Assessing the impact of seasonal population fluctuation on regional flood risk management

Alan Smith[*1], Andy Newing[2], Niall Quinn[3], David Martin[1] and Samantha Cockings[1]

[1]Geography and Environment, University of Southampton, UK
[2]School of Geography, University of Leeds, UK
[3]School of Geographical Sciences, University of Bristol, UK

03 November 2014

Summary

This paper focuses on the integration of population and environmental models to address the effect of seasonally varying populations on exposure to flood risk. A spatiotemporal population modelling tool, Population24/7, has been combined with LISFLOOD-FP inundation model outputs for a study area centred on St Austell, Cornwall, UK. Results indicate seasonal cycles in populations and their exposure to flood hazard which are not accounted for in traditional population datasets or flood hazard analyses and which provide potential enhancements to current practice.

KEYWORDS: Spatiotemporal population modelling, flood risk, Population24/7, LISFLOOD-FP, seasonality.

1. Introduction

Previous research applying high resolution spatiotemporal population modelling to flood risks has shown large variations in population exposure over time and space (e.g. Smith *et al.* 2014). A major refinement in this approach has been the inclusion of seasonally varying overnight visitor population estimates developed by Newing *et al.* (2013). These have been integrated within the flexible Population24/7 data framework (Martin *et al.* forthcoming) which can be used to produce spatiotemporal gridded population estimates using variable kernel density estimation methods.

This paper demonstrates analysis of seasonal variations in population exposure to flood risk using a local case study. It combines spatiotemporal population estimates with an extract from the national Environment Agency (EA) flood map and bespoke LISFLOOD-FP inundation modelling. The integration of seasonal tourist population estimates represents an advance in modelling spatio-temporal populations for applications such as population hazard exposure.

2. Case study: St Austell, Cornwall

This study is based on a 15 × 20 km study area centred on St Austell Bay, Cornwall, UK (Figure 1). Coastal resorts within the study area, such as Par, Polkeris and Fowey, experience considerable seasonal fluctuations in population driven by an influx of domestic overnight visitors.

[*] Alan.Smith@soton.ac.uk

The study area is subject to fluvial, tidal and surface water flooding. The warning system on the River Par provides less than two hours' notice of flooding (EA 2012a). The 'tide-locking' of local watercourses during high tides prevents drainage at coastal outlets and poses an additional risk of fluvial flooding. Tidal flood risk dominates the east of the study area. The Par area contains the highest number of properties at risk from current and predicted future flooding in Cornwall (EA 2012b).

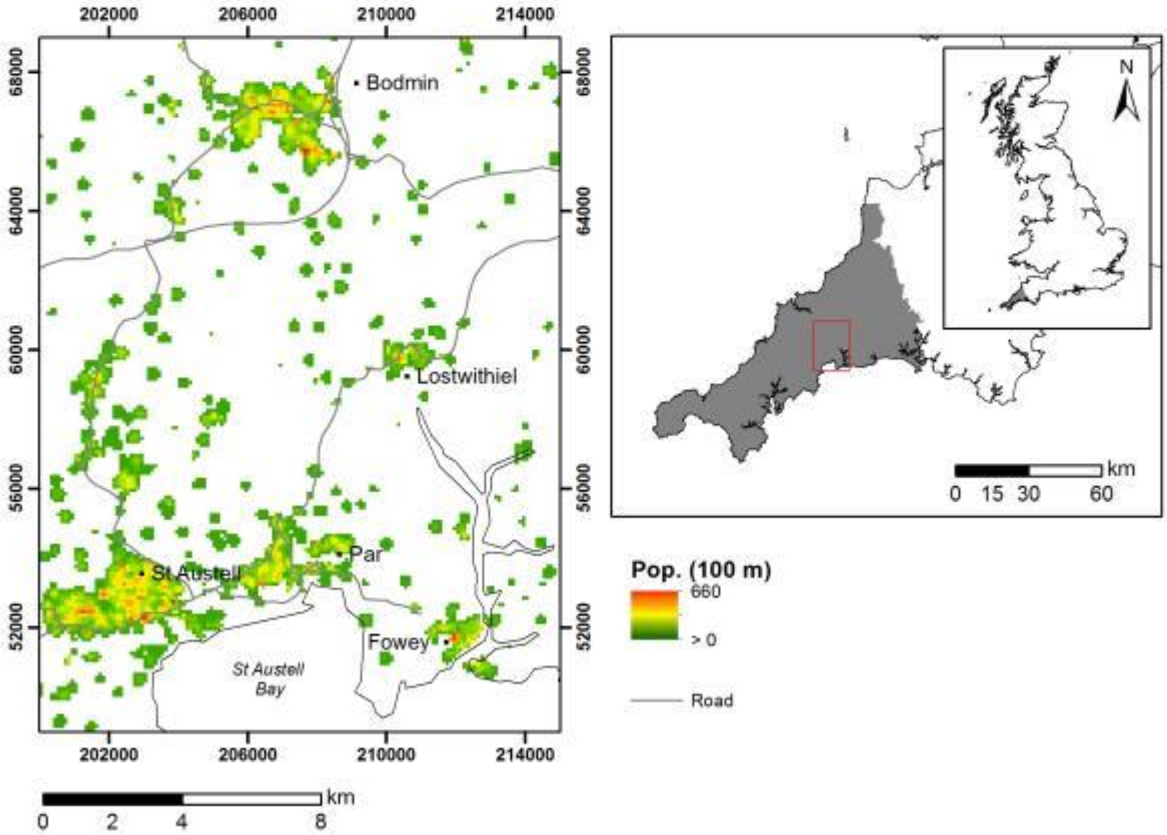

Figure 1 St Austell study area outlined in red, showing location within Cornwall (shaded grey) and Great Britain insets. An example 100 metre gridded population distribution provided for contextual purposes.

3. Methods and data

Hourly population estimates at 100 metre resolution have been produced for a 'typical' weekday in January, May and August 2010 using the SurfaceBuilder247 software tool (http://www.esrc.ac.uk/my-esrc/grants/RES-062-23-1811/read). These scenarios demonstrate the considerable variation seen in estimated seasonal visitor numbers within the case study area, reflecting the low, fringe and peak tourist seasons respectively.

Population is redistributed from origin (residential locations) to destination (e.g. locations of work, study, leisure) centroids. Population redistribution is constrained by a dasymetric background mask which includes the road transport network. The occupation of destination centroids is governed by a temporal profile specific to each site (e.g. a school occupied during school hours in term-time). The modelling framework is described in greater detail by Martin *et al.* (forthcoming). This particular application integrates novel overnight visitor population estimates within the modelling framework (Section 3.1) and combines these with bespoke flood inundation modelling using LISFLOOD-FP (Section 3.2).

3.1. Seasonal population fluctuation

Tourist visitor populations have a tendency to cluster in both space and time. In coastal areas, such as St Austell Bay, a concentration of visitor accommodation, attractions and other facilities generate spatial clusters of visitors, with numbers known to fluctuate at different times of the year, driven by the weather, local and national events, the institutional calendar and the operating season at accommodation sites and major attractions. In contrast to residential and workplace populations, very little is known about the spatial or temporal distribution of overnight visitors below the local authority district level.

We make use of a novel dataset estimating the seasonal and spatial distribution of visitors based on the provision and utilisation of tourist accommodation (Newing *et al.* 2013) Overnight visitor population estimates (Table 1) were built from the 'bottom-up' using local data collection and taking individual accommodation 'units' (e.g. a hotel room, self-catering cottage or camping pitch) as the building block, aggregated to the unit postcode or census Output Area (OA) level to form visitor 'origins'. Visitors staying with friends and relatives are distributed across the existing housing stock, whilst major holiday parks and camping and caravanning sites generate spatial and temporal clusters of overnight visitor populations in areas which may have few or no usual residents.

Table 1 Overnight visitor estimates within the St Austell study area

Month (season)	Overnight visitor estimate
January 2010 (Low)	1,049
May 2010 (Fringe)	6,269
August 2010 (Peak)	12,389

In common with the approach used for residential populations, visitor populations are redistributed from their overnight origins to daytime locations such as major attractions, the transport network and leisure locations which may not traditionally be thought of as clusters of population in the same way as workplaces, hospitals and retail centres. Given the coastal and estuarine nature of the study area, some of these locations may also be at flood risk.

3.2. Flood inundation modelling (LISFLOOD-FP)

Three flood scenarios representing return periods (R) of 100, 250 and 500 years have been created using LISFLOOD-FP, a raster based flood inundation model, for an 8 × 4 km subsection of the study area (Figure 2). The return period represents the likelihood of an event of a given magnitude occurring. In addition, the EA's flood map zone three (FMZ3) represents the amalgamation of return periods for events of 100 (fluvial) and 200 (tidal) years. FMZ3 contains a greater extent of inland fluvial flooding whereas the bespoke LISFLOOD-FP outputs specifically account for defences and other structures.

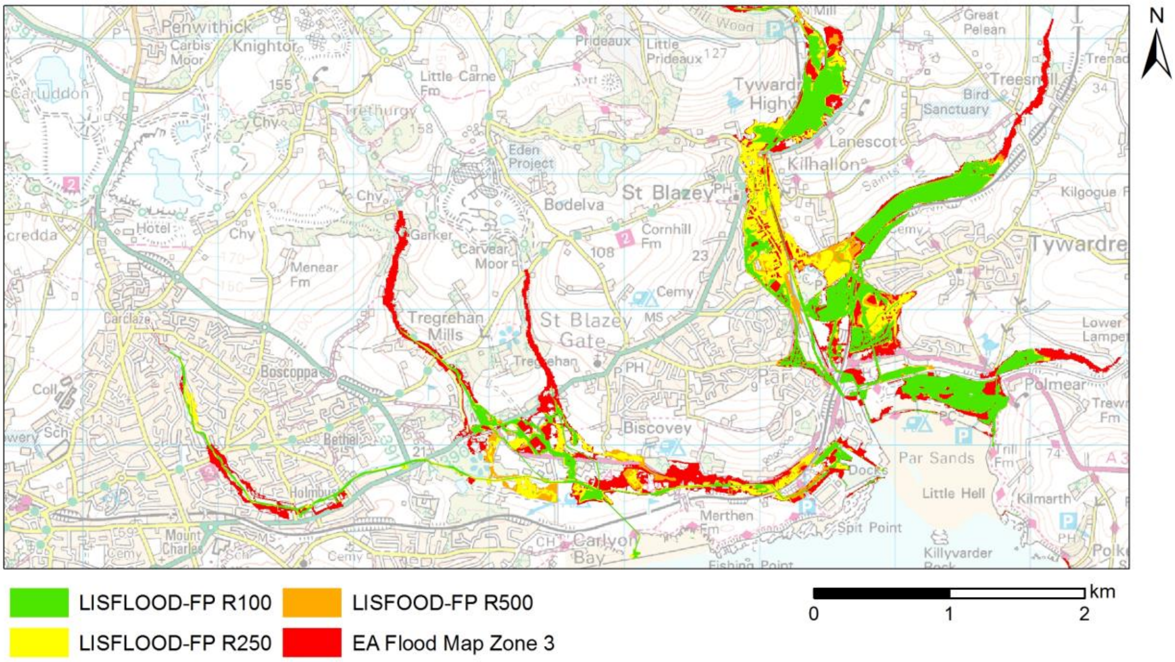

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Figure 2 Comparison of LISFLOOD-FP and EA flood inundations for the selected area within the study area covering St Austell and Par.

4. Results and discussion

This section presents the integration and analysis of spatiotemporal seasonal population estimates and flood inundation models. Figure 3 shows hourly spatiotemporal population estimates representing a ‘typical’ working weekday within each seasonal scenario. It shows the population exposure to the EA’s FMZ3 for the whole study area. It has been compared with static exposure estimates from rasterised census outputs representing: the baseline 2001 Census population at OA level (highest resolution available), 2001 Census daytime population at OA (only available for 2001) and the 2010 mid-year estimate (closest to target date but only available LSOA level).

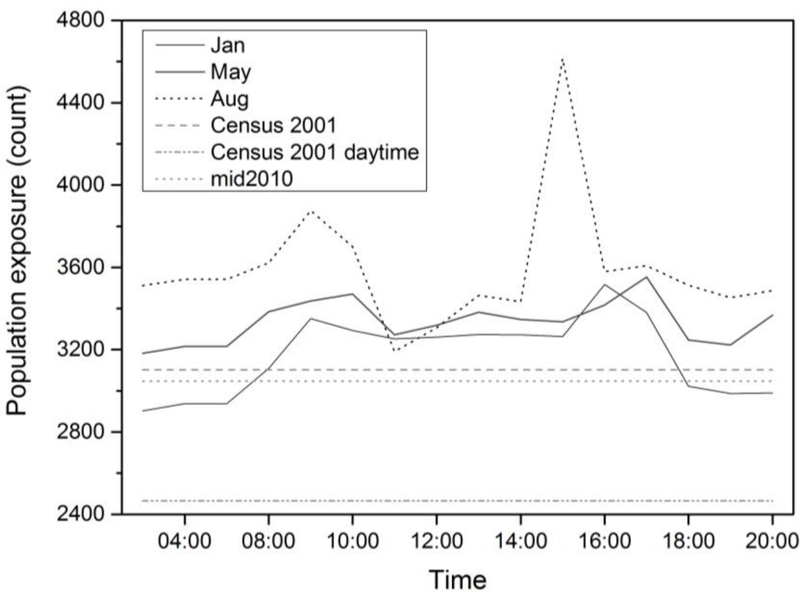

Figure 3 Flood exposure estimates from the EA Flood Map Zone 3 for the St Austell study area

The seasonal spatiotemporal variation is illustrated for weekday midday (12:00) and midnight (00:00) population estimates for two of the seasons modelled (January and August) (Figures 4 and 5). In both examples there is a general redistribution of the usually resident day-time population from the night-time locations to the main population centres (analogous with the main workplace locations), reflecting a daily transition from the surrounding rural areas into urban locations. The overnight visitor population increases by over 1000% January-August (Table 1) and is concentrated at leisure activity locations during the day.

Figure 6 shows modelled population results with OS map extracts and aerial imagery for 1 km national grid squares, providing detailed examples for an August weekday at 12:00 and 00:00. Daytime locations with example visitor leisure attractions are shown in (A) and (B). Night-time caravan and camping locations occupied by overnight visitors in August are shown in (C) and (D). The overnight visitors at these locations are completely missing from the traditional census datasets.

Population exposure to the varying flood risks, by season, residents and visitors for the St Austell study area is quantified in Table 2. This application has demonstrated what Martin *et al.* (forthcoming) term the 'modifiable spatiotemporal areal unit problem' whereby even the most detailed spatial data may be inadequate to support time-sensitive analyses. In this case, population exposure is highly dependent on time of day, season of the year and varying extent of flood inundation polygons.

Table 2 Daytime usually resident and visitor population exposure to three LISFLOOD-FP inundations scenarios (R = return period) and EA flood map zone three for January, May and August (increasing levels of inundation left to right).

Population	**LISFLOOD-FP R100**	**LISFLOOD-FP R250**	**LISFLOOD-FP R500**	**EA Flood Map**
Residents 12:00 Jan	542	939	1069	1725
Visitors 12:00 Jan	2	5	7	15
Total	*544*	*944*	*1076*	*1740*
Residents 12:00 May	546	994	1139	1729
Visitors 12:00 May	34	108	131	114
Total	*580*	*1102*	*1270*	*1843*
Residents 12:00 Aug	498	1019	1178	1741
Visitors 12:00 Aug	65	206	249	212
Total	*563*	*1225*	*1427*	*1953*

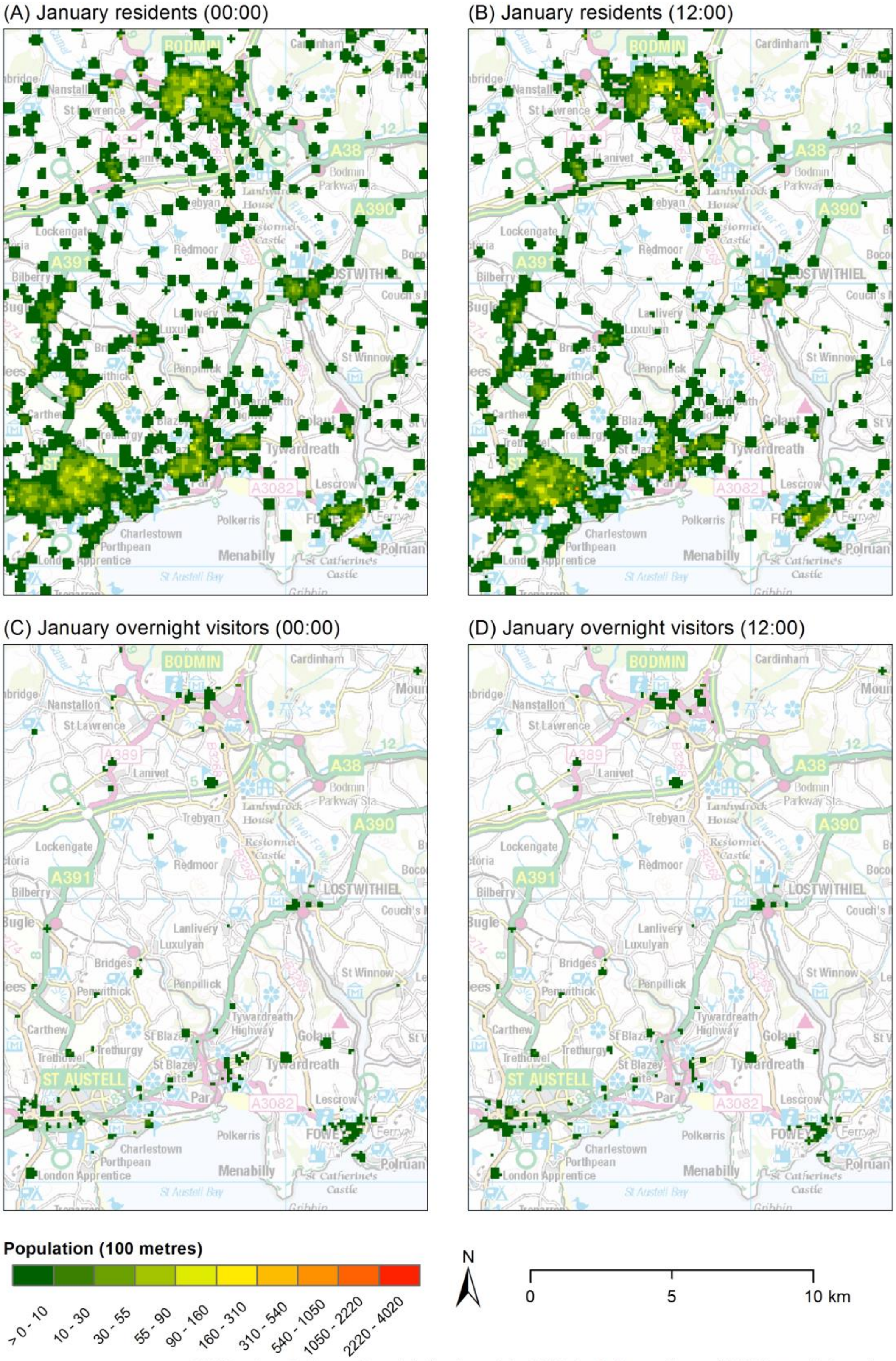

Figure 4 Modelled seasonal population outputs (100 m) for the St Austell study area for a January weekday. (A) Usually resident night-time (00:00) population, (B) Usually resident daytime (12:00) population, (C) Overnight visitor night-time (00:00) population and (D) Overnight visitor daytime (12:00) population.

Figure 5 Modelled seasonal population outputs (100 m) for the St Austell study area for an August weekday. (A) Usually resident night-time (00:00) population, (B) Usually resident daytime (12:00) population, (C) Overnight visitor night-time (00:00) population and (D) Overnight visitor daytime (12:00) population.

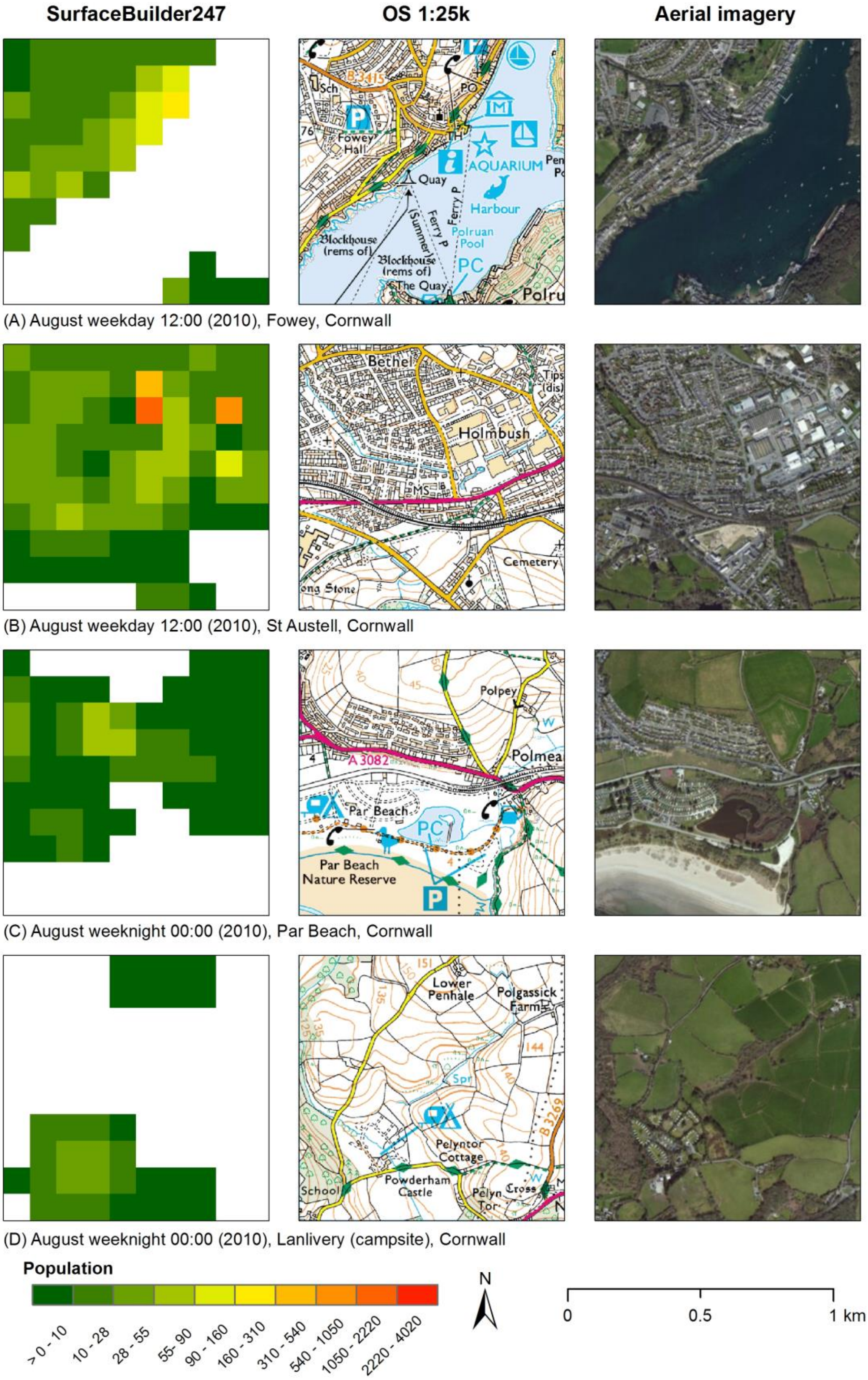

Figure 6 A detailed comparison of SurfaceBuilder247 (100 metre resolution) results within the St Austell study area with 1:25000 scale Ordnance Survey (OS) background mapping and aerial imagery for selected 1 km national grid squares. (A) and (B): August weekday 'daytime' population. (C) and (D): August weekday 'night-time' population.

5. Conclusions

The spatio-temporal modelling framework adopted here has facilitated the inclusion of a highly important seasonally varying tourist population into estimates of population exposure to flood risk. This not only enhances current insights into high resolution spatio-temporal population movements but also demonstrates the large potential impact of temporary populations on assessing flood risk and hazard exposure. Flood risk to people is variable and depends on many factors other than the usually resident population base. Such insights are simply not possible using static or traditional datasets in isolation. This approach exemplifies one possible integration of population and physical models for both environmental and wider applications.

6. Acknowledgements

This research is supported by a University of Southampton ESRC doctoral training award.
Data: Flood map data provided by the Environment Agency (April 2014).

7. Biographies

Alan Smith is an ESRC doctoral researcher in Geography and Environment at the University of Southampton. His research interests include spatio-temporal population modelling and the integration with environmental models.

Andy Newing is a lecturer in Retail Geography at the University of Leeds. His research interests include spatio-temporal population estimation for applications related to service provision and delivery.

Niall Quinn is a post-doctoral researcher in Geography at Bristol University. His research interests are focussed around uncertainties in flood risk prediction.

David Martin is a Professor of Geography at the University of Southampton. His research interests are focused on social science applications of geographical information systems. He developed the SURPOP and SurfaceBuilder methodologies and software.

Samantha Cockings is an Associate Professor in Geography at the University of Southampton. Her research interests include automated zone design, space-time modelling of populations and links between environment and health.

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