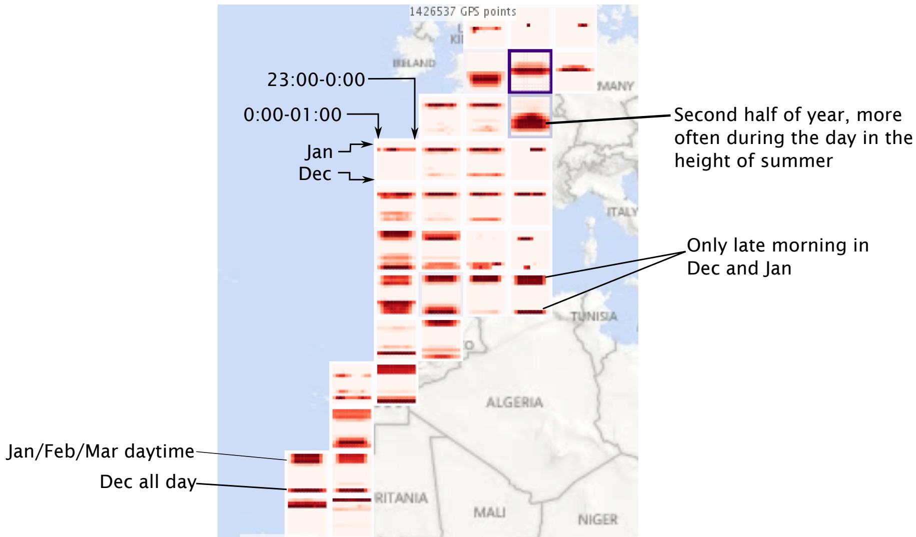

Figure 3: Tile map where each tile summaries data for a grid-square. Each tile is a matrix where rows are *months* and columns are *hours*, coloured by occupancy (by time) relative to occupany in that grid square. The seasonal shift apparent in Fig. 1 is also apparent in this single static image, with the addition of diurnal patterns of occupancy.

3 Tile maps that depict spatial variation in temporal signatures

Tile maps aggregate space into grid cells which we call 'tiles'. Into each tile, we place a visual representation of a temporal signature of the occupancy across the area represented by the tile. This is based on ideas from Andrienko and Andrienko (2010) and Slingsby et al. (2010).

Fig. 2 shows a tile map that depicts the seasonal shift in occupancy over space that was apparent in Fig. 1. In order to embed the temporal signatures into the map, we have sacrificed spatial precision by aggregating the spatial data into grid cells. Within these grid cells, we can embed a matrix of two temporal aspects – in this case, hour of day (columns) and month of year (rows) and colour these by the occupancy by time; Slingsby and van Loon (2016) contains details of how this is calculated.

This is not particularly insightful for the migration example, but it becomes more powerful for more complex spatio-temporal patterns. Fig. 4 shows a grid map for the Lesser Black-Backed Gulls from Fig. 1 and the temporal patterns of occupancy are varied and recognisable. As a static image, it provides the spatial distribution of temporal signatures of occupancy without requiring manual search with interactive brushings.

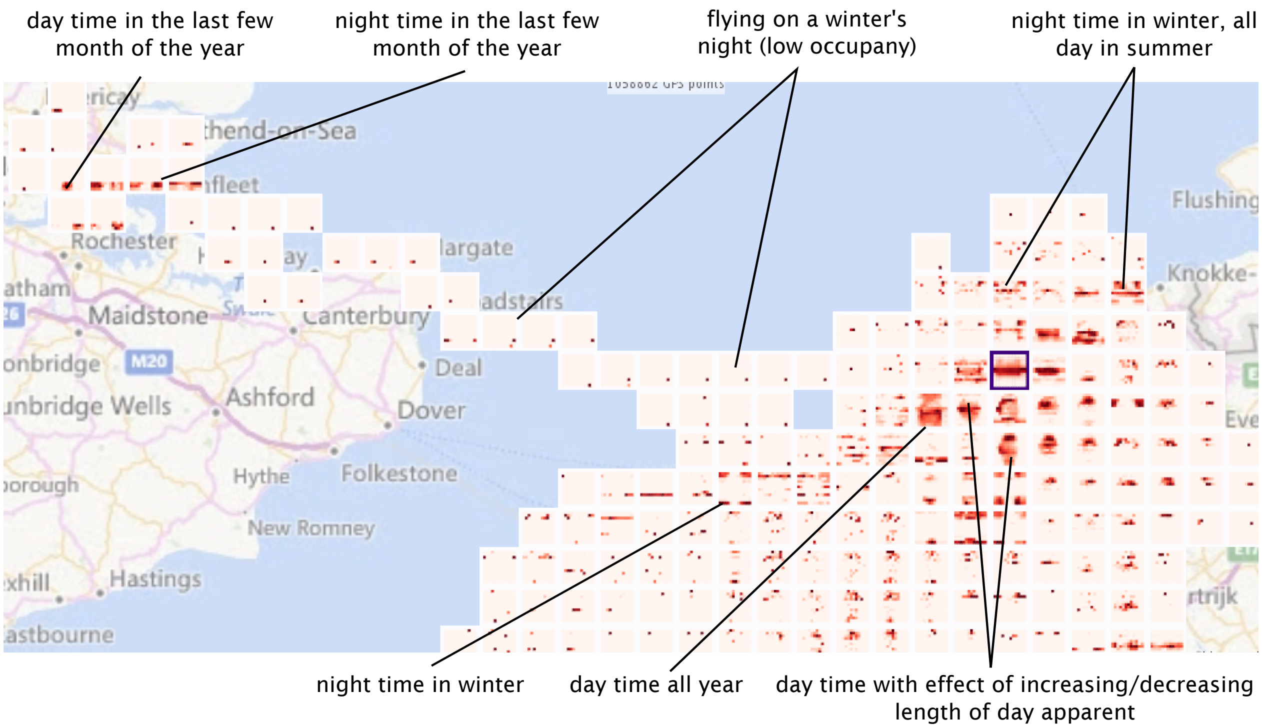

Figure 4: Tile map as in Fig. 2, but for Lesser Black-Backed Gulls. The glyph-like temporal signatures vary over space and are intuitive and recognisable.

4 Grid map issues

There are a number of issues that require consideration and further work.

4.1 Absolute vs relative occupancy

The occupancy matrix colour is scaled relative to each grid square, enabling relative occupancy signatures to be compared to each other. Overall, grid cells have different occupancy level. In Fig. 5, the darkness of the grid outline is proportional to the occupancy compared to that in other grid cells. The more highly occupied grid cells are likely to be feeding or sleeping locations, whereas the gulls probably only travel through the surrounding grid-cells, leading to noisy-looking temporal signatures. In Fig. 6, overall occupancy for grid cells is shown using height.

4.2 Interactivity, scale and MAUP

These grid maps have been implemented in BirdGpsExplorer and are one of the types of visual encodings offered. They are designed to show spatial variation in temporal signatures of occupancy

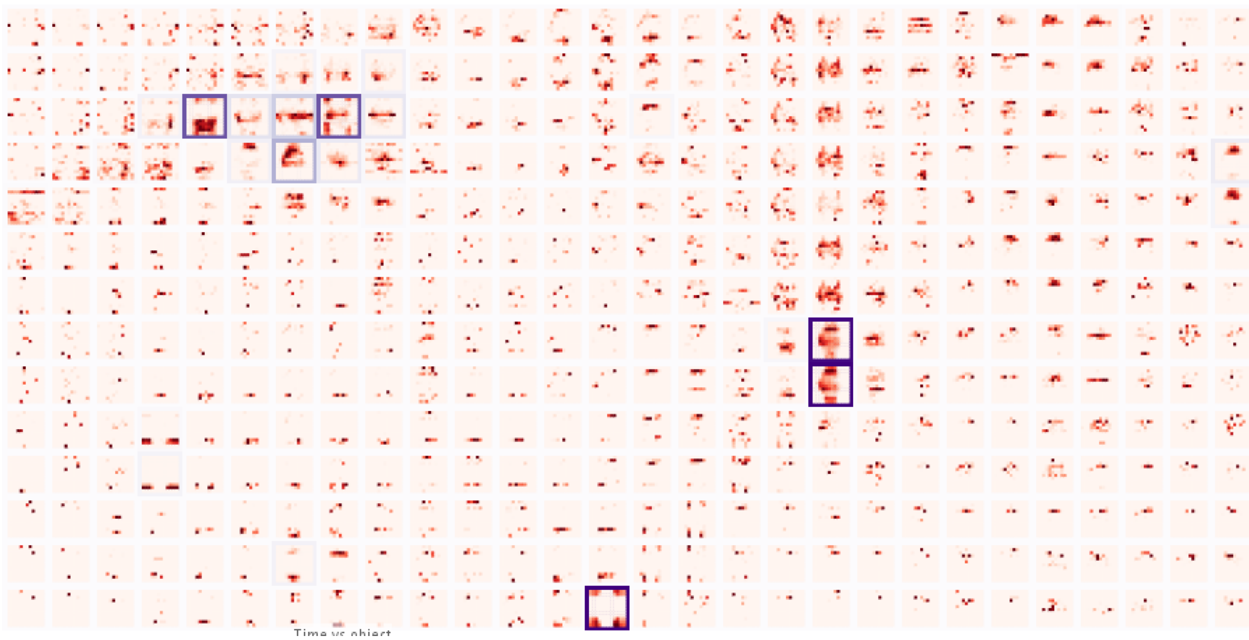

Figure 5: The colour in the occupancy matrix is scaled relative for each grid square, whereas the darkness of the coloured outline coloured outline is directly proportional to the occupancy compared to that in other grid cells.

as static graphics. However, there are two limitations.

The first is that each static image has space aggregated as a particular resolution, therefore can only really be visually interpreted at a particular scale. Interactive zooming resulting in re-aggregation of the data on the fly. There may also be other methods to depict scale effects in the static maps.

The second is that arbitrary imposition of the grid will lead of visually-difference grid-map solutions due to the Modifiable Areal Unit Problem (MAUP) (Openshaw, 1984). Simple map panning interaction results in on-the-fly reimposition of the grid, so the effects of MAUP can be interpreted, interactivity. Distance-decay smoothing between grid-cells may reduce the effect of this.

4.3 Potential for other glyphs inside tiles

The tiles may hold any summary glyph that summarises characteristics of the space covered by each tile. For example, OD Maps depict flows by embed destination maps for flows that originating from the space covered by the tile (Wood et al., 2010). We also demonstrate stacked barcharts that depict absolution and relative occupancy of the different individuals in Fig. 6.

The month-hour matrices we have been using are relevant for our application, but other aspects of time will be relevant for other aspects. For human-related activity, day of the week is relevant (e.g. Slingsby et al., 2010; Andrienko et al., 2016).

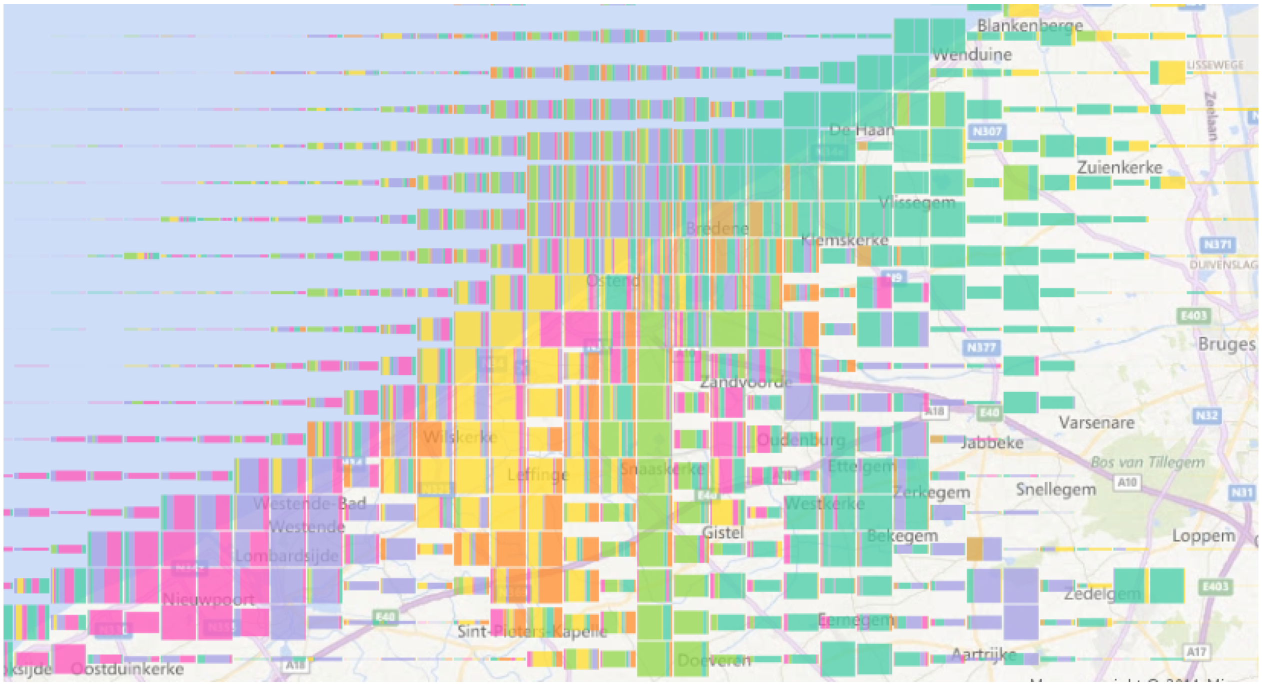

Figure 6: A tile map, but rather than temporal signatures inside each grid, stacked barcharts of the relative occupancy (width) and absolute occupancy (height) are embedded, showing the spatial occupancy of individuals.

5 Conclusion

Slingsby and van Loon (2016) made the case for the visual exploration of GPS tracks for movement ecology research. For our gulls example, month/hour based temporal signatures of occupancy of places is helpful for inferring feeding, sleeping and migrating (the latter to a lesser extent). Temporal tile maps such Fig. 4 provide glyphs that enable one to pick out significant places for gulls.

Although this is an improvement over the interactive search approach mentioned earlier, there are still issues of scale, MAUP and noise in signatures when the sample size become too small. We already have ideas of how to try to overcome some of these.

In further work, we wish to combine this with data-mining approaches so that we can identify temporal signatures of interest and automatically identify others with similar patterns of occupancy taking into account that fact that these may occur over different scales. Temporal signatures of occupancy are used to infer semantics of places in a variety of contexts, including those that are human (Andrienko et al., 2016).

6 Acknowledgements

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7 Biography

Aidan Slingsby is a Lecturer in Visual and Analytic Computing, designing, applying and evaluating visual support for the communication and analysis of spatiotemporal data in a variety of application areas.

Emiel van Loon is a Lecturer in Statistical Ecology, developing and applying statistical and measurement theory to the analysis of animal movement and distribution.

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