



INVEST: Investigating vulnerability of estuaries to climate change: annex

Chief Scientist's Group report

February 2026

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Dr Robert Bradburne
Chief Scientist

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Introduction

Researchers from Bangor University, The University of Liverpool, and The Environment Agency collaborated on the Investigating Vulnerability of Estuaries to Climate Change (INVEST) project to explore the nature of likely changes to English estuaries as a result of climate change.

An approach utilising multiple models was devised to produce a wide array of outputs. These outputs provide a foundation for future research and fill existing data gaps. Given the complexity of the models involved in the project it was not practical to include the full details of the methods within the main report.

This annex provides a detailed description of the modelling approaches which have been summarised in the main report.

In addition, this annex provides the “report cards” for each estuary modelled in this study. These report cards provide a summary of primary variables (such as temperature, residence time, and salinity) and how they are projected to change into the future.

Annex A: Climate data and Estuary drivers

A1: UKCP18 RCP8.5 Data and Perturbed Parameter Ensembles

Table A1.1. Global warming values in degrees centigrade [°C] from the UKCP18 HadGEM3-GC3.05-PPE relative to 1850-1900 for the periods 2020-2039 and 2040-2079, with the Effective Climate Sensitivity (EffCS) in °C. The global warming values are derived from model variant simulated changes to global surface air temperature (GSAT) relative to the 1986-2005 baseline plus the observed warming from the 1850-1900 mean to the 1986-2006 mean calculated using time series from the IPCC Sixth Assessment Report Working Group 1 (IPCC AR6 WG1) Summary for Policy Makers figure 1 (Figure SPM.1).

Ensemble member	2020-2039 GSAT [°C]	2040-2079 GSAT [°C]	EffCS [°C]
r001i1p00000	2.08	3.85	5.34
r001i1p01113	2.21	4.13	5.00
r001i1p01554	1.98	3.69	4.96
r001i1p01649	2.11	3.85	5.35
r001i1p01843	2.00	3.75	4.87
r001i1p01935	1.99	3.56	4.41
r001i1p02123	2.10	4.27	5.34
r001i1p02242	1.96	3.68	5.05
r001i1p02305	2.10	3.83	4.81
r001i1p02335	1.88	3.65	5.58
r001i1p02491	2.09	3.83	4.88
r001i1p02868	1.92	3.53	5.10

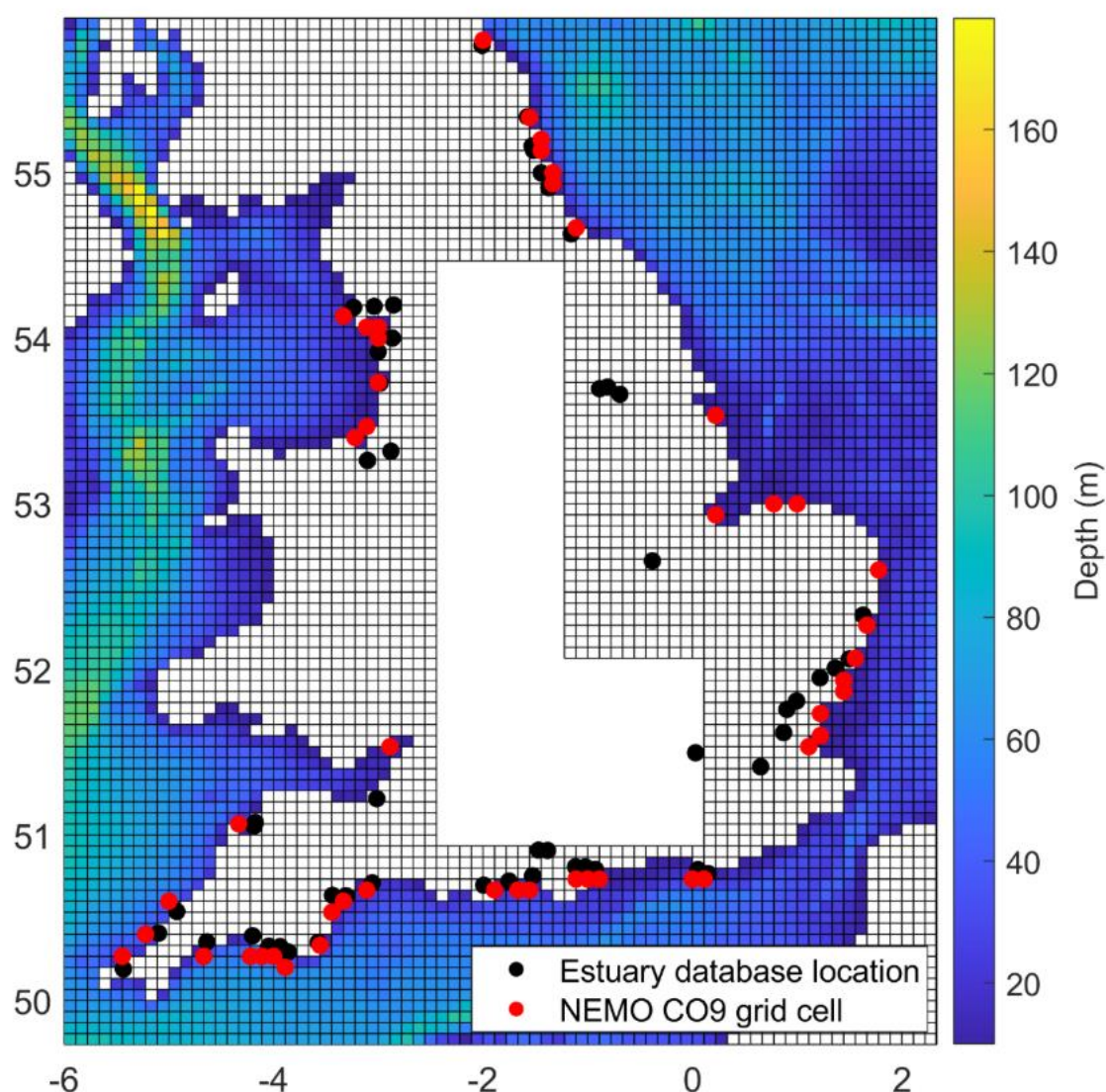


Figure A1.1: Bathymetry and grid for the NWS 7 km marine model grid cell, including location of the 52 estuaries (black dots, taken from the Estuaries Database) and nearest grid cell (red dots).

Table A1.2 lists estuaries which share the same grid cell from NEMO CO9 because the resolution of the model means the mouths of these estuaries occur in the same cell, or the resolution of the grid does not resolve the coastal features well.

Marine and fluvial stressors are presented for five gauges in the Humber estuary (Trent at North Muskham (ID: 28022), Don at Doncaster (ID: 27021), Aire at Beal (ID: 27003), Wharfe at Wetherby Flint Mill (ID: 27002), and Ouse at Skelton (ID: 27009)), but just one Delft3D numerical model for the Humber, based on the Trent gauge (ID: 28022), was created to produce residence times for this gauge only.

Table A1.2: Estuaries that share the same NWS 7 km marine model grid cell.

Domain	INVEST estuary	Gauge name	Lon	Lat	Grid ref	AMM7 grid cell	
						Lon	Lat
Severn	Torridge	Torridge at Torrington	-4.18753	51.05416	SS4678030590	-4.33349	51.06722
Severn	Taw	Taw at Umberteigh	-4.174575	51.07573	SS4775932962	-4.33349	51.06722
Liverpool Bay	Wyre	Wyre at St Michaels	-3.00143	53.91889	SD3432647437	-3.00017	54.0007
Liverpool Bay	Lune	Lune at Caton	-2.86619	54.00145	SD4332056505	-3.00017	54.0007
Liverpool Bay	Kent	Kent at Sedgwick	-2.85443	54.20181	SD4436078788	-3.00017	54.13404
Liverpool Bay	Leven	Leven at Newby Bridge	-3.04048	54.19294	SD3221077964	-3.00017	54.13404
Humber	Trent	Trent at North Muskham	-0.692777	53.66243294	SE8647719232	0.22202	53.53401
Humber	Don	Don at Doncaster	-0.886459	53.69600988	SE7362122750	0.22202	53.53401
Humber	Ouse	Ouse at Skelton	-0.810085	53.70594955	SE7864523937	0.22202	53.53401
South Thames	Colne	Colne at Lexden	0.994459	51.80951	TM0652316560	1.22201	51.73392
South Thames	Blackwater	Blackwater at Appleford Bridge	0.901937	51.75871	TM0037210653	1.22201	51.73392
South Thames	Thames	Thames at Kingston	0.0300496	51.49688844	TQ4101579503	1.1109	51.53391
South Thames	Medway	Medway at Teston / East Farleigh	0.651679	51.4125	TQ8450071500	1.1109	51.53391
Portsmouth	Portsmouth Harbour	Wallington at North Fareham	-1.11706	50.80819	SU6230801331	-1.1113	50.73387
Portsmouth	Blackwater	Blackwater at Ower	-1.469182	50.90834536	SU3741812231	-1.1113	50.73387
Portsmouth	Itchen	Itchen at Riverside Park	-1.383322	50.90673996	SU4345612100	-1.1113	50.73387

A2: Coincident driver conditions

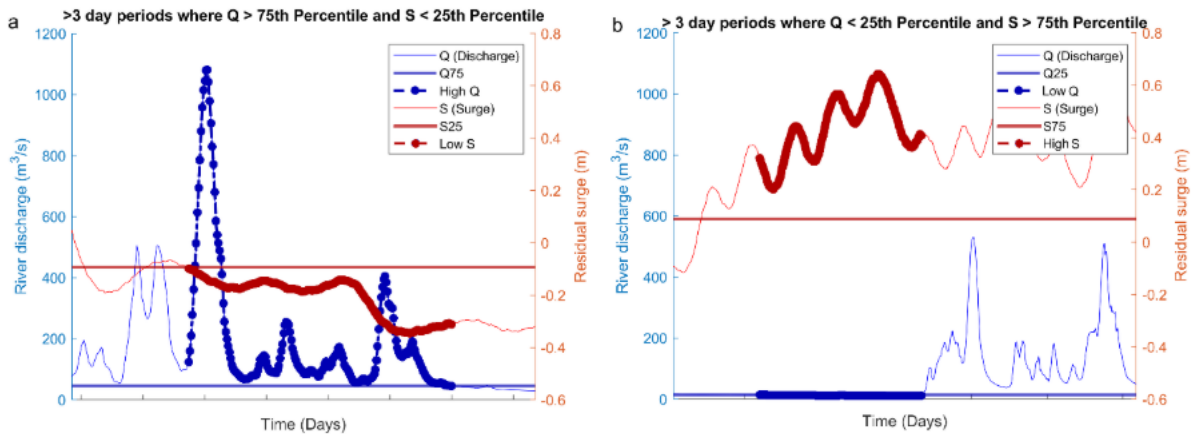


Figure A1.2: Process for identifying combined river discharge and surge conditions where a) river discharge exceeds 75th percentile and S is below 25th percentile for 3 days or more; b) river discharge is below 25th percentile and S exceeds 75th percentile for 3 days or more.

A peaks-over-threshold analysis (Lyddon et al., 2022) identified peaks in discharge that exceeded a moving threshold of the data for each ensemble (calculated based on a three-month moving mean + 95th percentile of each 20-year time slice) (red circles in Figure S5). The hydrograph storm window, based on the average hydrograph duration (1984-2013) is 38 hours for the River Ribble (Lyddon et al., 2022). The largest skew surge within the hydrograph storm window, i.e., within 19 hours before and after the peak in river discharge, was identified. This analysis repeated across 12 ensemble members and three time slices.

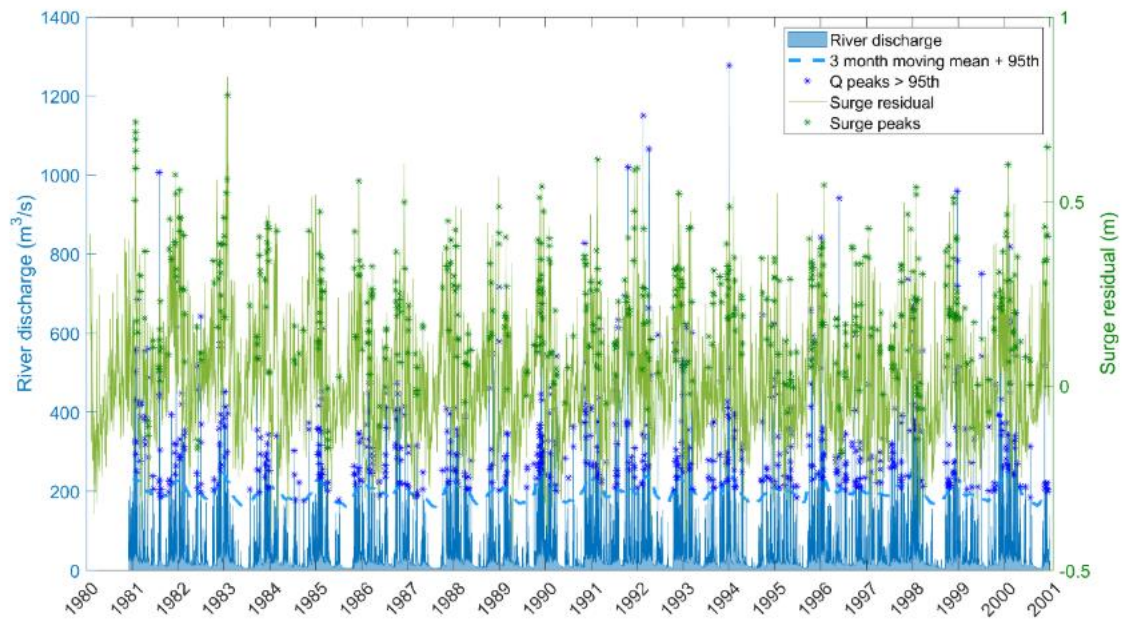


Figure A1.3: Peaks over threshold analysis for identifying extreme river discharge magnitudes/timings and associated peak skew surge within a hydrograph storm window (37 hours). This analysis was applied to all river discharge and skew surge data. River discharge (blue line), peaks in river discharge (blue stars) that exceed the 3 month moving mean + 95th percentile (blue dashed line), storm surge residual (green line), and maximum storm surge residual (green stars) within a 37-hour hydrograph window. This time series is presented for the baseline scenario (1980 – 2000), ensemble 0000.

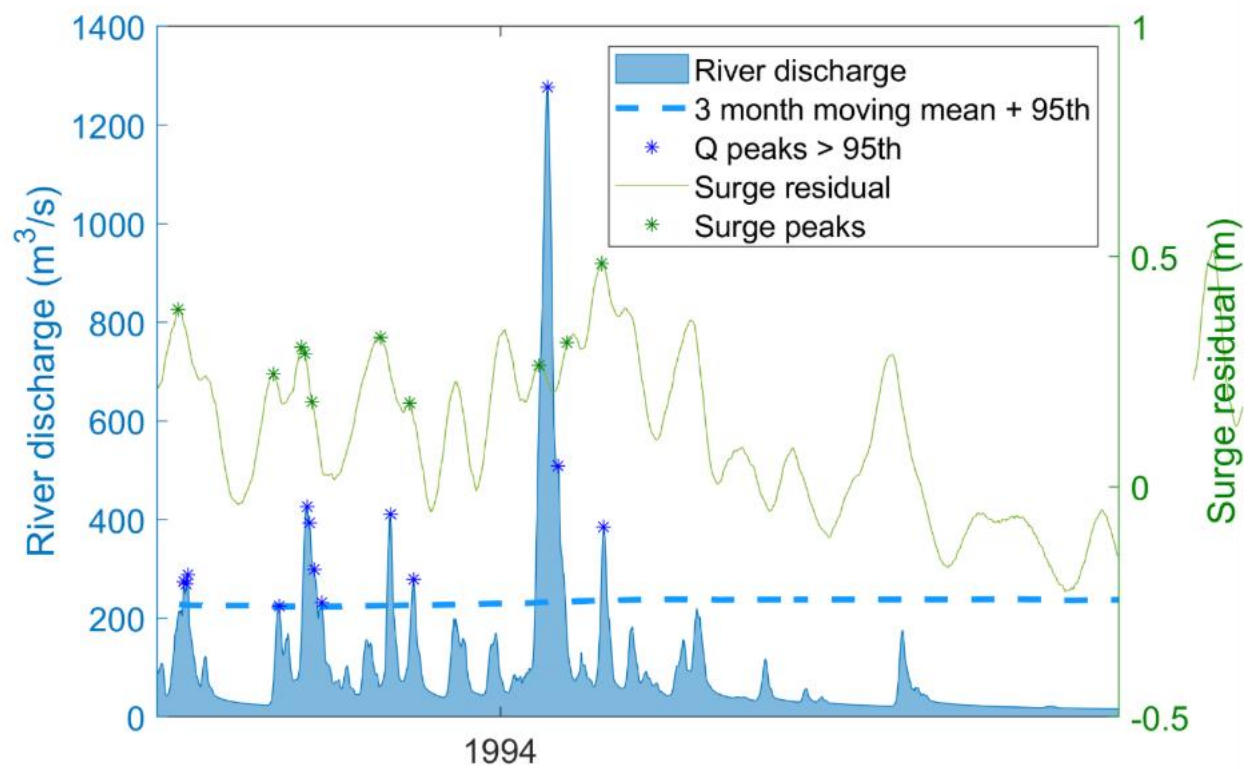


Figure A1.4: Zoom of Figure A1.3 (1993/1994) showing peaks over threshold analysis to identify marine / hydrology co-occurrences.

Annex B: Hydrological model calibration

B1. DECIPHeR catchment hydrological model

We use a climate-hydrological modelling framework to assess the impact of future climate based on the UKCP local climate projections on river flows in 10 estuaries across the INVEST regions: **Tees**, **Humber**, **Colne**, **Blackwater**, **Southampton Water**, **Exe**, **Dart**, **Taw-Torridge**, **Mersey**, and **Ribble**. Figure A6.1 shows the locations of the catchments where the hydrological model is calibrated, and river flows are simulated. Figure B1.1 shows a summary of the methodology used for the calibration and evaluation of the national-scale hydrological model (DECIPHeR).

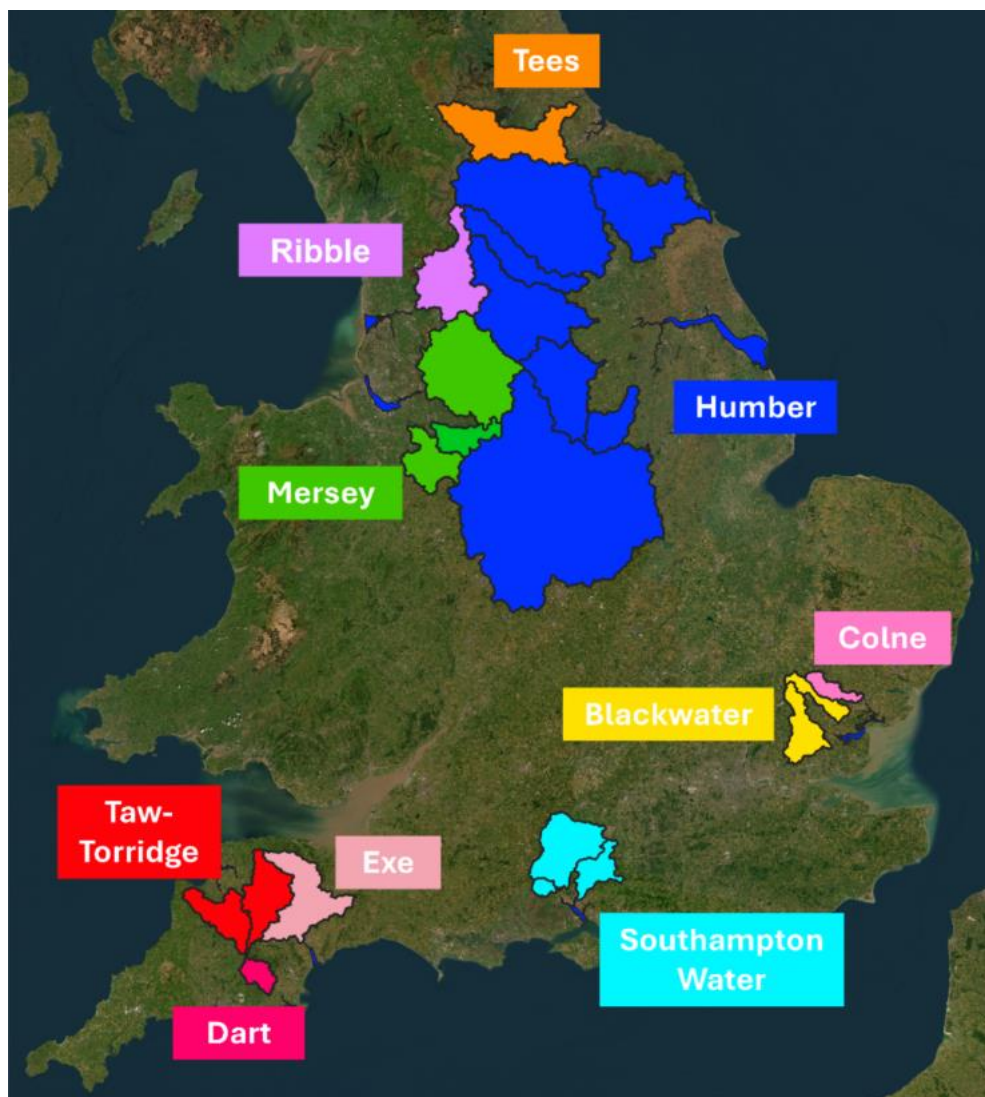


Figure B1.1. Locations of the catchments where DECIPHeR is calibrated and hourly river flow projections are produced. These catchments are upstream of the 10 estuaries across the INVEST regions.

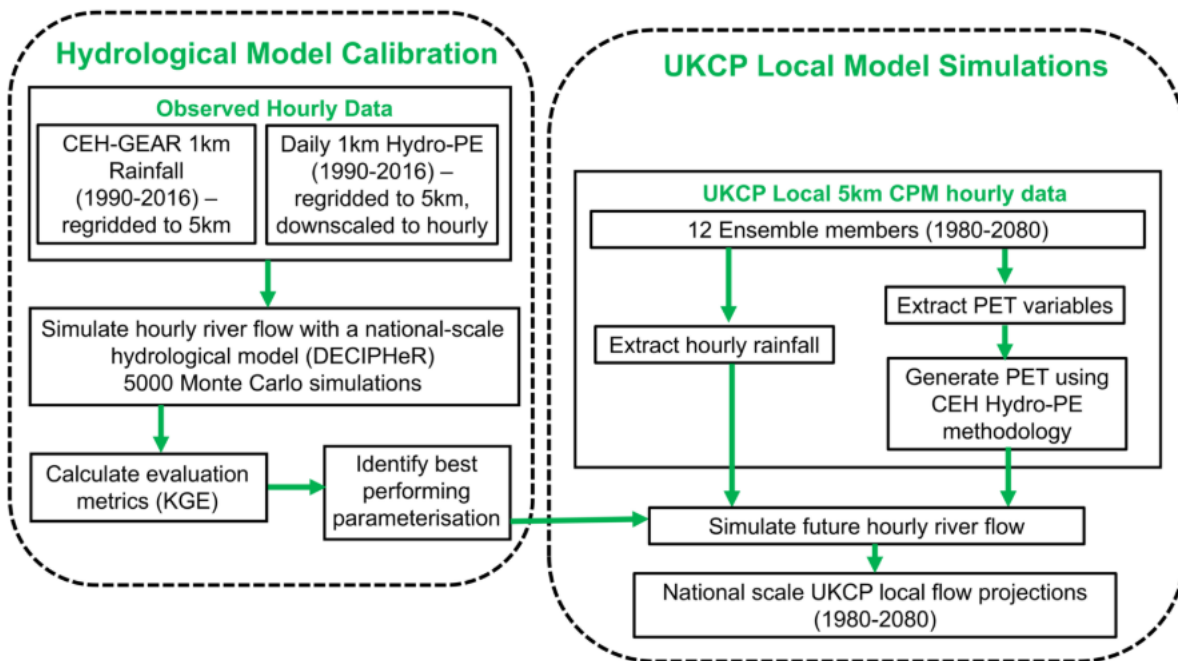


Figure B1.2. Overview of the hydrological modelling framework used in this work. DECIPHeR is calibrated using observed hourly rainfall and potential evapotranspiration data in the catchments upstream of 10 estuaries in the INVEST regions (see Figure B1.1). The best performing parameter set in each catchment is then used for the UKCP local river flow projection simulations.

DECIPHeR (Coxon et al., 2019; Lane et al., 2021) is a flexible hydrological modelling framework that simulates and predicts hydrologic flows from spatial scales of small headwater catchments to entire continents. It has been applied, developed and extensively evaluated across Great Britain demonstrating good performance across a range of catchment types (Coxon et al., 2019; Lane et al., 2021).

The DECIPHeR setup is split into two parts. To build the model domain, we use a 50m gridded digital elevation model (DEM) produced using LiDAR data (Environment Agency, 2022) where available across Great Britain and infilled with UK NEXTMAP (Intermap Technologies, 2009). This is processed to ensure the removal of any sinks or flat areas. The DECIPHeR River network is generated by extracting headwater cells from the Ordnance Survey MasterMap Water Network Layer (Ordnance Survey, 2024) which are then routed downstream via the steepest slope. The locations of the most downstream gauging station in the 22 catchments (Figure B1.1) were used to specify the points on the river network where simulated river flow was required. Catchment areas and masks are used as a reference to find the river network cell for the gauging station locations.

DECIPHeR uses hydrological response units (HRUs) to discretise the model domain into non-contiguous spatial units that are defined as sharing similar characteristics in landscape and climatic attributes. Each HRU is treated as an individual model store which can have different spatial inputs (e.g., rainfall, PET), model parameters and/or model structures to represent localised hydrological processes. For this work, we split the 22 study catchments into HRUs based on three classes of slope, three classes of accumulated area and 5km input grids (consistent with the UKCP local climate data used for river flow projections). This

process, compared to a gridded model approach, allows the model to be run at much higher resolution for critical areas, e.g., where there are large variations in slope or accumulated area. The default model structure (shown in Figure B1.3) is based on the widely used Dynamic TOPMODEL (Beven and Freer, 2001). The model version that has been used for this work also includes any reservoirs within catchments (Salwey et al. 2024). Reservoirs are incorporated by placing their outflow locations as nodes on the river network. These nodes break up the river within a catchment so that river flow at reservoirs can be manipulated according to the defined operating rules. These reservoir operating rules have been shown to increase model performance in reservoir-impacted catchments (Salwey et al. 2024).

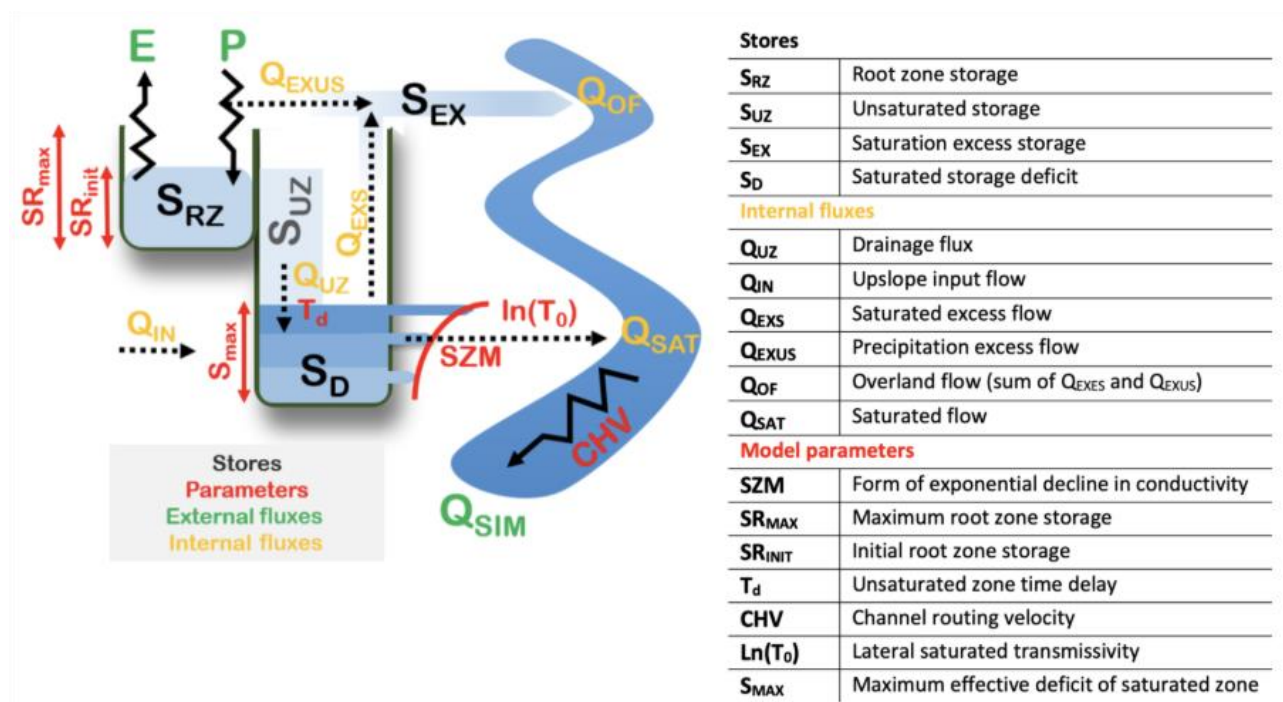


Figure B1.3. Conceptual diagram of the DECIPHeR model structure and overview of the model stores, fluxes and parameters (from Coxon et al., 2019).

B2. DECIPHeR Model Calibration and Evaluation

DECIPHeR has seven model parameters (Figure B1.3) which describe how much water the soils can store and how permeable they are, the river channel velocity, and the transmissivity of the sub-surface (Coxon et al., 2019). DECIPHeR uses the multiscale parameter regionalisation (MPR) method (Samaniego et al. 2010; Lane et al. 2021) to establish a connection between hydrological model parameters and physical catchment characteristics. MPR links model parameters to spatial catchment attributes (e.g., land use, soil texture, bulk density, hydrogeology productivity, porosity, soil depth) using transfer functions. These functions are used to produce high-resolution parameter fields which are upscaled to the model resolution. Transfer functions were defined for each of DECIPHeRs seven model parameters (Lane et al. 2021) and the transfer function parameters are calibrated against observed hourly river flows in each of the 22 catchments. In each catchment we ran 5000

simulations within a Monte Carlo simulation framework to randomly sample the transfer function parameters between set bounds. Reservoir transfer functions are defined based on catchments where compensation flow data and abstraction estimates are available to determine which catchment and reservoir attributes (e.g., catchment area, rainfall, reservoir capacity) exhibit the strongest relationships with the fluxes. The calibration of the reservoir transfer function parameters is taken from Salwey et al. (2024).

DECIPHeR was run continuously to simulate hourly discharge for the calibration simulation over the available observed data period 1990-2016. Calibration simulations were run with hourly observed precipitation (CEH-GEAR; Lewis et al. 2018) and potential evapotranspiration (PET) (Hydro-PE; Robinson et al. 2023). Both data products were regridded from their native resolution of 1km to 5km to match the UKCP local data resolution. Hydro-PE was downscaled from daily to hourly by using sunrise and sunset times for each day and using a normal distribution to divide the daily PET total across daylight hours. Model simulations were evaluated against observed hourly river flow data from the Environment Agency. Kling-Gupta Efficiency (KGE; Gupta et al., 2009) is a commonly used performance metric and considers three types of model errors; error in mean flow, error in flow variability and correlation between observed and simulated flows. Best performing calibration simulation KGE scores are shown in Table B1.1 and includes any additional information on catchment specific calibration.

Below are the calibration results for three example catchments: Ribble at Samlesbury (71001), Colne at Lexden (37005) and Dart at Austin Bridge (46003). Figure B2.1 shows the hydrographs for 2 years in each catchment. We find that DECIPHeR is performing well, capturing the timing and magnitude of hourly flows, for a range of catchments with different flow regimes. Figure B2.2 shows the mean monthly river flow profile for each catchment. Here we find that DECIPHeR is able to capture the seasonality of the river flows. Figure B2.3 shows the comparison of the annual maxima (AMAX) in the observed against the modelled data. DECIPHeR is able to capture the AMAX flows, but with some biases. For example, in the Colne (37005) DECIPHeR is able to capture AMAX flows well up to around $20\text{m}^3\text{s}^{-1}$, but overestimates for higher flows. This is likely impacted by issues with the gauging station data, as the out of bank flows are underestimated due to bypassing at very high flows.

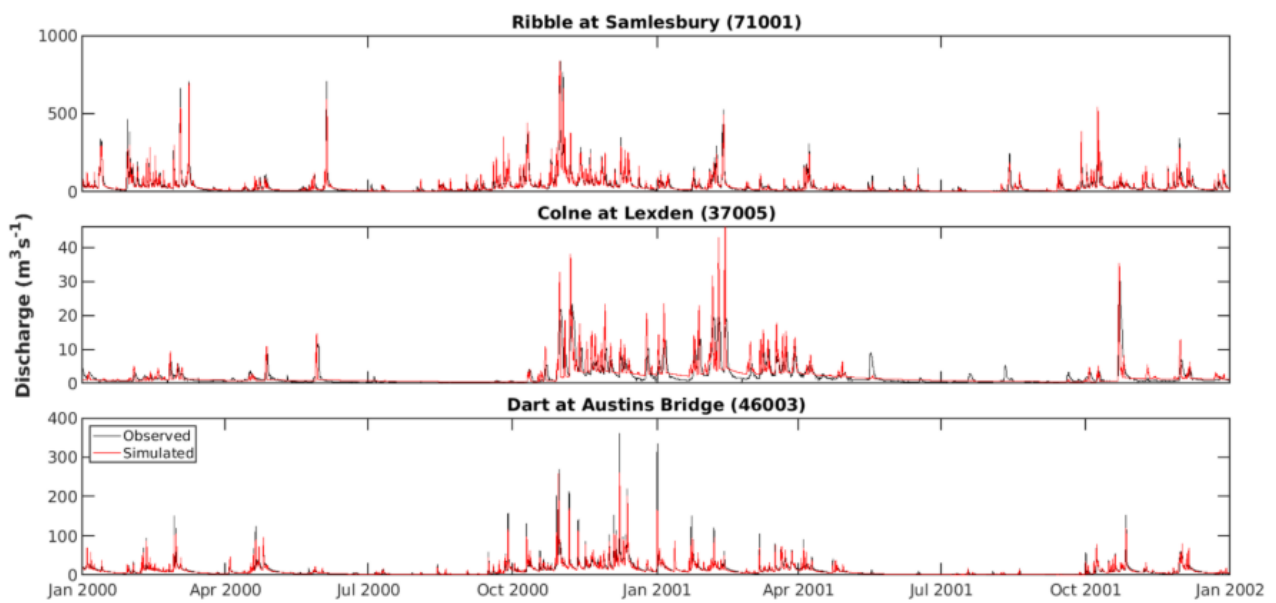


Figure B2.1. Hydrographs for two years (2000-2001) for the hourly observed data and the best performing model parameterisation in 3 example catchments. DECIPHeR captures the timing and magnitude of hourly flows well in catchments.

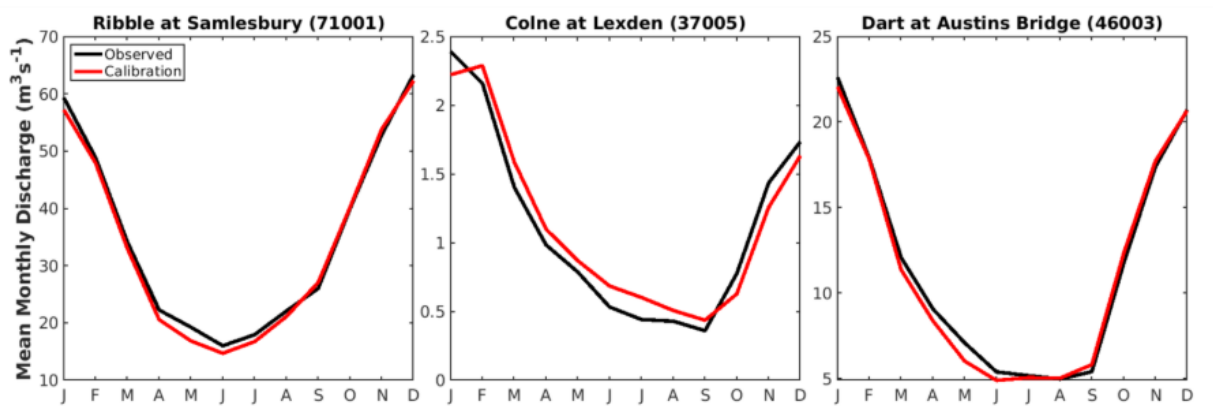


Figure B2.2. Comparison of the mean monthly discharge profile between the observed hourly data and the best performing hydrological model parameterisation in 3 example catchments.

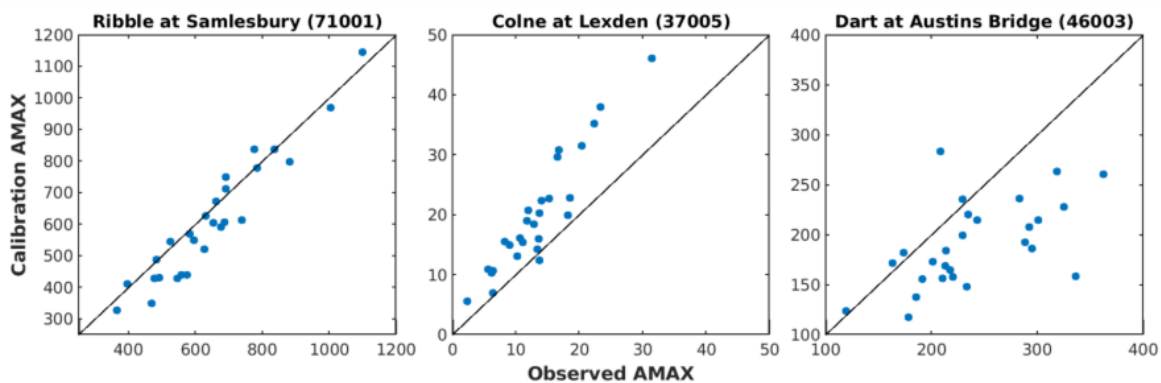


Figure B2.3. Comparison of the annual maxima (AMAX) flows in the observed data and the best performing hydrological model parameterisation in 3 example catchments.

Annex C: High resolution bathymetry of English estuaries

C1: Introduction

This document describes the data sources and process of production of high-resolution bathymetries for the seven coastal regions of England. Each section of this document focuses on a specific region, detailing the datasets and techniques used to generate the final bathymetry. Each section is divided into three sub-sections, detailing the development process of the bathymetries and their final delivery in .tiff and .xyz file formats.

1. Datasets and sources

Provides a detailed overview of the main data providers and their associated datasets (Table 1). Each dataset is described with key attributes, including the data source, download format, grid cell size or scale, horizontal and vertical datums, any applied adjustments, and relevant notes where applicable. Additionally, when publicly available datasets were insufficient, the process of supplementary river mapping is outlined.

2. Merging data and interpolation methods

Details the processes used to group and integrate the various datasets in this research, culminating in a single, 20 m spatial resolution raster file. This section covers the spatial distribution of data sources, the polygons used to define the model domain, and the interpolation techniques employed. Additionally, it details the chosen spatial resolution, edge-smoothing methods, and the manual mapping of river features.

3. Limitations and important notes

Provides future users with essential information about any constraints or potential drawbacks associated with the regional bathymetries. These limitations can arise from various factors, including dataset spatial coverage, resolution and scale, interpolation techniques, and datum correction constraints.

It is important to highlight that the Severn and Exe regions (Southwest, A and G) differ in methodology from the other areas in this project. The key distinction lies in the "Merging Data and Interpolation Methods" section. For Severn and Exe, each estuary was constructed separately at an exceptionally high resolution (<10 m) before being merged with EMODnet bathymetry to create the final 20 m bathymetry.

At the time, the author lacked access to large Admiralty and LiDAR datasets, requiring data downloads from official provider websites, which imposed size limitations and slowed progress. In contrast, DEMs for the other five regions were interpolated from comprehensive datasets provided directly by EA (SurfZone DEM) and UKHO (Admiralty surveys), covering entire model domains. This approach accelerated the overall DEM generation process, though each interpolation took longer due to the significantly larger dataset compared to the individual estuary interpolations used for Severn and Exe.

Annex D: Delft hydrodynamic modelling of 52 English estuaries

D1. Delft model parameterisation

Physical and numerical parameterisations of D-Flow are necessary to approximate the governing equations of the regional estuary models, and to optimise and calibrate the simulations. The finite-volume Sobek + Saadilud solver was used to approximate the shallow water equations that describe the motion of water. The Monotone central limiter scheme (second-order central difference method) was used to capture sharp gradients in water advection. The Advection type Perot $q(u|u-u)$ fast parameter was used to approximate the transport of bulk substances (e.g., salinity). The Manning's equation (friction coefficient = 0.023) was used to represent near bed frictional resistance to the flow. To account for turbulence closure problems in the momentum equations, Delft3D FM uses a horizontal eddy viscosity numerical scheme to simulate the rate at which scalar quantities, such as temperature or salinity, diffuse horizontally. The Smagorinsky-Lilly subgrid-scale model is used to update the Smagorinsky factor (values between 0.20-0.22) based on local flow conditions to determine the horizontal eddy viscosity and diffusivity. The maximum model time step was 30 s (internal time step = 1 s), ensuring model stability (max. Courant number = 0.7) for each of the regional meshes described section 3.2.1. Simulations were performed in 2D depth-averaged mode. This configuration will therefore neglect potentially important three-dimensional processes driving estuary circulation, mixing, and ultimately residence times. However, a suite of simulations were performed in 3D and compared against 2D depth-averaged simulations, whereby there were close similarity between the 3D/2D simulated residence times, due to the tidally energetic and well-mixed hydrodynamics of the estuaries.

D2. Delft model validation

Table D2.1: Percentile differential of modelled vs observed tidal constituents M2 and S2 phase & amplitude for the Severn region at Ilfracombe, Liverpool Bay region at Heysham, Tyne region at North Shields, Humber region at Immingham, North Thames sub-region at Lowestoft, South Thames sub-region at Sheerness, Portsmouth region at Newhaven and Exe region at Devonport.

	M2 amp	M2 phase	S2 amp	S2 phase
Severn	-29.614	9.229	-21.535	2.550
Liverpool Bay	-21.022	-97.844	-59.493	119.436
Tyne	-15.396	8.922	-15.487	-0.471
Humber	-41.532	45.725	-60.152	74.014
North Thames	-48.543	13.114	-48.963	4.290
South Thames	-50.185	-55.674	-57.847	-40.985
Portsmouth	-28.549	-82.691	-17.848	366.716
Exe	12.231	1.407	13.481	-5.153

Table D2.2: Root Means Squared Error (RMSE), mean bias correction, correlation coefficient and percentile differential validation of modelled vs observed salinity within each regional domain and sub-domain.

	RMSE	Mean bias	Correlation	Percentile diff
Severn	3.99	1.89	0.37	7.49
Liverpool Bay	2.47	-1.01	0.98	-12.60
Tyne	6.62	3.55	0.86	16.05
Humber	4.51	3.69	0.96	14.69
North Thames	3.34	2.54	0.07	8.48
South Thames	8.83	7.75	-0.10	31.72
Portsmouth	3.82	3.45	0.93	12.41
Exe	4.79	3.57	0.72	13.57

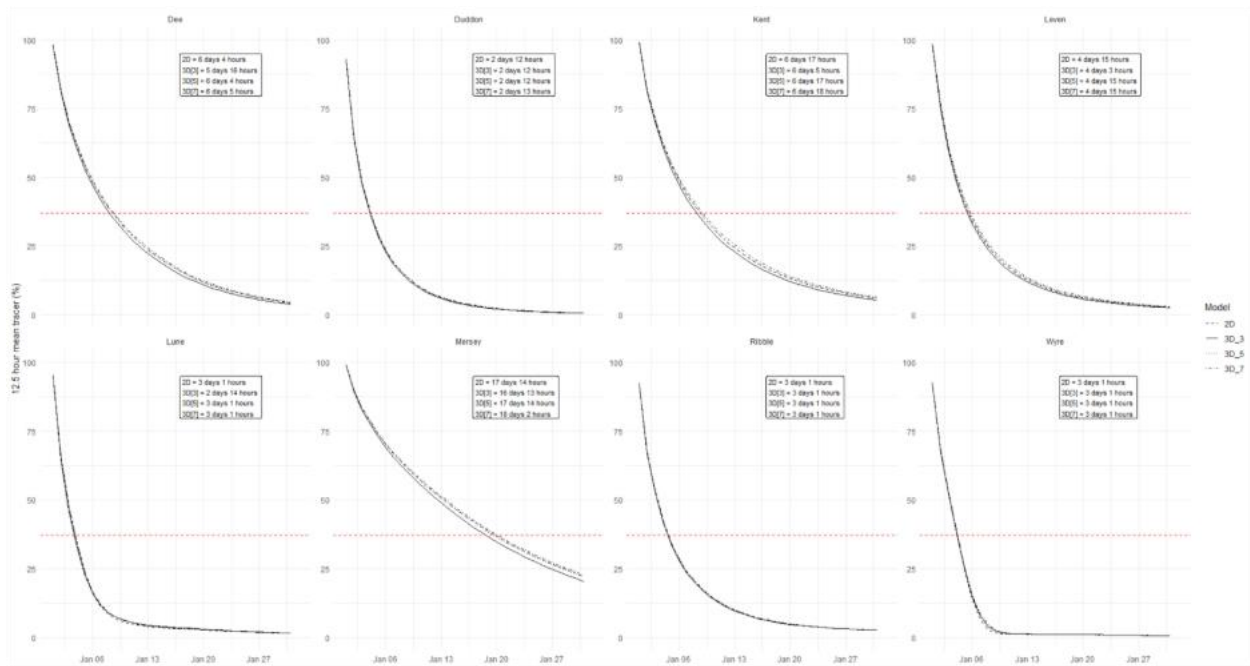


Figure D2.1: Delft3D vs Delft2D 12.5-hour mean residence time decay curves of the Liverpool Bay region under constant $10\text{m}^3/\text{s}$ river discharge and a Mid (to Neap) conservative tracer release tidal state. Comparative 2D depth-averaged, 3D-3 sigma layer, 3D-5 sigma layer and 3D-7 sigma layer were simulated. 2D depth-averaged and 3D-5 sigma layer produced the same residence time decay curves.

D3. Delft model baseline simulations

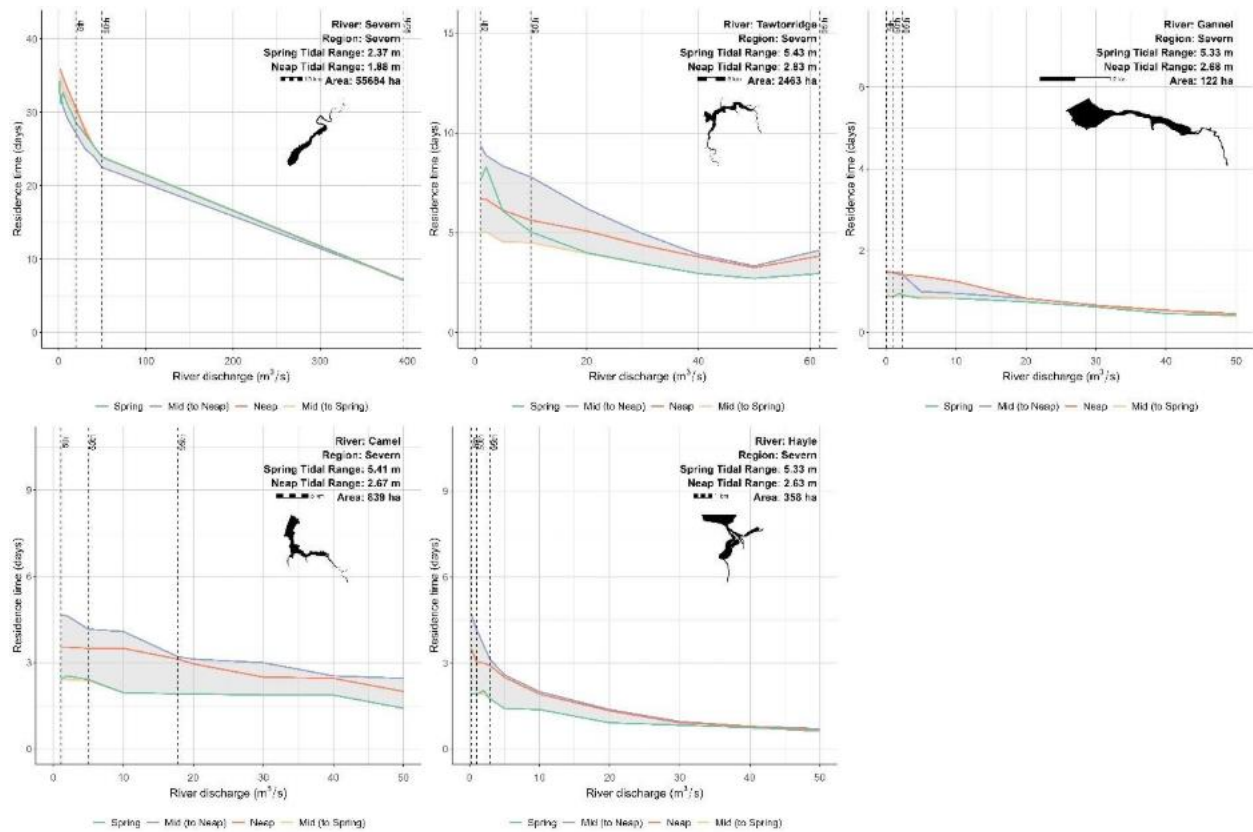


Figure D3.1: Delft-simulated residence times of the five modelled estuaries in the Severn region, based on the baseline time slice. The figures show how residence time varies in response to river flow (x-axis), and to tidal range (the four curves indicate the release time of the pollutant tracer within the spring-neap tidal cycle). Inset maps and text give an indication of how estuary shape and area further influence residence times.

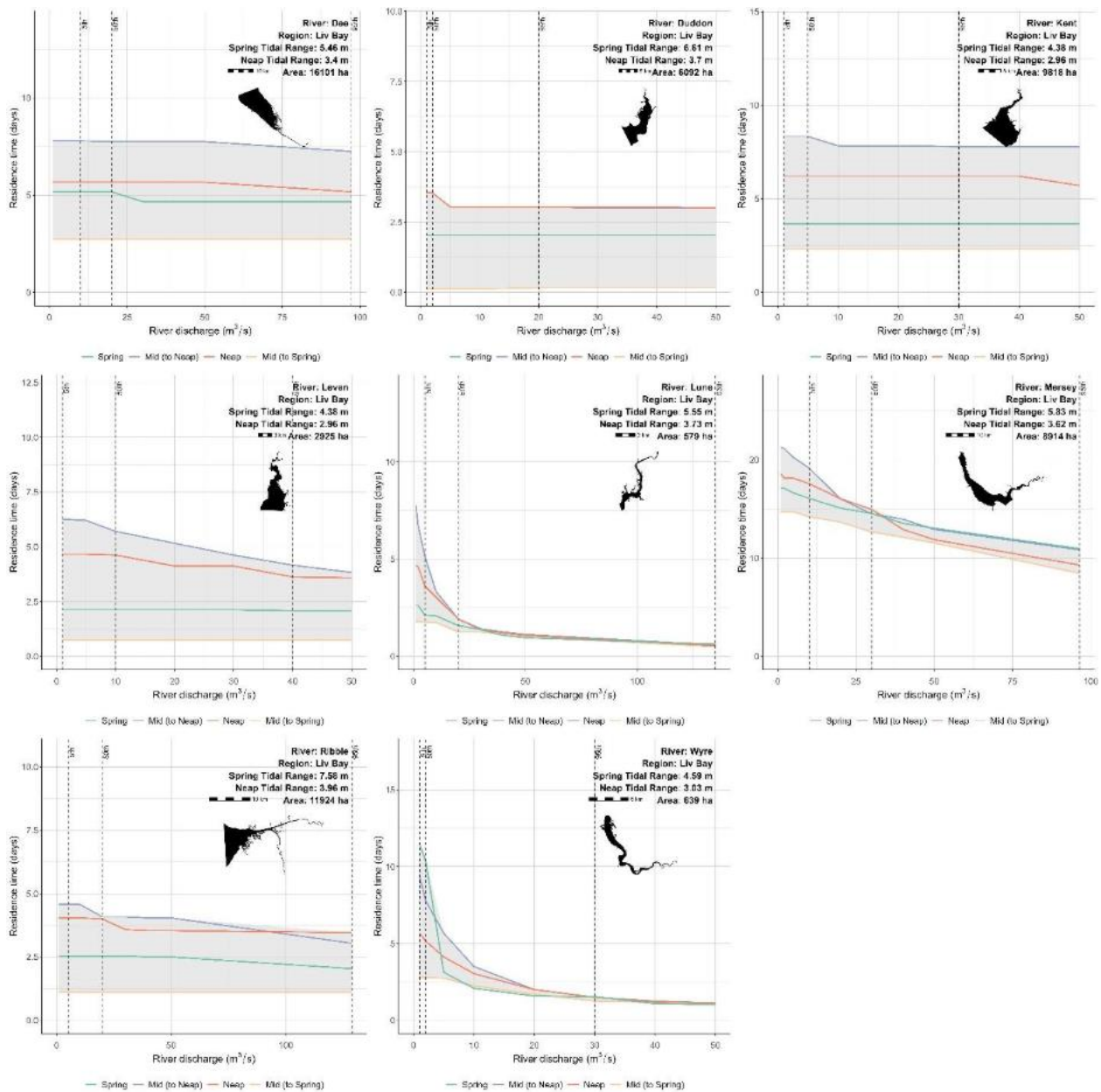


Figure D3.2: Delft-simulated residence times of the eight modelled estuaries in the Liverpool Bay region, based on the baseline time slice. The figures show how residence time varies in response to river flow (x-axis), and to tidal range (the four curves indicate the release time of the pollutant tracer within the spring-neap tidal cycle). Inset maps and text give an indication of how estuary shape and area further influence residence times.

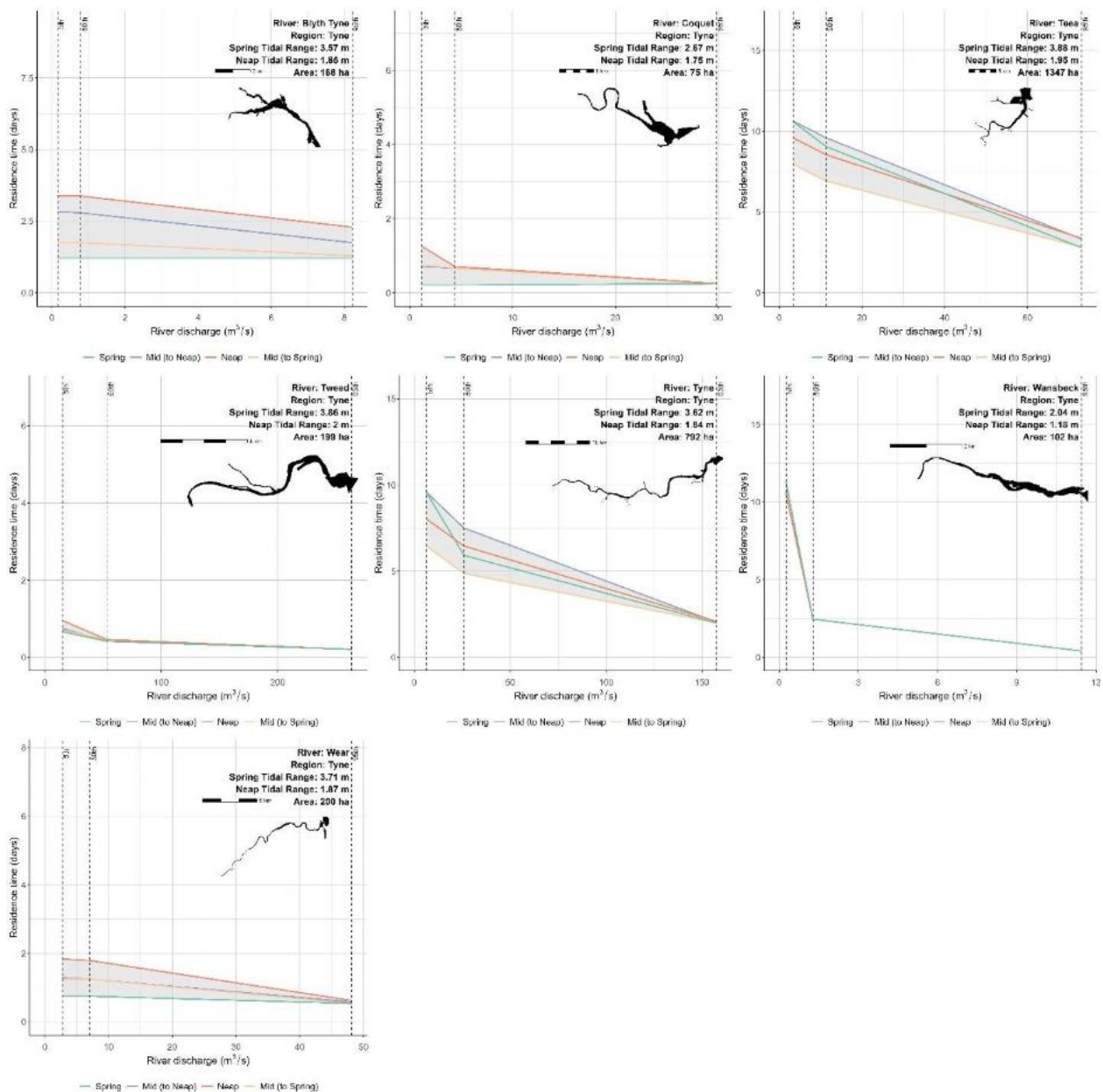


Figure D3.3: Delft-simulated residence times of the seven modelled estuaries in the Tyne region, based on the baseline time slice. The figures show how residence time varies in response to river flow (x-axis), and to tidal range (the four curves indicate the release time of the pollutant tracer within the spring-neap tidal cycle). Inset maps and text give an indication of how estuary shape and area further influence residence times.

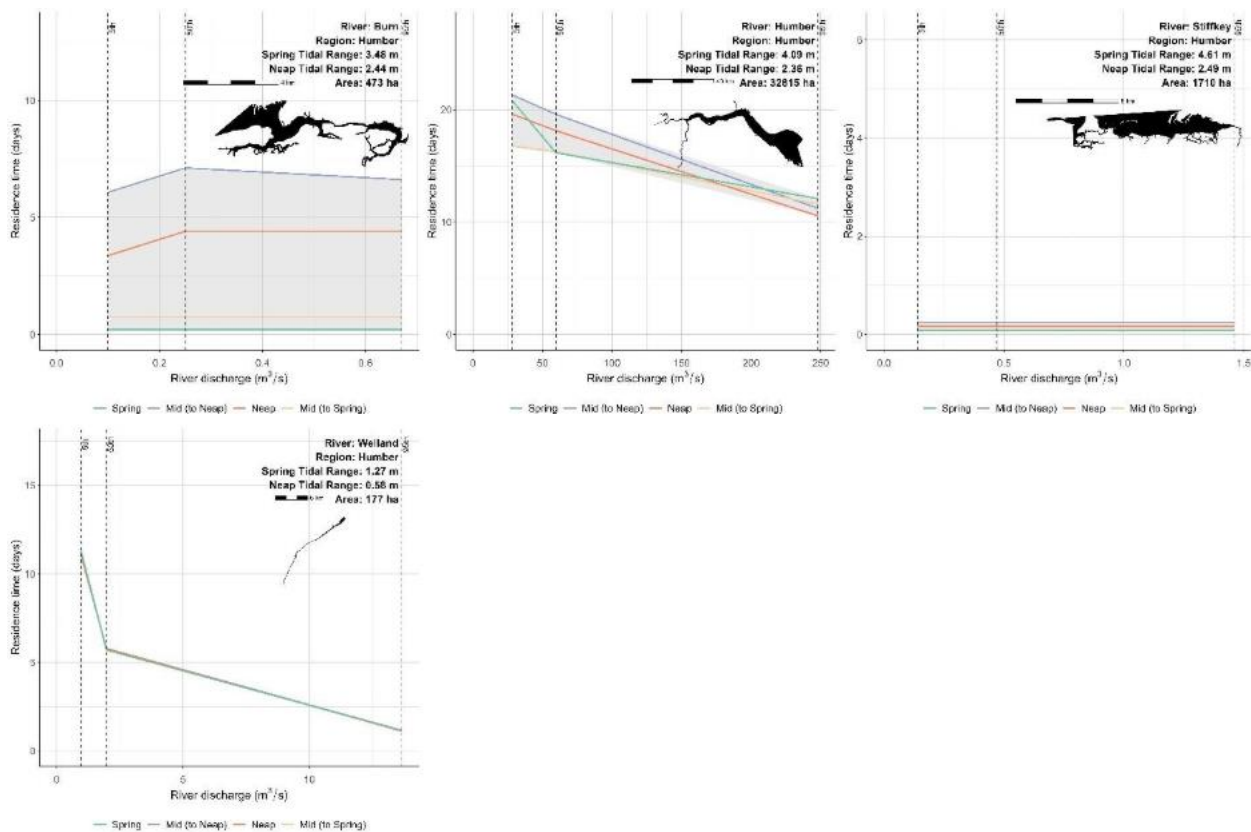


Figure D3.4: Delft-simulated residence times of the four modelled estuaries in the Humber region, based on the baseline time slice. The figures show how residence time varies in response to river flow (x-axis), and to tidal range (the four curves indicate the release time of the pollutant tracer within the spring-neap tidal cycle). Inset maps and text give an indication of how estuary shape and area further influence residence times.

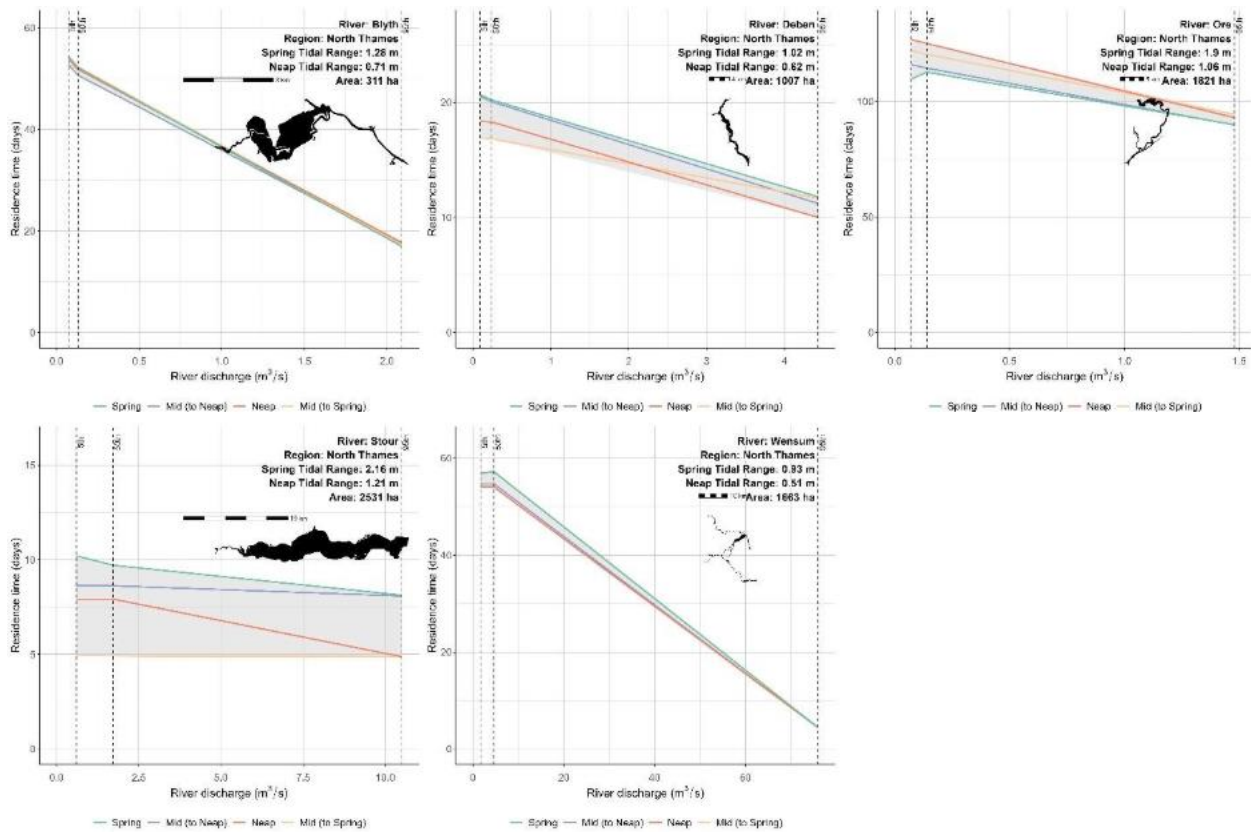


Figure D3.5: Delft-simulated residence times of the five modelled estuaries in the Thames North sub-region, based on the baseline time slice. The figures show how residence time varies in response to river flow (x-axis), and to tidal range (the four curves indicate the release time of the pollutant tracer within the spring-neap tidal cycle). Inset maps and text give an indication of how estuary shape and area further influence residence times.

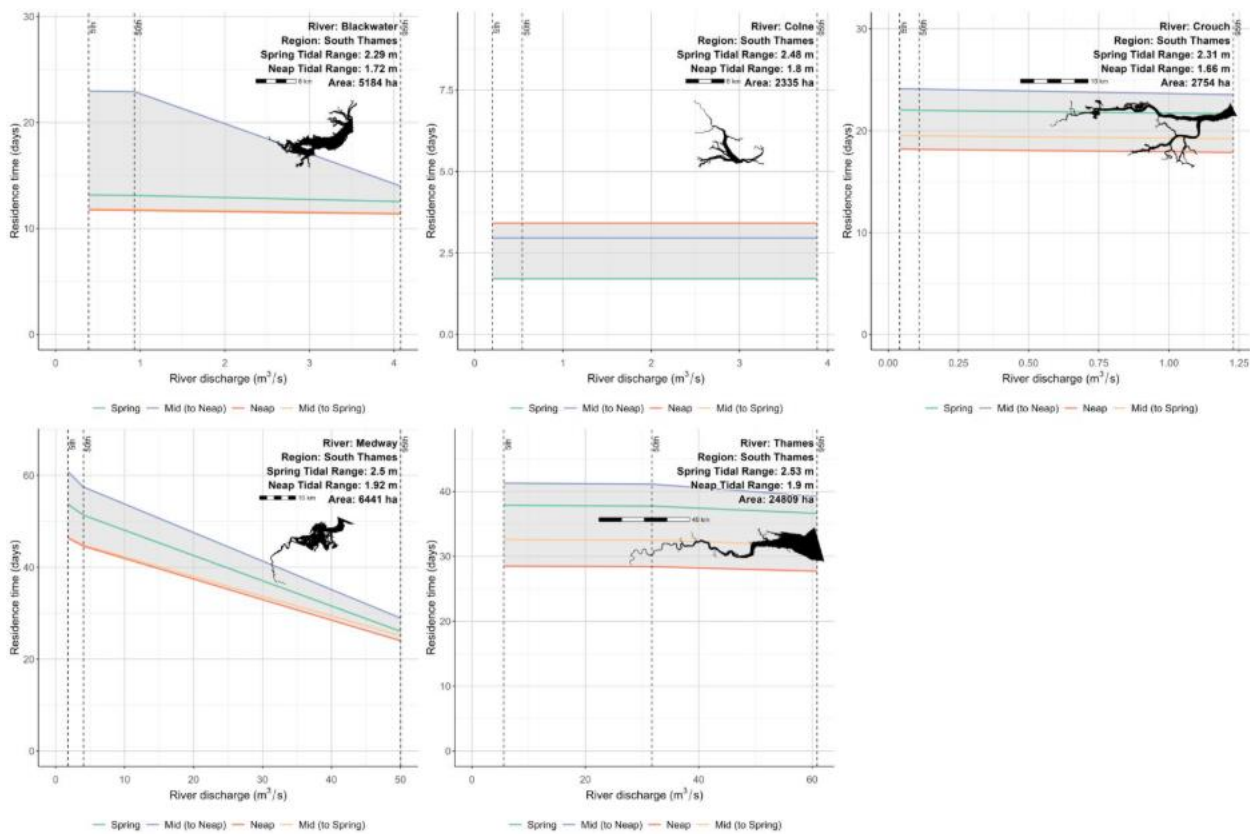


Figure D3.6: Delft-simulated residence times of the five modelled estuaries in the Thames South sub-region, based on the baseline time slice. The figures show how residence time varies in response to river flow (x-axis), and to tidal range (the four curves indicate the release time of the pollutant tracer within the spring-neap tidal cycle). Inset maps and text give an indication of how estuary shape and area further influence residence times.

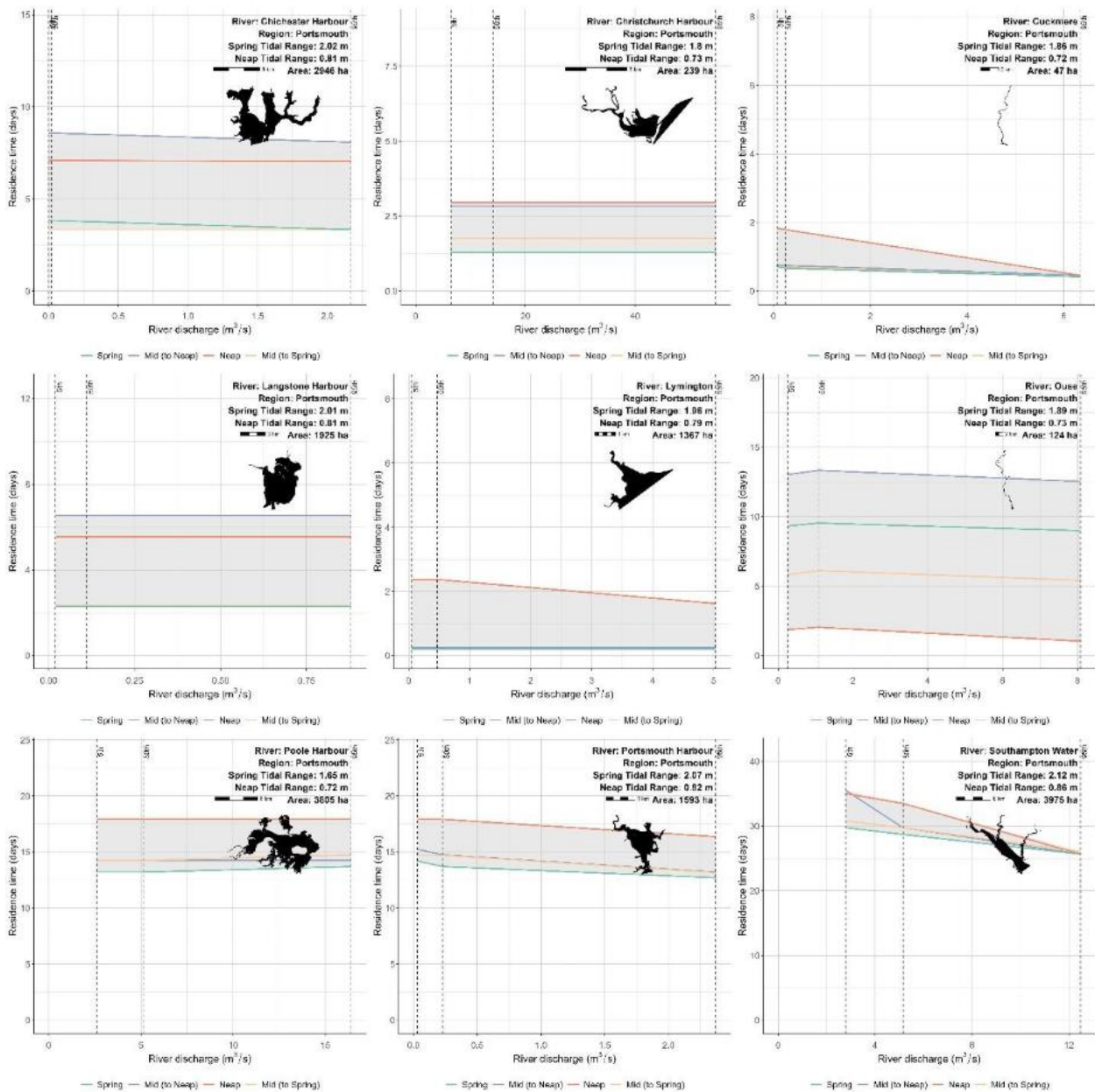


Figure D3.7: Delft-simulated residence times of the nine modelled estuaries in the Portsmouth region, based on the baseline time slice. The figures show how residence time varies in response to river flow (x-axis), and to tidal range (the four curves indicate the release time of the pollutant tracer within the spring-neap tidal cycle). Inset maps and text give an indication of how estuary shape and area further influence residence times.

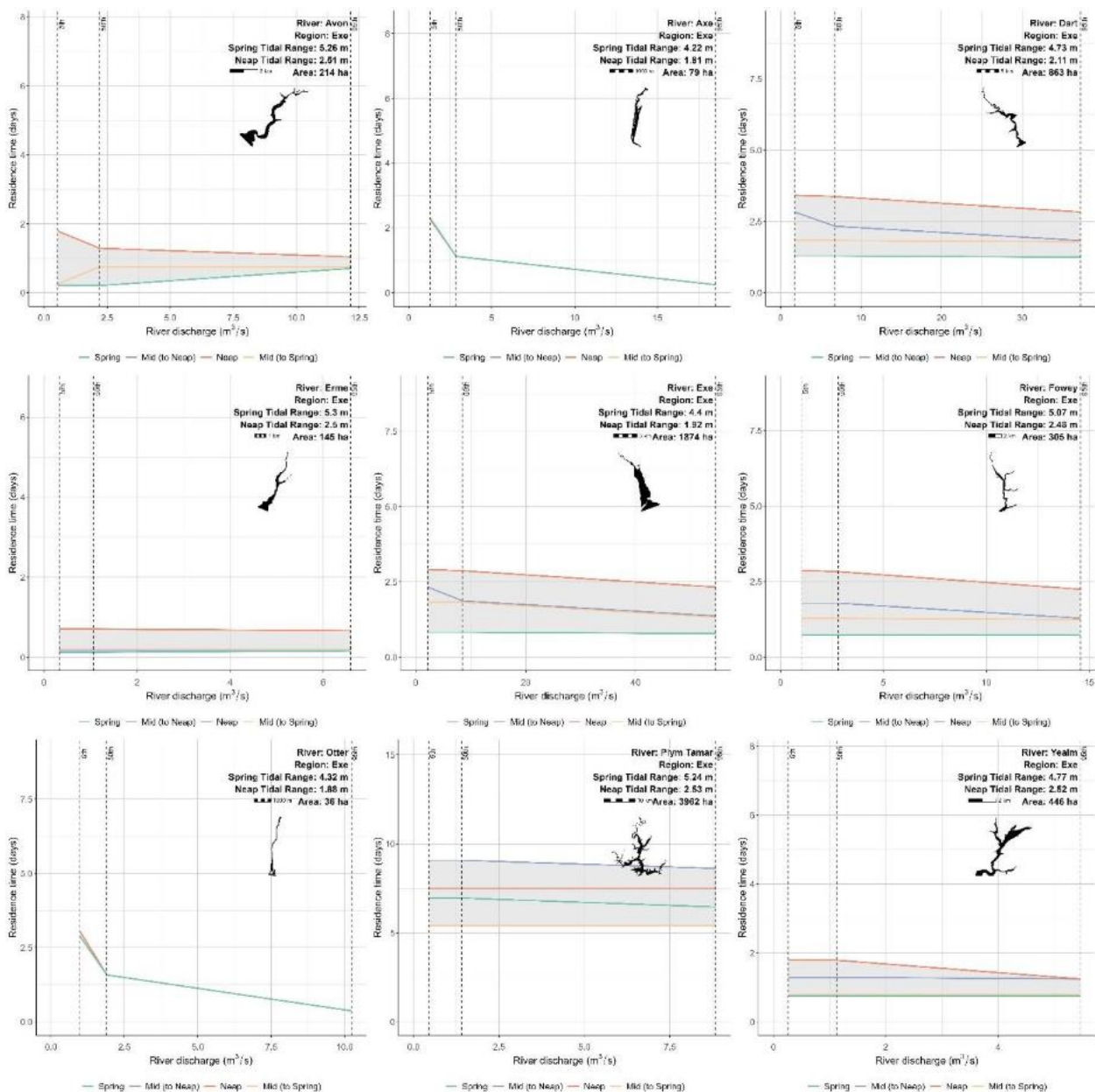


Figure D3.8: Delft-simulated residence times of the nine modelled estuaries in the Exe region, based on the baseline time slice. The figures show how residence time varies in response to river flow (x-axis), and to tidal range (the four curves indicate the release time of the pollutant tracer within the spring-neap tidal cycle). Inset maps and text give an indication of how estuary shape and area further influence residence times.

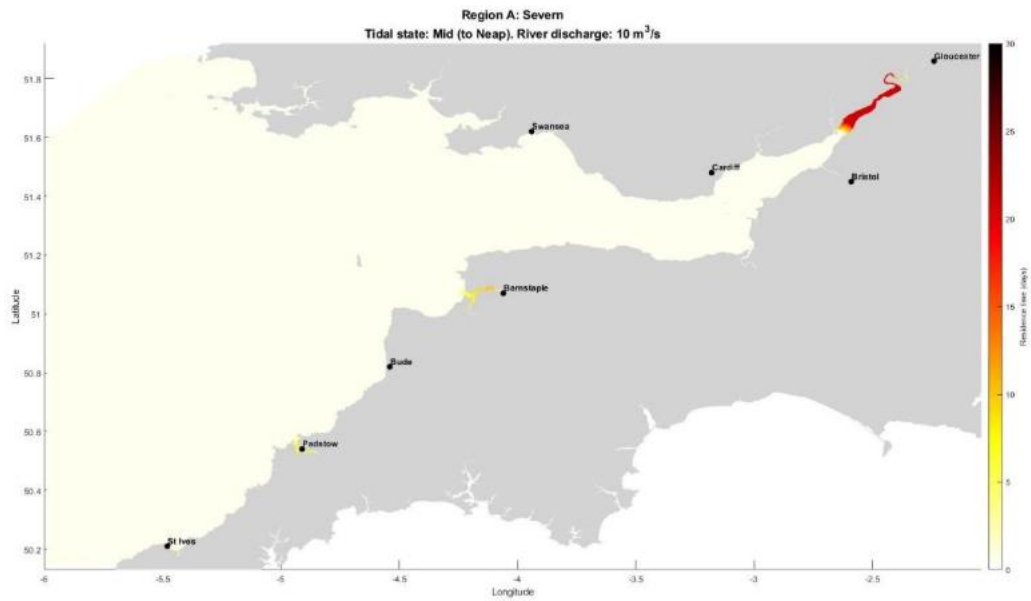


Figure D3.9: Delft-simulated within-estuary 12.5-hour mean residence times of the five modelled estuaries in the Severn region, based on the baseline time slice, Mid (to Neap) tidal state and constant $10 \text{ m}^3/\text{s}$ river discharge.

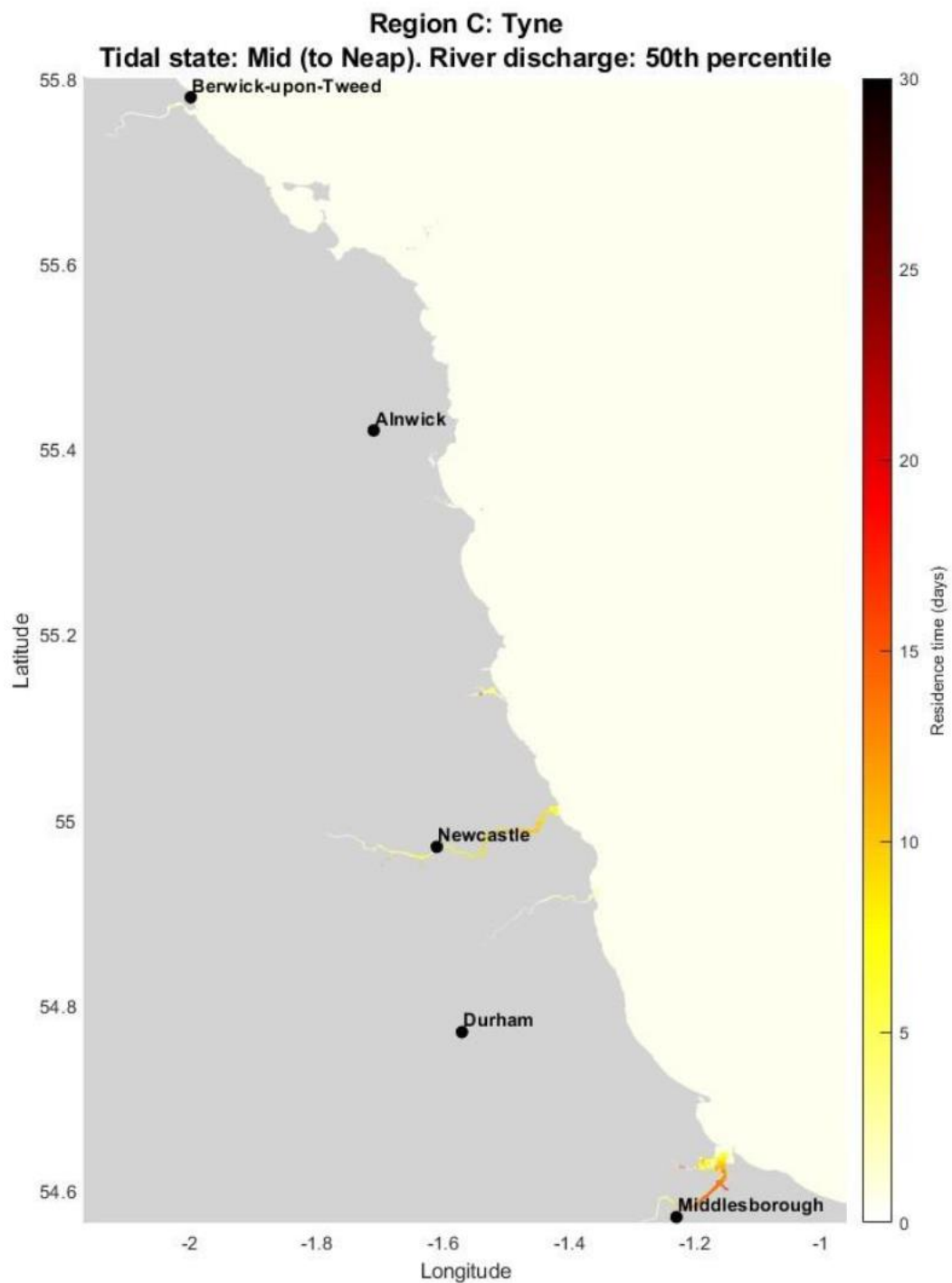


Figure D3.10: Delft-simulated within-estuary 12.5-hour mean residence times of the seven modelled estuaries in the Tyne region, based on the baseline time slice, Mid (to Neap) tidal state and constant 50th percentile river discharge.

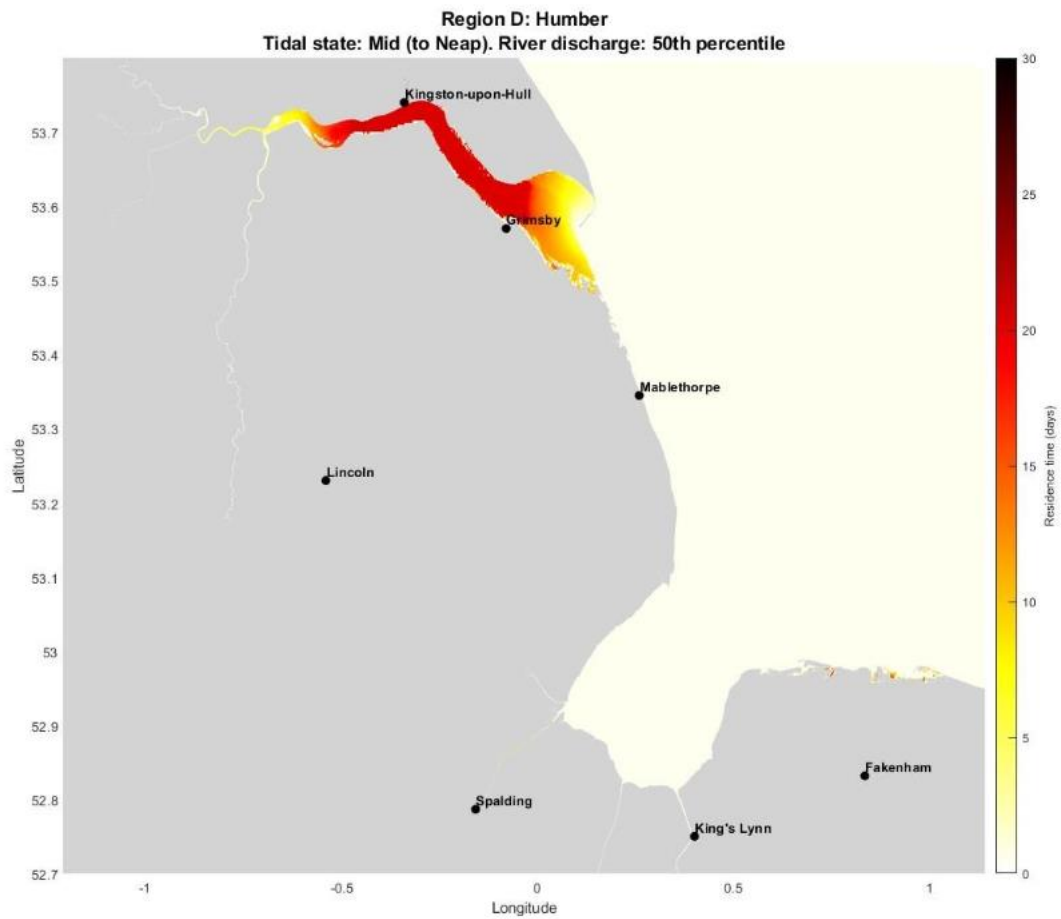


Figure D3.11: Delft-simulated within-estuary 12.5-hour mean residence times of the four modelled estuaries in the Humber region, based on the baseline time slice, Mid (to Neap) tidal state and constant 50th percentile river discharge.

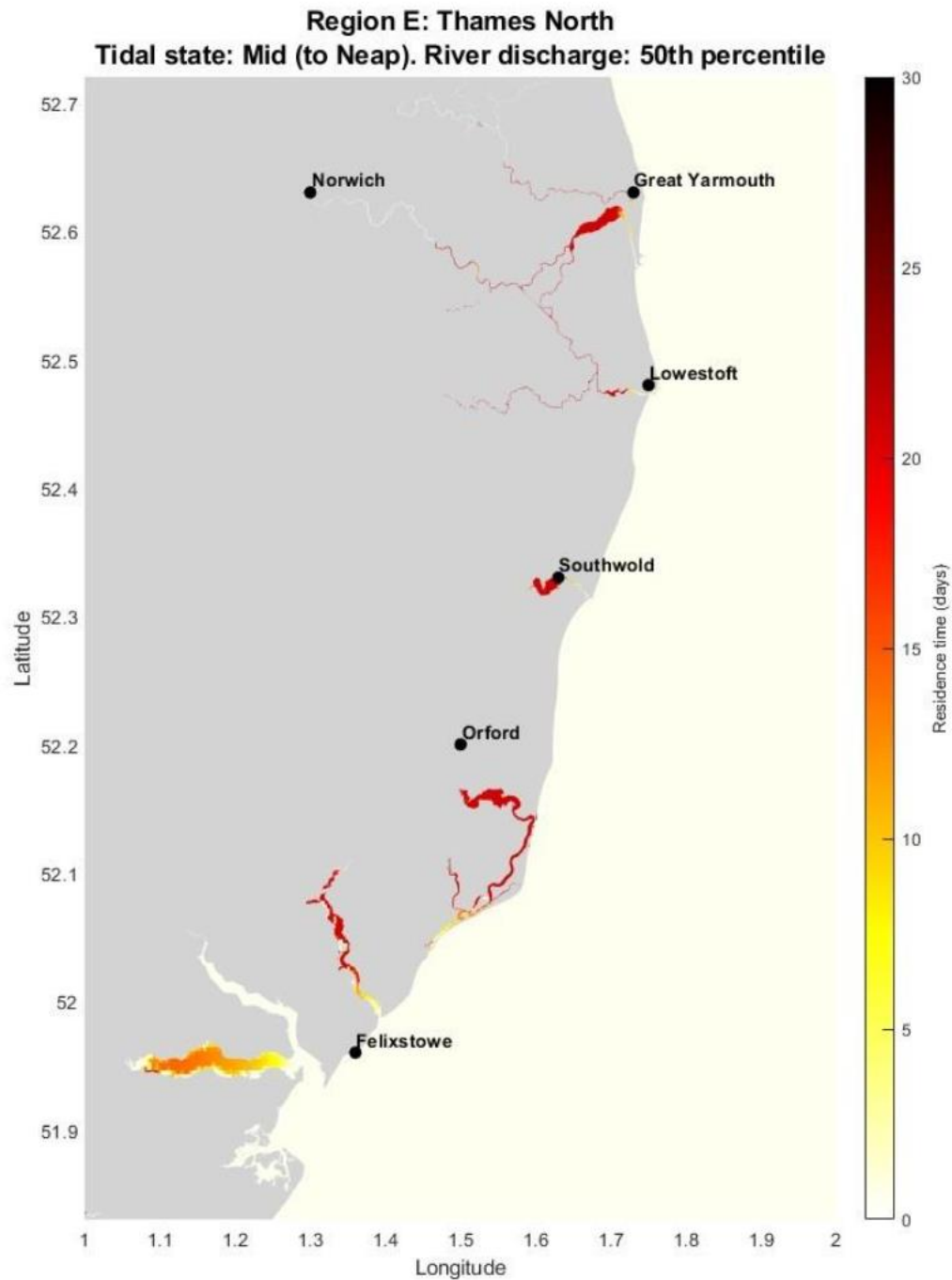


Figure D3.12: Delft-simulated within-estuary 12.5-hour mean residence times of the five modelled estuaries in the North Thames sub-region, based on the baseline time slice, Mid (to Neap) tidal state and constant 50th percentile river discharge.

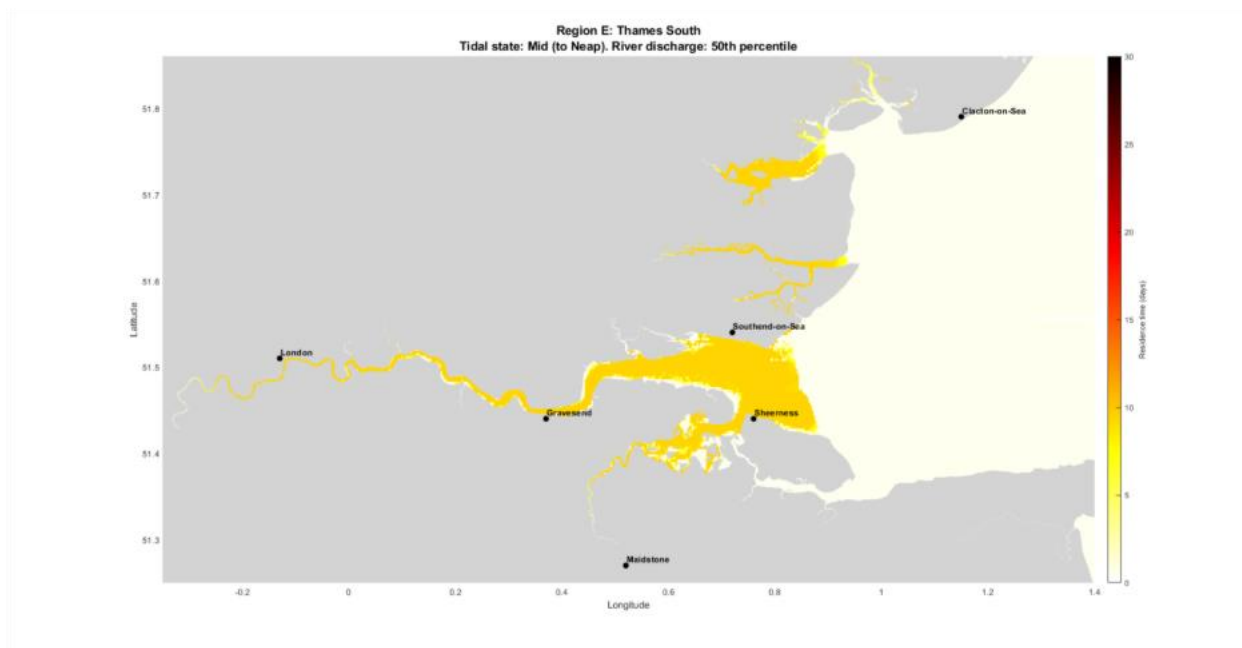


Figure D3.13: Delft-simulated within-estuary 12.5-hour mean residence times of the five modelled estuaries in the South Thames sub-region, based on the baseline time slice, Mid (to Neap) tidal state and constant 50th percentile river discharge.

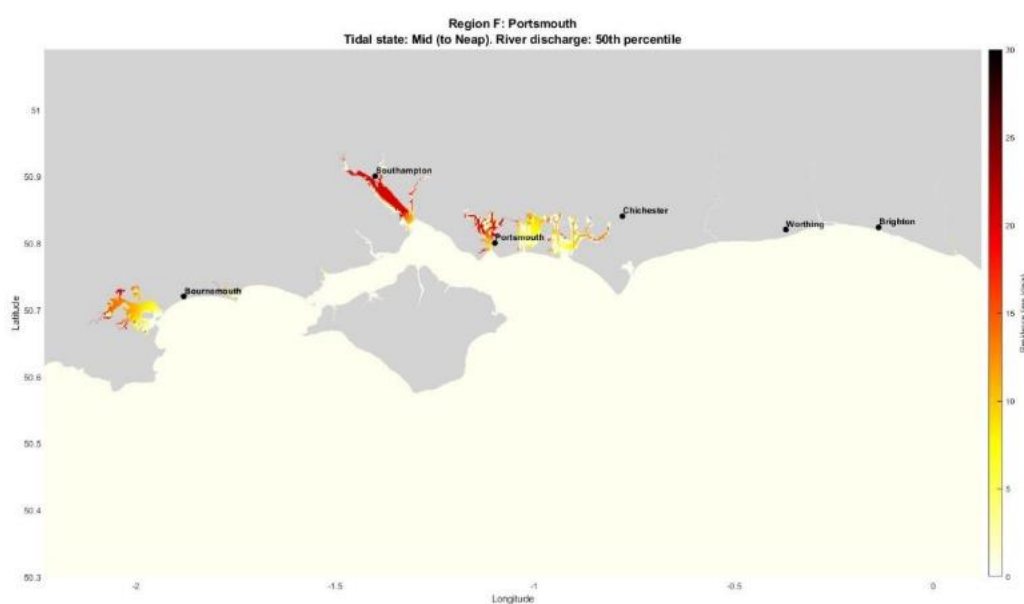


Figure D3.14: Delft-simulated within-estuary 12.5-hour mean residence times of the nine modelled estuaries in the Portsmouth region, based on the baseline time slice, Mid (to Neap) tidal state and constant 50th percentile river discharge.

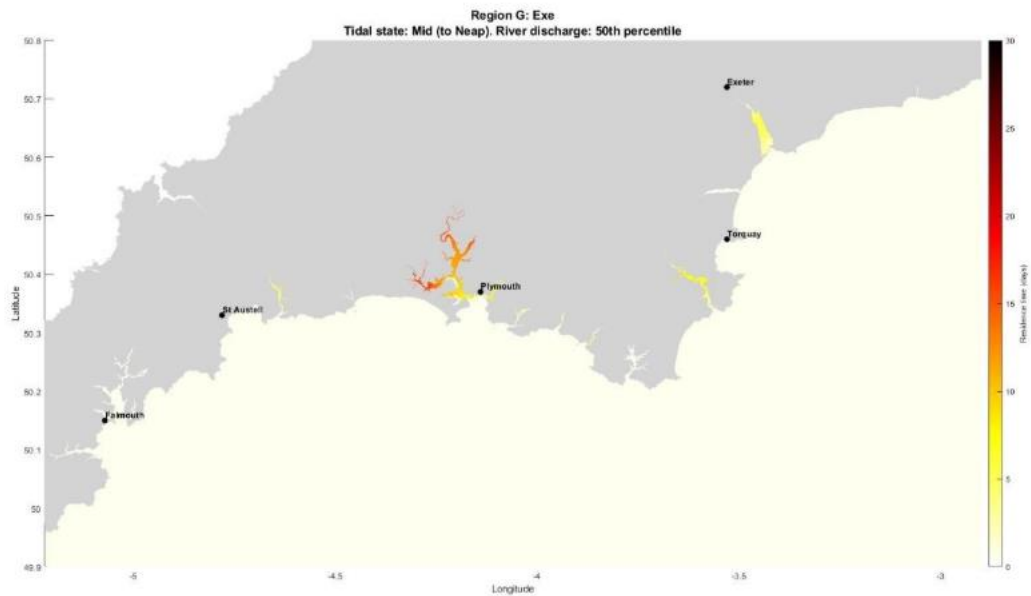


Figure D3.15: Delft-simulated within-estuary 12.5-hour mean residence times of the nine modelled estuaries in the Exe region, based on the baseline time slice, Mid (to Neap) tidal state and constant 50th percentile river discharge.

D4. Delft model sea-level rise simulations

Table D4.1: RCP8.5 regional sea-level rise (m) projections

	2050	2100
Severn	0.29	0.78
Liv Bay	0.24	0.66
Tyne	0.25	0.67
Humber	0.30	0.78
Thames N	0.31	0.81
Thames S	0.30	0.80
Portsmouth	0.30	0.79
Exe	0.31	0.80

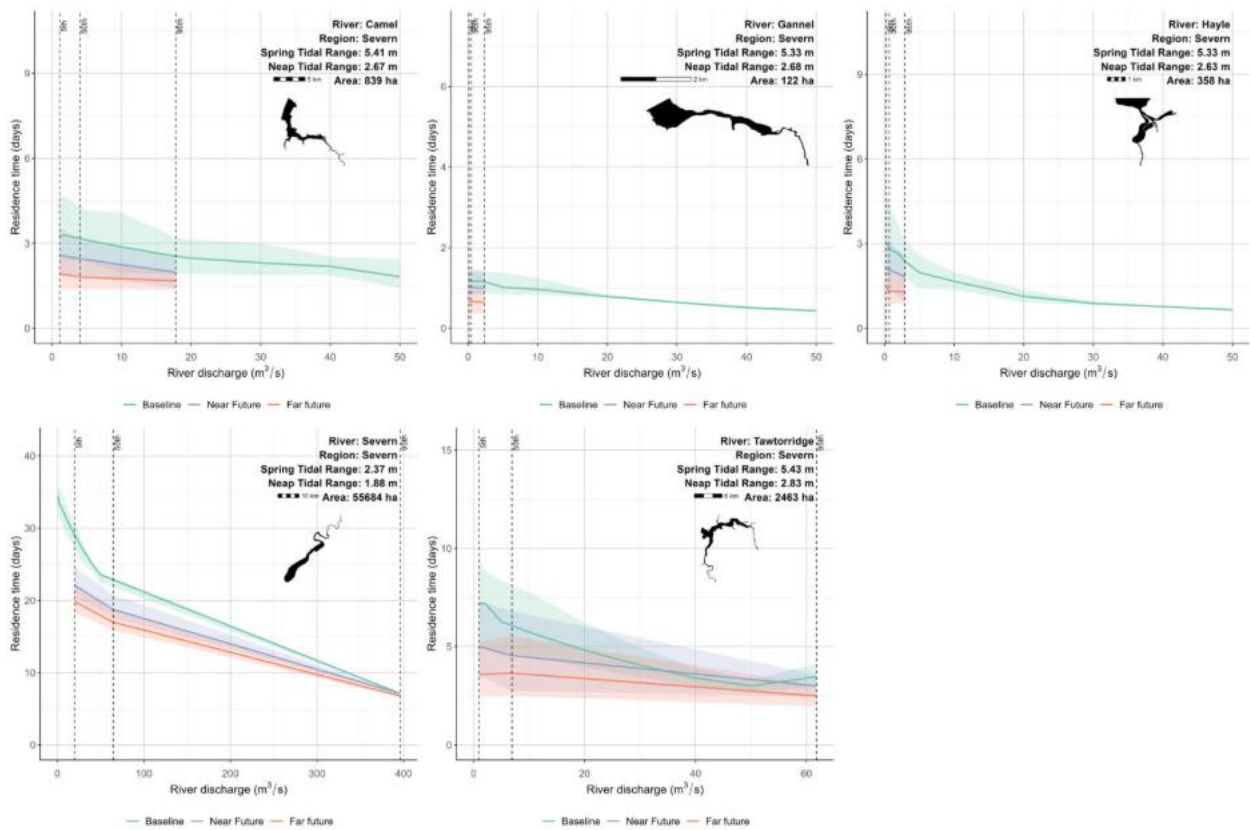


Figure D4.1: Delft-simulated residence times of the five modelled estuaries in the Severn region, based on RCP8.5 sea-level rise projections representative of the baseline (green), near-future (blue), and far-future (red) time slices. The figures show how residence time varies in response to river flow (x-axis), and to tidal range (shaded areas). Vertical dashed lines indicate 5th/50th/95th percentile river flows representative of the baseline time slice. Inset maps and text give an indication of how estuary shape and area further influence residence times.

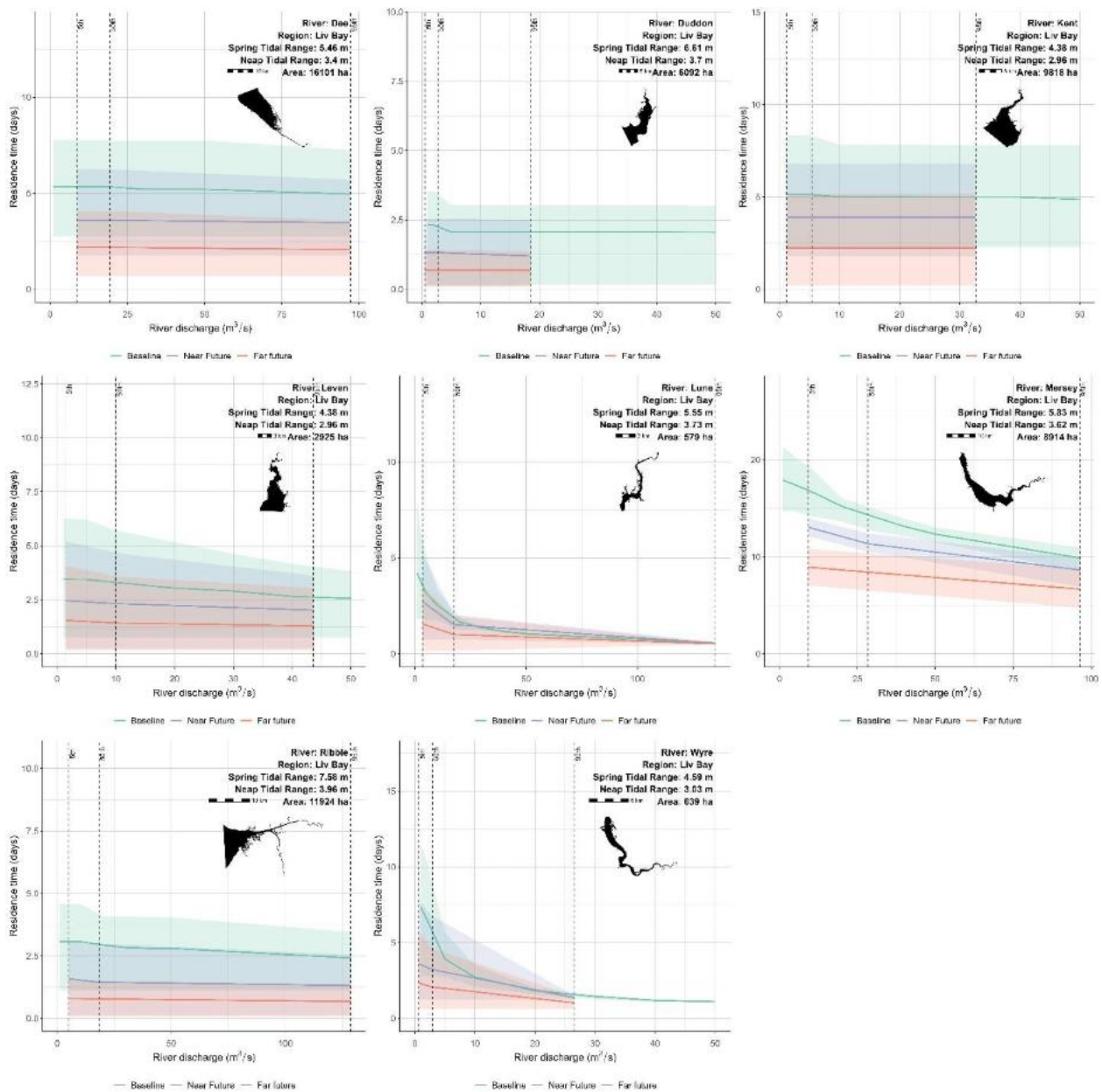


Figure D4.2: Delft-simulated residence times of the eight modelled estuaries in the Liverpool Bay region, based on RCP8.5 sea-level rise projections representative of the baseline (green), near-future (blue), and far-future (red) time slices. The figures show how residence time varies in response to river flow (x-axis), and to tidal range (shaded areas). Vertical dashed lines indicate 5th/50th/95th percentile river flows representative of the baseline time slice. Inset maps and text give an indication of how estuary shape and area further influence residence times.

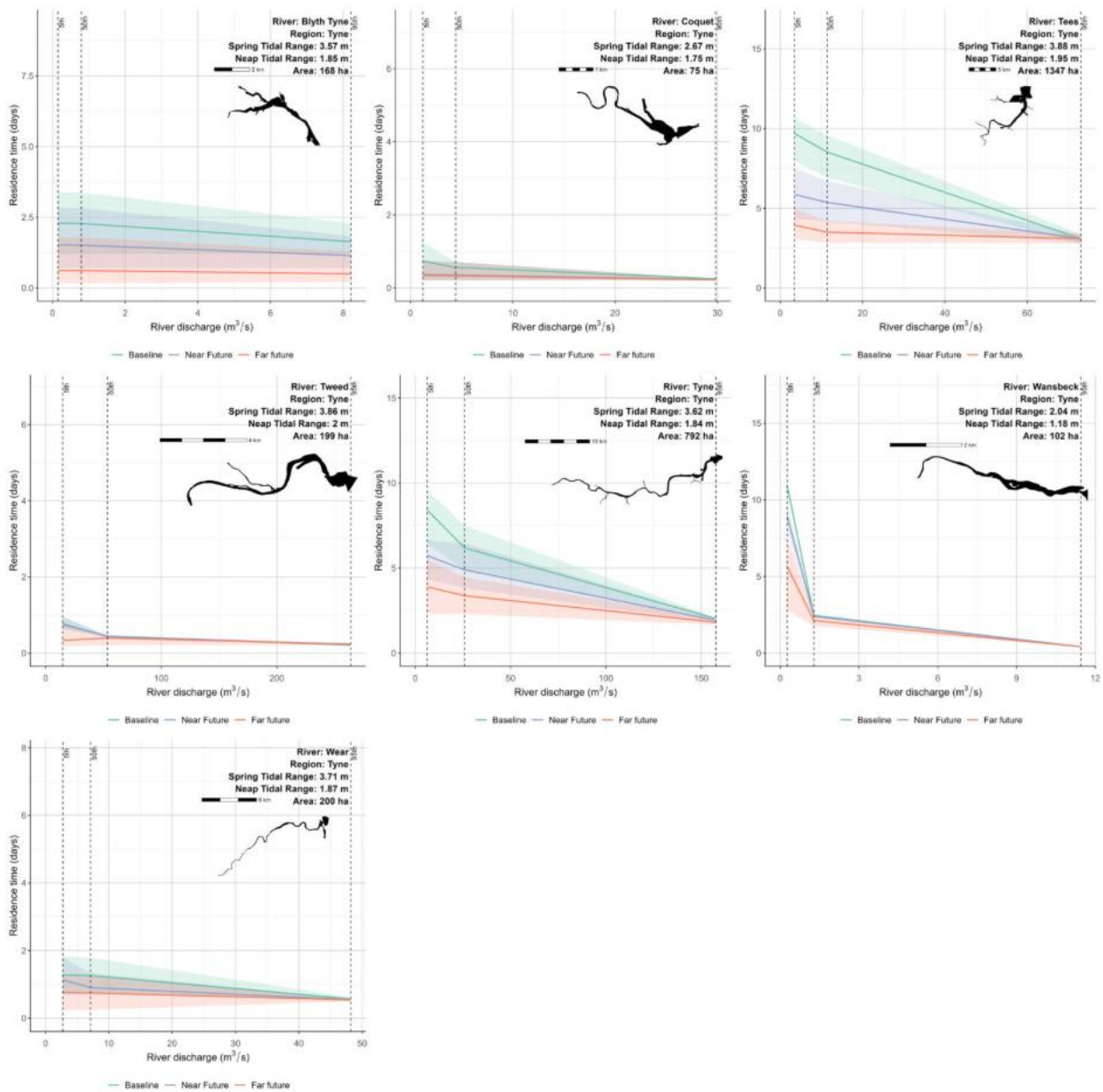


Figure D4.3: Delft-simulated residence times of the seven modelled estuaries in the Tyne region, based on RCP8.5 sea-level rise projections representative of the baseline (green), near-future (blue), and far-future (red) time slices. The figures show how residence time varies in response to river flow (x-axis), and to tidal range (shaded areas). Vertical dashed lines indicate 5th/50th/95th percentile river flows representative of the baseline time slice. Inset maps and text give an indication of how estuary shape and area further influence residence times.

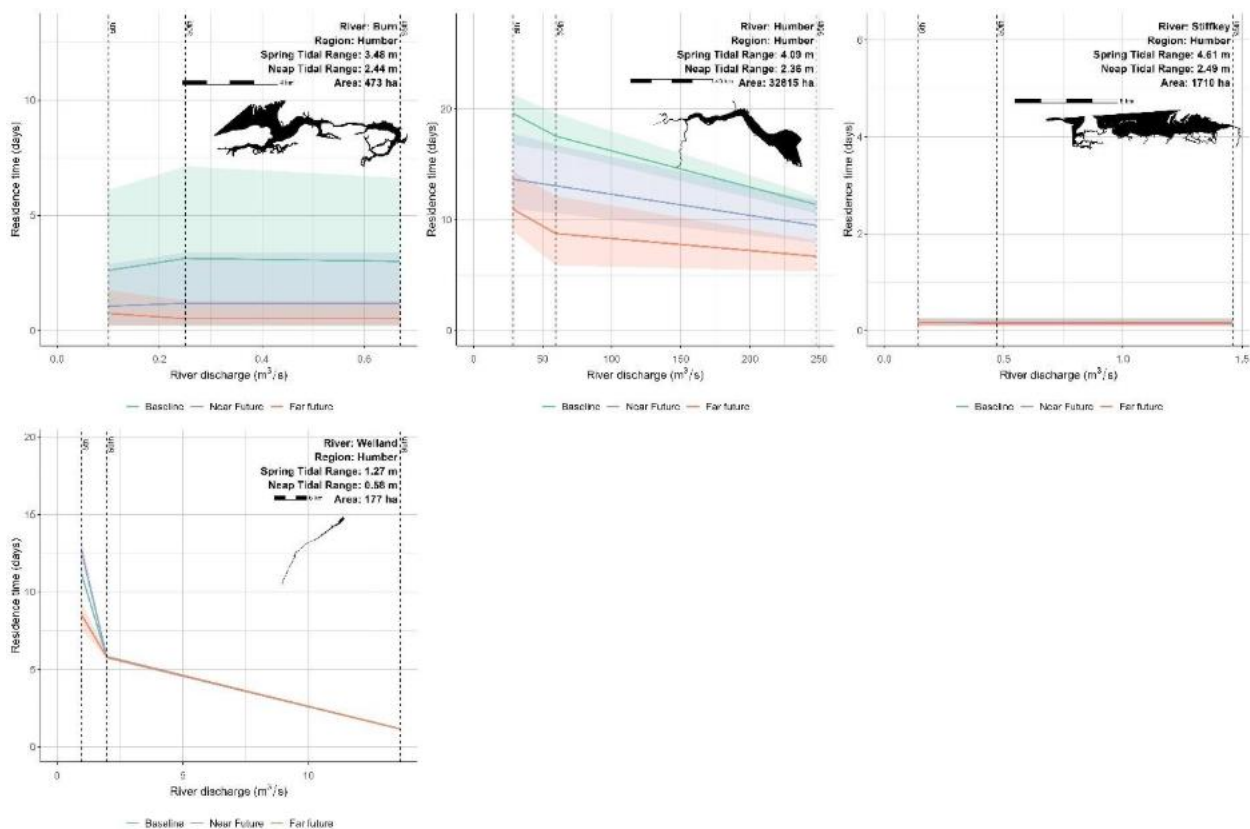


Figure D4.4: Delft-simulated residence times of the four modelled estuaries in the Humber region, based on RCP8.5 sea-level rise projections representative of the baseline (green), near-future (blue), and far-future (red) time slices. The figures show how residence time varies in response to river flow (x-axis), and to tidal range (shaded areas). Vertical dashed lines indicate 5th/50th/95th percentile river flows representative of the baseline time slice. Inset maps and text give an indication of how estuary shape and area further influence residence times.

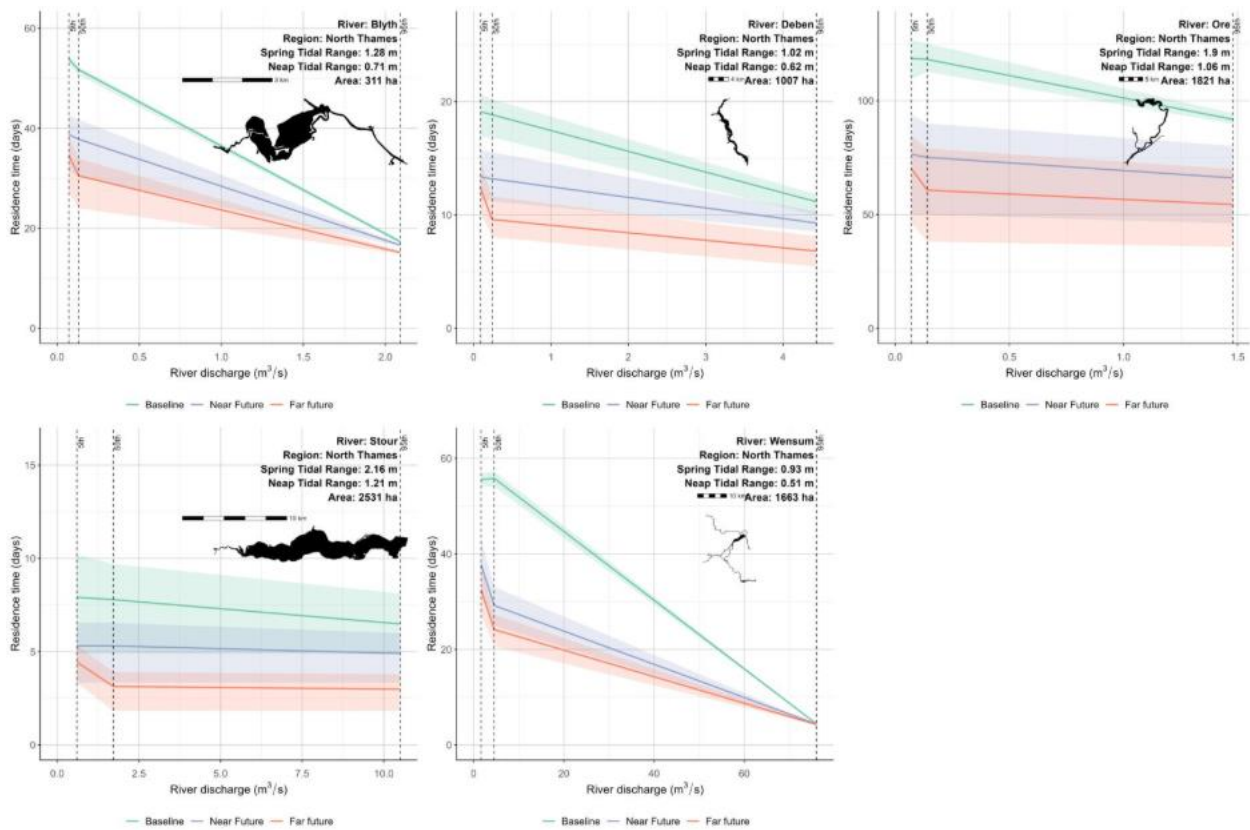


Figure D4.5: Delft-simulated residence times of the five modelled estuaries in the Thames North sub-region, based on RCP8.5 sea-level rise projections representative of the baseline (green), near-future (blue), and far-future (red) time slices. The figures show how residence time varies in response to river flow (x-axis), and to tidal range (shaded areas). Vertical dashed lines indicate 5th/50th/95th percentile river flows representative of the baseline time slice. Inset maps and text give an indication of how estuary shape and area further influence residence times.

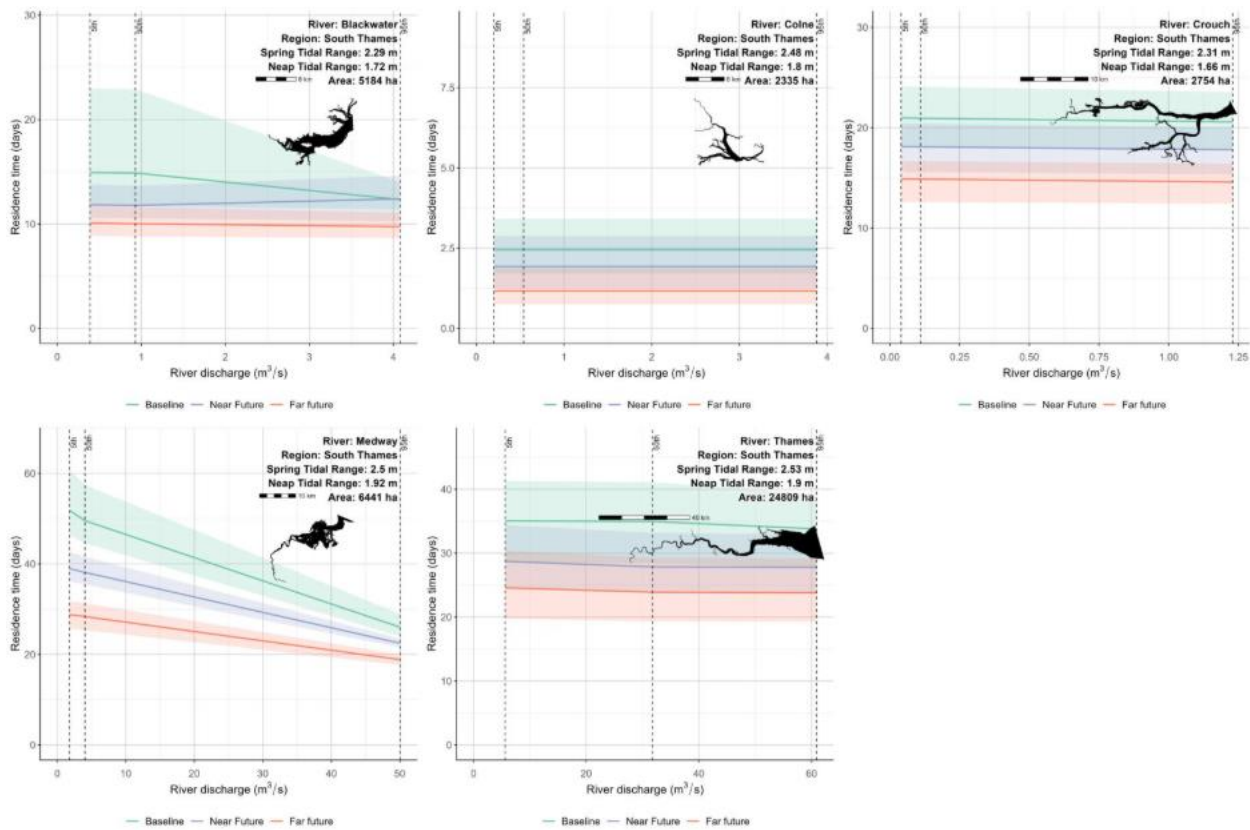


Figure D4.6: Delft-simulated residence times of the five modelled estuaries in the Thames South sub-region, based on RCP8.5 sea-level rise projections representative of the baseline (green), near-future (blue), and far-future (red) time slices. The figures show how residence time varies in response to river flow (x-axis), and to tidal range (shaded areas). Vertical dashed lines indicate 5th/50th/95th percentile river flows representative of the baseline time slice. Inset maps and text give an indication of how estuary shape and area further influence residence times.

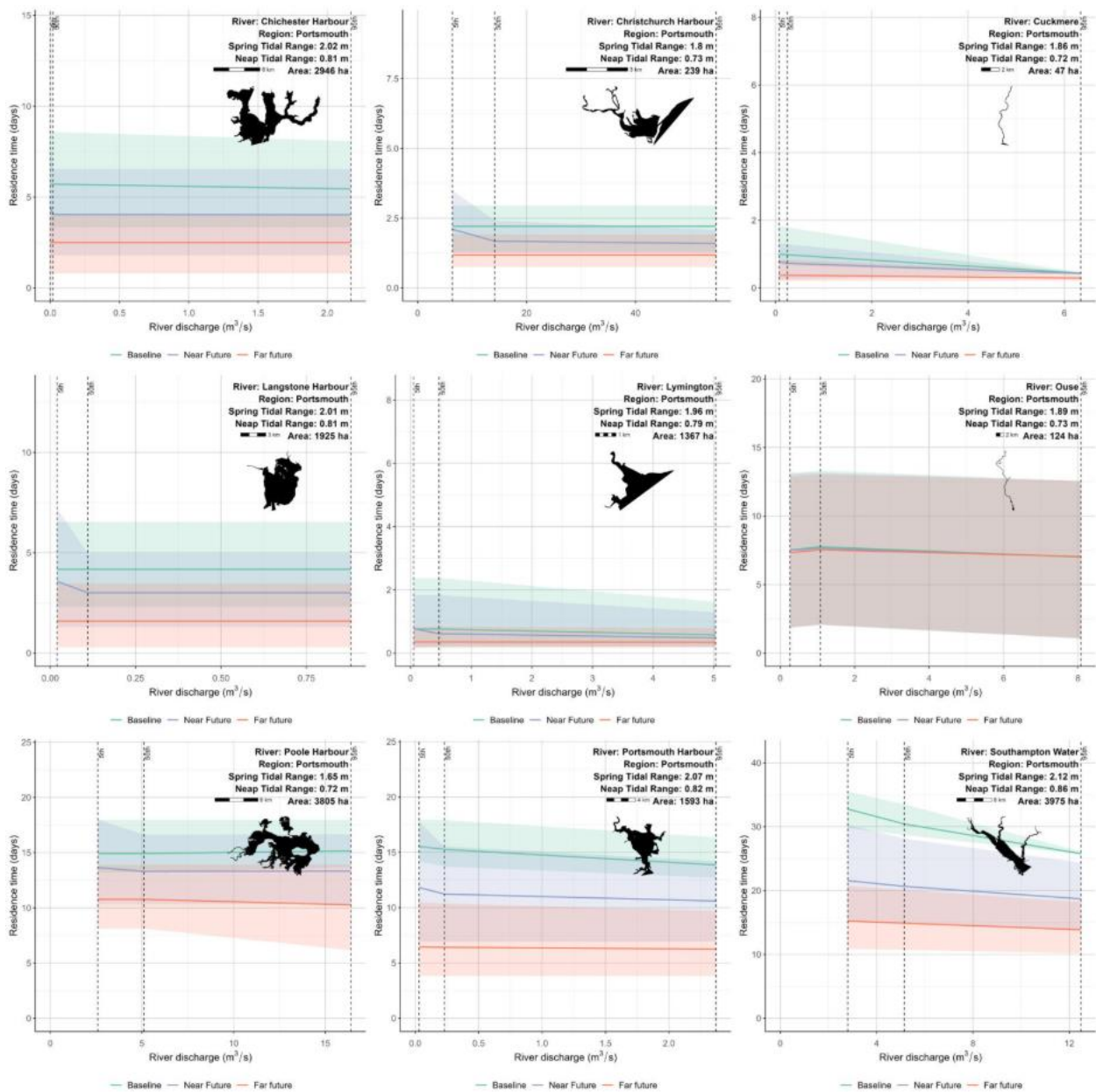


Figure D4.7: Delft-simulated residence times of the nine modelled estuaries in the Portsmouth region, based on RCP8.5 sea-level rise projections representative of the baseline (green), near-future (blue), and far-future (red) time slices. The figures show how residence time varies in response to river flow (x-axis), and to tidal range (shaded areas). Vertical dashed lines indicate 5th/50th/95th percentile river flows representative of the baseline time slice. Inset maps and text give an indication of how estuary shape and area further influence residence times.

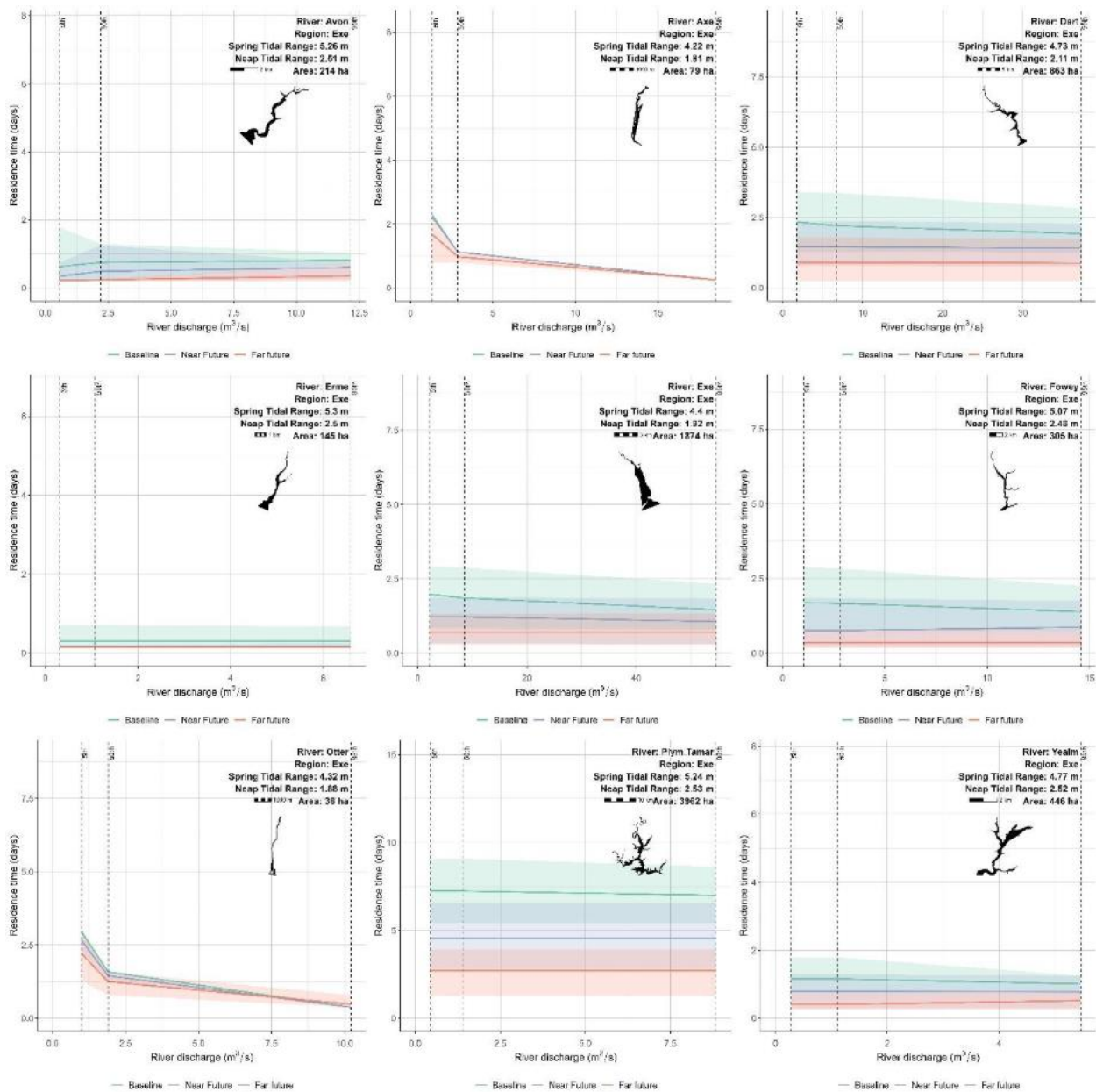


Figure D4.8: Delft-simulated residence times of the nine modelled estuaries in the Exe region, based on RCP8.5 sea-level rise projections representative of the baseline (green), near-future (blue), and far-future (red) time slices. The figures show how residence time varies in response to river flow (x-axis), and to tidal range (shaded areas). Vertical dashed lines indicate 5th/50th/95th percentile river flows representative of the baseline time slice. Inset maps and text give an indication of how estuary shape and area further influence residence times.

D5. Future estuary volume and variability

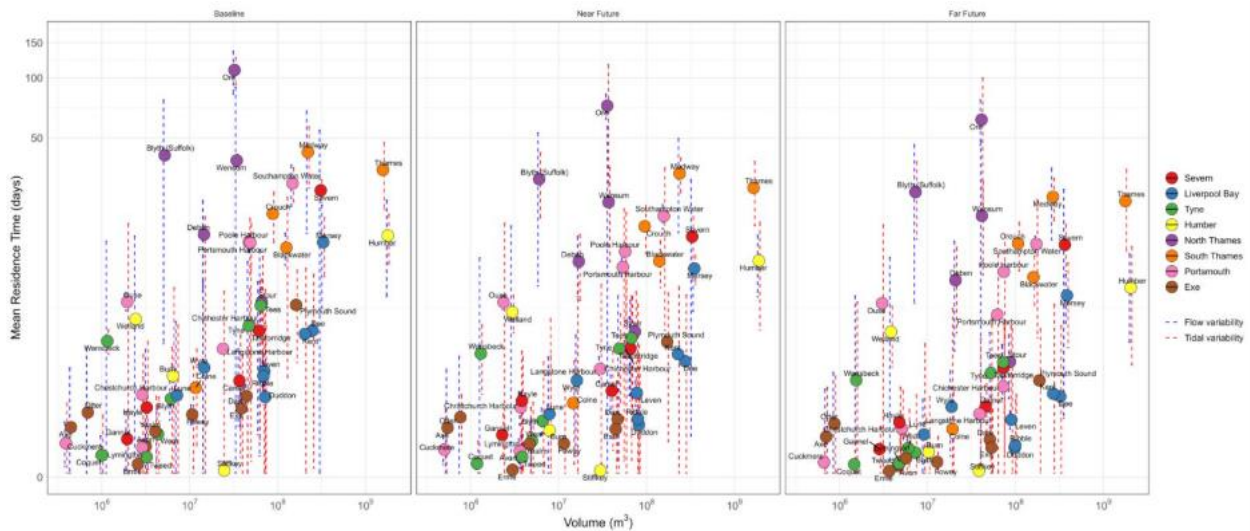


Figure D5.1: Relationship between estuary mean volume and Delft-simulated residence time (including variability due to tidal and fluvial conditions), for the baseline (left), near-future (middle), and far-future (right) periods. Future volumes assume a hold the line policy and a fixed coastline.

Annex E: Estuary Box Models for four English estuaries

E1: Introduction

The estuary box model can be used as a framework for calculating e-flushing times which can be used to directly compare residence times generated by a Delft hydrodynamic model. From this point, residence time here is synonymous with the residence times generated from the Delft models as this is calibrated to the Delft models. From a validated Delft model, this can be used to calibrate the EBM which can predict future flushing times. A calibration value time series is needed, as well as future input data generated from another hydrodynamic model, in the form of predicted surface heights and future tidal prism changes.

The EBM can be split into the Tidal Prism and Salt Balance methods, where for the bulk of this work the tidal prism method is used as it requires less input data. Specifically, does not need to use salinity data which can be difficult to predict accurately.

The EBM methodology is described below, followed by the results applied to four estuaries: Ribble, Tees, Exe, and Dart.

E2: Methodology

Simulation estuary tidal prism

To improve the robustness of a static tidal prism-based flushing time, we use a digital elevation model (DEM), which allows for dynamic volume changes as sea level rises (SLR) (Huggett et al., 2021).

$$TP = \sum_{i=1}^{N-1} tLWtHW|Q_{tidal}| \cdot \Delta t + |Q_{river}| \cdot \Delta t \quad TP = \sum_{i=1}^{N-1} tLWtHWQ_{tidal} \cdot \Delta t + Q_{river} \cdot \Delta t$$

SLR does not directly impact tidal ranges since both low and high tides rise at the same rate. However, secondary effects occur, such as changes to the wetting and drying areas within a bay, leading to a larger volume as more surface area is flooded for longer durations. This can influence estuarine shape and tidal resonance, potentially increasing tidal range—like the Severn Estuary or Bay of Fundy, (Quinn et al., 2013).

For this study, we assume a hold-the-line scenario, meaning the estuary's shape and surface area remain unchanged. A new shapefile would be needed to account for evolving bathymetry due to SLR based on SLR flood scenarios. Coastal defences would also need to be accounted for.

Volume is calculated by taking the MSL bathymetry and applying a land mask to remove erroneous values. Volume adjustments are made based on the DEM and SLR increase. For example, if SLR increases by 1m, the additional volume is estimated by multiplying 1m by the surface area at MSL. Cells above 0 MSL are treated as land, but those newly submerged by SLR are added to the estuarine volume. This process is repeated annually.

Two methods exist for calculating the tidal prism:

1. Volumetric method
2. Surface height-based method (used here due to data limitations)

The tidal prism is calculated by identifying high and low tide points in MSL. This determines the tidal range and allows multiple flushing time calculations per cycle (~12.42 hours), improving statistical accuracy. However, flushing time for a given period may exceed the period itself.

To account for SLR dynamically, high and low tide points are recalculated separately for every DEM cell. Cells are classified as wet or dry, improving on the basic tidal range-based approach. For example:

- A cell at 0.5m above MSL in the original DEM is dry. After 1m SLR, it becomes -0.5m and contributes to volume.
- A cell at -0.5m below MSL becomes -1.5m, reflecting additional water gain.

This method incorporates wetting and drying effects, allowing us to assess SLR impacts on tidal prisms into the future.

Calibration Coefficient (return flow factor)

A key component of the TP method is the calibration factor (b) or return flow factor, representing the total exchange of water per tidal cycle as a percentage (between 0 and 1) (Sanford et al., 1992). This factor is calibrated using hydrodynamic models, such as the Delft3D Flexible Mesh Suite, enabling rapid assessment of estuarine hydrodynamics for future water quality and health analysis.

Calibration involves comparing flushing times from Delft3D models against numerical solutions. The best b value is determined through an iterative process, running all possible values until the results match the calibrated dataset. For future analysis, we apply this method to three Delft3D scenarios:

- Baseline
- Near future
- Far future

Running the Tidal Prism EBM

This model is operated by running the following scripts:

1. First, raw data must be collected and resampled (in the case of .mat files, these are processed into NetCDF format).
 - a. Process the raw data through the script: `raw_tide_to_netcdf_for_EBM.py`
2. Then process the output through: `TP_EBM_360_to_365.py`
 - a. This converts the 360-day data from the 12 UKCP18 GCM-PPE models which are in 360-day years, to real time.
 - b. At this point, the dataset has been corrected to real-world data and is ready for a calibration coefficient to be calculated.
3. The Dynamic DEM script should be run to process the DEMs for usage in the Python model: `dynamic_DEM_handler.py`
 - a. This script generates easy to handle DEMs for the python code from shapefiles and tiffs.
4. Calibration is performed using the: `TP_EBM_calibration.py` script
 - a. which uses the dynamic DEMs produced for each estuary as inputs alongside the NetCDF 365-day files.
 - b. This script generates a validation, which should be analysed as the automated predicted b equation is not always sufficient.

- i. The b equation generated is saved to a database file which automatically feeds into the TP_EBM.py script.
 - c. The model is then run using a calibration file corresponding to the estuary name (CSV format), located in the calibration files directory.
 - d. These files also include a subset of data from the UKCP18 GCM-PPE models
 - e. TP_EBM.py will automatically pick up the associated calibration file and use the appropriate dynamic DEM.
 - f. The model does not directly produce visual outputs unless run through the: TP_EBM_plotter.py script.
 - g. This saves a series of figures into the figures folder under the estuary name.
5. Lastly run the actual model TP_EBM.py which generates three 20-year segments, corresponding to a baseline, near and far scenario and keeps the images in a separate figures folder.

Any section can be rerun independently, provided the previous one has been completed. This modular setup allows for flexibility and experimentation without excessive computational time, as each processed data file is saved for reuse as well as analysis.

The Calculations

The TP based EBM is primarily on the Flushing Time equation, as developed by Monsen (Monsen et al., 2002):

$$Tf = VTP(1-b) \cdot TM2 \quad Tf = VTP1-b \cdot TM2$$

The flushing time equation uses the dynamic volume (V) which is calculated based off the SLR of the year it exist and the relevant DEM. Although if the entire estuary is above MSL, the estuary will be regarded as having no volume as the volume is tidal dependant. A small value can be added in this case to prevent the model from breaking, as a substitute for the freshwater that would exist within the estuarine domain. The tidal prism (TP) dynamically calculated again from the DEM as well as SLR adjustments added on specific to the region. The return flow factor (b) and the adjusted to the M2 tide.

$$b = 1 - V \cdot TM2 \cdot Tf \cdot TP \quad b = 1 - V \cdot TM2 \cdot Tf \cdot TP$$

The b equation is a novel development. Instead of trying to predict what b should be, through a simplistic trial and error approach. You can take existing values from the hydrodynamic models to generate a range of values for b, these values can then be plotted and curves drawn. This is achieved by rearranging the flushing time equation to get b, which can then use flushing times calculated in the Delft hydrodynamic models as inputs. However, due to limitations in the number of values of b we can generate due to insufficient hydrodynamic models, we must add in extra values of b along a predicted curve. Due to the unique nature of how b functions, we cannot simply extrapolate a linear curve as fluctuations in riverine discharge can cause erratic and erroneous values for b, such as values below 0 and above 1. To handle this case, a novel approach was used to generate a sinusoidal curve, to cap the extension of the b values beyond possible values seen in the calibration. Also, the maximum and minimum tidal prism, and river discharge values are added in from the UKCP18 GCM-PP datasets to improve robustness on these outlier values.

$$b(TP) = b_{max} - b_{min} \frac{1 + \exp(-k(TP - TP_0))}{1 + \exp(-k(TP_{max} - TP_0))} + b_{min}$$

This leads to the final return flow factor predicting equation, utilising minimum and maximum values of predicted b, as well as calculating the curve between the values and generating a sinusoidal prediction.

Annex F: Estuary Report Cards

The INVEST project examined how water quality in different English estuaries may be affected by climate change into the future. Changes to the marine (sea surface temperature, sea surface salinity, and storm surge) and riverine (discharge) environment were examined. Additionally, hydrodynamic models were set up for each individual estuary to understand how changes to estuarine mixing may occur in the future. Climate impacts were assessed using the Met Office UKCP18 projections which were run under the RCP 8.5 pathway. RCP 8.5 is a high end scenario assuming a high level (~4oC) of warming. Results of this analysis are presented in the following sections. For a full description of this project and the data behind these visualisations, please refer to the project technical report.

Avon

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	50.31428
Longitude	-3.80111
Tidal Range	4.65 m
Gauge Name	Avon at Loddiswell
Estuary Size	638000.0 m ²
5th percentile flow	0.496 m ³ /s
50th percentile flow	2.14 m ³ /s
95th percentile flow	12.0 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

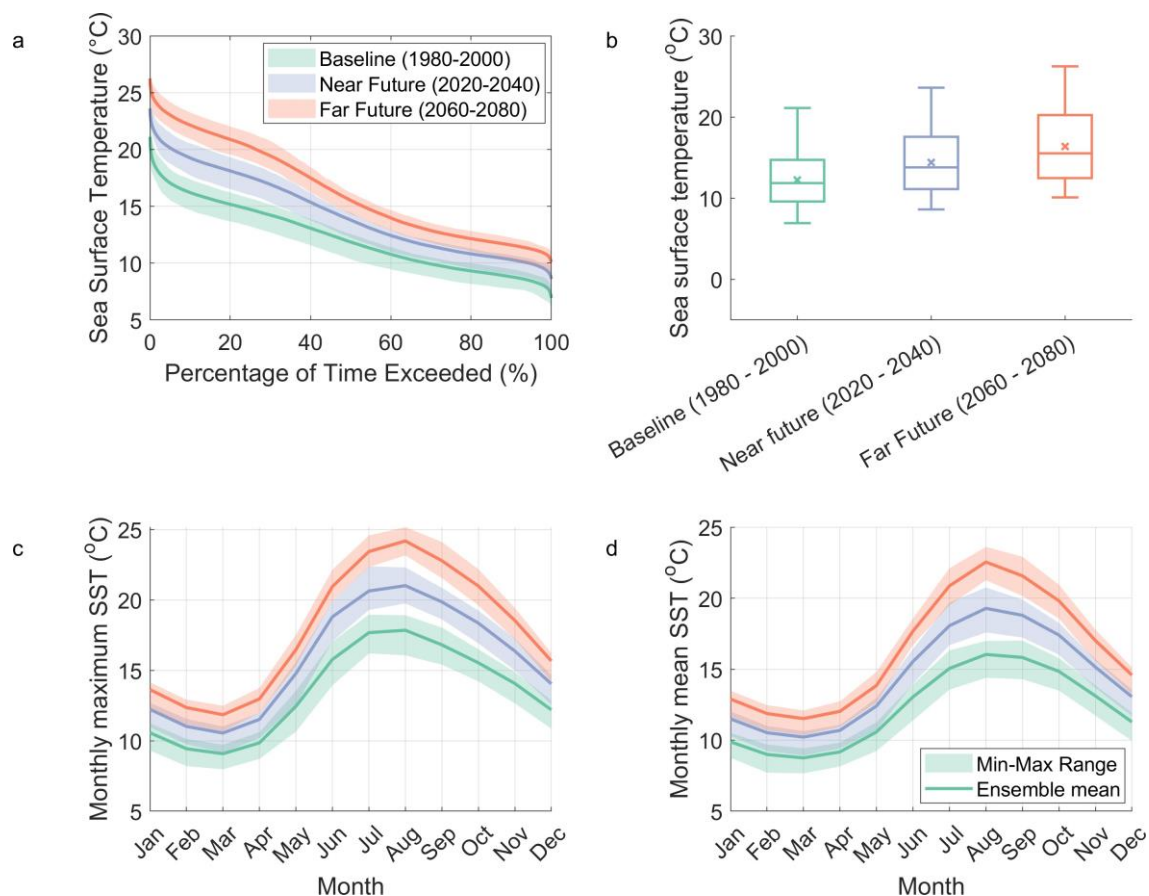
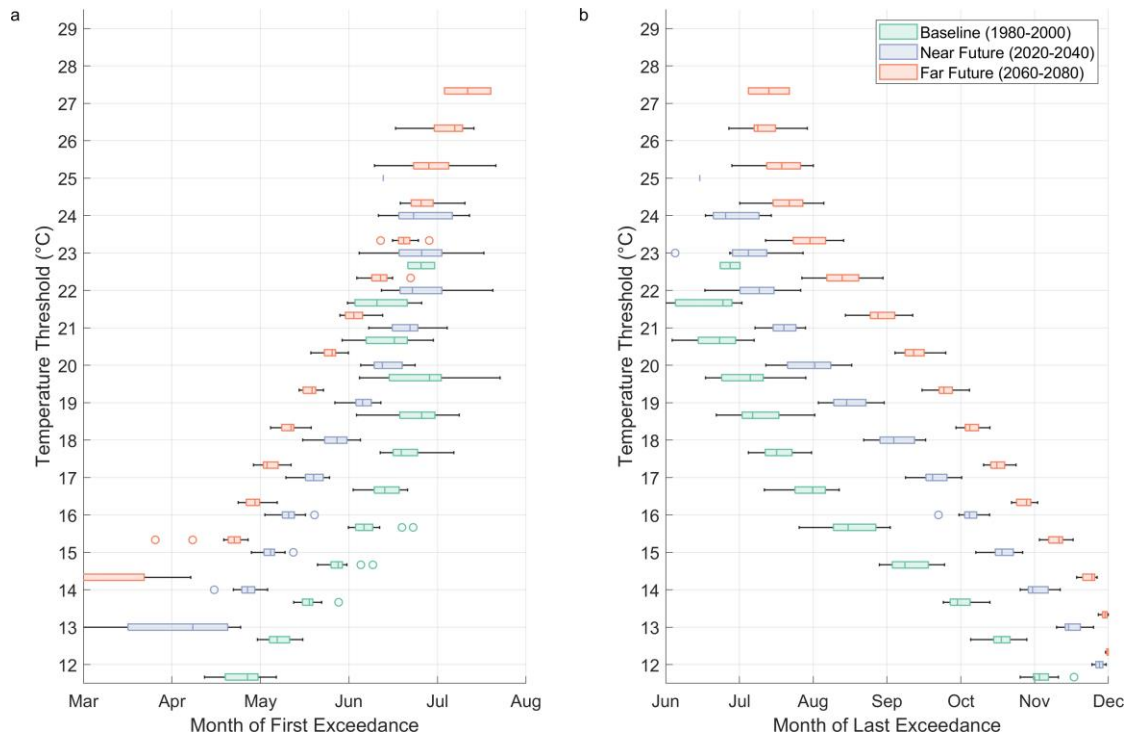


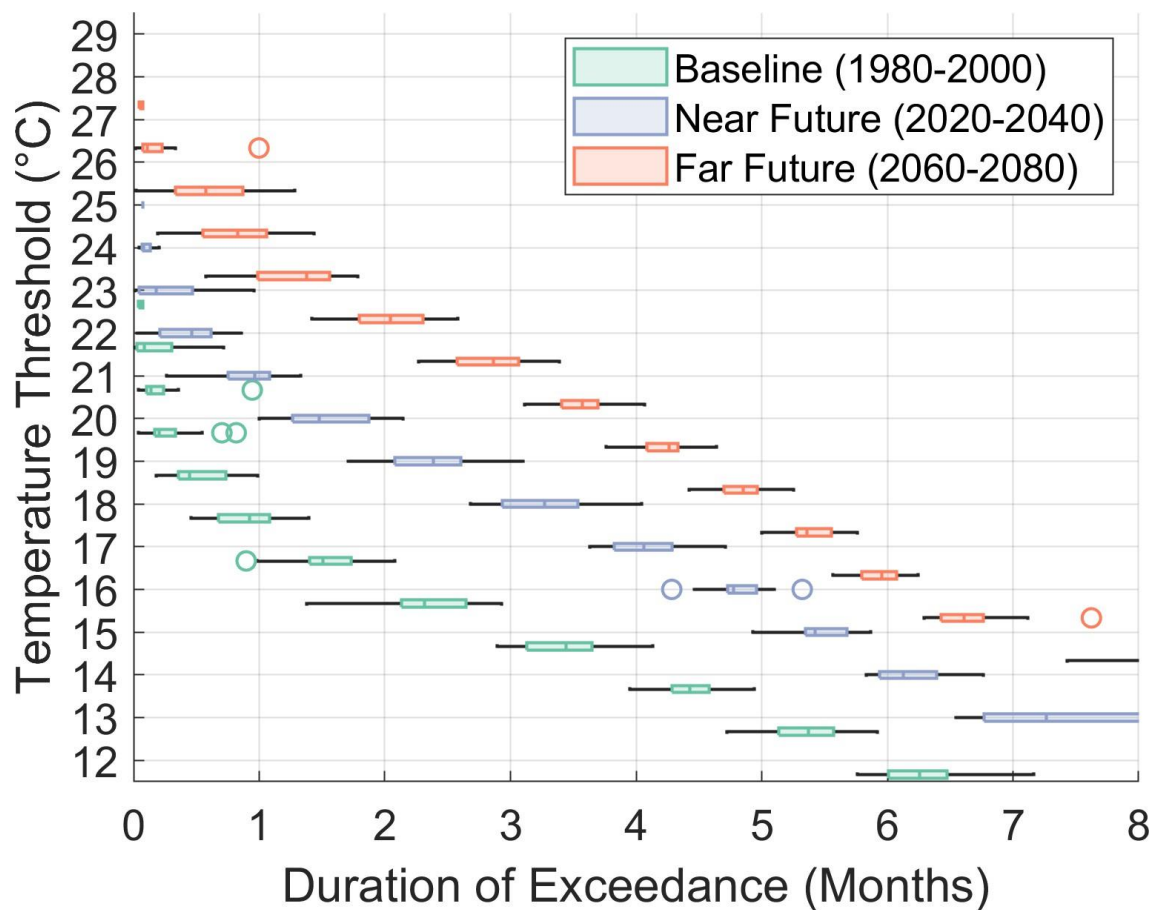
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

- (a) Temperature duration curves represent distribution of SSTs over time to highlight changes in cold and warm extremes.
- (b) Percentile shifts show increasing mean, median, and extremes, indicating prolonged warming over time.
- (c) Rising monthly maximum in every month of the year highlights likelihood of intensified high heat events.
- (d) Rising monthly mean suggests long-term climate-driven warming.



Changes in first and last occurrences of temperature thresholds compared to historical data. Note that these plots are not intended to identify the specific date on which a temperature may occur, rather they indicate the trend in the onset of specific temperature thresholds.



Projected temperature changes under different climate scenarios. Box and whisker plots show the range of different modelled durations of temperatures under the 12 different UKCP 18 ensemble members. Open circles indicate outlier values.

Section 2 - Sea surface salinity changes

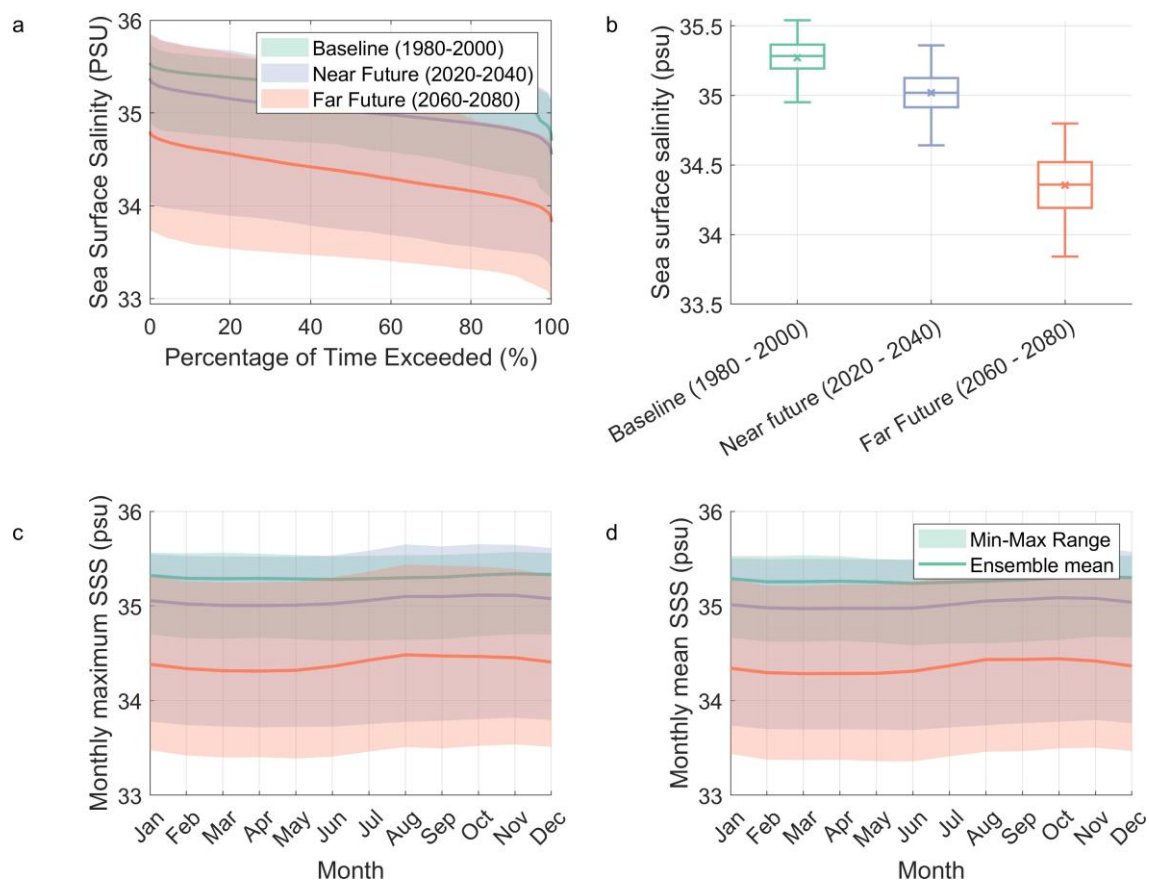


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
- (b) Percentile shifts show decreasing mean, median, and extremes, indicating a trend towards freshening over time.
- (c) Monthly maxima decrease across all months.
- (d) Decreasing monthly means suggest long-term ice-melt driven freshening.

Section 3 - Residual surge changes

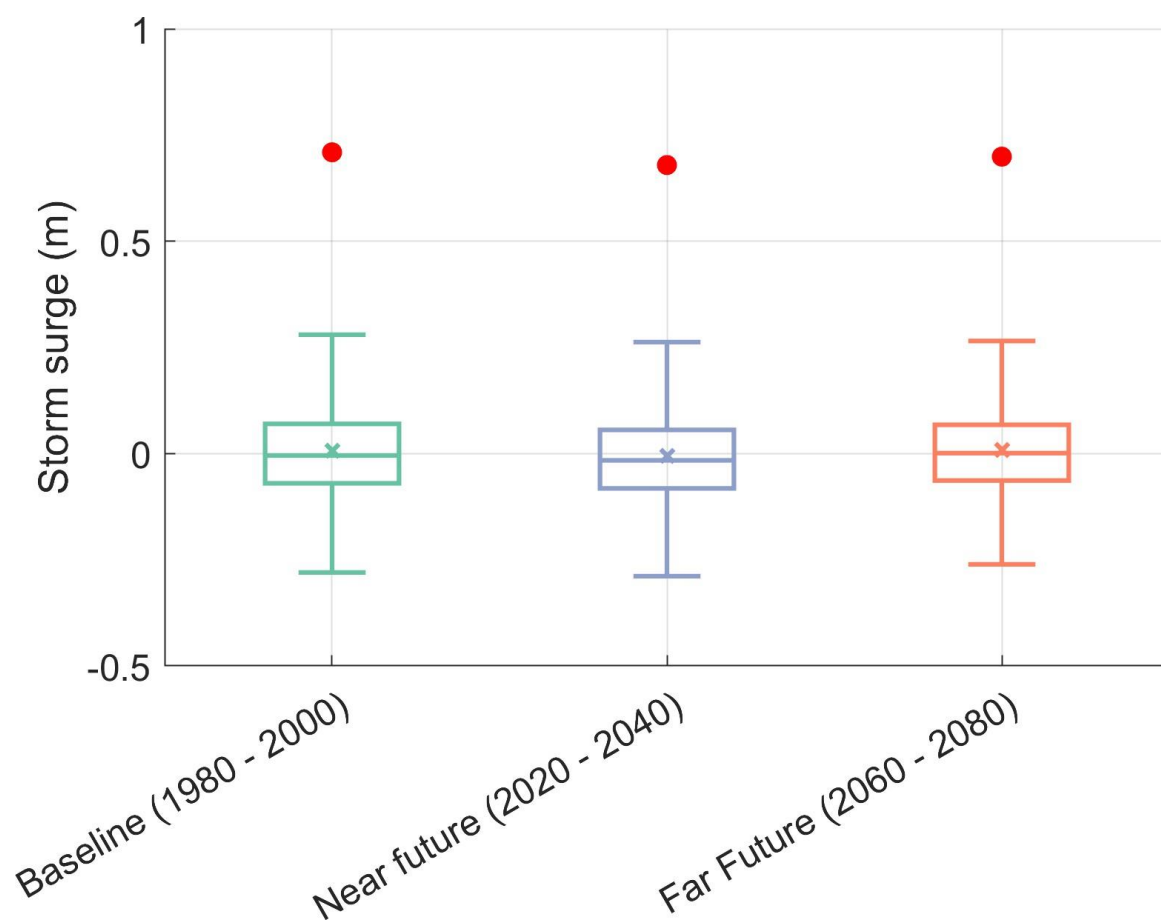


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

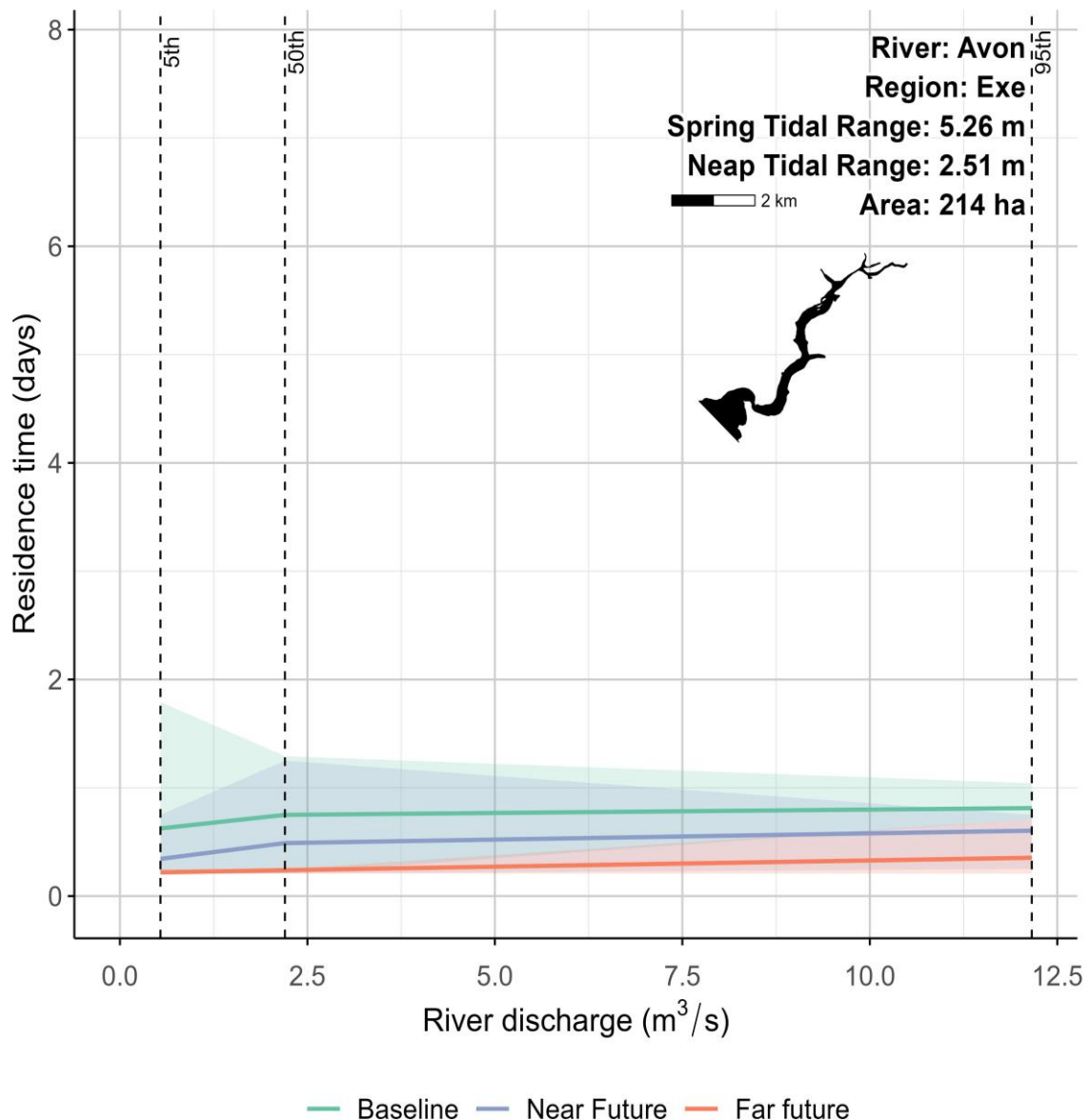


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)
Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	50.75275
Longitude	-3.04747
Tidal Range	3.7 m
Gauge Name	Axe at Whitford
Estuary Size	28400.0 m ²
5th percentile flow	1.26 m ³ /s
50th percentile flow	2.85 m ³ /s
95th percentile flow	18.2 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

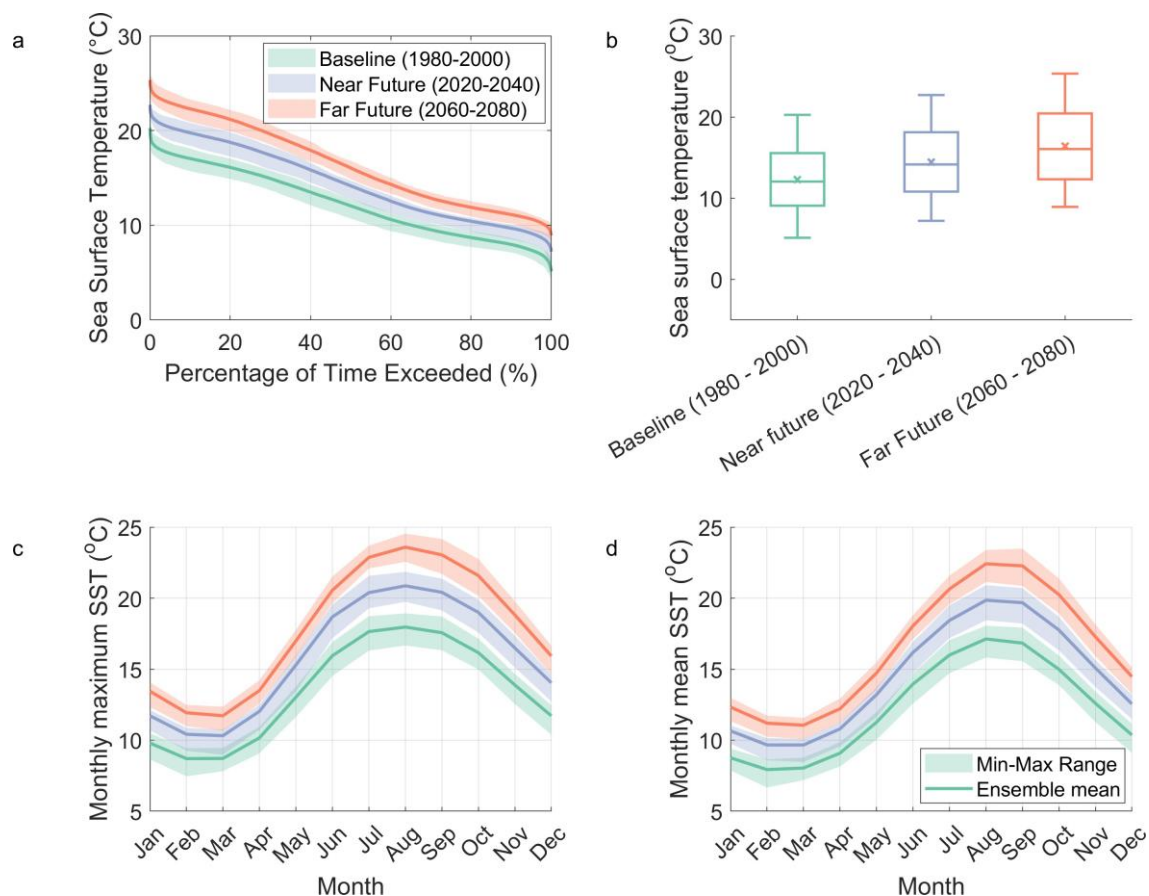
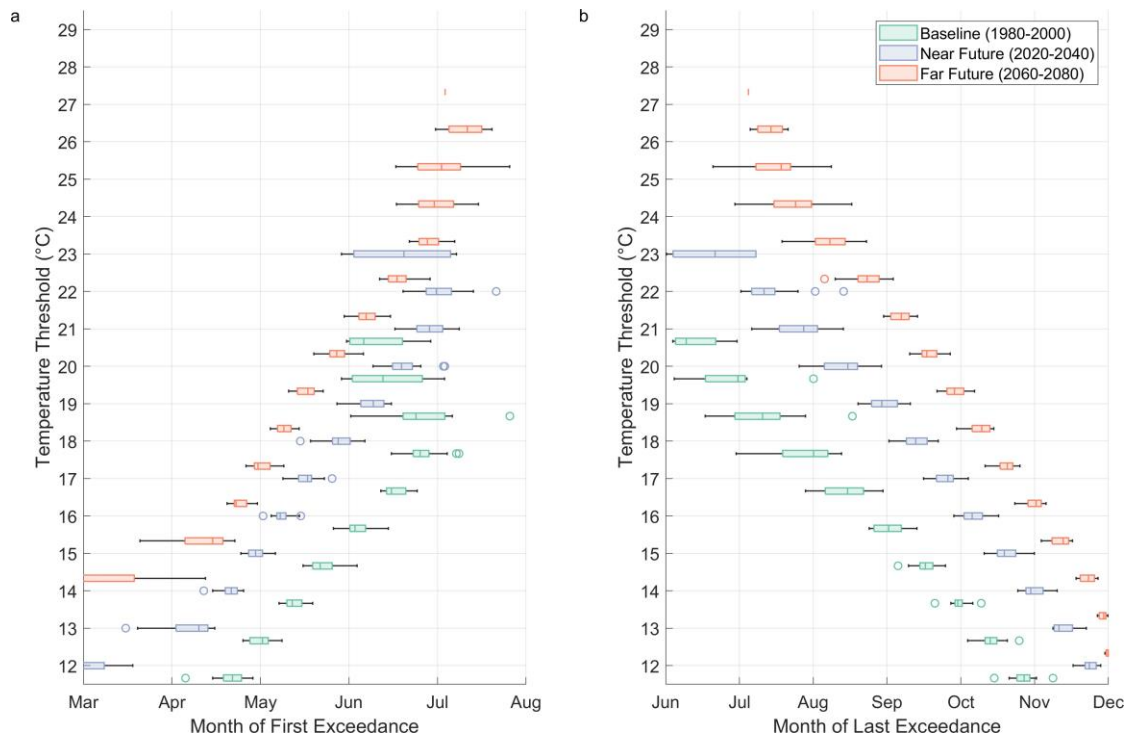


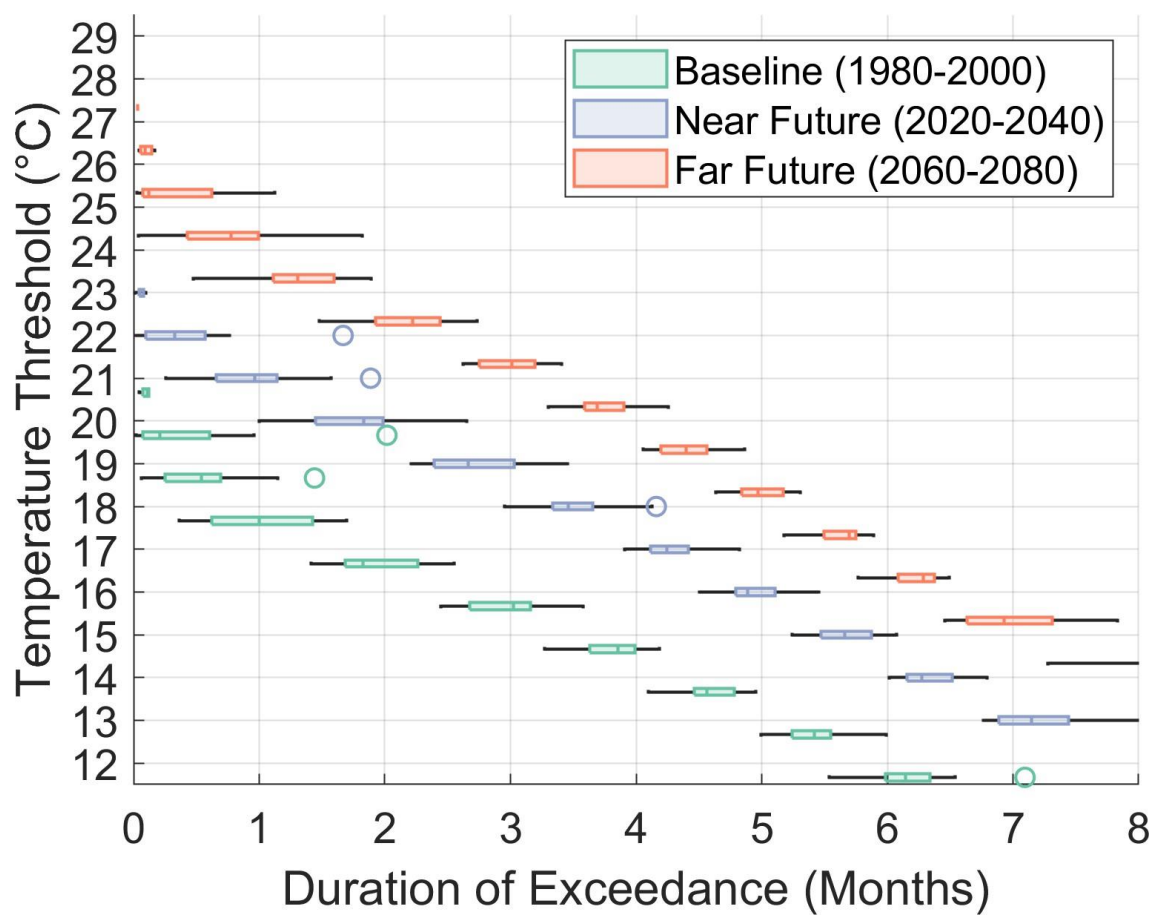
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- (a) Temperature duration curves represent distribution of SSTs over time to highlight changes in cold and warm extremes.
- (b) Percentile shifts show increasing mean, median, and extremes, indicating prolonged warming over time.
- (c) Rising monthly maximum in every month of the year highlights likelihood of intensified high heat events.
- (d) Rising monthly mean suggests long-term climate-driven warming.

Changes in first and last occurrences of temperature thresholds compared to historical data. Note that these plots are not intended to identify the specific date on which a temperature may occur, rather they indicate the trend in the onset of specific temperature thresholds.





Projected temperature changes under different climate scenarios. Box and whisker plots show the range of different modelled durations of temperatures under the 12 different UKCP 18 ensemble members. Open circles indicate outlier values.

Section 2 - Sea surface salinity changes

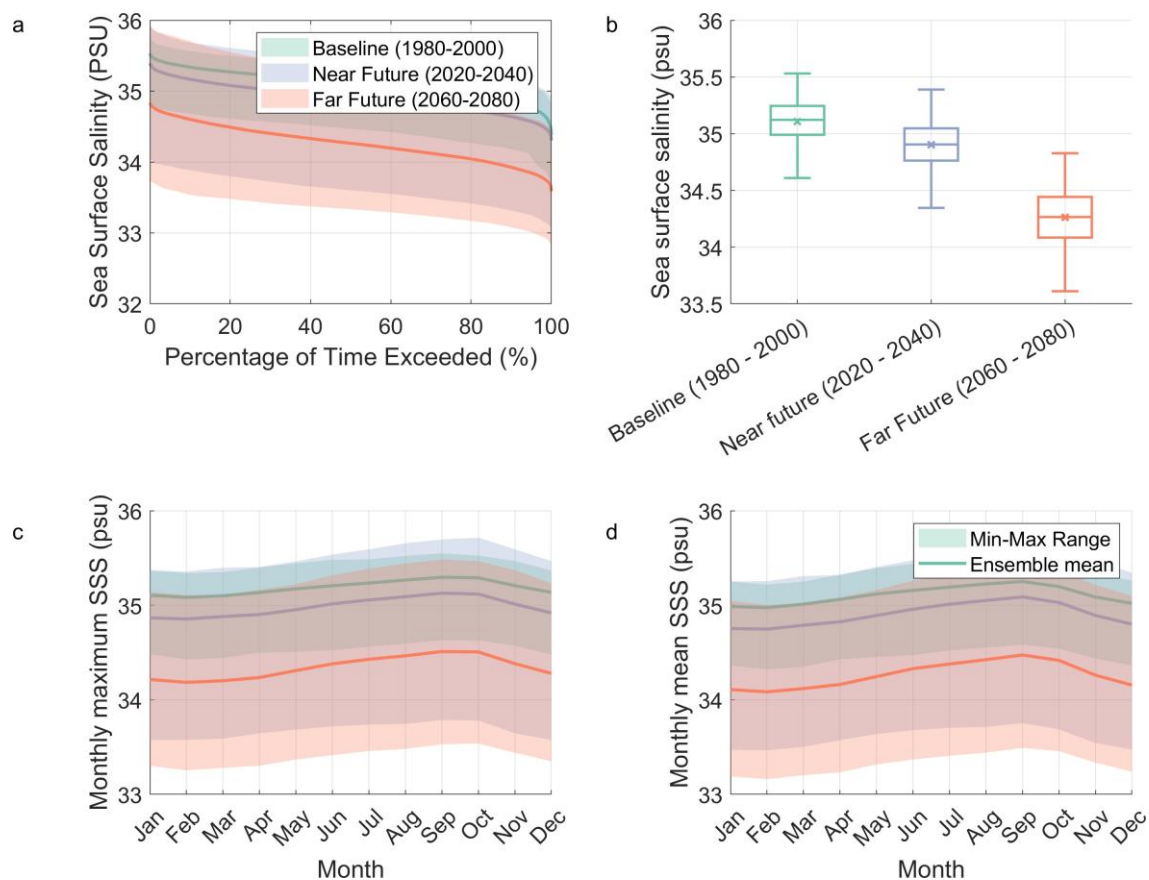


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
- (b) Percentile shifts show decreasing mean, median, and extremes, indicating a trend towards freshening over time.
- (c) Monthly maxima decrease across all months.
- (d) Decreasing monthly means suggest long-term ice-melt driven freshening.

Section 3 - Residual surge changes

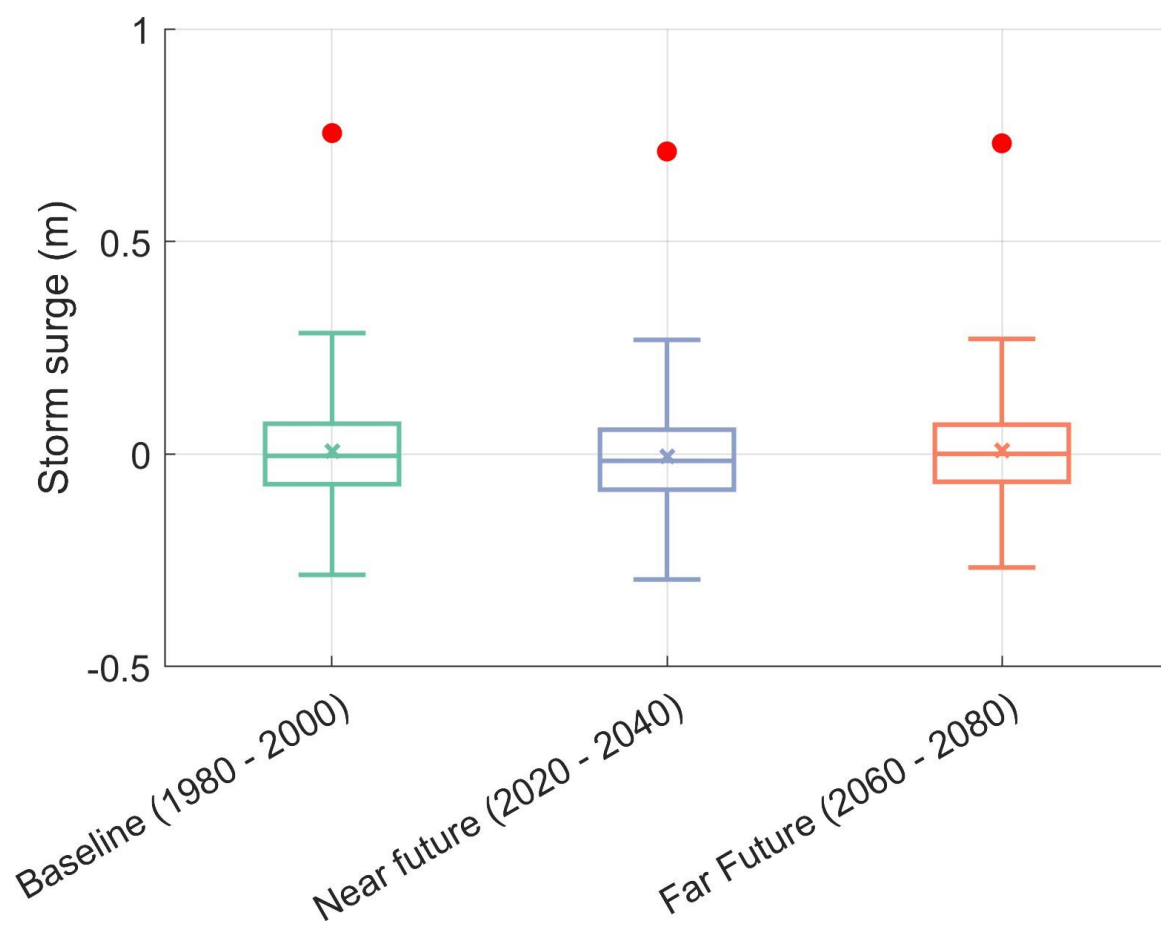


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

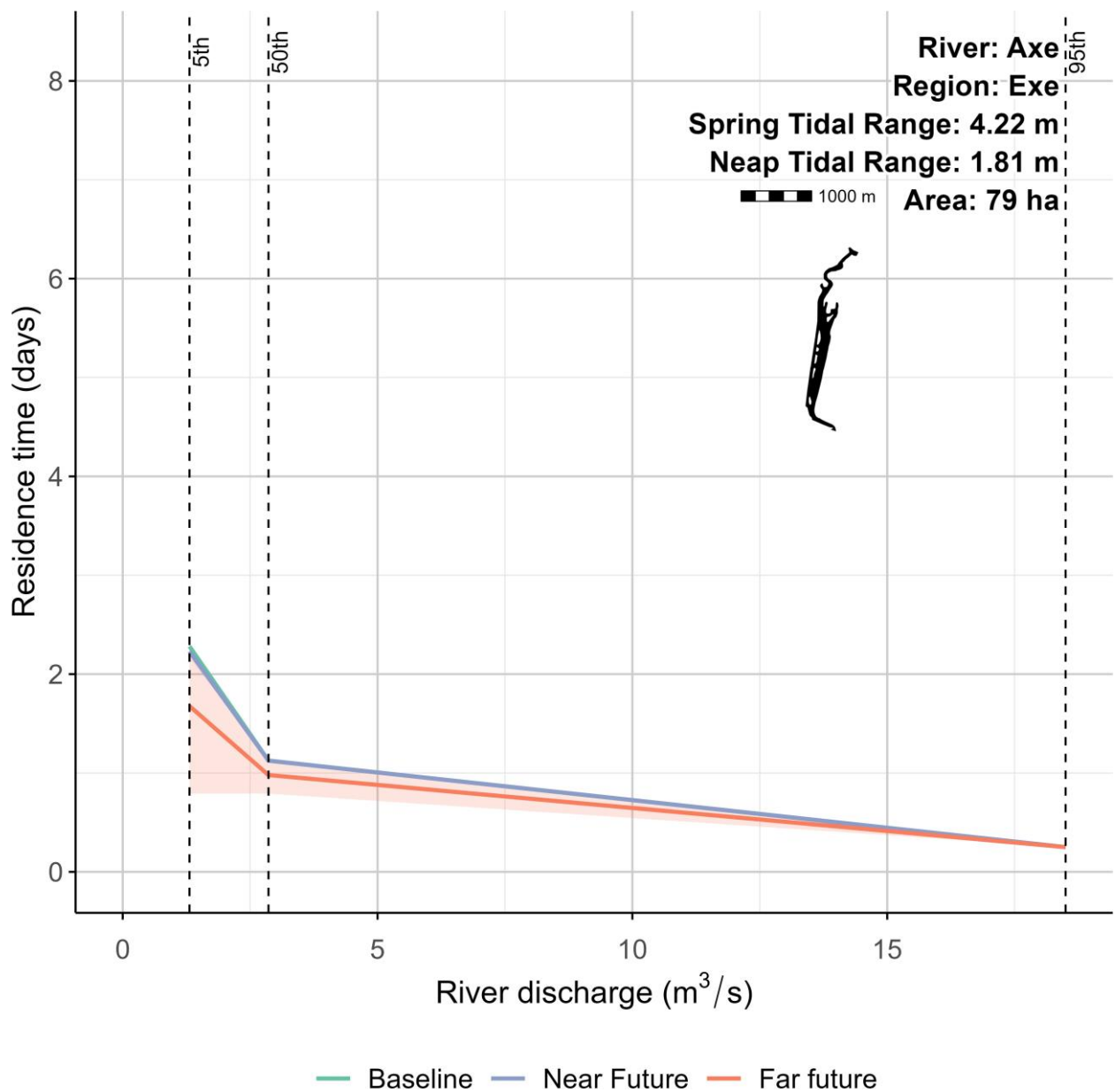


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Blyth

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	55.11384
Longitude	-1.62067
Tidal Range	4.2 m
Gauge Name	Blyth at Hartford Bridge
Estuary Size	1350000.0 m ²
5th percentile flow	0.135 m ³ /s
50th percentile flow	0.798 m ³ /s
95th percentile flow	8.28 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

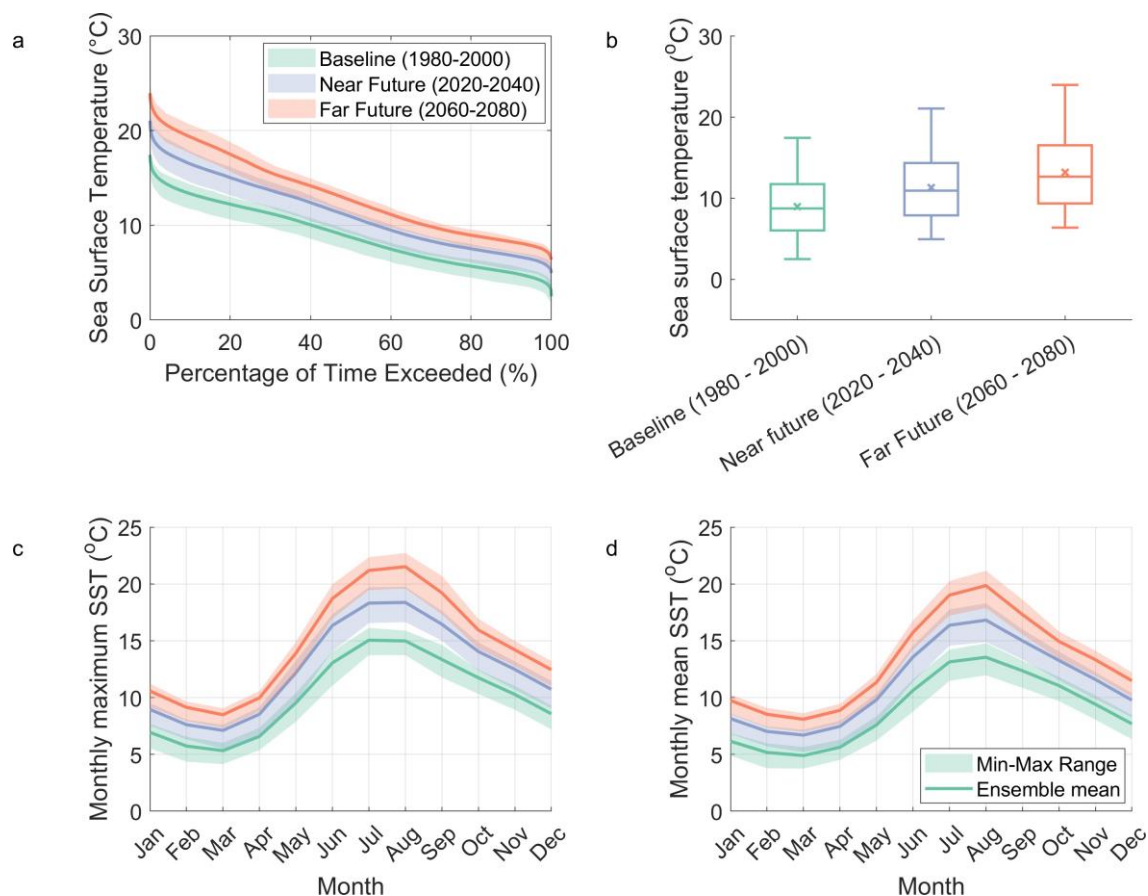
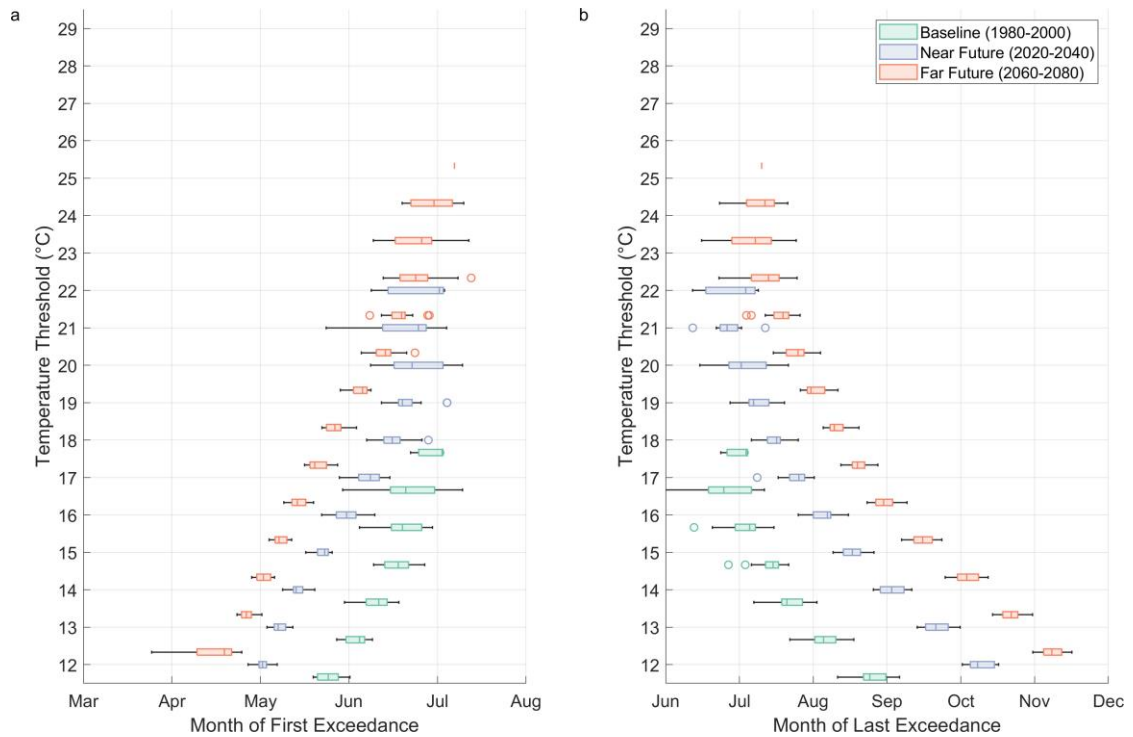


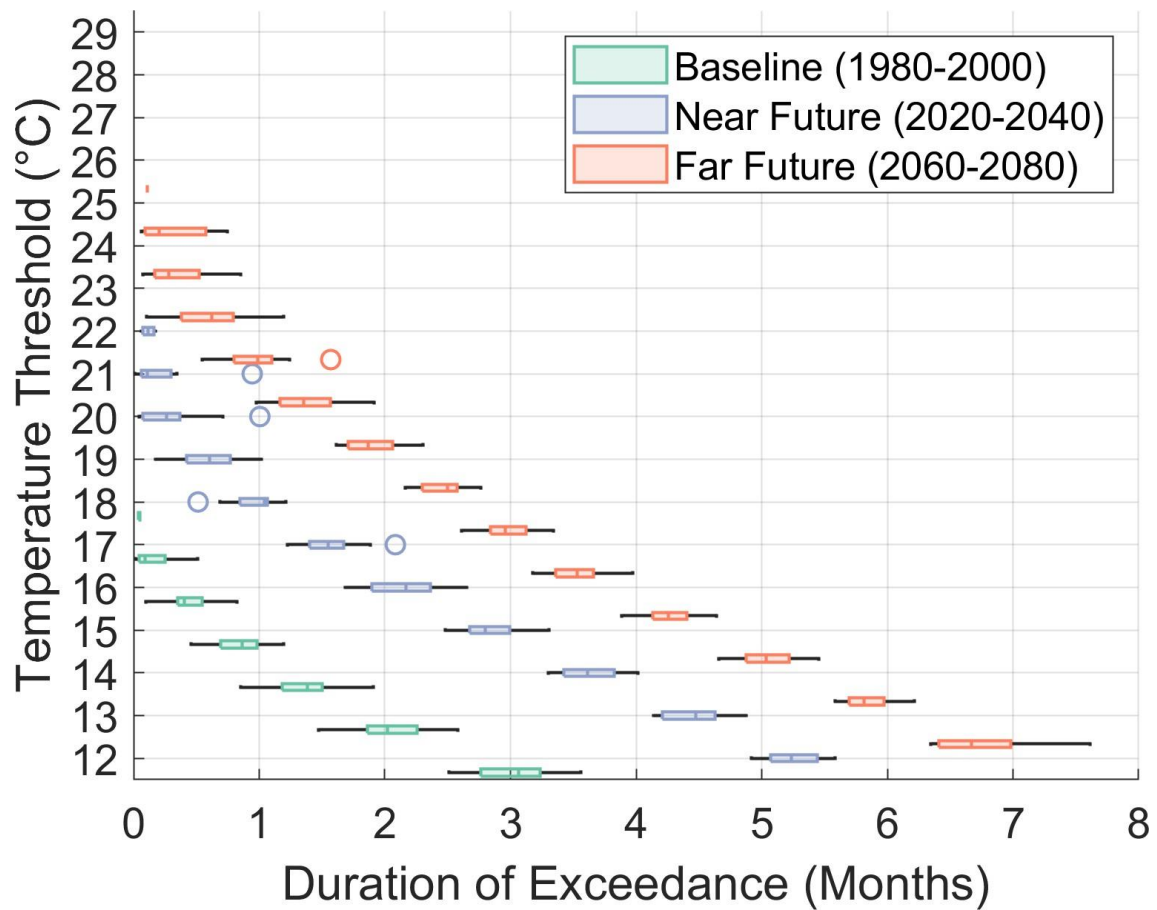
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

- (a) Temperature duration curves represent distribution of SSTs over time to highlight changes in cold and warm extremes.
- (b) Percentile shifts show increasing mean, median, and extremes, indicating prolonged warming over time.
- (c) Rising monthly maximum in every month of the year highlights likelihood of intensified high heat events.
- (d) Rising monthly mean suggests long-term climate-driven warming.



Changes in first and last occurrences of temperature thresholds compared to historical data. Note that these plots are not intended to identify the specific date on which a temperature may occur, rather they indicate the trend in the onset of specific temperature thresholds.



Projected temperature changes under different climate scenarios. Box and whisker plots show the range of different modelled durations of temperatures under the 12 different UKCP 18 ensemble members. Open circles indicate outlier values.

Section 2 - Sea surface salinity changes

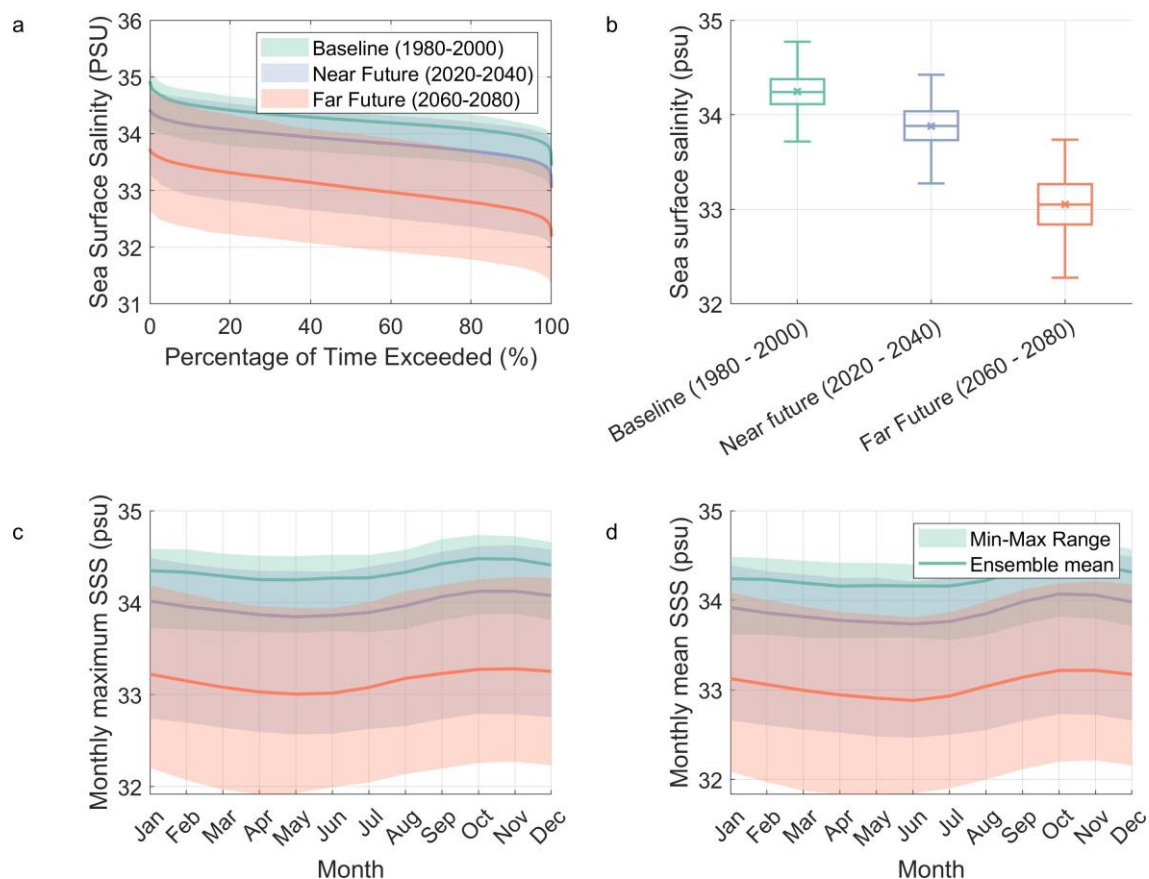


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
- (b) Percentile shifts show decreasing mean, median, and extremes, indicating a trend towards freshening over time.
- (c) Monthly maxima decrease across all months.
- (d) Decreasing monthly means suggest long-term ice-melt driven freshening.

Section 3 - Residual surge changes

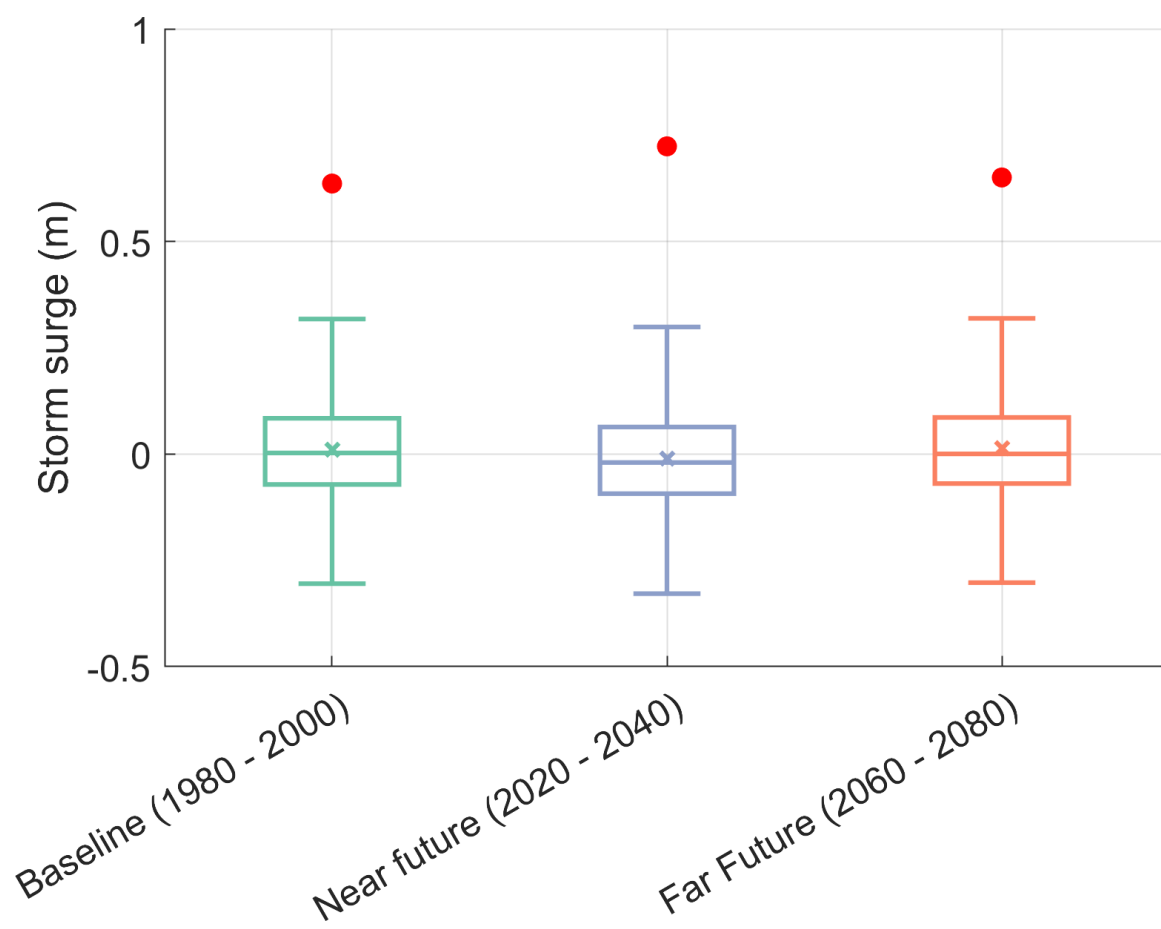


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

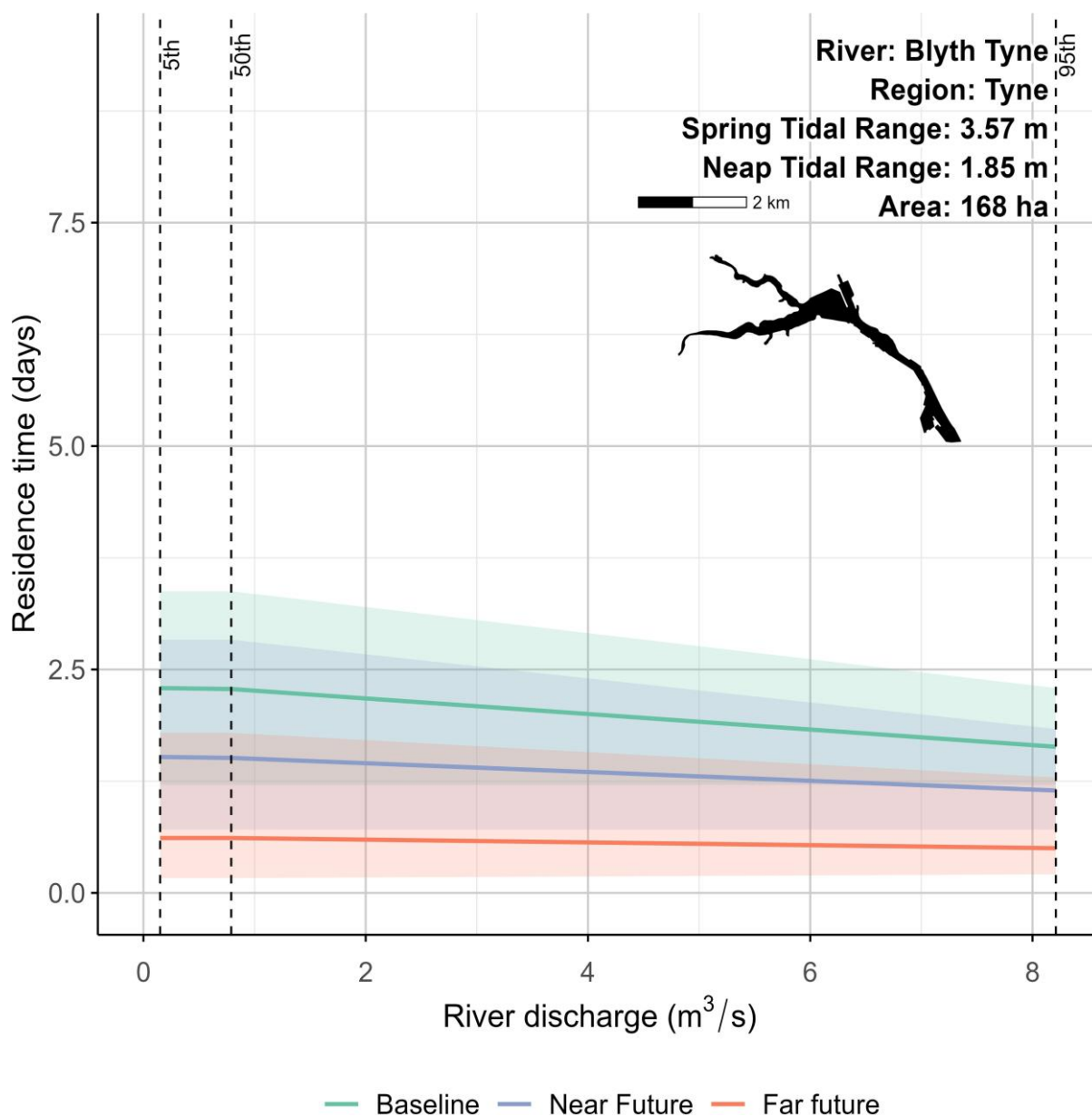


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Blyth_Suffolk

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	52.33713
Longitude	1.53072
Tidal Range	1.9 m
Gauge Name	Bylth at Holton
Estuary Size	2460000.0 m ²
5th percentile flow	0.066 m ³ /s
50th percentile flow	0.1344 m ³ /s
95th percentile flow	1.79 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

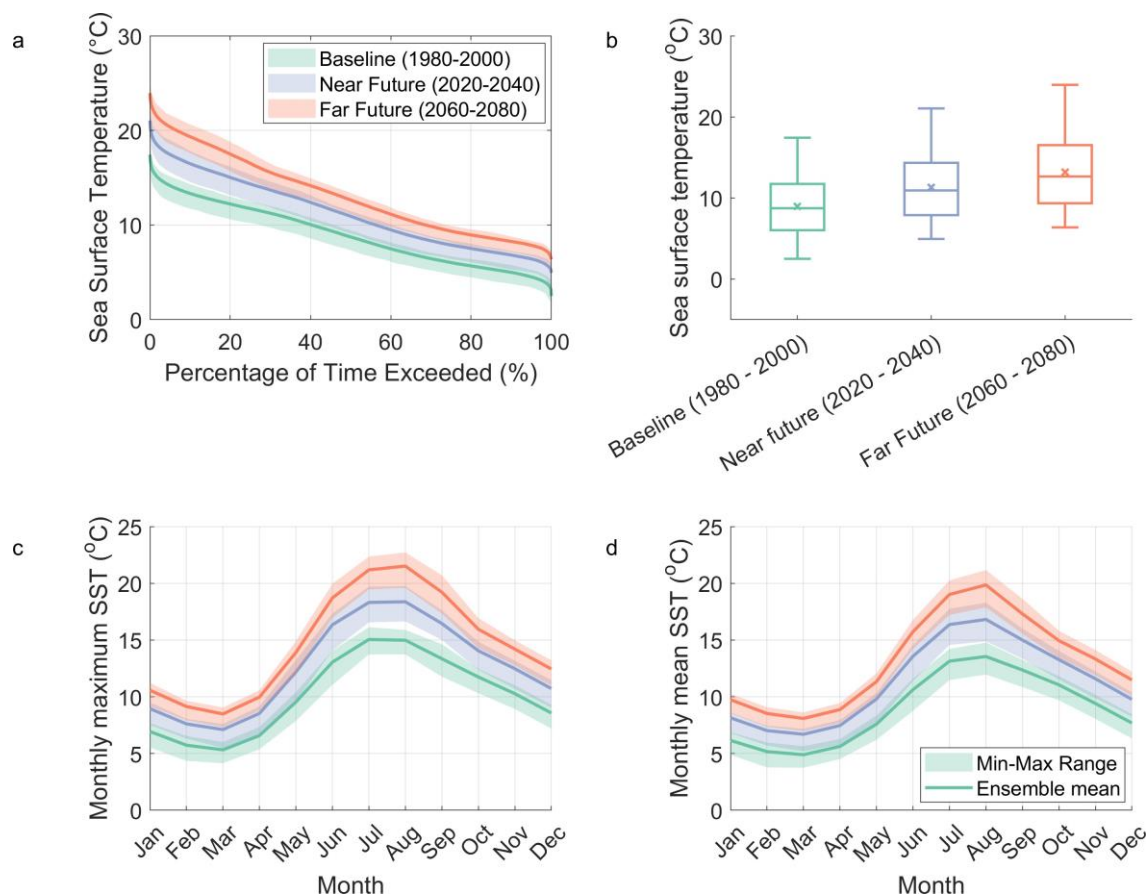
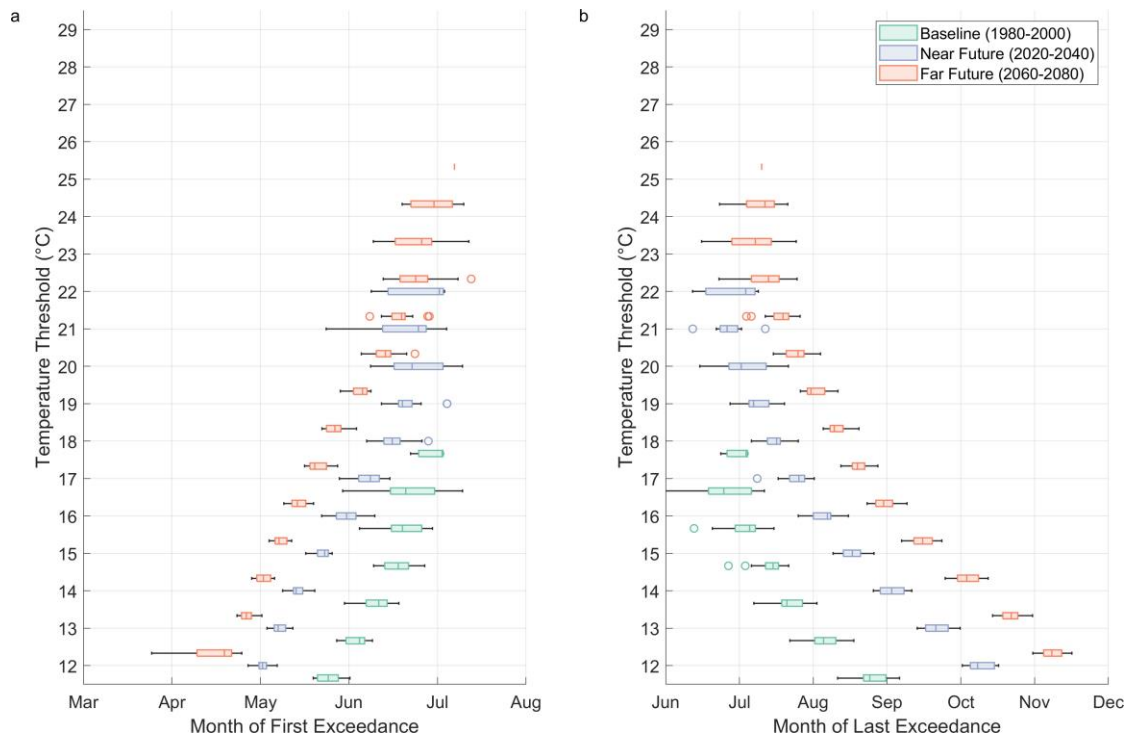


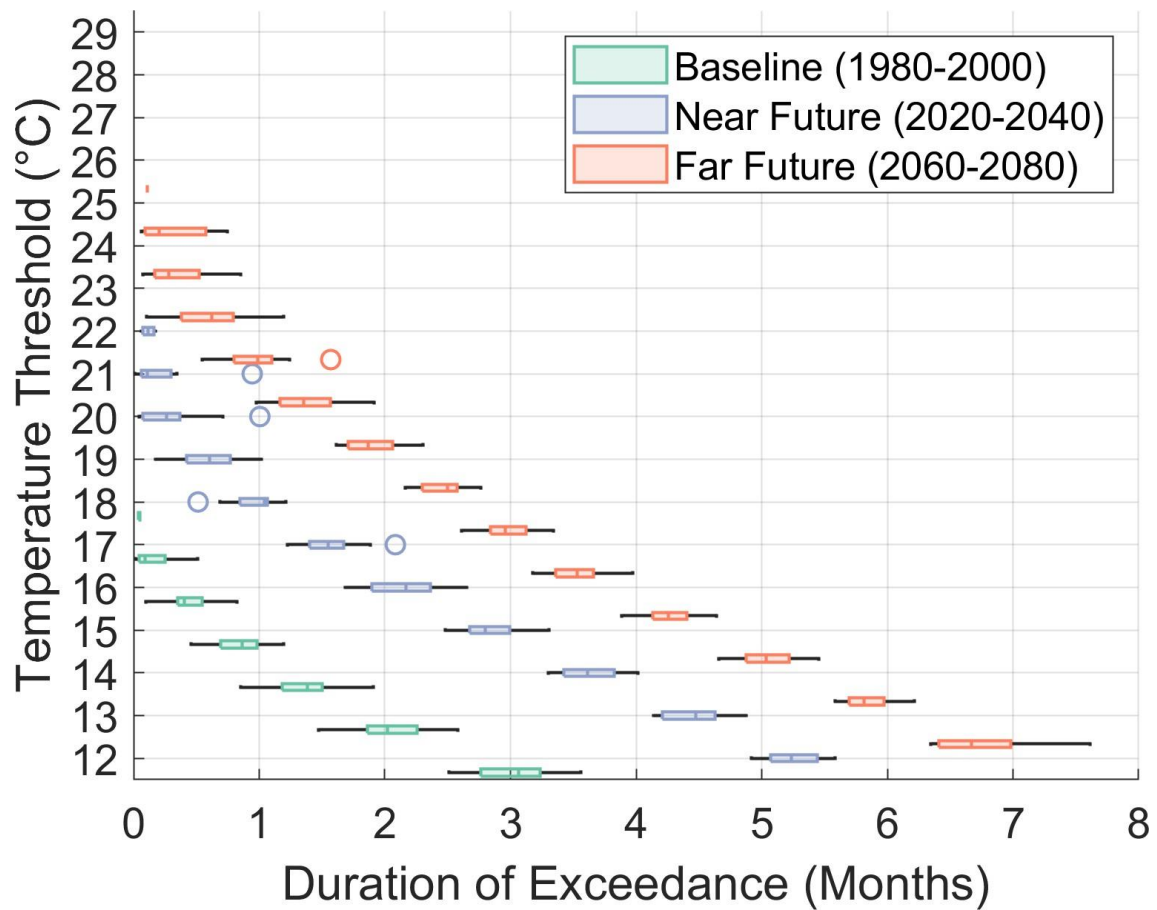
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

- (a) Temperature duration curves represent distribution of SSTs over time to highlight changes in cold and warm extremes.
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Projected temperature changes under different climate scenarios. Box and whisker plots show the range of different modelled durations of temperatures under the 12 different UKCP 18 ensemble members. Open circles indicate outlier values.

Section 2 - Sea surface salinity changes

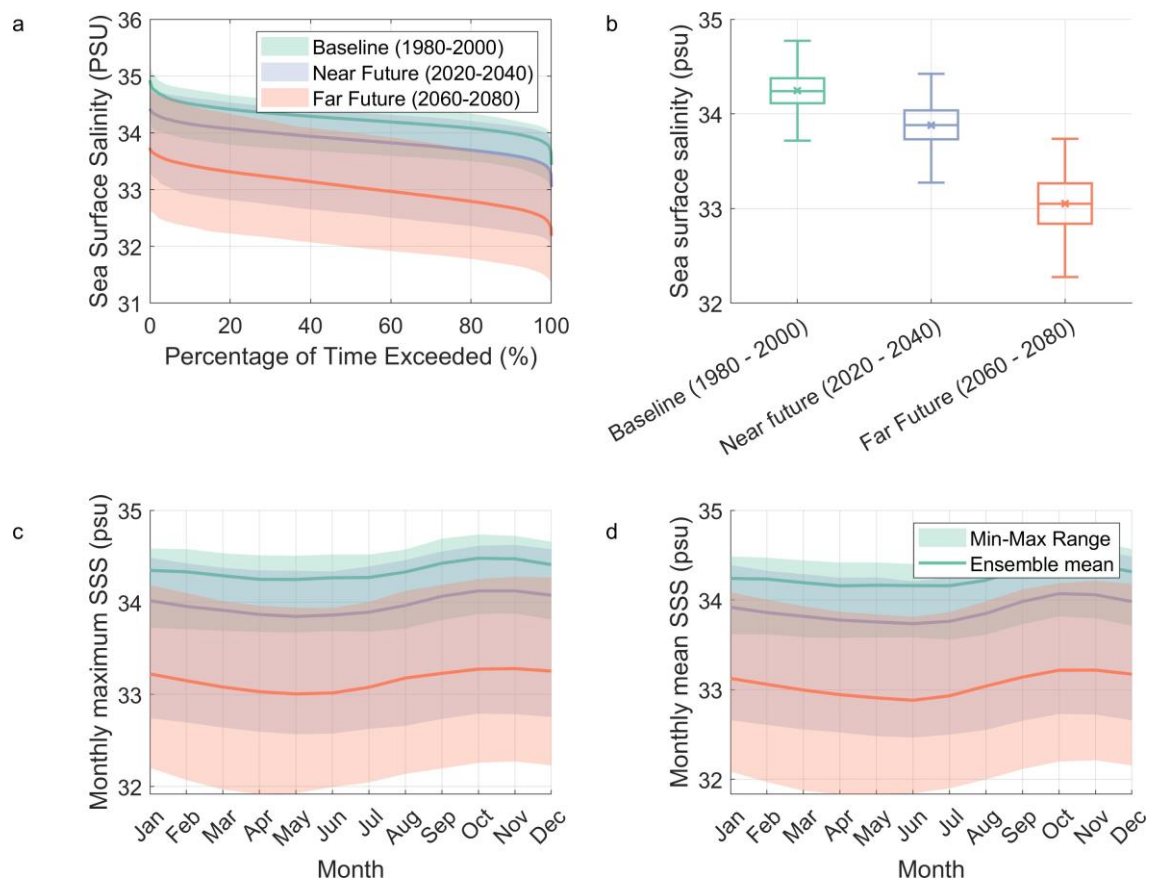


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
- (b) Percentile shifts show decreasing mean, median, and extremes, indicating a trend towards freshening over time.
- (c) Monthly maxima decrease across all months.
- (d) Decreasing monthly means suggest long-term ice-melt driven freshening.

Section 3 - Residual surge changes

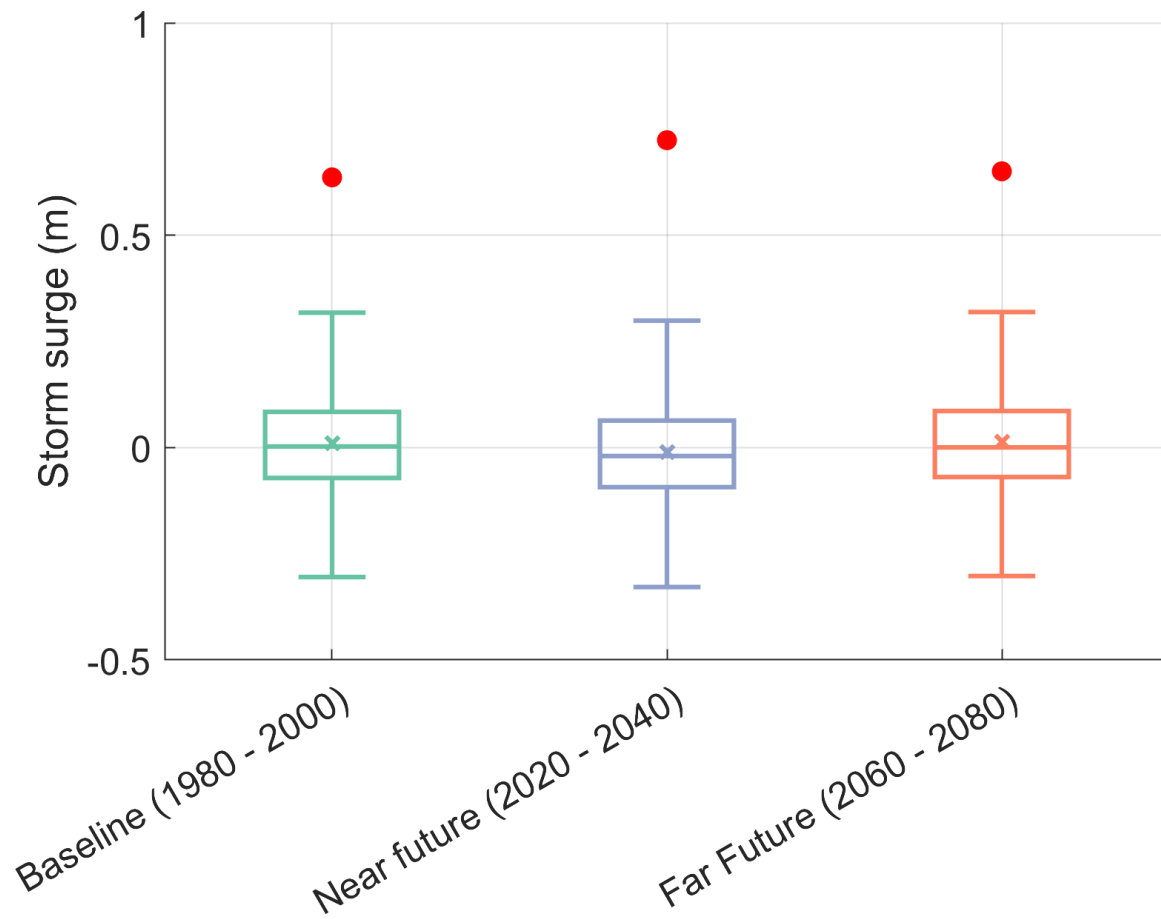


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

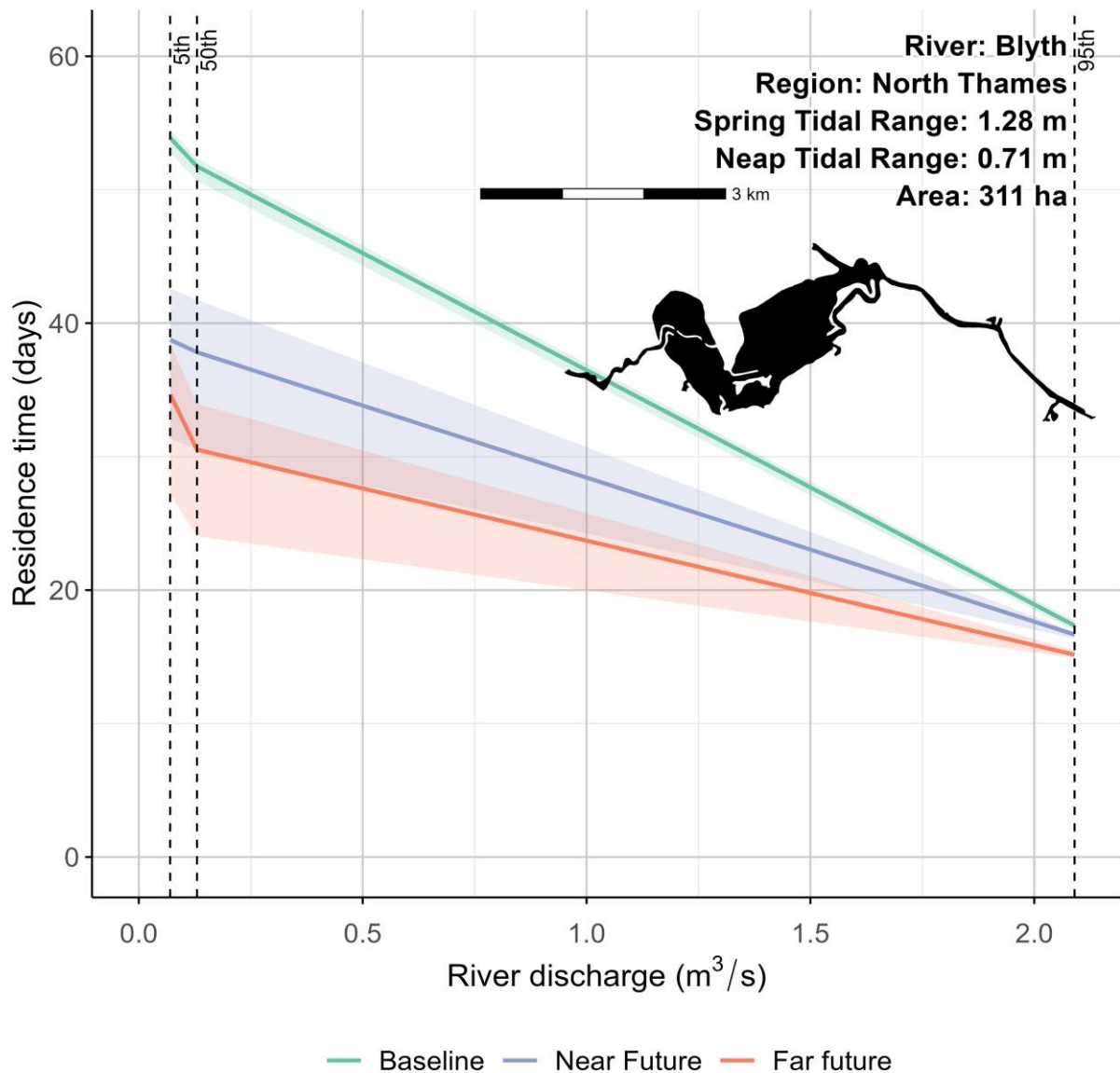


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Burn

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	52.95037
Longitude	0.74037
Tidal Range	4.67 m
Gauge Name	Burn at Burnham Overy
Estuary Size	1350000.0 m ²
5th percentile flow	0.104 m ³ /s
50th percentile flow	0.267 m ³ /s
95th percentile flow	0.679 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

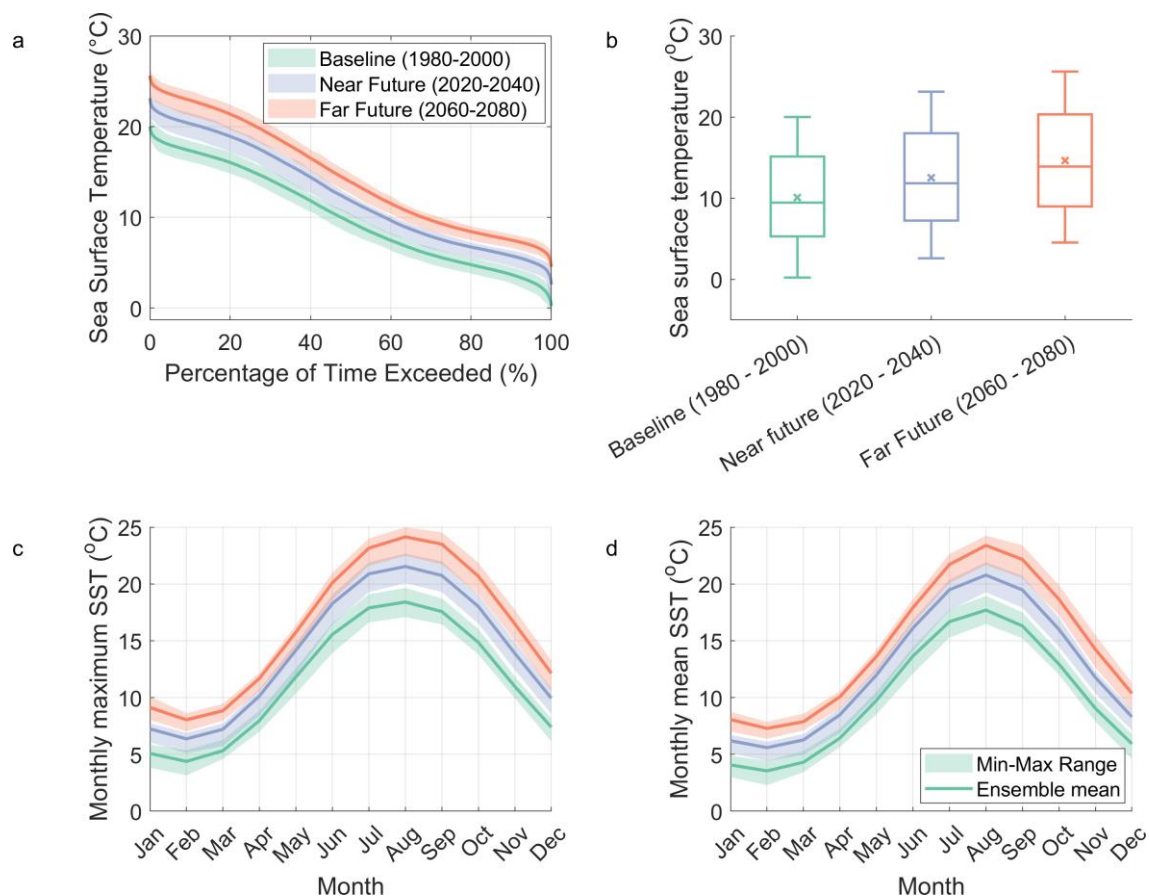
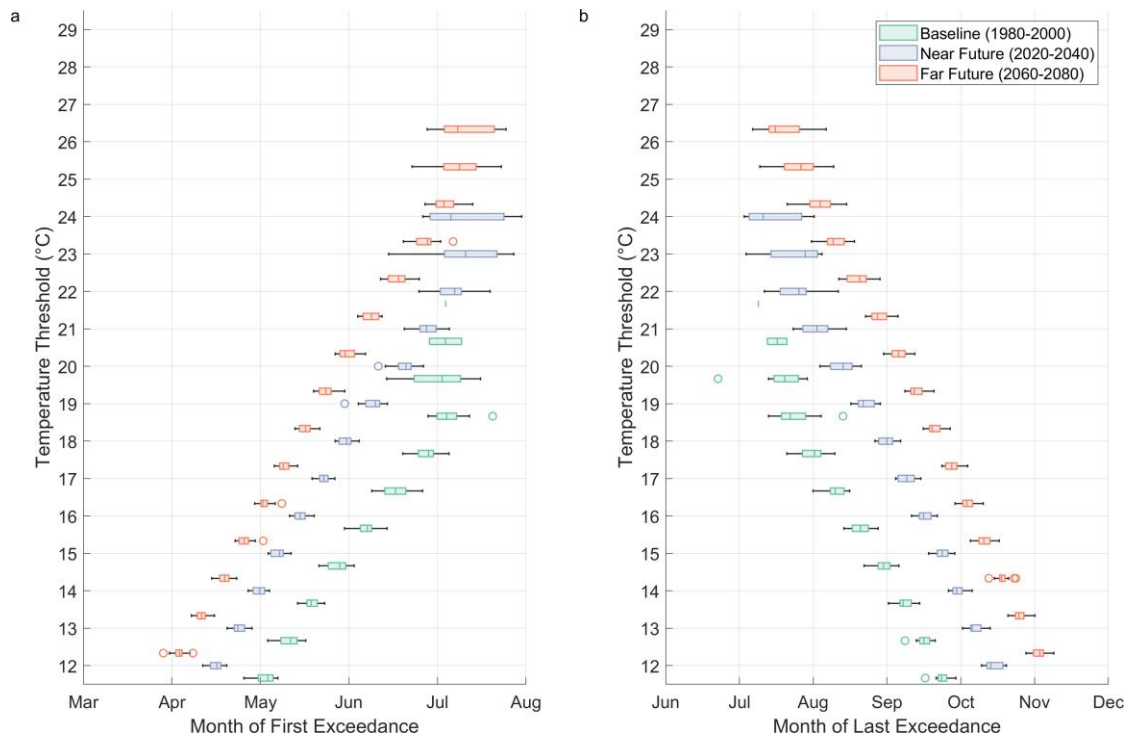


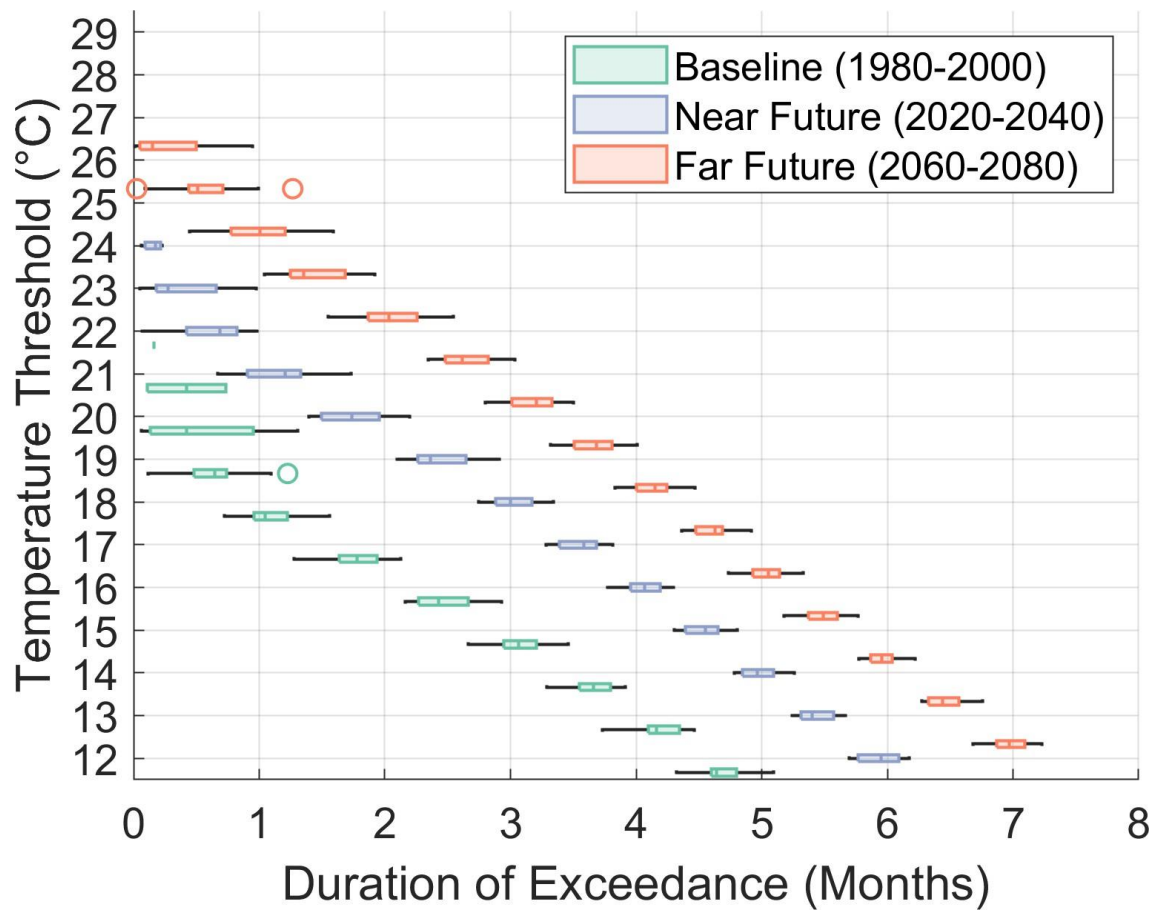
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

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Projected temperature changes under different climate scenarios. Box and whisker plots show the range of different modelled durations of temperatures under the 12 different UKCP 18 ensemble members. Open circles indicate outlier values.

Section 2 - Sea surface salinity changes

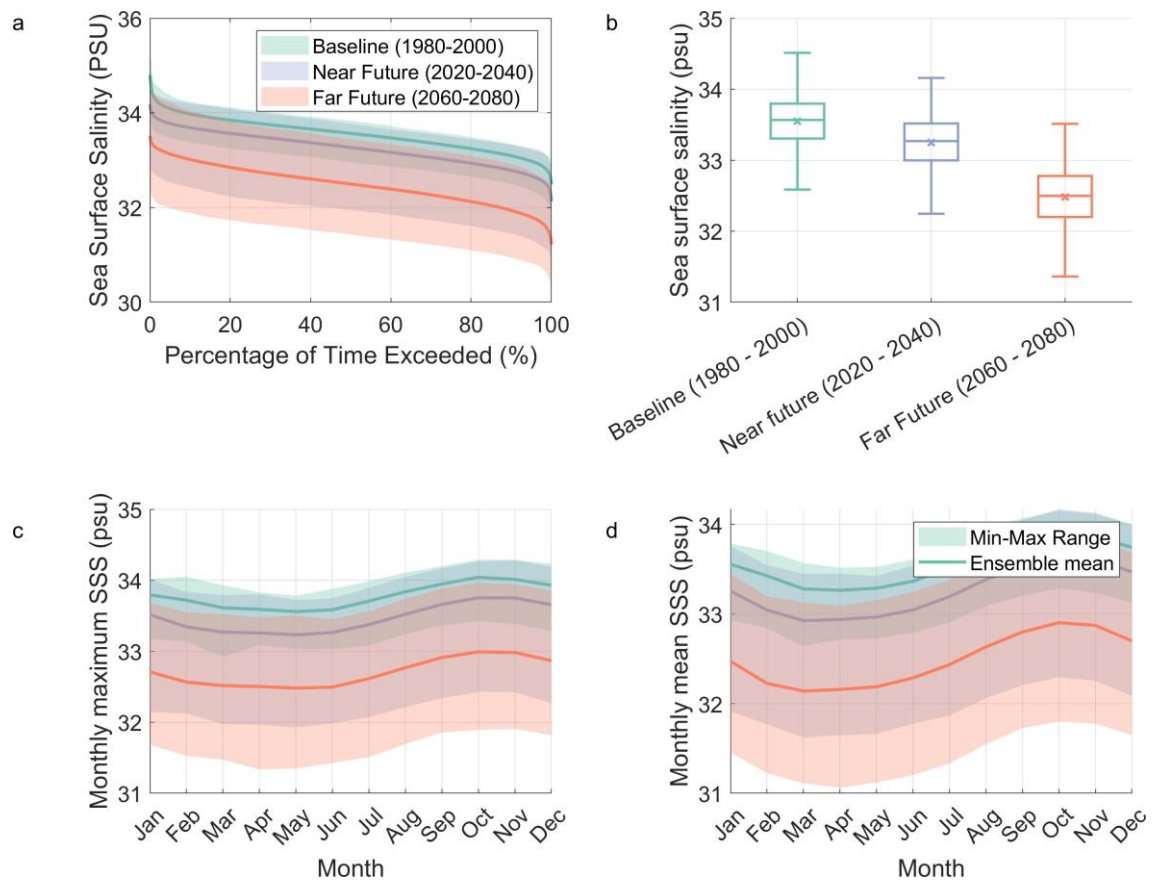


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
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Section 3 - Residual surge changes

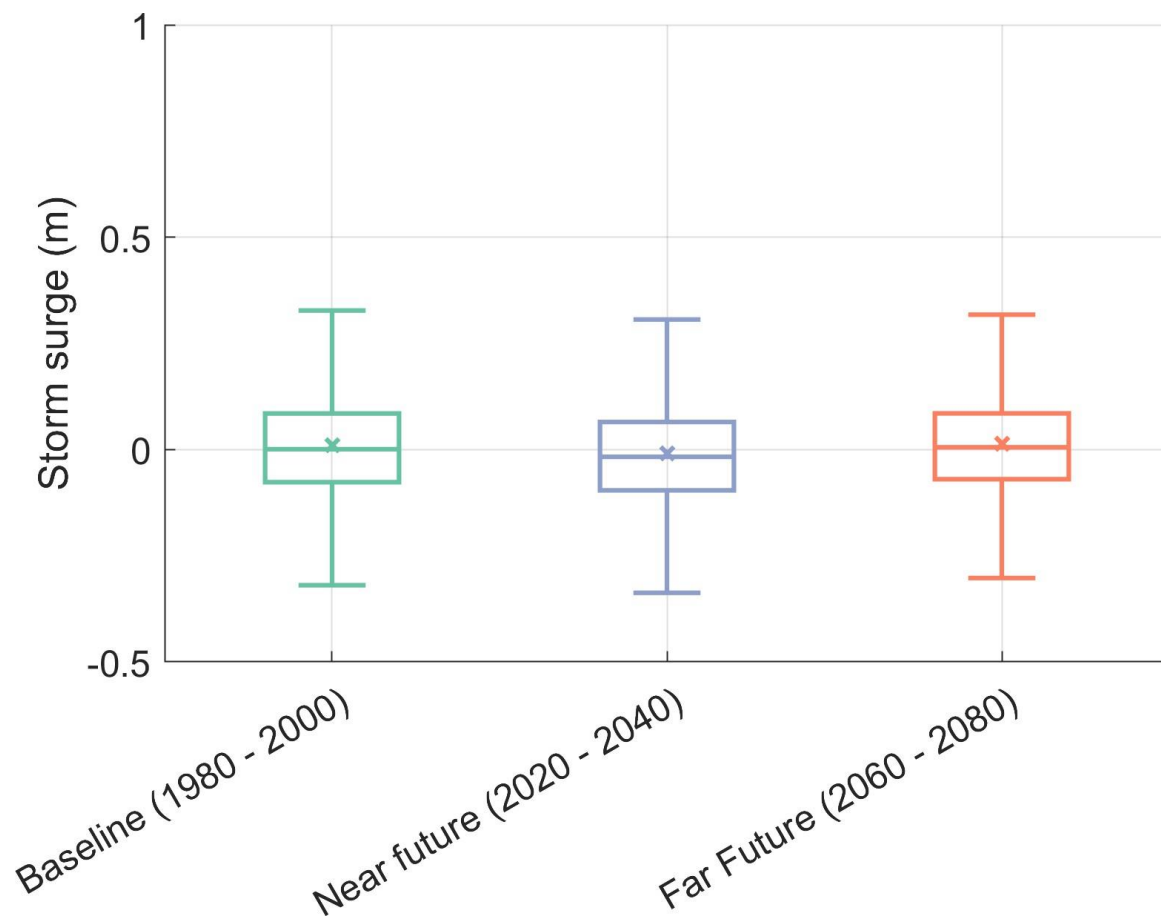


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

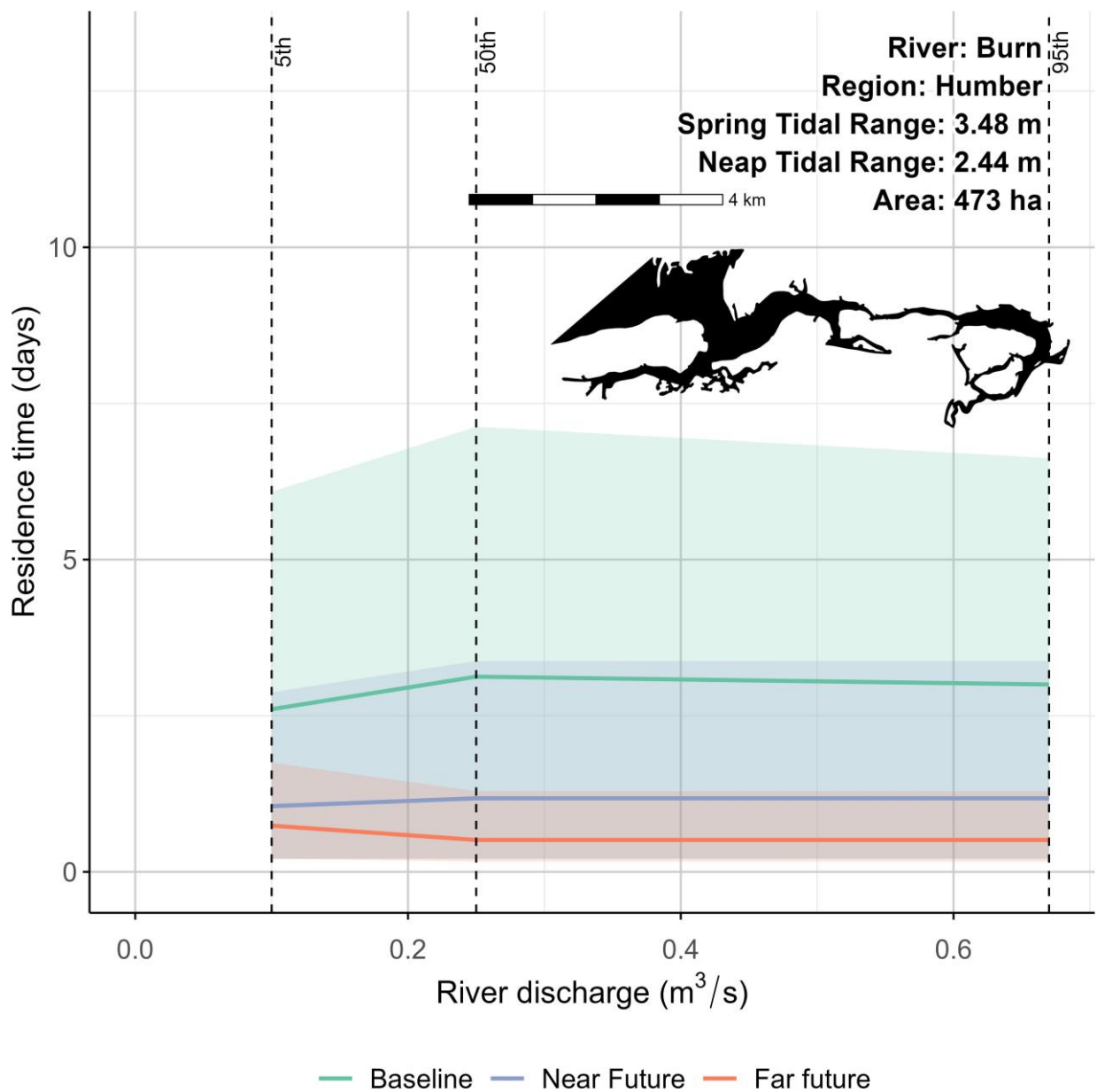


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)
Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Camel

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	50.4741
Longitude	-4.75723
Tidal Range	6.5 m
Gauge Name	Camel at Bodmin Dunmere
Estuary Size	6950000.0 m ²
5th percentile flow	0.572 m ³ /s
50th percentile flow	2.855 m ³ /s
95th percentile flow	13.5 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

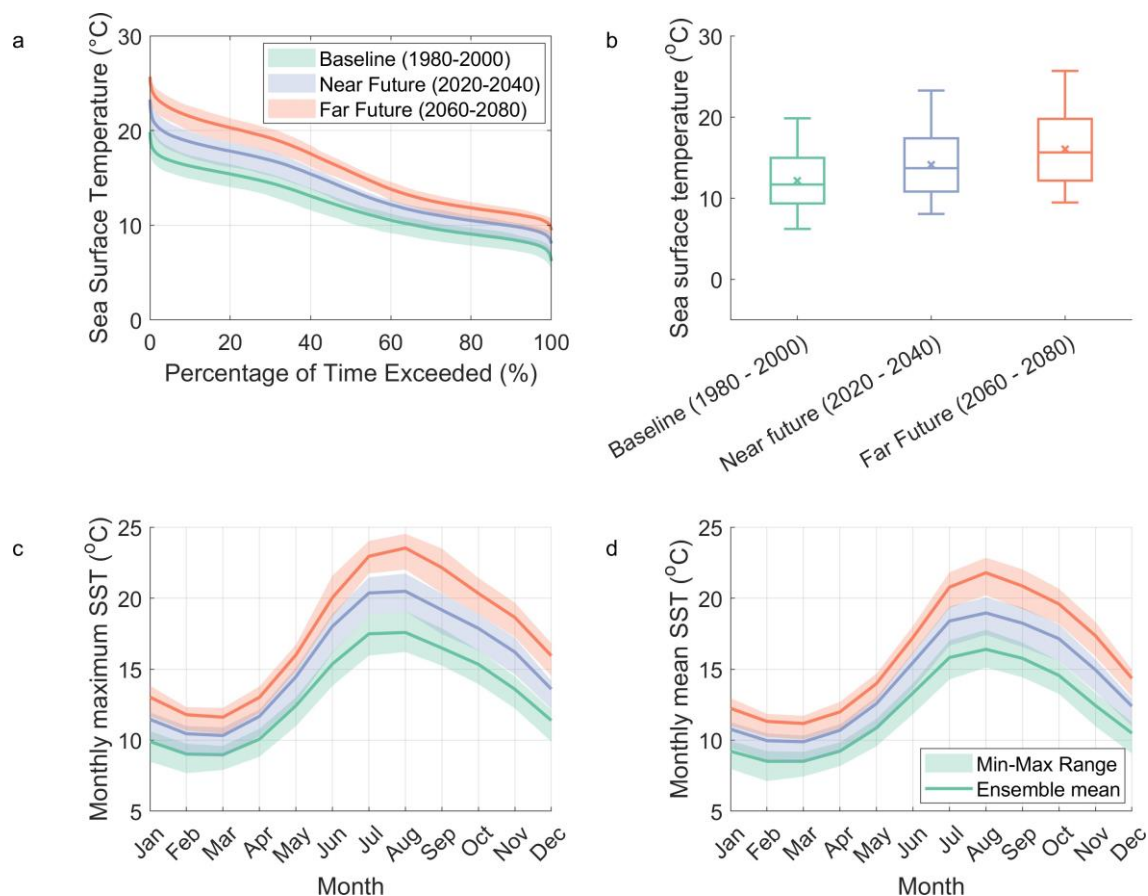
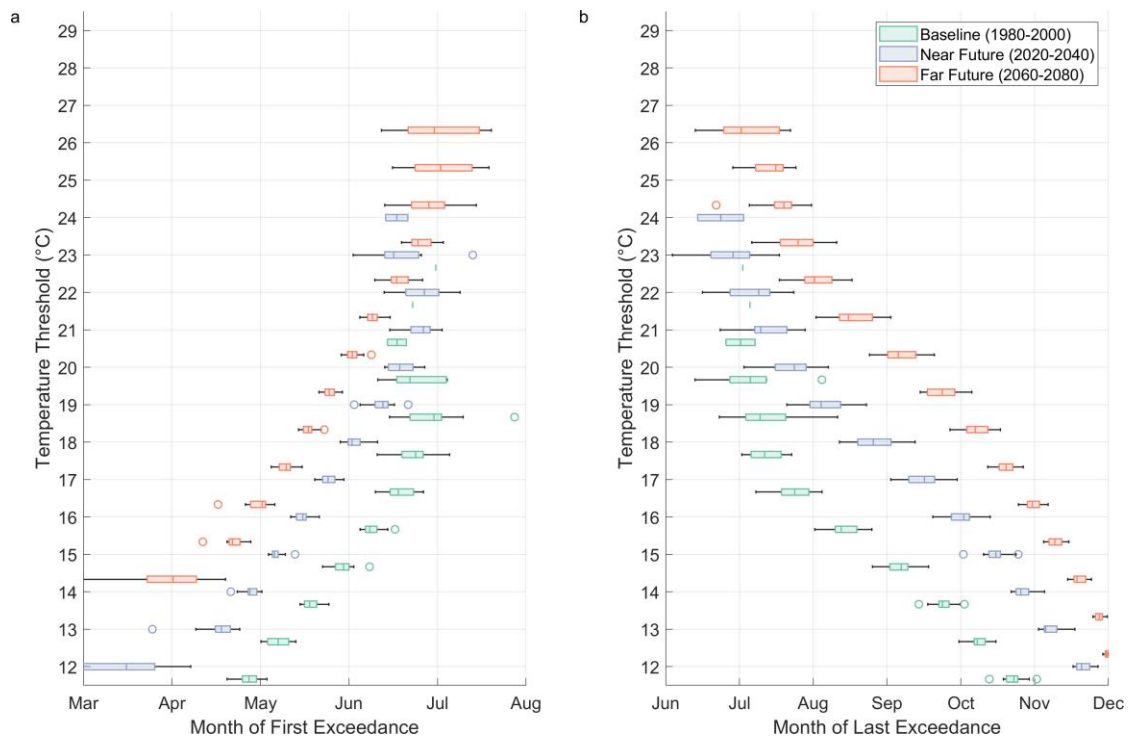


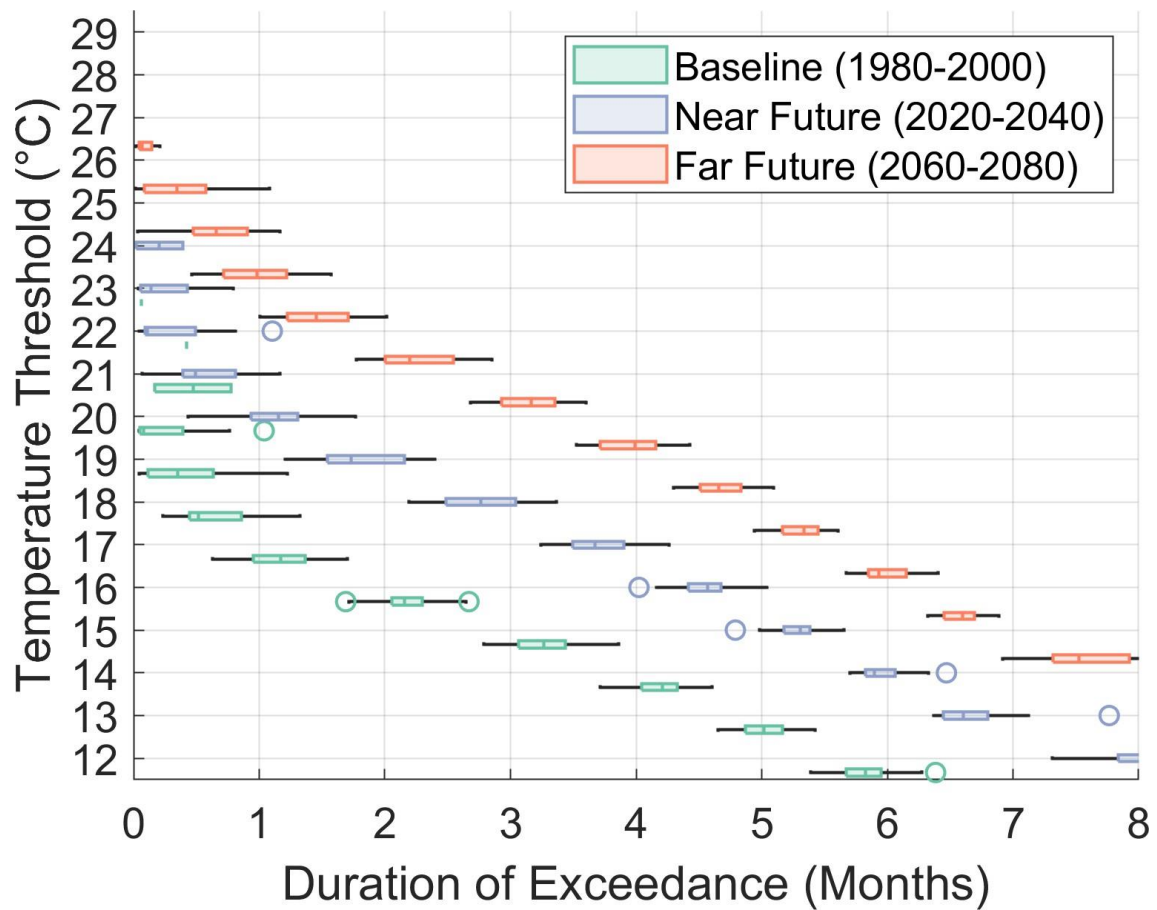
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

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Projected temperature changes under different climate scenarios. Box and whisker plots show the range of different modelled durations of temperatures under the 12 different UKCP 18 ensemble members. Open circles indicate outlier values.

Section 2 - Sea surface salinity changes

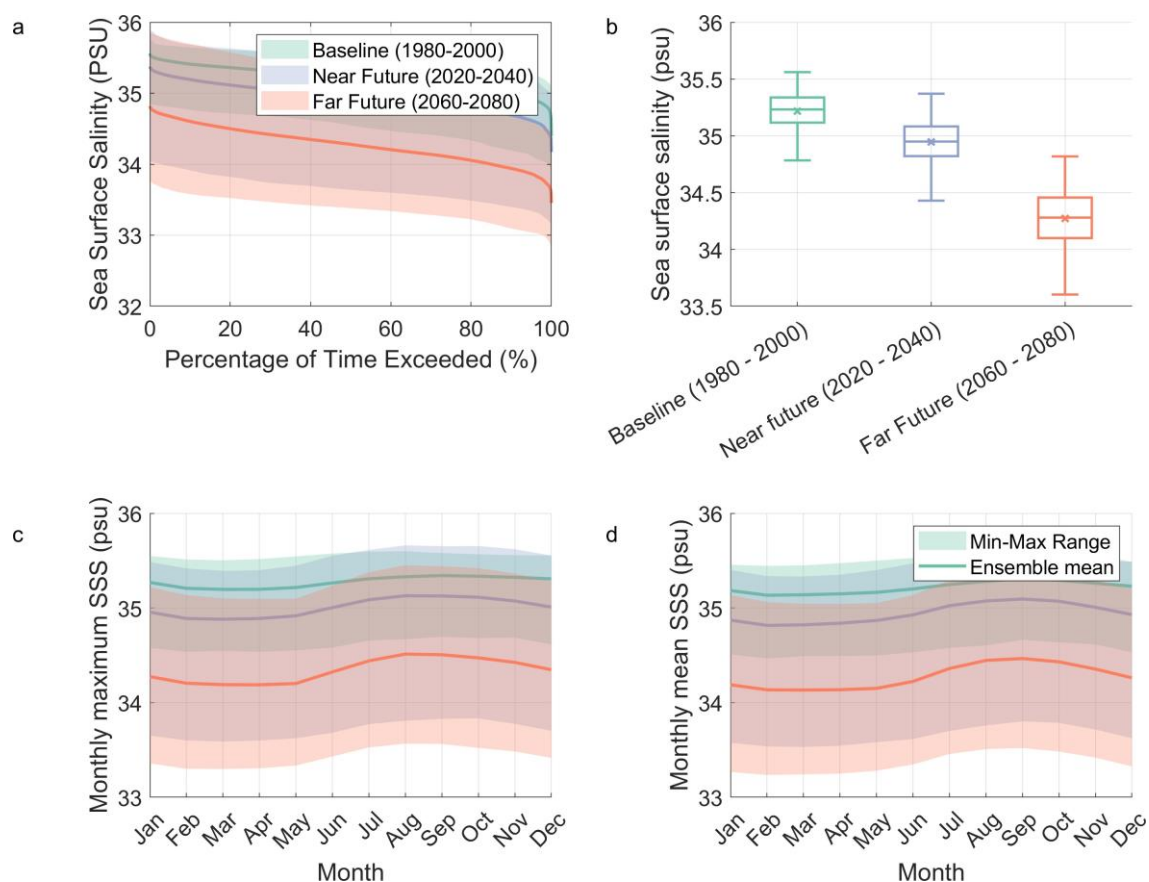


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
- (b) Percentile shifts show decreasing mean, median, and extremes, indicating a trend towards freshening over time.
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Section 3 - Residual surge changes

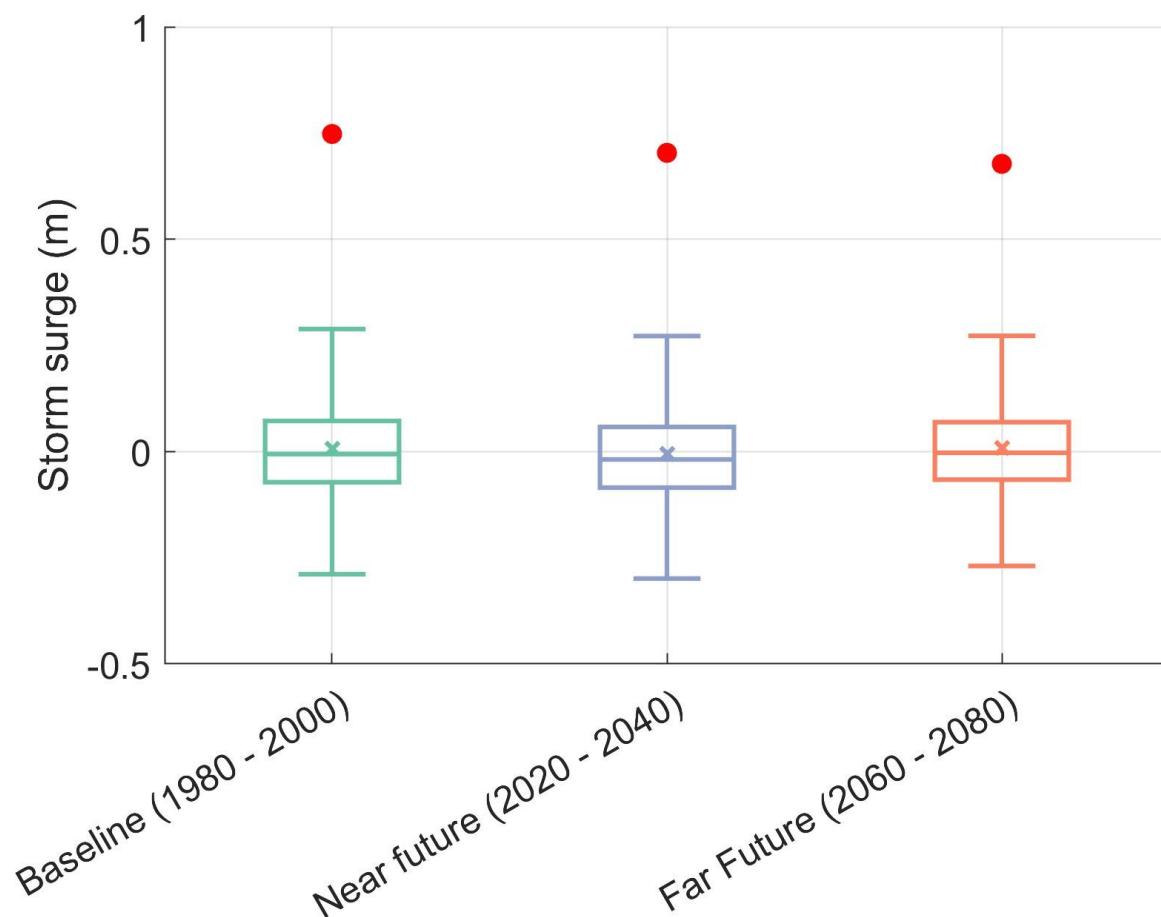


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

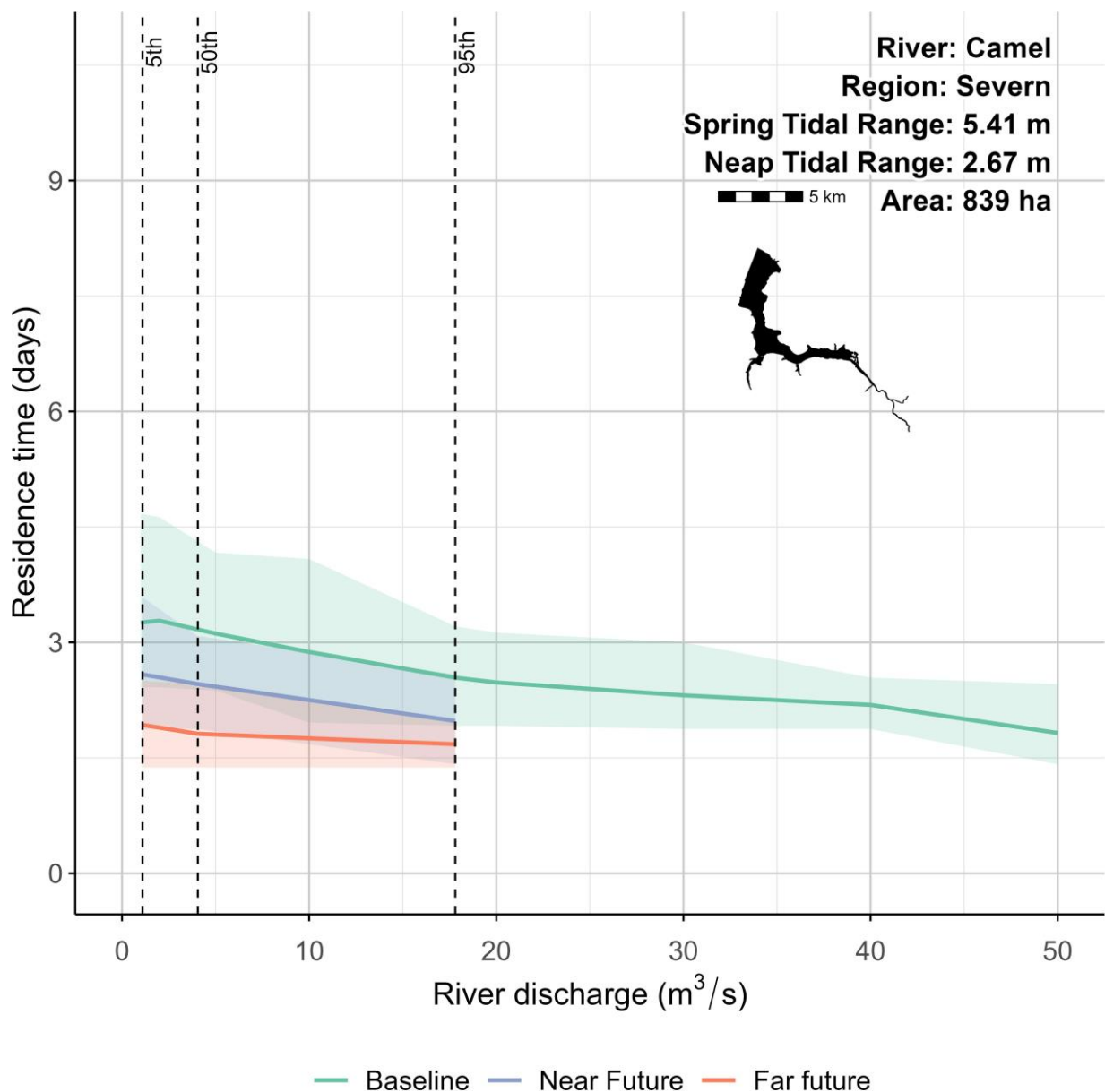


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Chichester

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	50.861
Longitude	-0.92855
Tidal Range	4.0 m
Gauge Name	Ems at Westbourne
Estuary Size	13200000.0 m ²
5th percentile flow	0.016 m ³ /s
50th percentile flow	0.21 m ³ /s
95th percentile flow	1.85 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

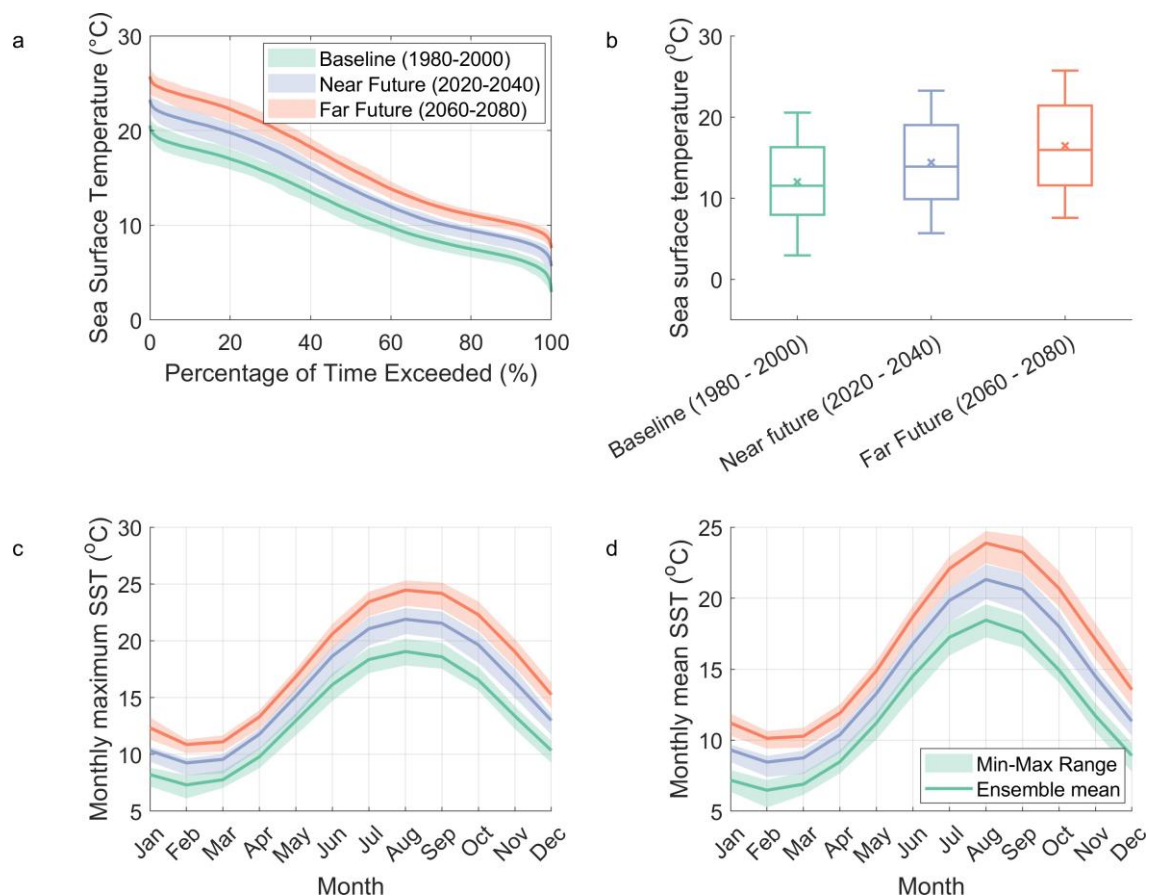
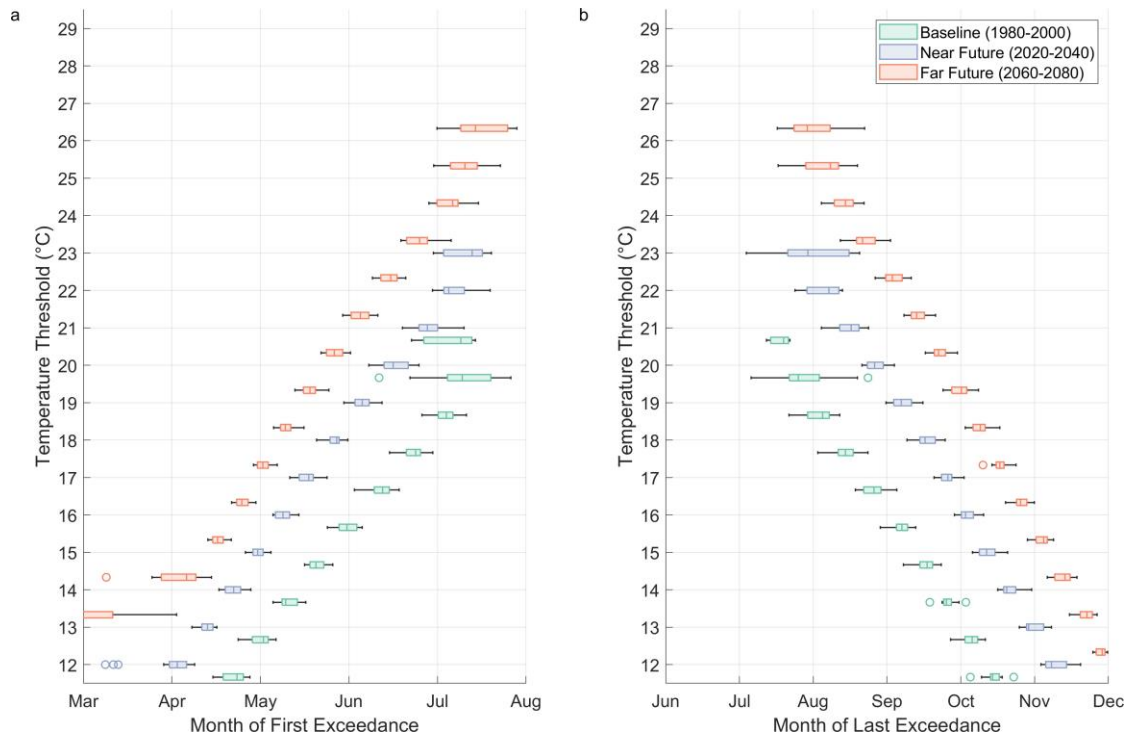


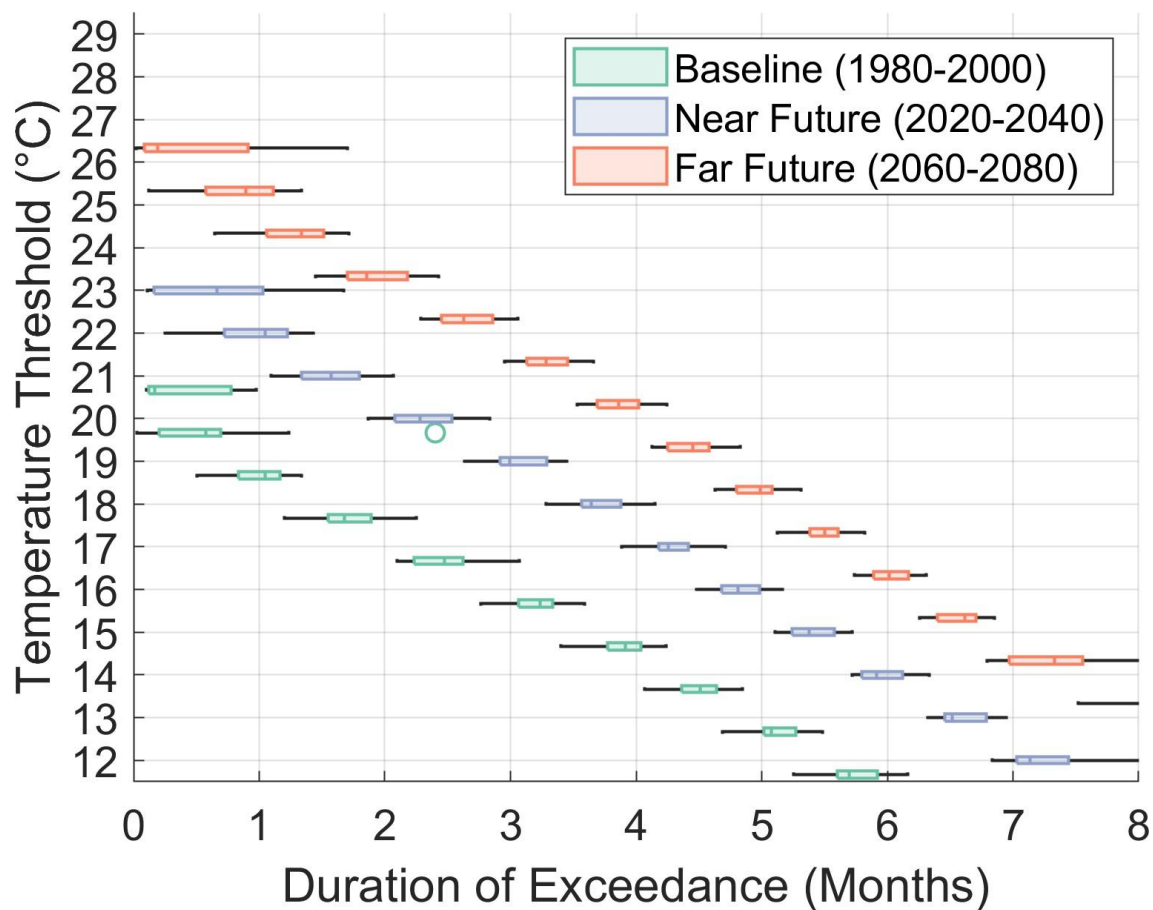
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

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Section 2 - Sea surface salinity changes

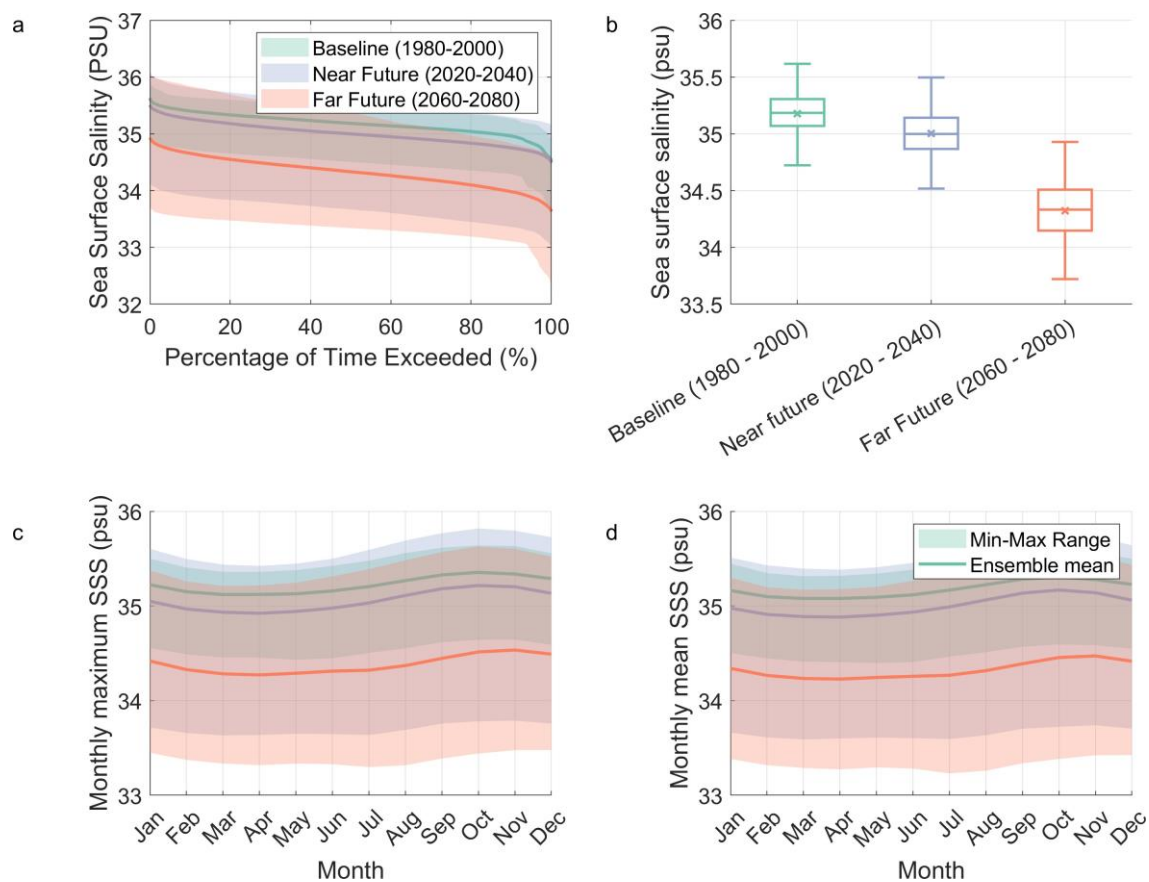


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
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- (d) Decreasing monthly means suggest long-term ice-melt driven freshening.

Section 3 - Residual surge changes

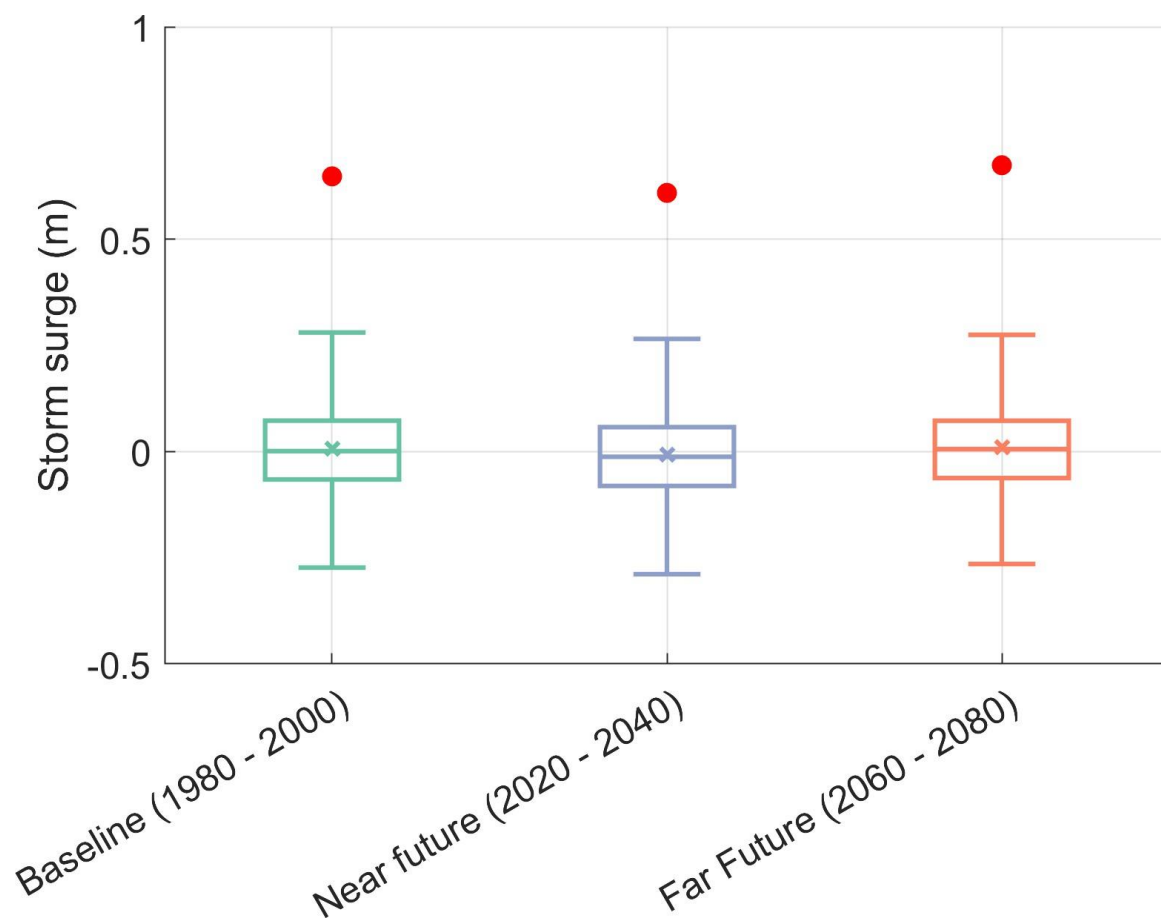


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

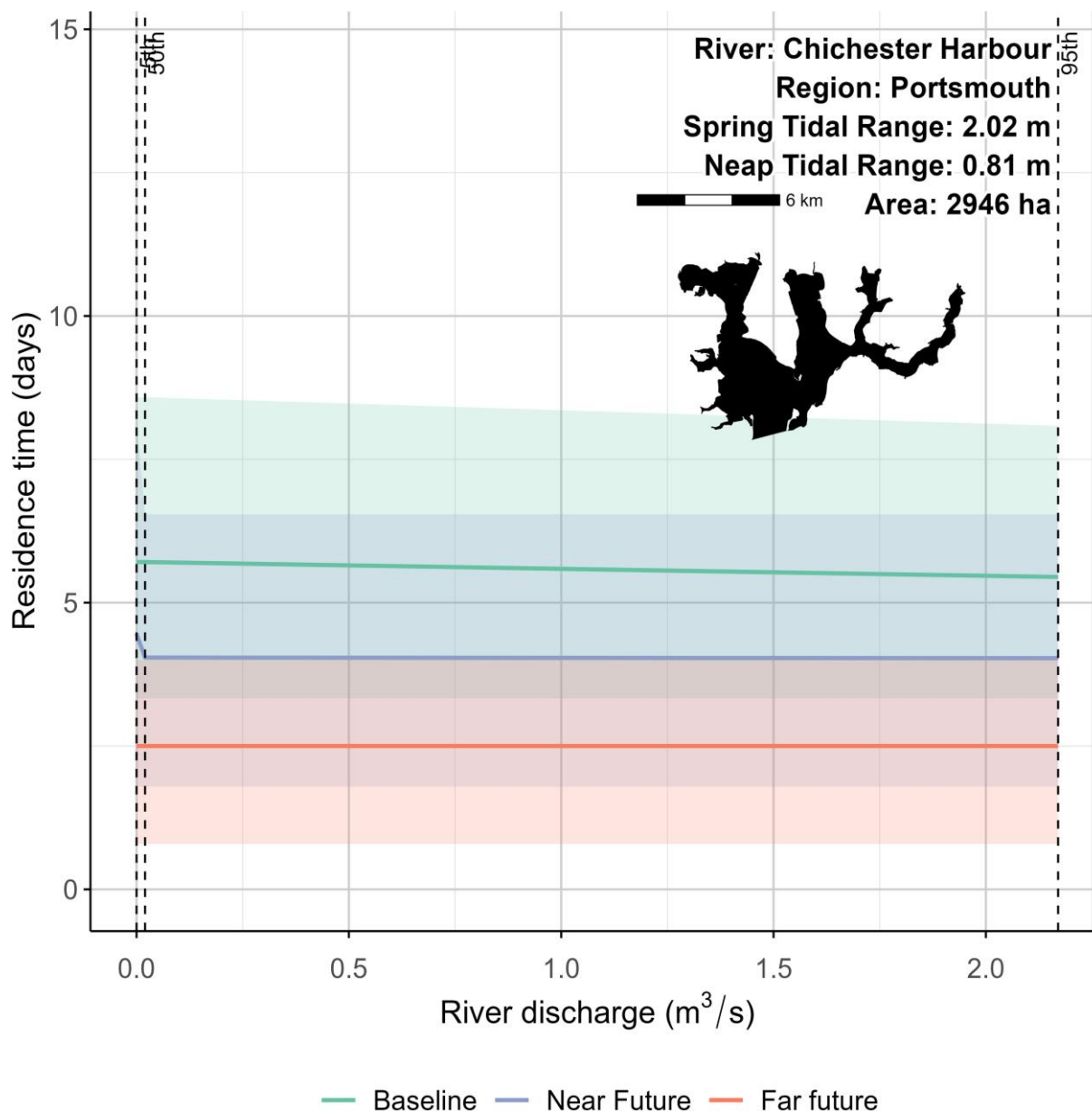


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Colne

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	51.809514
Longitude	0.994459
Tidal Range	4.6 m
Gauge Name	Lexden
Estuary Size	7870000.0 m ²
5th percentile flow	0.203 m ³ /s
50th percentile flow	0.563 m ³ /s
95th percentile flow	3.752 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

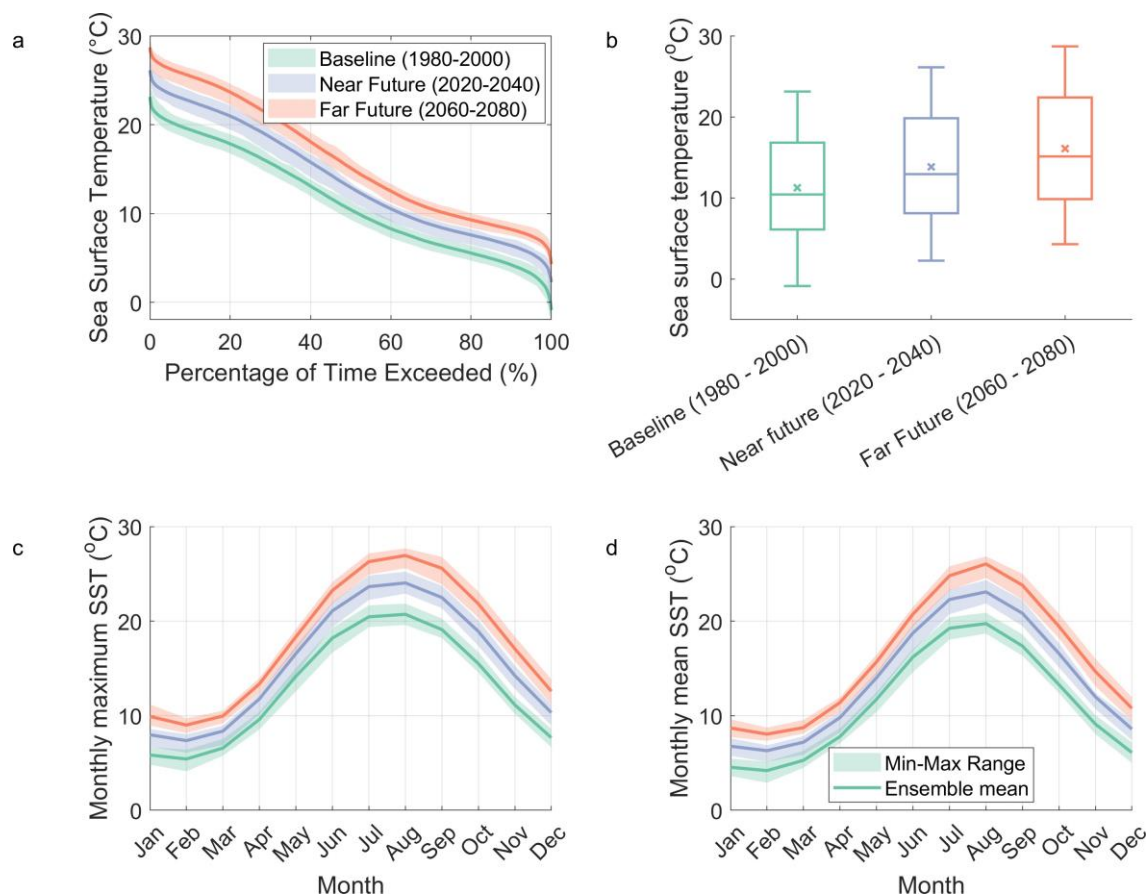
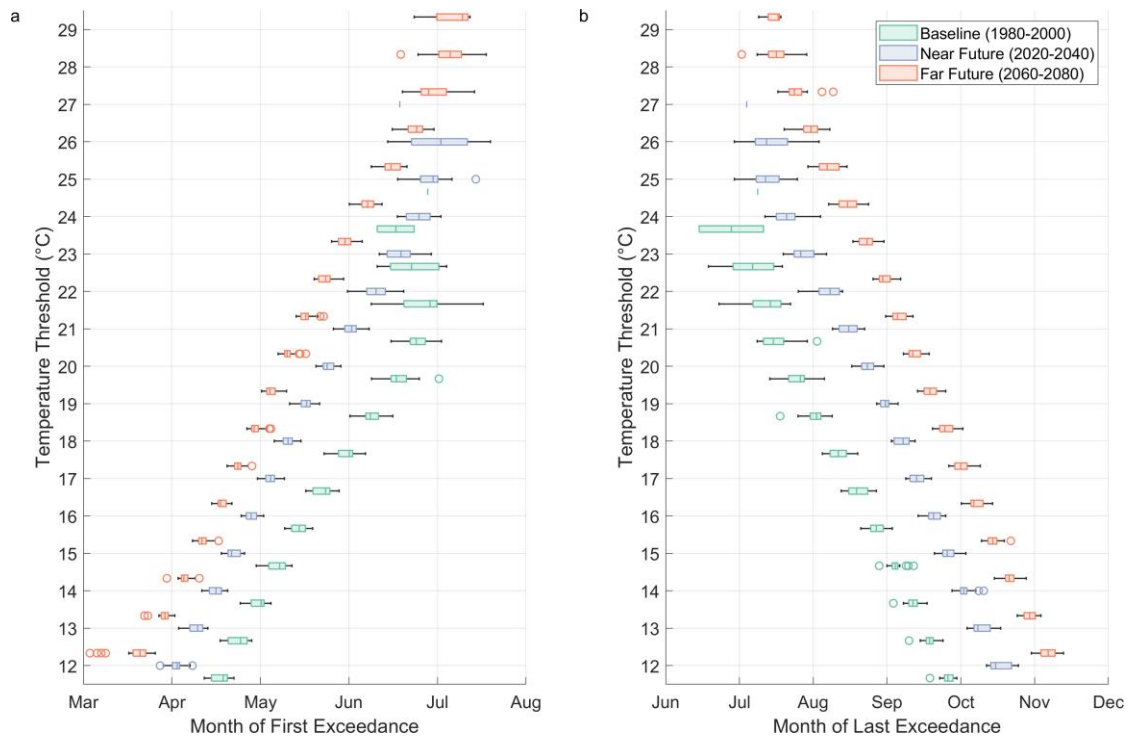


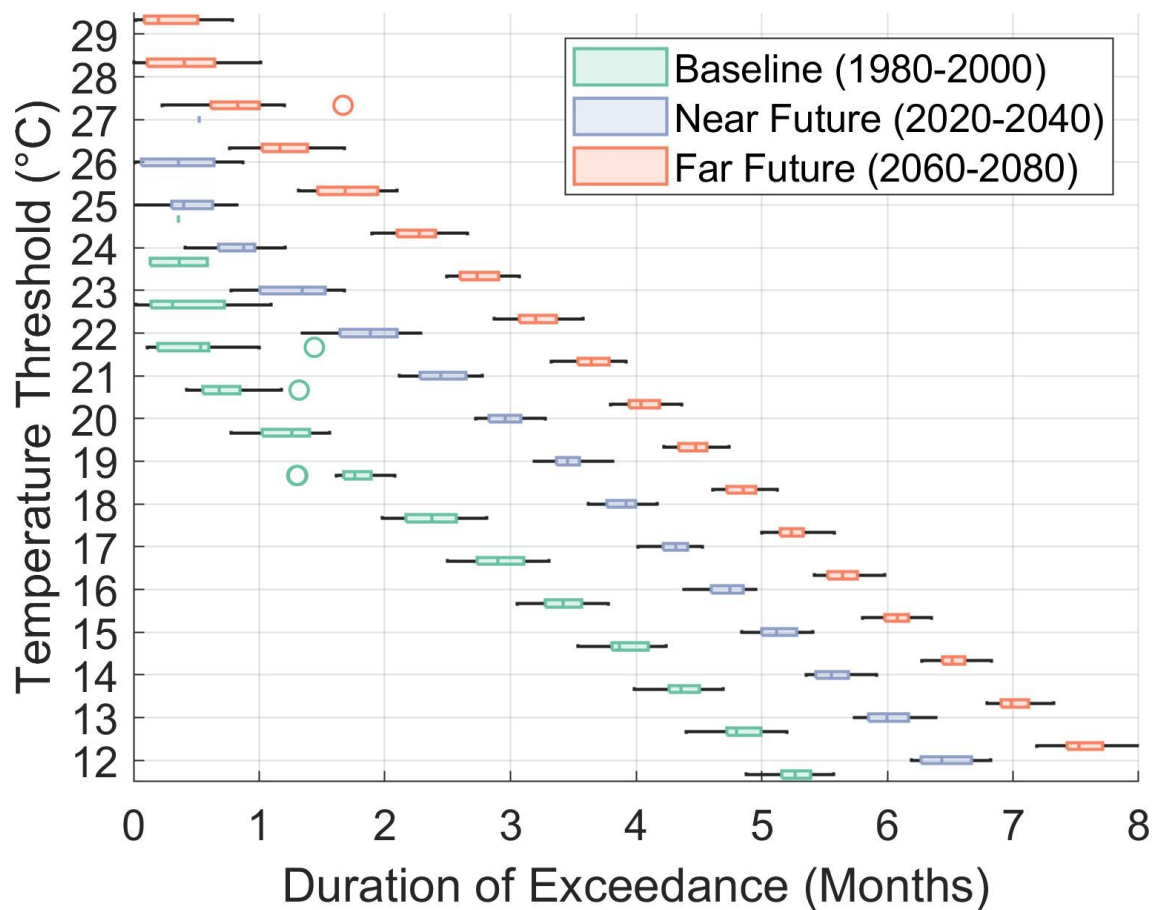
Figure description

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Section 2 - Sea surface salinity changes

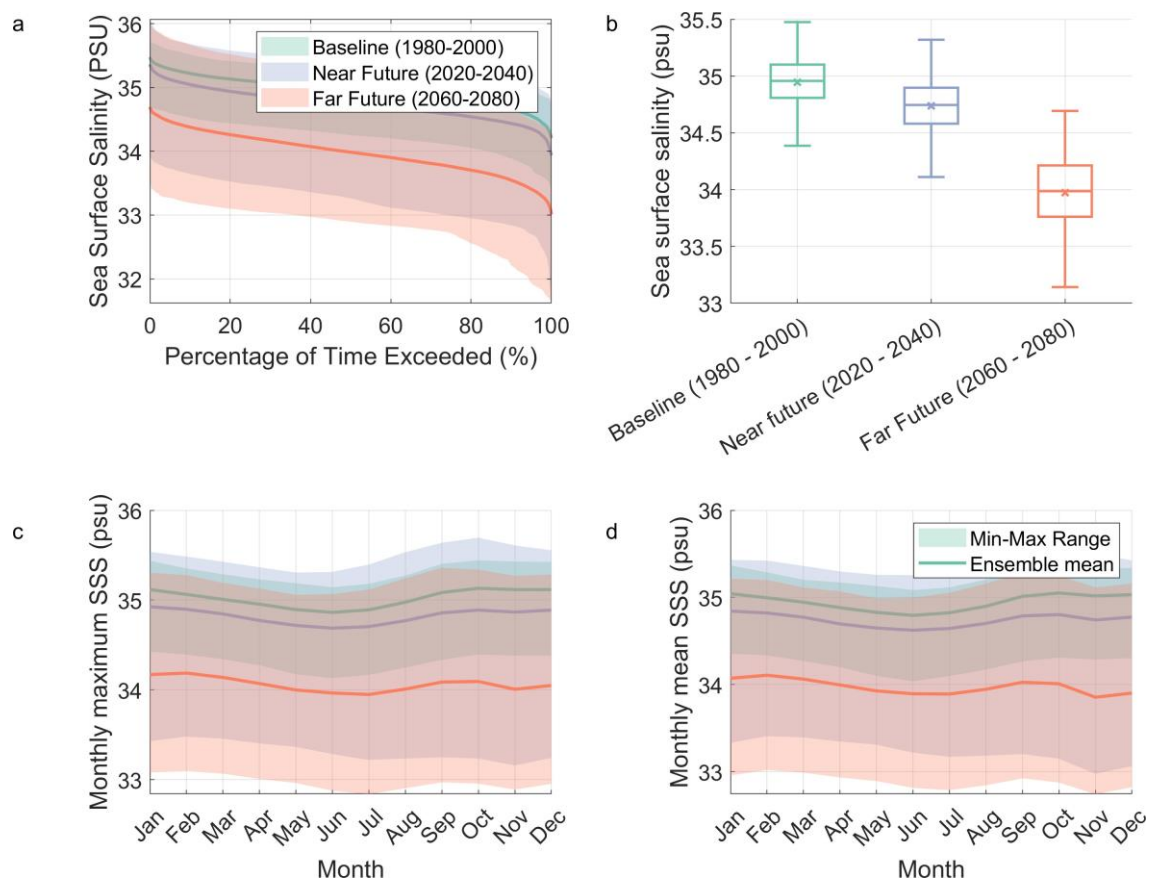


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
- (b) Percentile shifts show decreasing mean, median, and extremes, indicating a trend towards freshening over time.
- (c) Monthly maxima decrease across all months.
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Section 3 - Residual surge changes

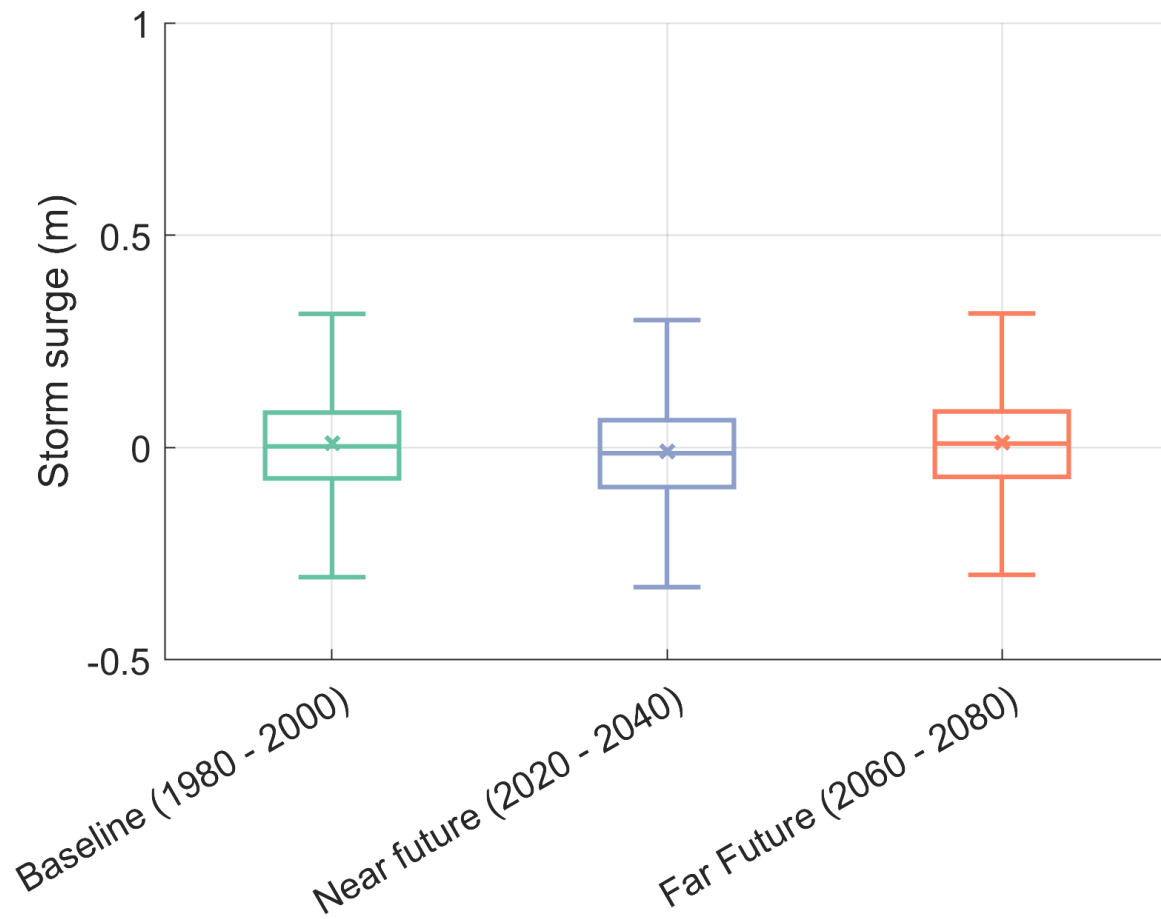


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - River discharge changes

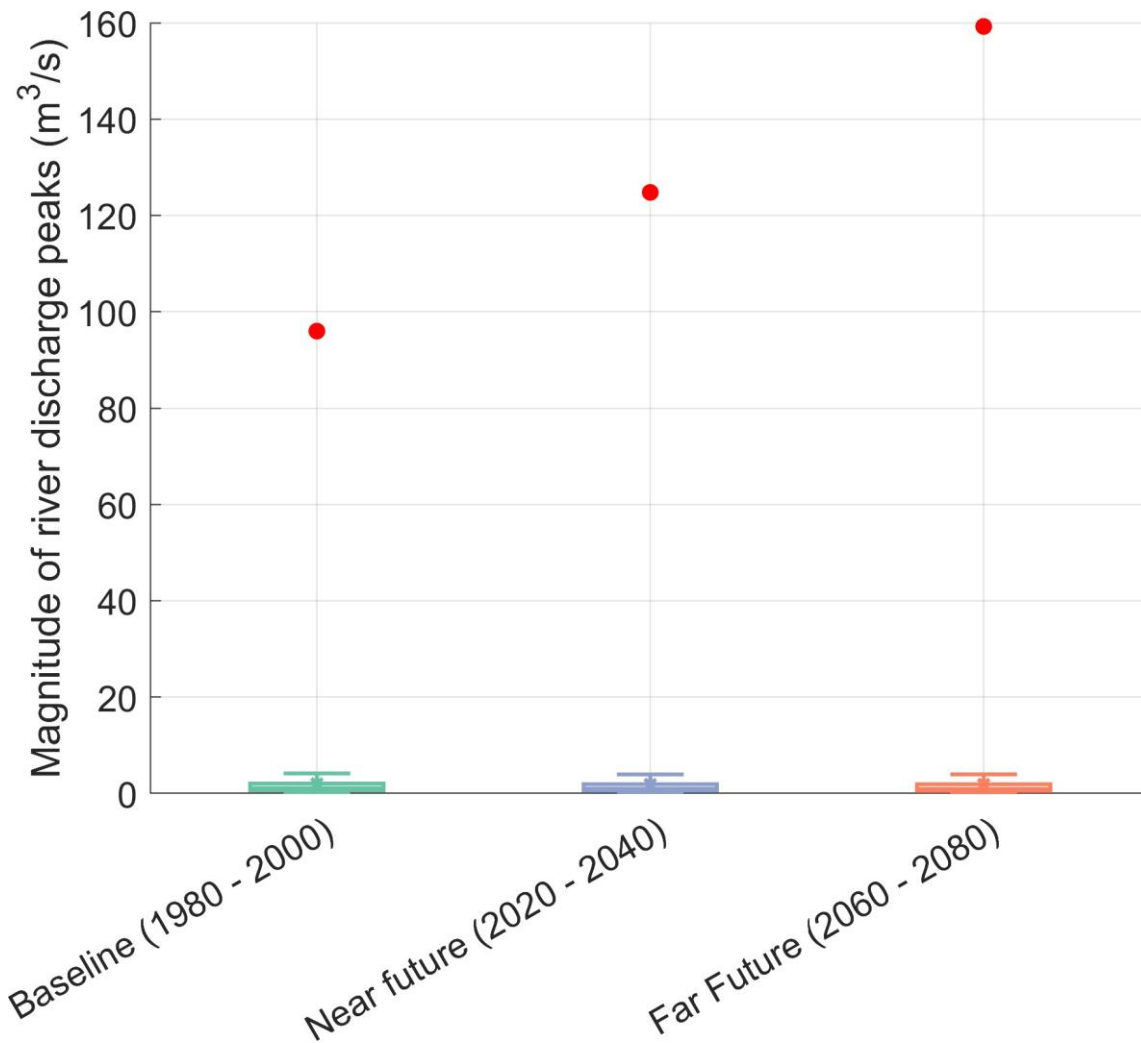


Figure description

Box and whisker plots of discharge percentiles under baseline (1980-2000), near-future (2020-2040) and far-future (2060-2080)

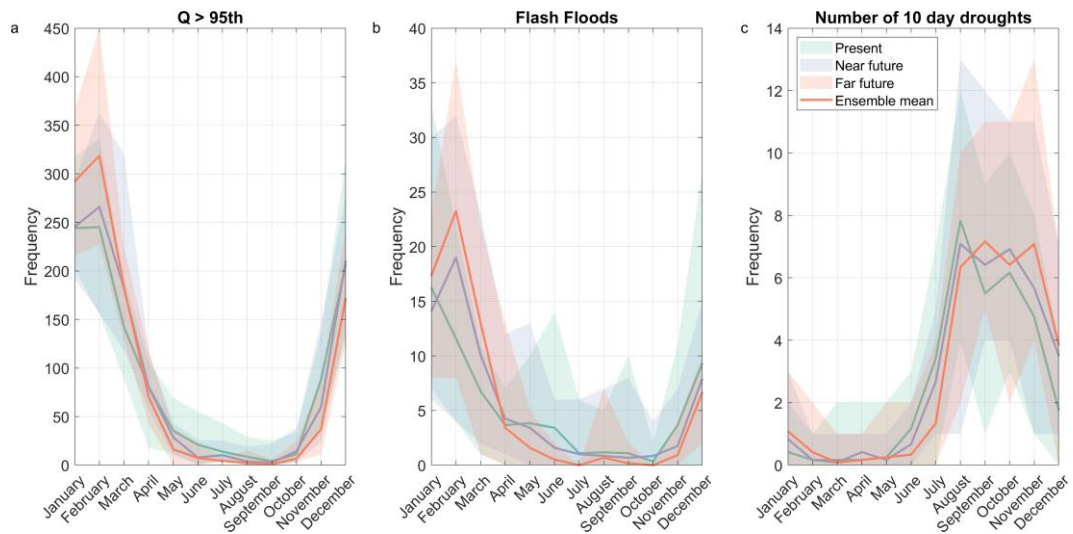


Figure description

Discharge conditions under baseline (1980-2000), near-future (2020-2040) and far-future (2060-2080) showing frequency of (a): Occurrence of high flow (>95th percentile events) per month (hourly resolution), (b): Flash flood events (increase in discharge of >50 m³/s, (c): low flow events lasting longer than 10 days).

Section 5 - Residence times changes

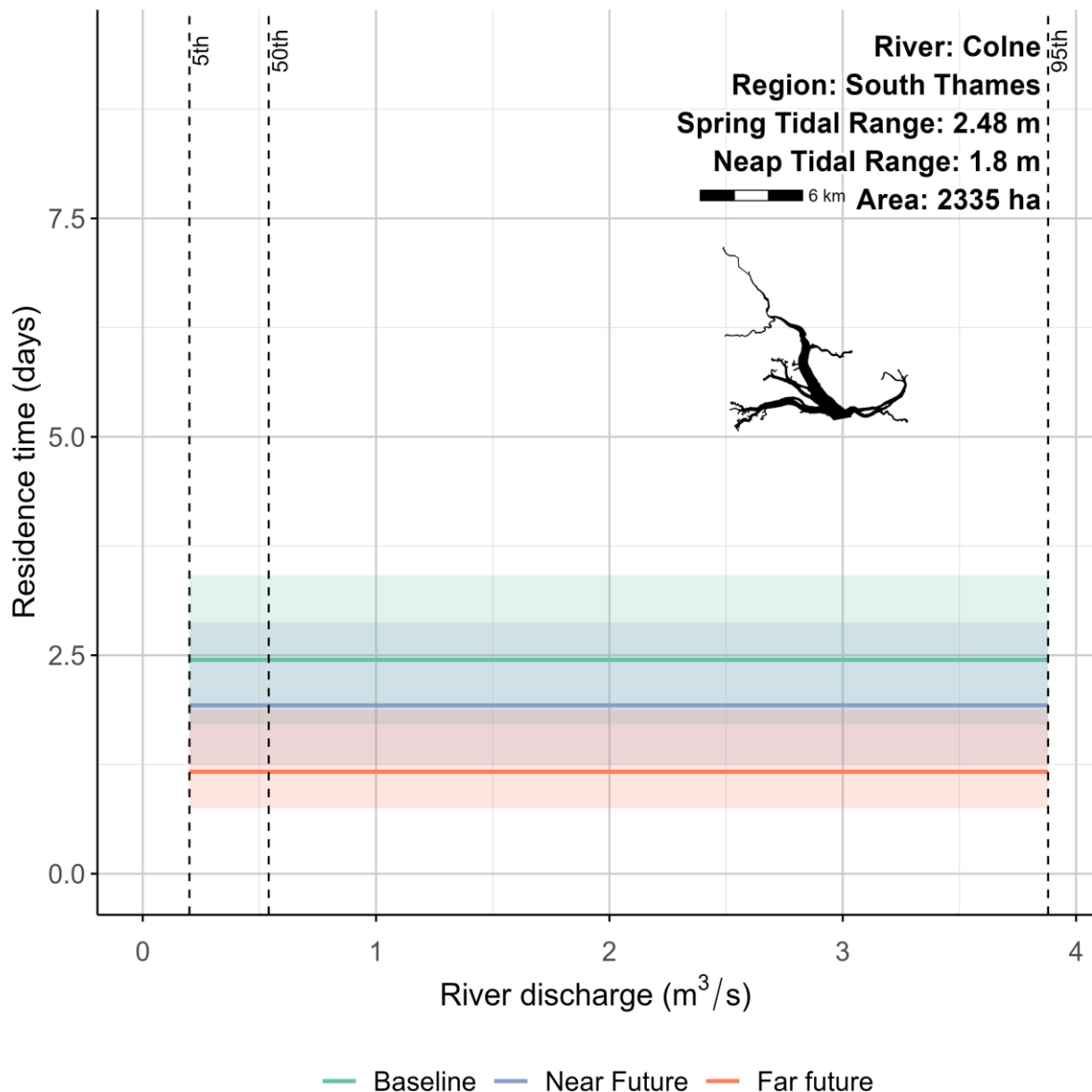


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)
Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Coquet

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	53.33361
Longitude	-1.63206
Tidal Range	4.2 m
Gauge Name	Coquet at Morwick
Estuary Size	335000.0 m ²
5th percentile flow	1.32 m ³ /s
50th percentile flow	4.67 m ³ /s
95th percentile flow	29.7 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

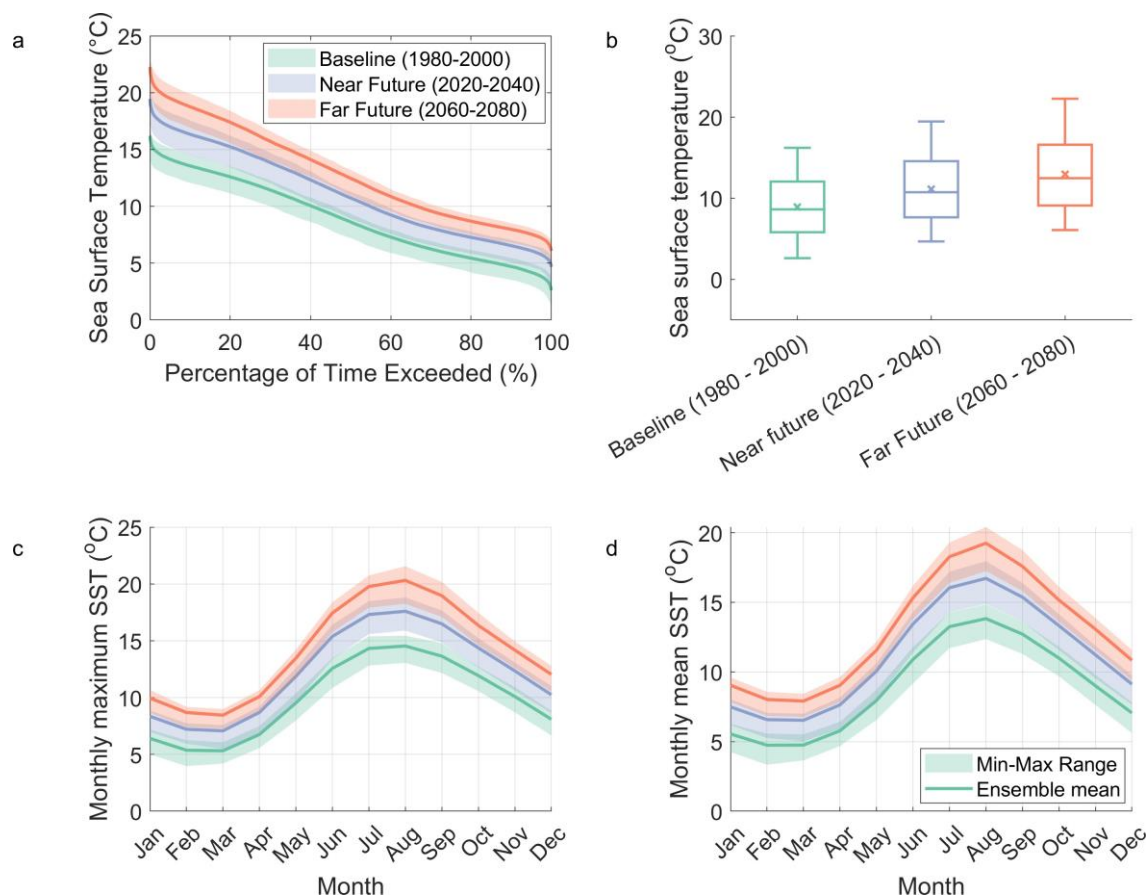
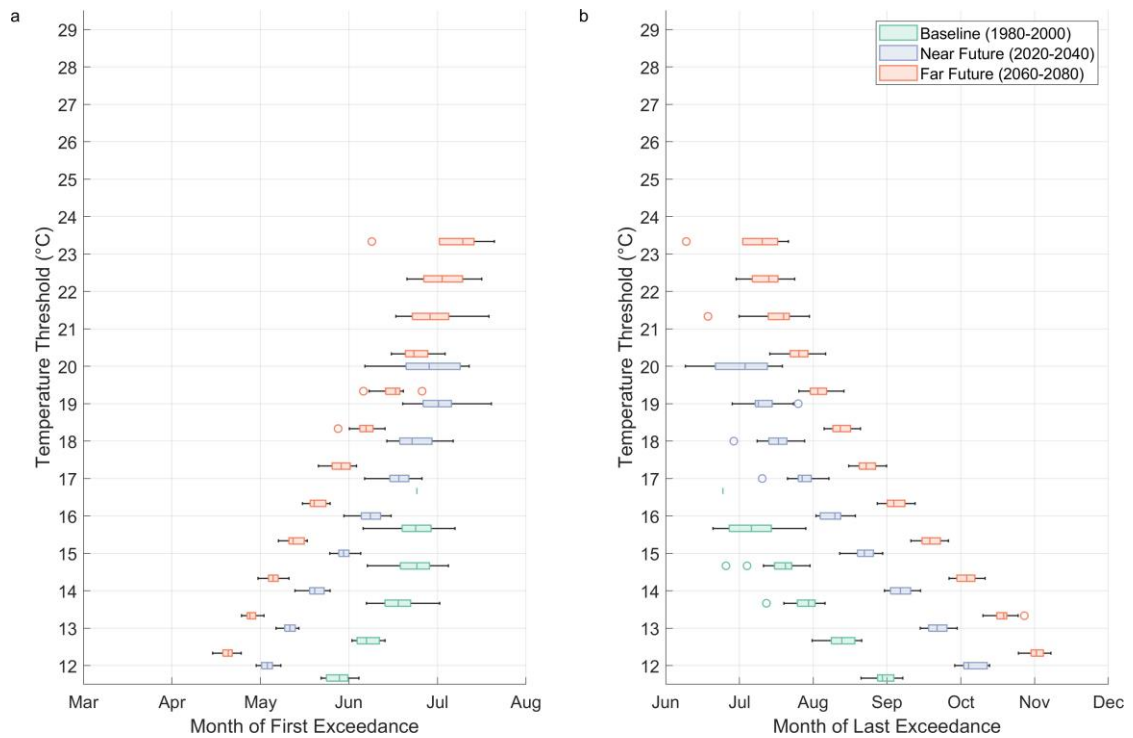


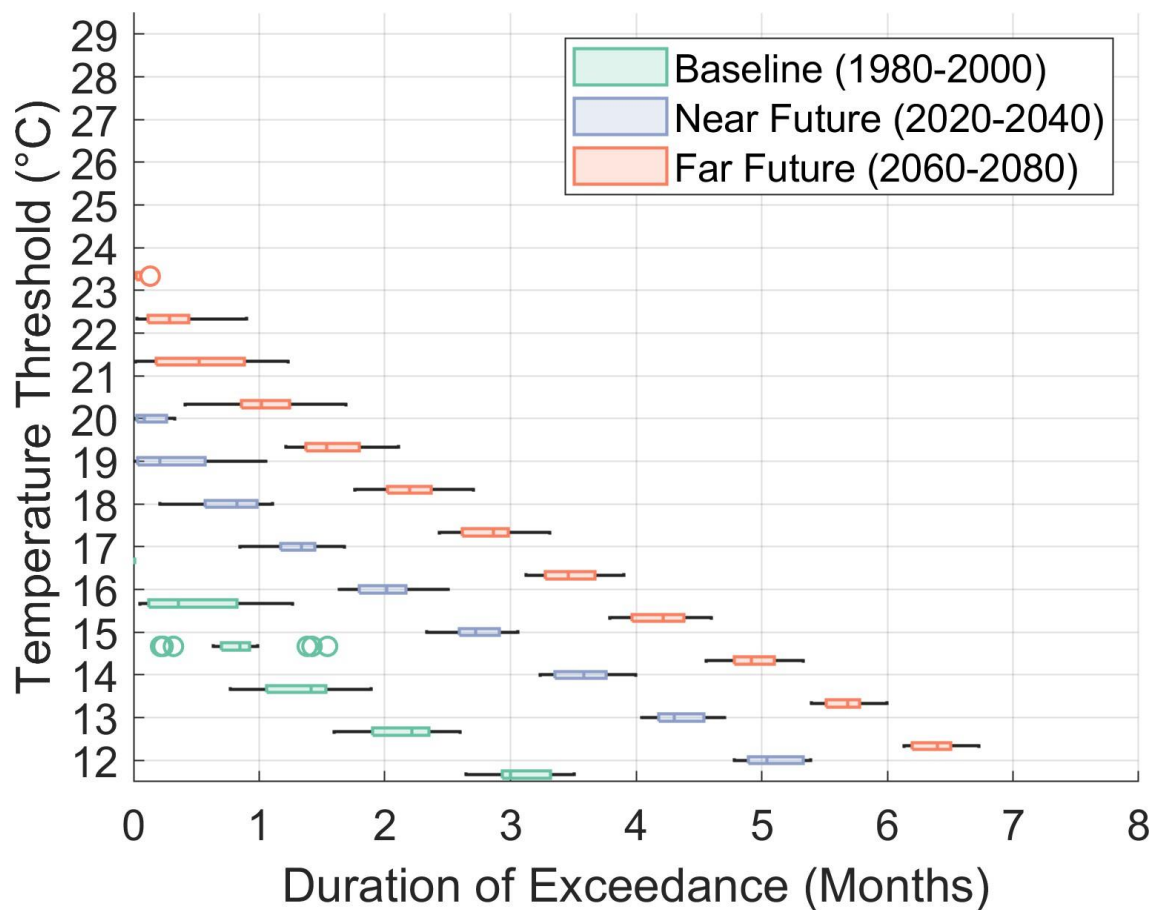
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

- (a) Temperature duration curves represent distribution of SSTs over time to highlight changes in cold and warm extremes.
- (b) Percentile shifts show increasing mean, median, and extremes, indicating prolonged warming over time.
- (c) Rising monthly maximum in every month of the year highlights likelihood of intensified high heat events.
- (d) Rising monthly mean suggests long-term climate-driven warming.



Changes in first and last occurrences of temperature thresholds compared to historical data. Note that these plots are not intended to identify the specific date on which a temperature may occur, rather they indicate the trend in the onset of specific temperature thresholds.



Projected temperature changes under different climate scenarios. Box and whisker plots show the range of different modelled durations of temperatures under the 12 different UKCP 18 ensemble members. Open circles indicate outlier values.

Section 2 - Sea surface salinity changes

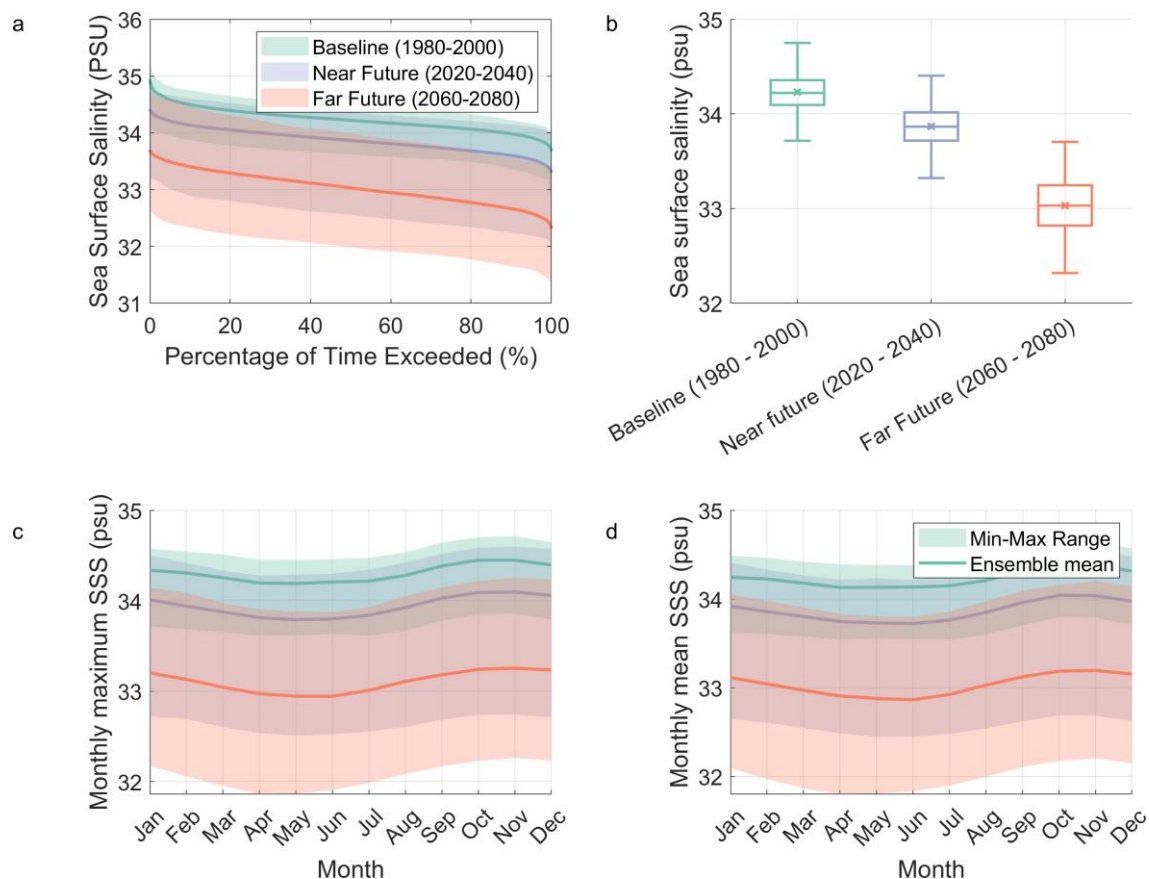


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
- (b) Percentile shifts show decreasing mean, median, and extremes, indicating a trend towards freshening over time.
- (c) Monthly maxima decrease across all months.
- (d) Decreasing monthly means suggest long-term ice-melt driven freshening.

Section 3 - Residual surge changes

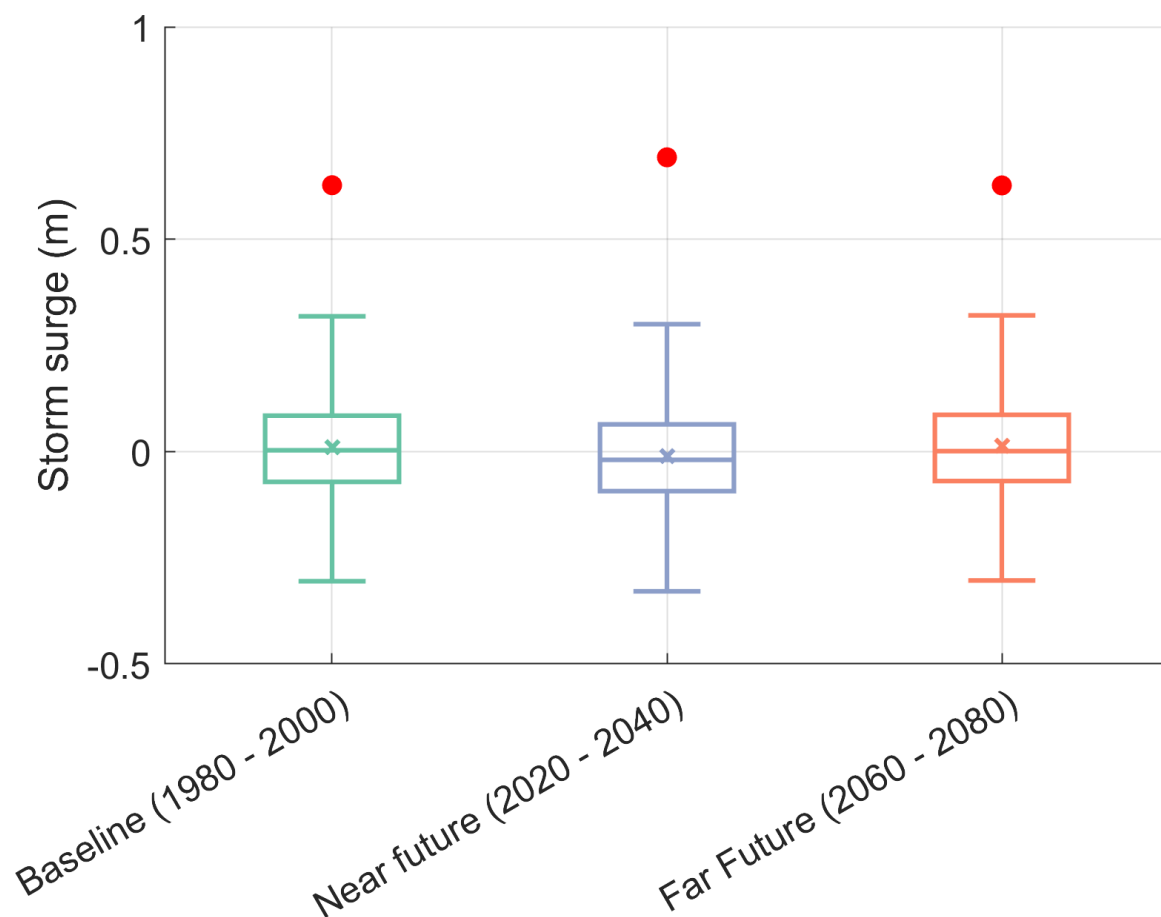


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

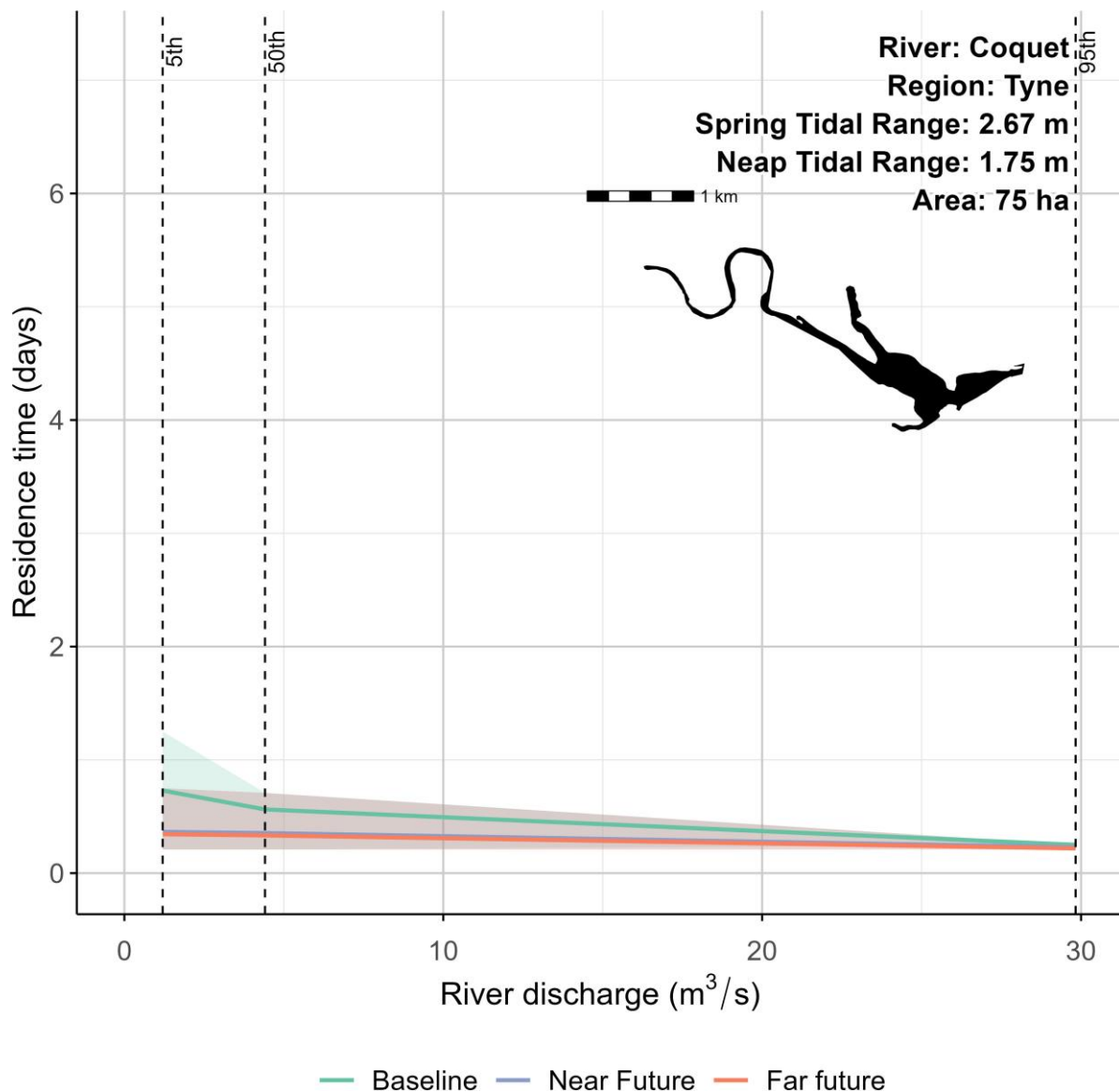


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)
Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Crouch

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	51.618373
Longitude	0.871307
Tidal Range	5.0 m
Gauge Name	Wickford
Estuary Size	21000000.0 m ²
5th percentile flow	0.043 m ³ /s
50th percentile flow	0.125 m ³ /s
95th percentile flow	1.36 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

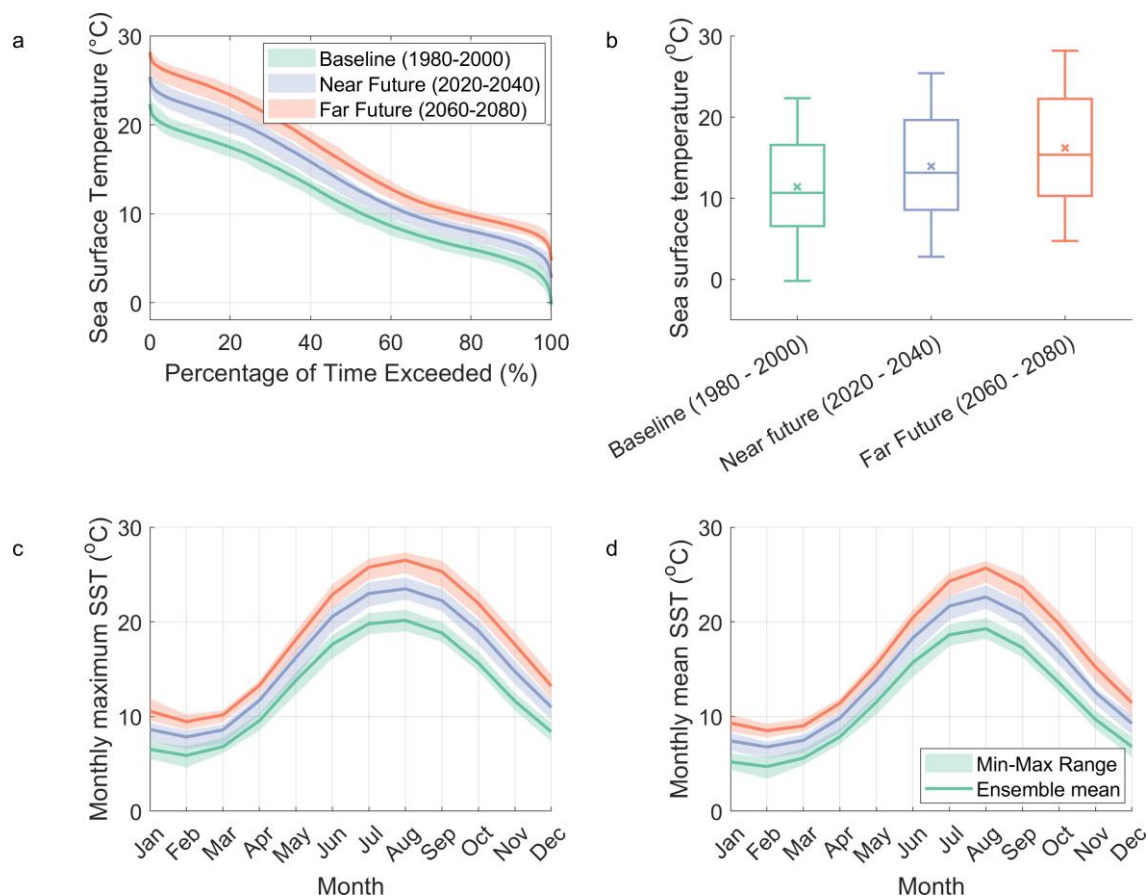
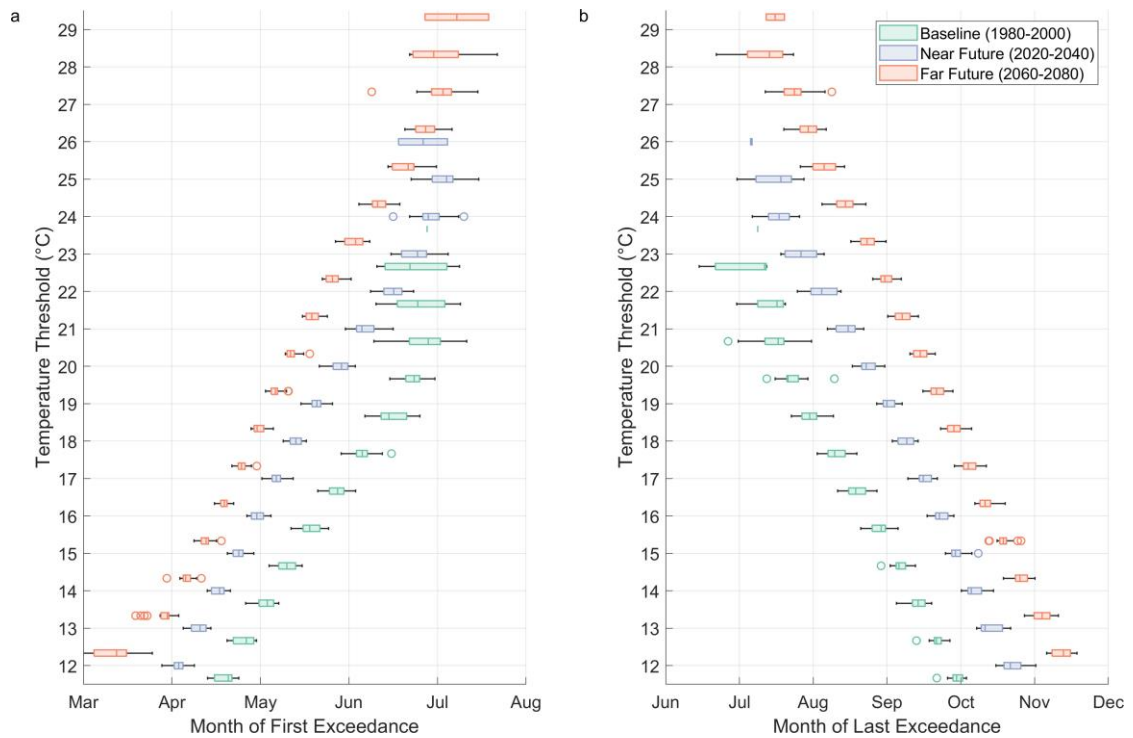


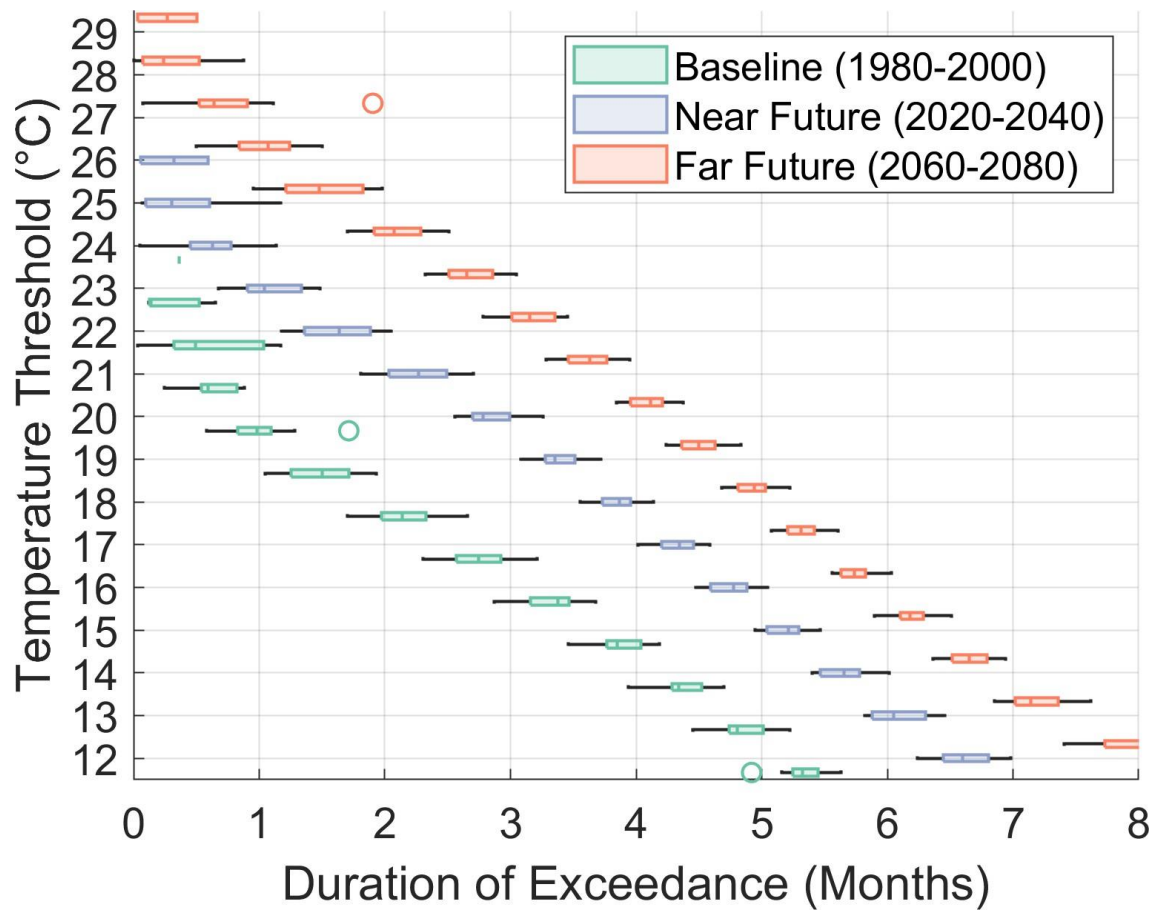
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

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Projected temperature changes under different climate scenarios. Box and whisker plots show the range of different modelled durations of temperatures under the 12 different UKCP 18 ensemble members. Open circles indicate outlier values.

Section 2 - Sea surface salinity changes

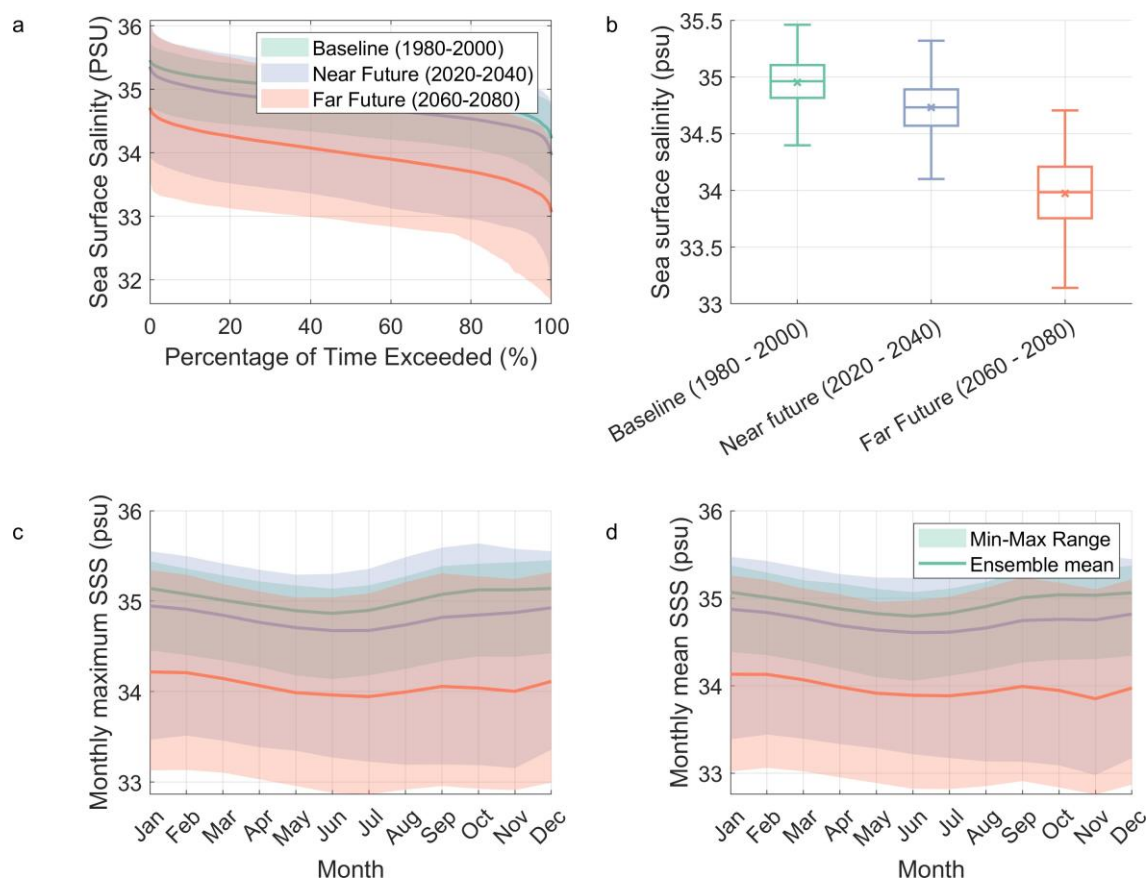


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
- (b) Percentile shifts show decreasing mean, median, and extremes, indicating a trend towards freshening over time.
- (c) Monthly maxima decrease across all months.
- (d) Decreasing monthly means suggest long-term ice-melt driven freshening.

Section 3 - Residual surge changes

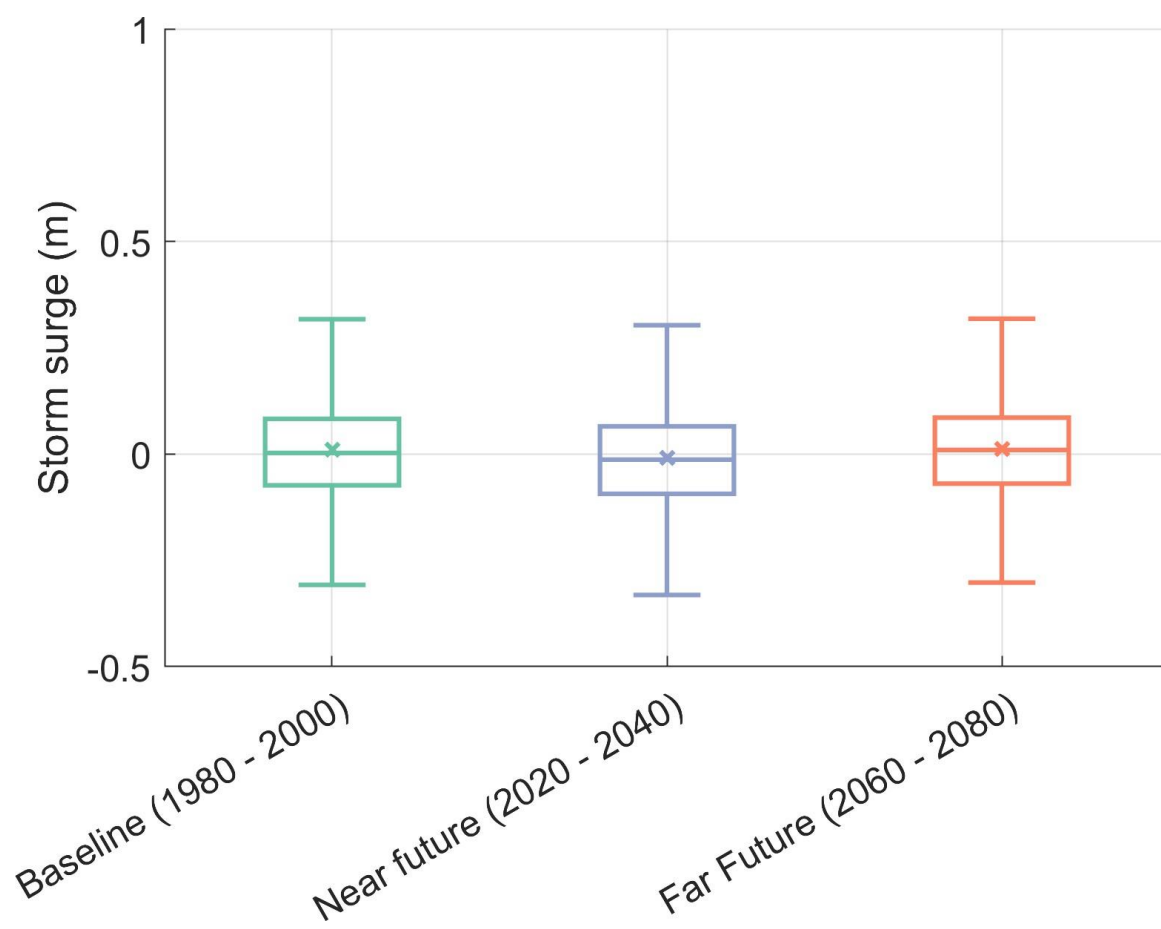


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

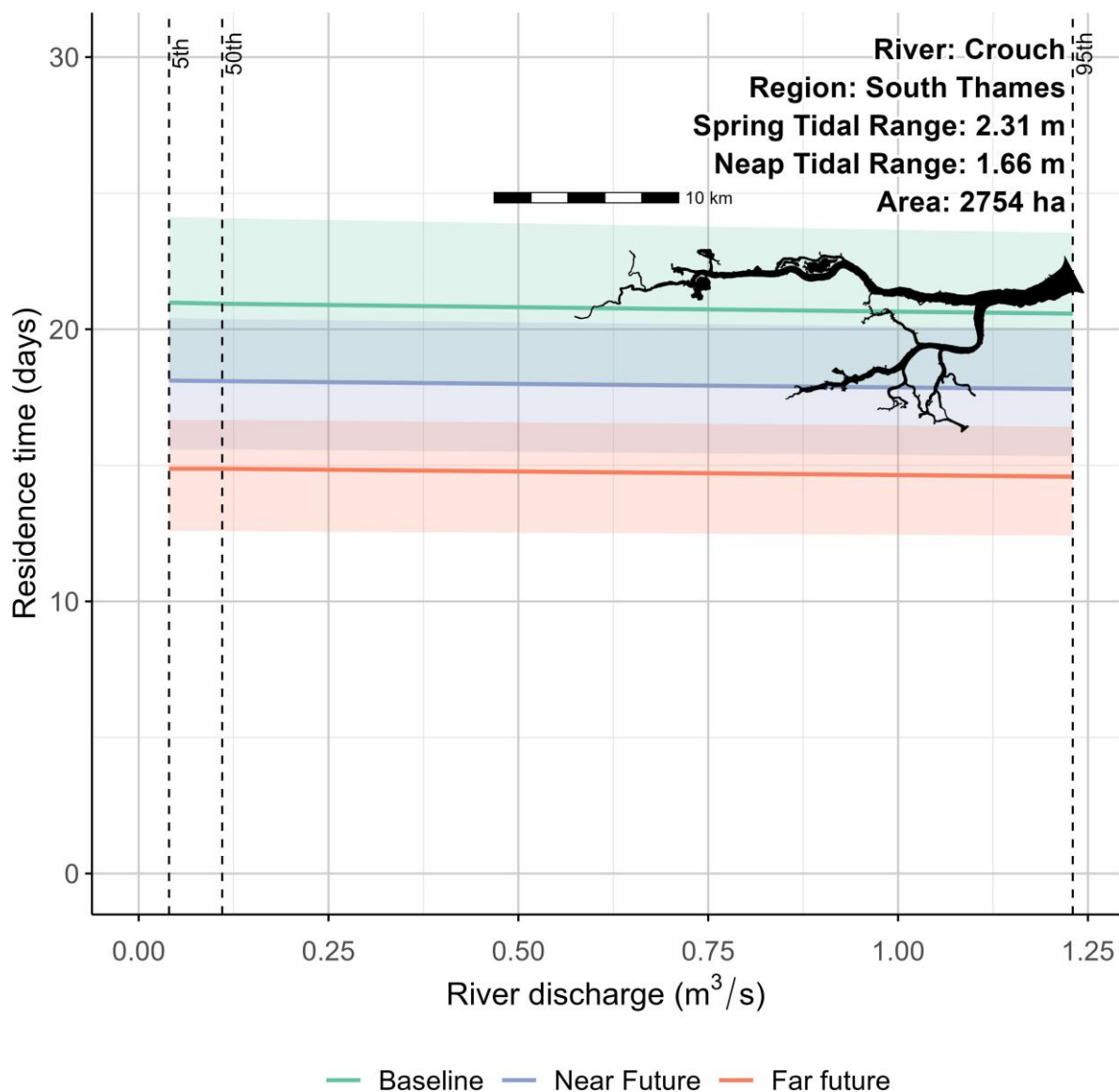


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Cuckmere

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	50.82561
Longitude	-0.17508
Tidal Range	6.0 m
Gauge Name	Cuckmere at Sherman Bridge
Estuary Size	222000.0 m ²
5th percentile flow	0.074 m ³ /s
50th percentile flow	0.339 m ³ /s
95th percentile flow	6.01 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

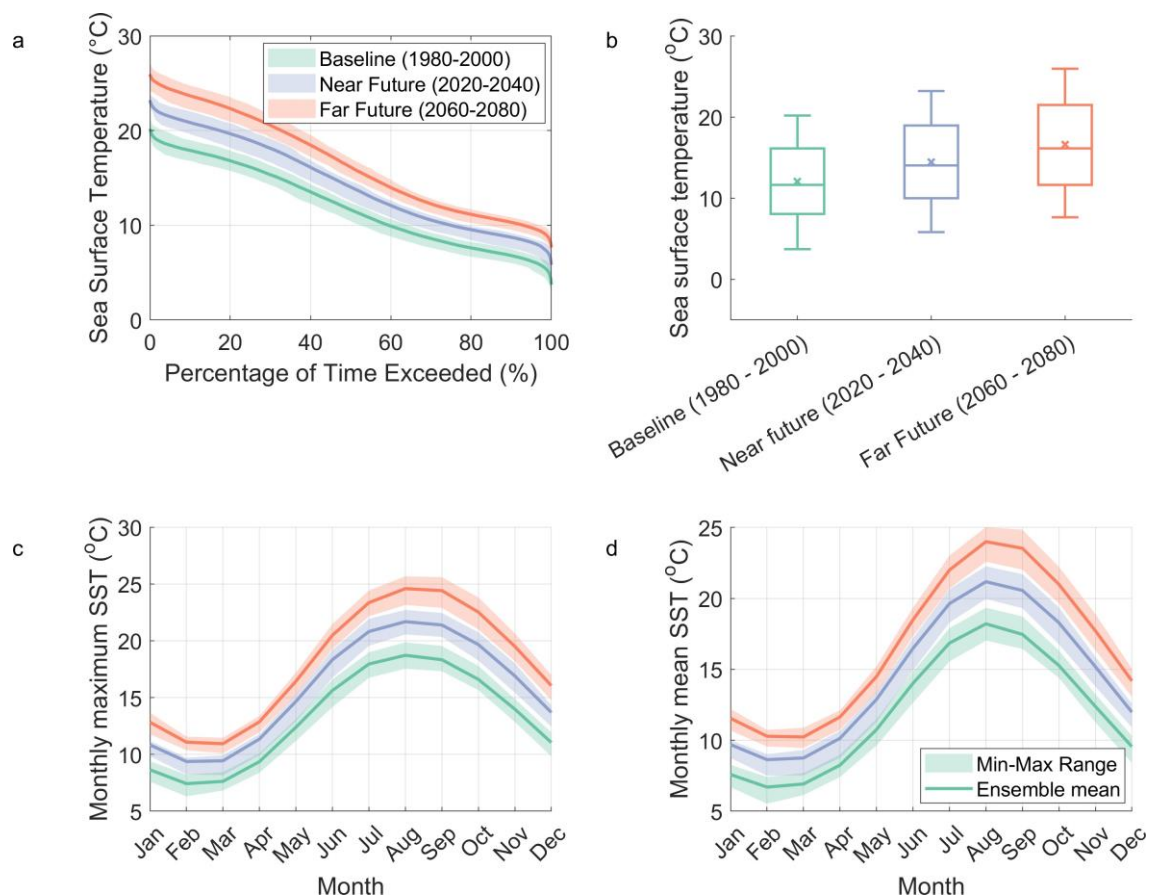
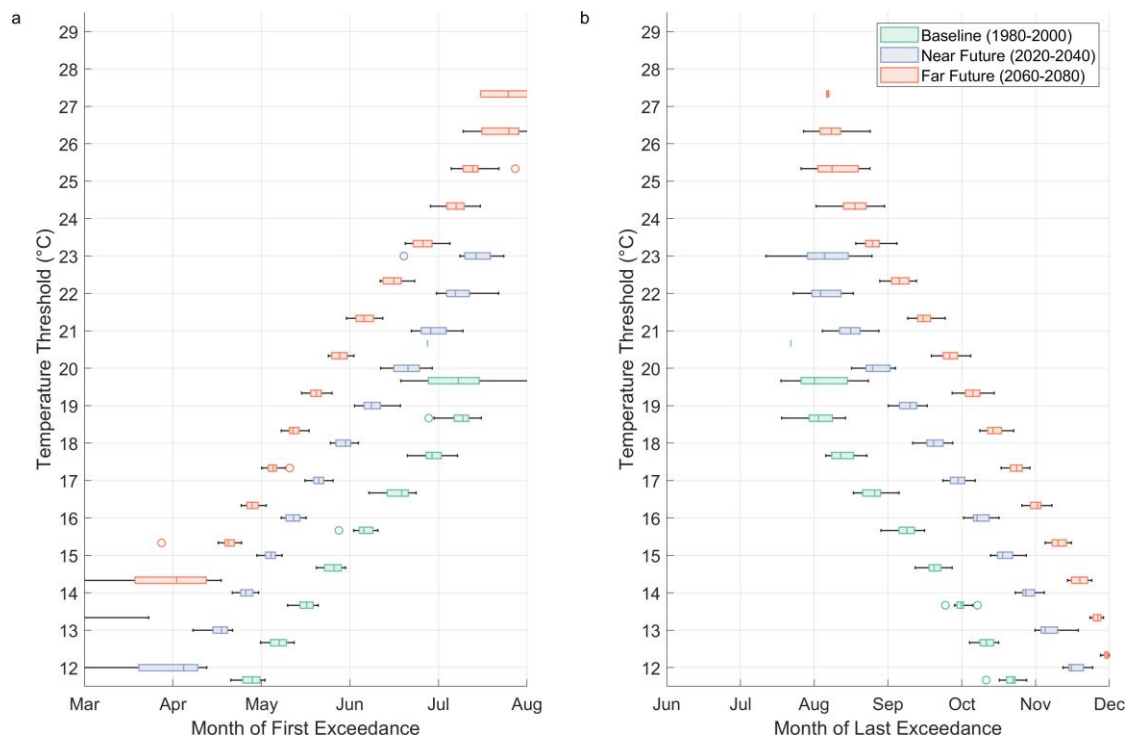


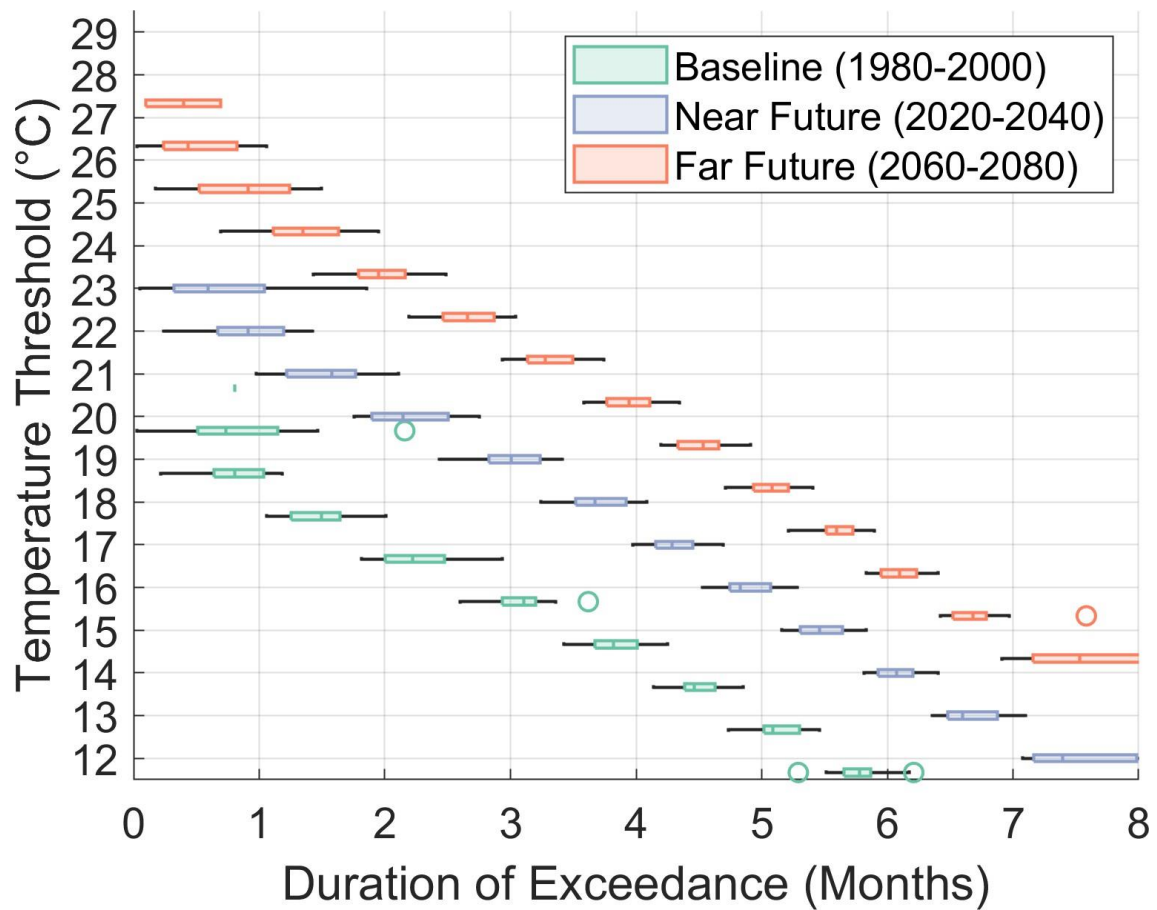
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

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Section 2 - Sea surface salinity changes

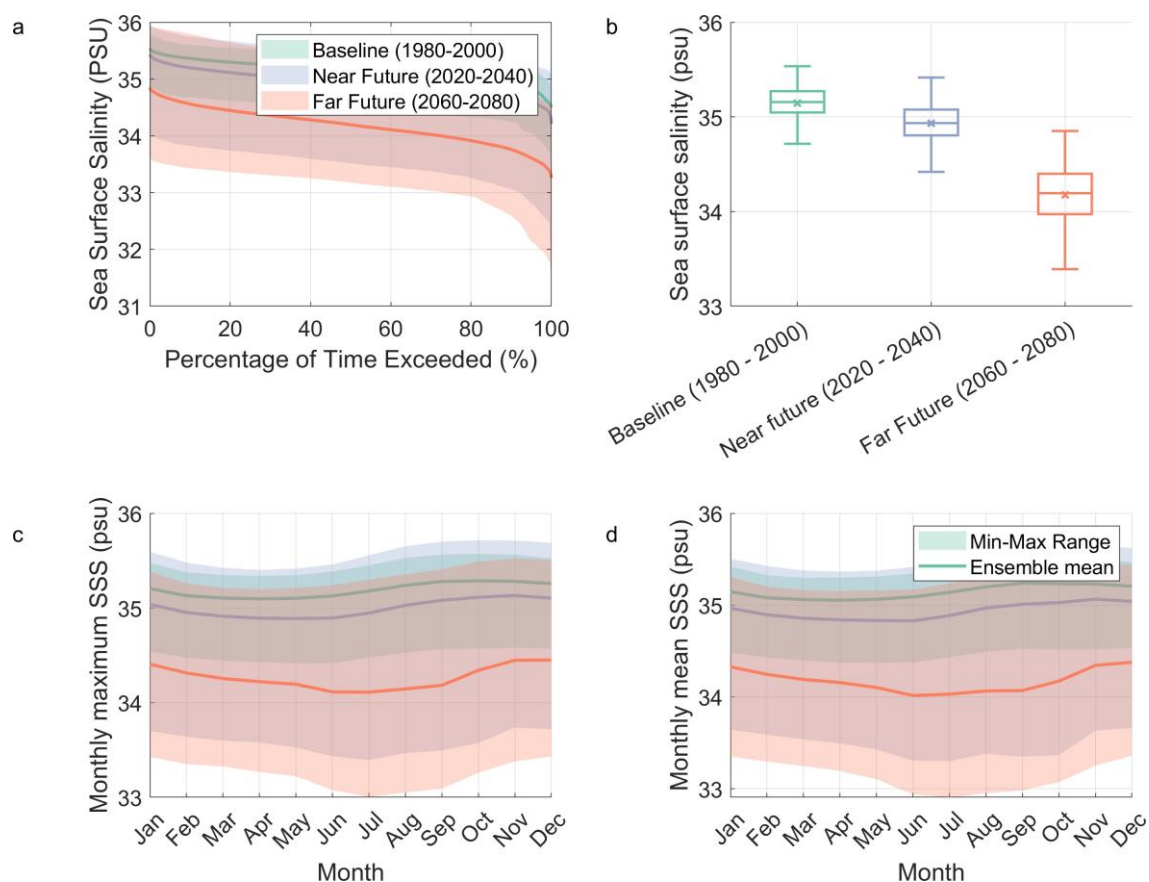


Figure description

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Section 3 - Residual surge changes

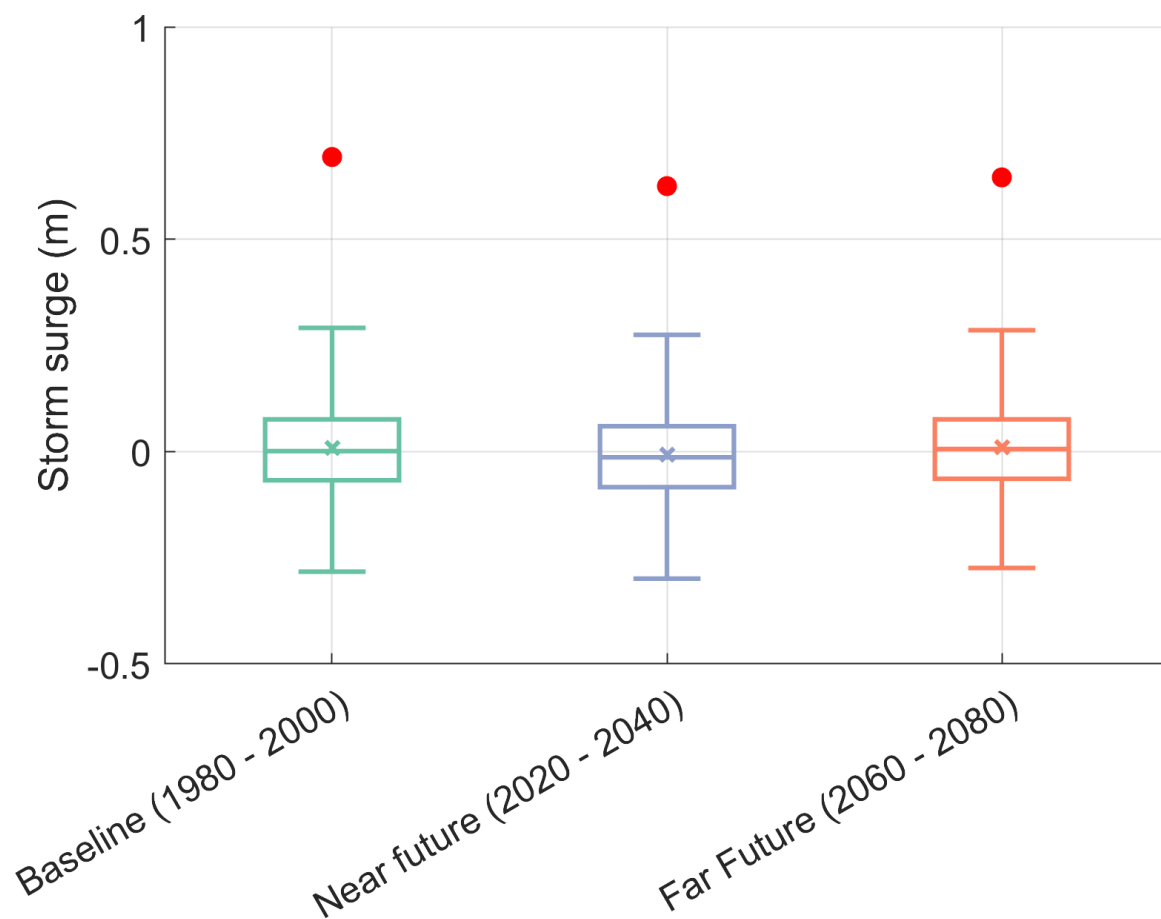


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

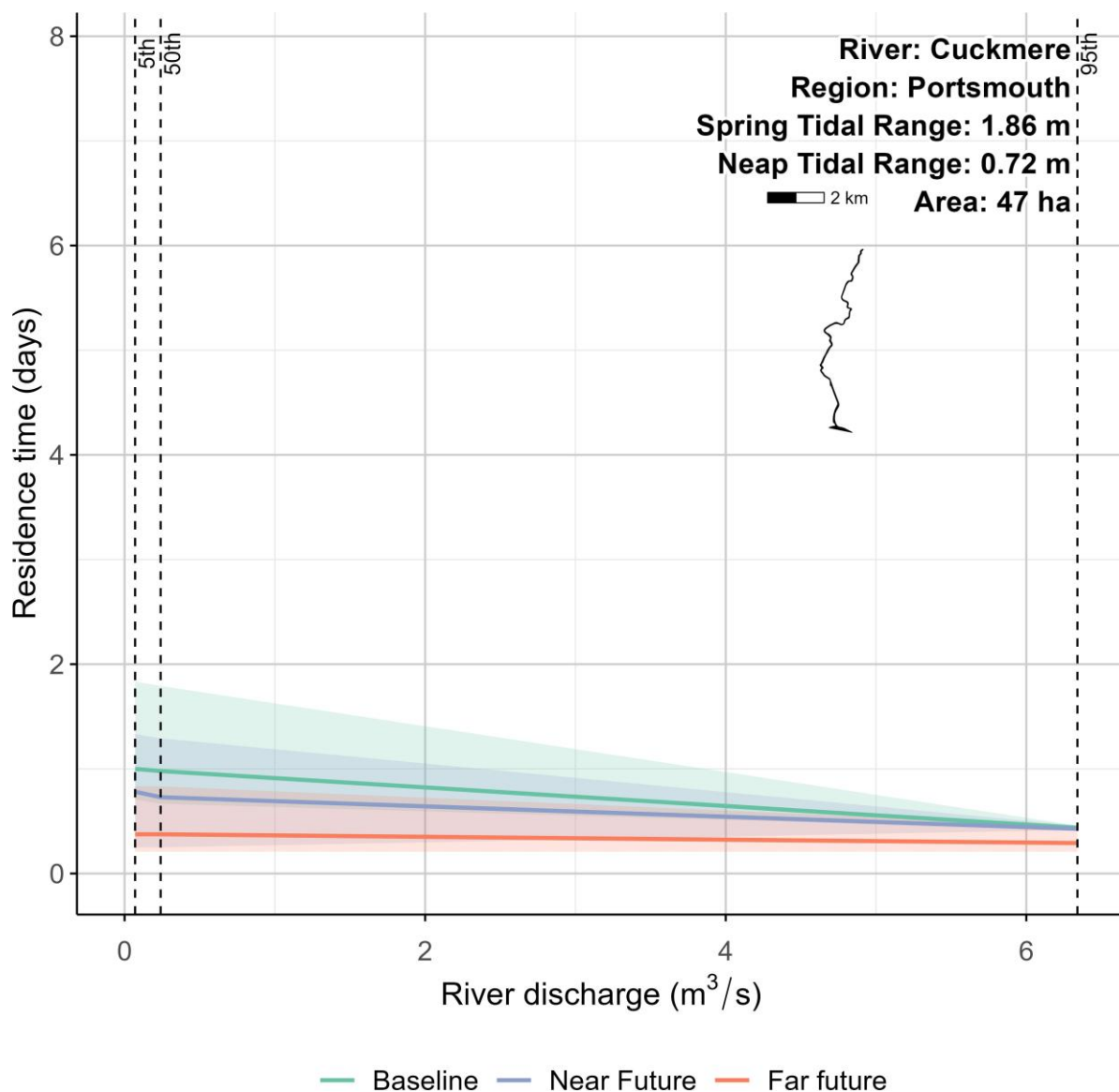


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)
Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Dart

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	50.48015
Longitude	-3.77993
Tidal Range	4.3 m
Gauge Name	Dart at Austins Bridge
Estuary Size	7920000.0 m ²
5th percentile flow	1.62 m ³ /s
50th percentile flow	7.001 m ³ /s
95th percentile flow	36.1 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

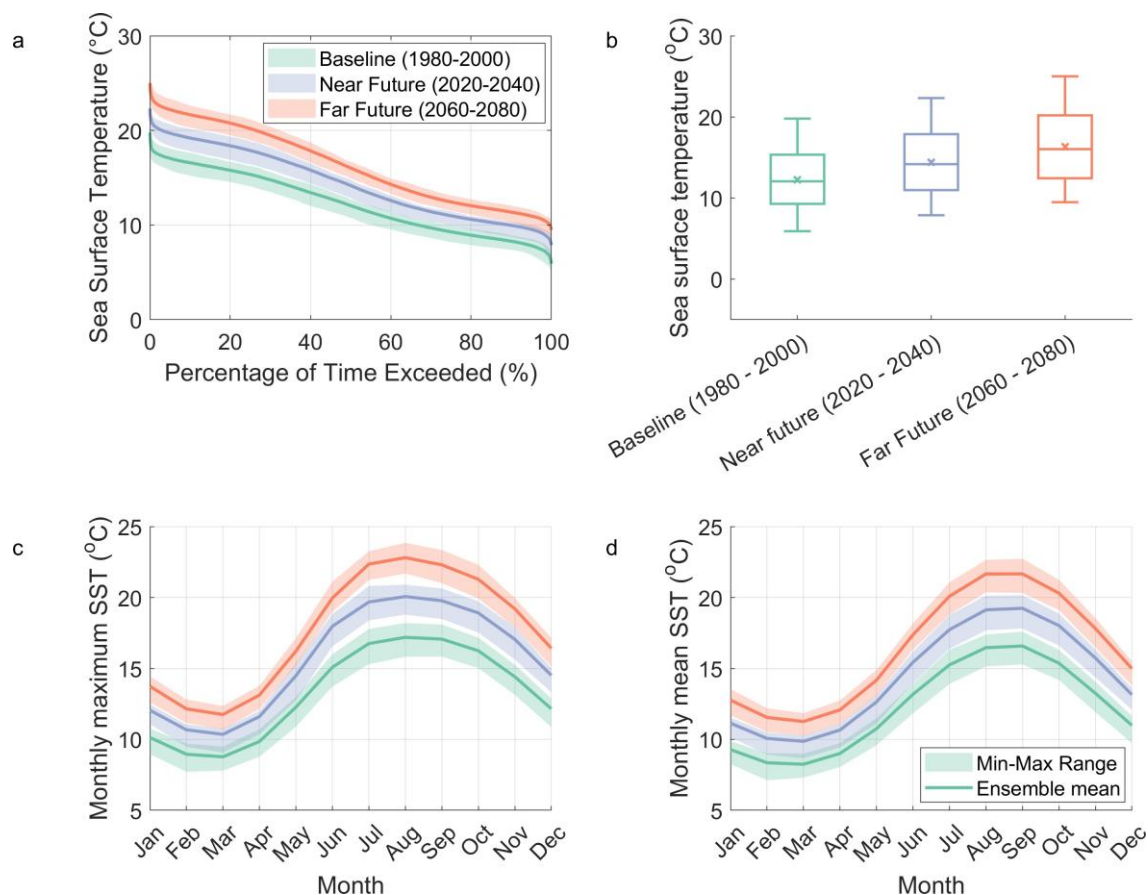
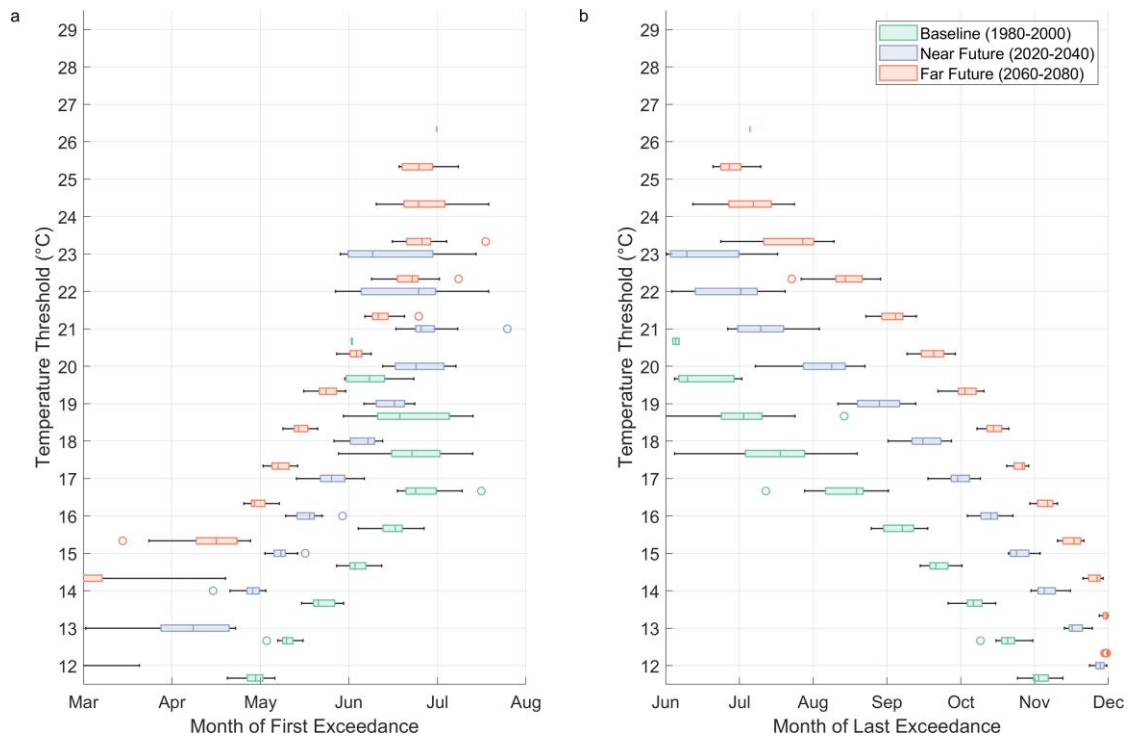


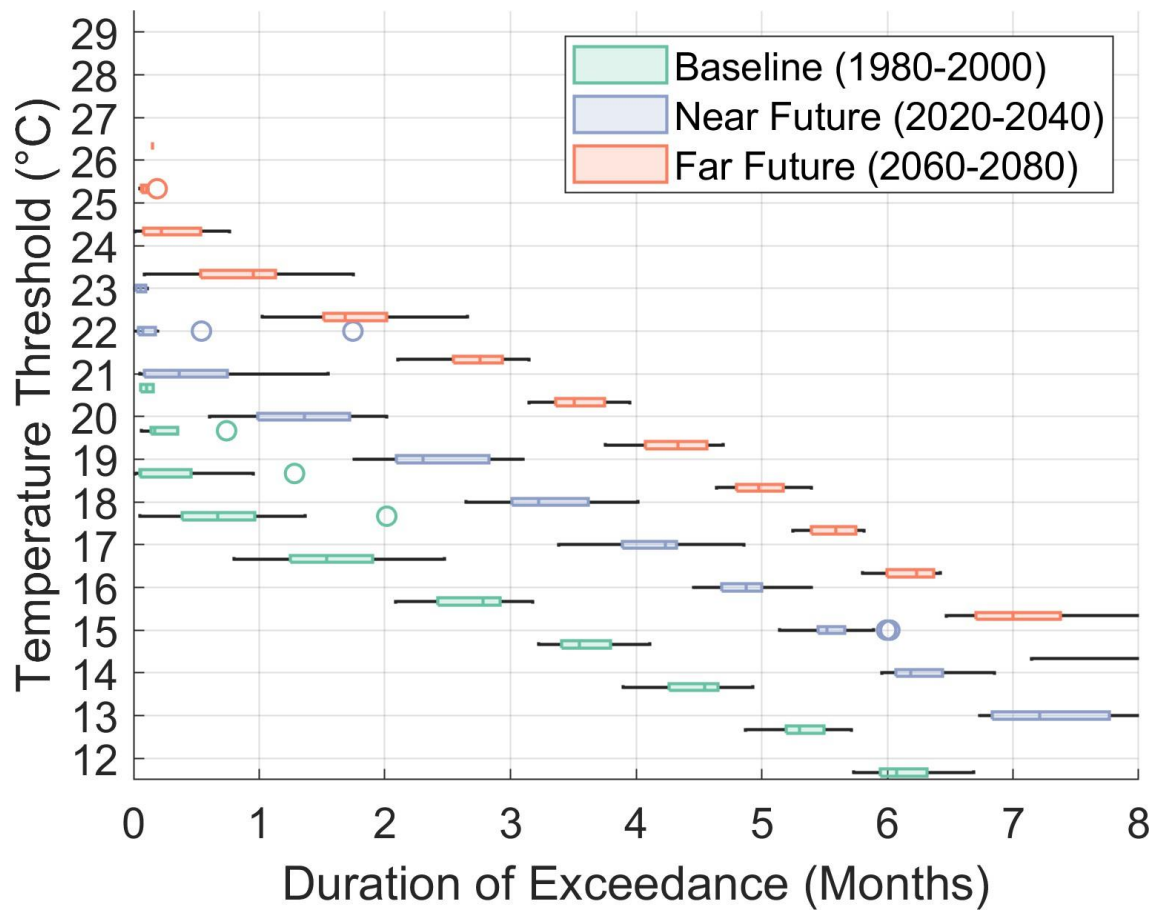
Figure description

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Section 2 - Sea surface salinity changes

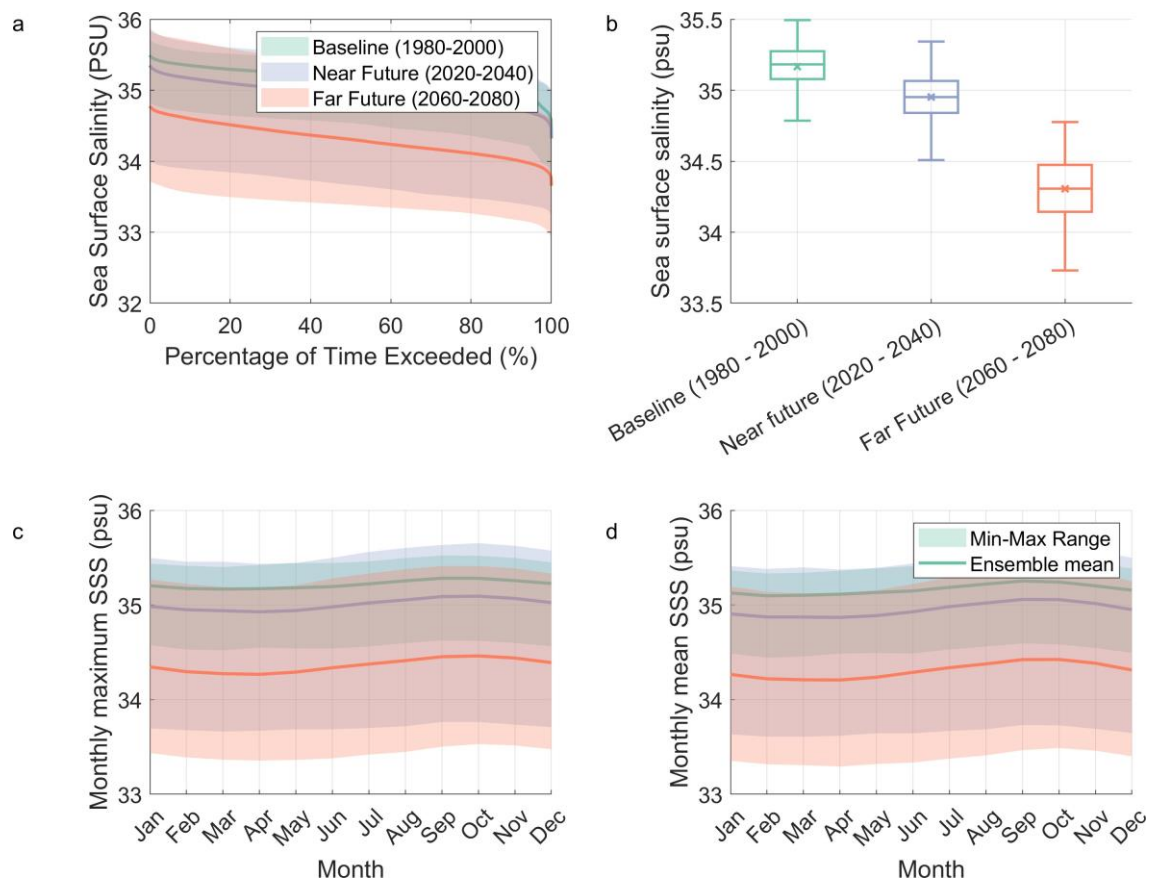


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
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Section 3 - Residual surge changes

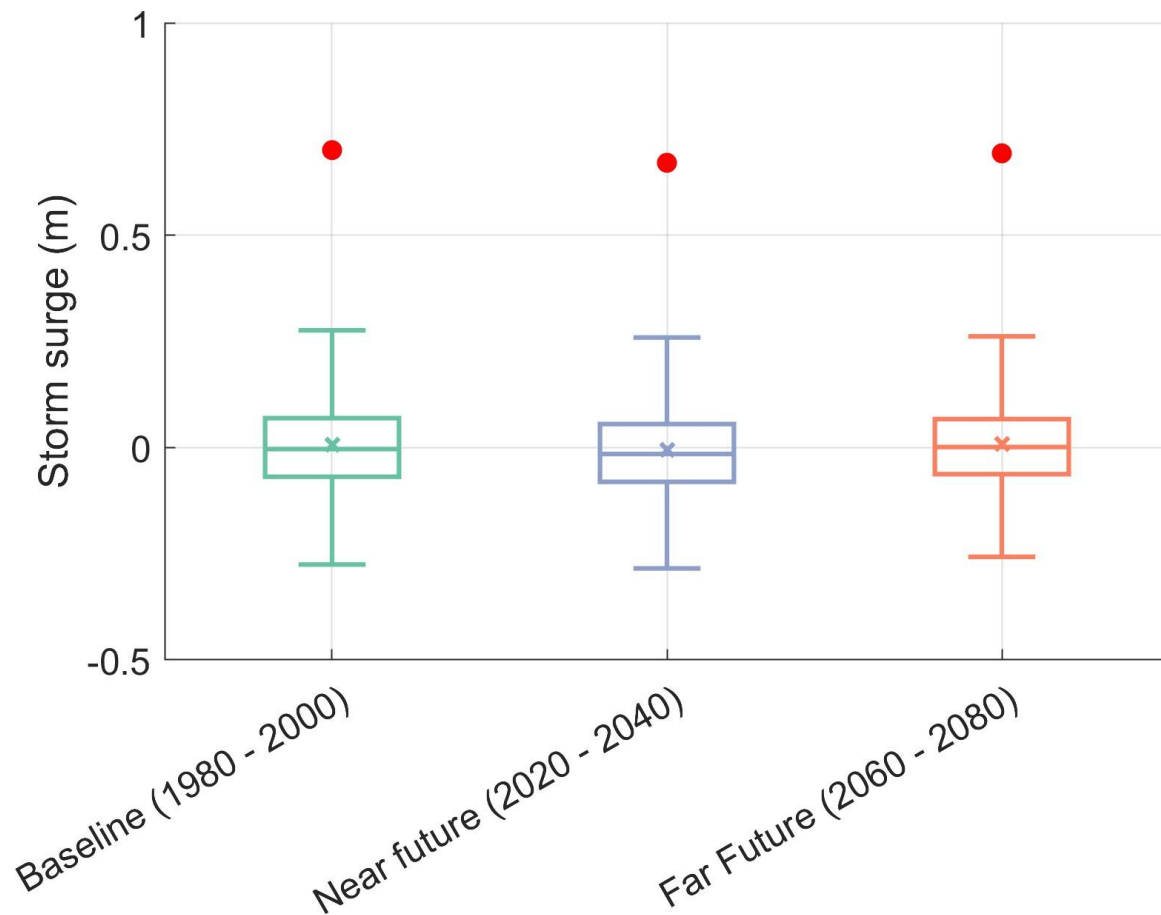


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - River discharge changes

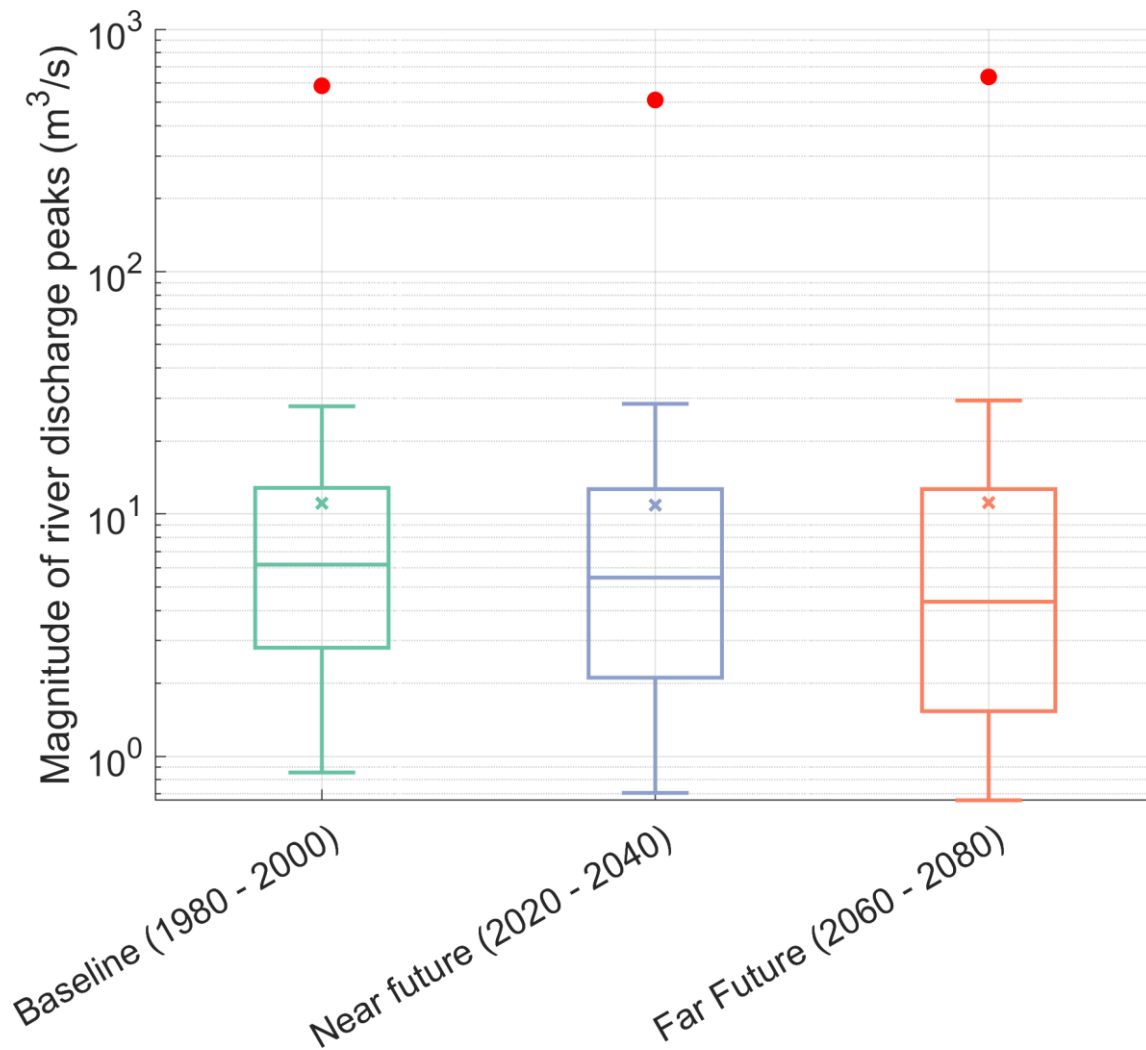


Figure description

Box and whisker plots of discharge percentiles under baseline (1980-2000), near-future (2020-2040) and far-future (2060-2080)

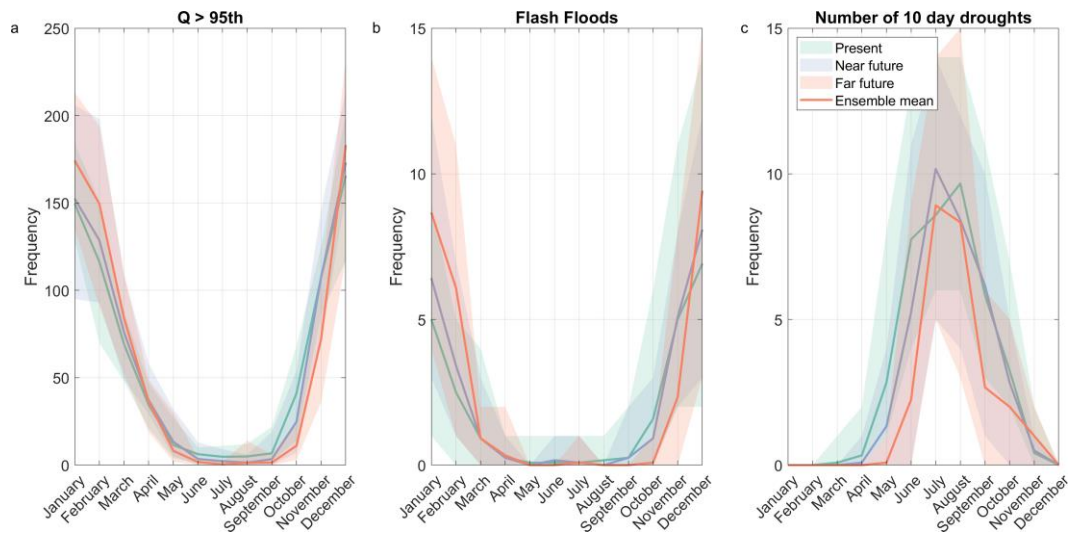


Figure description

Discharge conditions under baseline (1980-2000), near-future (2020-2040) and far-future (2060-2080) showing frequency of (a): Occurrence of high flow (>95th percentile events) per month (hourly resolution), (b): Flash flood events (increase in discharge of >50 m³/s, (c): low flow events lasting longer than 10 days).

Section 5 - Residence times changes

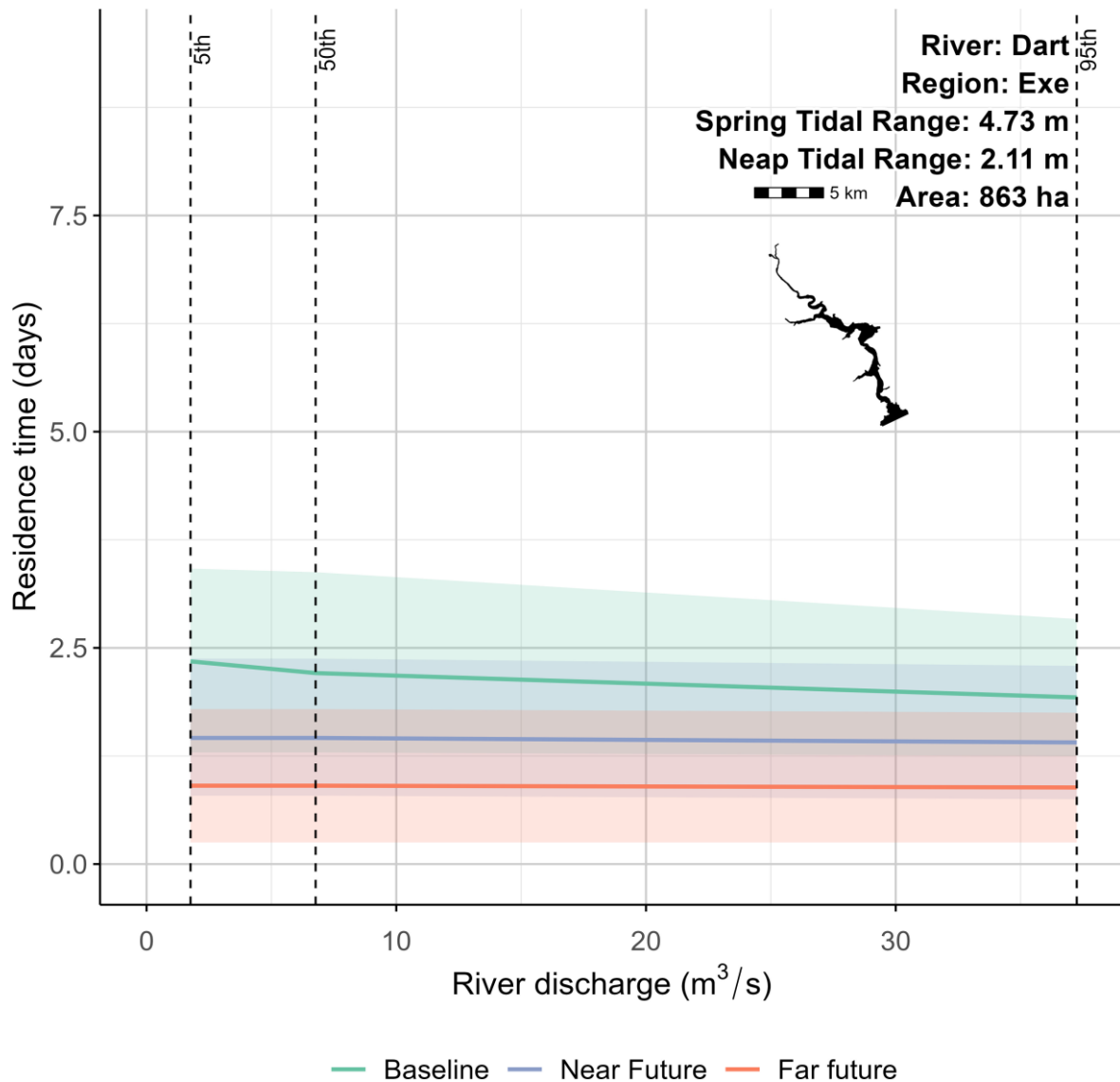


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)
Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Deben

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	52.12962
Longitude	1.39073
Tidal Range	3.25 m
Gauge Name	Deben at Naunton Hall
Estuary Size	6310000.0 m ²
5th percentile flow	0.084 m ³ /s
50th percentile flow	0.267 m ³ /s
95th percentile flow	3.44 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

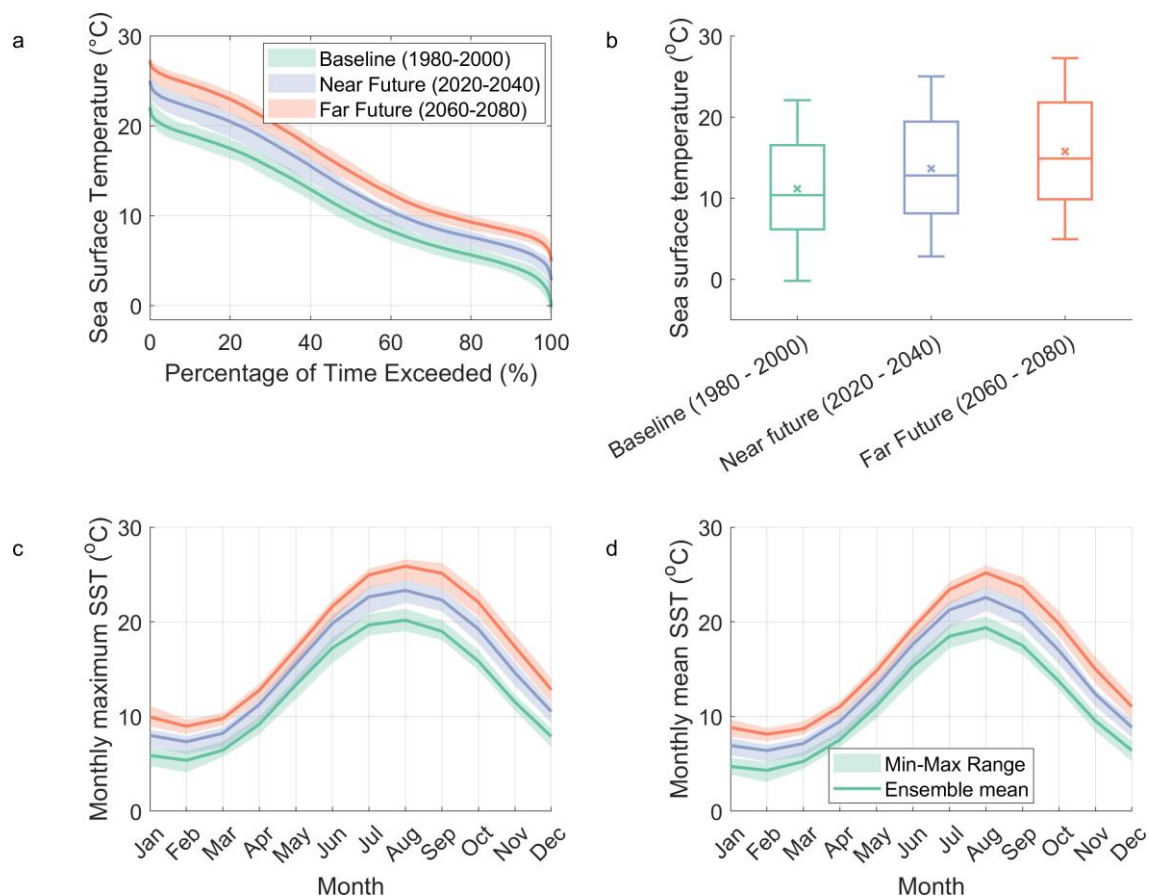
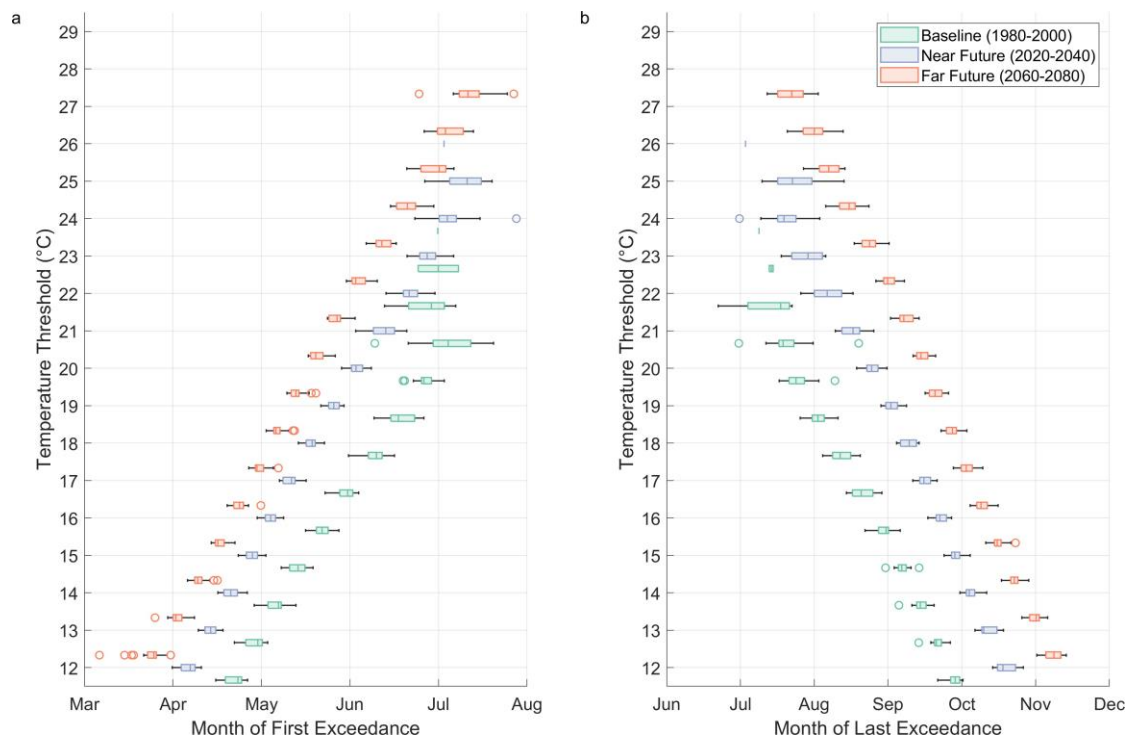


Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

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Section 2 - Sea surface salinity changes

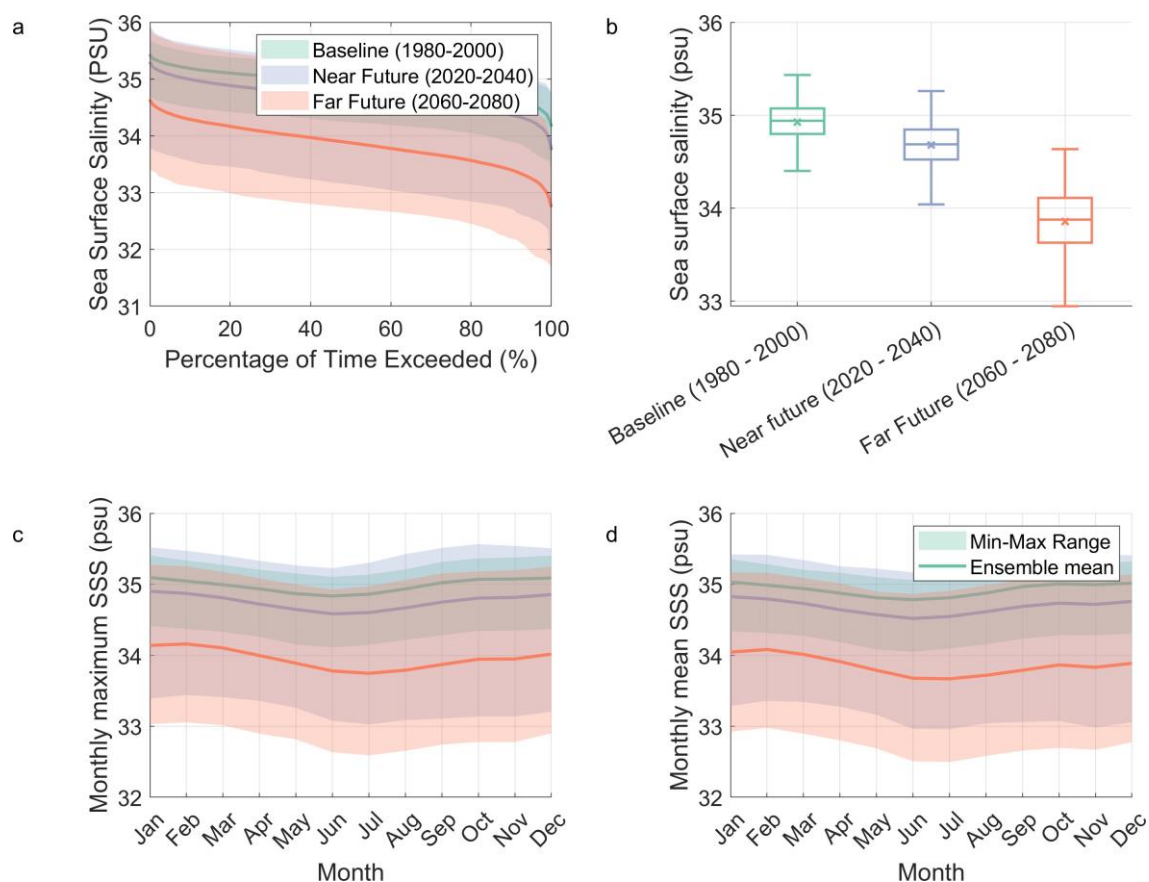


Figure description

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Section 3 - Residual surge changes

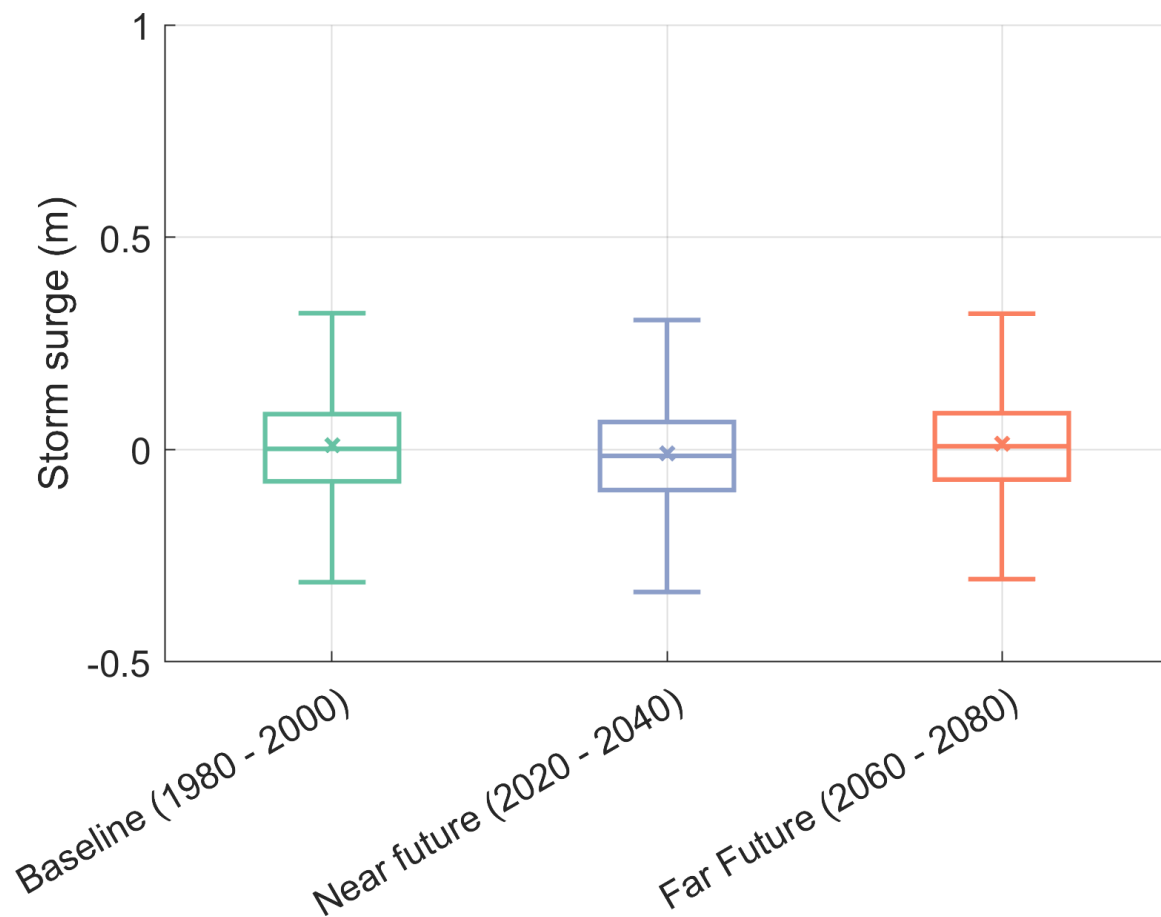


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

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Section 4 - Residence times changes

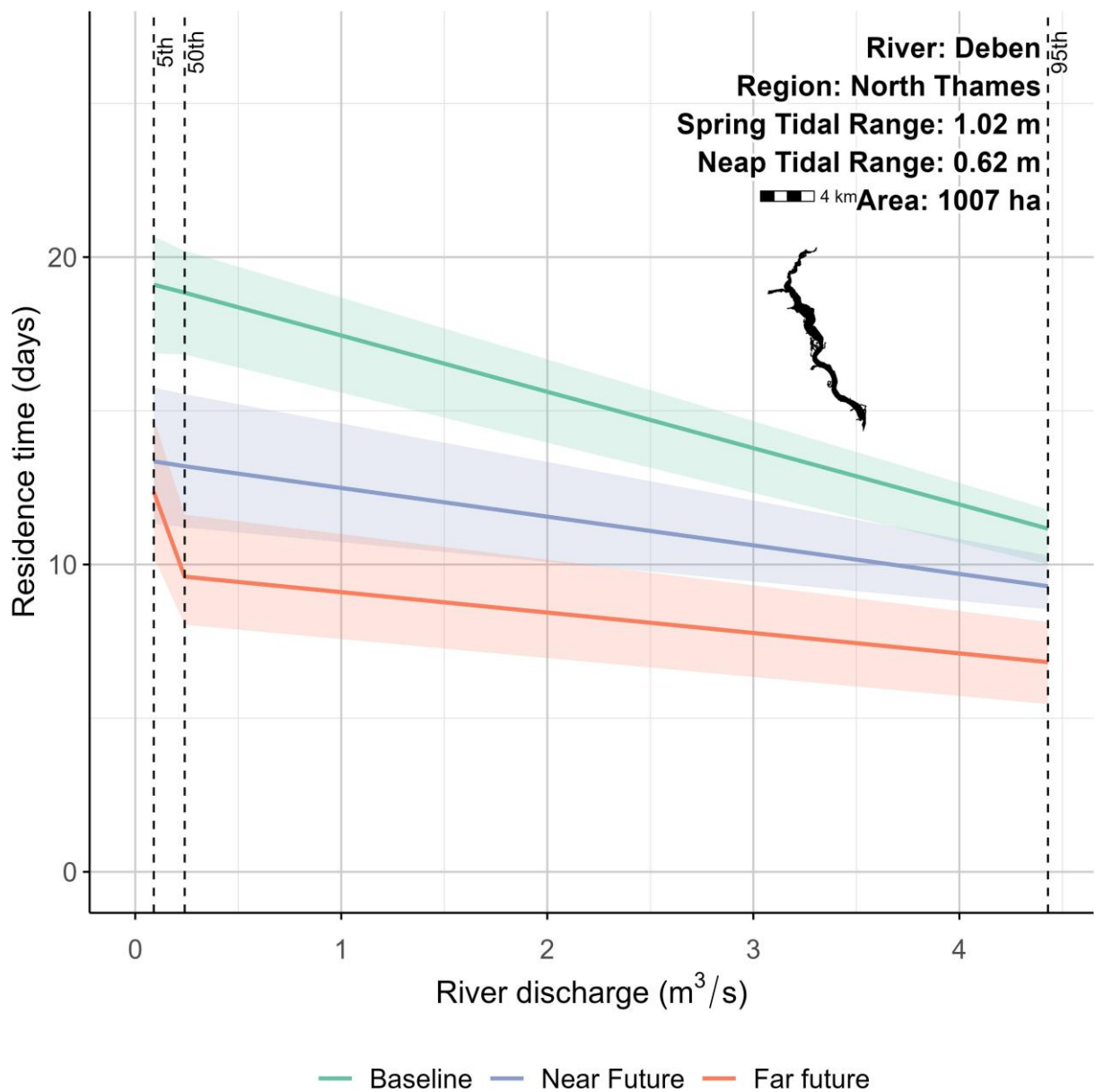


Figure description

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Dee

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	53.18789
Longitude	-2.88437
Tidal Range	nan m
Gauge Name	Dee at Chester Suspension Bridge
Estuary Size	nan m ²
5th percentile flow	5.13 m ³ /s
50th percentile flow	18.4 m ³ /s
95th percentile flow	119.0 m ³ /s
Notes	Not Listed on Estuarine Database Viewer

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

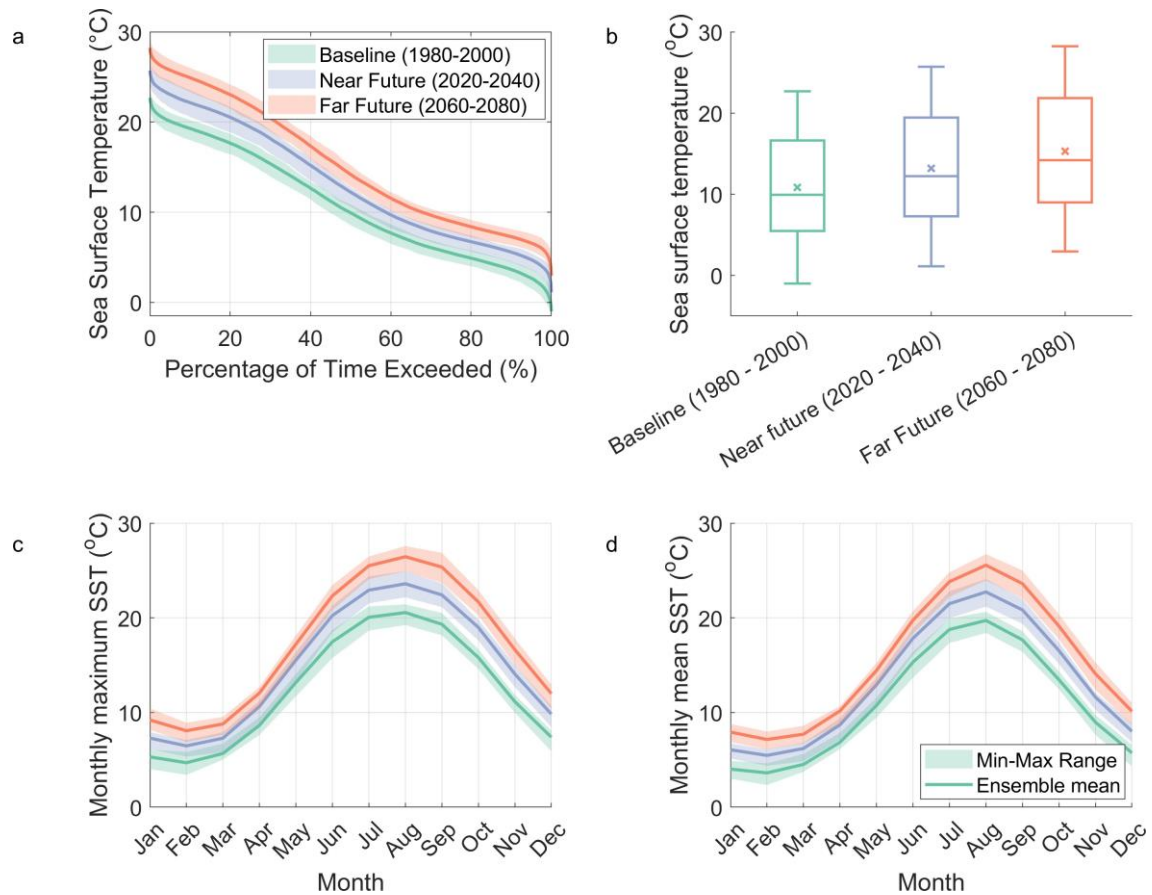
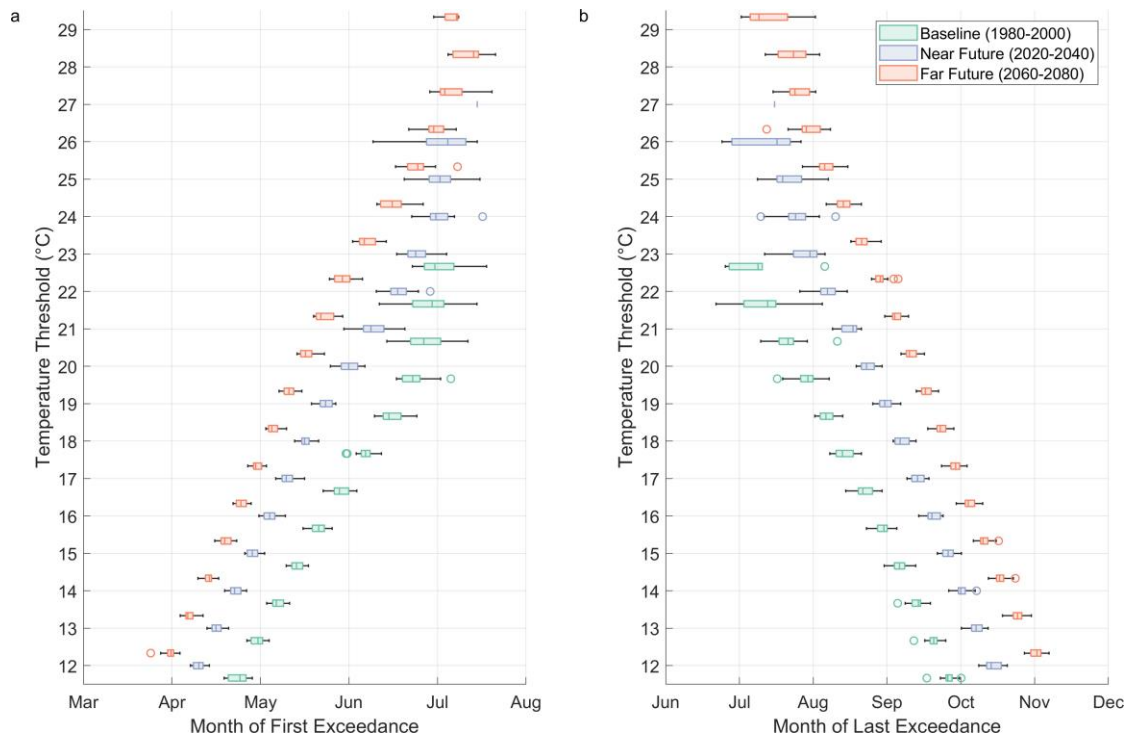


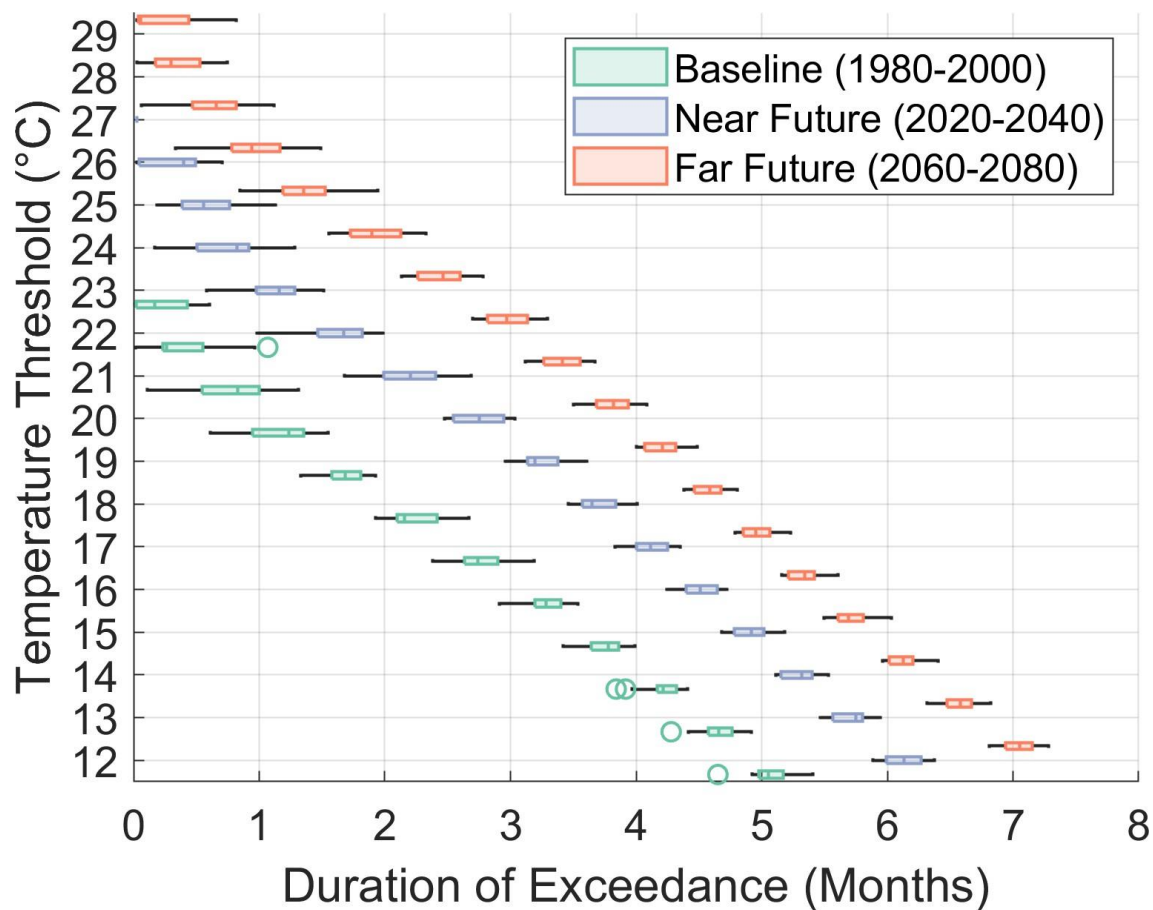
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Section 2 - Sea surface salinity changes

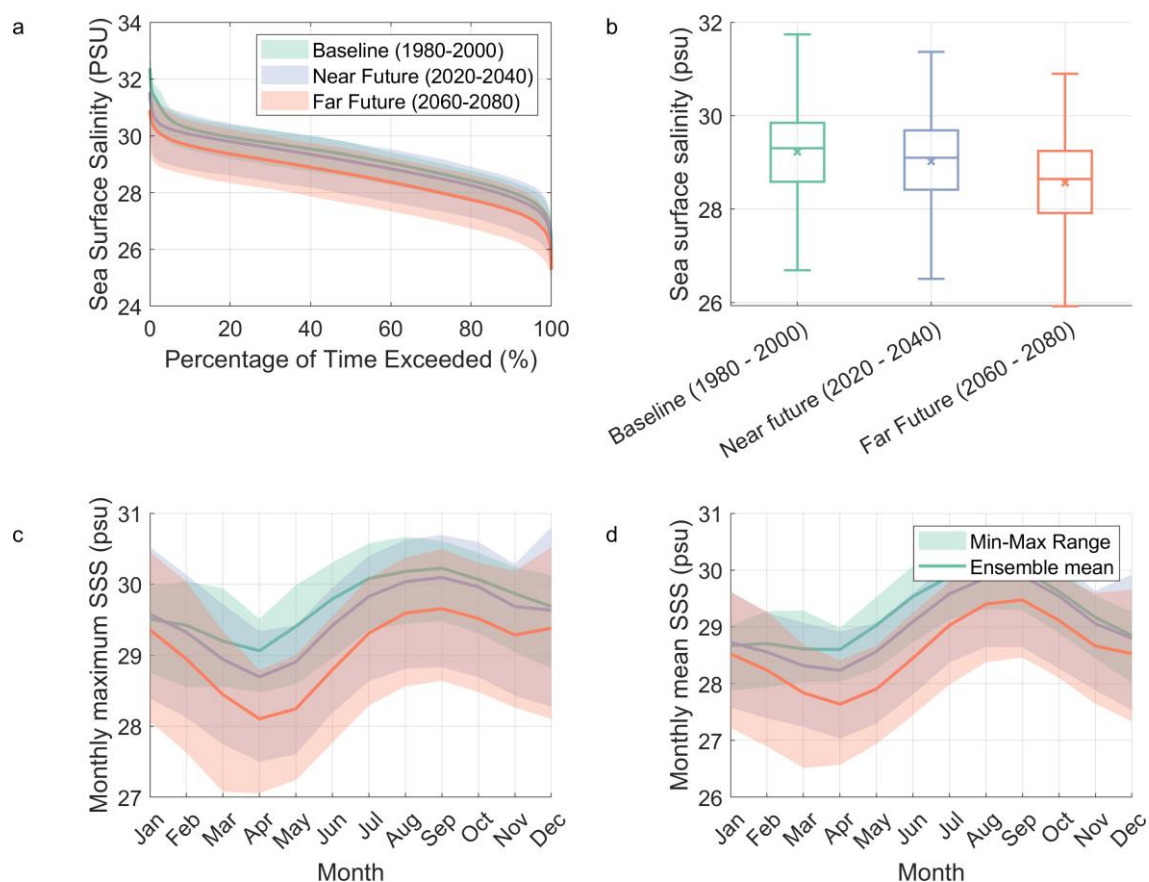


Figure description

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Section 3 - Residual surge changes

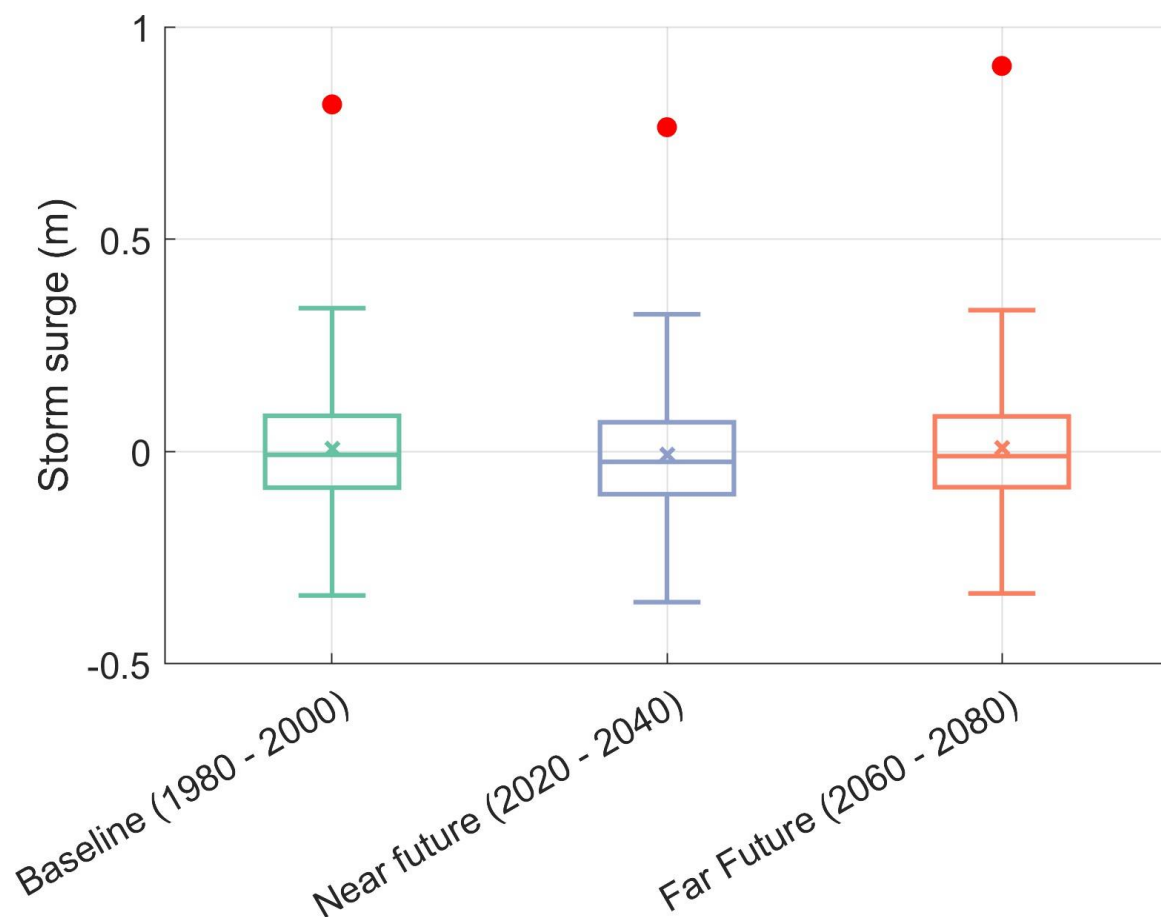


Figure description

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Section 4 - Residence times changes

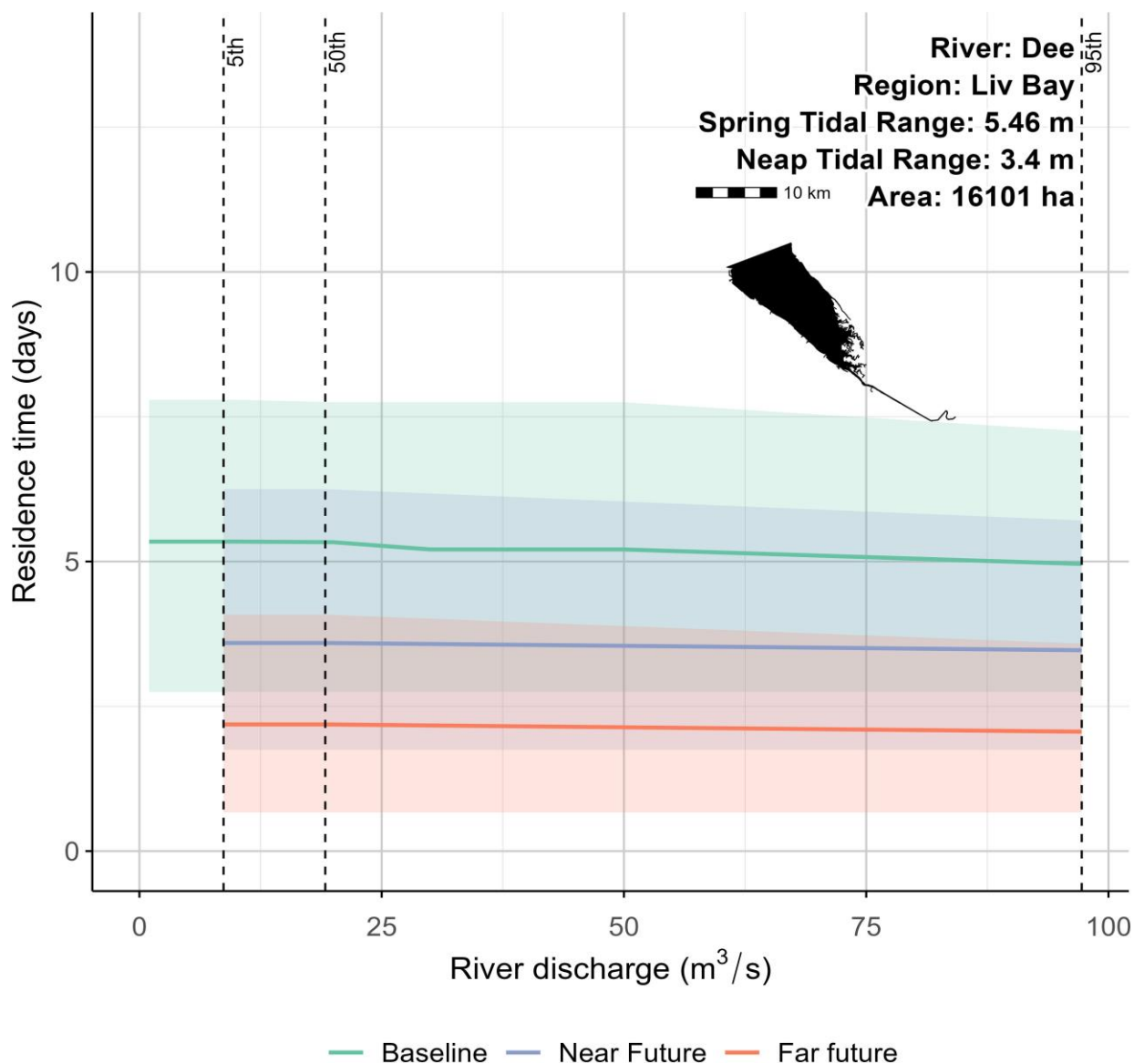


Figure description

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Duddon

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	54.29547
Longitude	-3.23772
Tidal Range	7.6 m
Gauge Name	Duddon at Duddon Hall
Estuary Size	19100000.0 m ²
5th percentile flow	0.468 m ³ /s
50th percentile flow	2.691 m ³ /s
95th percentile flow	17.9 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

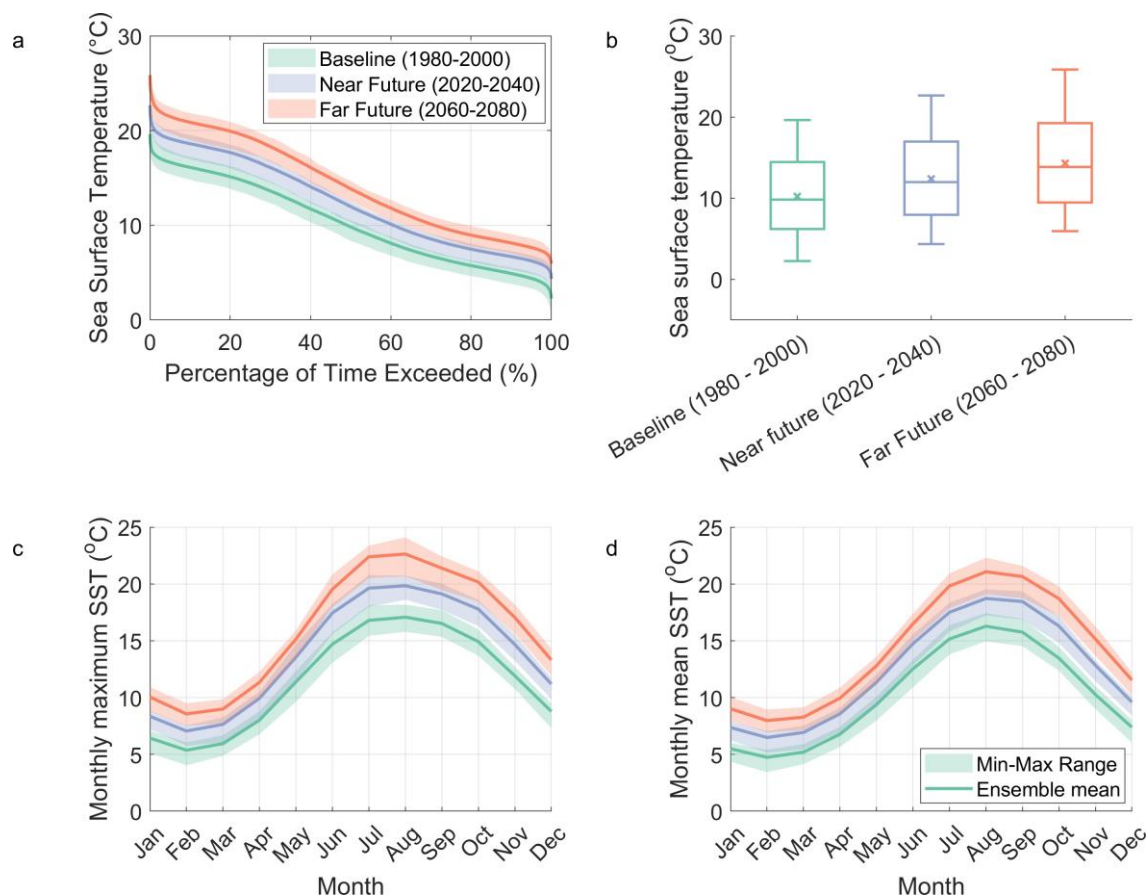
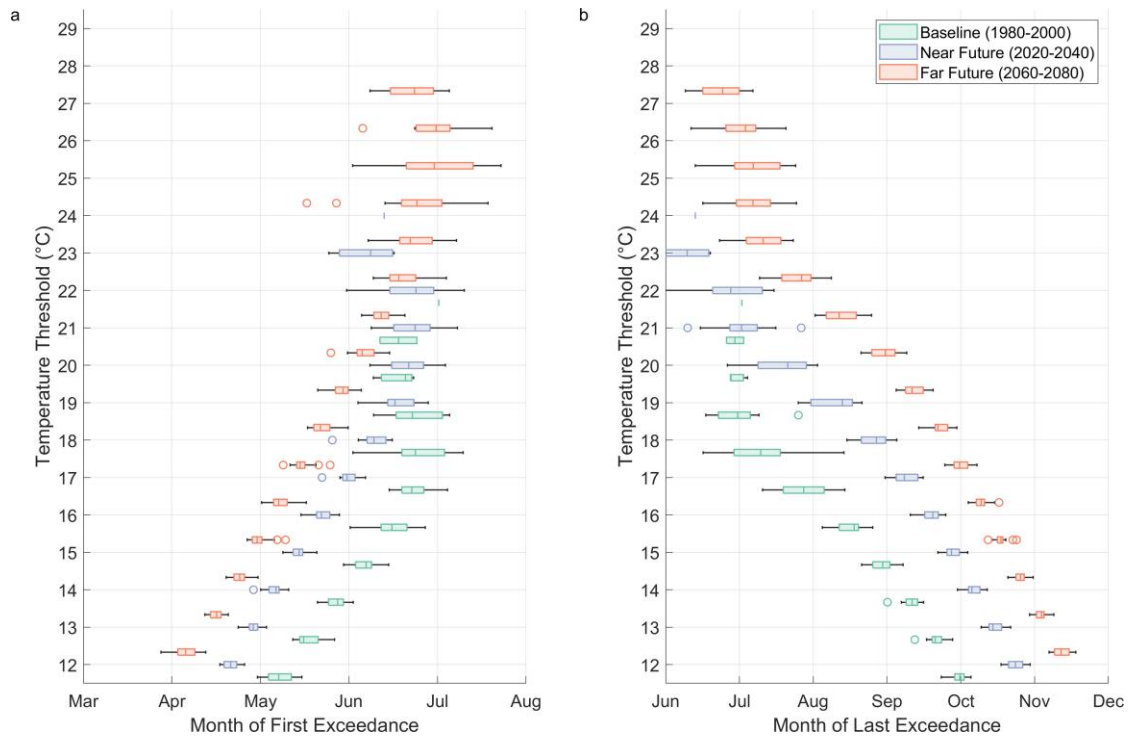


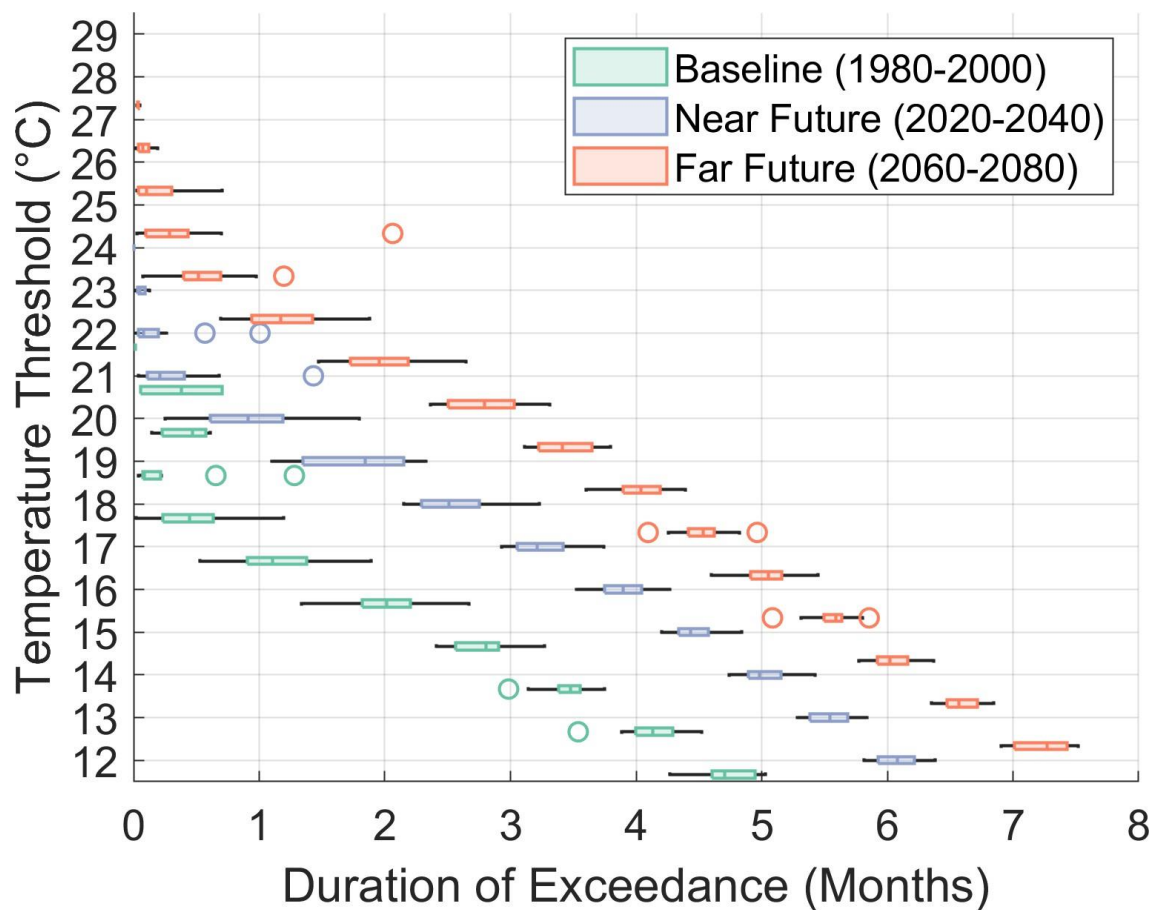
Figure description

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Section 2 - Sea surface salinity changes

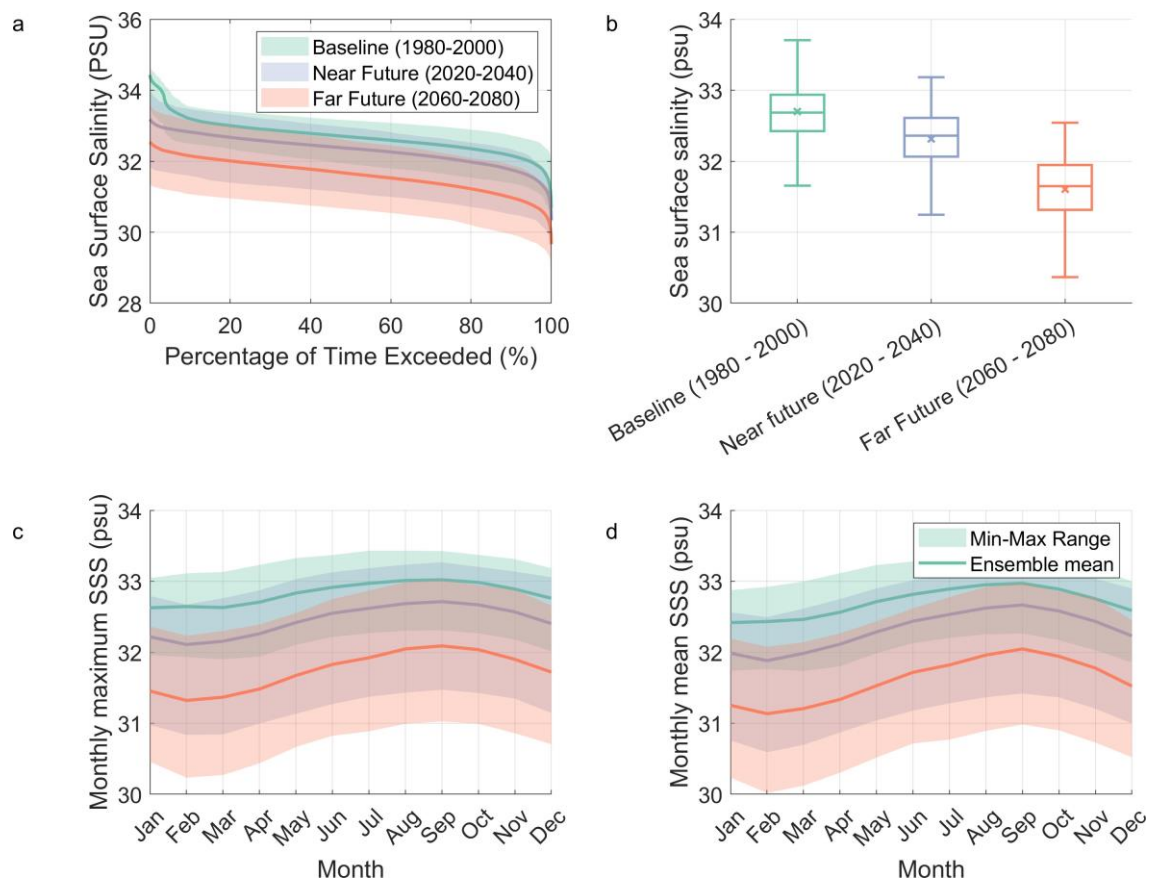


Figure description

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Section 3 - Residual surge changes

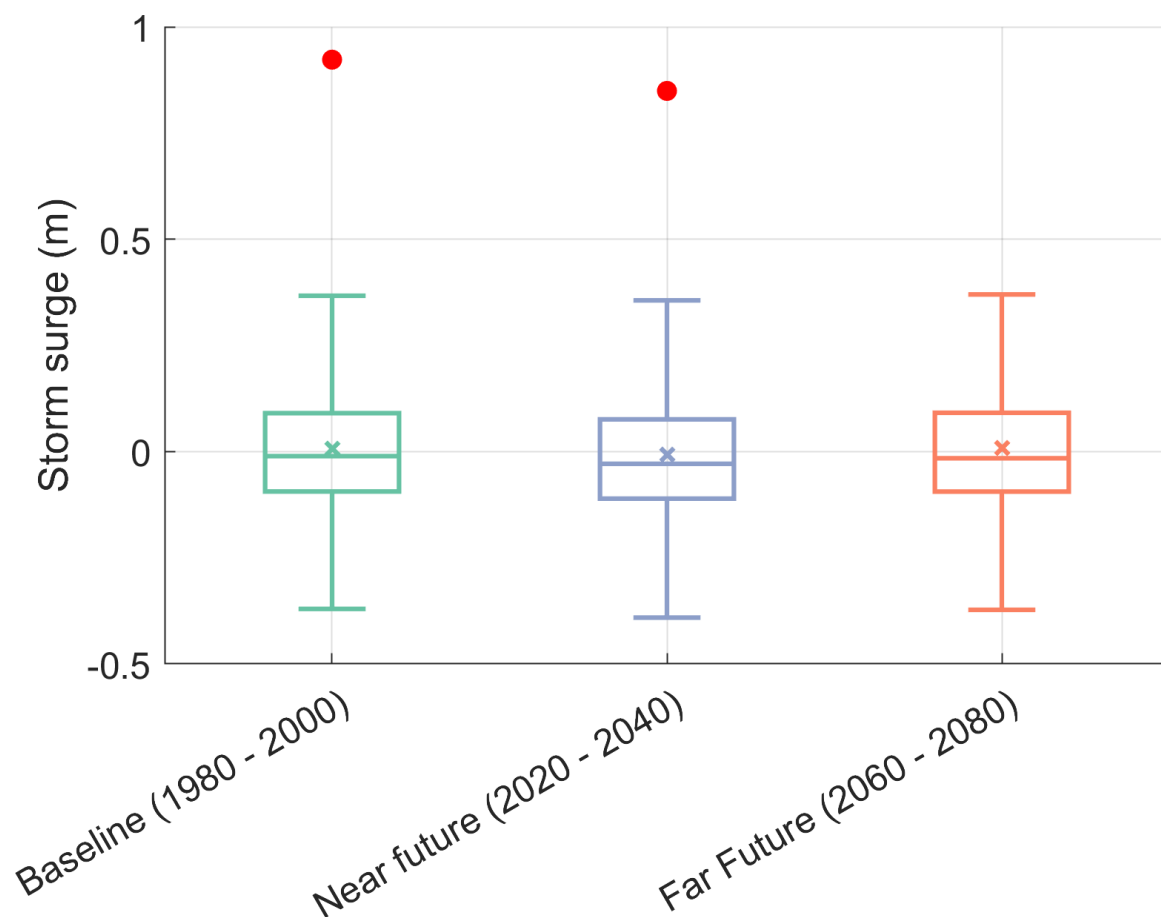


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

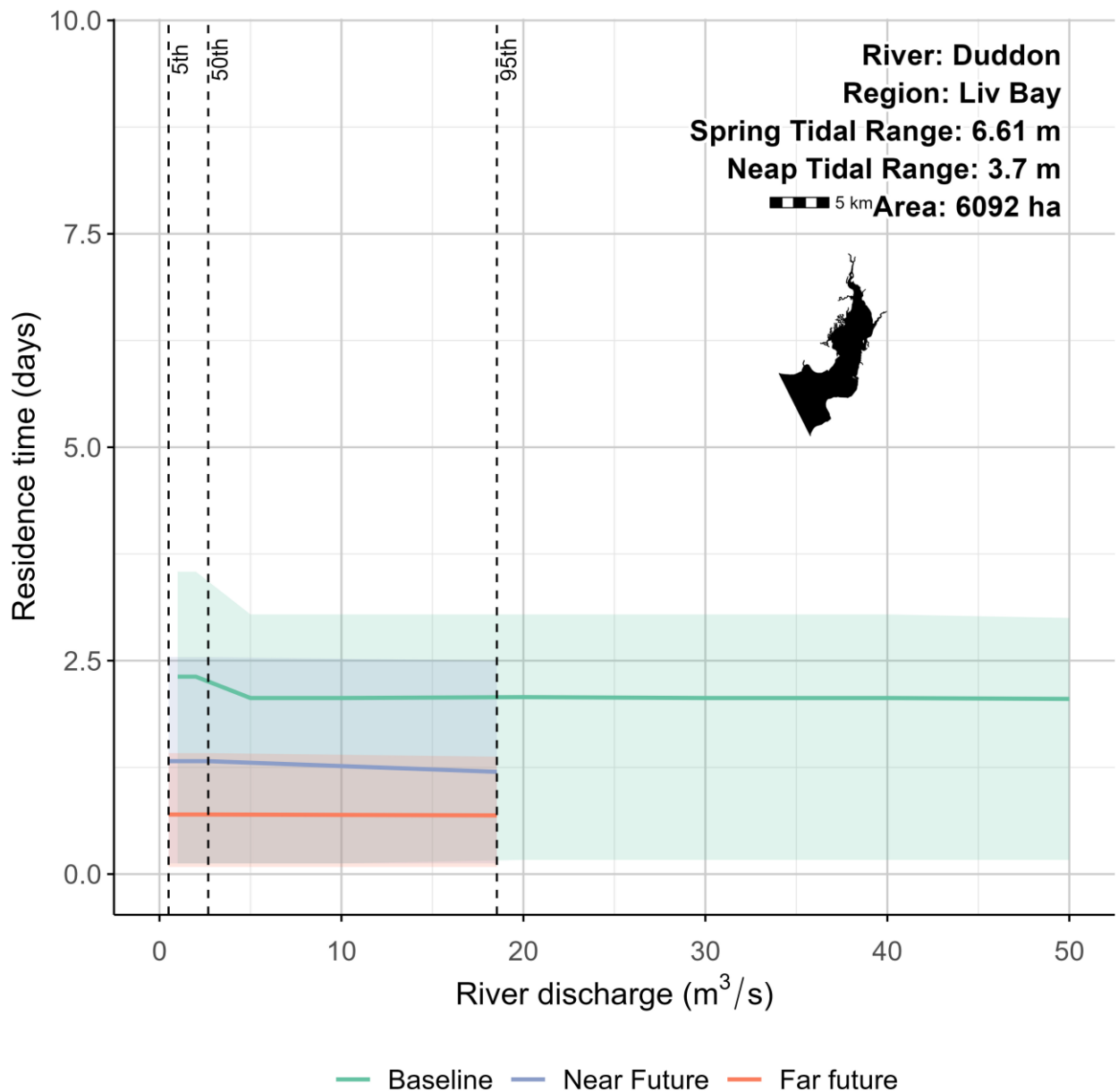


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Erme

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	50.36312
Longitude	-3.9114
Tidal Range	4.64 m
Gauge Name	Erme at Ermington
Estuary Size	615000.0 m ²
5th percentile flow	0.279 m ³ /s
50th percentile flow	1.1 m ³ /s
95th percentile flow	6.626 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

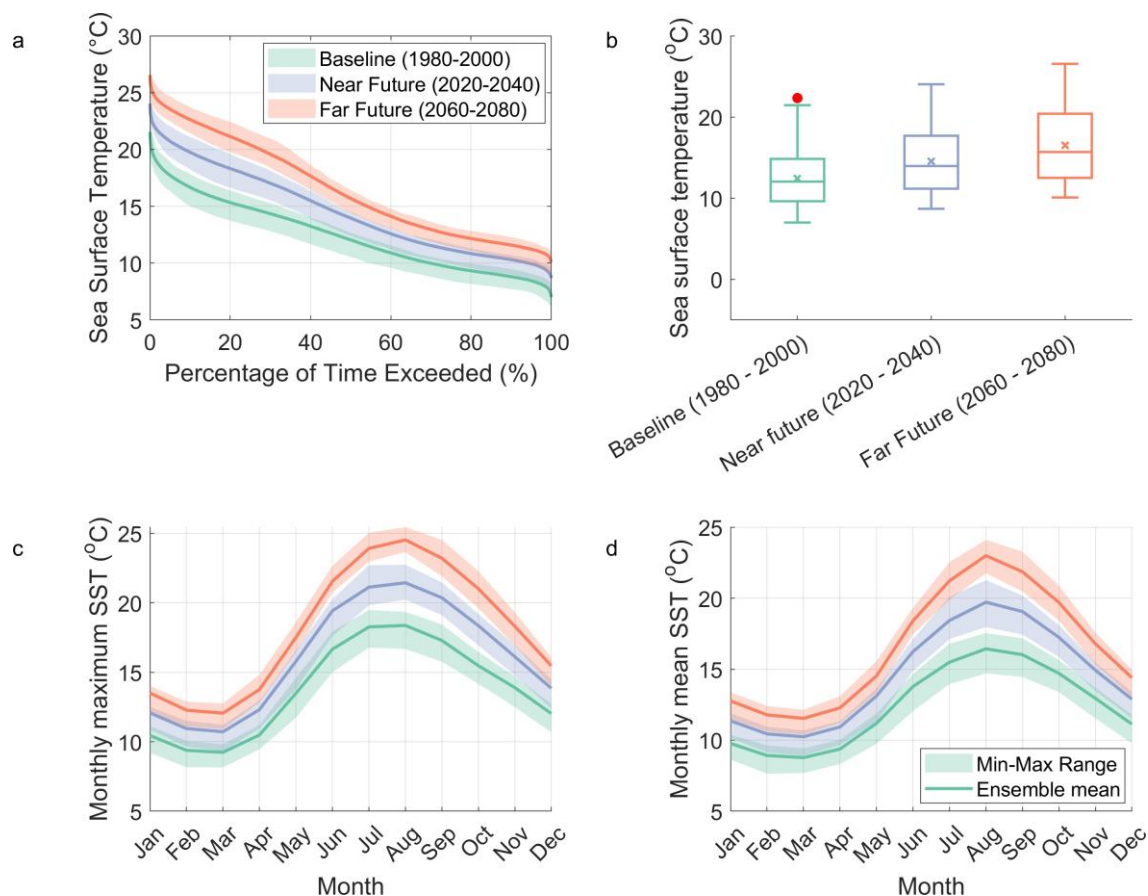
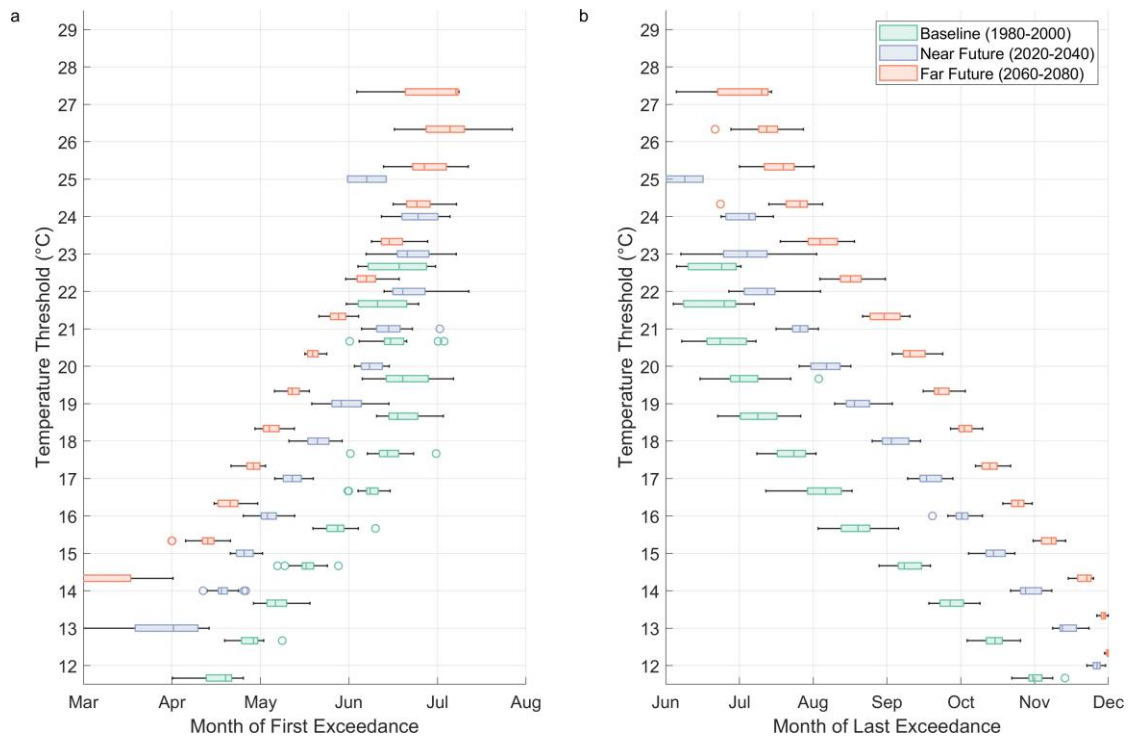


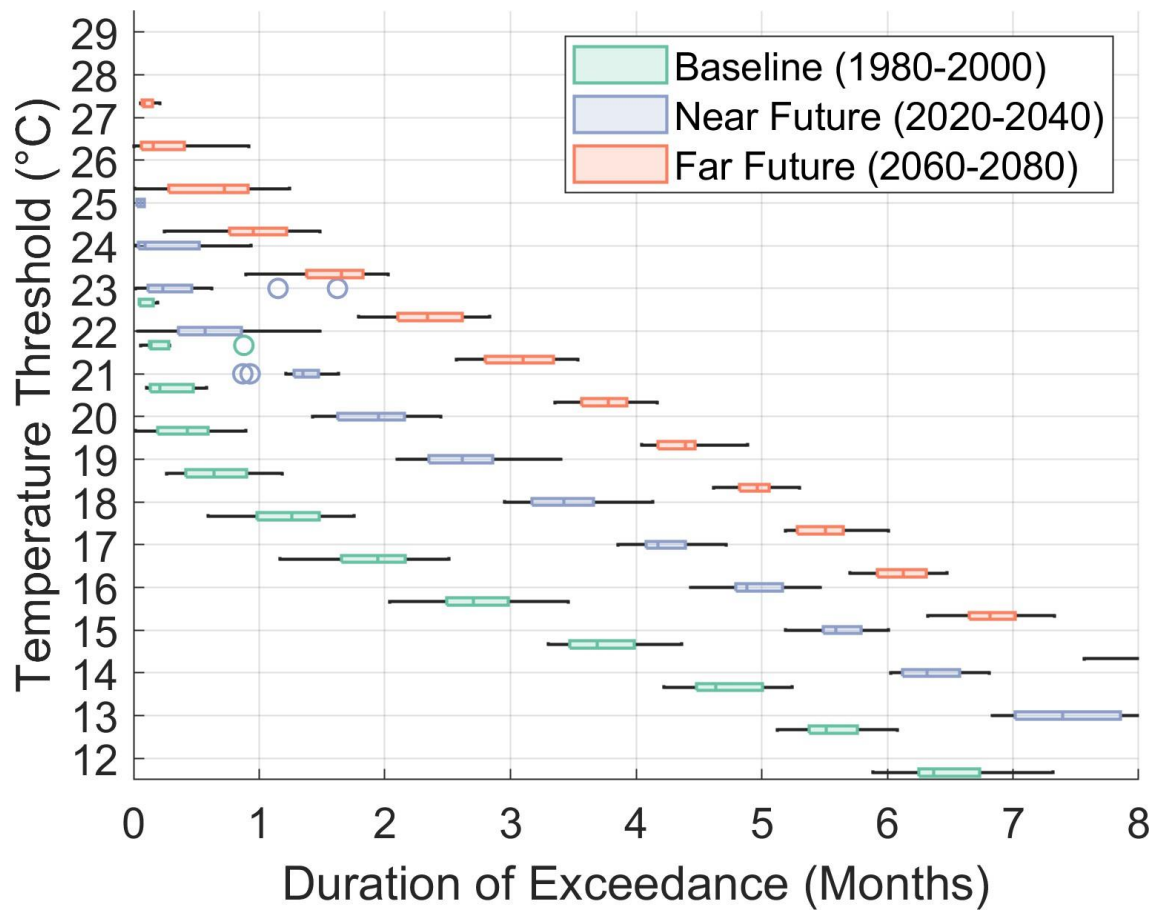
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

- (a) Temperature duration curves represent distribution of SSTs over time to highlight changes in cold and warm extremes.
- (b) Percentile shifts show increasing mean, median, and extremes, indicating prolonged warming over time.
- (c) Rising monthly maximum in every month of the year highlights likelihood of intensified high heat events.
- (d) Rising monthly mean suggests long-term climate-driven warming.



Changes in first and last occurrences of temperature thresholds compared to historical data. Note that these plots are not intended to identify the specific date on which a temperature may occur, rather they indicate the trend in the onset of specific temperature thresholds.



Projected temperature changes under different climate scenarios. Box and whisker plots show the range of different modelled durations of temperatures under the 12 different UKCP 18 ensemble members. Open circles indicate outlier values.

Section 2 - Sea surface salinity changes

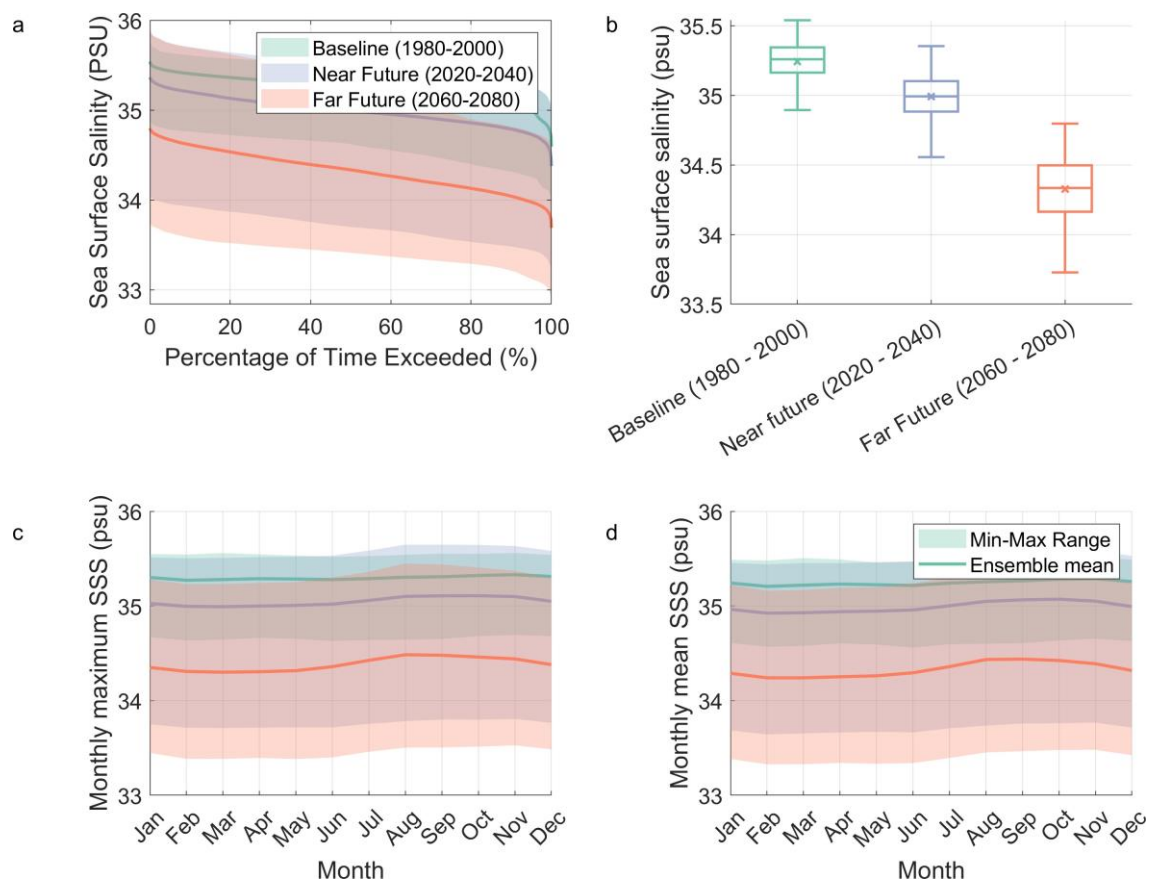


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
- (b) Percentile shifts show decreasing mean, median, and extremes, indicating a trend towards freshening over time.
- (c) Monthly maxima decrease across all months.
- (d) Decreasing monthly means suggest long-term ice-melt driven freshening.

Section 3 - Residual surge changes

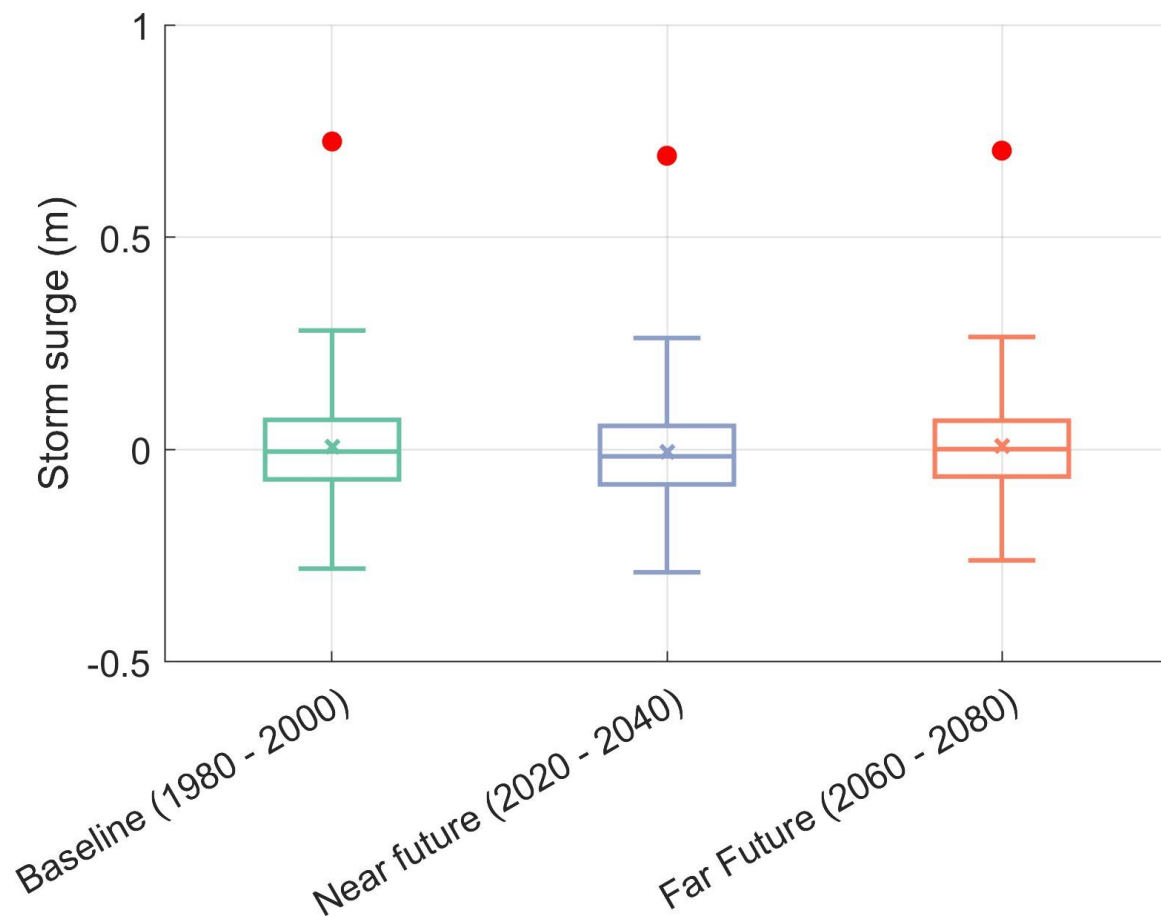


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

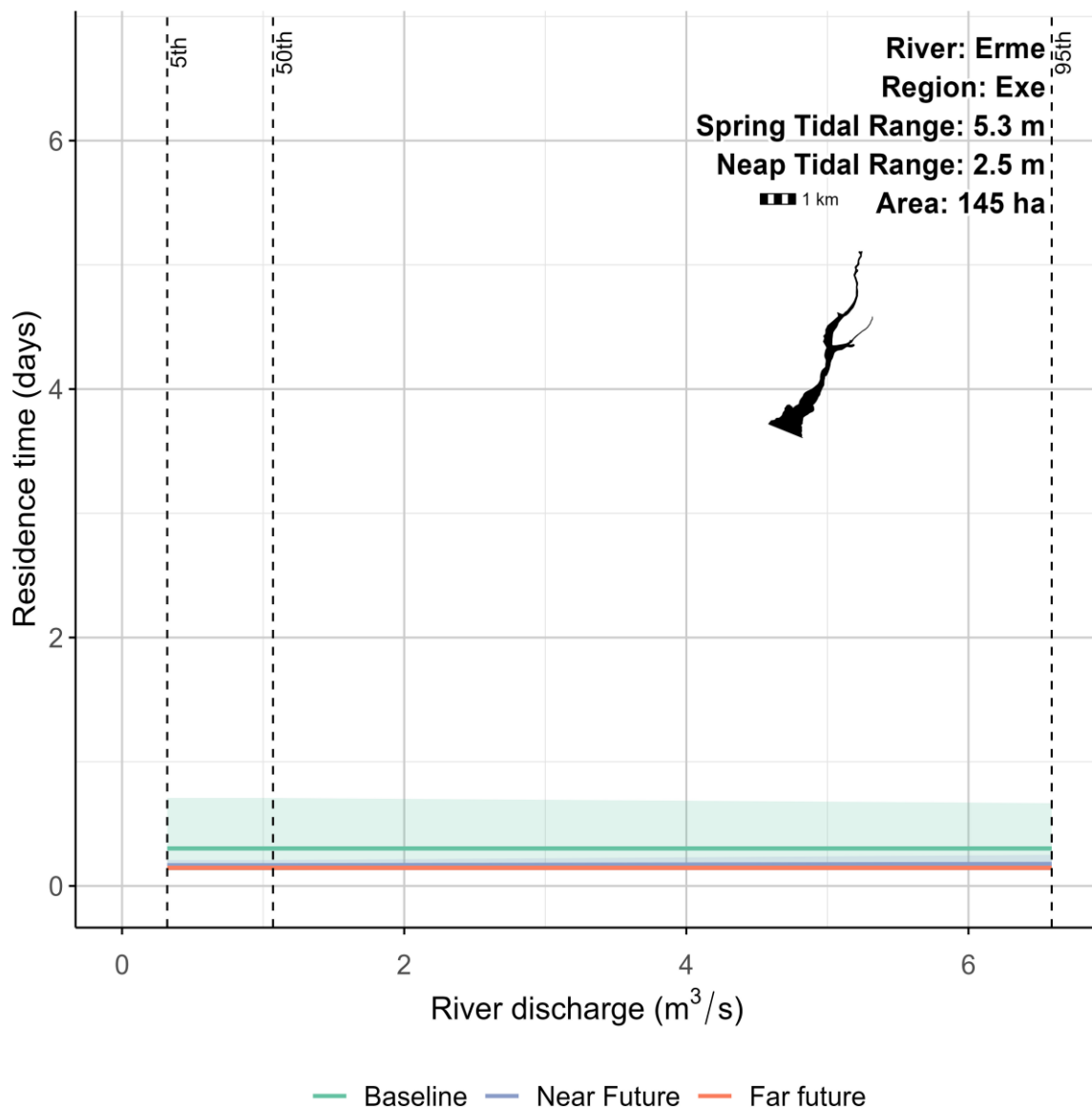


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Exe

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	50.71681
Longitude	-3.52694
Tidal Range	3.6 m
Gauge Name	Exe at Trews Weir
Estuary Size	17600000.0 m ²
5th percentile flow	4.066 m ³ /s
50th percentile flow	13.8 m ³ /s
95th percentile flow	84.75 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

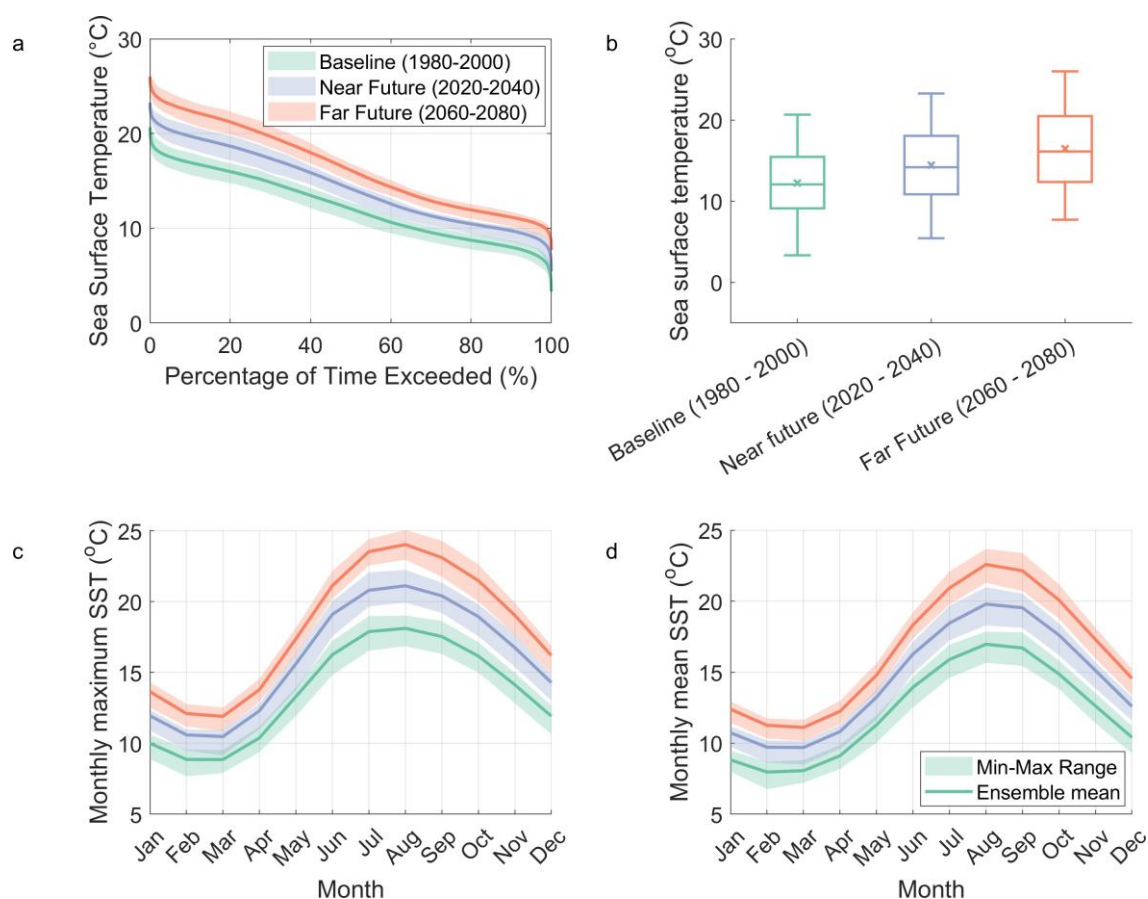
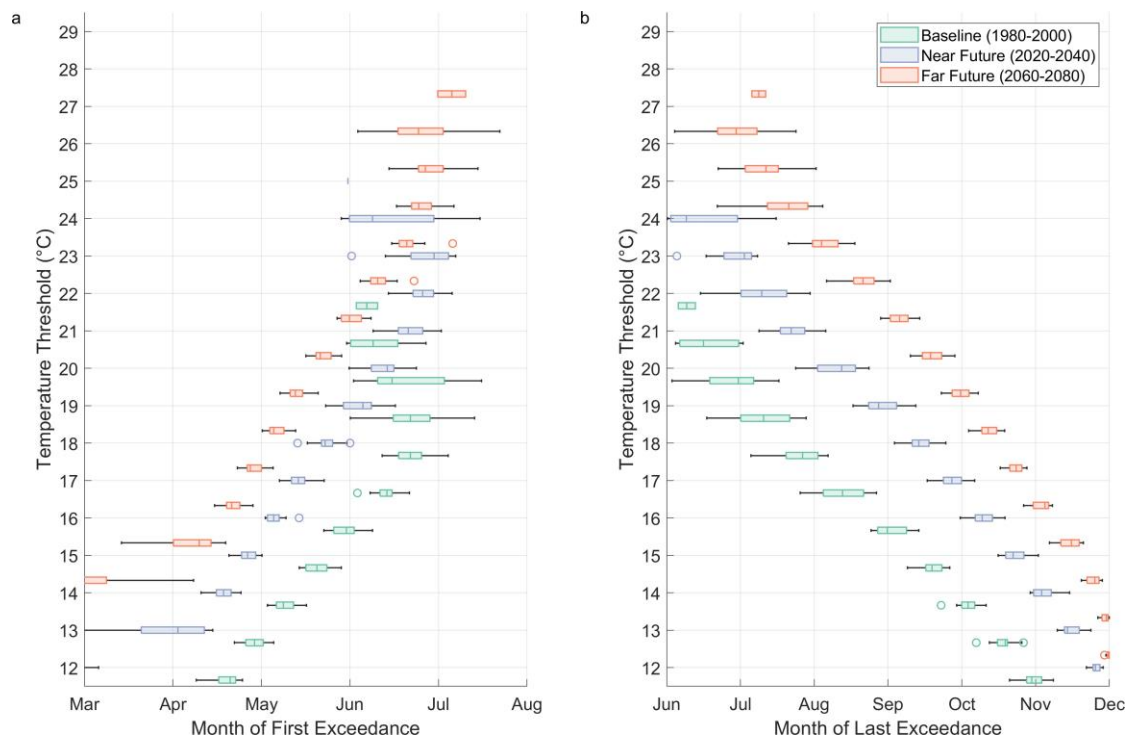


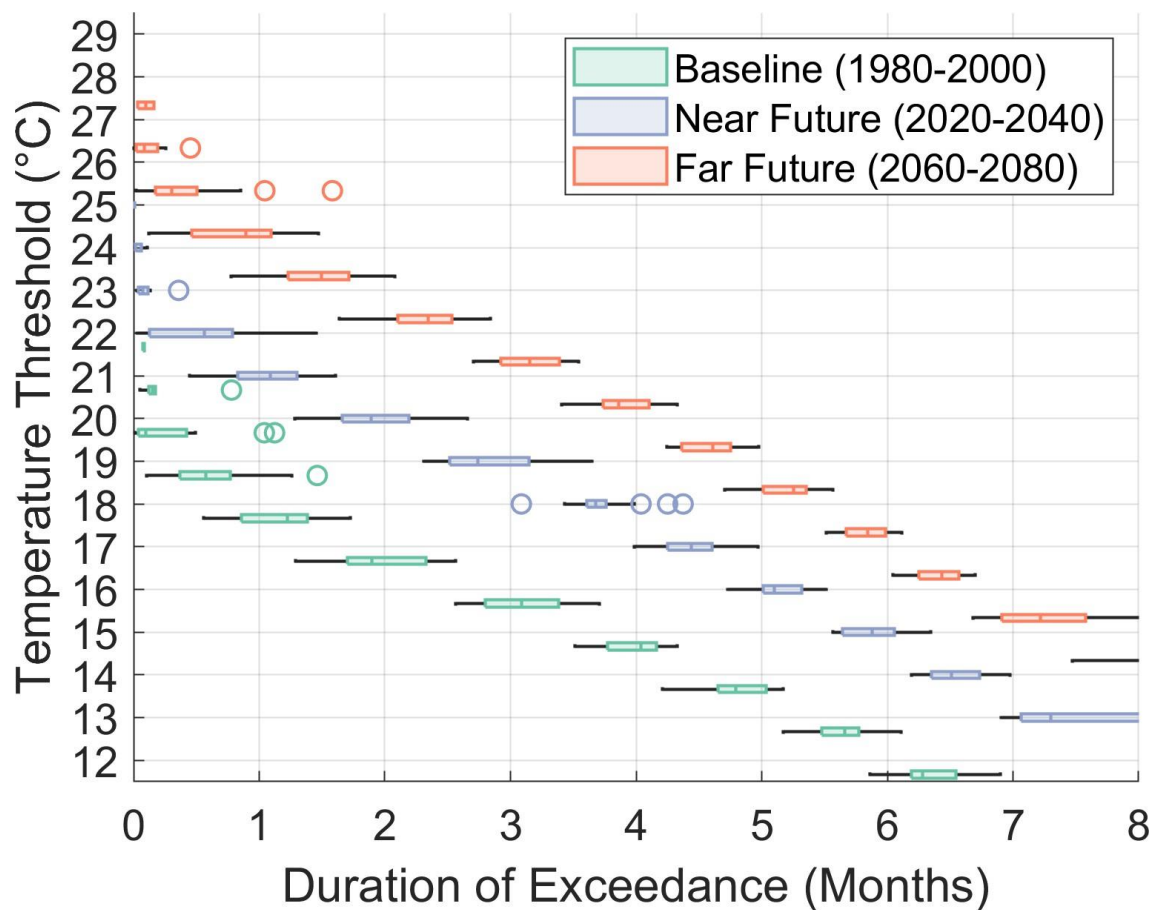
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

- (a) Temperature duration curves represent distribution of SSTs over time to highlight changes in cold and warm extremes.
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Projected temperature changes under different climate scenarios. Box and whisker plots show the range of different modelled durations of temperatures under the 12 different UKCP 18 ensemble members. Open circles indicate outlier values.

Section 2 - Sea surface salinity changes

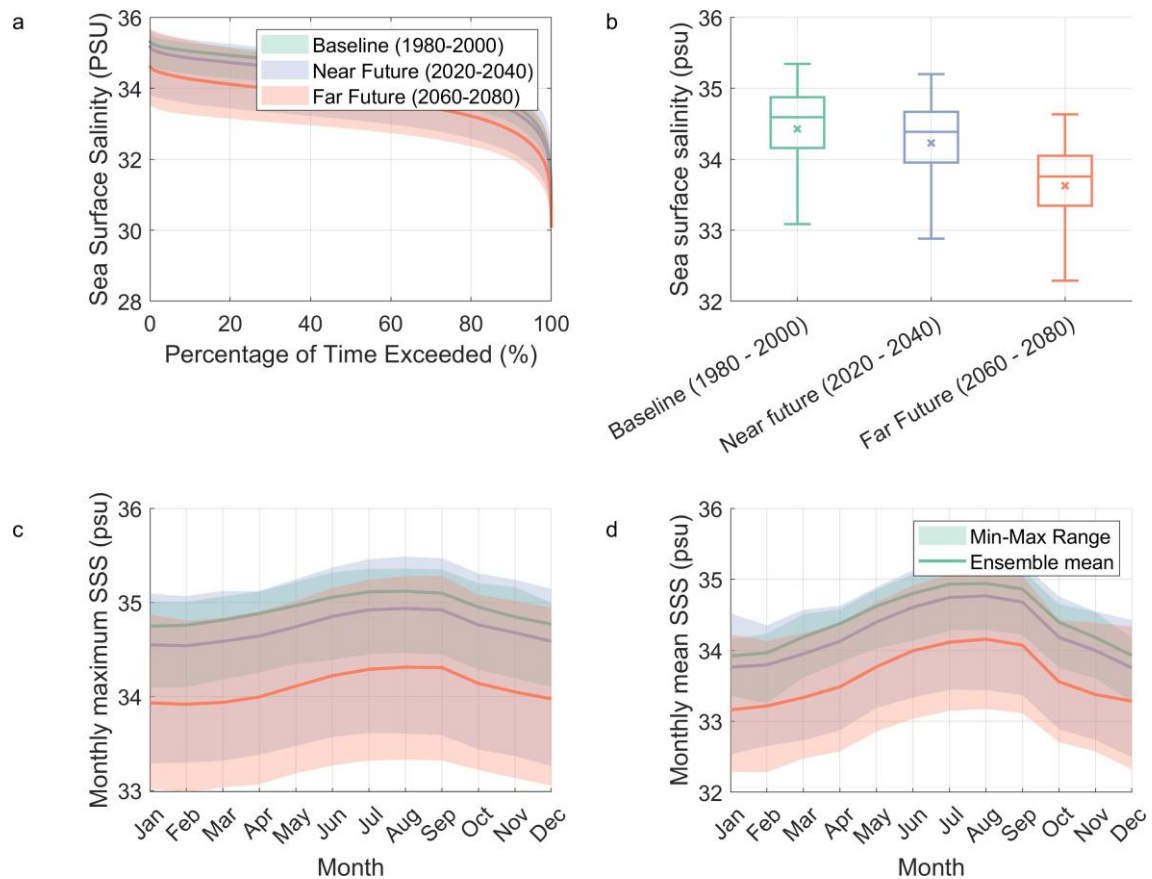


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
- (b) Percentile shifts show decreasing mean, median, and extremes, indicating a trend towards freshening over time.
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- (d) Decreasing monthly means suggest long-term ice-melt driven freshening.

Section 3 - Residual surge changes

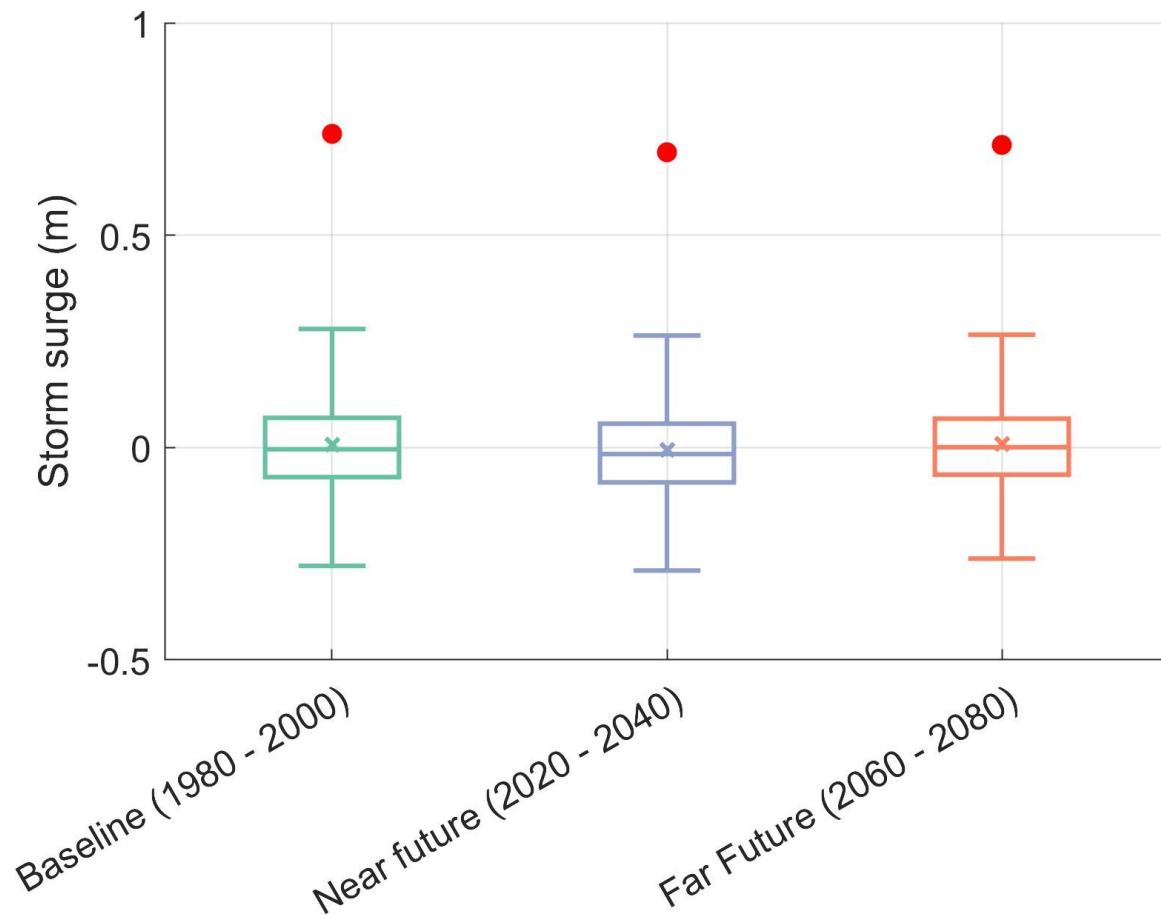


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - River discharge changes

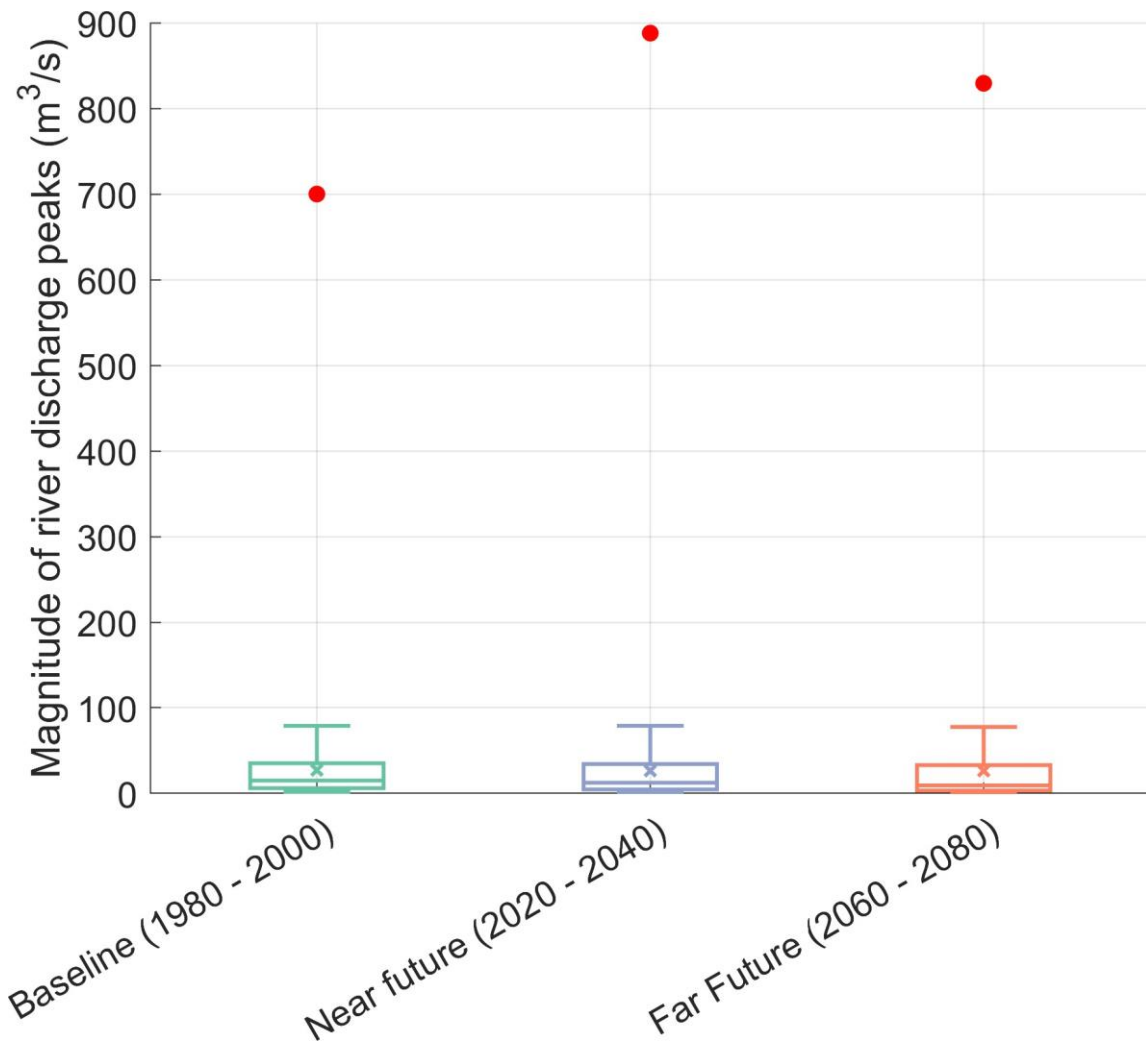


Figure description

Box and whisker plots of discharge percentiles under baseline (1980-2000), near-future (2020-2040) and far-future (2060-2080)

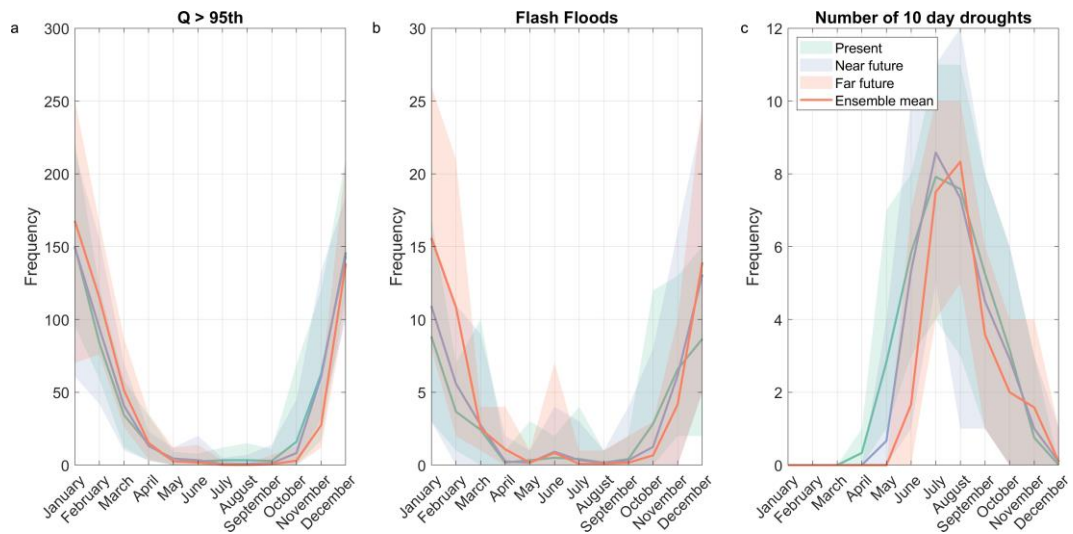


Figure description

Discharge conditions under baseline (1980-2000), near-future (2020-2040) and far-future (2060-2080) showing frequency of (a): Occurrence of high flow (>95th percentile events) per month (hourly resolution), (b): Flash flood events (increase in discharge of >50 m³/s, (c): low flow events lasting longer than 10 days).

Section 5 - Residence times changes

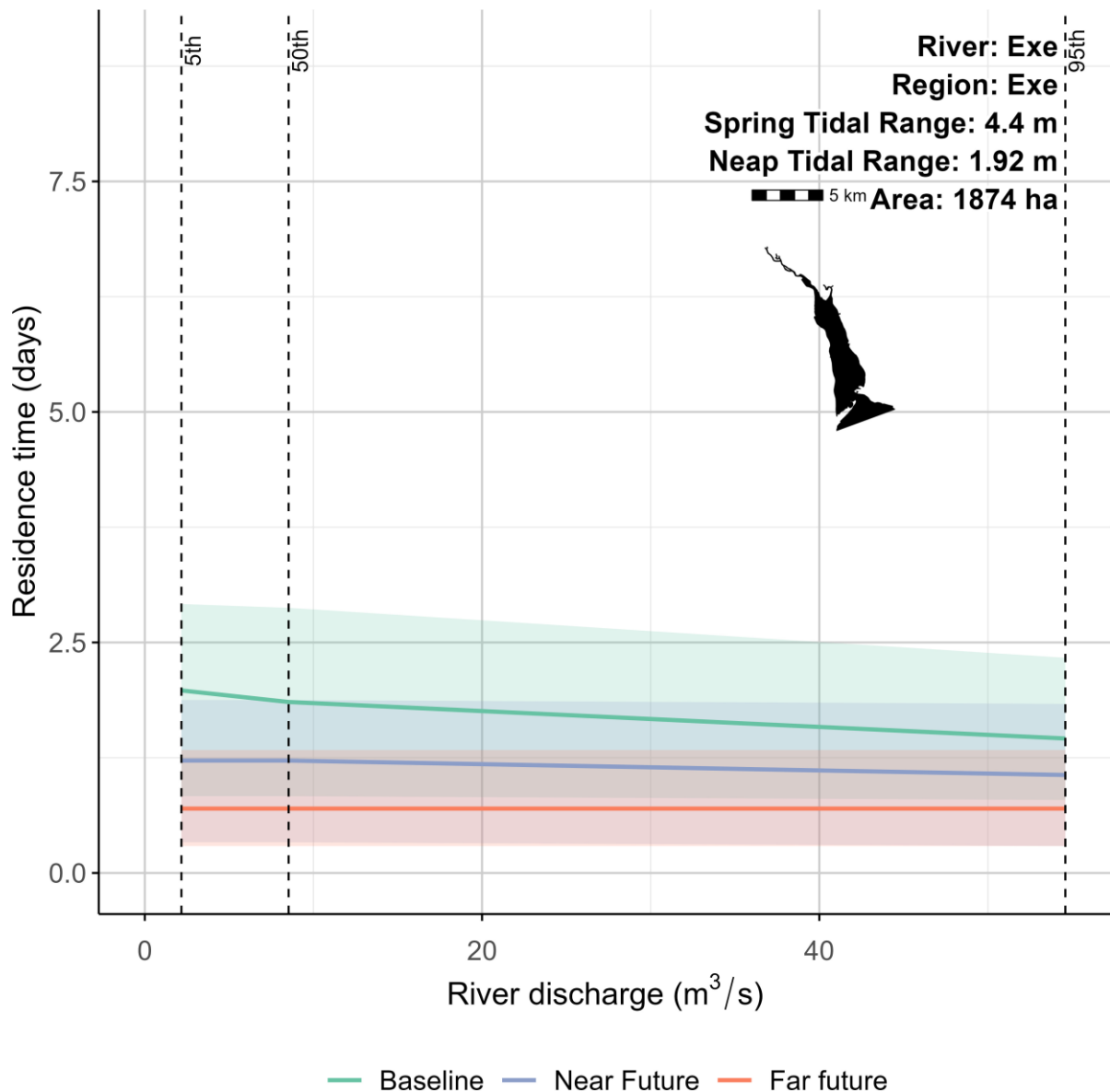


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)
Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Fowey

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	50.43151
Longitude	-4.67953
Tidal Range	4.8 m
Gauge Name	Fowey at Restormel
Estuary Size	2560000.0 m ²
5th percentile flow	0.883 m ³ /s
50th percentile flow	3.032 m ³ /s
95th percentile flow	14.19 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

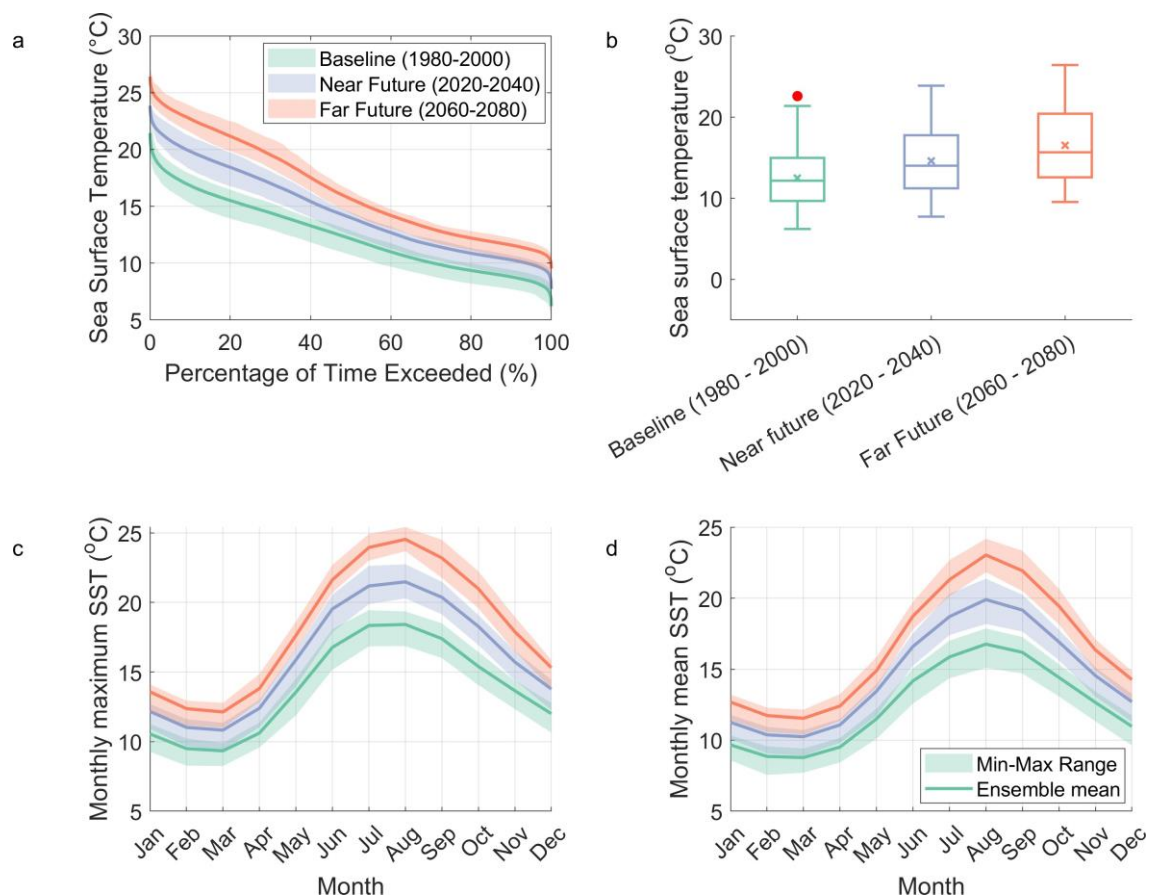
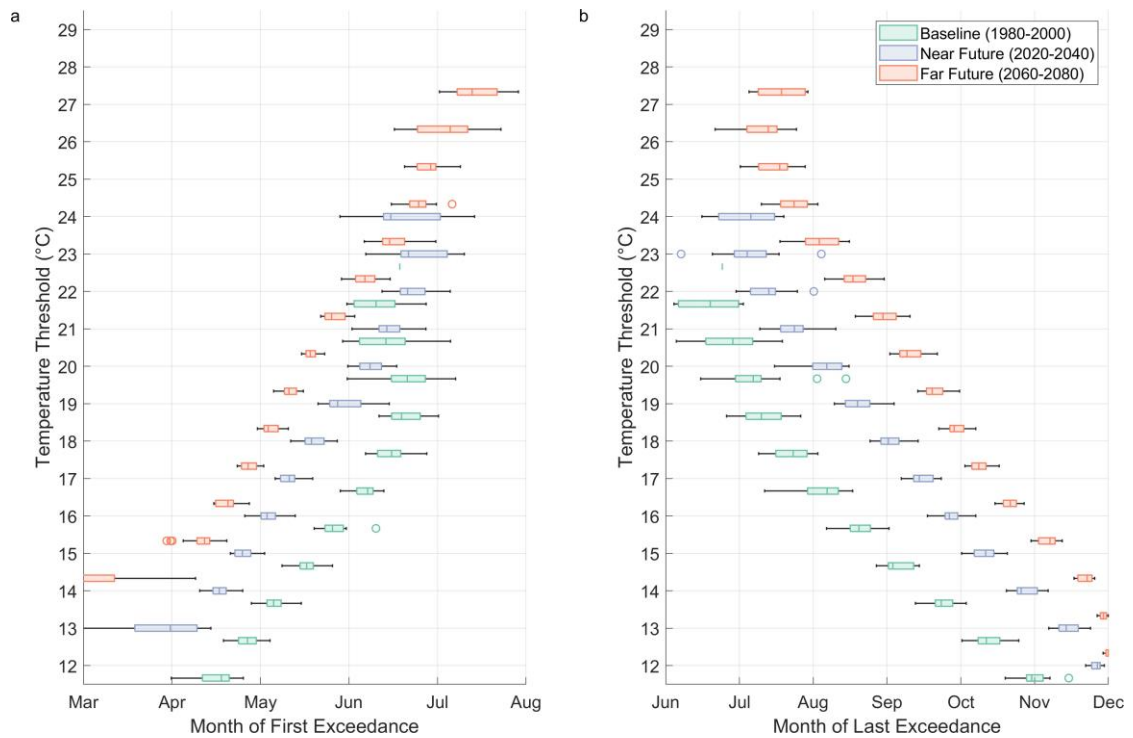


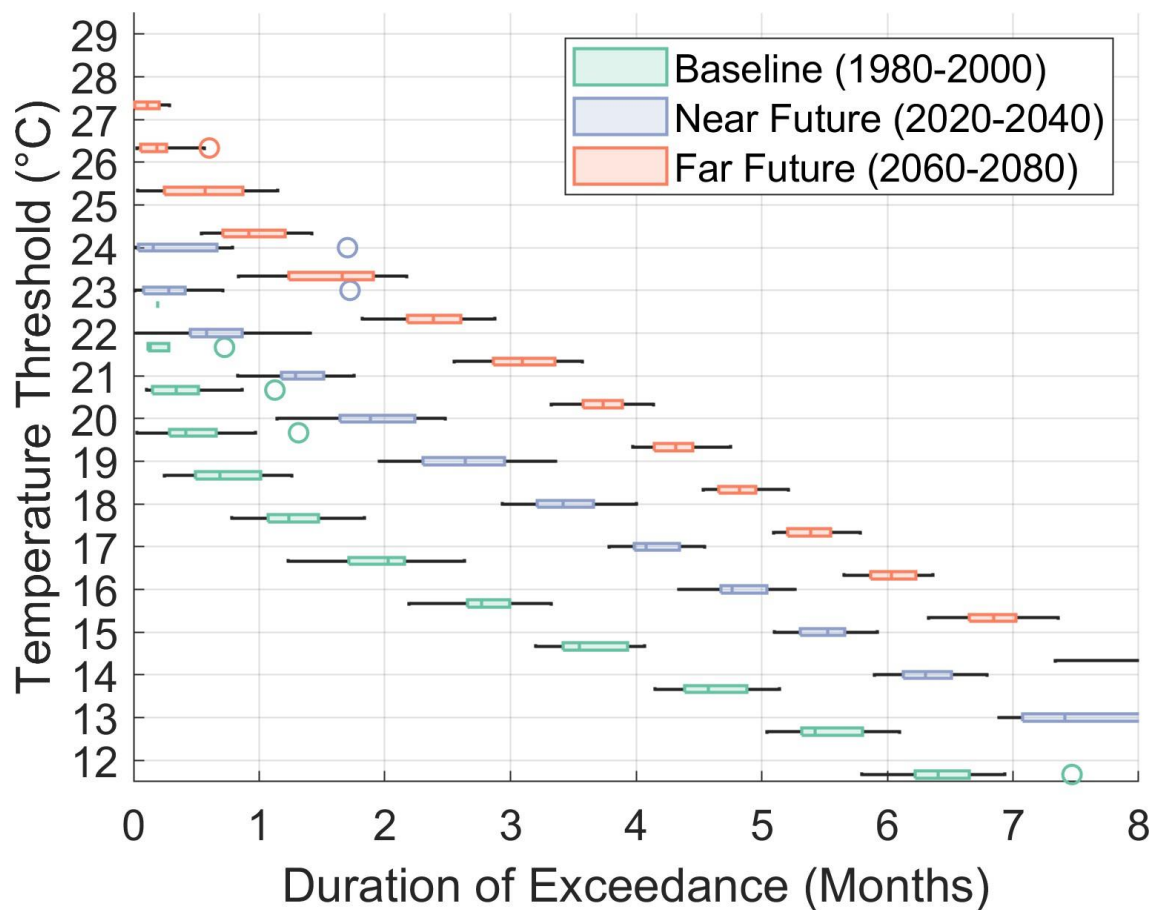
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

- (a) Temperature duration curves represent distribution of SSTs over time to highlight changes in cold and warm extremes.
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Projected temperature changes under different climate scenarios. Box and whisker plots show the range of different modelled durations of temperatures under the 12 different UKCP 18 ensemble members. Open circles indicate outlier values.

Section 2 - Sea surface salinity changes

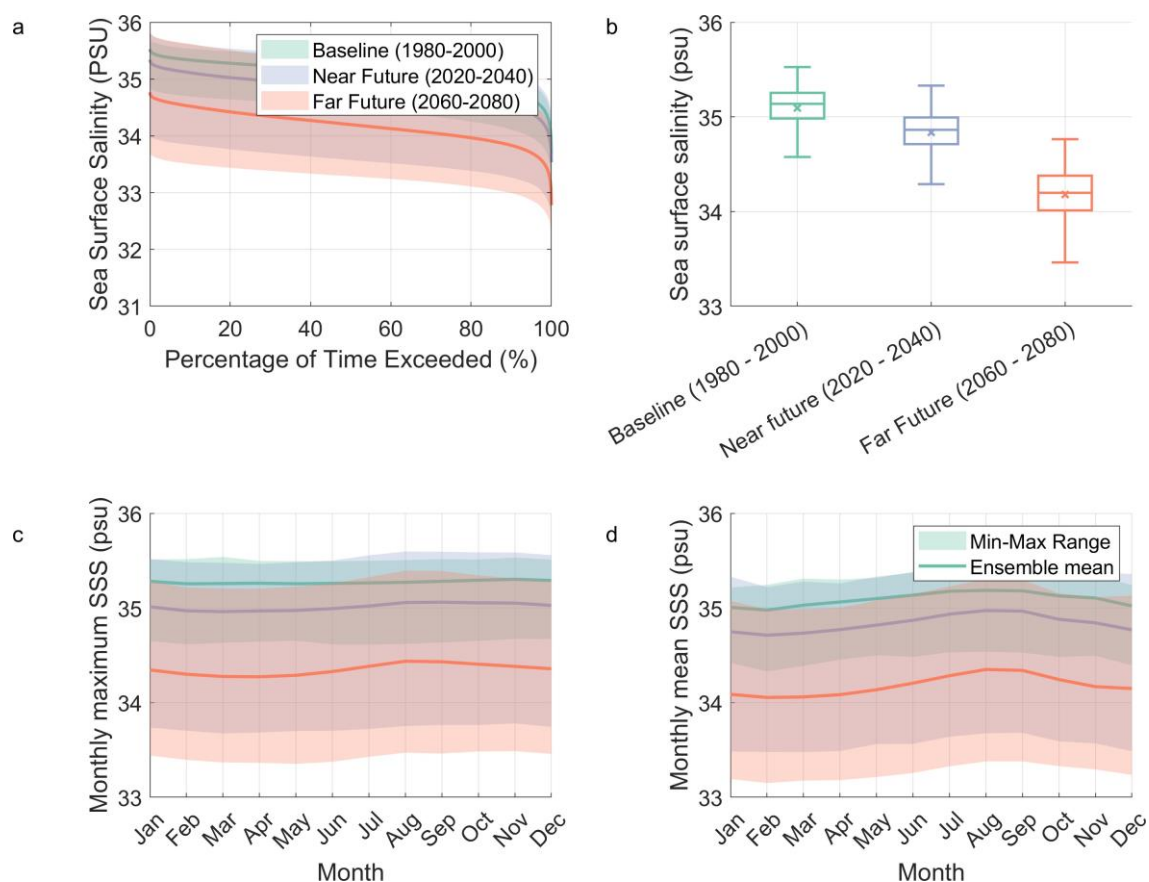


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
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Section 3 - Residual surge changes

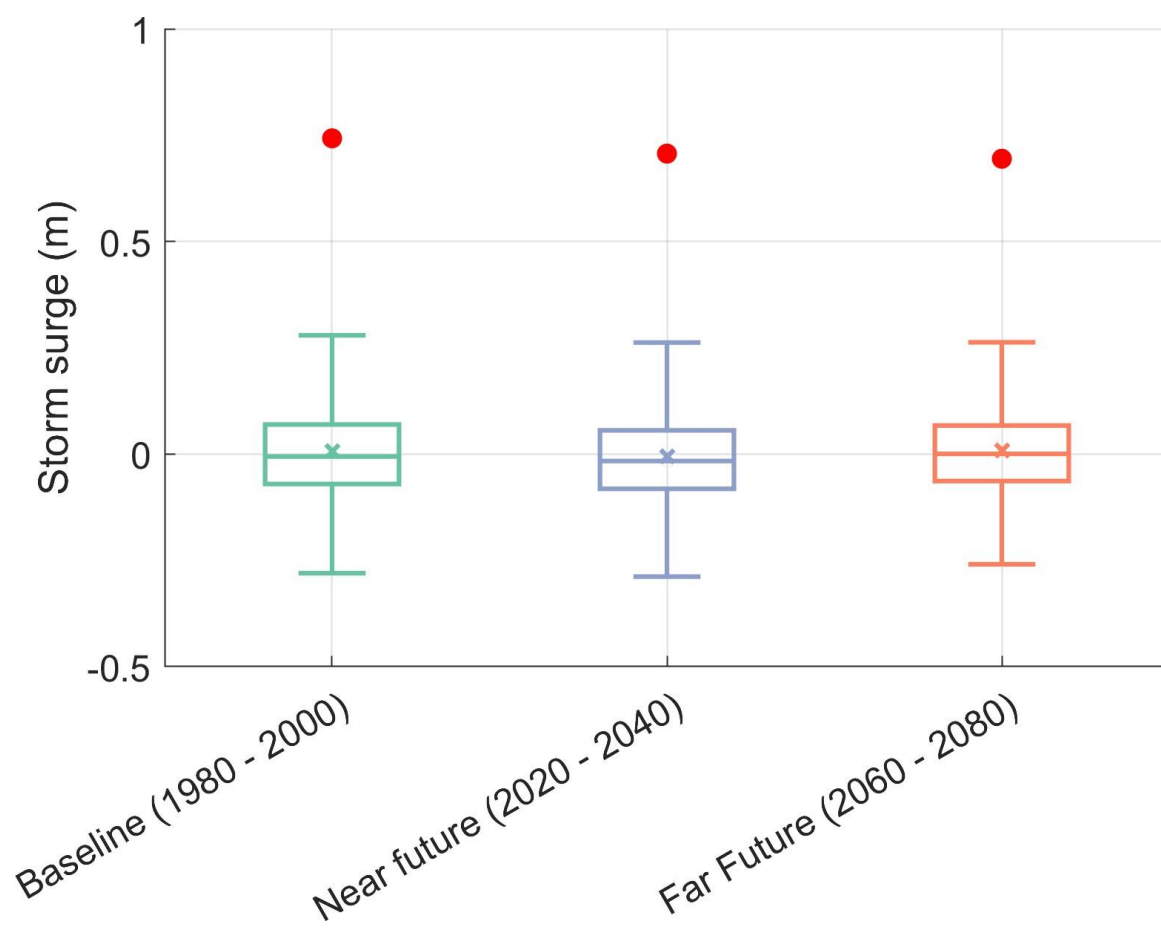


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

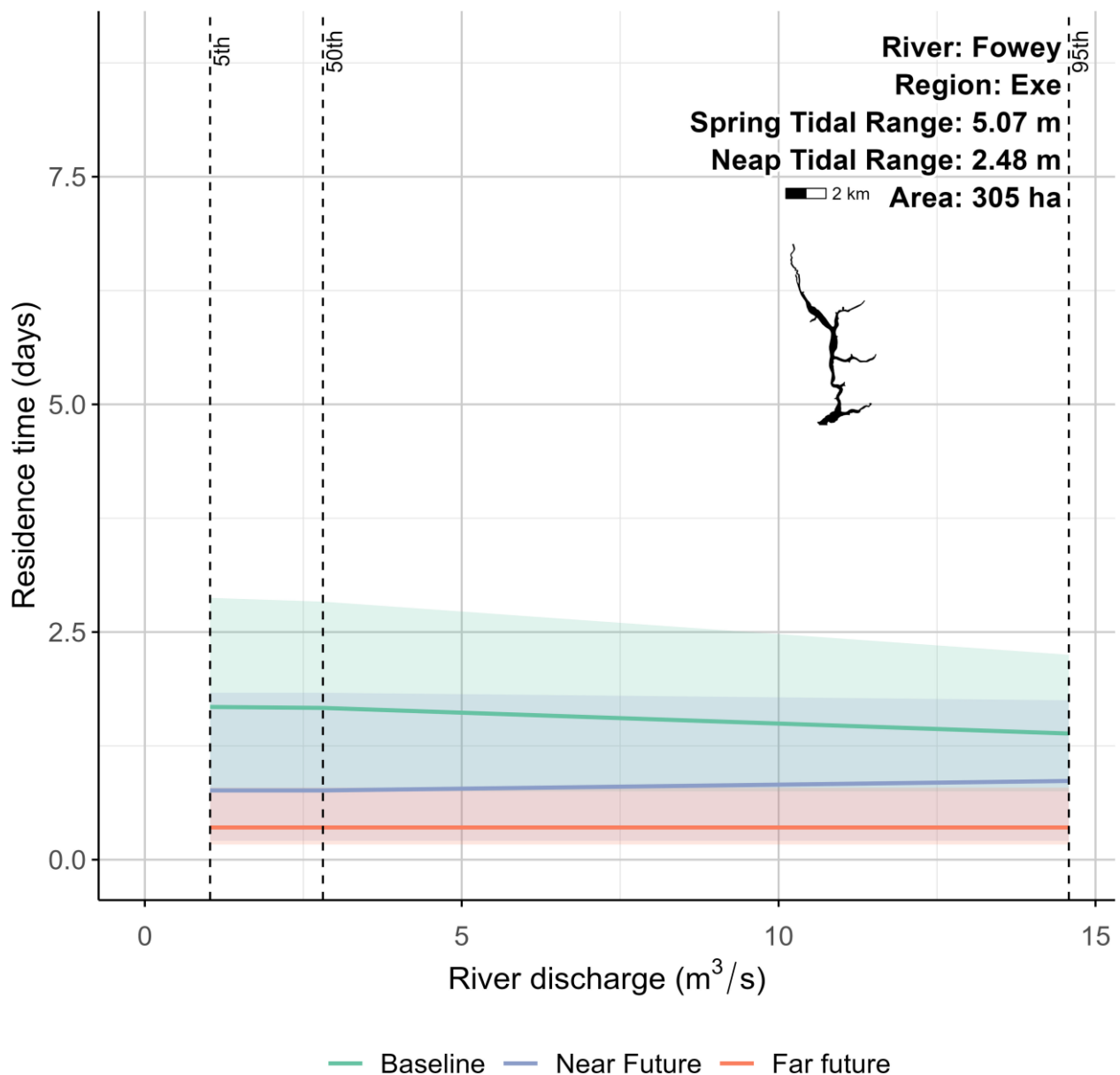


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Gannel

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	50.39313
Longitude	-5.05631
Tidal Range	6.4 m
Gauge Name	Gannel at Gwills
Estuary Size	786000.0 m ²
5th percentile flow	0.091 m ³ /s
50th percentile flow	0.448 m ³ /s
95th percentile flow	2.3 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

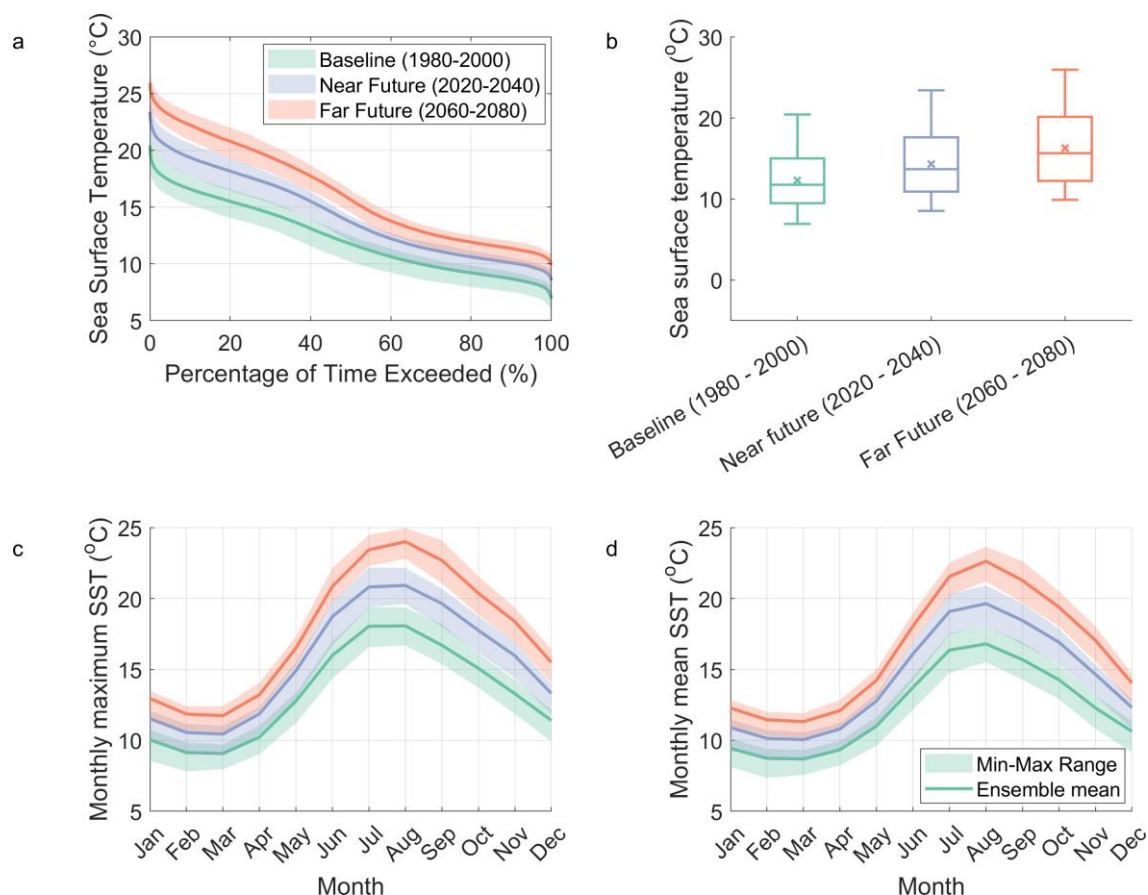
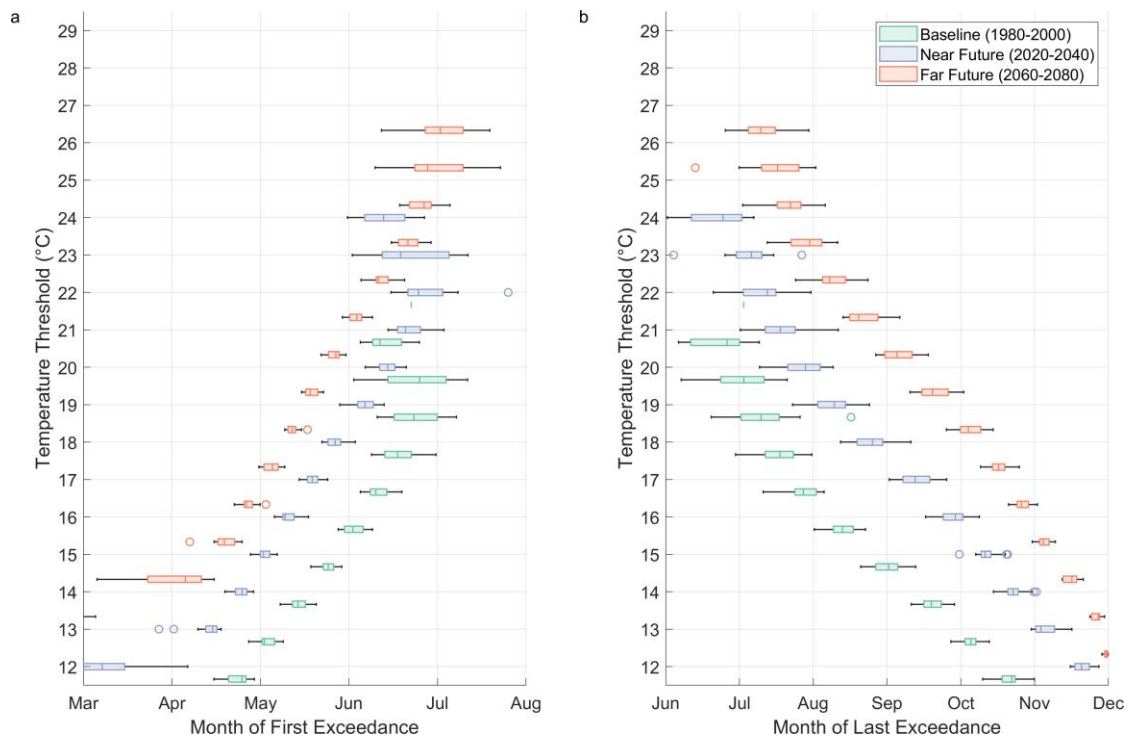


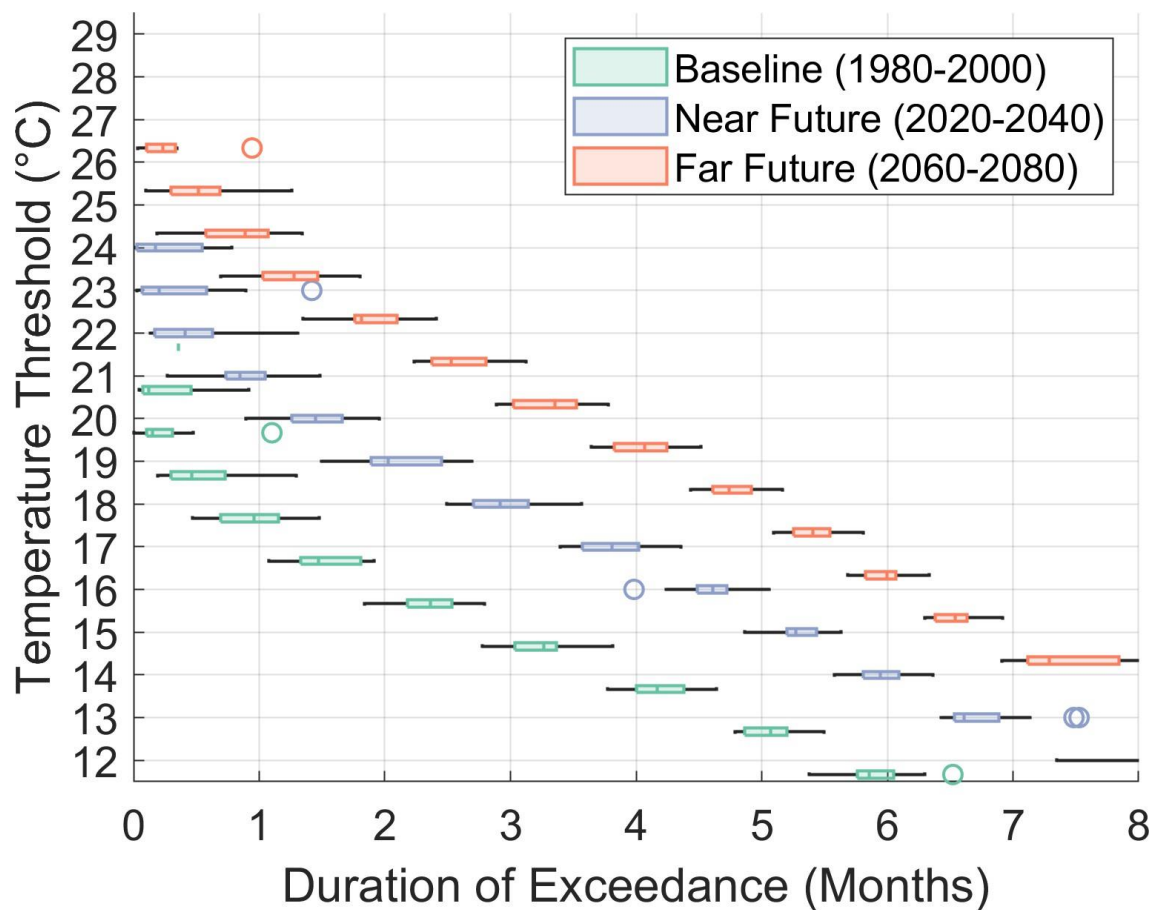
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

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Section 2 - Sea surface salinity changes

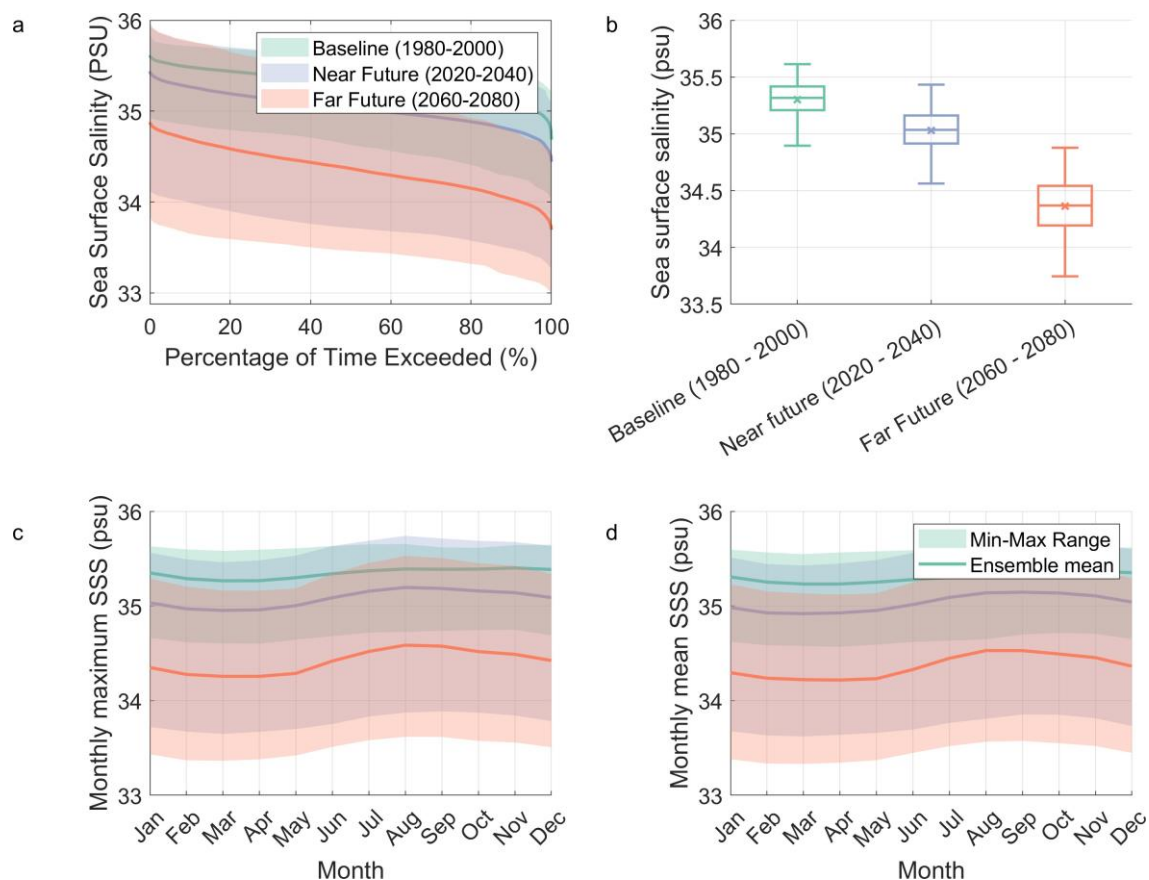


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
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Section 3 - Residual surge changes

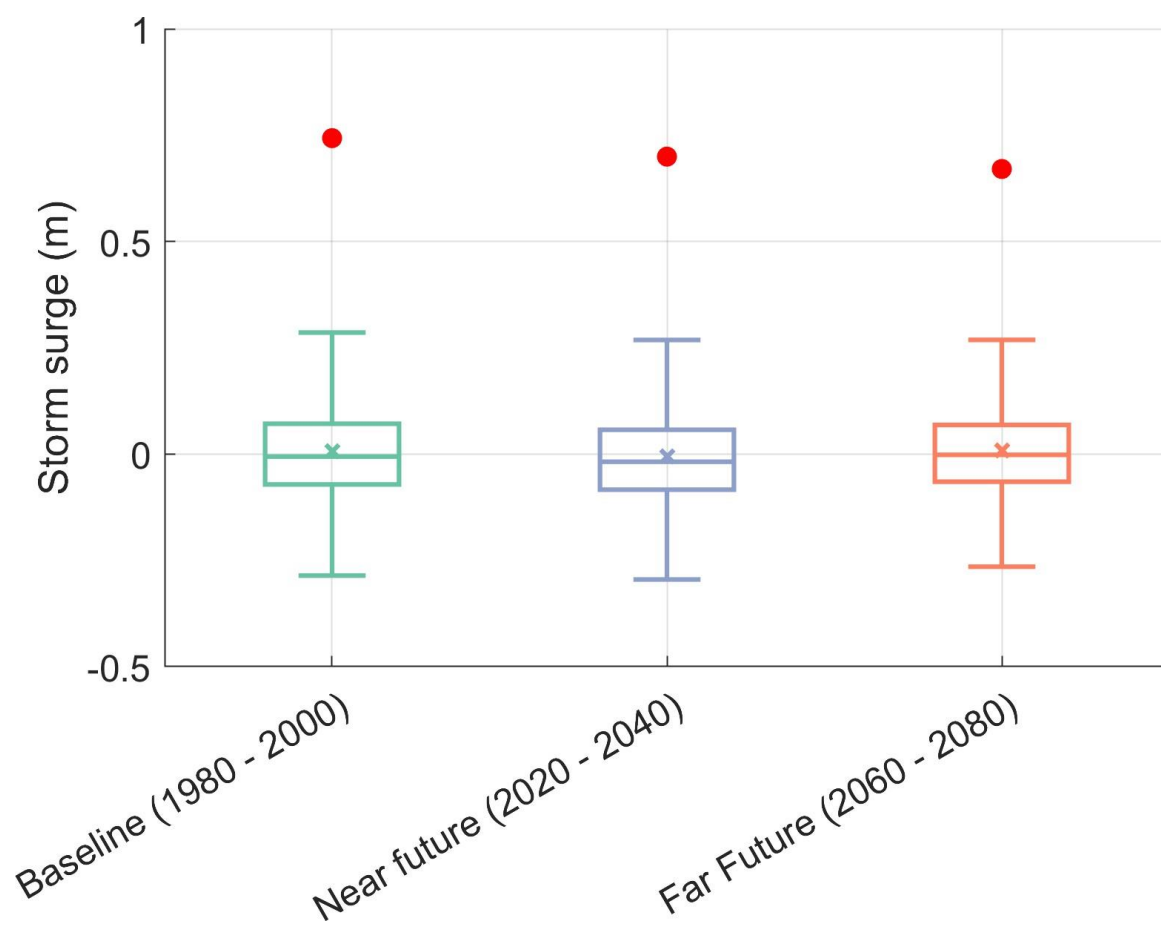


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

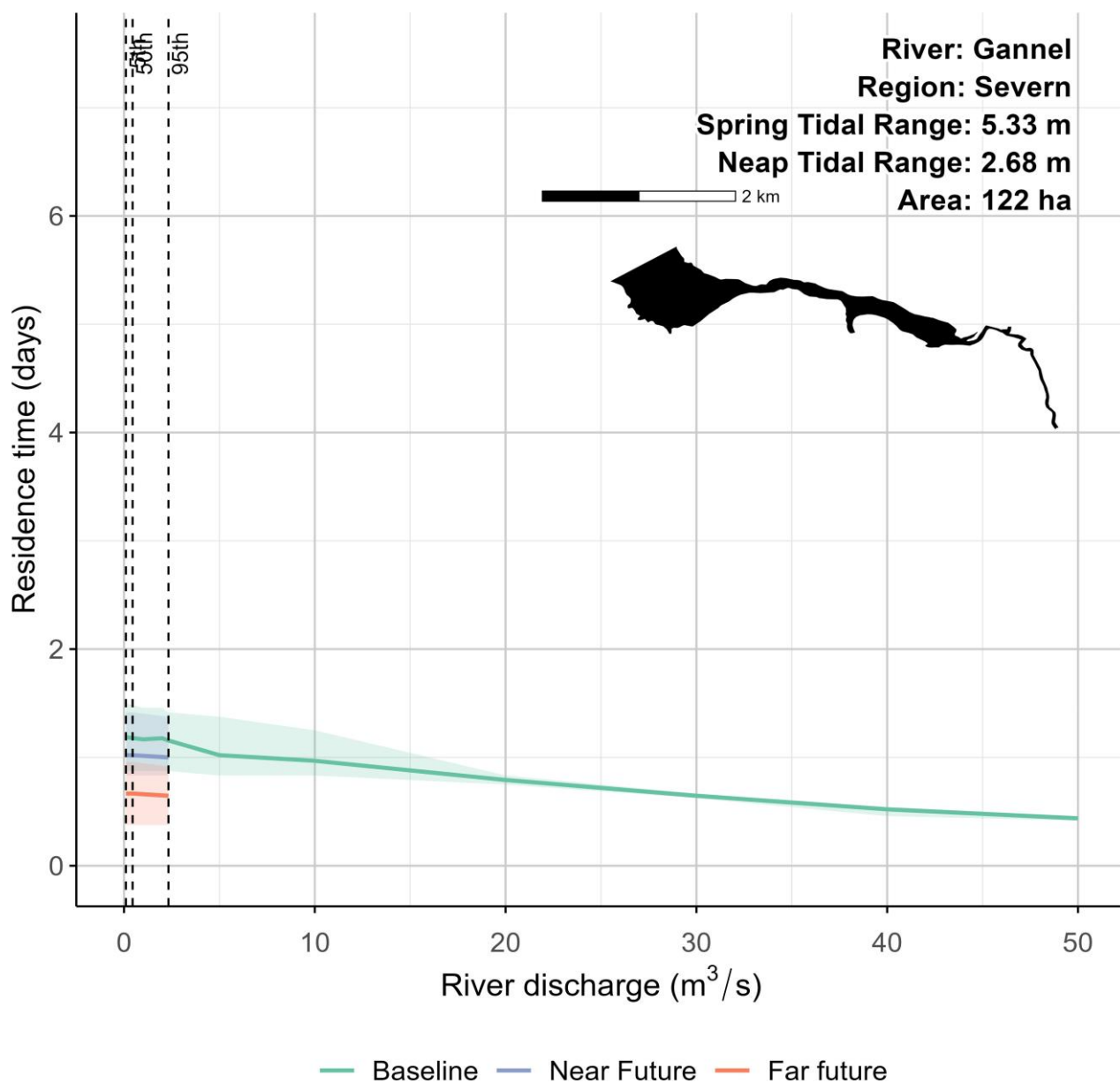


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Hayle

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	50.15676
Longitude	-5.43391
Tidal Range	5.8 m
Gauge Name	Hayle at St Erth
Estuary Size	512000.0 m ²
5th percentile flow	0.231 m ³ /s
50th percentile flow	0.695 m ³ /s
95th percentile flow	2.79 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

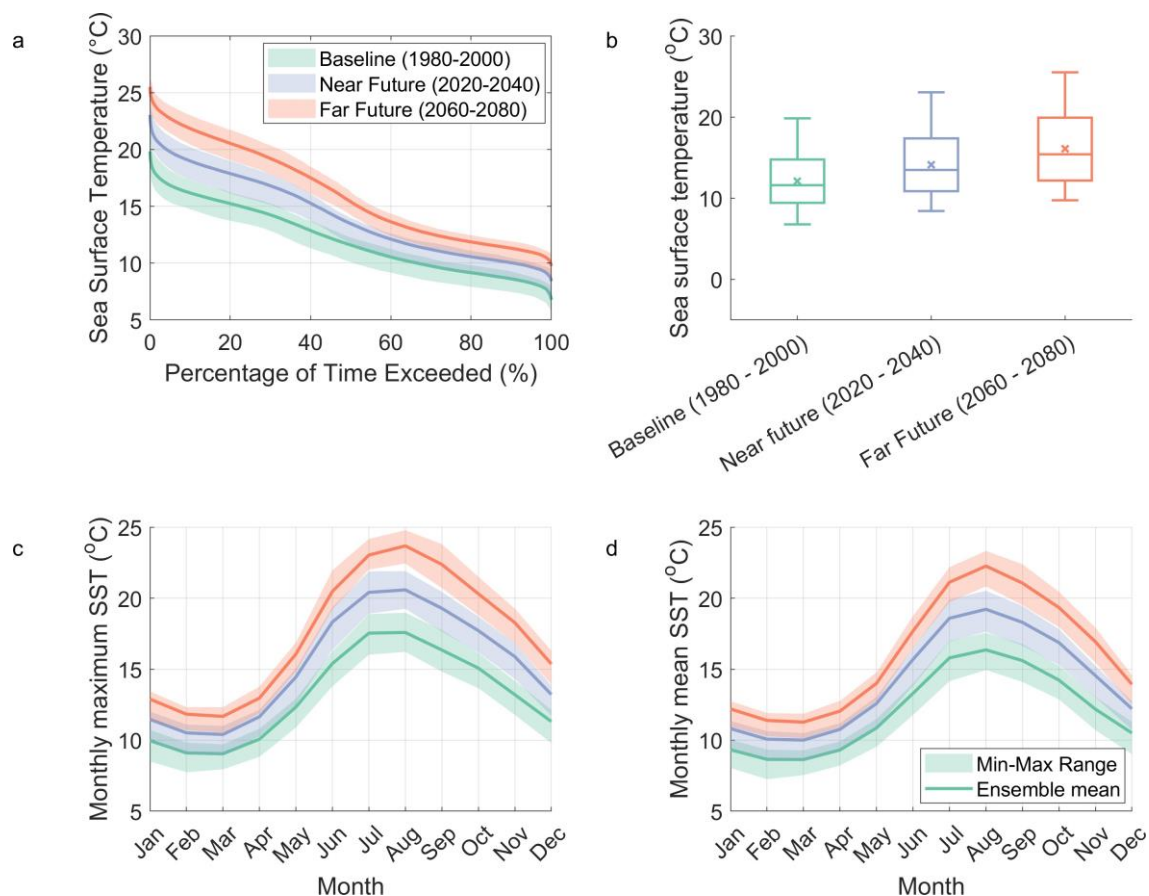
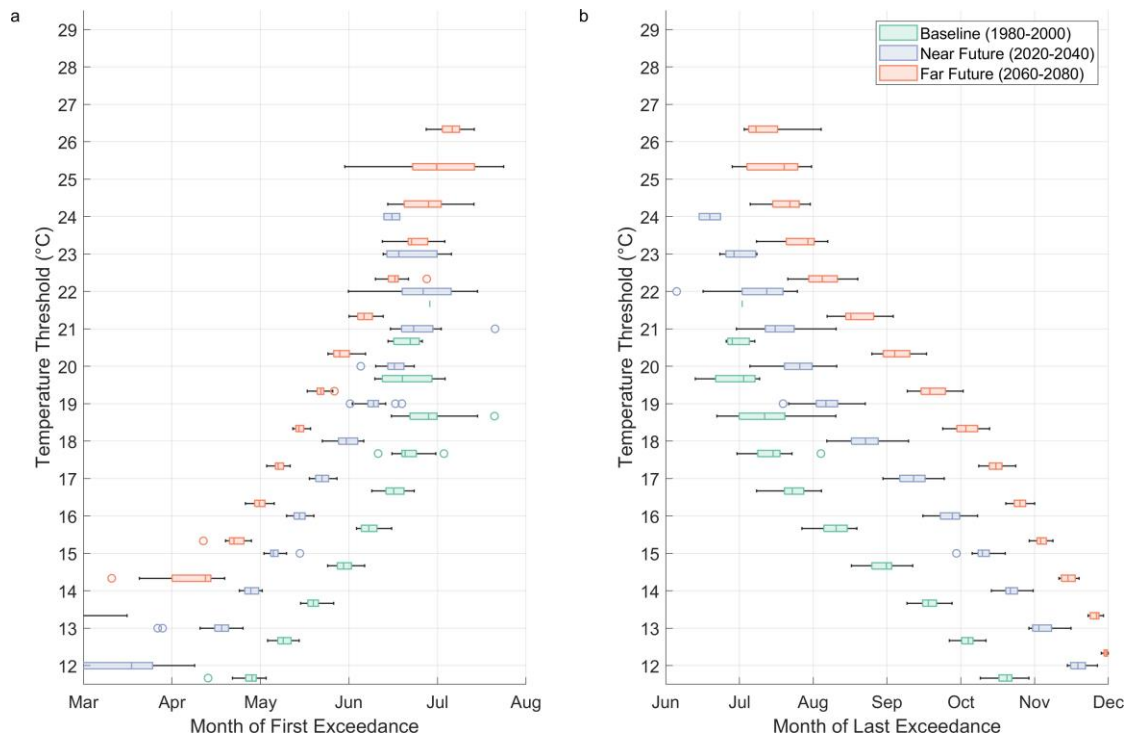


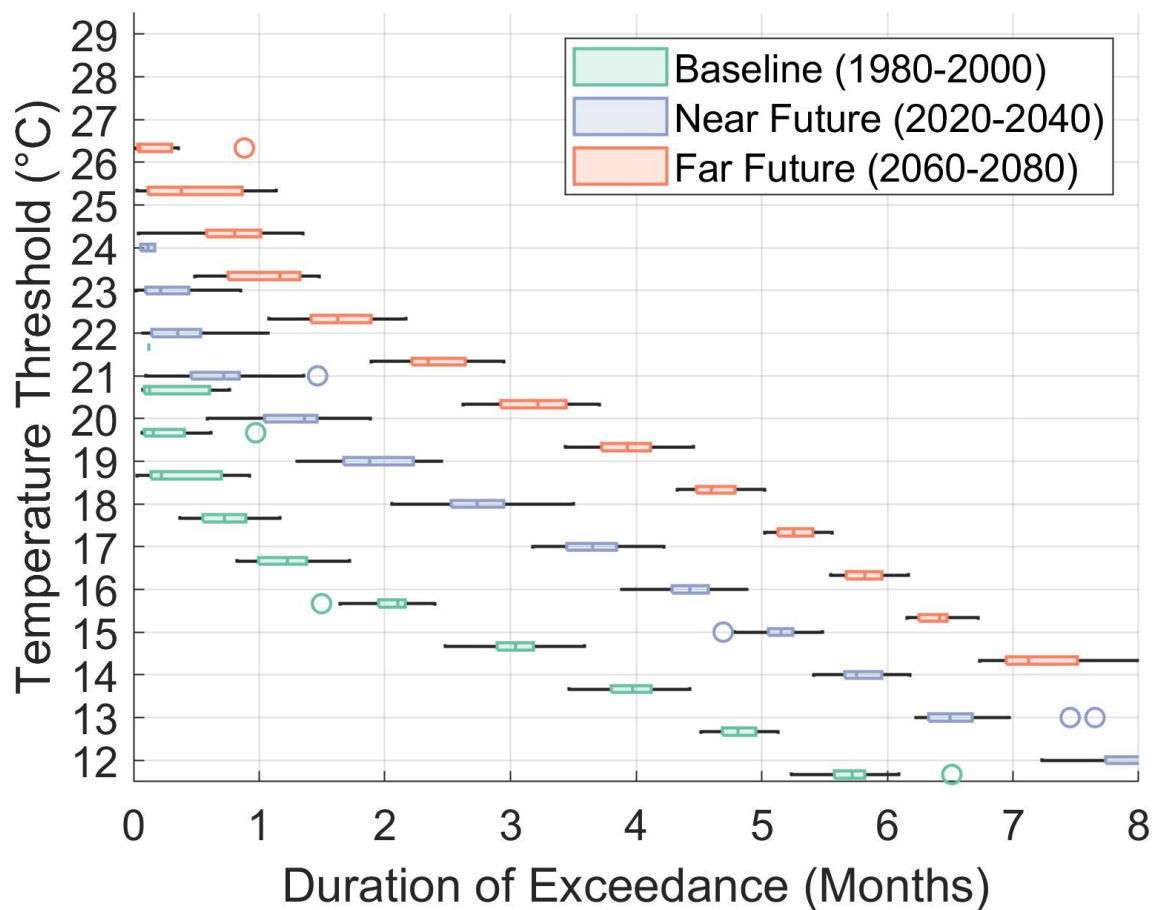
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

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Section 2 - Sea surface salinity changes

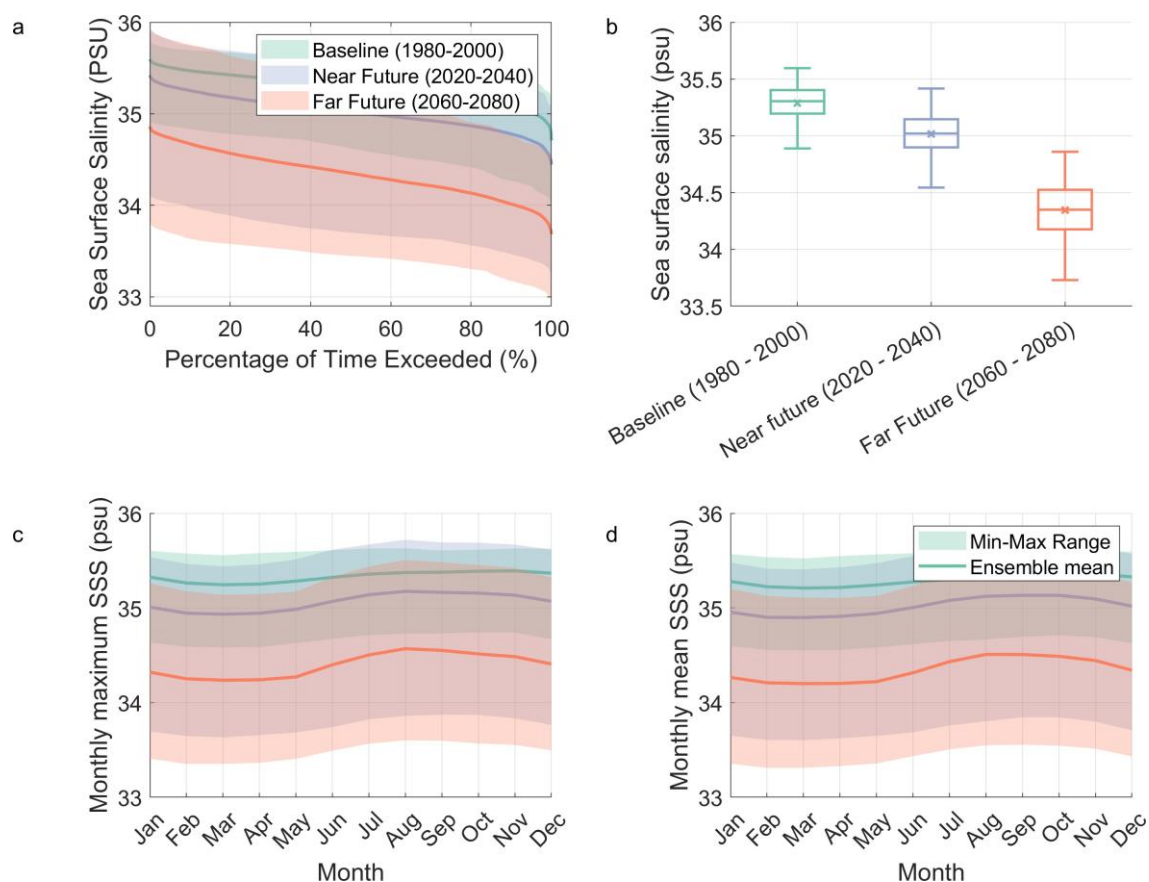


Figure description

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- (b) Percentile shifts show decreasing mean, median, and extremes, indicating a trend towards freshening over time.
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Section 3 - Residual surge changes

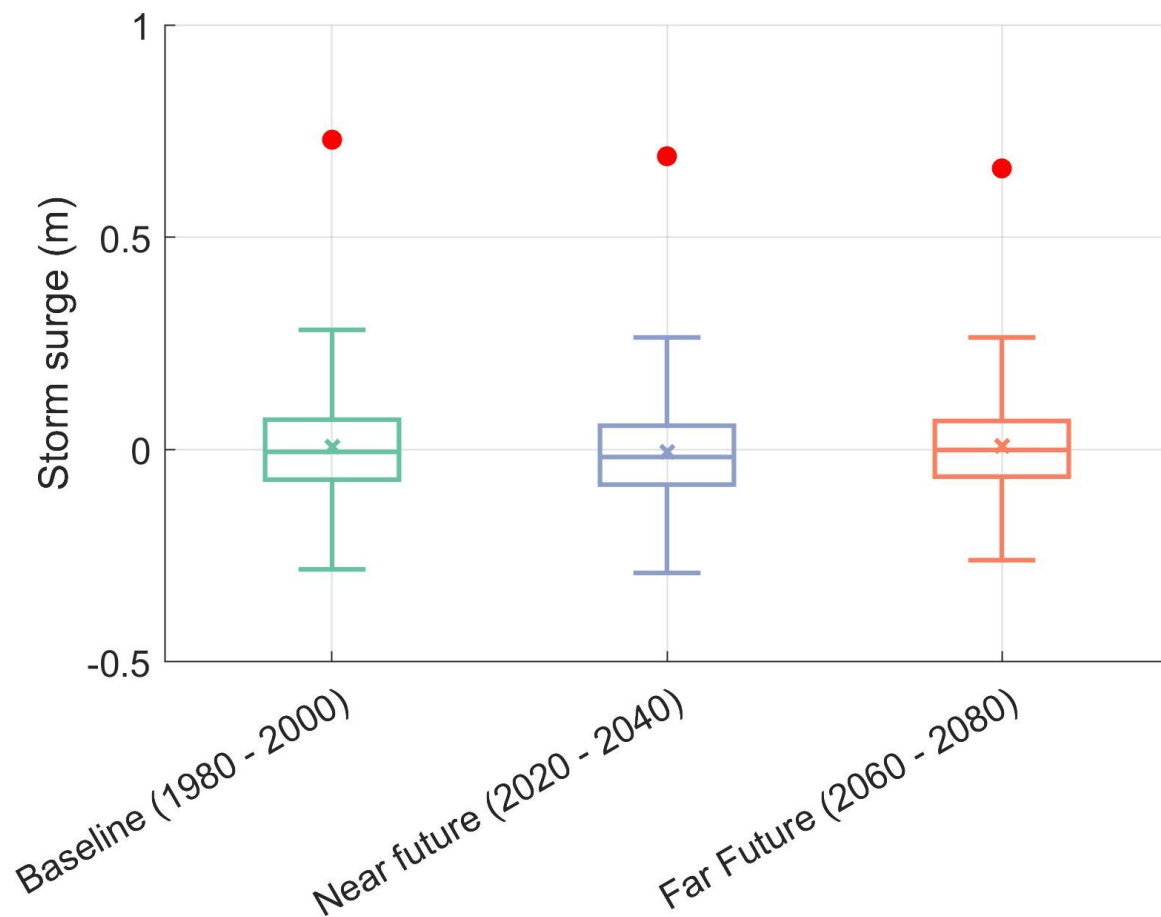


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

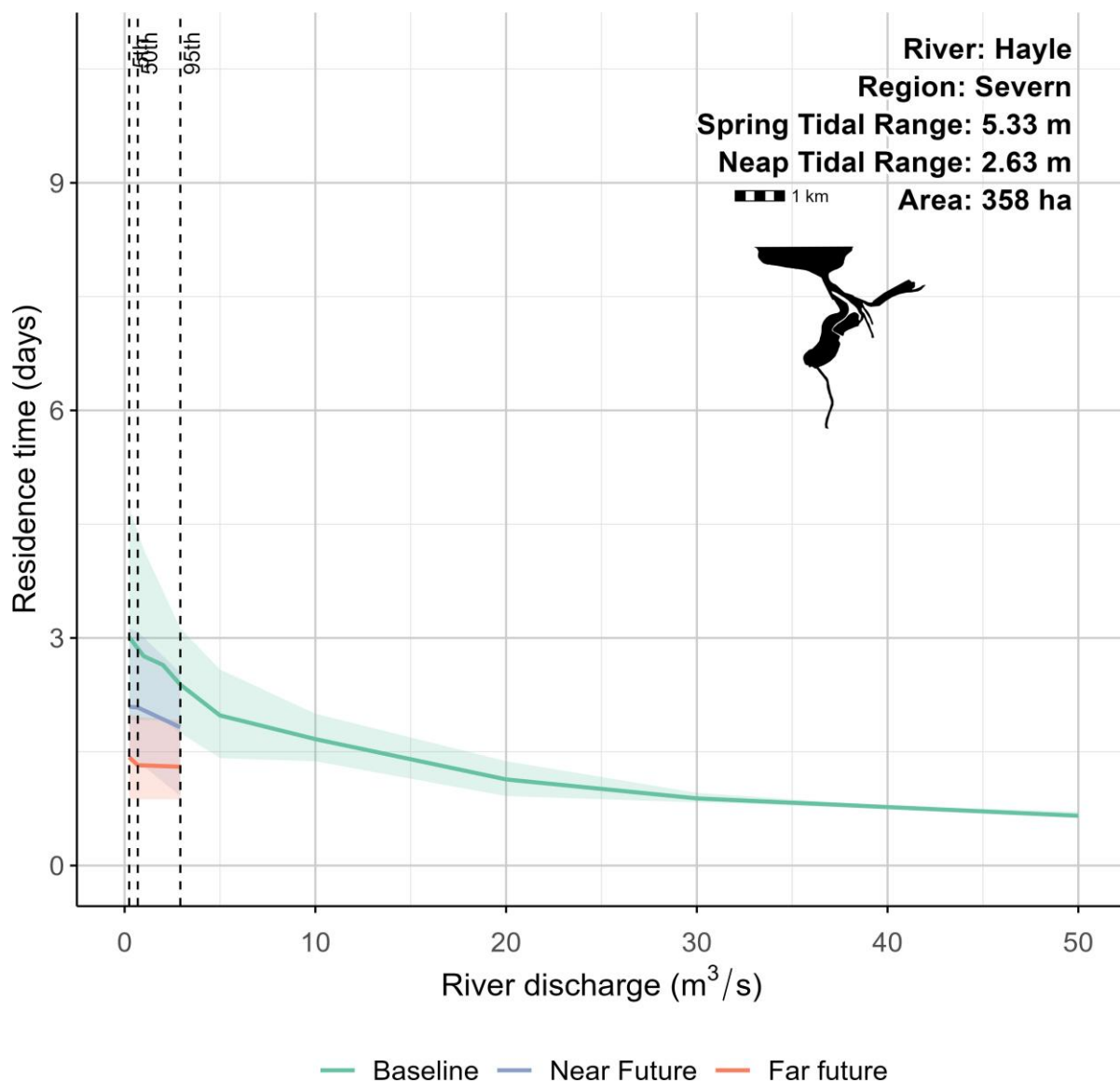


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Humber_Trent

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	53.13596
Longitude	-0.79906
Tidal Range	5.8 m
Gauge Name	Trent at North Muskham
Estuary Size	288000000.0 m ²
5th percentile flow	28.05 m ³ /s
50th percentile flow	63.05 m ³ /s
95th percentile flow	253.1 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

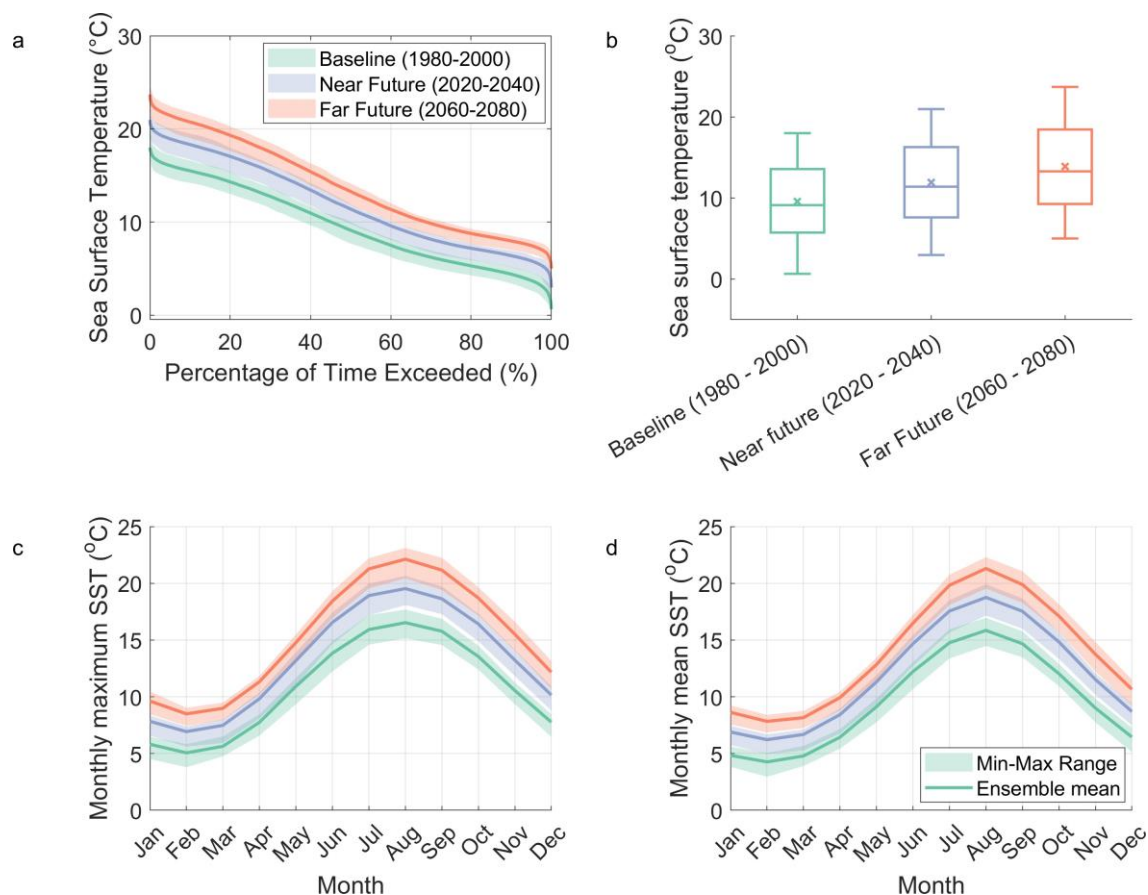
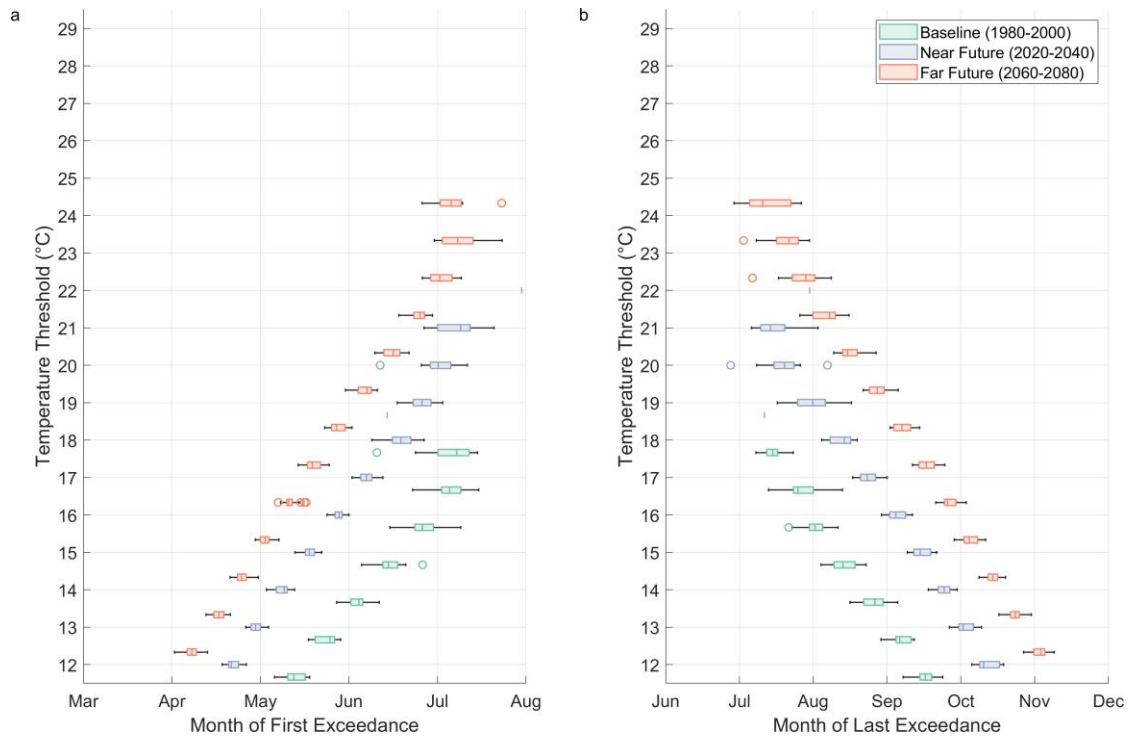


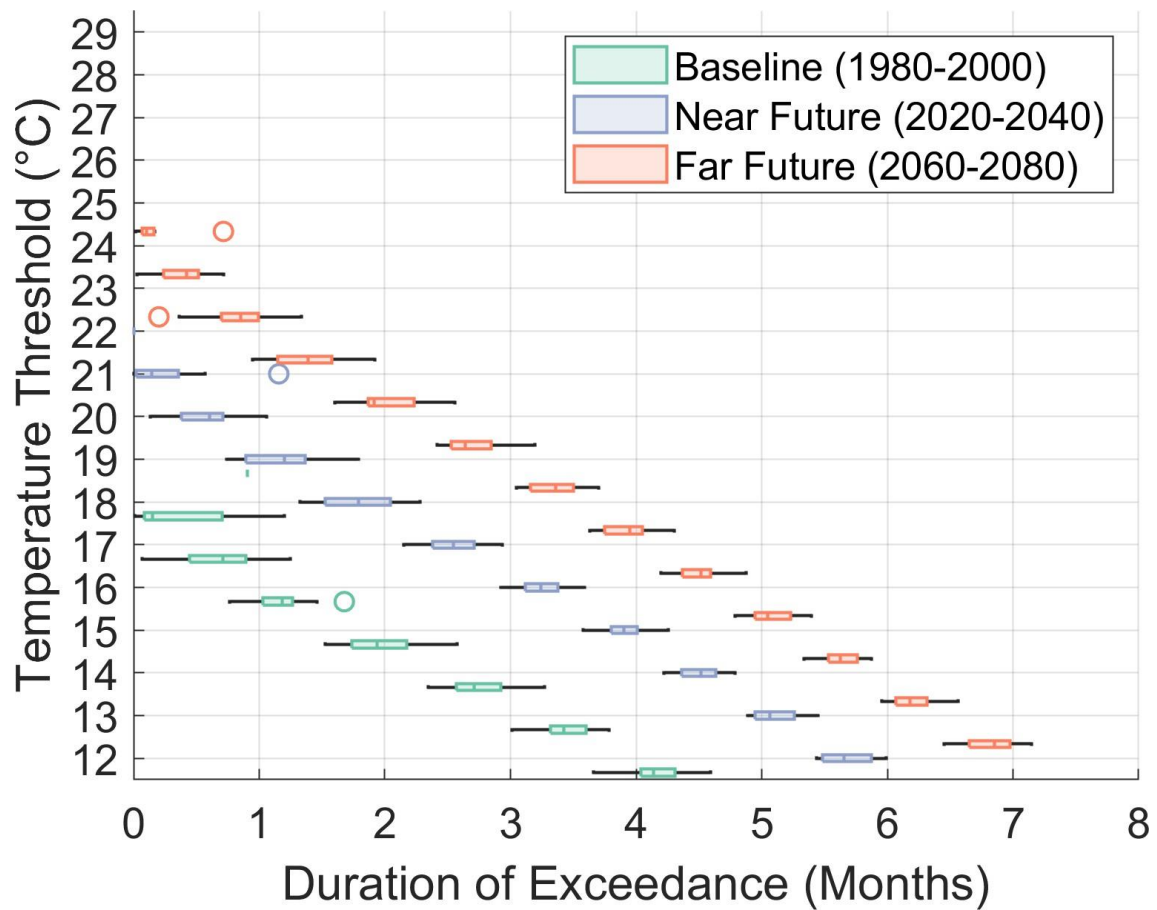
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

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Section 2 - Sea surface salinity changes

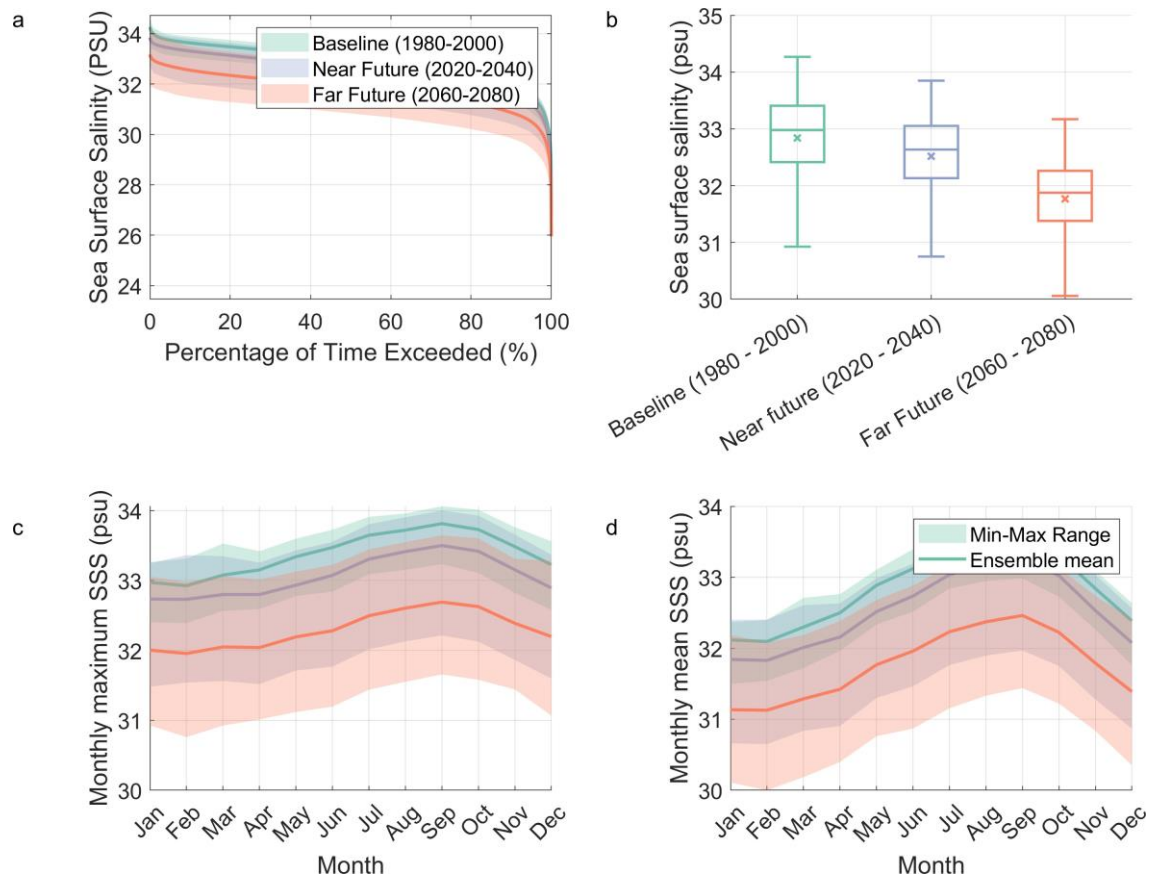


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
- (b) Percentile shifts show decreasing mean, median, and extremes, indicating a trend towards freshening over time.
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Section 3 - Residual surge changes

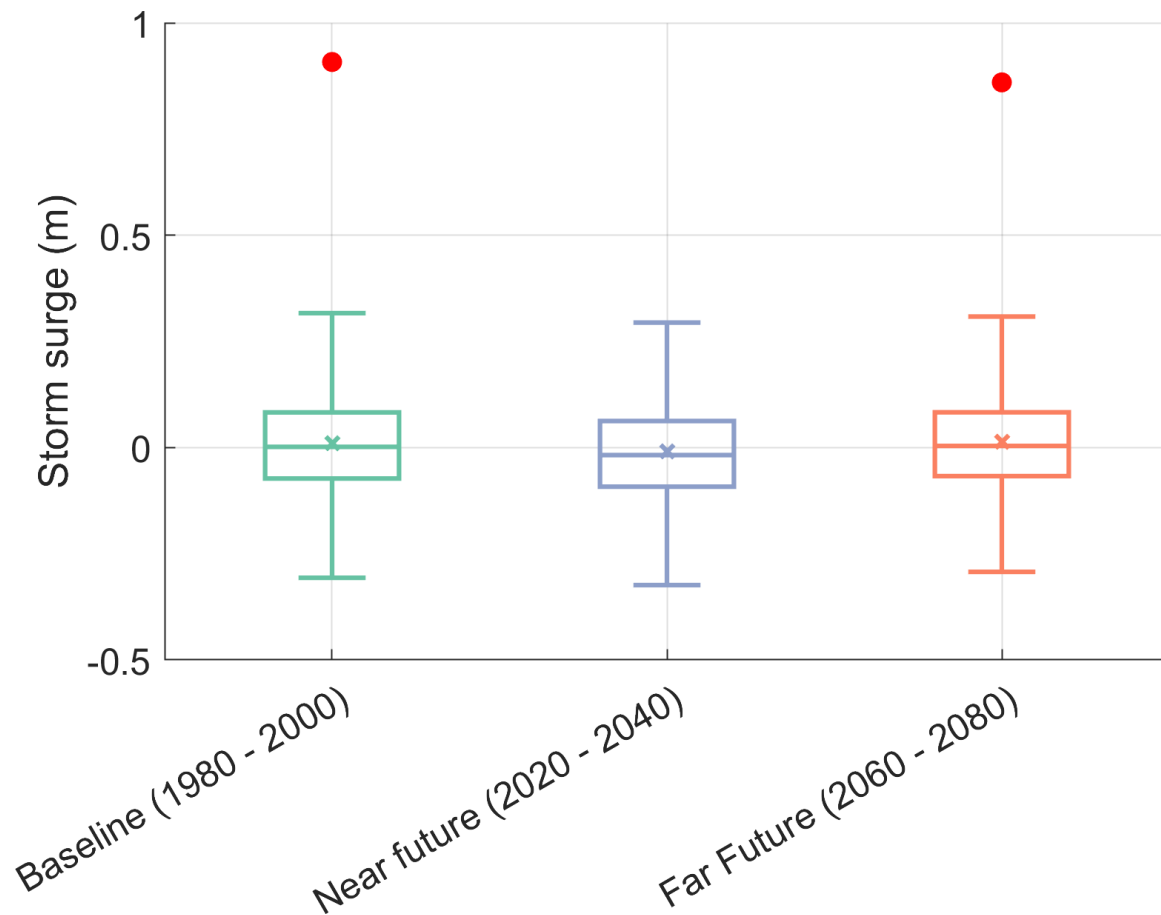


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

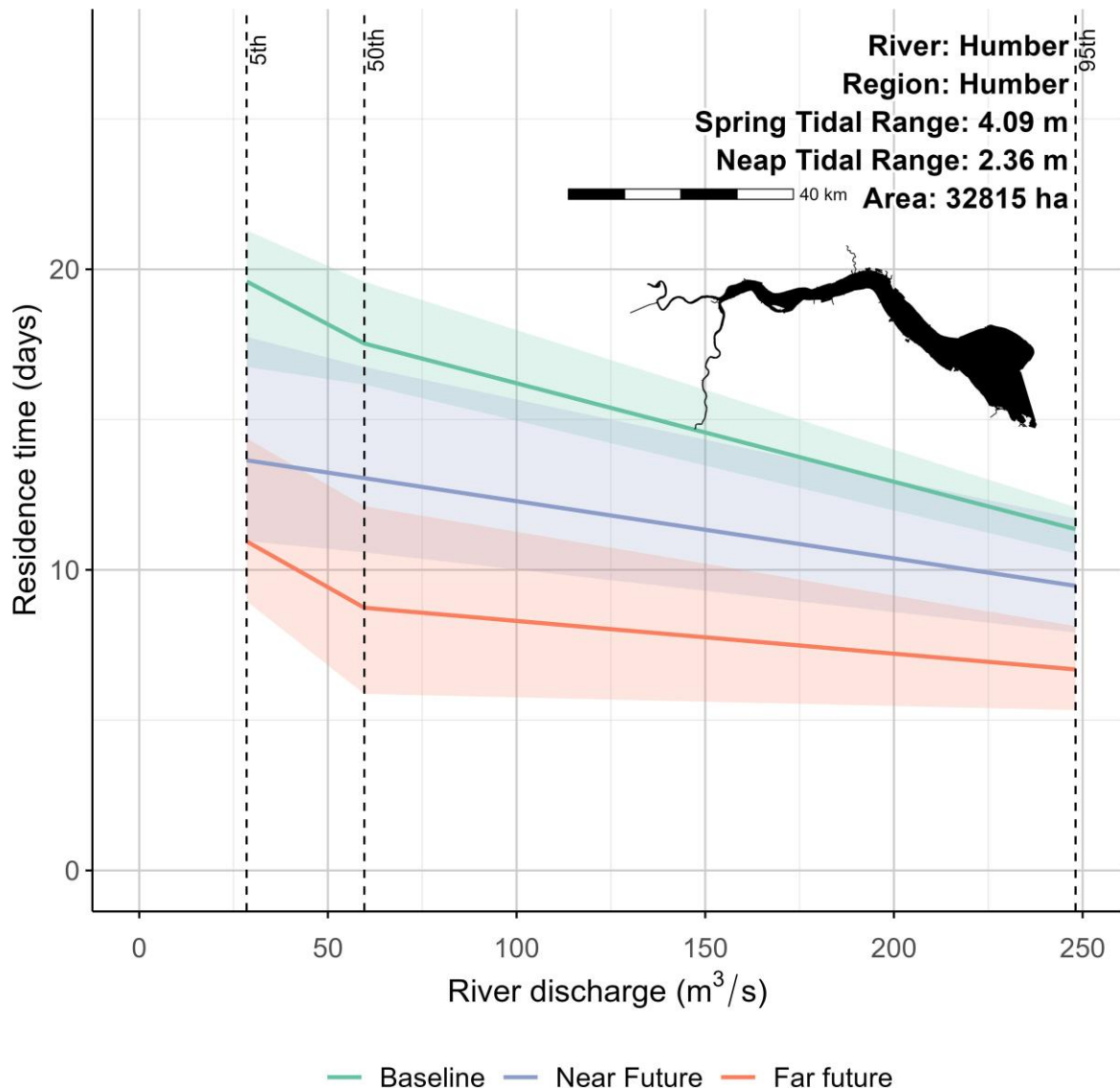


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)
Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Kent

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	54.27998
Longitude	-2.75581
Tidal Range	7.9 m
Gauge Name	Kent at Sedgwick
Estuary Size	333000000.0 m ²
5th percentile flow	1.18 m ³ /s
50th percentile flow	5.32 m ³ /s
95th percentile flow	30.6 m ³ /s
Notes	Tidal Range and Volume for Morecombe Bay

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

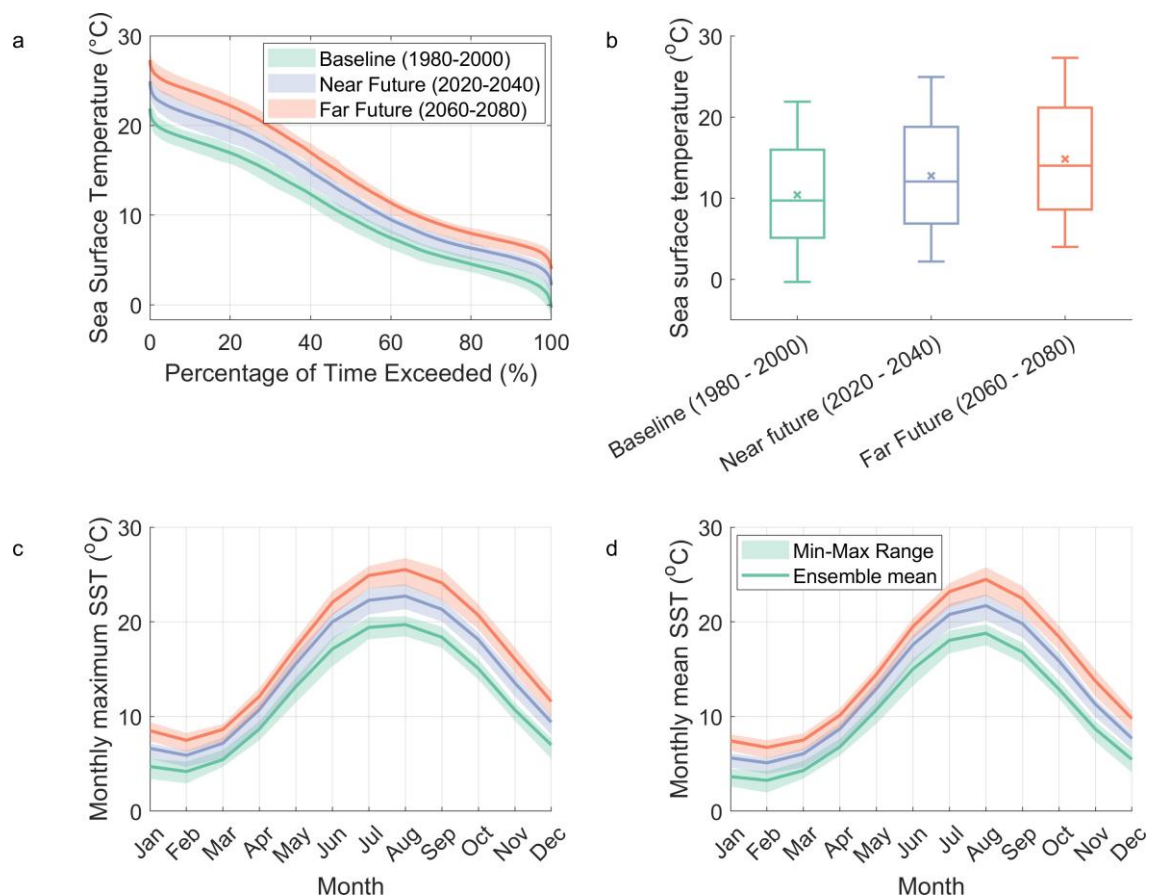
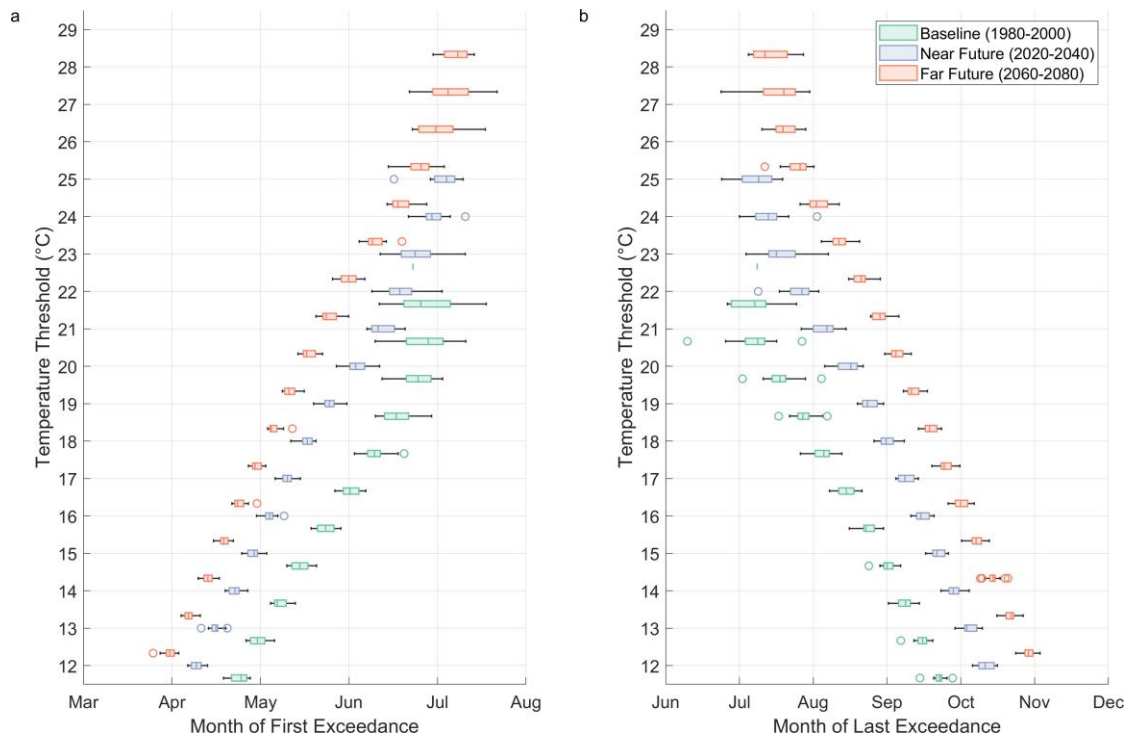


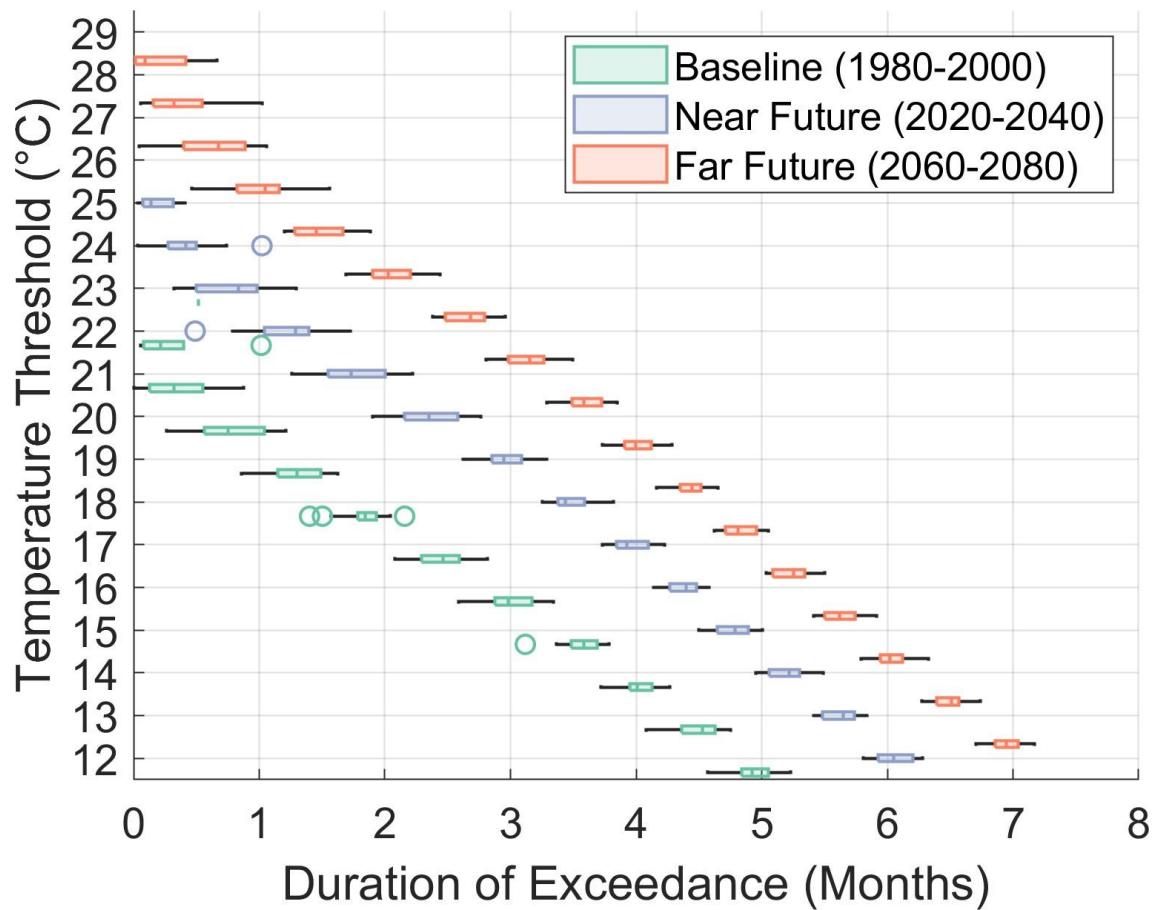
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

- (a) Temperature duration curves represent distribution of SSTs over time to highlight changes in cold and warm extremes.
- (b) Percentile shifts show increasing mean, median, and extremes, indicating prolonged warming over time.
- (c) Rising monthly maximum in every month of the year highlights likelihood of intensified high heat events.
- (d) Rising monthly mean suggests long-term climate-driven warming.



Changes in first and last occurrences of temperature thresholds compared to historical data. Note that these plots are not intended to identify the specific date on which a temperature may occur, rather they indicate the trend in the onset of specific temperature thresholds.



Projected temperature changes under different climate scenarios. Box and whisker plots show the range of different modelled durations of temperatures under the 12 different UKCP 18 ensemble members. Open circles indicate outlier values.

Section 2 - Sea surface salinity changes

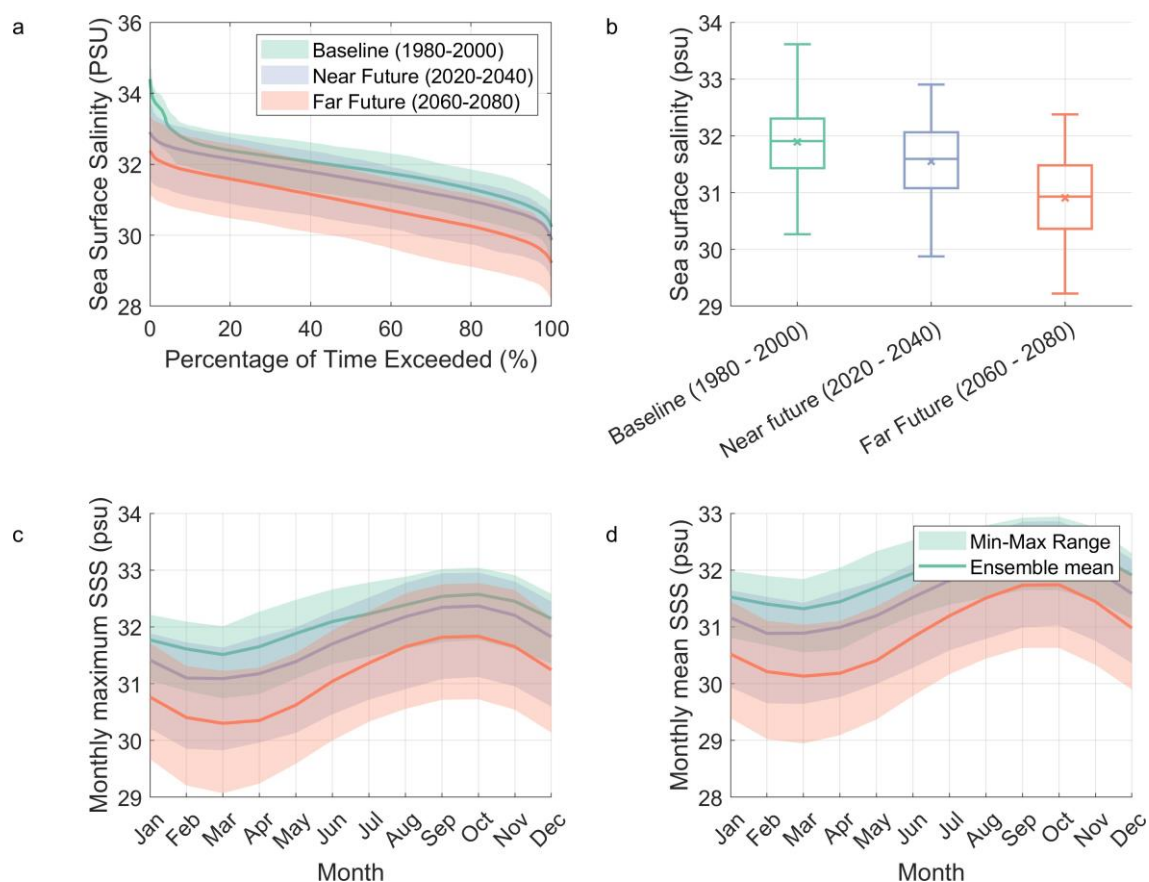


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
- (b) Percentile shifts show decreasing mean, median, and extremes, indicating a trend towards freshening over time.
- (c) Monthly maxima decrease across all months.
- (d) Decreasing monthly means suggest long-term ice-melt driven freshening.

Section 3 - Residual surge changes

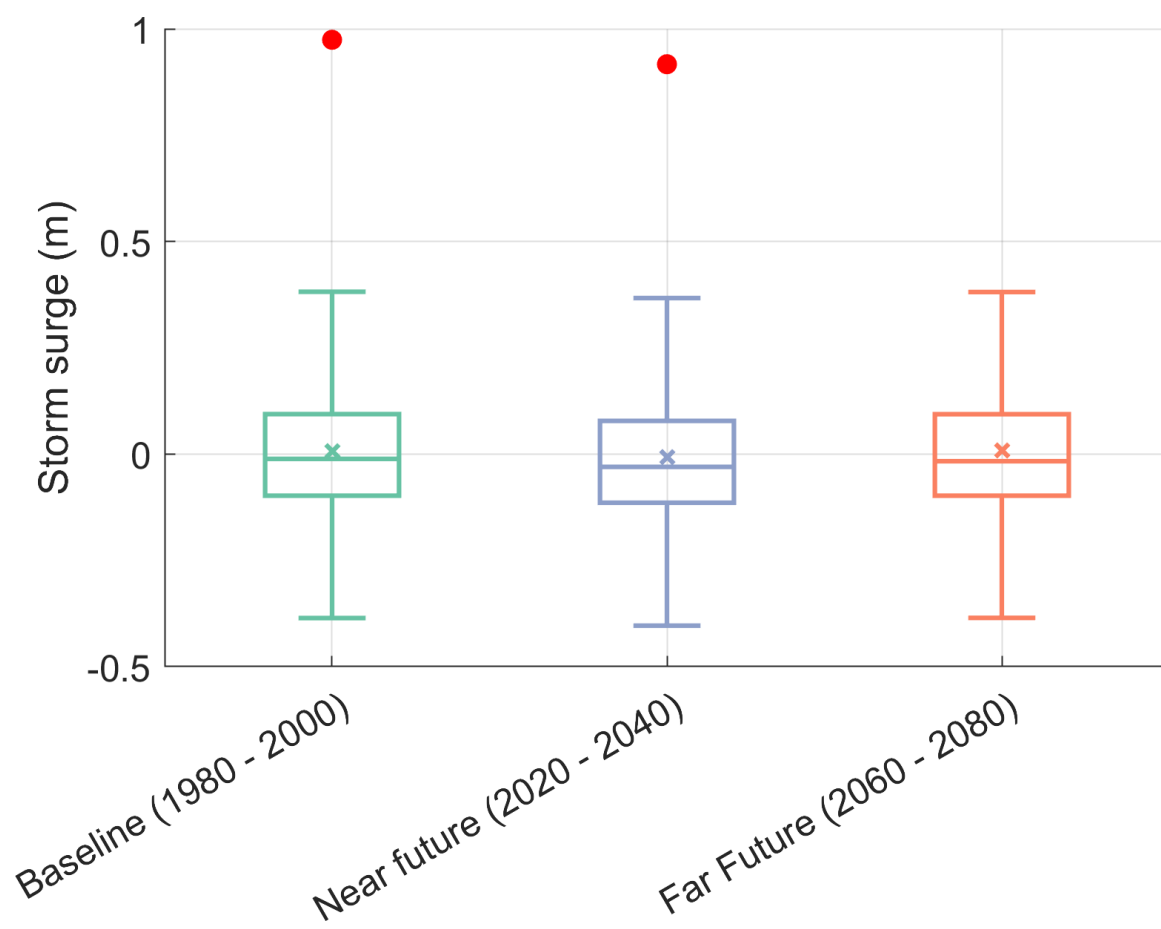


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

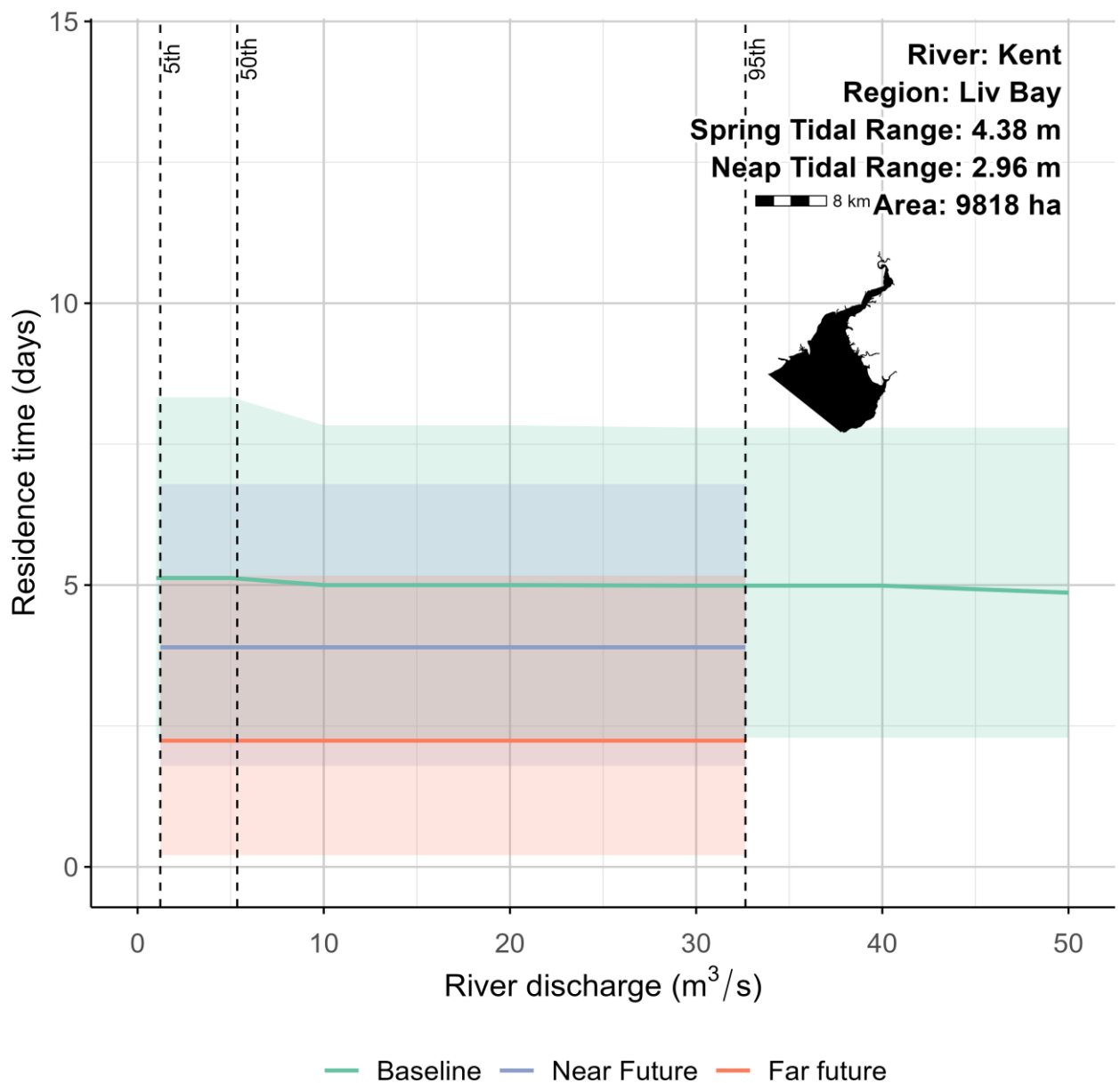


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)
Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Langstone_Harbour

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	50.85543
Longitude	-0.99115
Tidal Range	4.0 m
Gauge Name	Hermitage Stream at Havant
Estuary Size	14500000.0 m ²
5th percentile flow	0.025 m ³ /s
50th percentile flow	0.12 m ³ /s
95th percentile flow	0.872 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

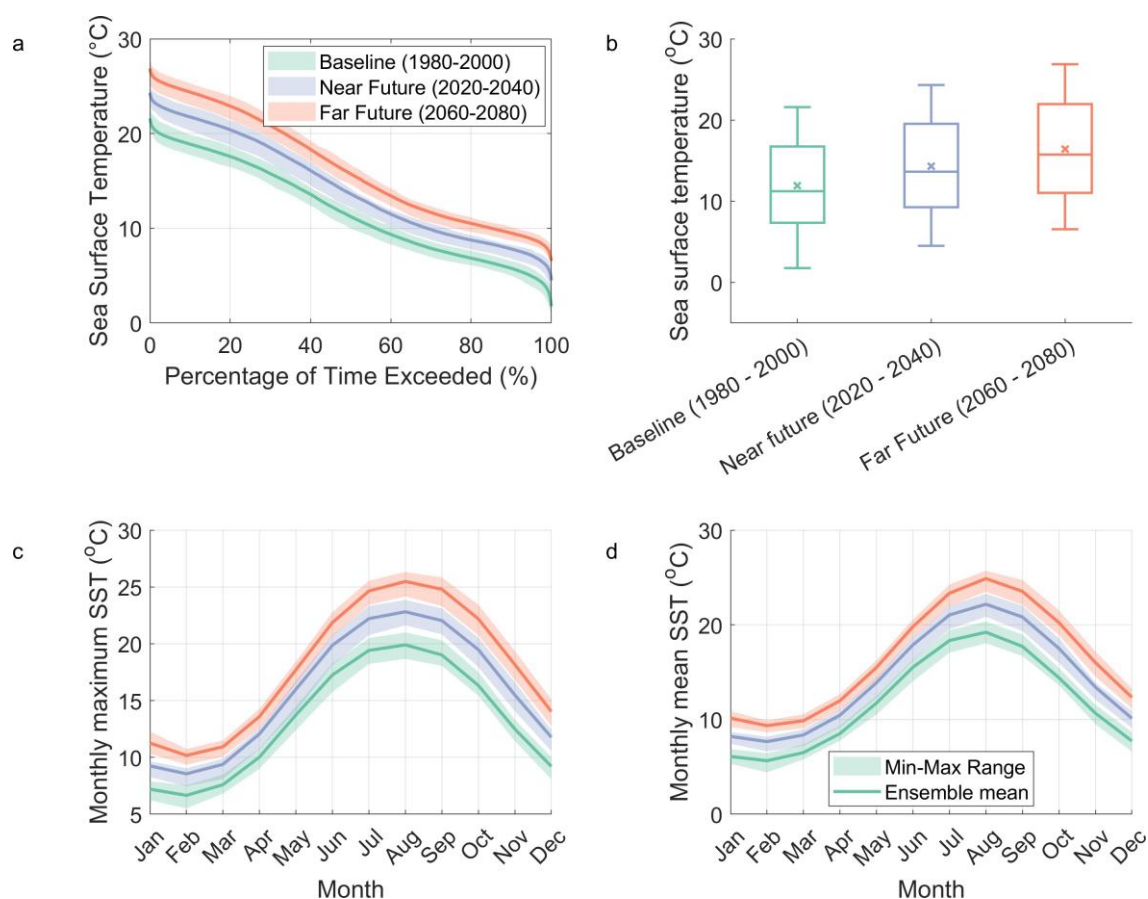
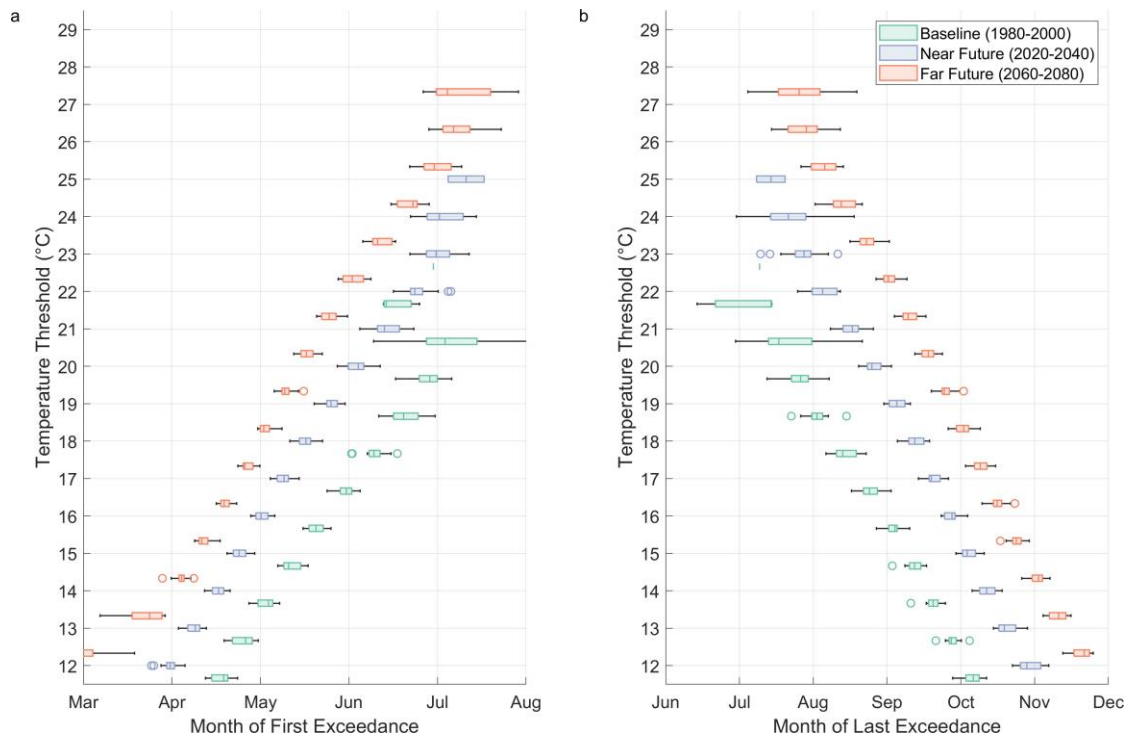


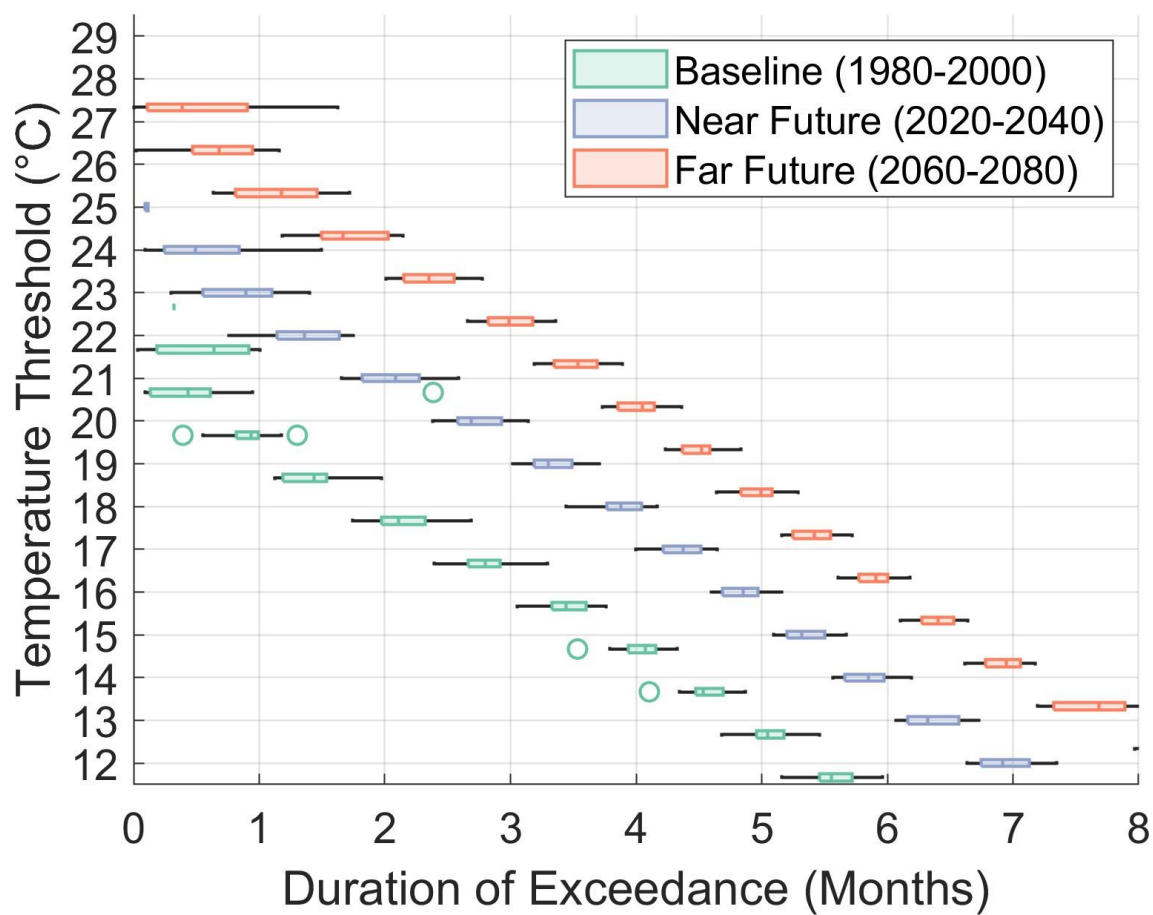
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

- (a) Temperature duration curves represent distribution of SSTs over time to highlight changes in cold and warm extremes.
- (b) Percentile shifts show increasing mean, median, and extremes, indicating prolonged warming over time.
- (c) Rising monthly maximum in every month of the year highlights likelihood of intensified high heat events.
- (d) Rising monthly mean suggests long-term climate-driven warming.



Changes in first and last occurrences of temperature thresholds compared to historical data. Note that these plots are not intended to identify the specific date on which a temperature may occur, rather they indicate the trend in the onset of specific temperature thresholds.



Projected temperature changes under different climate scenarios. Box and whisker plots show the range of different modelled durations of temperatures under the 12 different UKCP 18 ensemble members. Open circles indicate outlier values.

Section 2 - Sea surface salinity changes

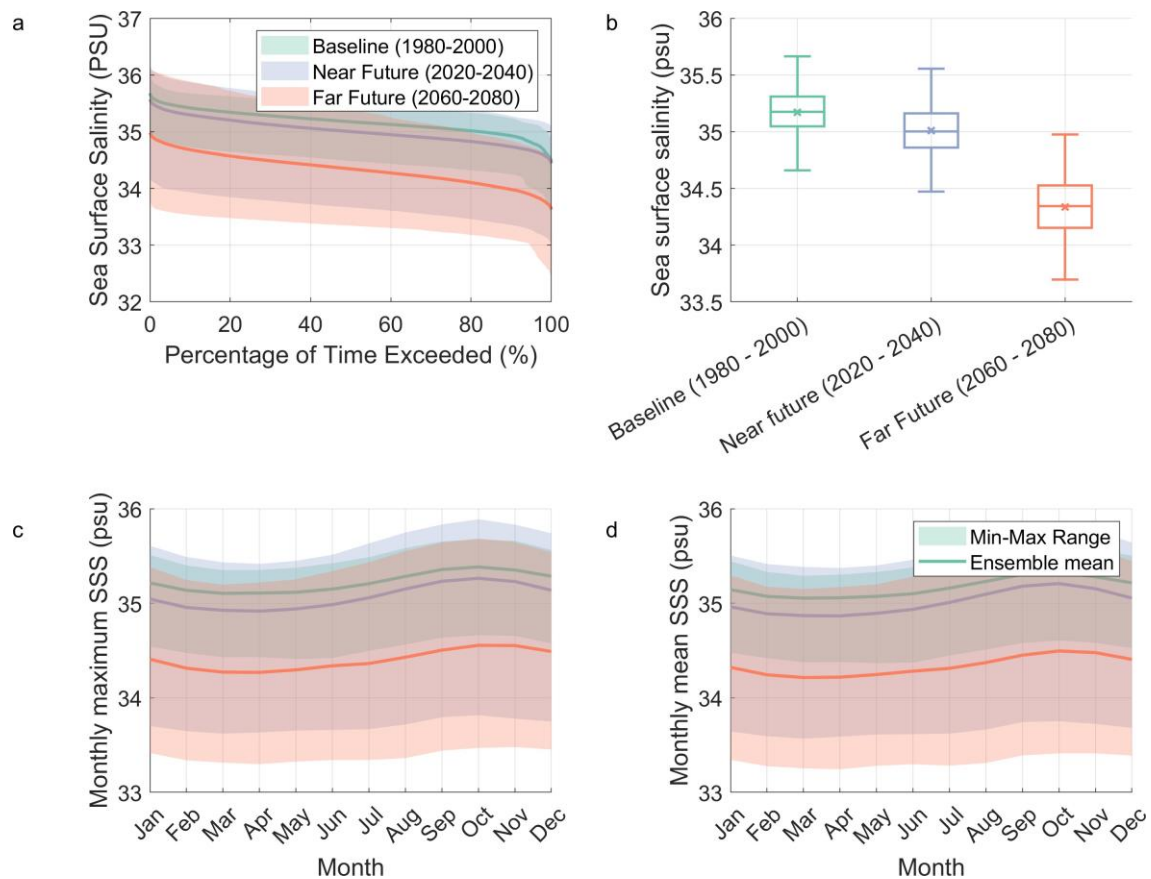


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
- (b) Percentile shifts show decreasing mean, median, and extremes, indicating a trend towards freshening over time.
- (c) Monthly maxima decrease across all months.
- (d) Decreasing monthly means suggest long-term ice-melt driven freshening.

Section 3 - Residual surge changes

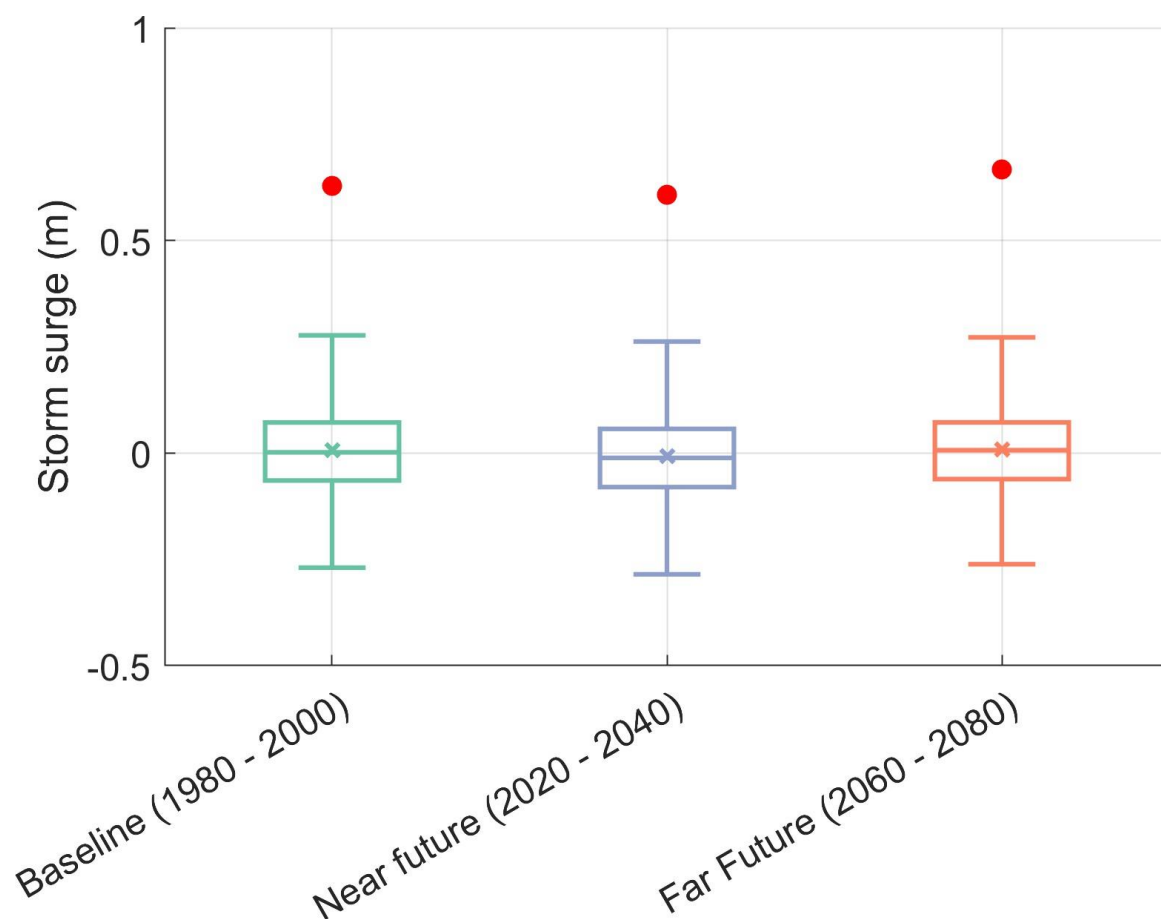


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

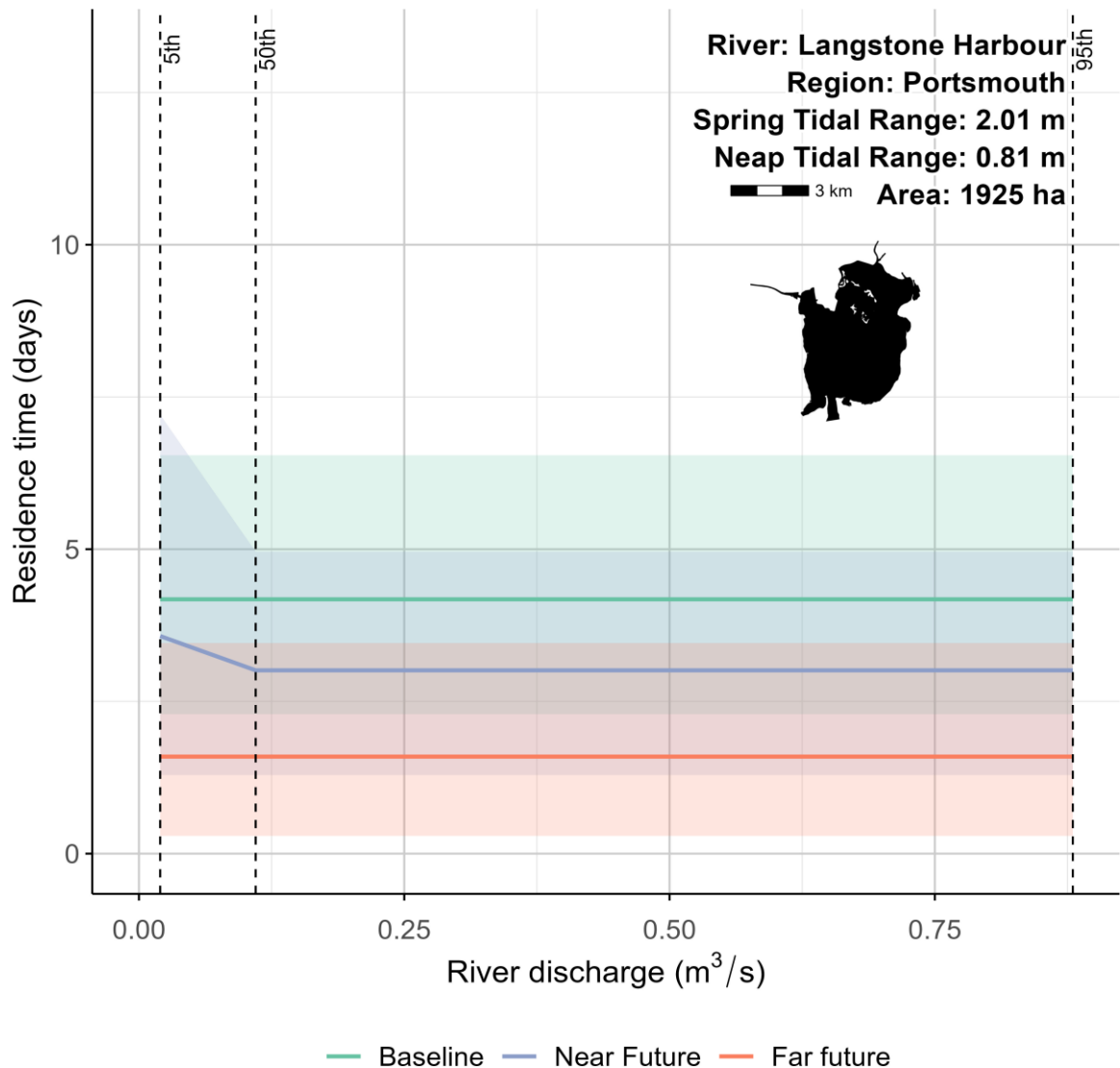


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Leven

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	54.268
Longitude	-2.97435
Tidal Range	7.9 m
Gauge Name	Leven at Newby Bridge
Estuary Size	333000000.0 m ²
5th percentile flow	1.326 m ³ /s
50th percentile flow	10.1 m ³ /s
95th percentile flow	40.86 m ³ /s
Notes	Tidal Range and Volume for Morecombe Bay

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

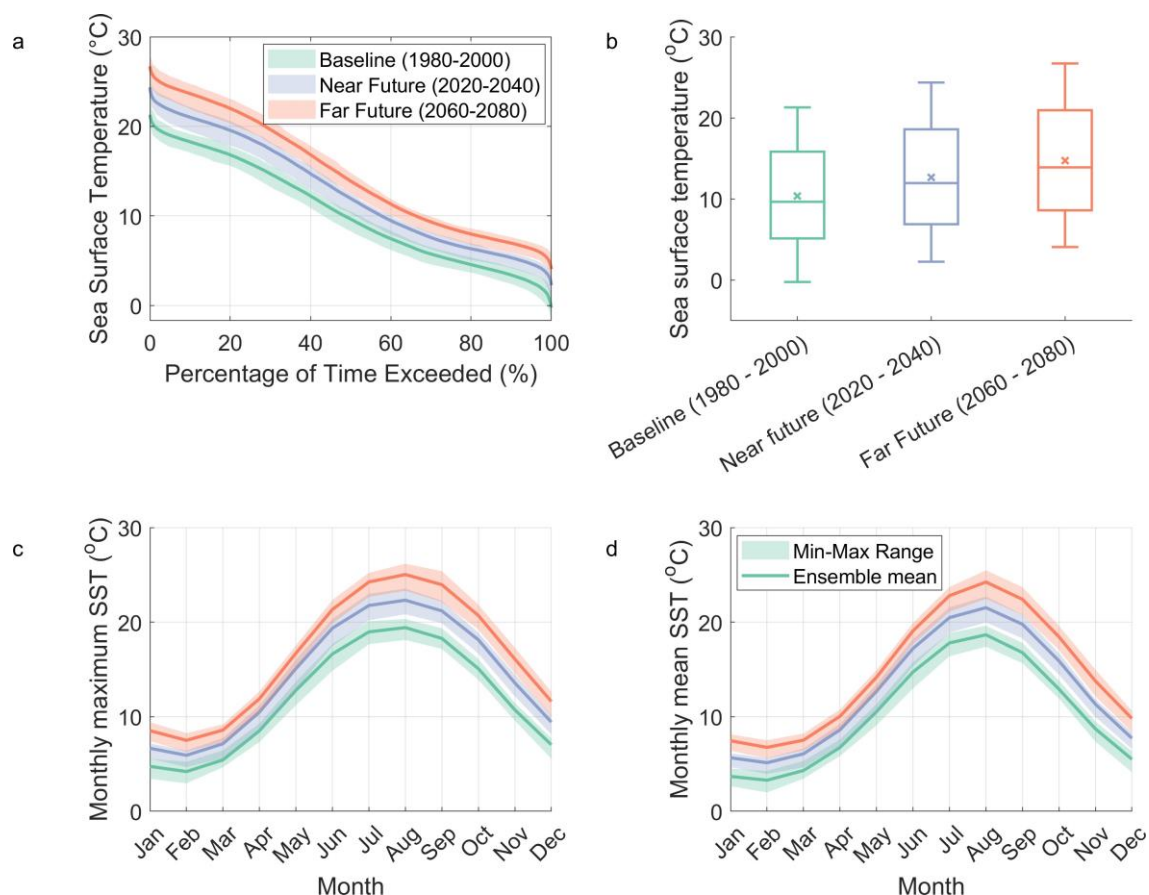
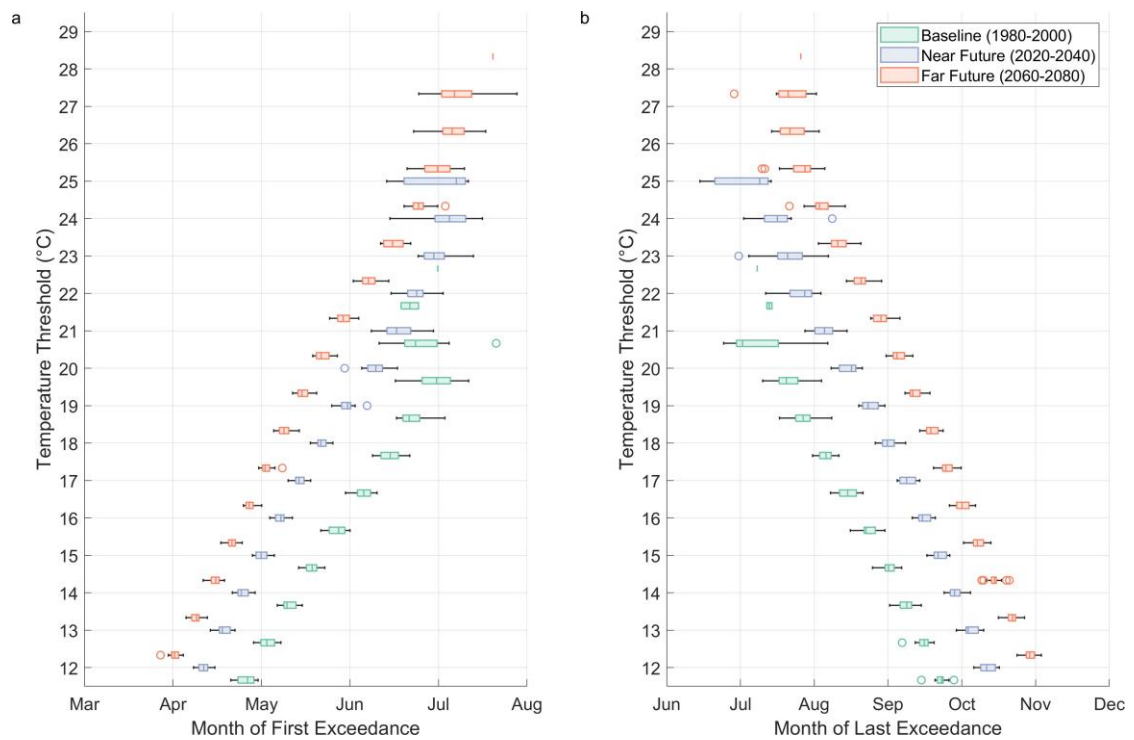


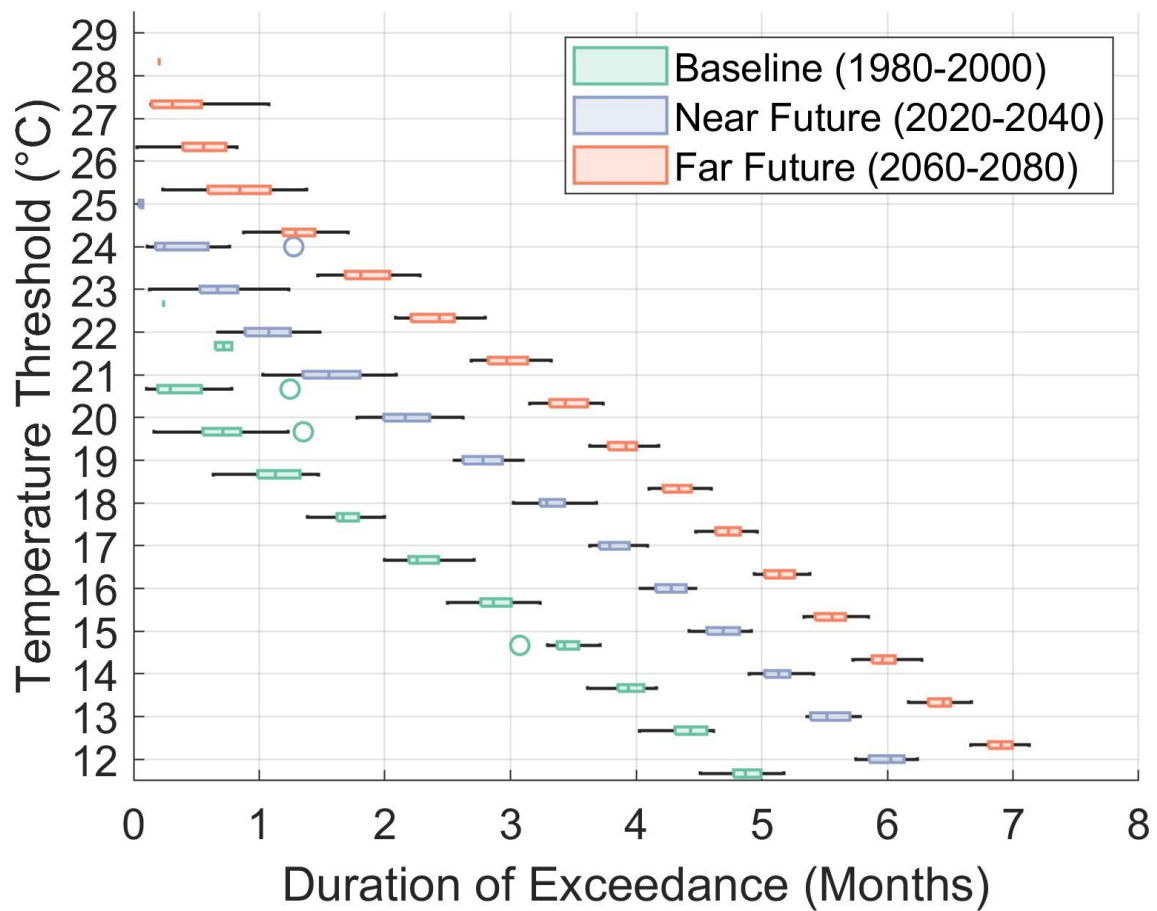
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

- (a) Temperature duration curves represent distribution of SSTs over time to highlight changes in cold and warm extremes.
- (b) Percentile shifts show increasing mean, median, and extremes, indicating prolonged warming over time.
- (c) Rising monthly maximum in every month of the year highlights likelihood of intensified high heat events.
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Changes in first and last occurrences of temperature thresholds compared to historical data. Note that these plots are not intended to identify the specific date on which a temperature may occur, rather they indicate the trend in the onset of specific temperature thresholds.



Projected temperature changes under different climate scenarios. Box and whisker plots show the range of different modelled durations of temperatures under the 12 different UKCP 18 ensemble members. Open circles indicate outlier values.

Section 2 - Sea surface salinity changes

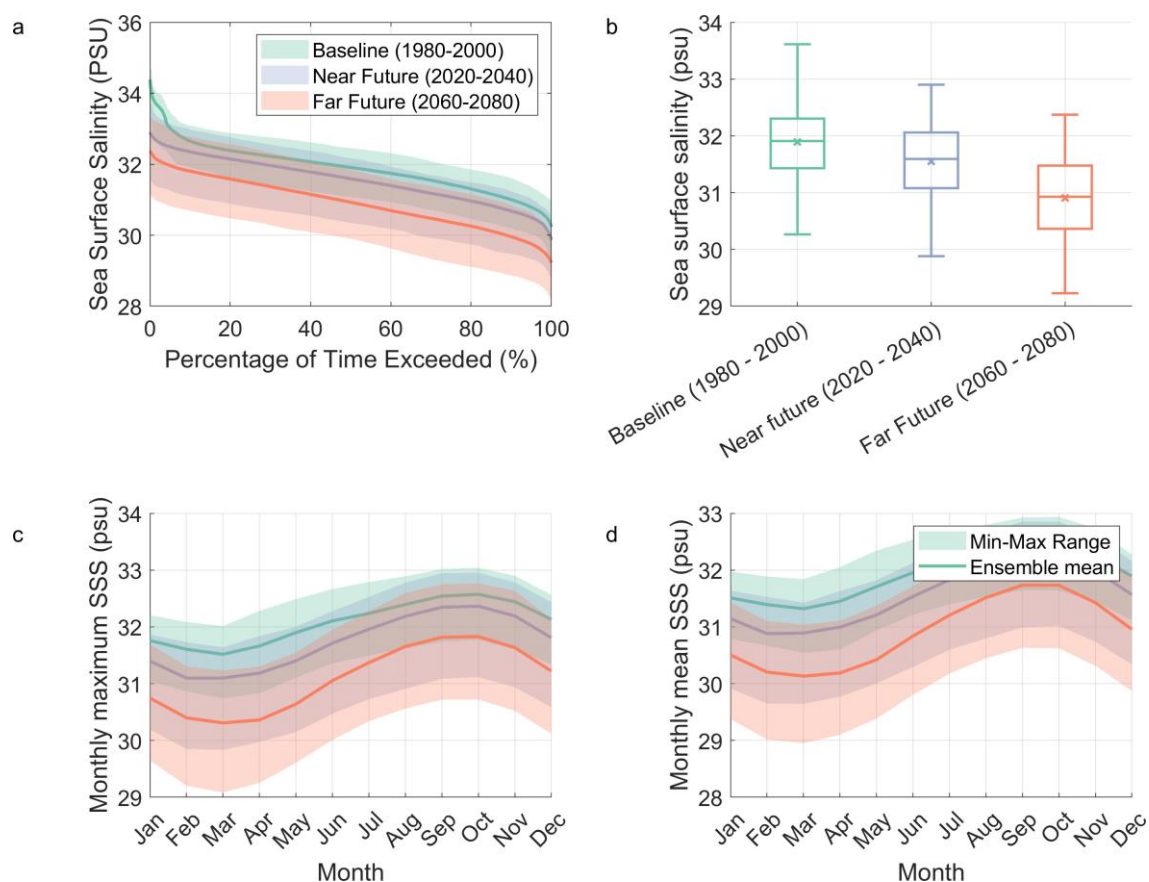


Figure description

- (a) Temperature duration curves represent distribution of SSTs over time to highlight changes in cold and warm extremes.
- (b) Percentile shifts show increasing mean, median, and extremes, indicating prolonged warming over time.
- (c) Rising monthly maximum in every month of the year highlights likelihood of intensified high heat events.
- (d) Rising monthly mean suggests long-term climate-driven warming.

Section 3 - Residual surge changes

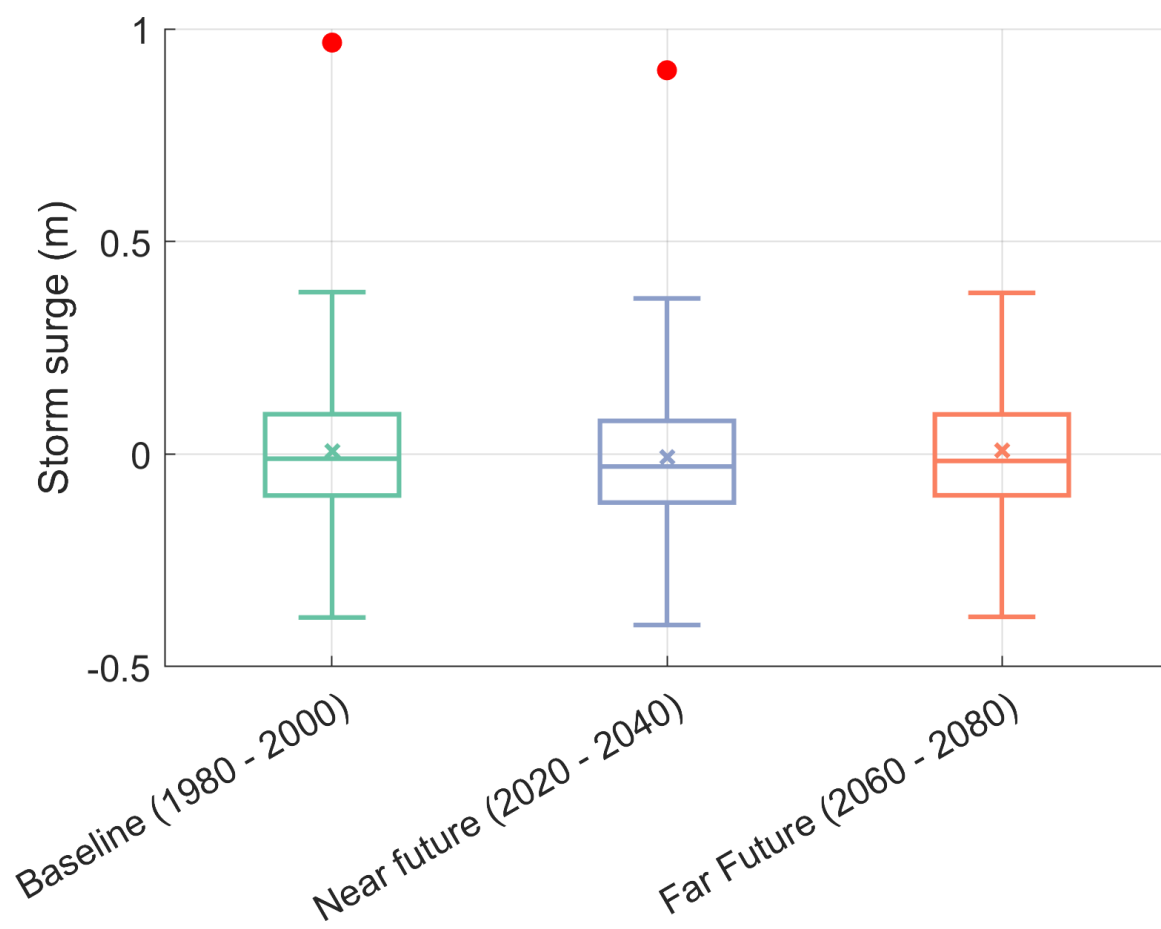


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

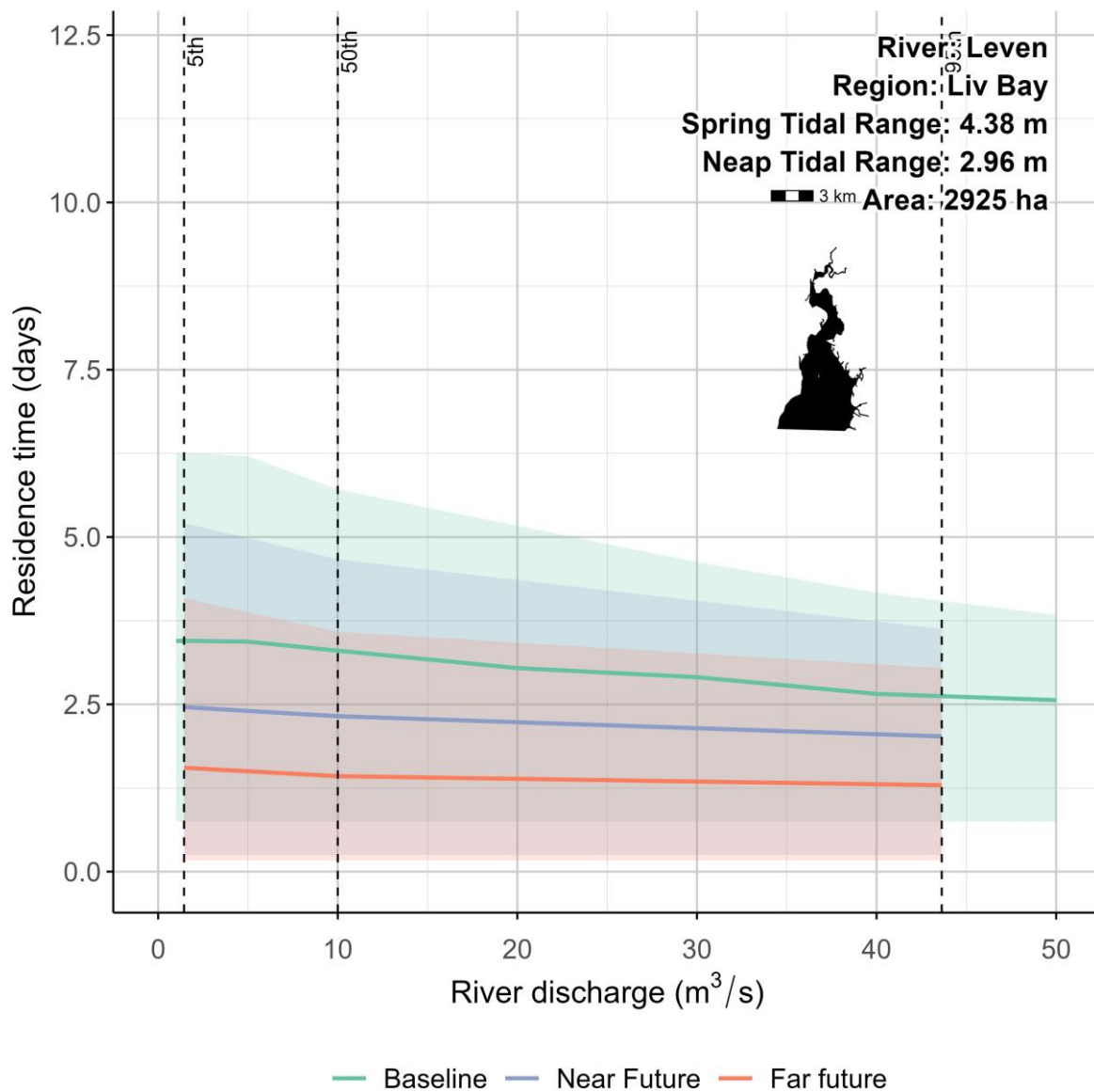


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Lune

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	54.08143
Longitude	-2.72212
Tidal Range	7.9 m
Gauge Name	Lune at Caton
Estuary Size	333000000.0 m²
5th percentile flow	3.28 m³/s
50th percentile flow	17.96 m³/s
95th percentile flow	132.0 m³/s
Notes	Tidal Range and Volume for Morecombe Bay

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

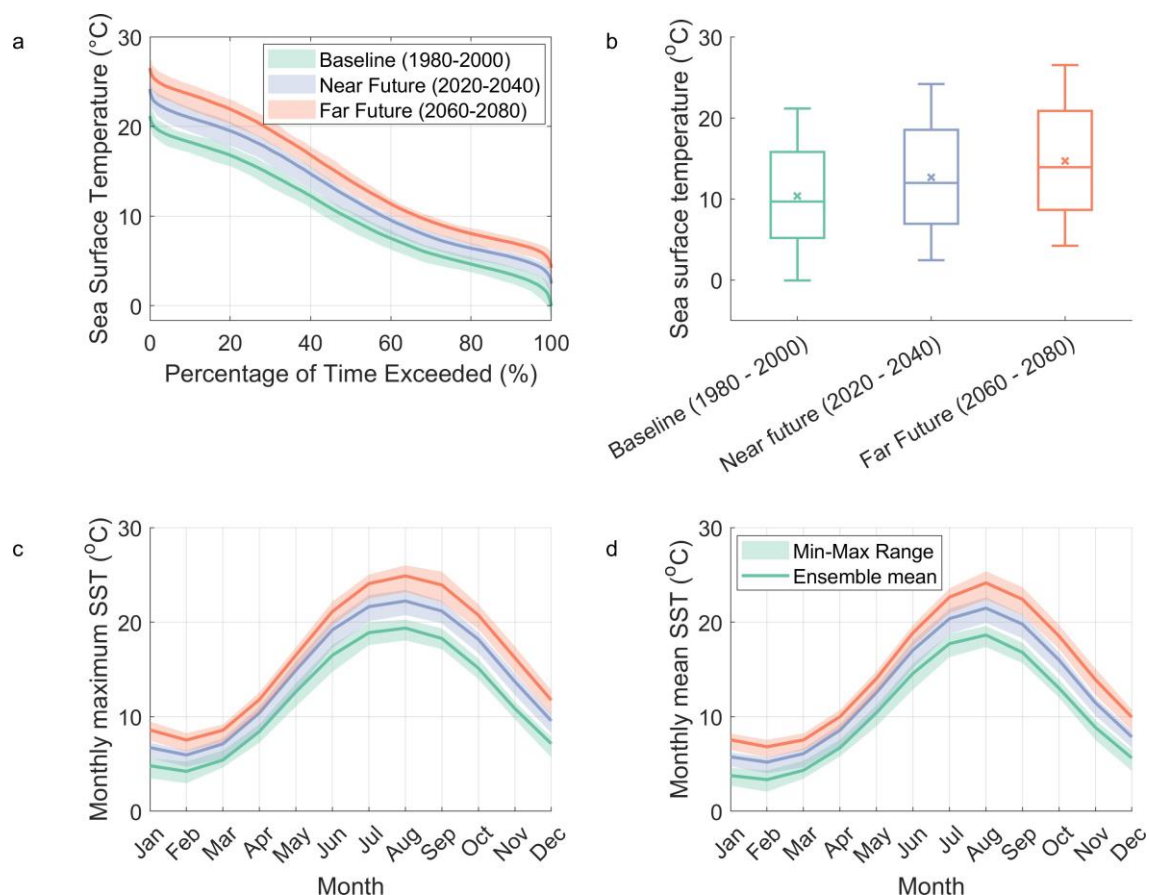
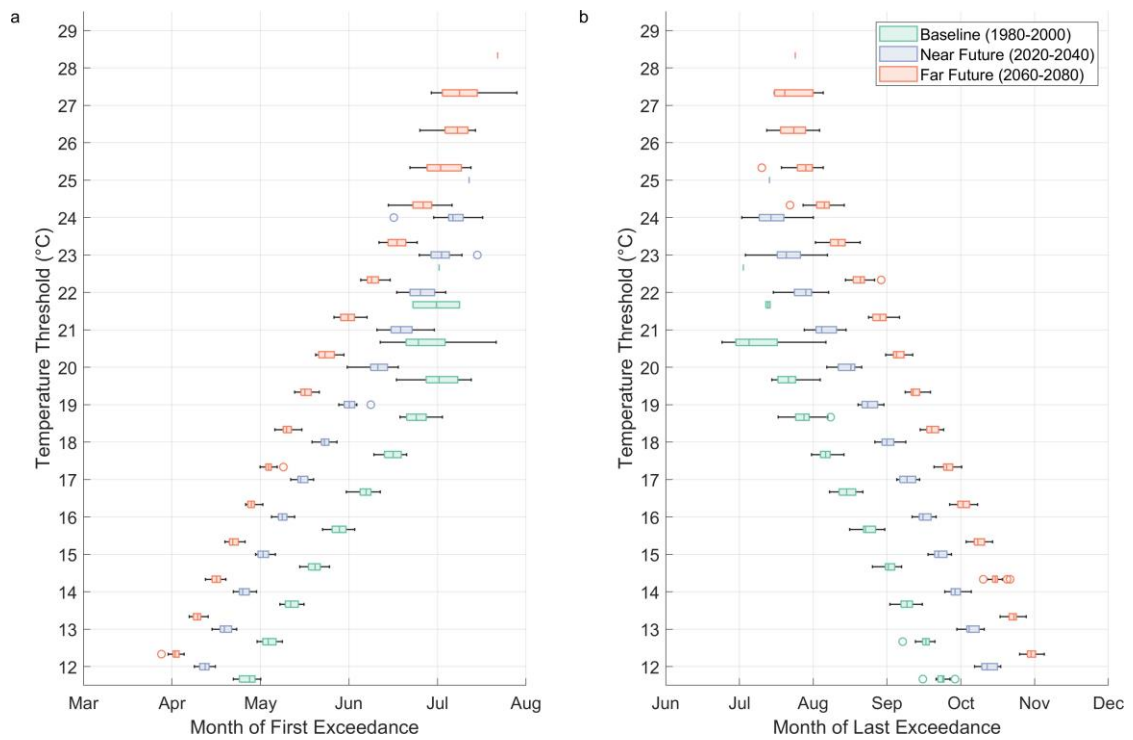


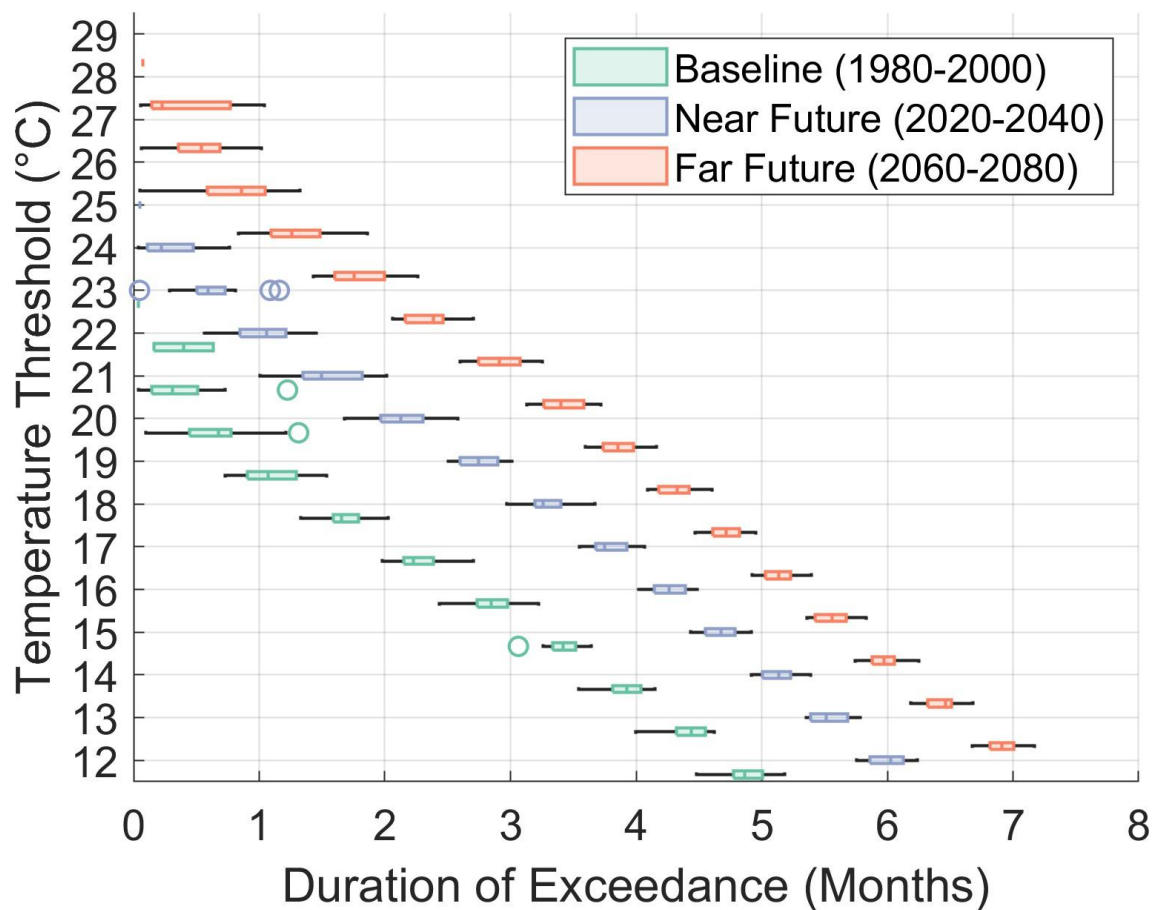
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

- (a) Temperature duration curves represent distribution of SSTs over time to highlight changes in cold and warm extremes.
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Projected temperature changes under different climate scenarios. Box and whisker plots show the range of different modelled durations of temperatures under the 12 different UKCP 18 ensemble members. Open circles indicate outlier values.

Section 2 - Sea surface salinity changes

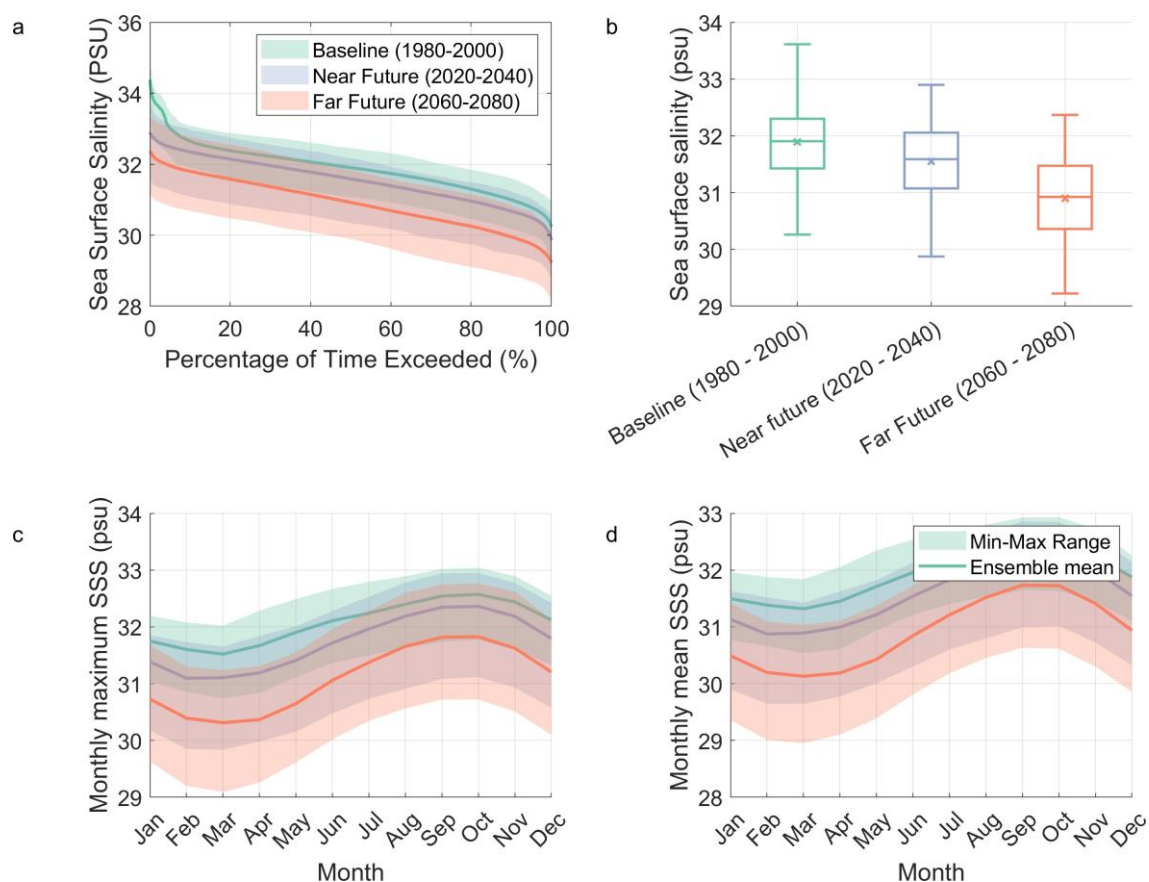


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
- (b) Percentile shifts show decreasing mean, median, and extremes, indicating a trend towards freshening over time.
- (c) Monthly maxima decrease across all months.
- (d) Decreasing monthly means suggest long-term ice-melt driven freshening.

Section 3 - Residual surge changes

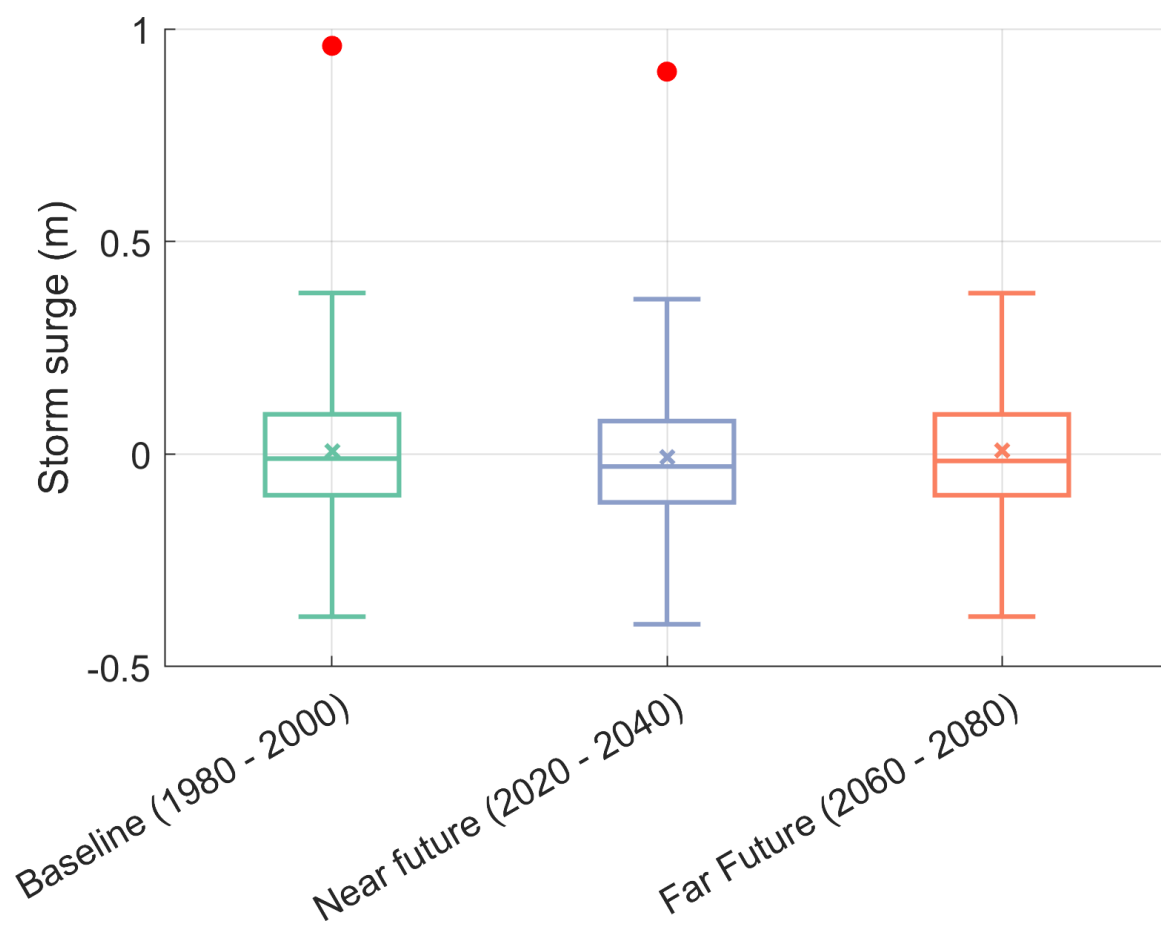


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

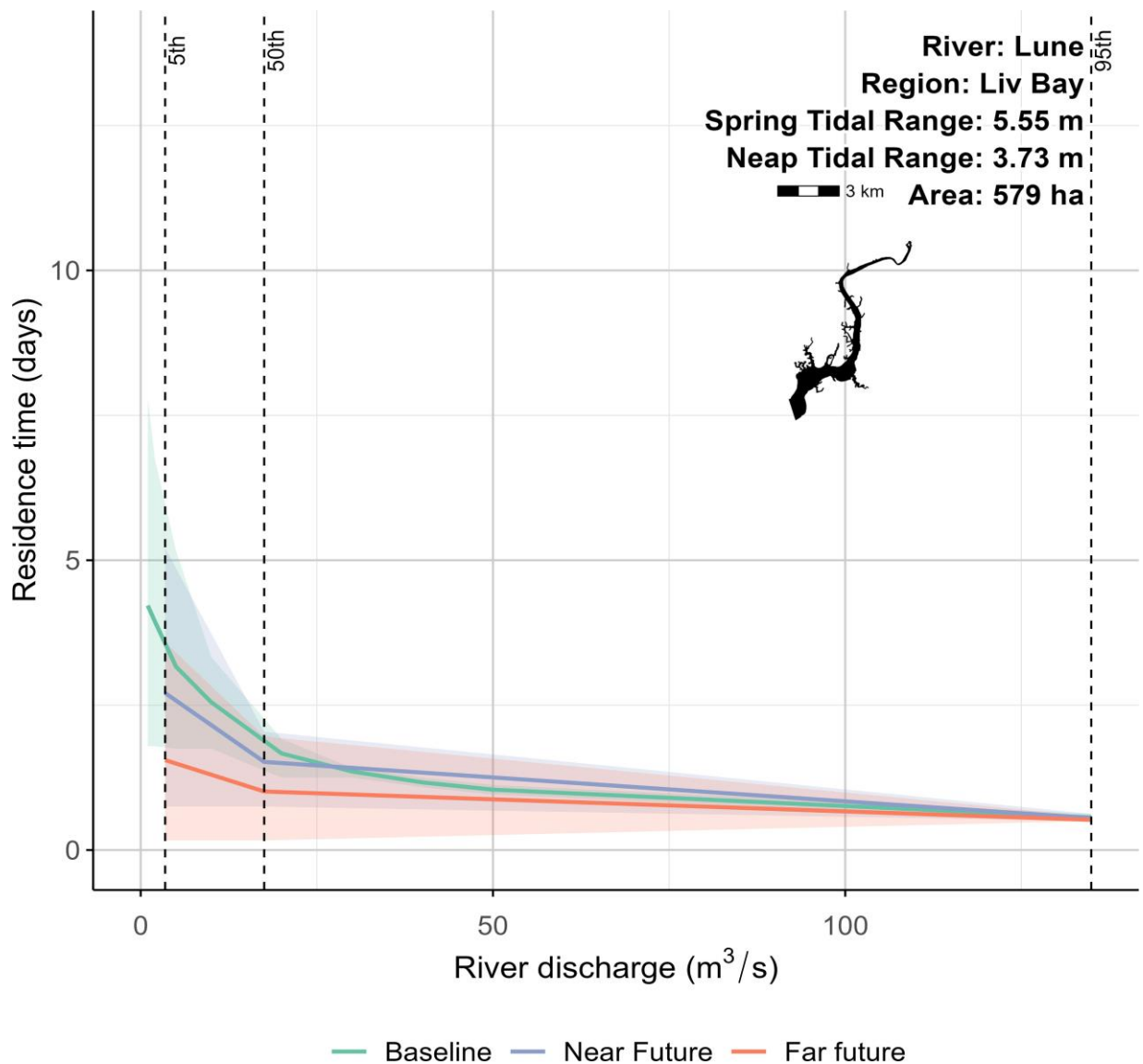


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Lymington

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	50.81571
Longitude	-1.55044
Tidal Range	2.4 m
Gauge Name	Lymington at Brockenhurst
Estuary Size	1260000.0 m ²
5th percentile flow	0.055 m ³ /s
50th percentile flow	0.481 m ³ /s
95th percentile flow	4.81 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

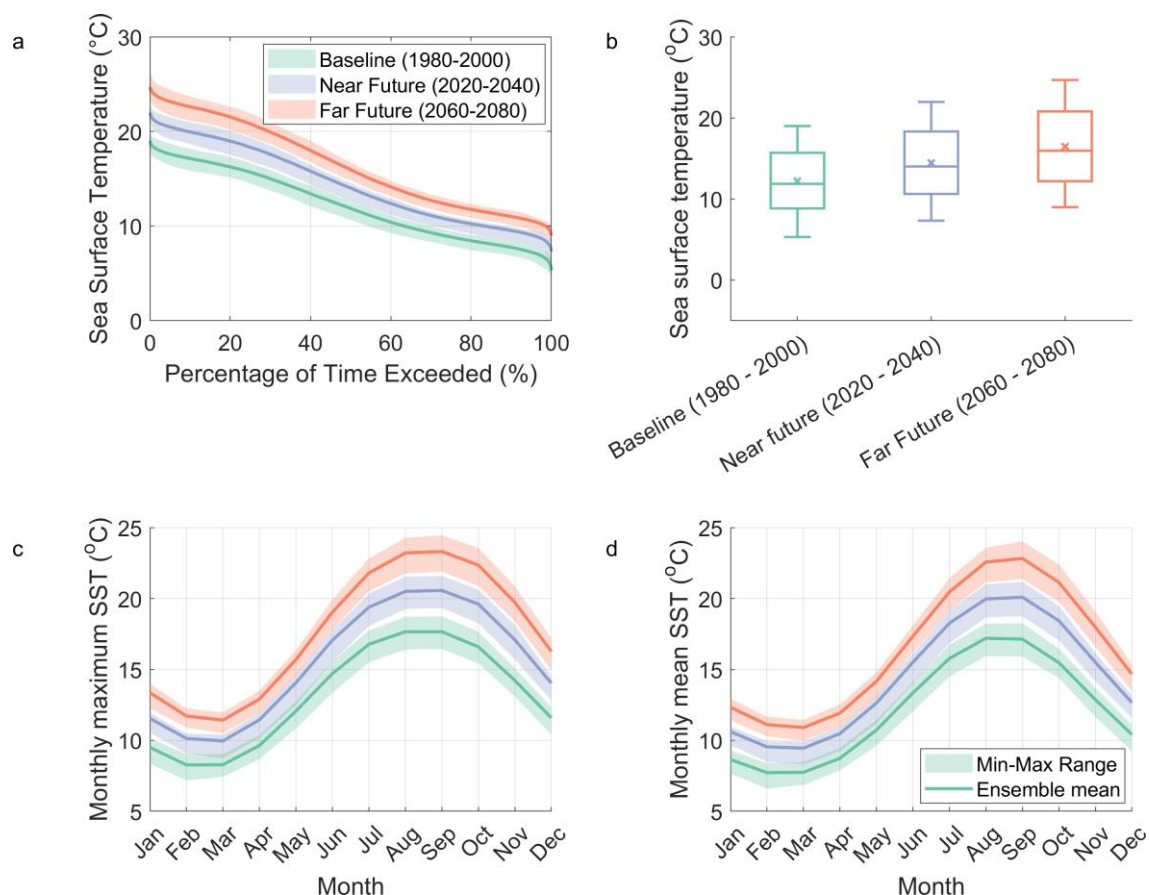
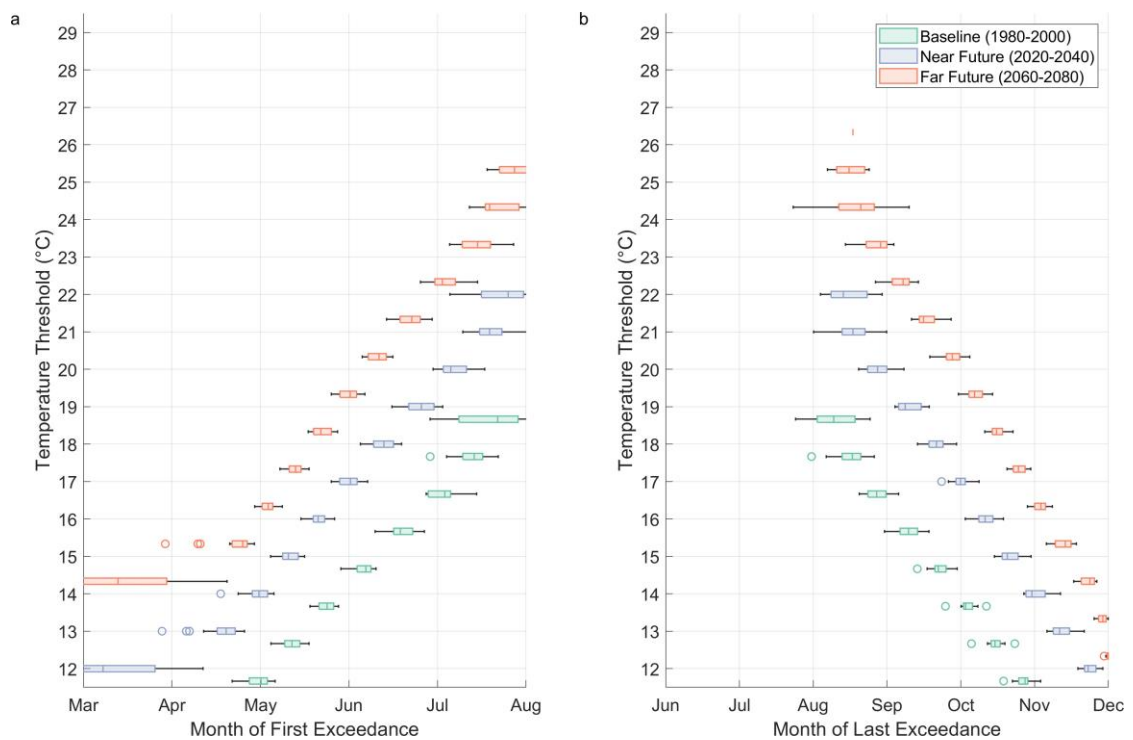


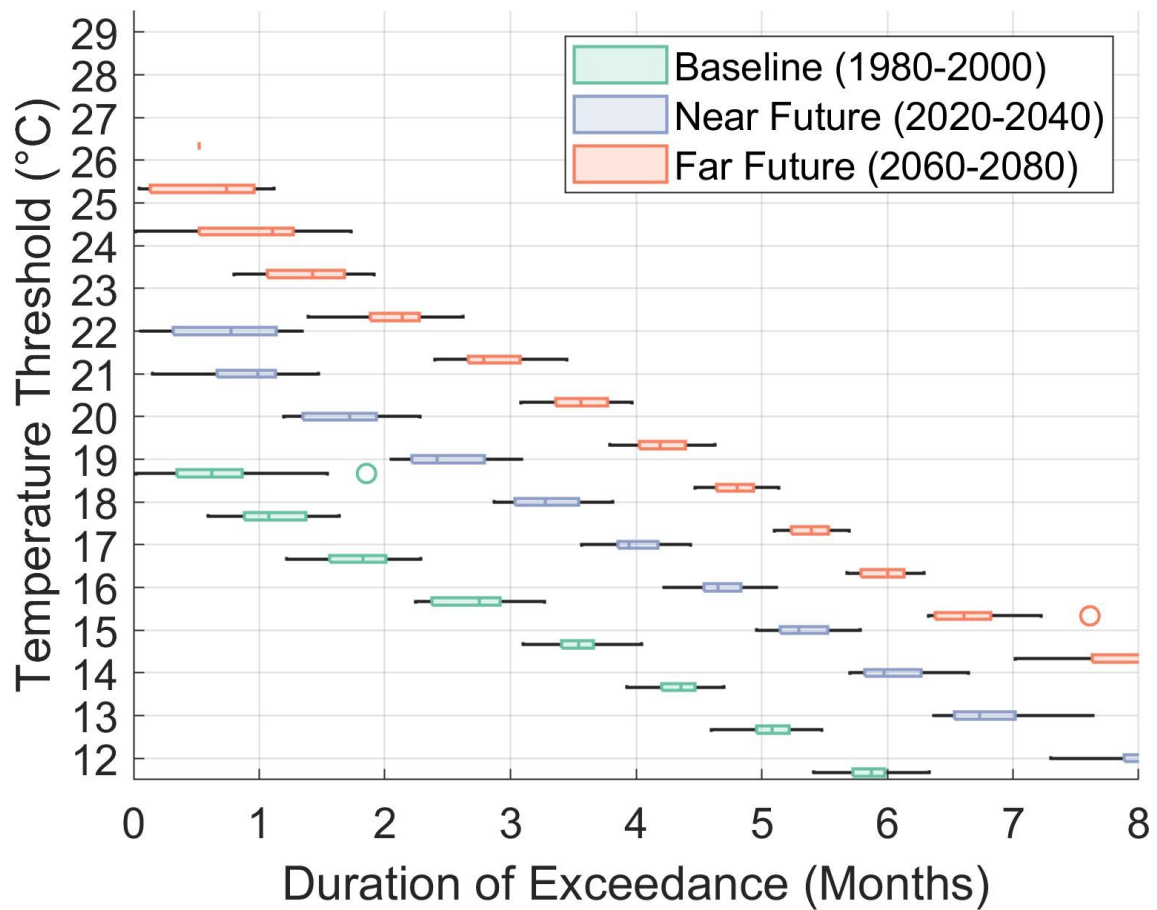
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

- (a) Temperature duration curves represent distribution of SSTs over time to highlight changes in cold and warm extremes.
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Projected temperature changes under different climate scenarios. Box and whisker plots show the range of different modelled durations of temperatures under the 12 different UKCP 18 ensemble members. Open circles indicate outlier values.

Section 2 - Sea surface salinity changes

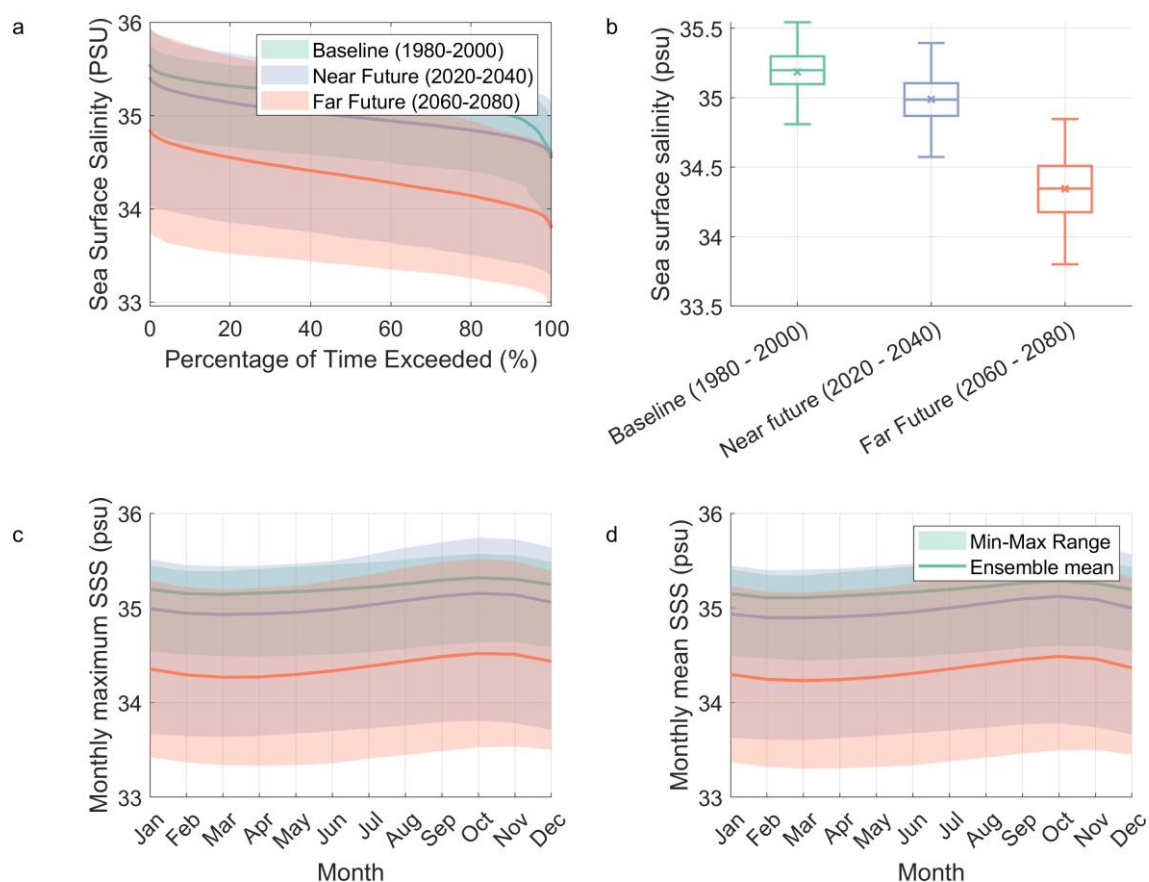


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
- (b) Percentile shifts show decreasing mean, median, and extremes, indicating a trend towards freshening over time.
- (c) Monthly maxima decrease across all months.
- (d) Decreasing monthly means suggest long-term ice-melt driven freshening.

Section 3 - Residual surge changes

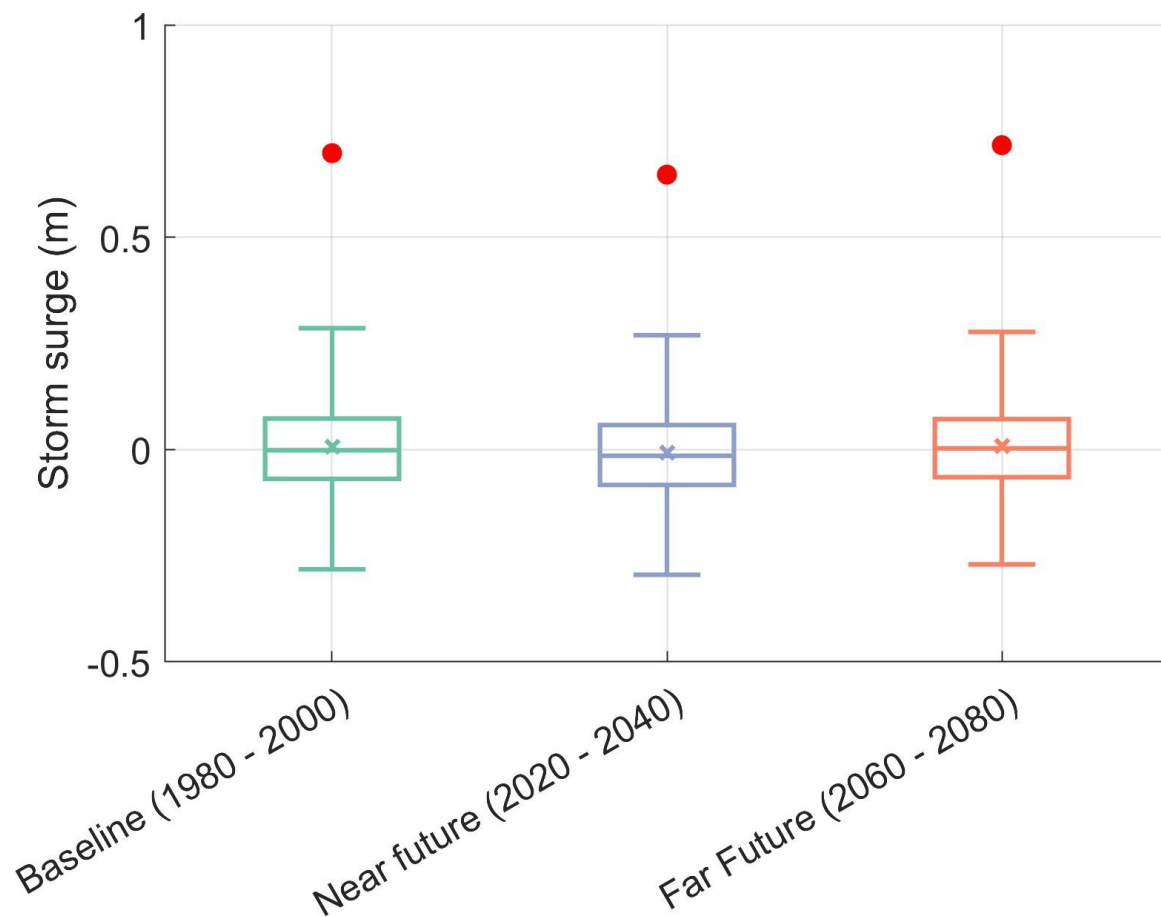


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

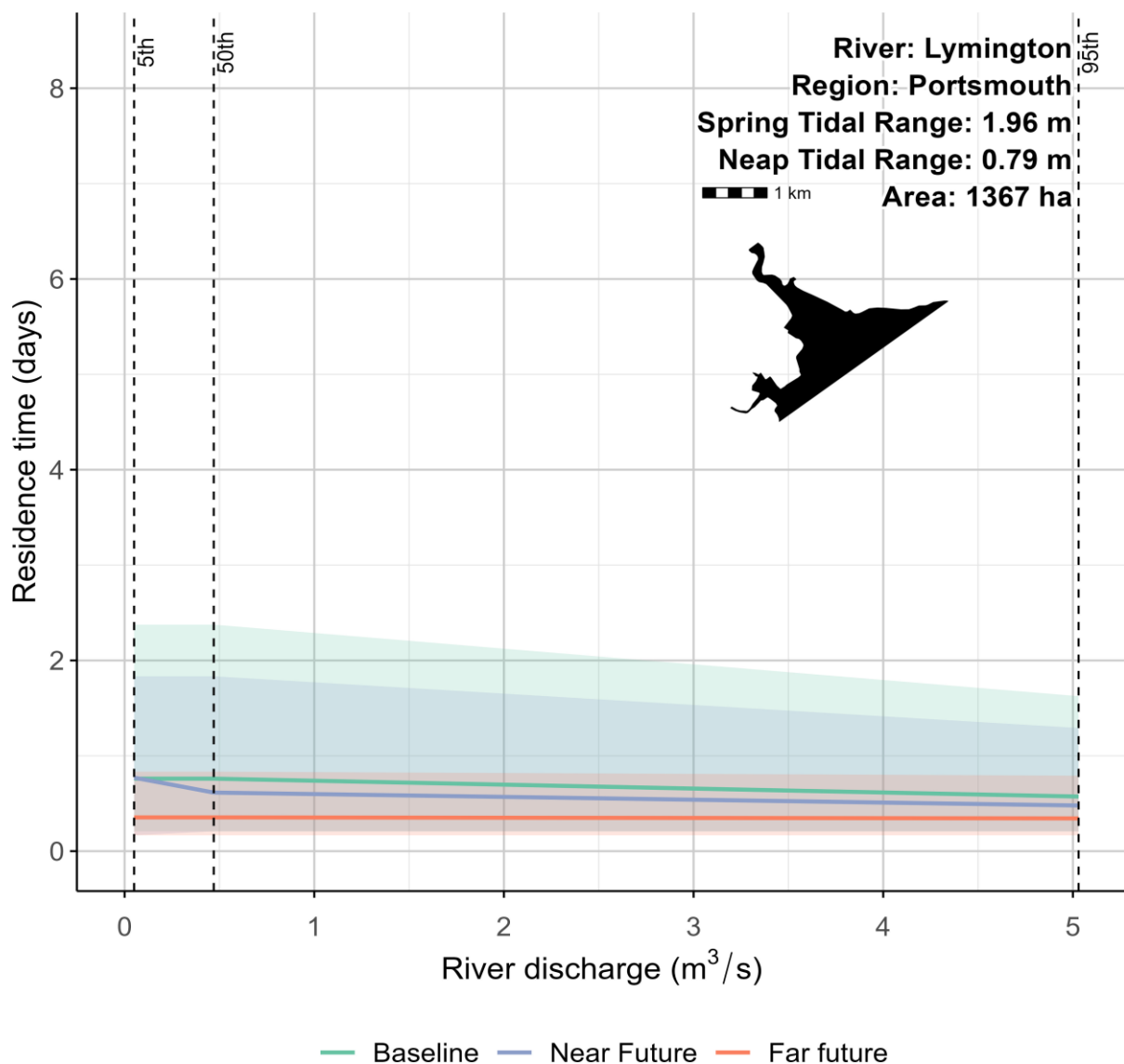


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Medway

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	51.412498
Longitude	0.651679
Tidal Range	5.2 m
Gauge Name	Medway at Teston
Estuary Size	37800000.0 m ²
5th percentile flow	1.59 m ³ /s
50th percentile flow	4.52 m ³ /s
95th percentile flow	46.64 m ³ /s
Notes	Estuaries Database lists gauge at

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

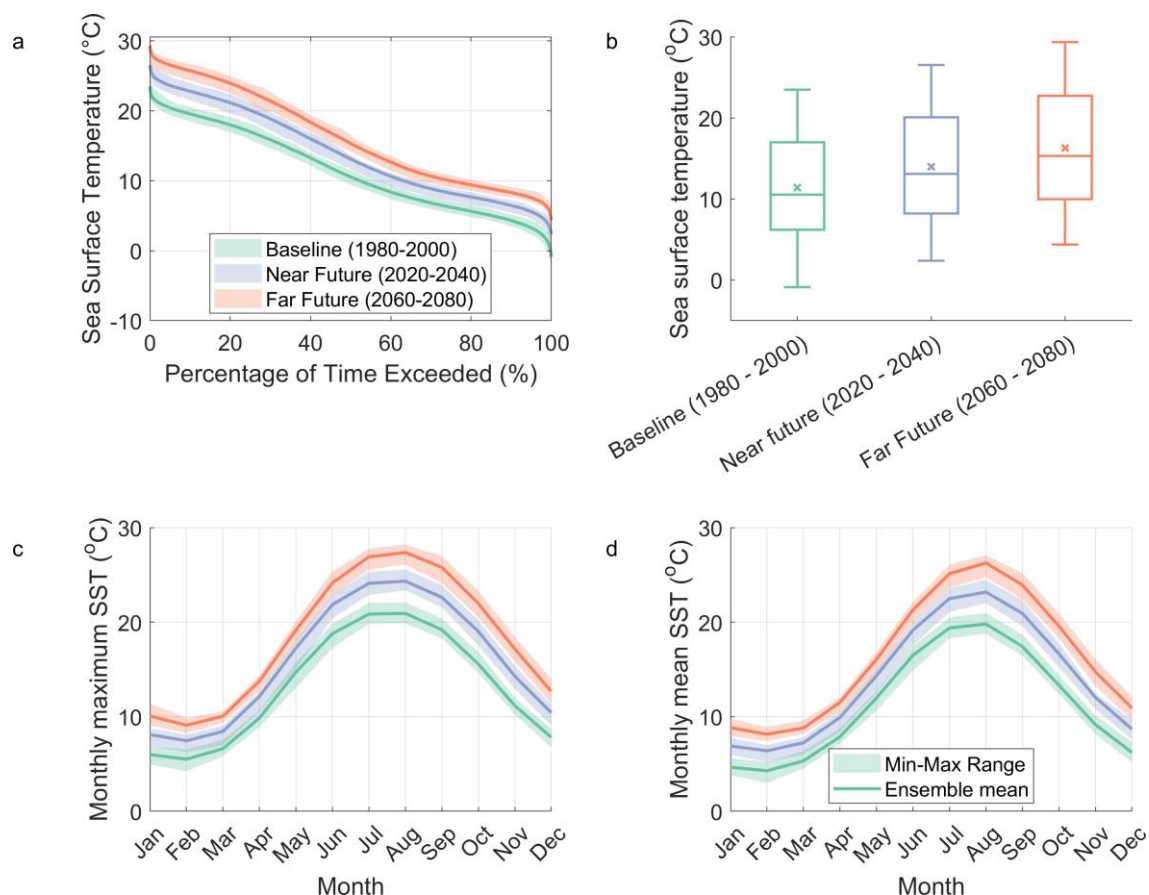
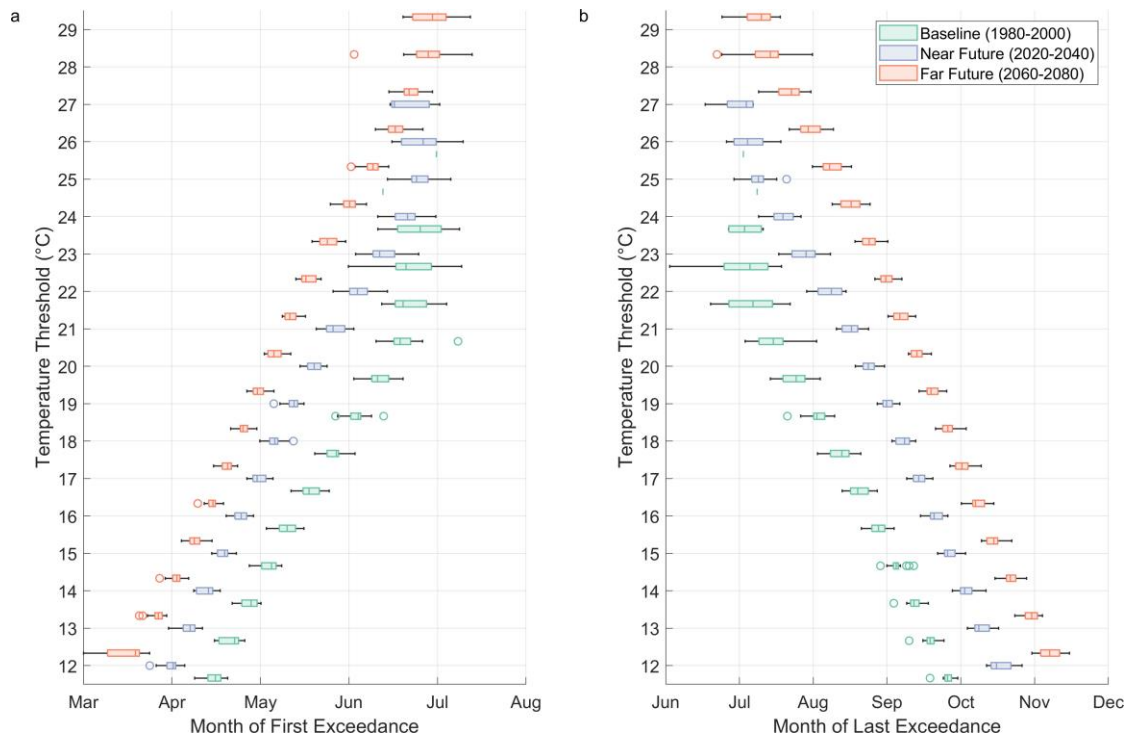


Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

- (a) Temperature duration curves represent distribution of SSTs over time to highlight changes in cold and warm extremes.
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Section 2 - Sea surface salinity changes

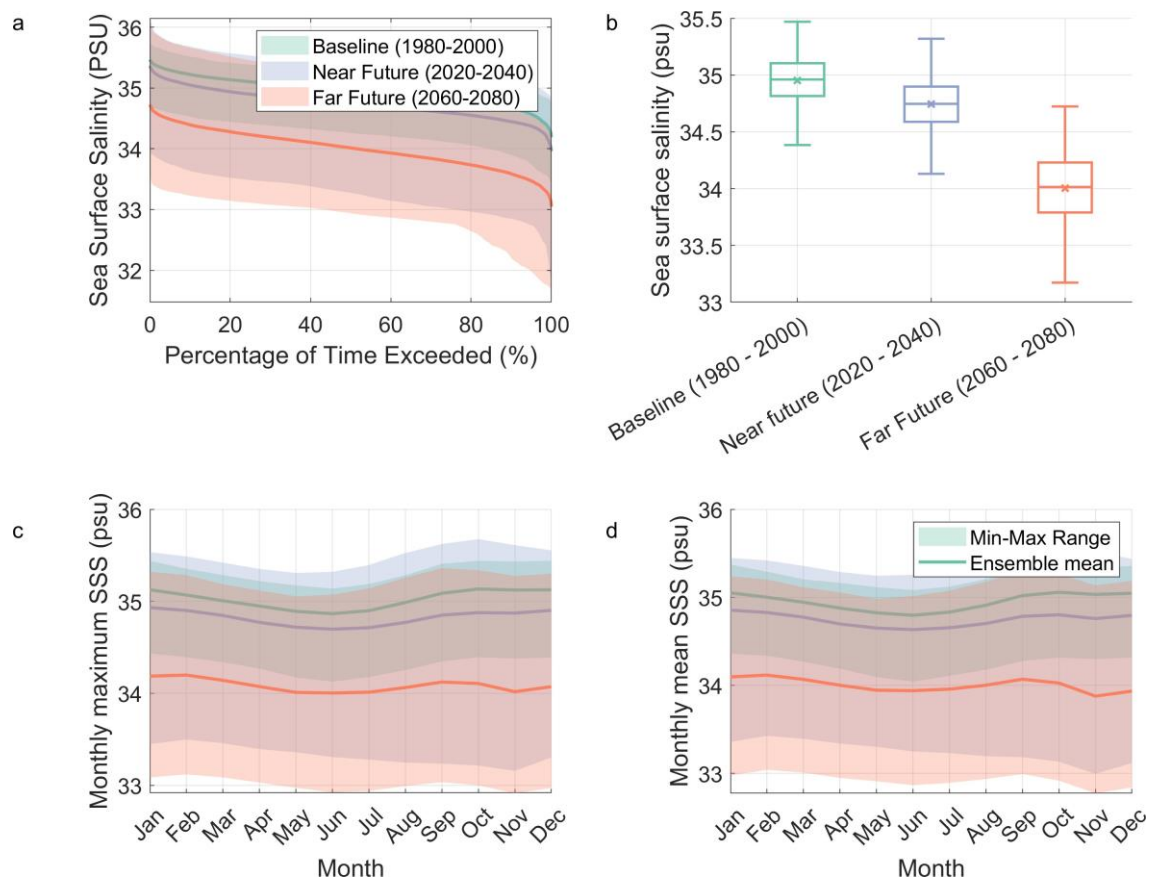


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
- (b) Percentile shifts show decreasing mean, median, and extremes, indicating a trend towards freshening over time.
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- (d) Decreasing monthly means suggest long-term ice-melt driven freshening.

Section 3 - Residual surge changes

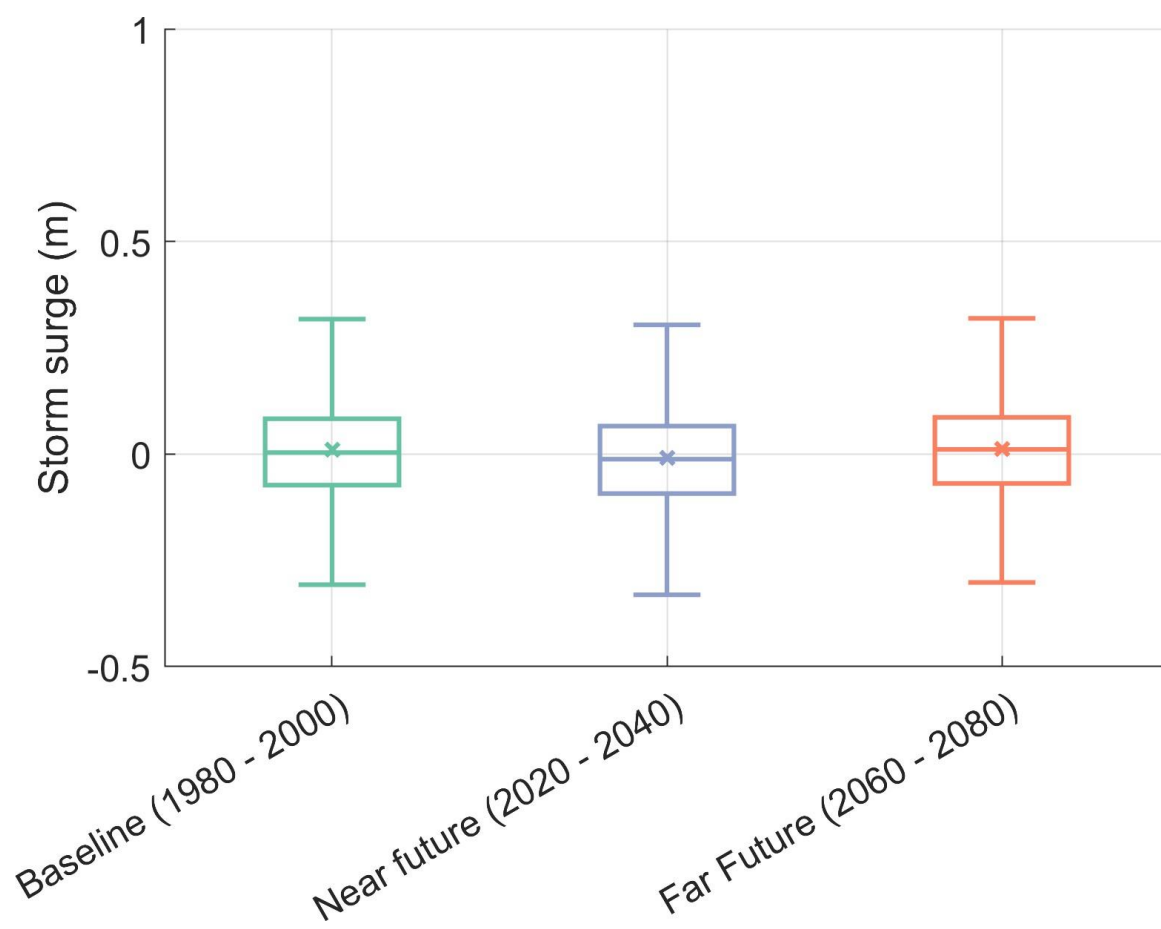


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

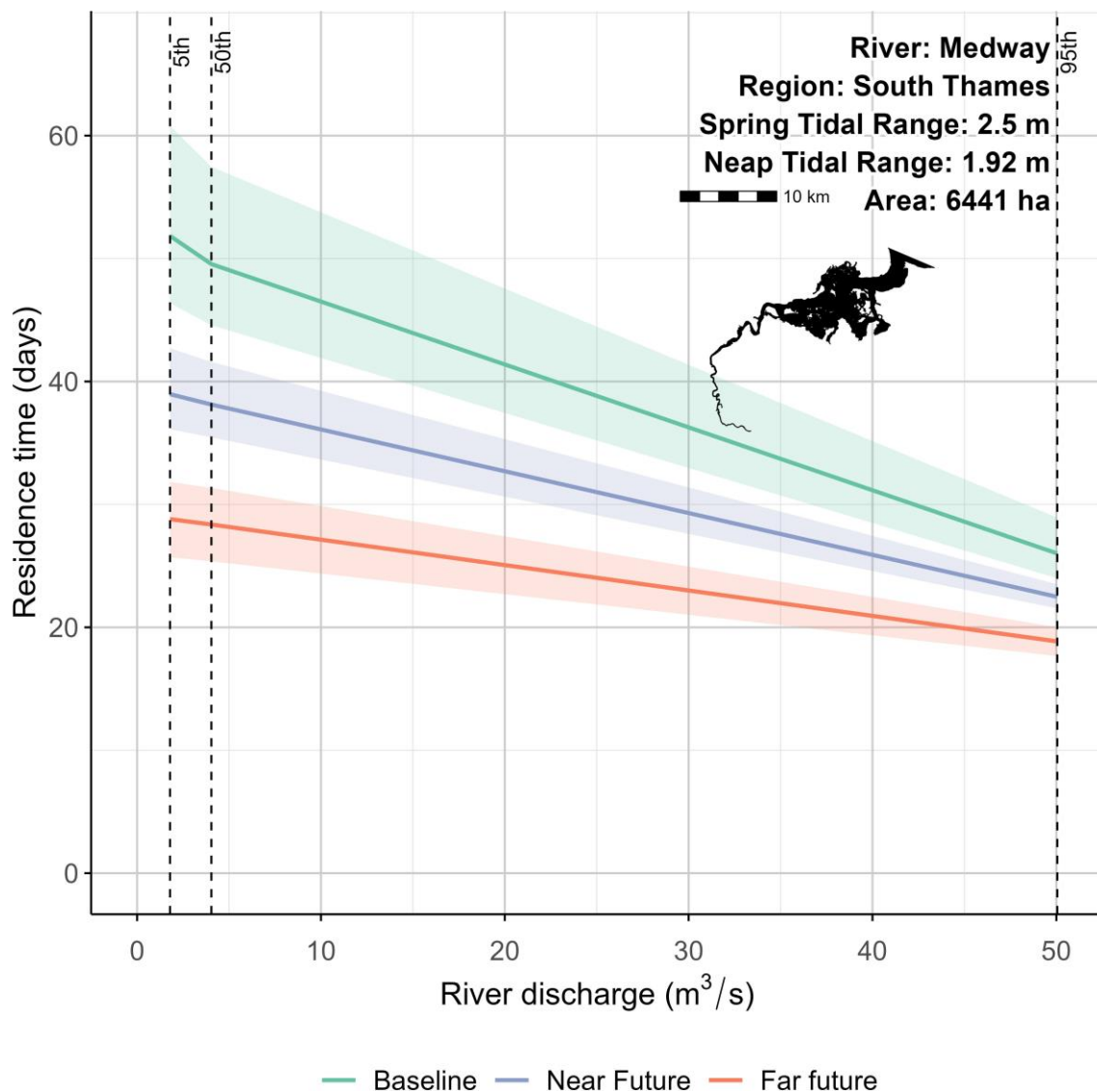


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)
Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Mersey

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	53.37935
Longitude	-2.60883
Tidal Range	8.3 m
Gauge Name	Mersey at Westy
Estuary Size	61500000.0 m ²
5th percentile flow	9.43 m ³ /s
50th percentile flow	29.02 m ³ /s
95th percentile flow	92.6 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

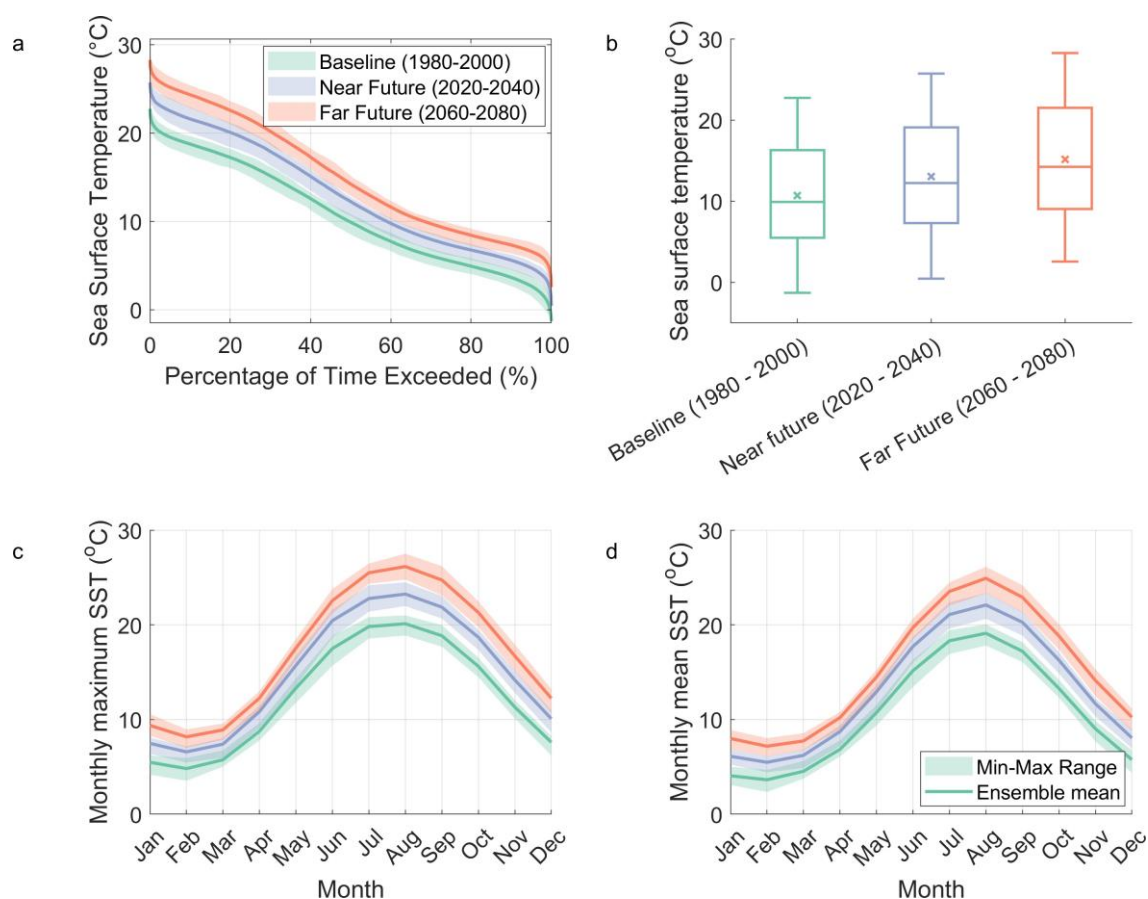
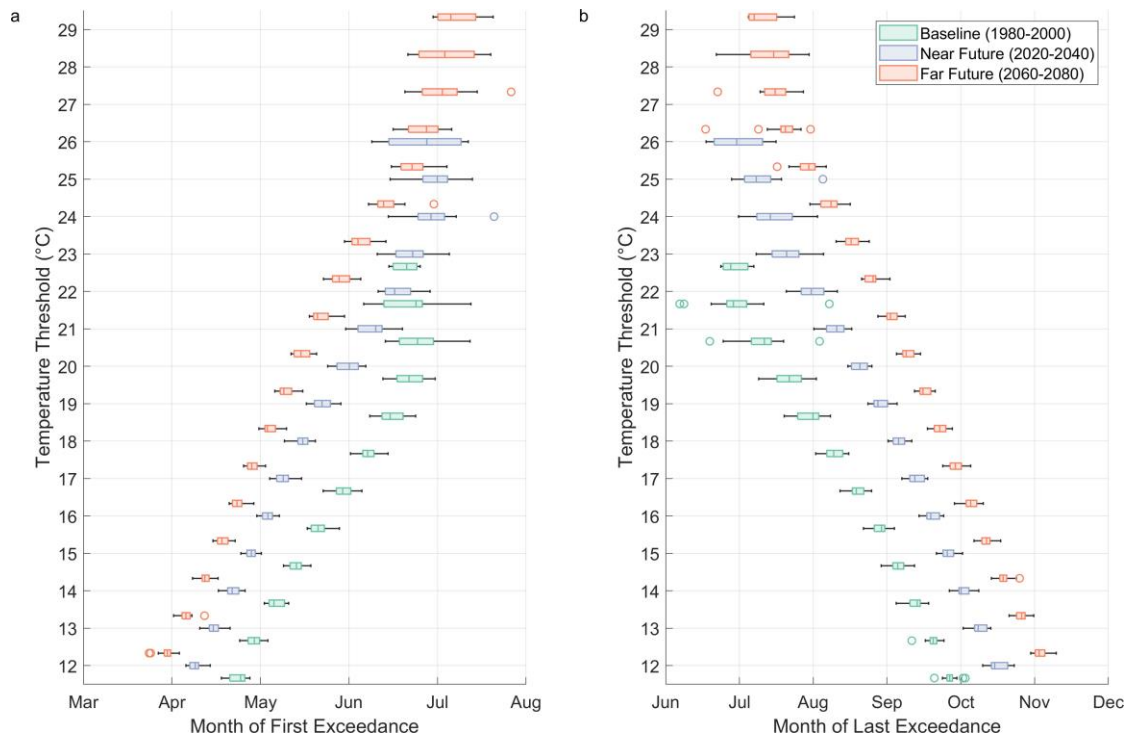


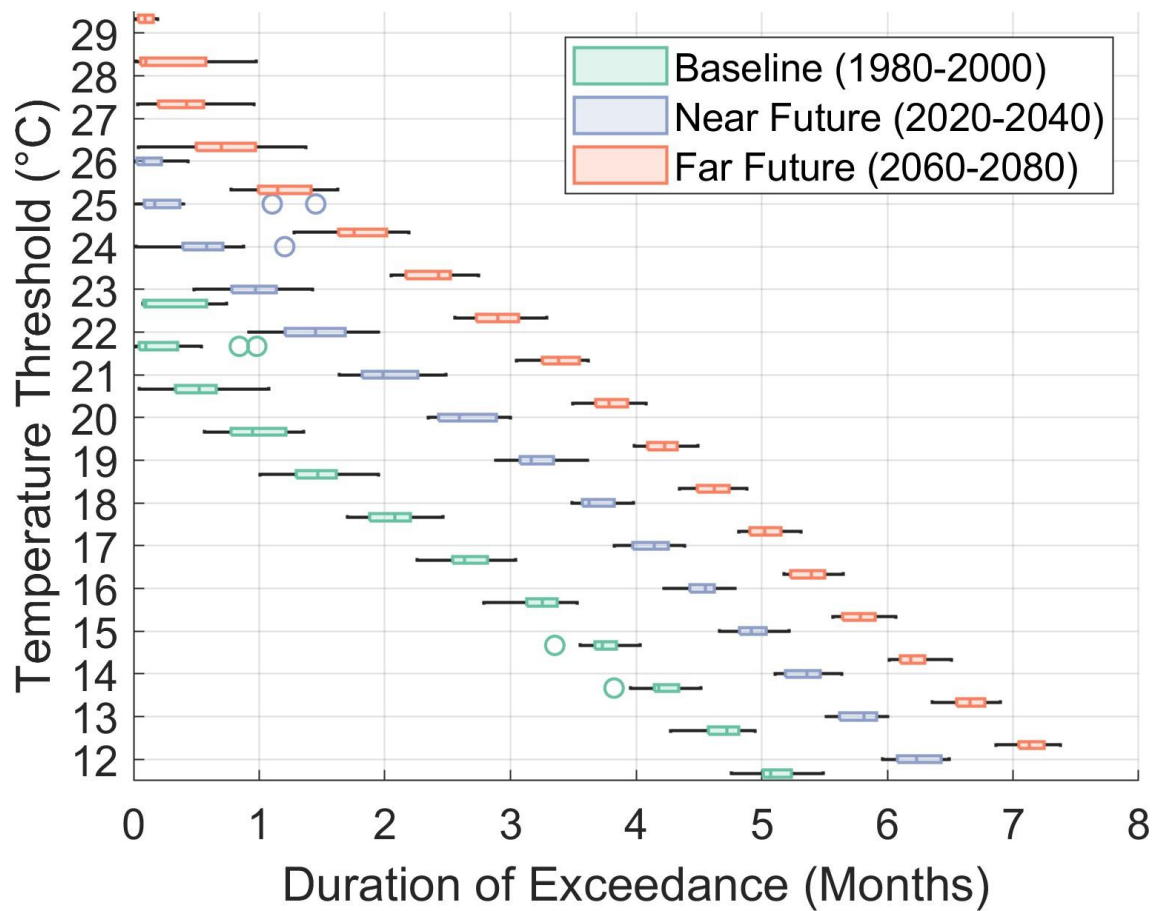
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

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Projected temperature changes under different climate scenarios. Box and whisker plots show the range of different modelled durations of temperatures under the 12 different UKCP 18 ensemble members. Open circles indicate outlier values.

Section 2 - Sea surface salinity changes

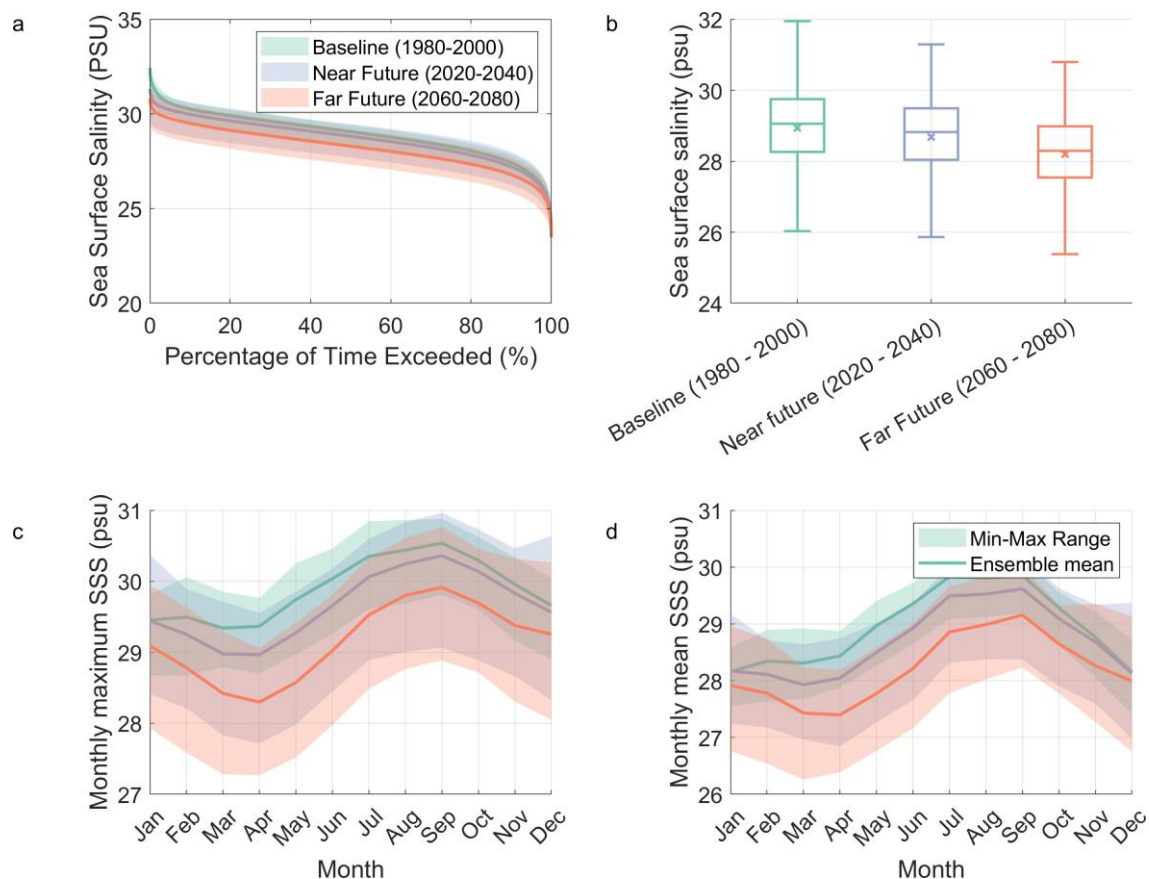


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
- (b) Percentile shifts show decreasing mean, median, and extremes, indicating a trend towards freshening over time.
- (c) Monthly maxima decrease across all months.
- (d) Decreasing monthly means suggest long-term ice-melt driven freshening.

Section 3 - Residual surge changes

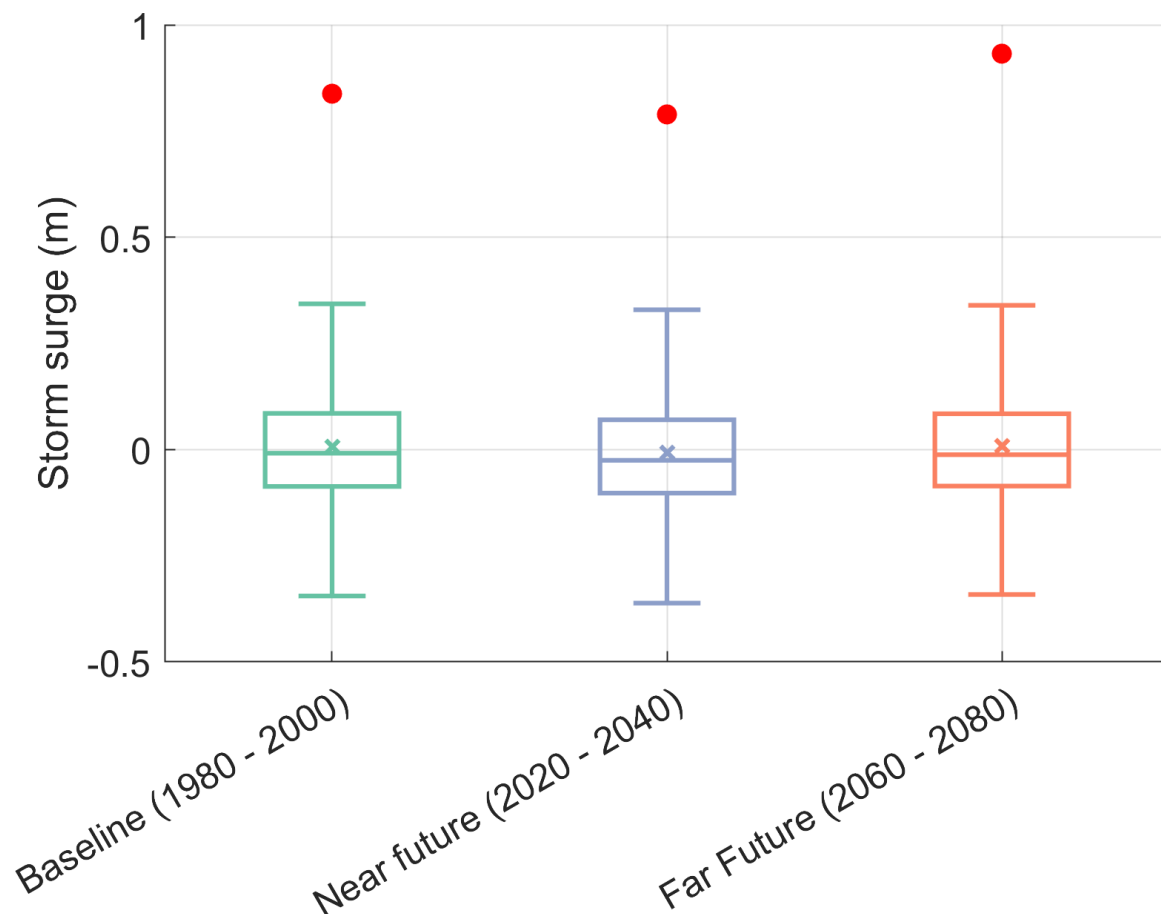


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - River discharge changes

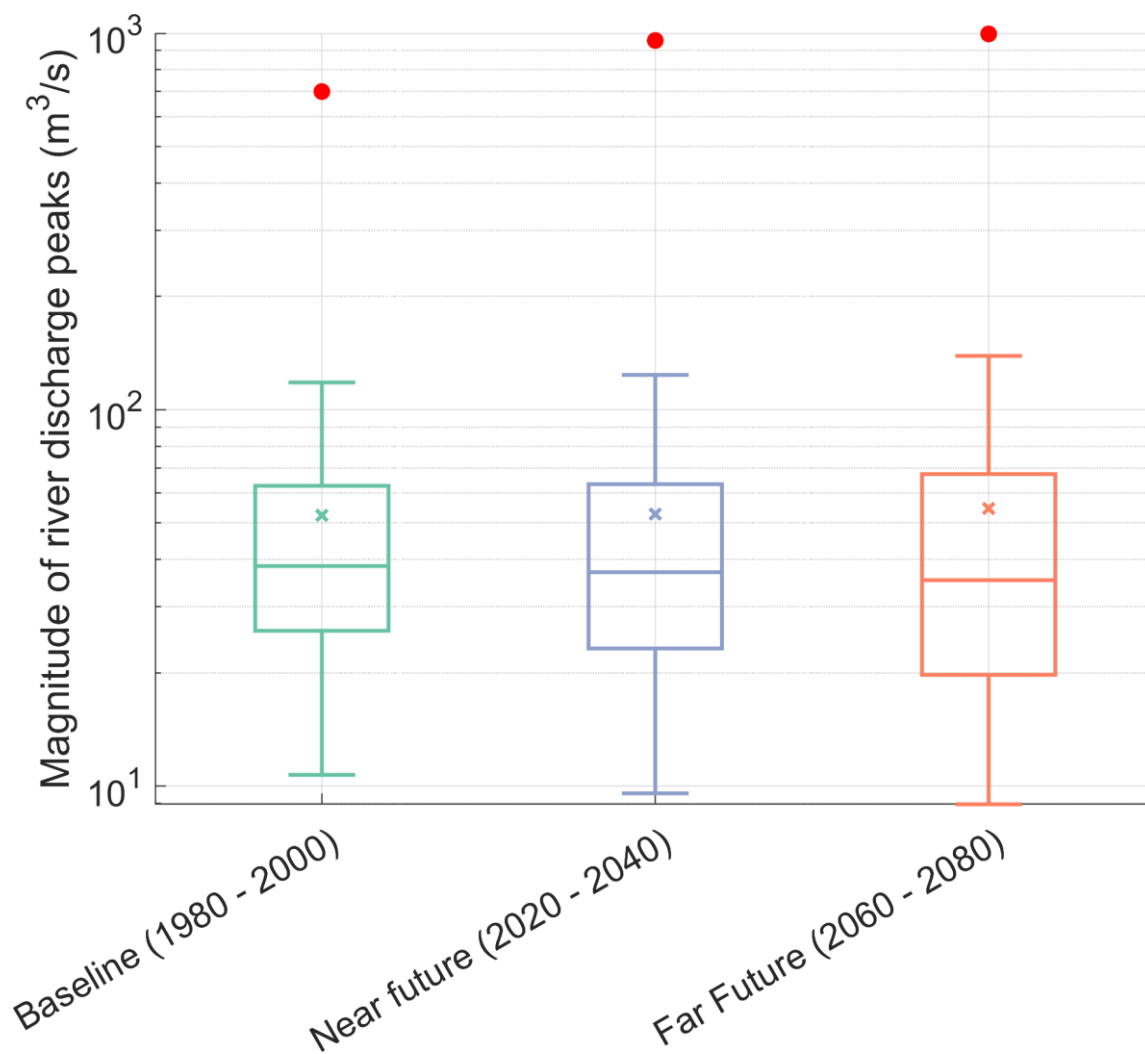


Figure description

Box and whisker plots of discharge percentiles under baseline (1980-2000), near-future (2020-2040) and far-future (2060-2080)

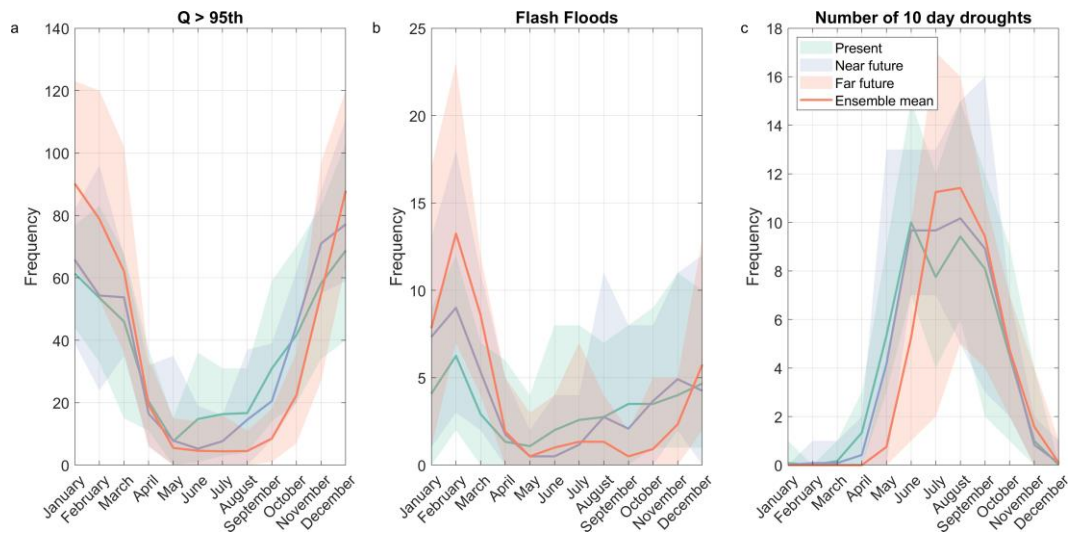


Figure description

Discharge conditions under baseline (1980-2000), near-future (2020-2040) and far-future (2060-2080) showing frequency of (a): Occurrence of high flow (>95th percentile events) per month (hourly resolution), (b): Flash flood events (increase in discharge of >50 m³/s, (c): low flow events lasting longer than 10 days).

Section 5 - Residence times changes

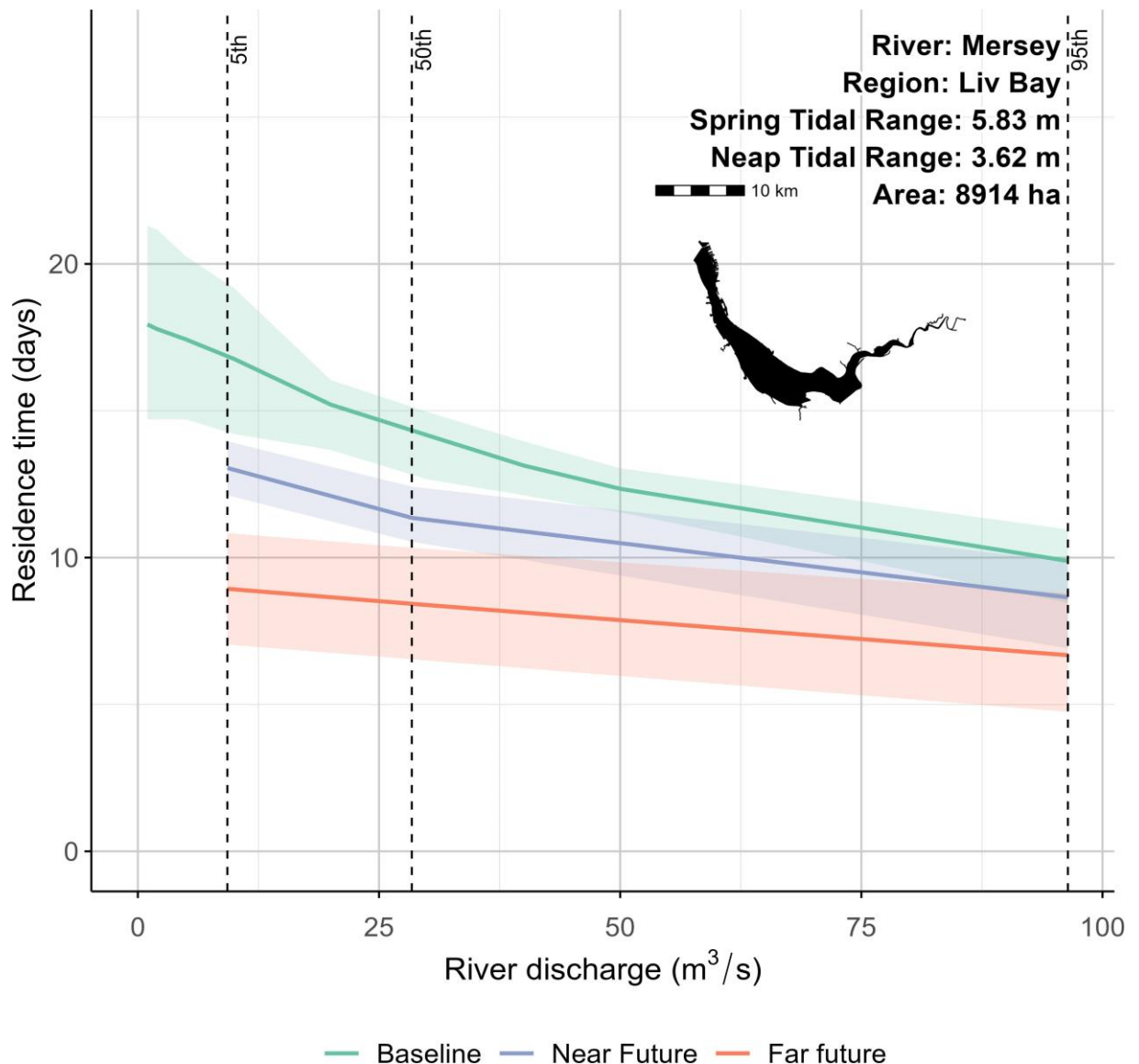


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080) Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Ore

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	52.17178
Longitude	1.45044
Tidal Range	2.8 m
Gauge Name	Ore at Beversham
Estuary Size	10400000.0 m ²
5th percentile flow	0.067 m ³ /s
50th percentile flow	0.142 m ³ /s
95th percentile flow	1.11 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

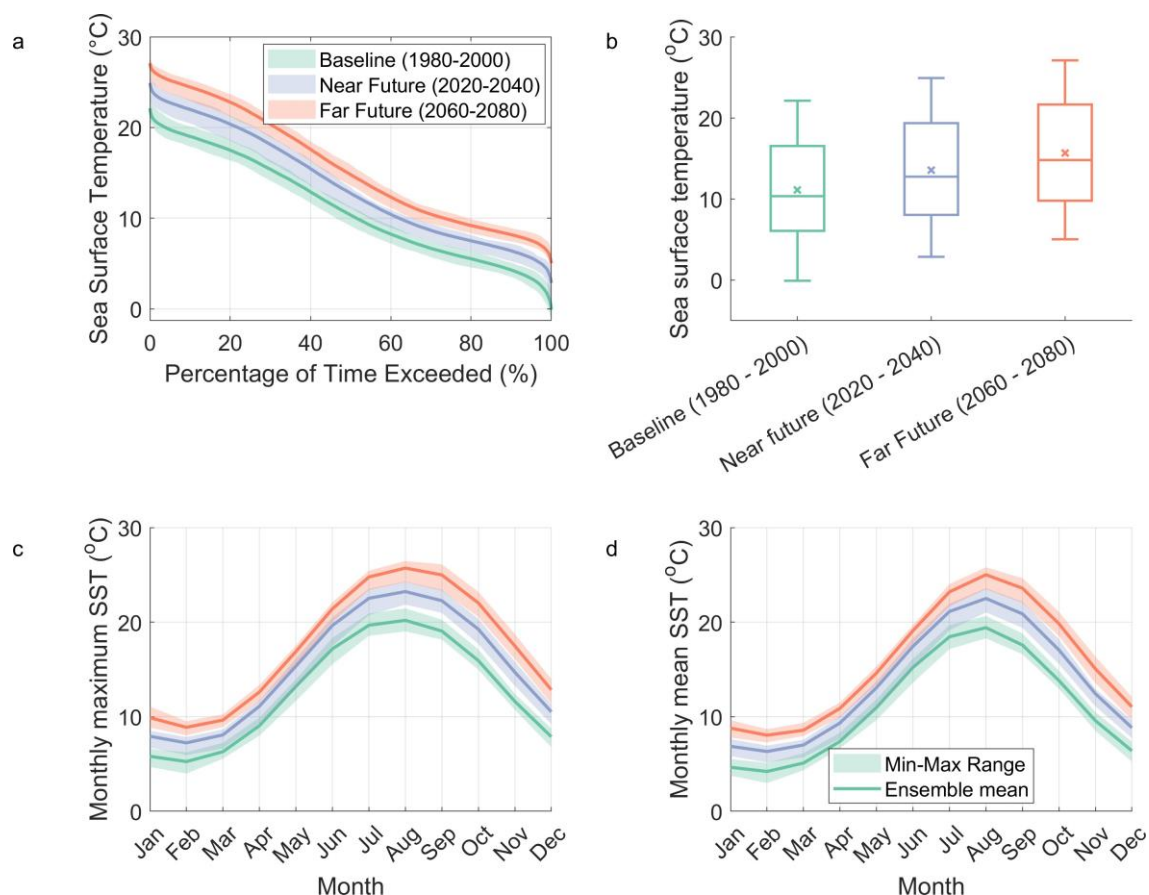
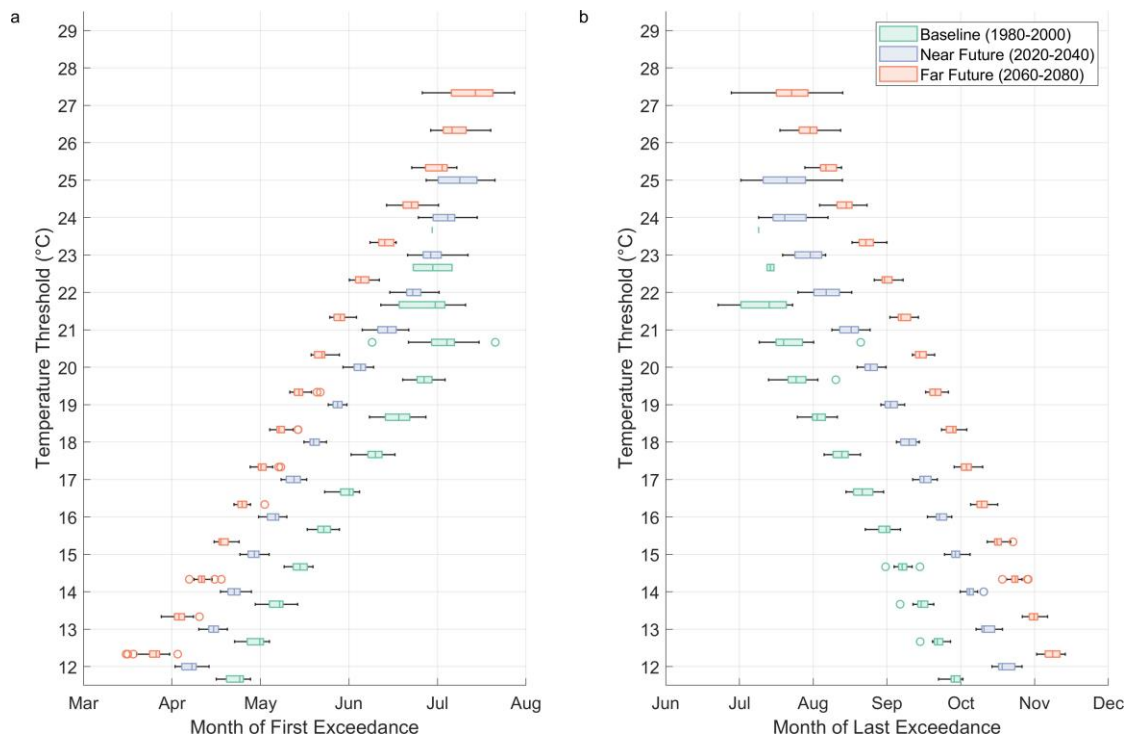


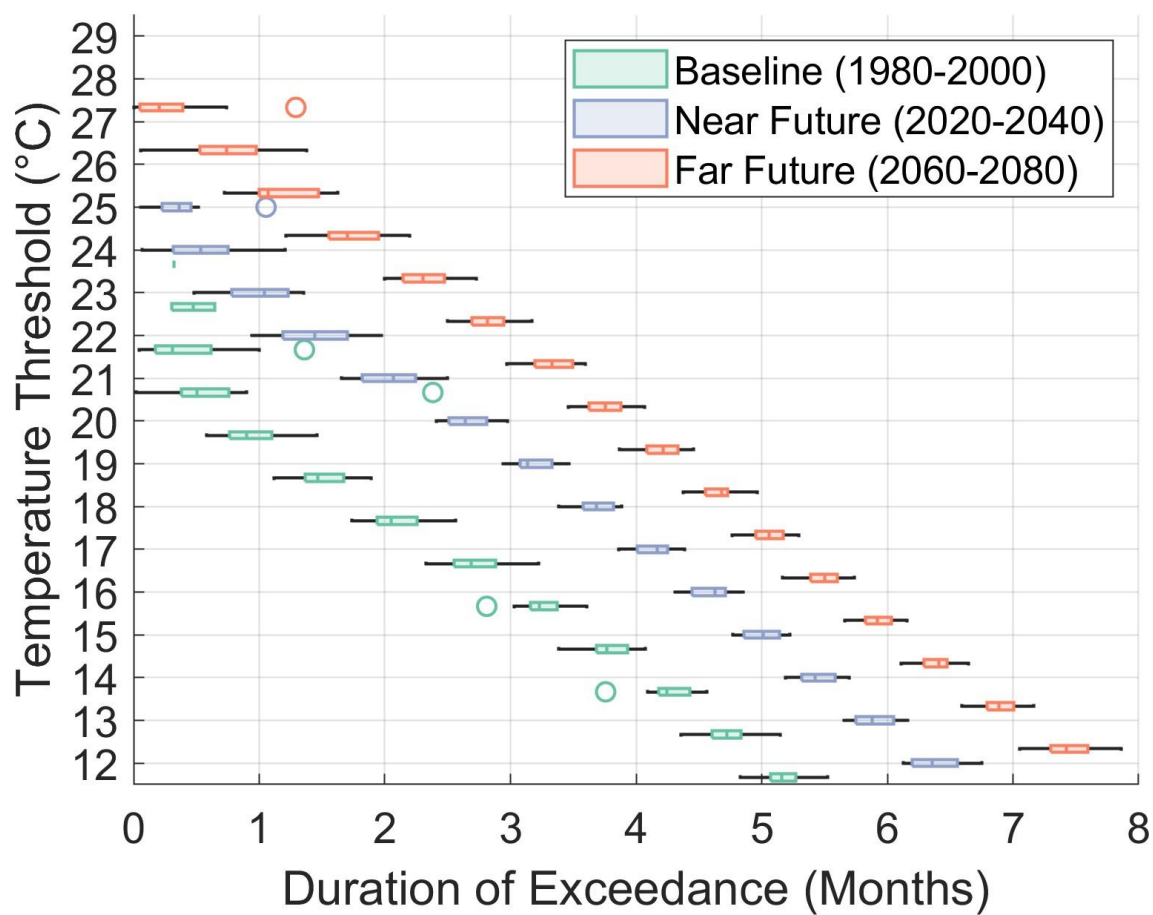
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

- (a) Temperature duration curves represent distribution of SSTs over time to highlight changes in cold and warm extremes.
- (b) Percentile shifts show increasing mean, median, and extremes, indicating prolonged warming over time.
- (c) Rising monthly maximum in every month of the year highlights likelihood of intensified high heat events.
- (d) Rising monthly mean suggests long-term climate-driven warming.



Changes in first and last occurrences of temperature thresholds compared to historical data. Note that these plots are not intended to identify the specific date on which a temperature may occur, rather they indicate the trend in the onset of specific temperature thresholds.



Projected temperature changes under different climate scenarios. Box and whisker plots show the range of different modelled durations of temperatures under the 12 different UKCP 18 ensemble members. Open circles indicate outlier values.

Section 2 - Sea surface salinity changes

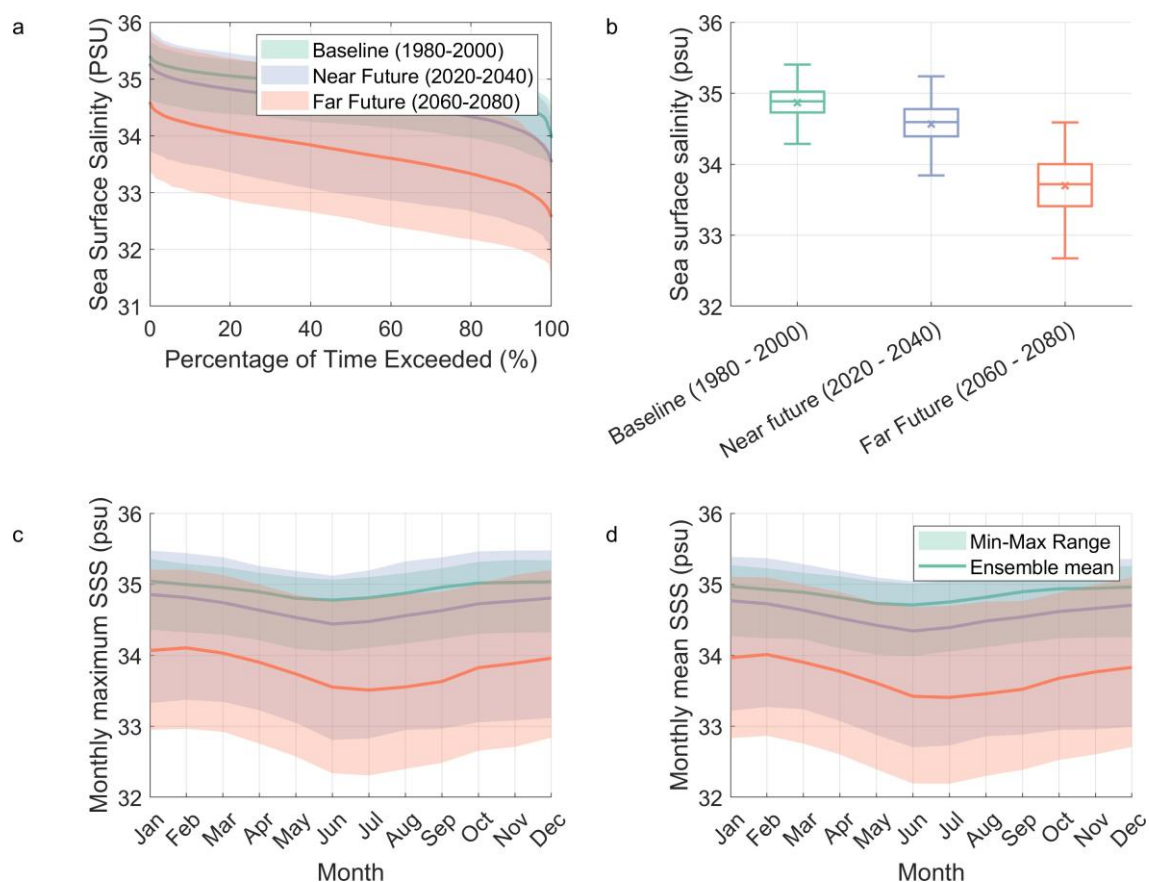


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
- (b) Percentile shifts show decreasing mean, median, and extremes, indicating a trend towards freshening over time.
- (c) Monthly maxima decrease across all months.
- (d) Decreasing monthly means suggest long-term ice-melt driven freshening.

Section 3 - Residual surge changes

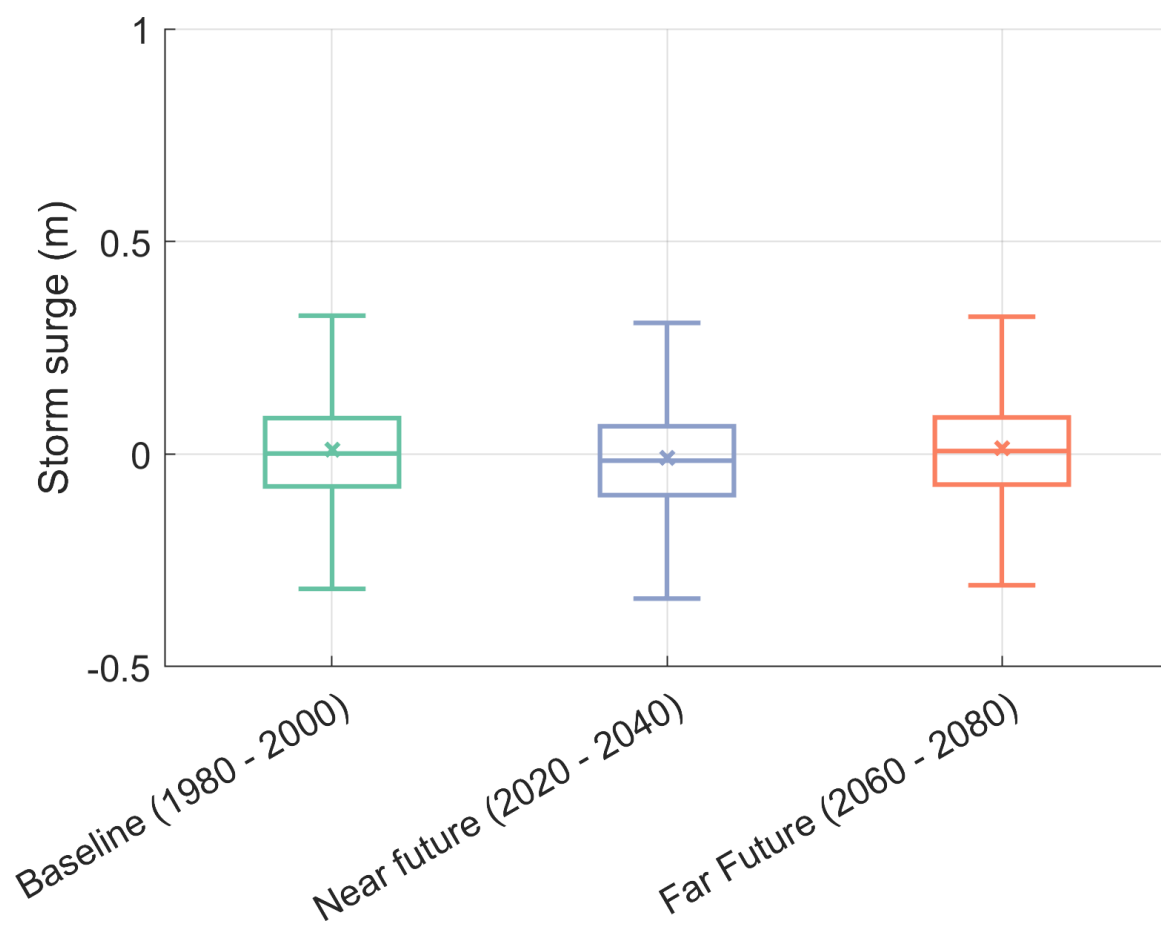


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

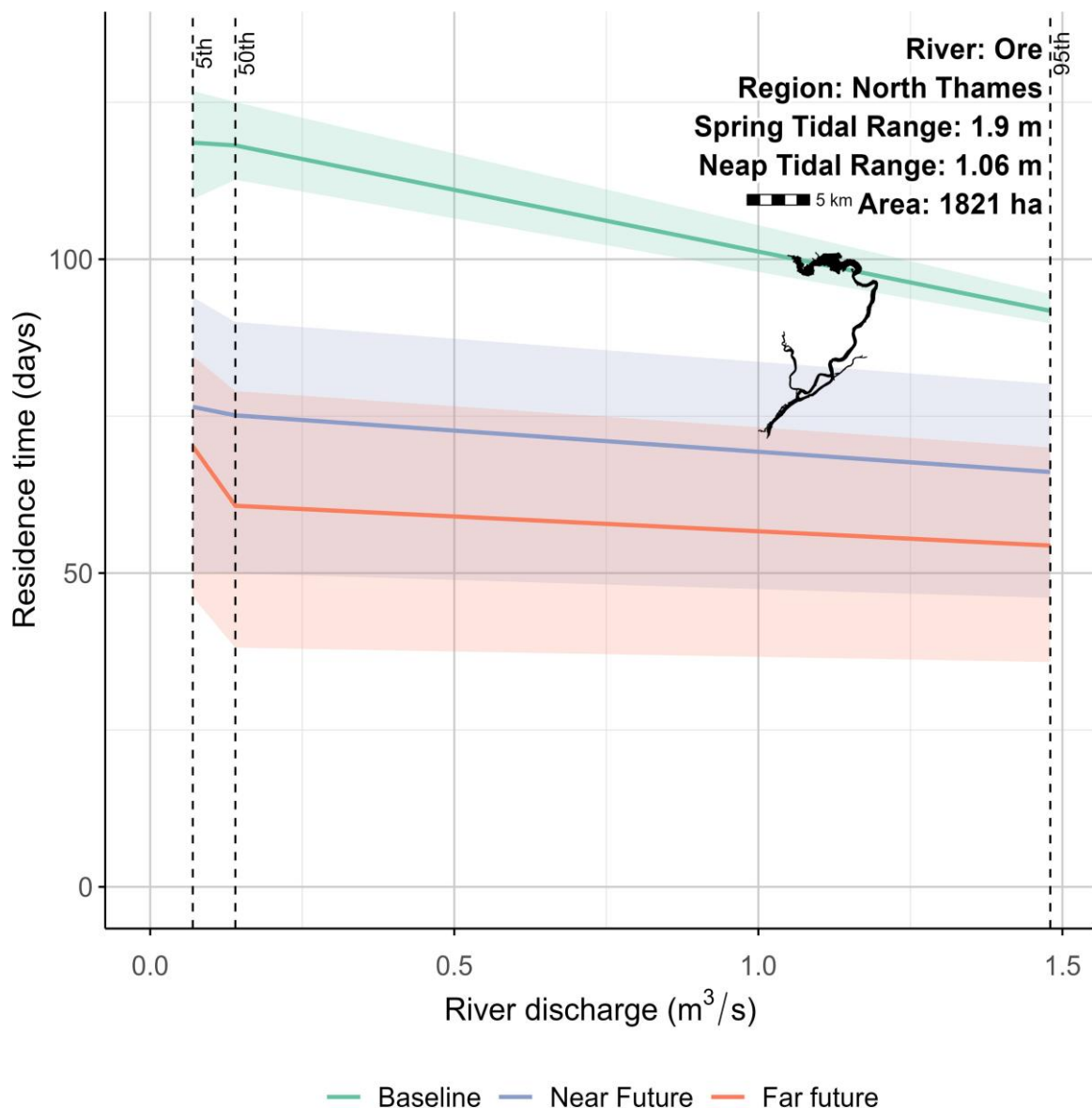


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Otter

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	50.68841
Longitude	-3.29502
Tidal Range	3.6 m
Gauge Name	Otter at Dotton
Estuary Size	nan m ²
5th percentile flow	0.973 m ³ /s
50th percentile flow	1.89 m ³ /s
95th percentile flow	10.3 m ³ /s
Notes	Estuaries Database lists mean tide surface

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

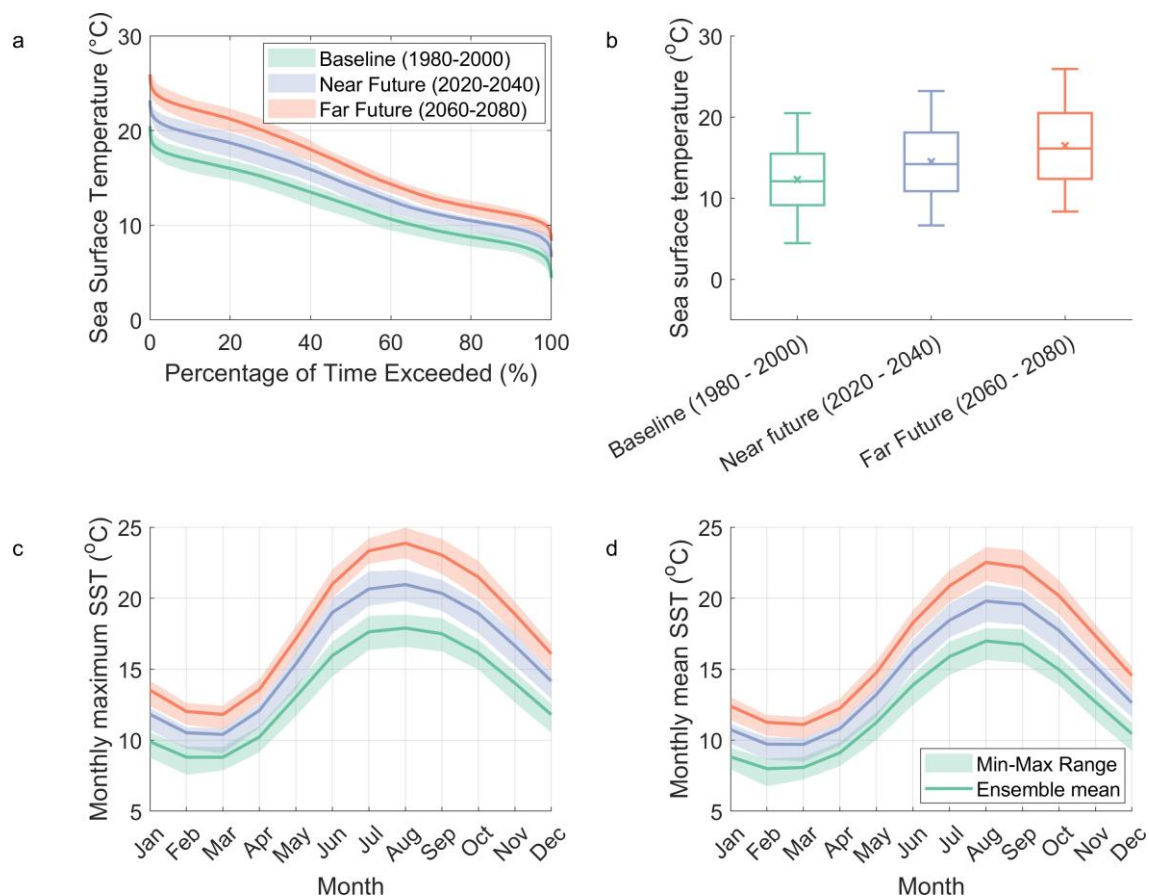
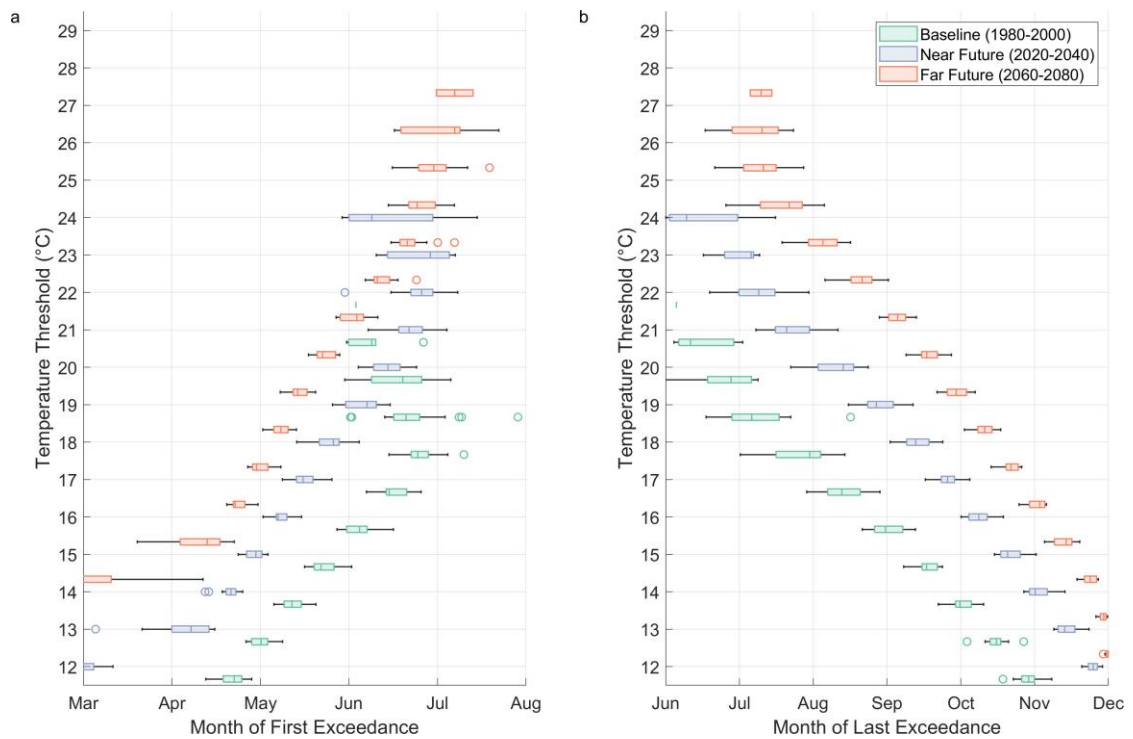


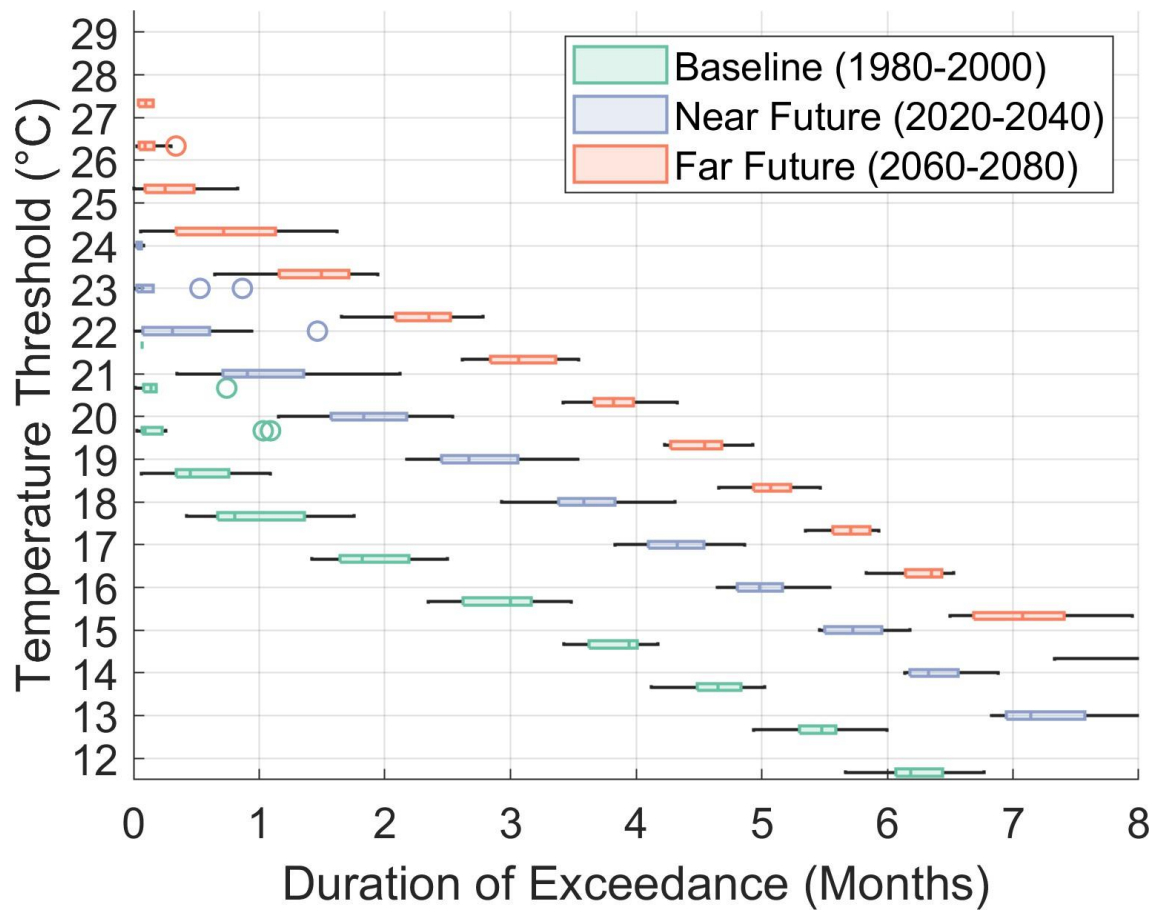
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

- (a) Temperature duration curves represent distribution of SSTs over time to highlight changes in cold and warm extremes.
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Changes in first and last occurrences of temperature thresholds compared to historical data. Note that these plots are not intended to identify the specific date on which a temperature may occur, rather they indicate the trend in the onset of specific temperature thresholds.



Projected temperature changes under different climate scenarios. Box and whisker plots show the range of different modelled durations of temperatures under the 12 different UKCP 18 ensemble members. Open circles indicate outlier values.

Section 2 - Sea surface salinity changes

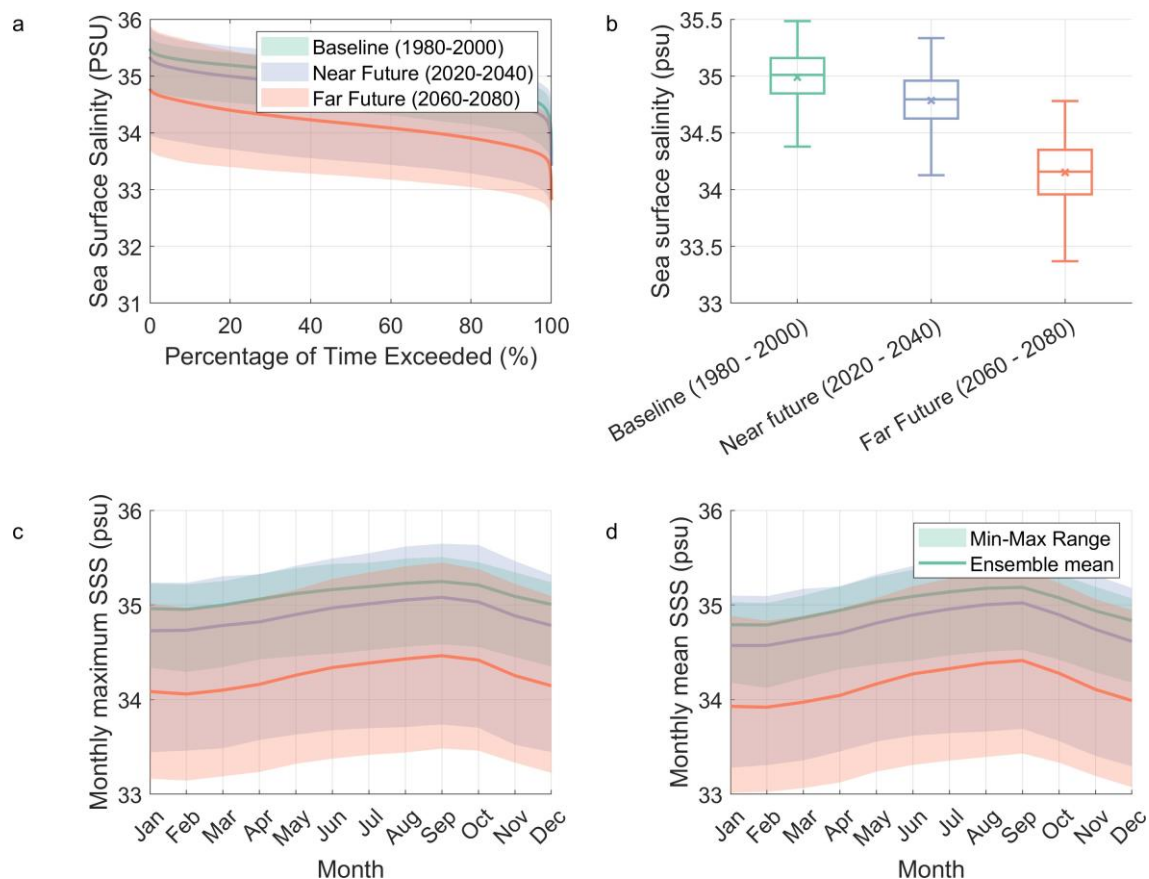


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
- (b) Percentile shifts show decreasing mean, median, and extremes, indicating a trend towards freshening over time.
- (c) Monthly maxima decrease across all months.
- (d) Decreasing monthly means suggest long-term ice-melt driven freshening.

Section 3 - Residual surge changes

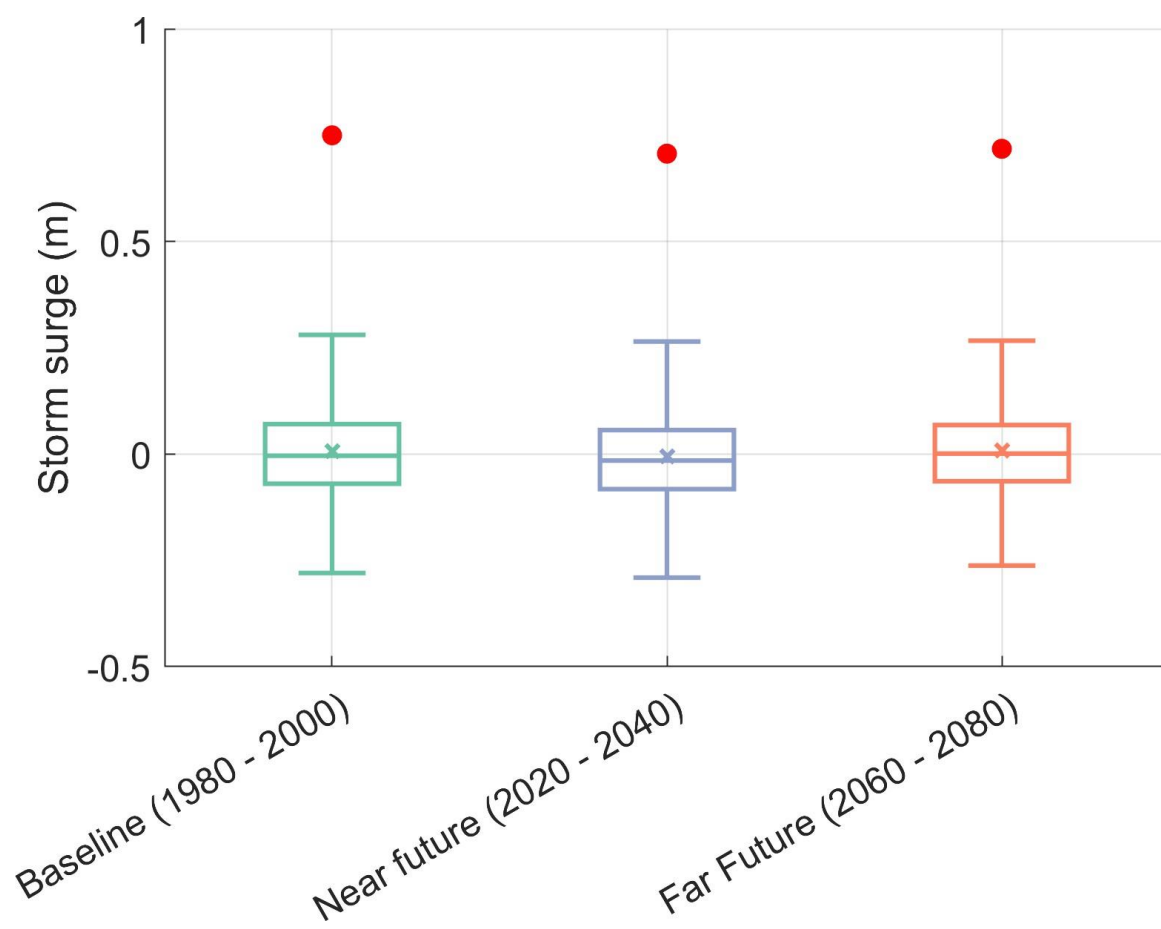


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

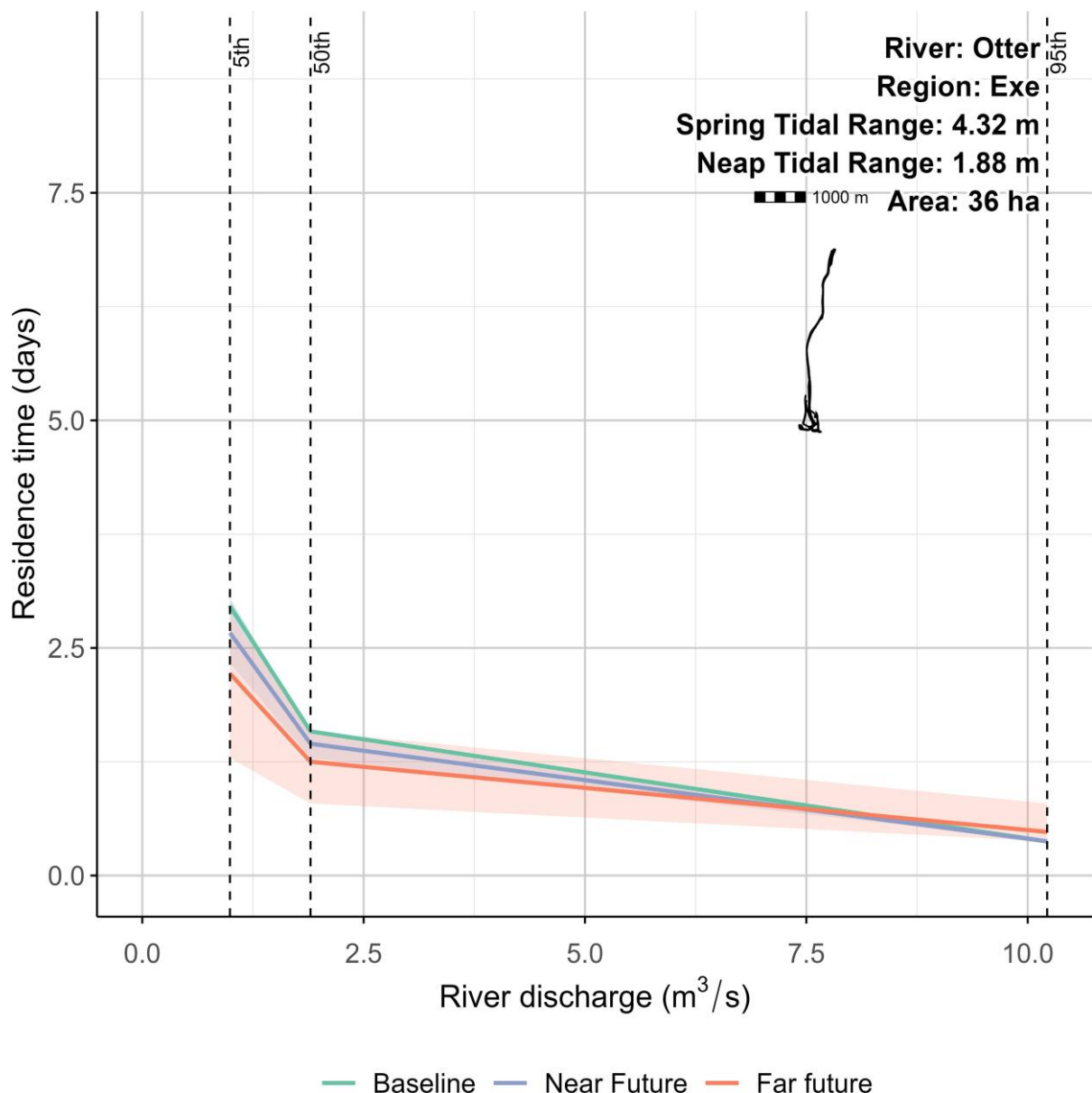


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Ouse

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	50.91475
Longitude	-0.03883
Tidal Range	6.0 m
Gauge Name	Ouse at Barcombe Mills
Estuary Size	944000.0 m ²
5th percentile flow	0.292 m ³ /s
50th percentile flow	1.422 m ³ /s
95th percentile flow	12.34 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

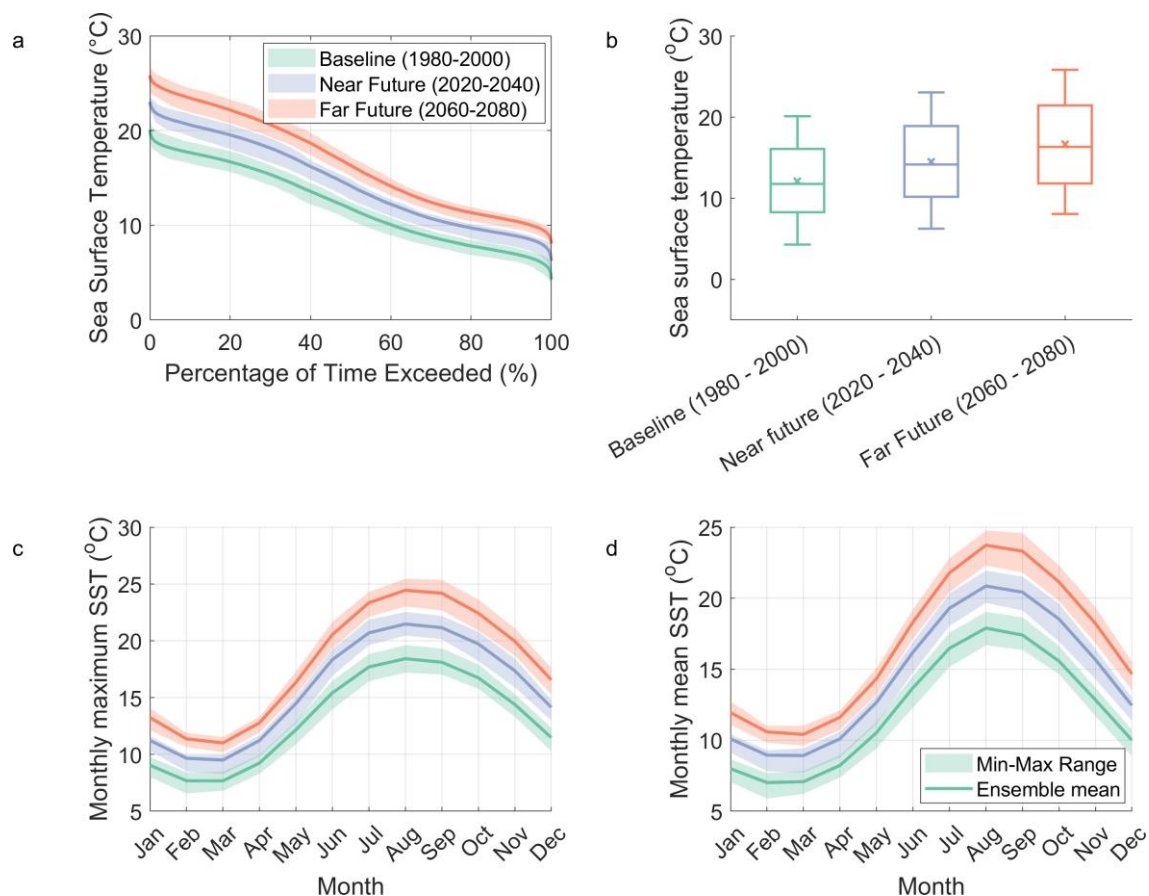
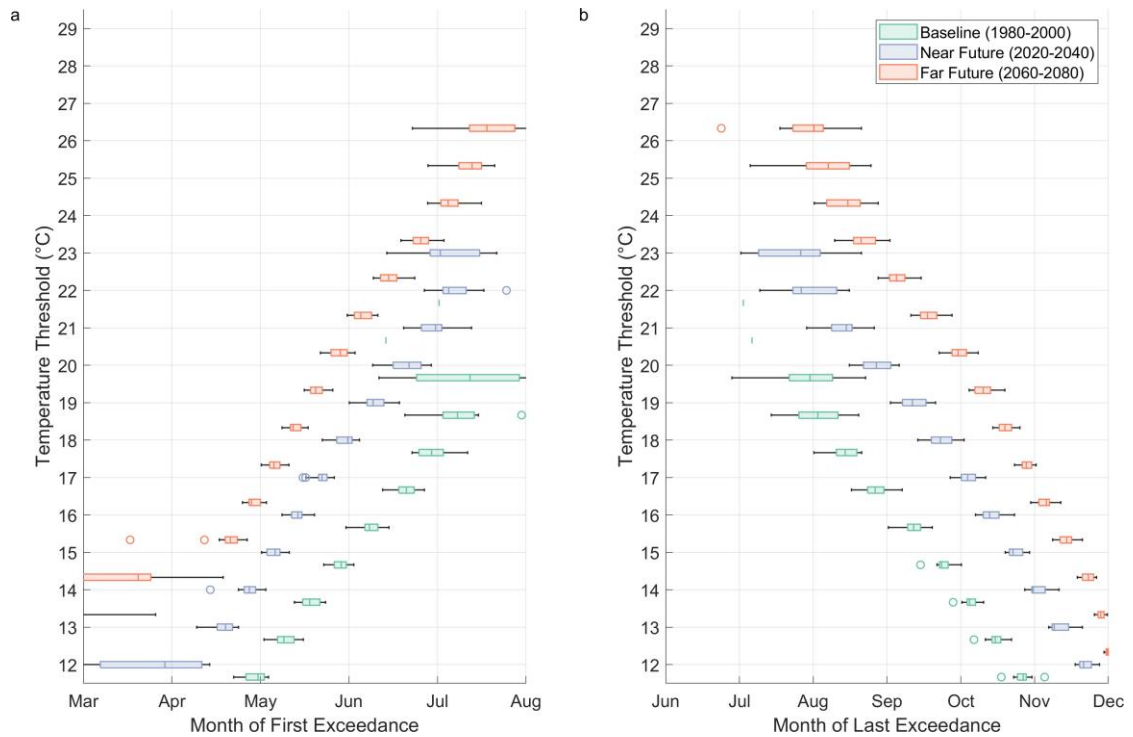


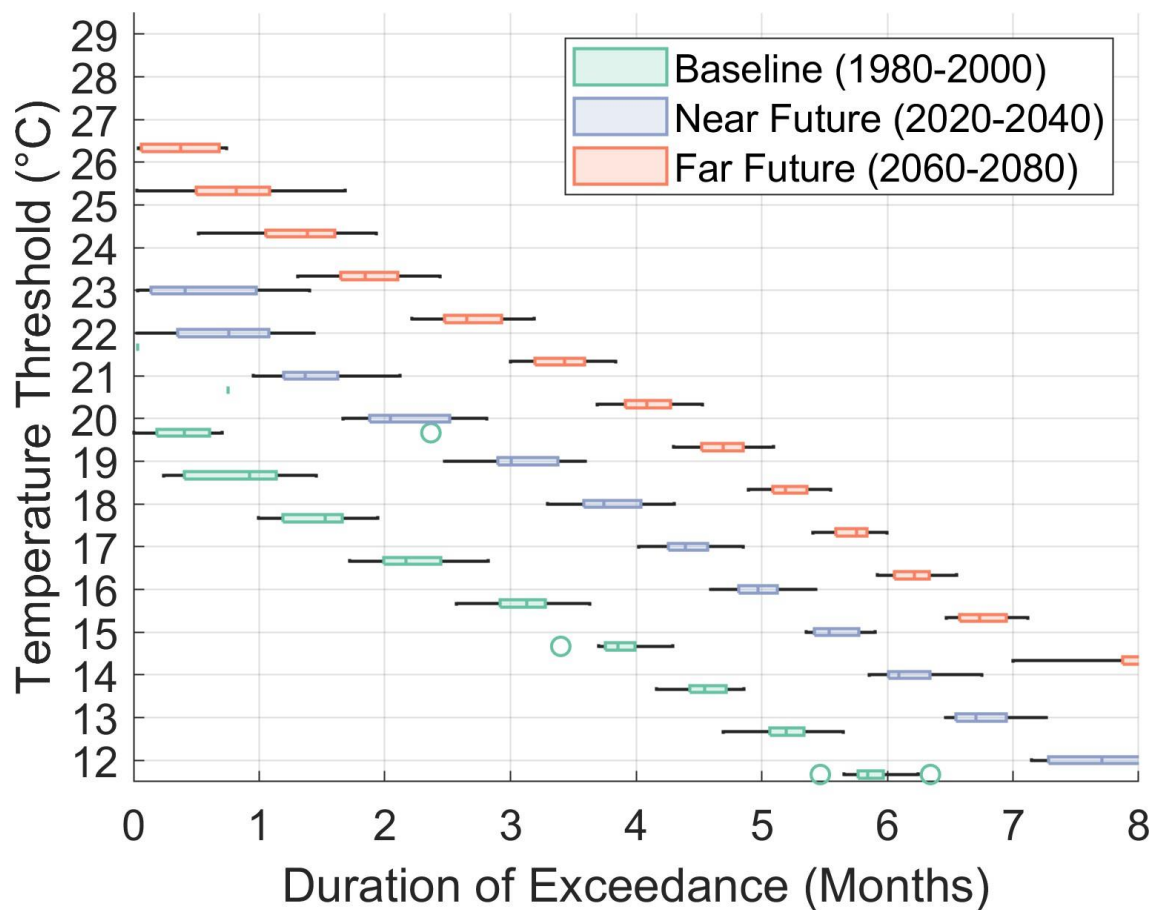
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

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Projected temperature changes under different climate scenarios. Box and whisker plots show the range of different modelled durations of temperatures under the 12 different UKCP 18 ensemble members. Open circles indicate outlier values.

Section 2 - Sea surface salinity changes

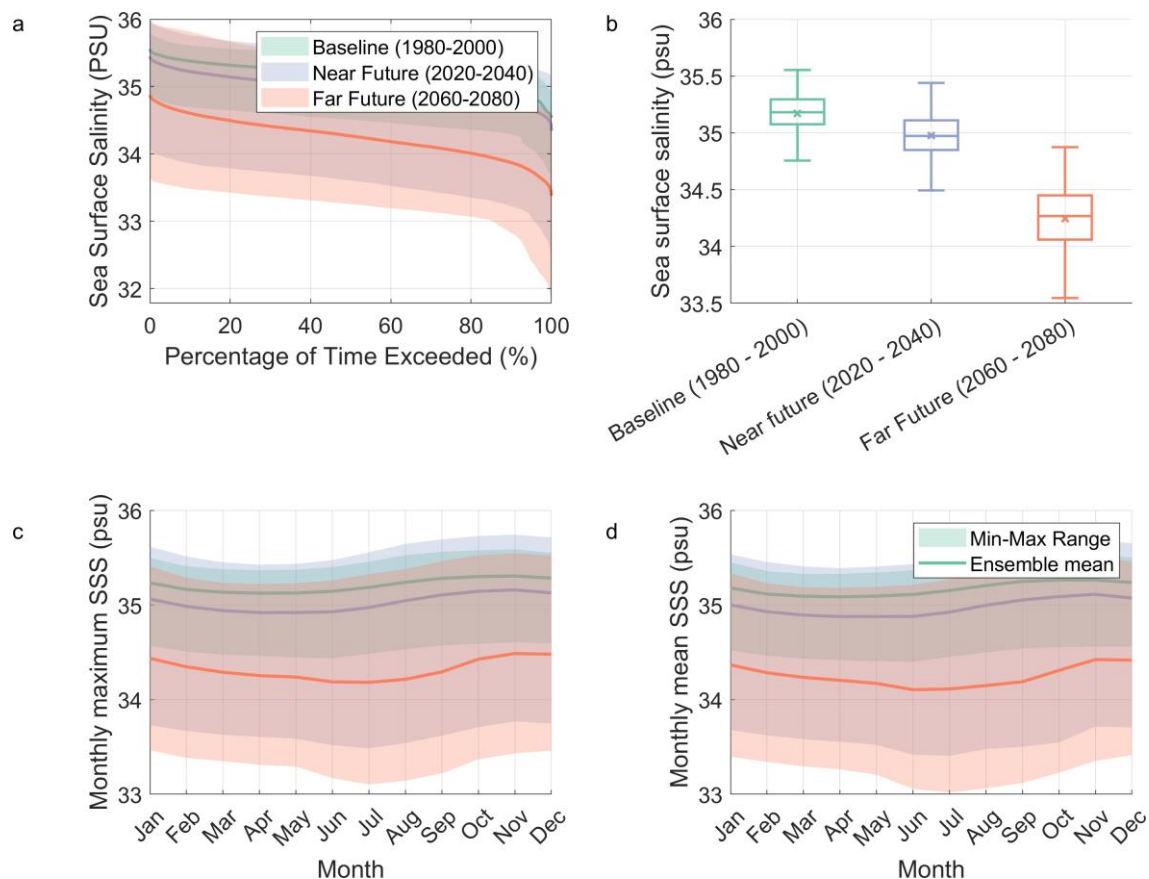


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
- (b) Percentile shifts show decreasing mean, median, and extremes, indicating a trend towards freshening over time.
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- (d) Decreasing monthly means suggest long-term ice-melt driven freshening.

Section 3 - Residual surge changes

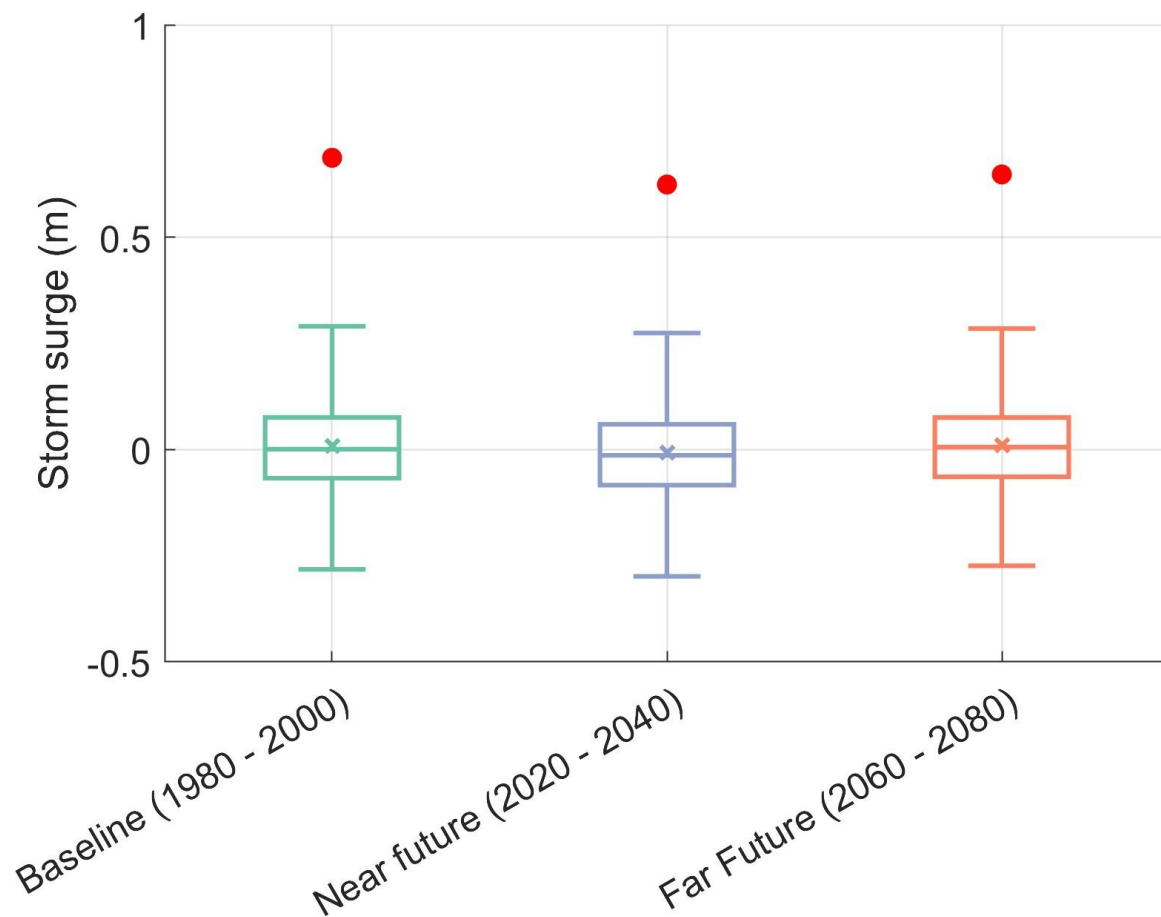


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

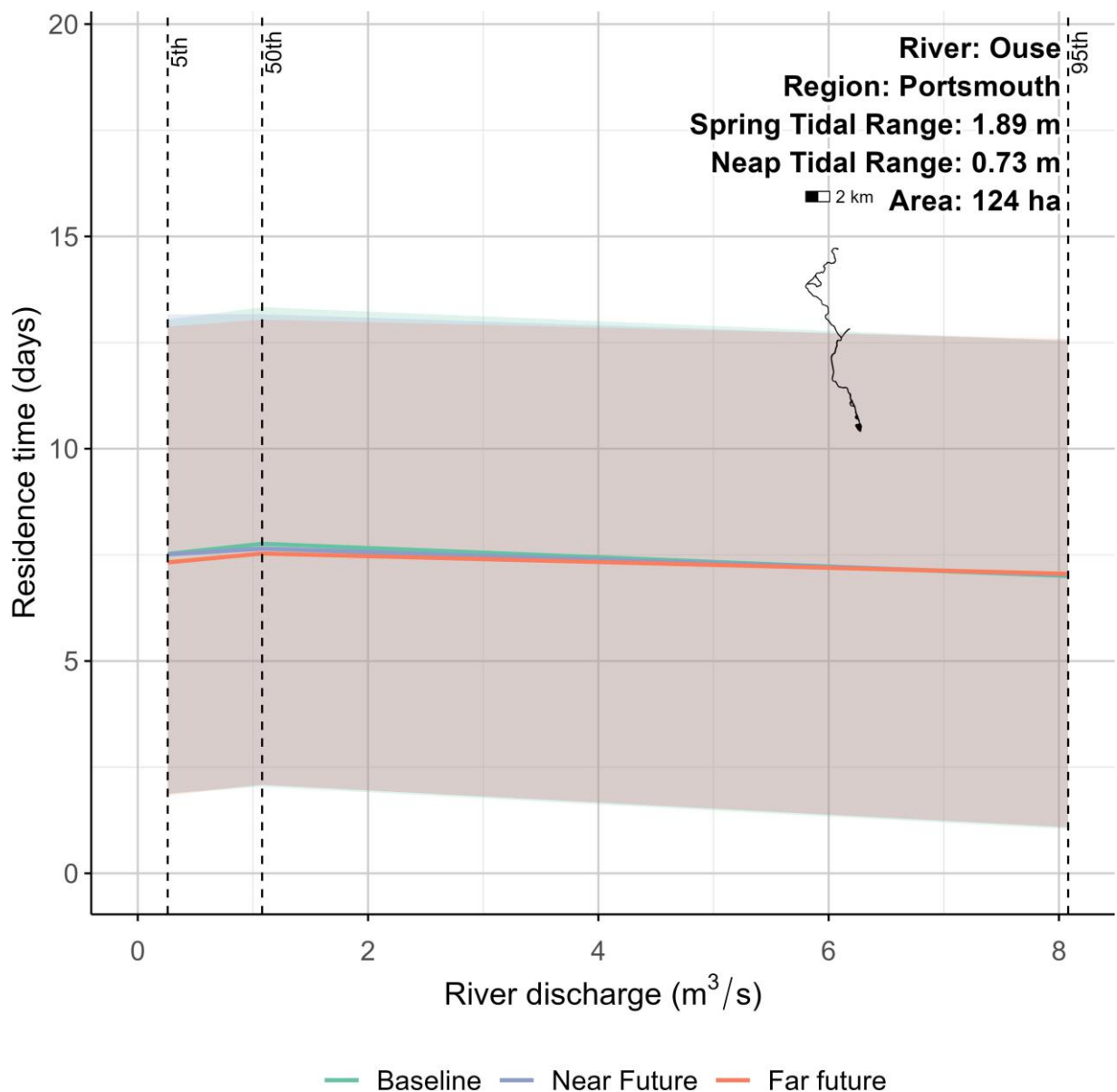


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Plymouth

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	50.53093
Longitude	-4.22178
Tidal Range	4.7 m
Gauge Name	Tamar at Gunnislake
Estuary Size	27300000.0 m ²
5th percentile flow	2.27 m ³ /s
50th percentile flow	11.8 m ³ /s
95th percentile flow	82.0 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

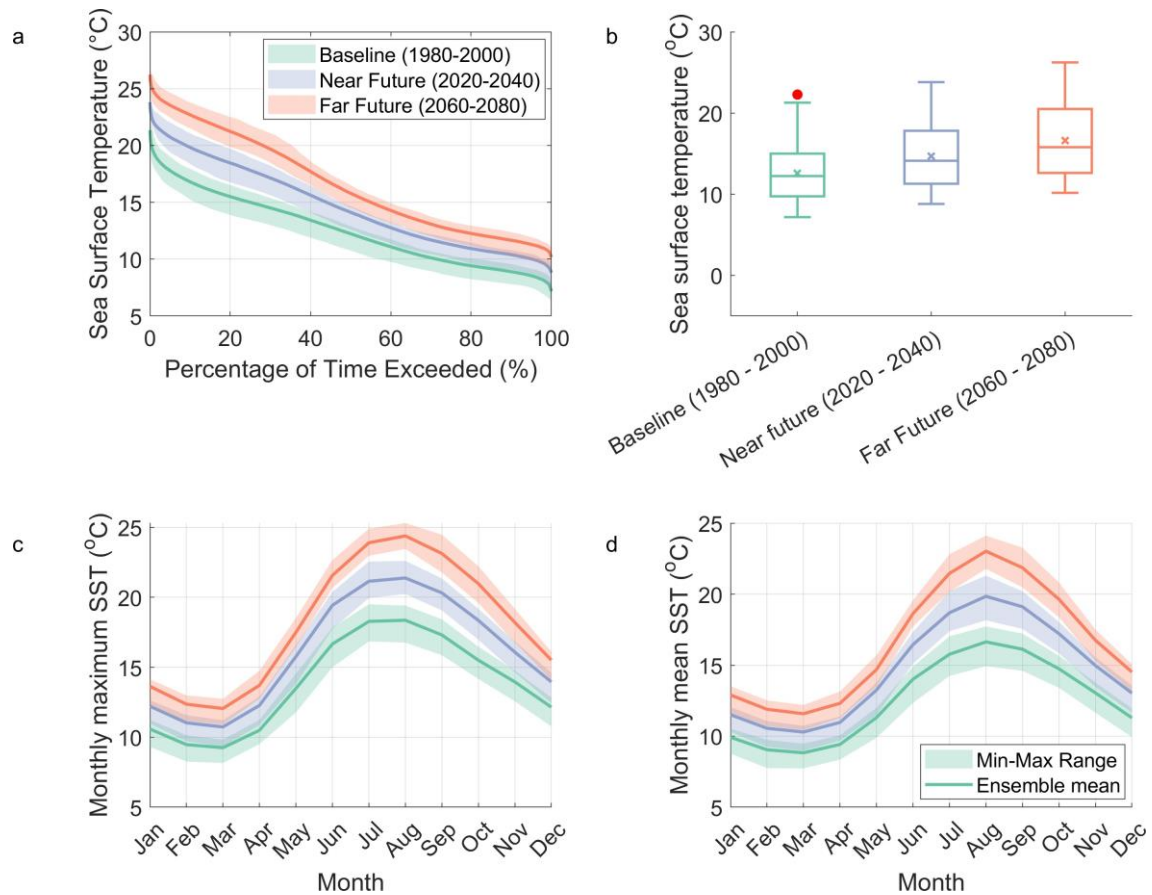
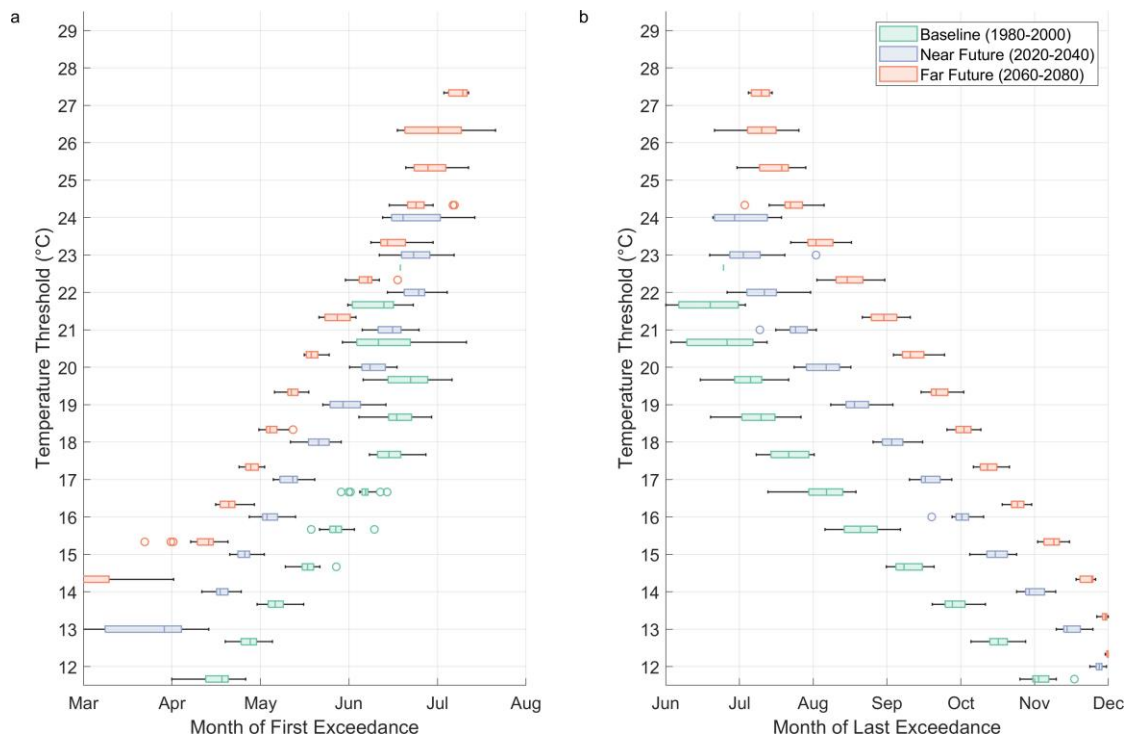


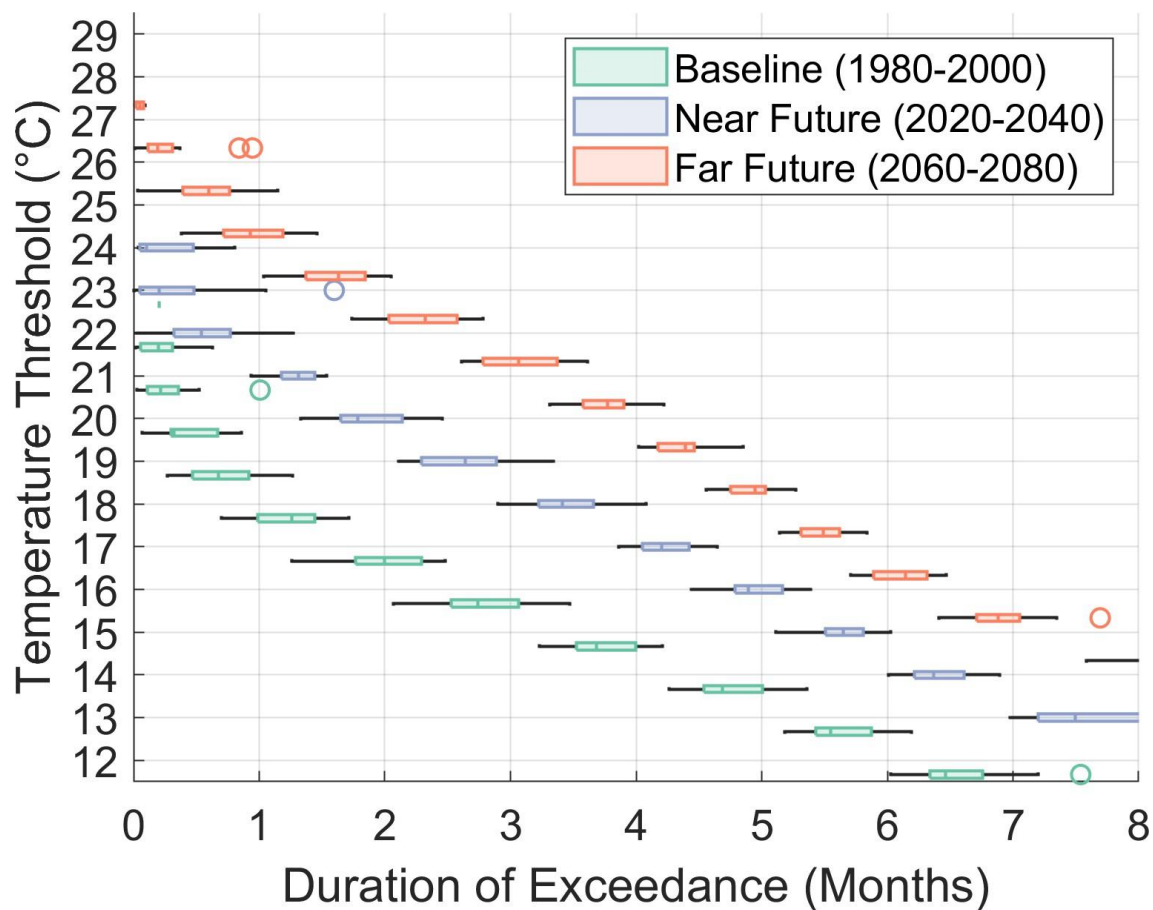
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

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Projected temperature changes under different climate scenarios. Box and whisker plots show the range of different modelled durations of temperatures under the 12 different UKCP 18 ensemble members. Open circles indicate outlier values.

Section 2 - Sea surface salinity changes

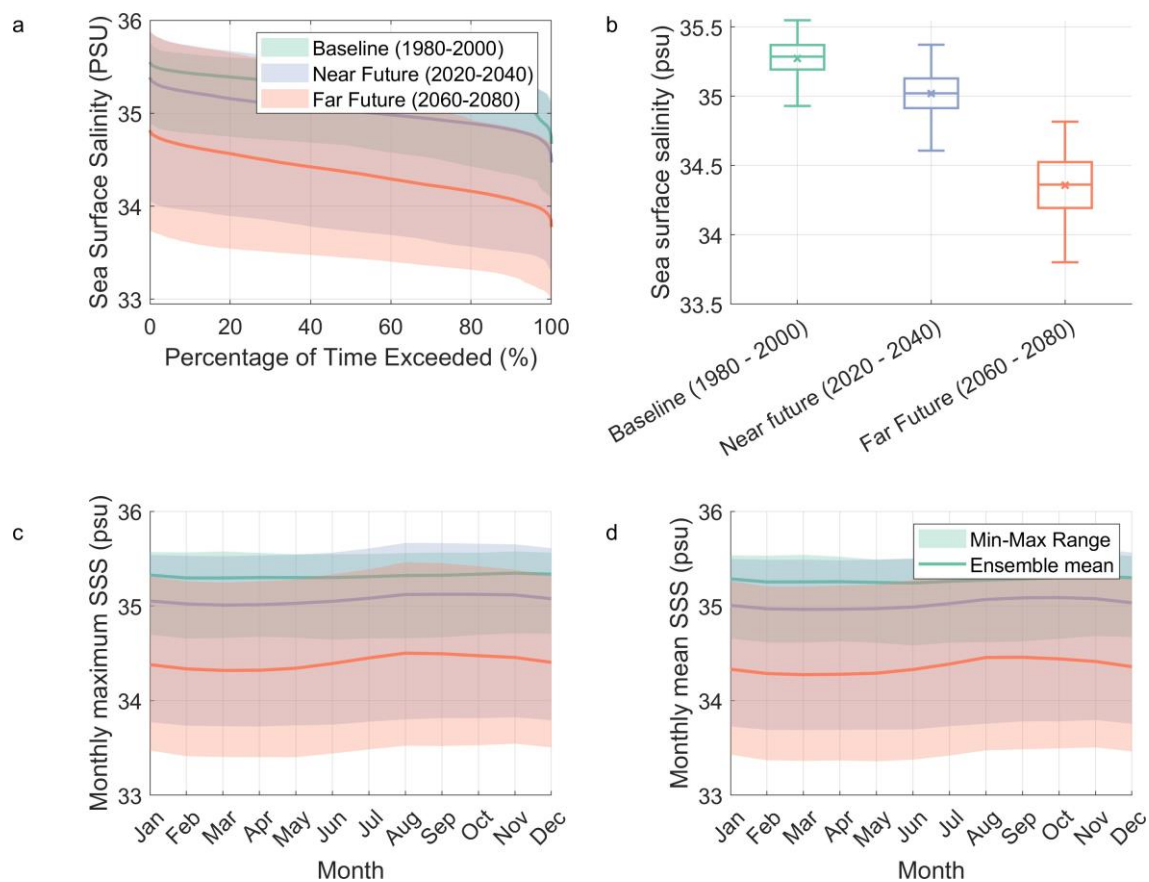


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
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- (d) Decreasing monthly means suggest long-term ice-melt driven freshening.

Section 3 - Residual surge changes

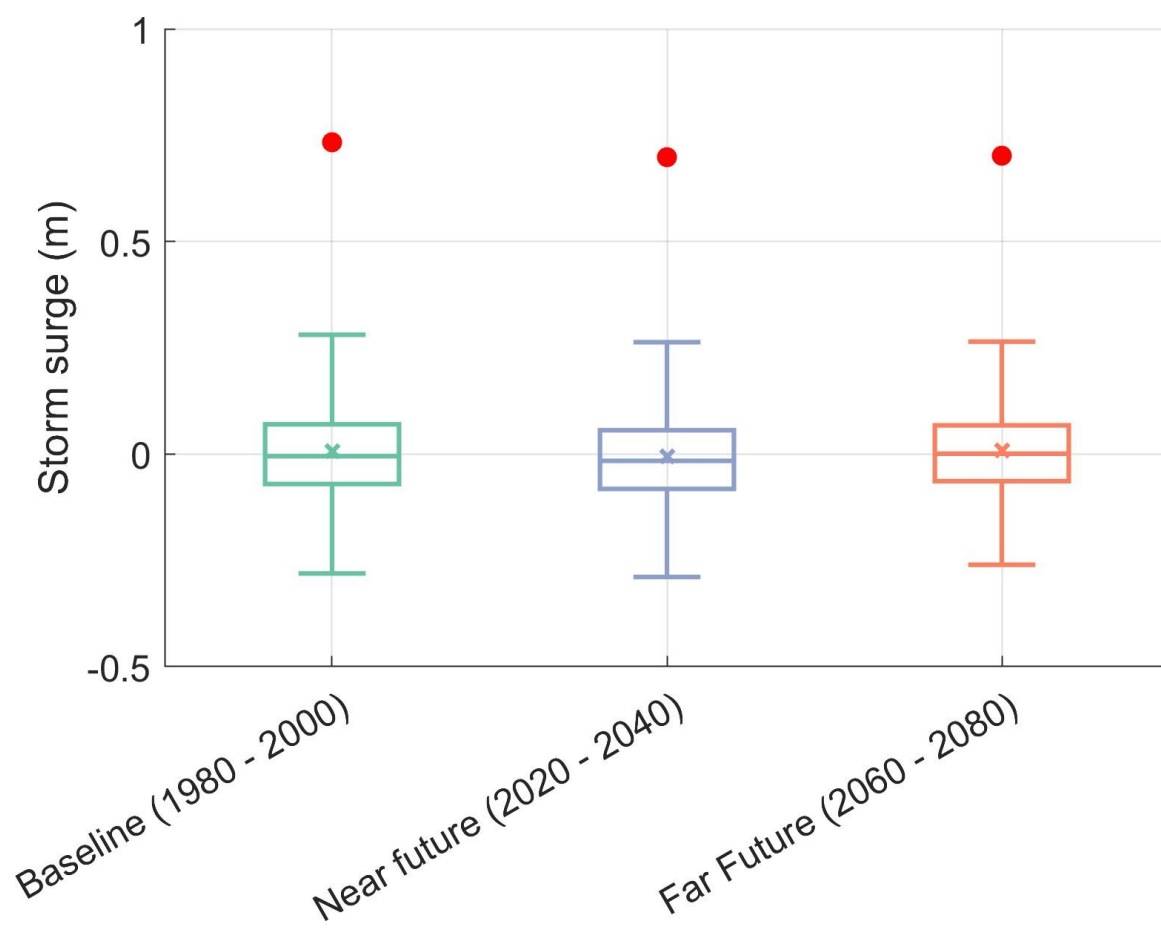


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

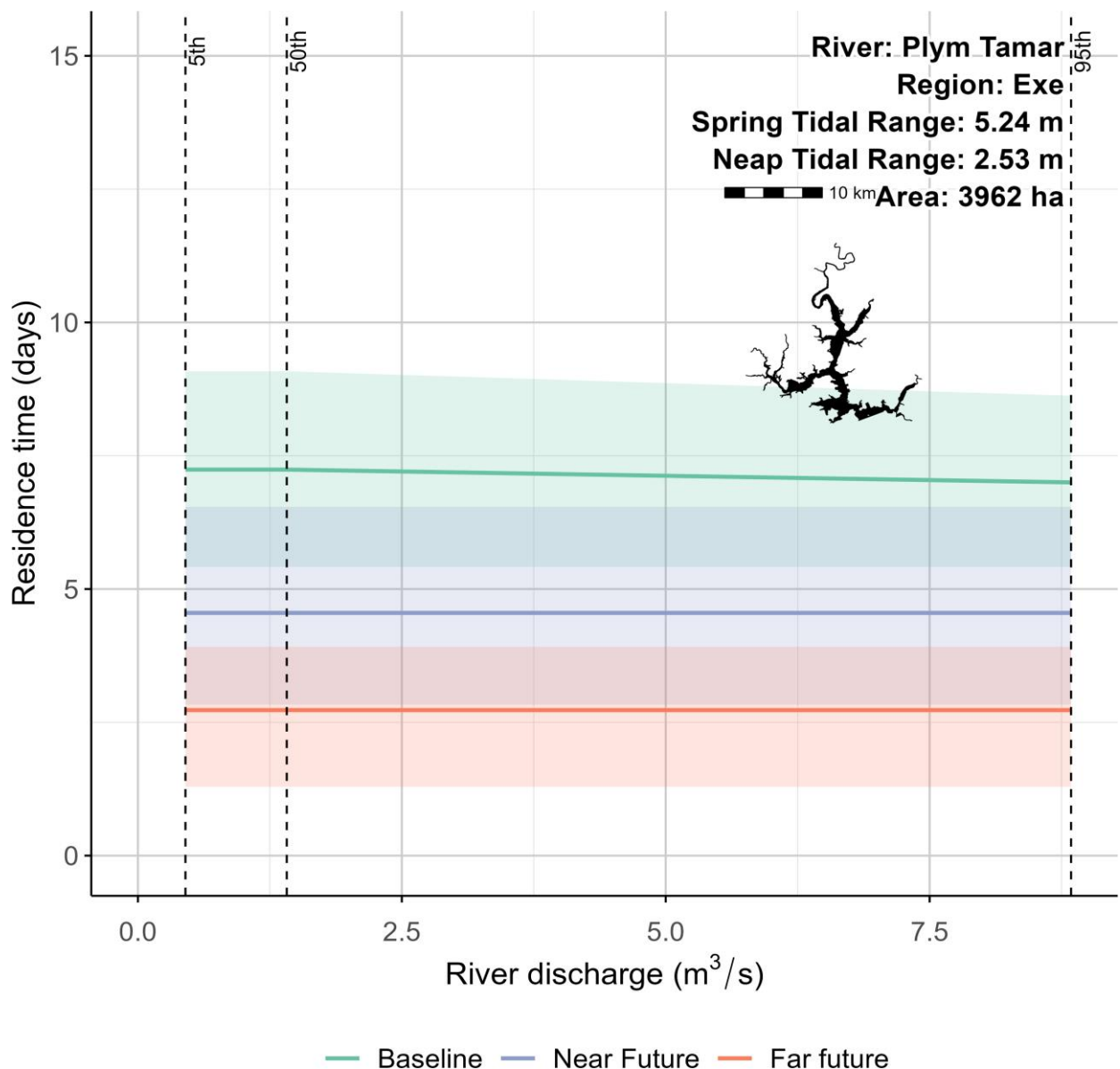


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Poole

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	50.68724
Longitude	-2.12413
Tidal Range	1.6 m
Gauge Name	Piddle at Baggs Mill
Estuary Size	30400000.0 m ²
5th percentile flow	0.792 m ³ /s
50th percentile flow	1.86 m ³ /s
95th percentile flow	6.55 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

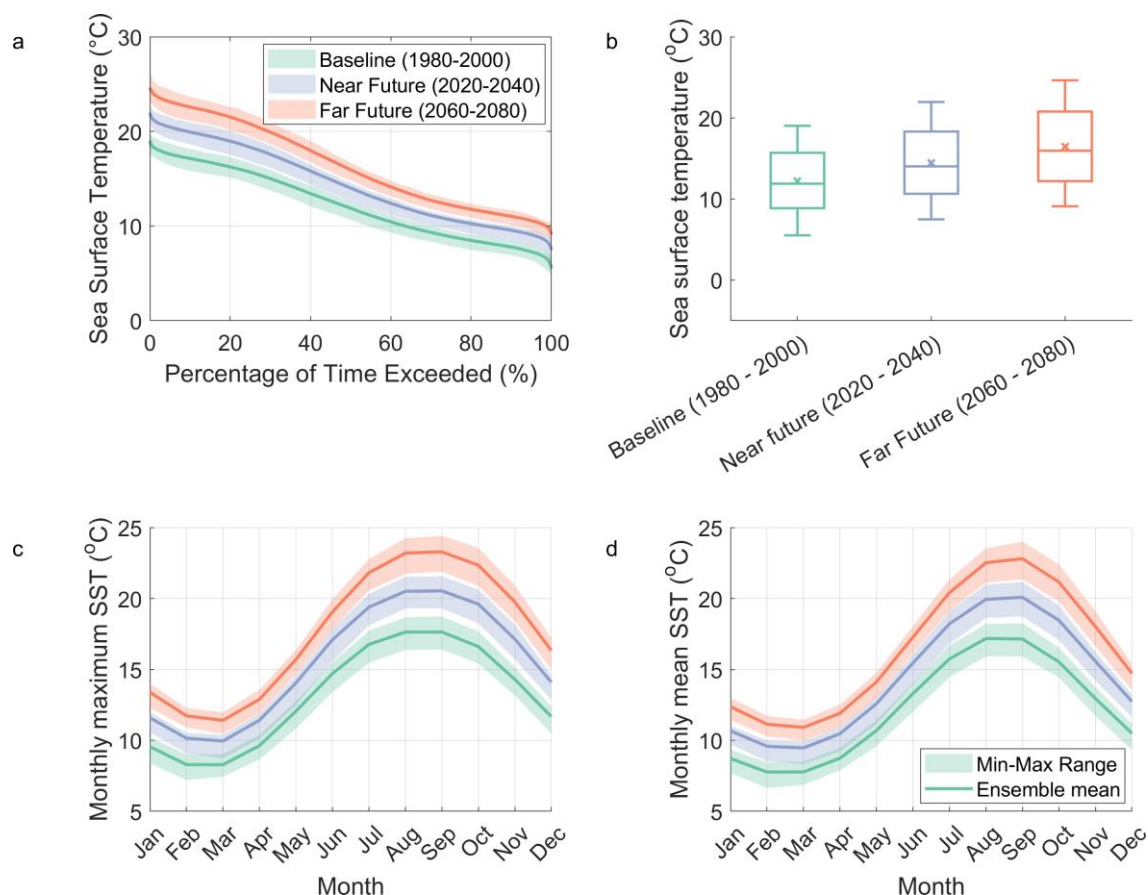
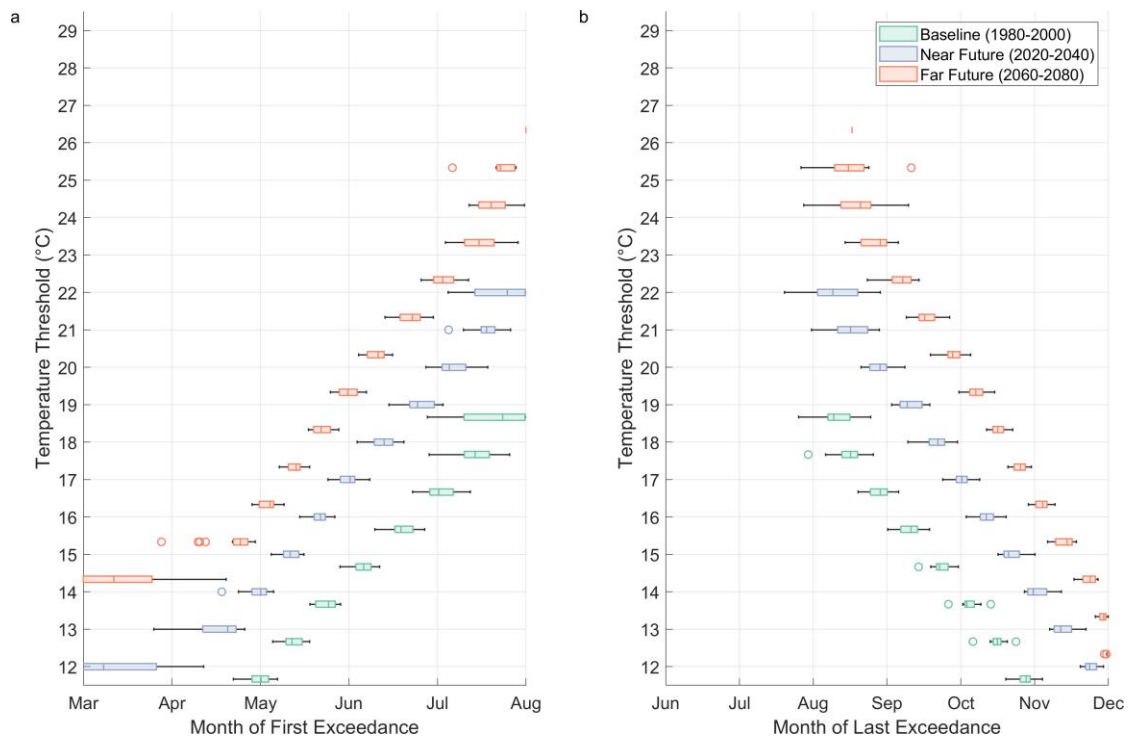


Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

- (a) Temperature duration curves represent distribution of SSTs over time to highlight changes in cold and warm extremes.
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Section 2 - Sea surface salinity changes

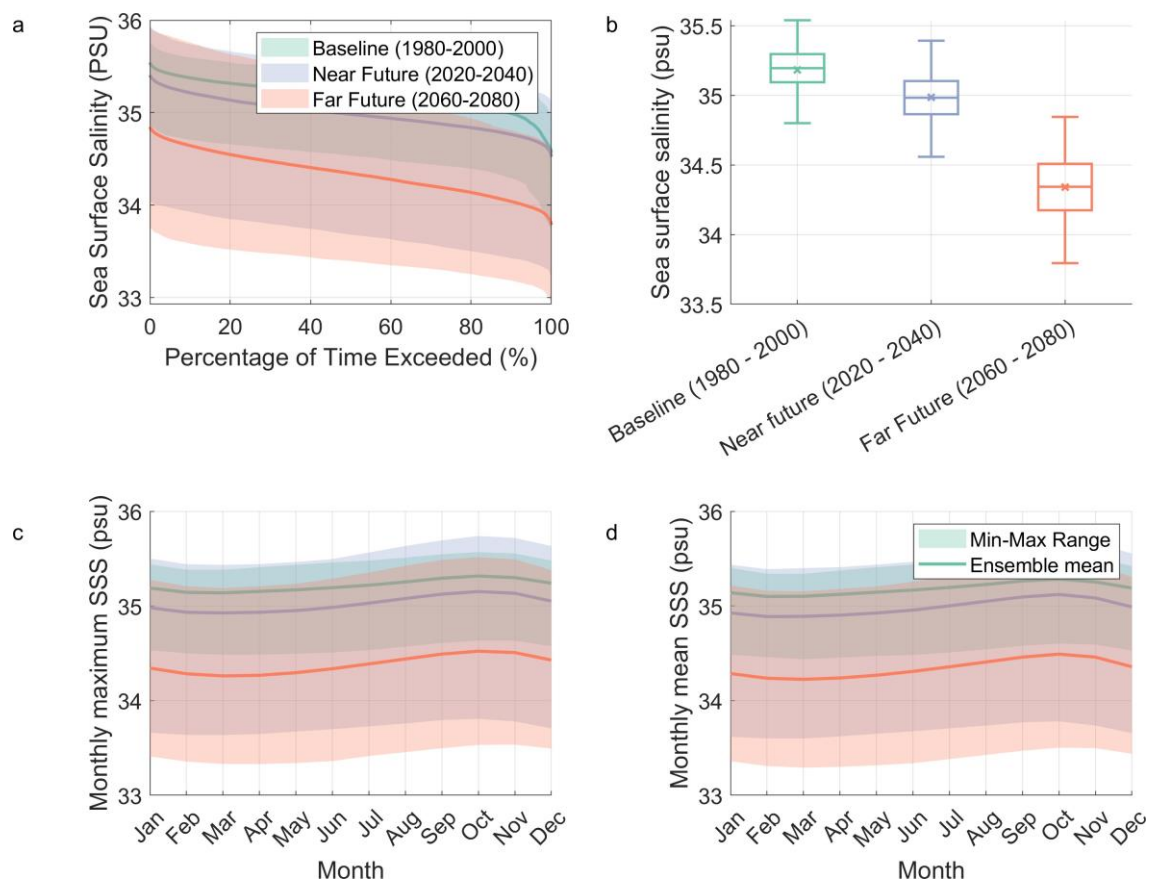


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
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Section 3 - Residual surge changes

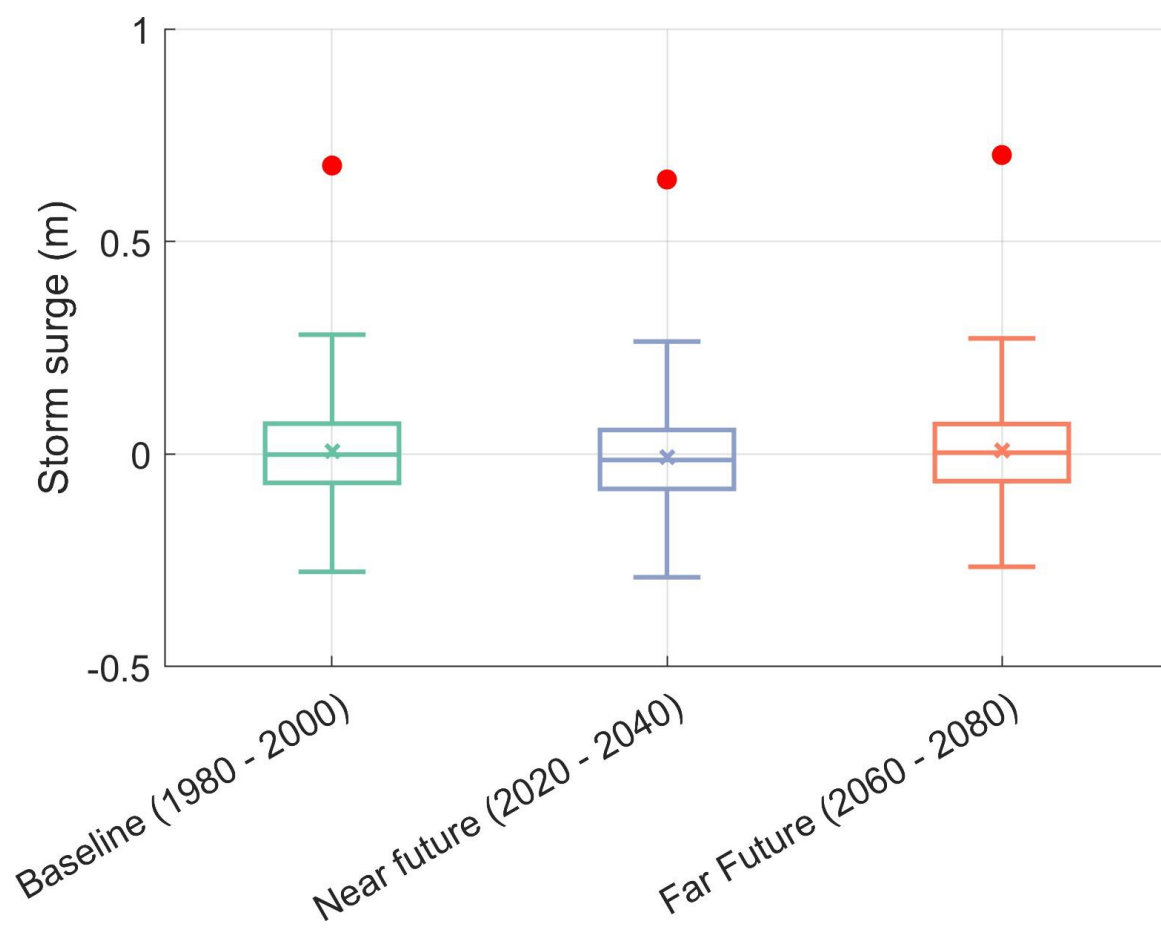


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

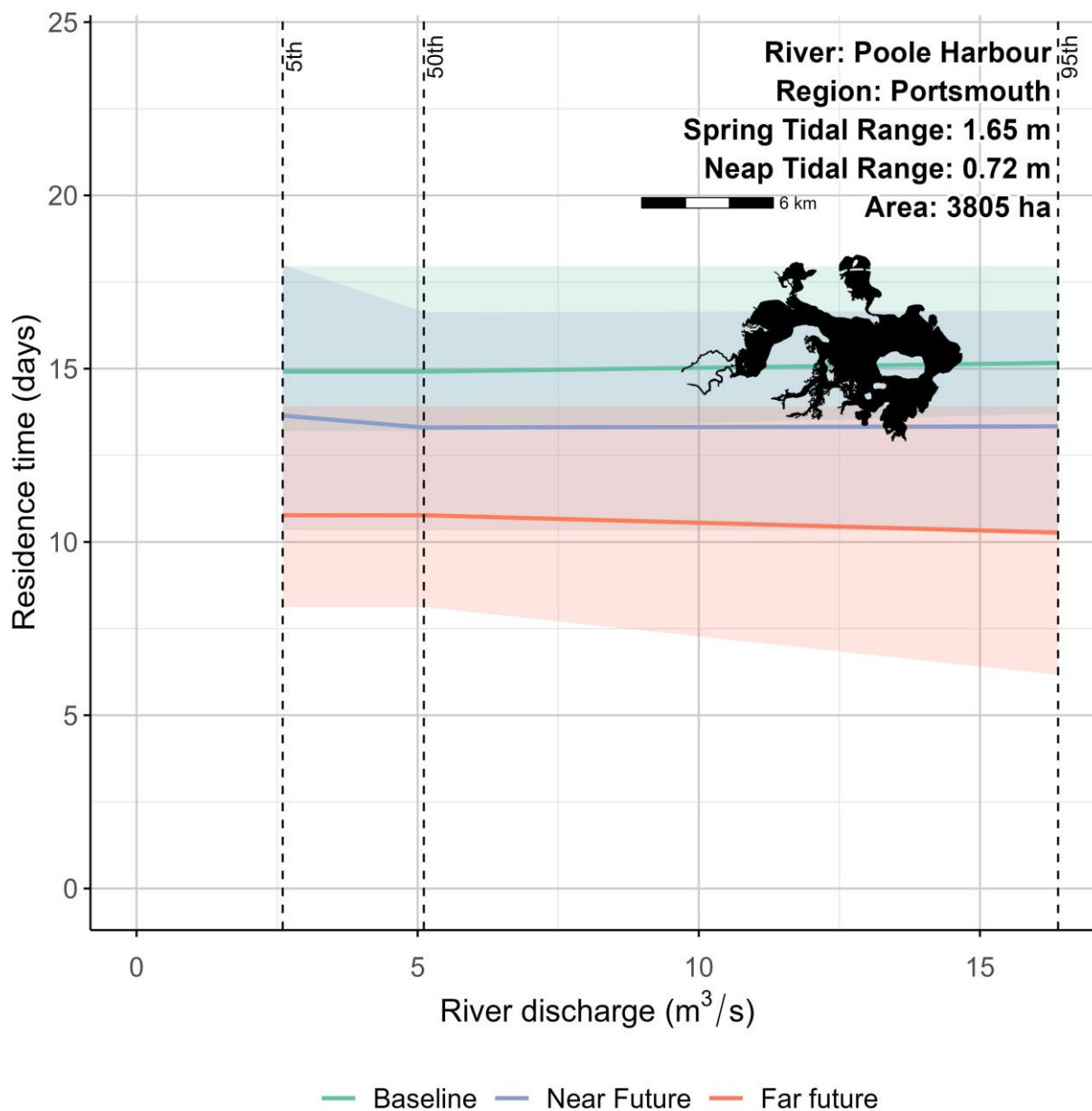


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Portsmouth_Harbour

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	50.86351
Longitude	1.16623
Tidal Range	3.9 m
Gauge Name	Wallington at North Fareham
Estuary Size	11100000.0 m ²
5th percentile flow	0.034 m ³ /s
50th percentile flow	0.259 m ³ /s
95th percentile flow	2.492 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

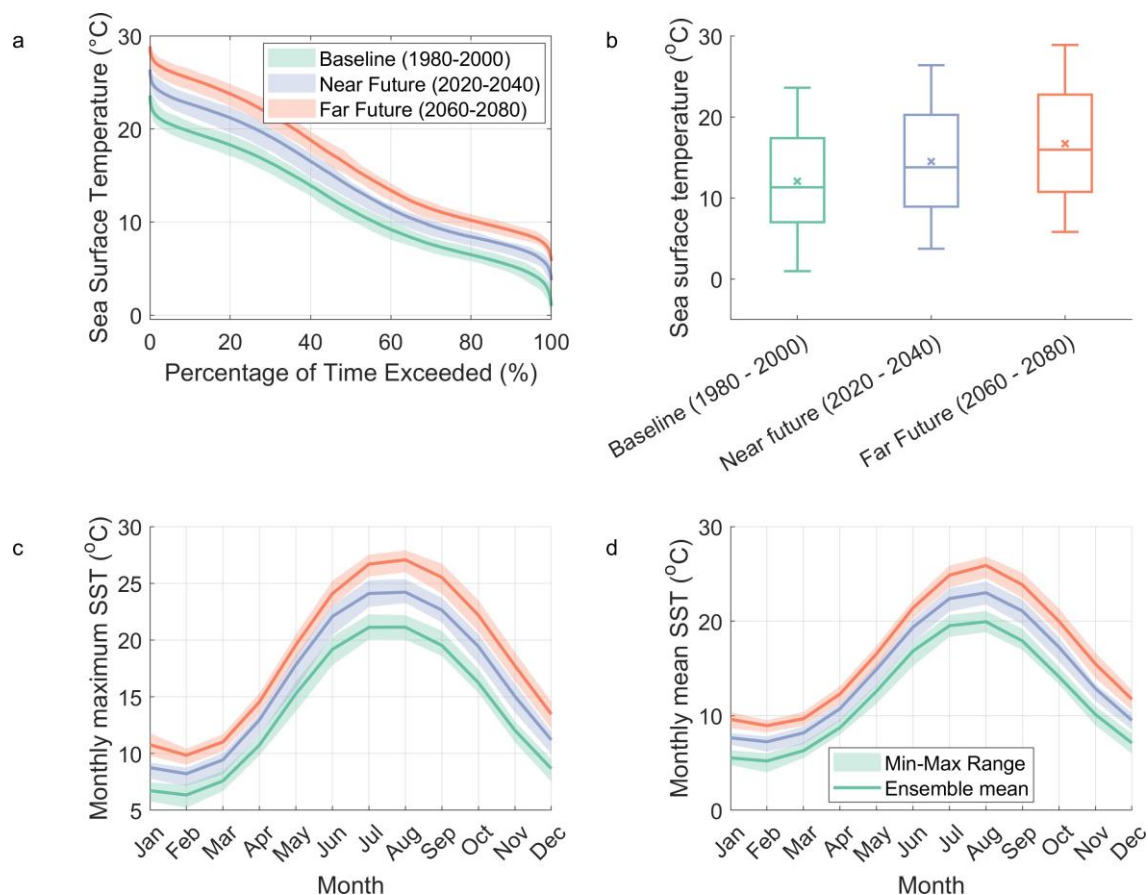
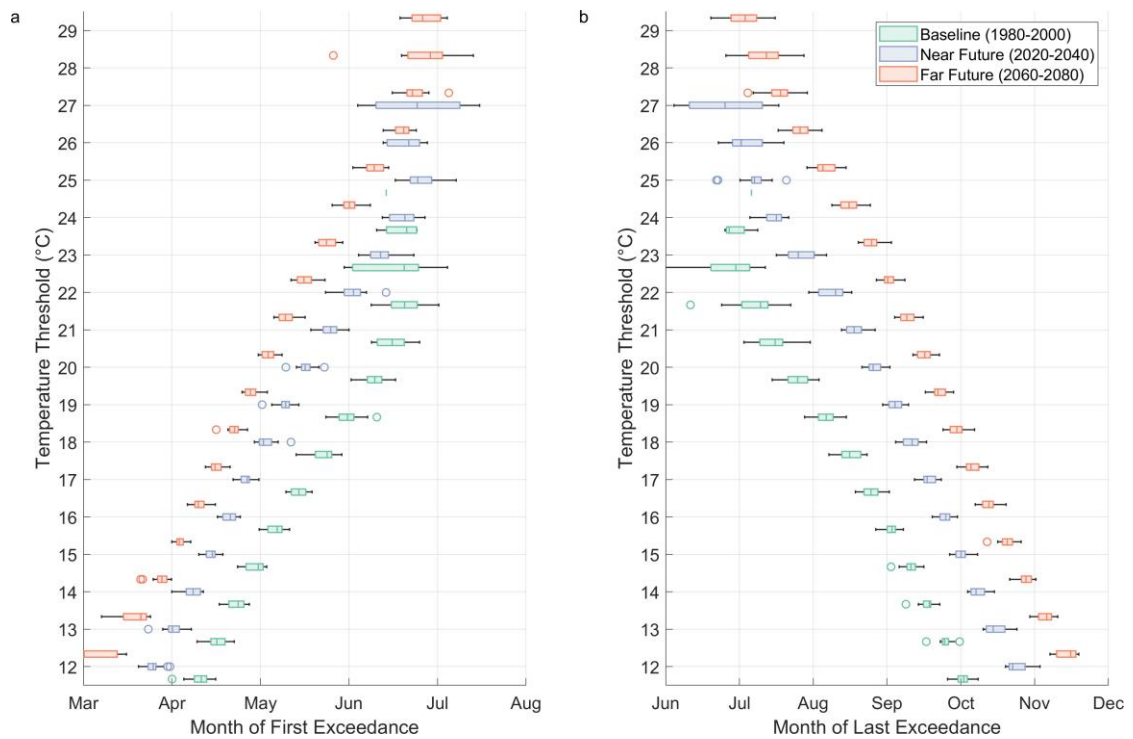


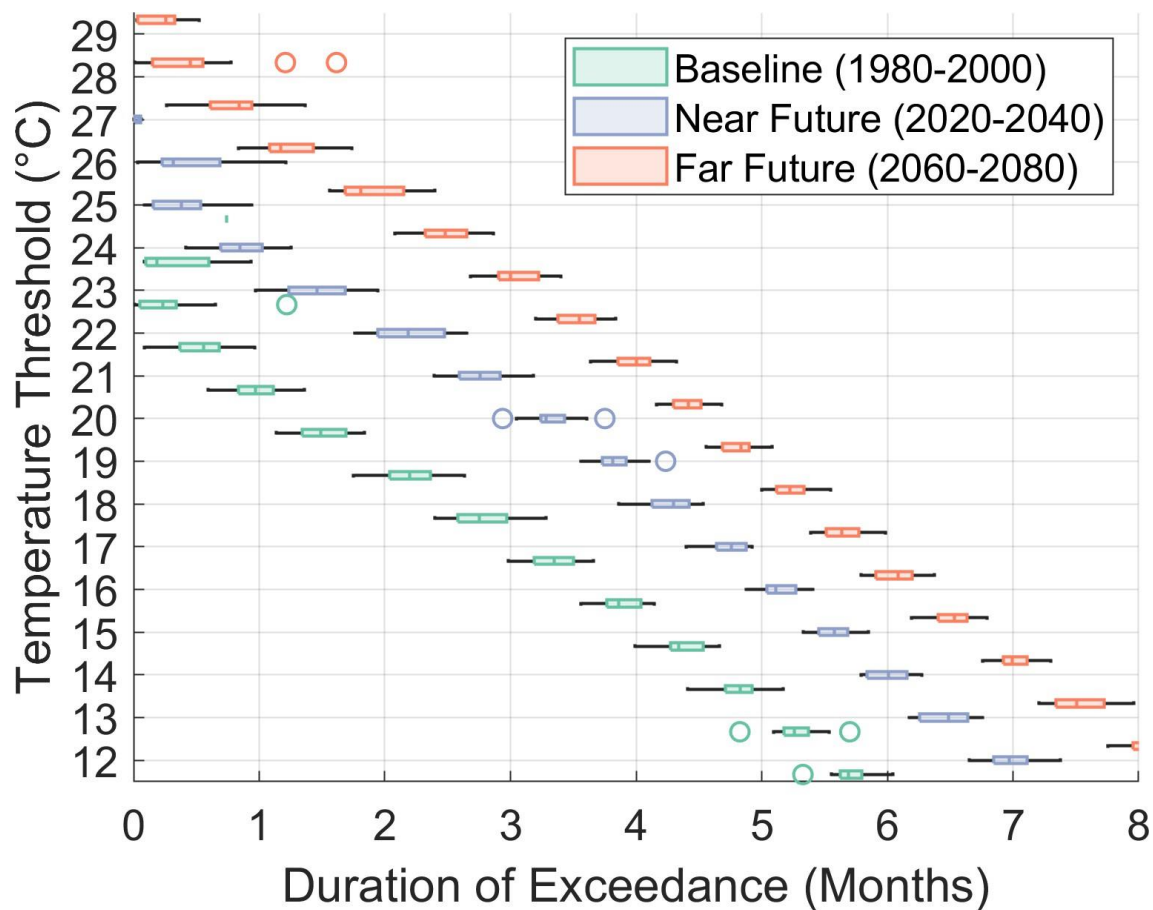
Figure description

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Section 2 - Sea surface salinity changes

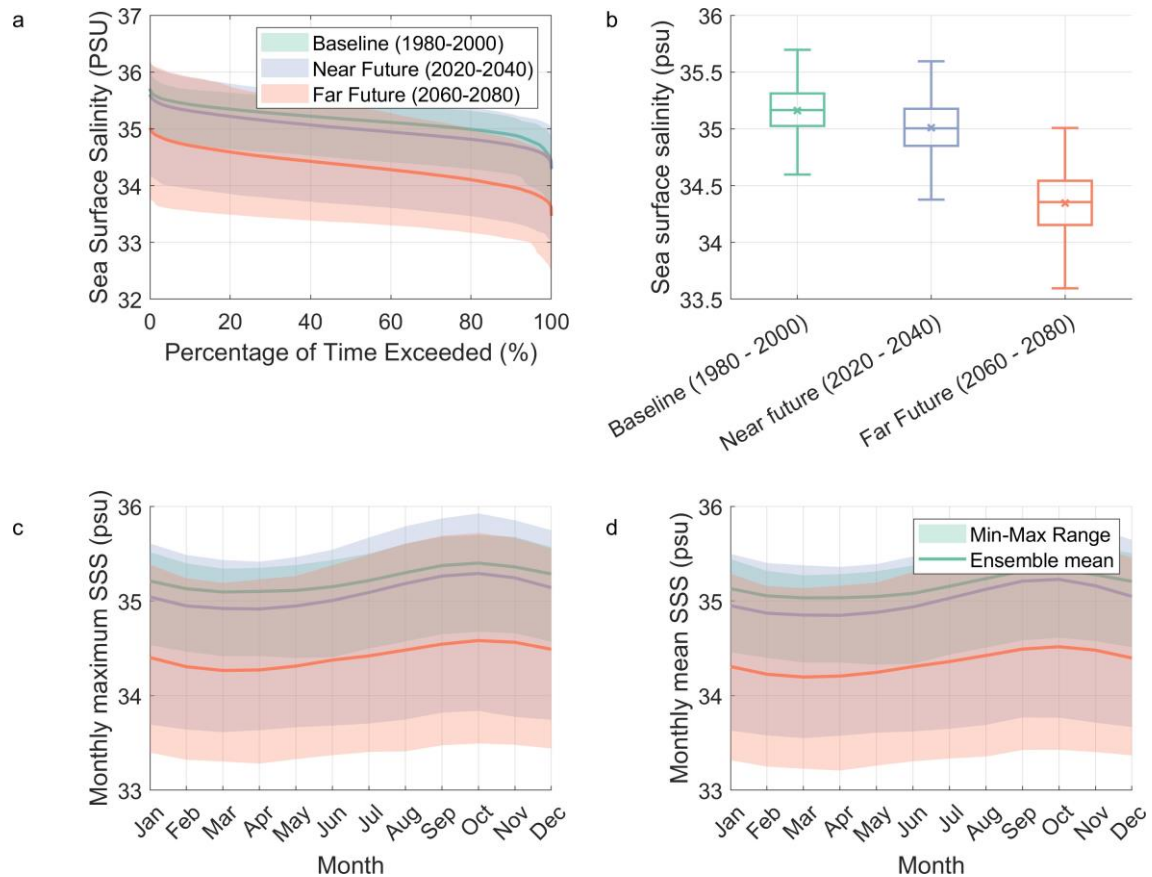


Figure description

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Section 3 - Residual surge changes

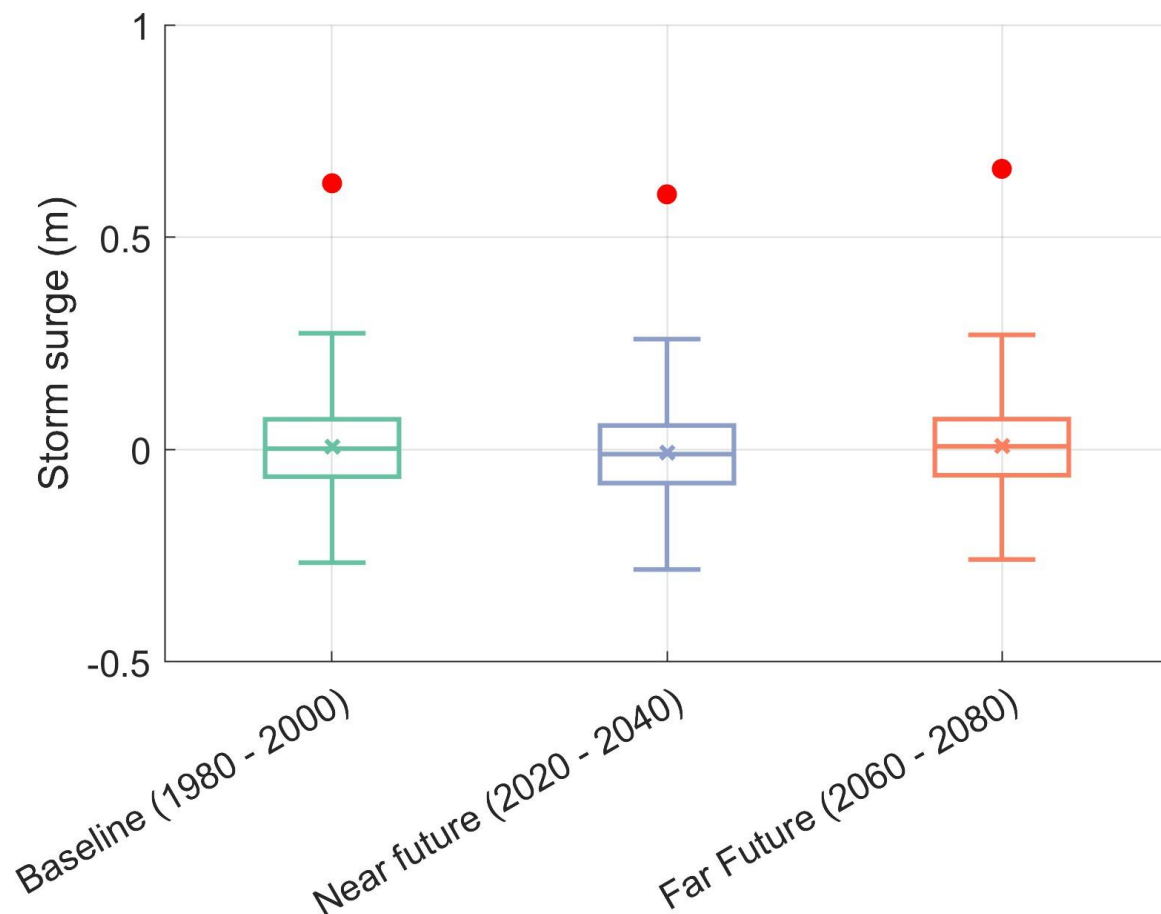


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

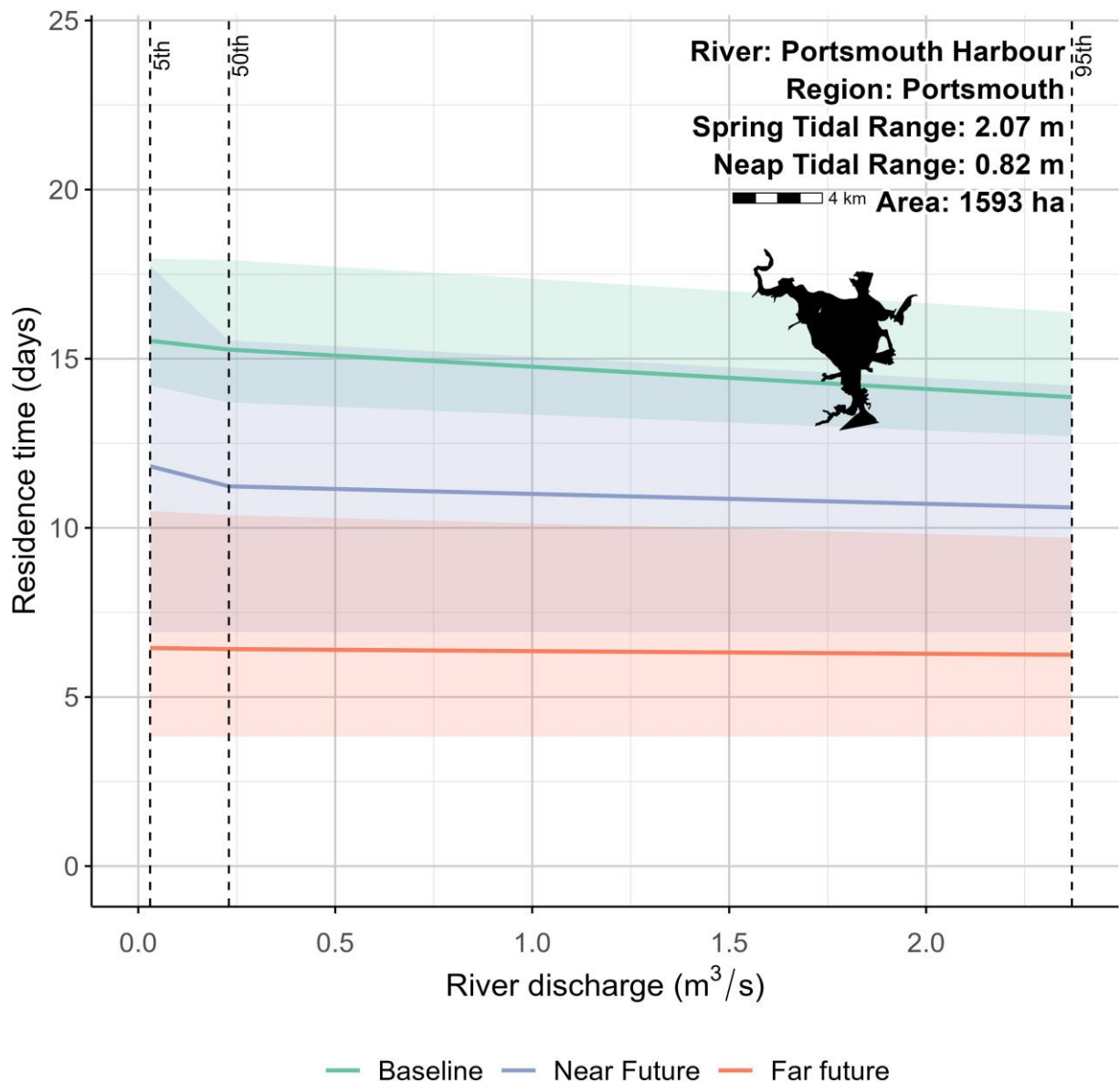


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)
Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Ribble

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	53.72961
Longitude	-2.98442
Tidal Range	8.3 m
Gauge Name	Ribble at Samlesbury
Estuary Size	24500000.0 m ²
5th percentile flow	4.75 m ³ /s
50th percentile flow	17.1 m ³ /s
95th percentile flow	125.0 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

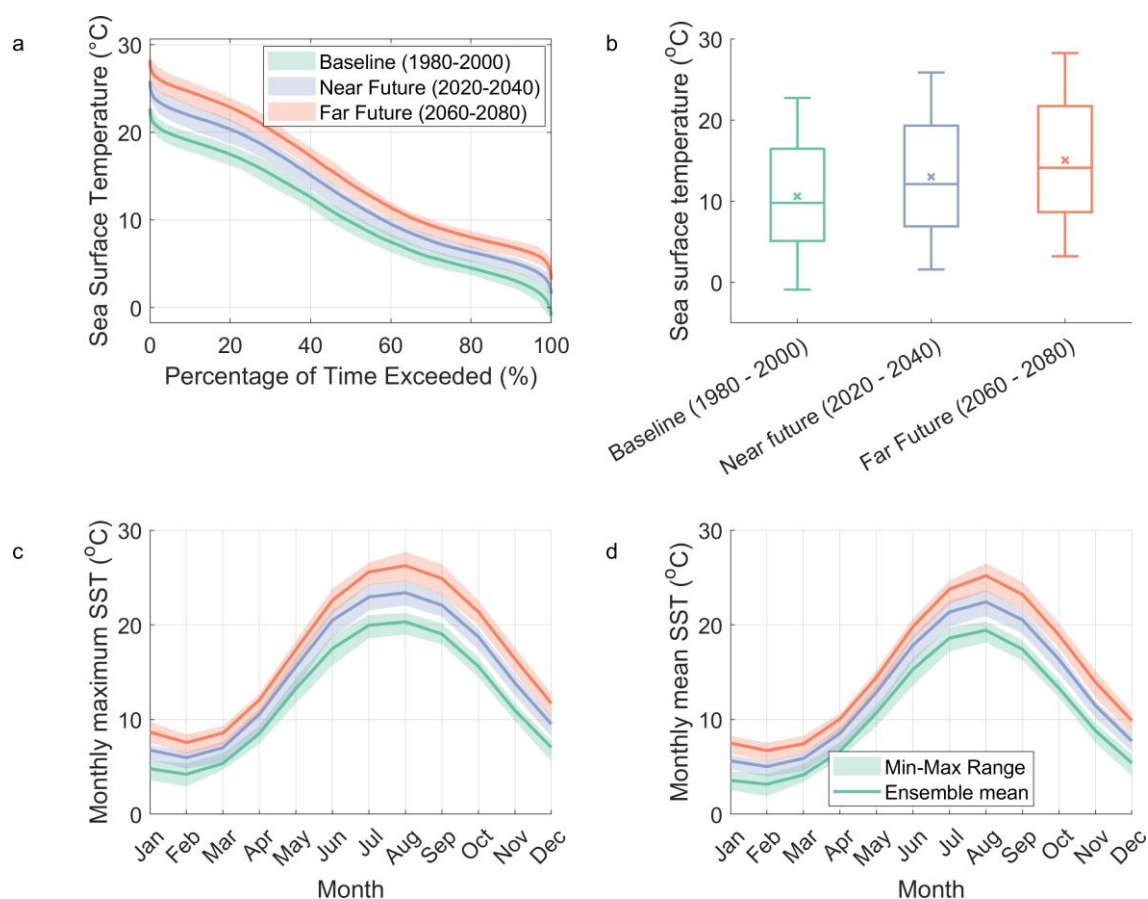
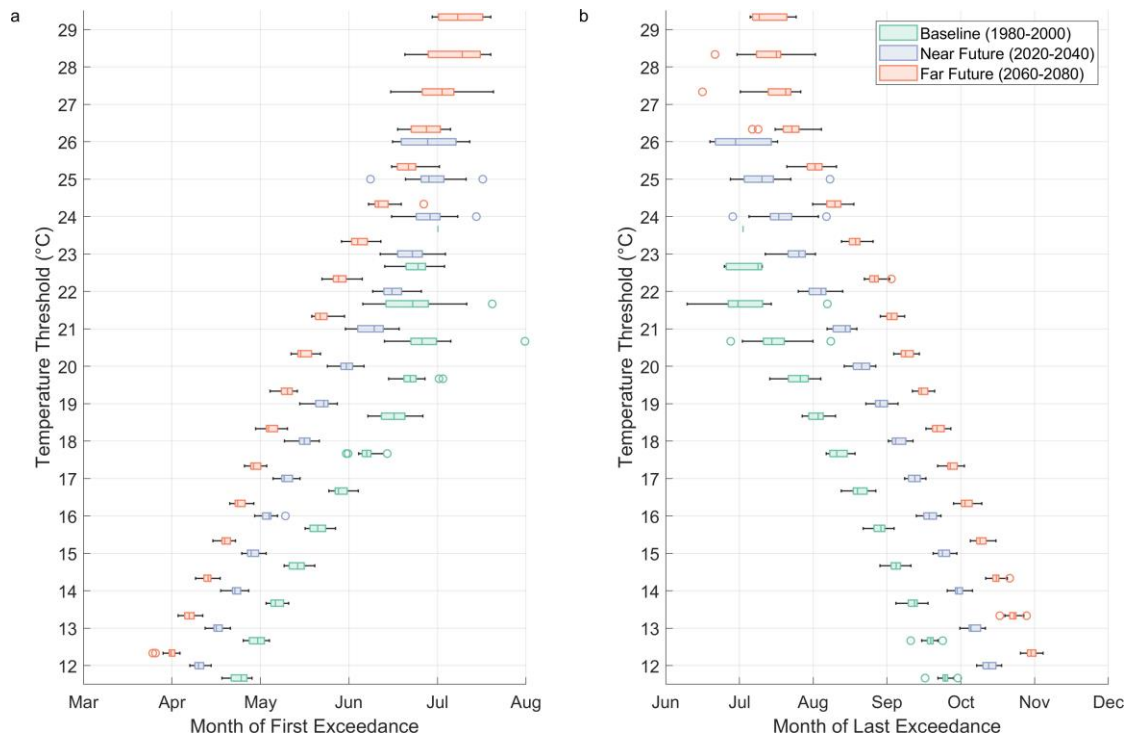


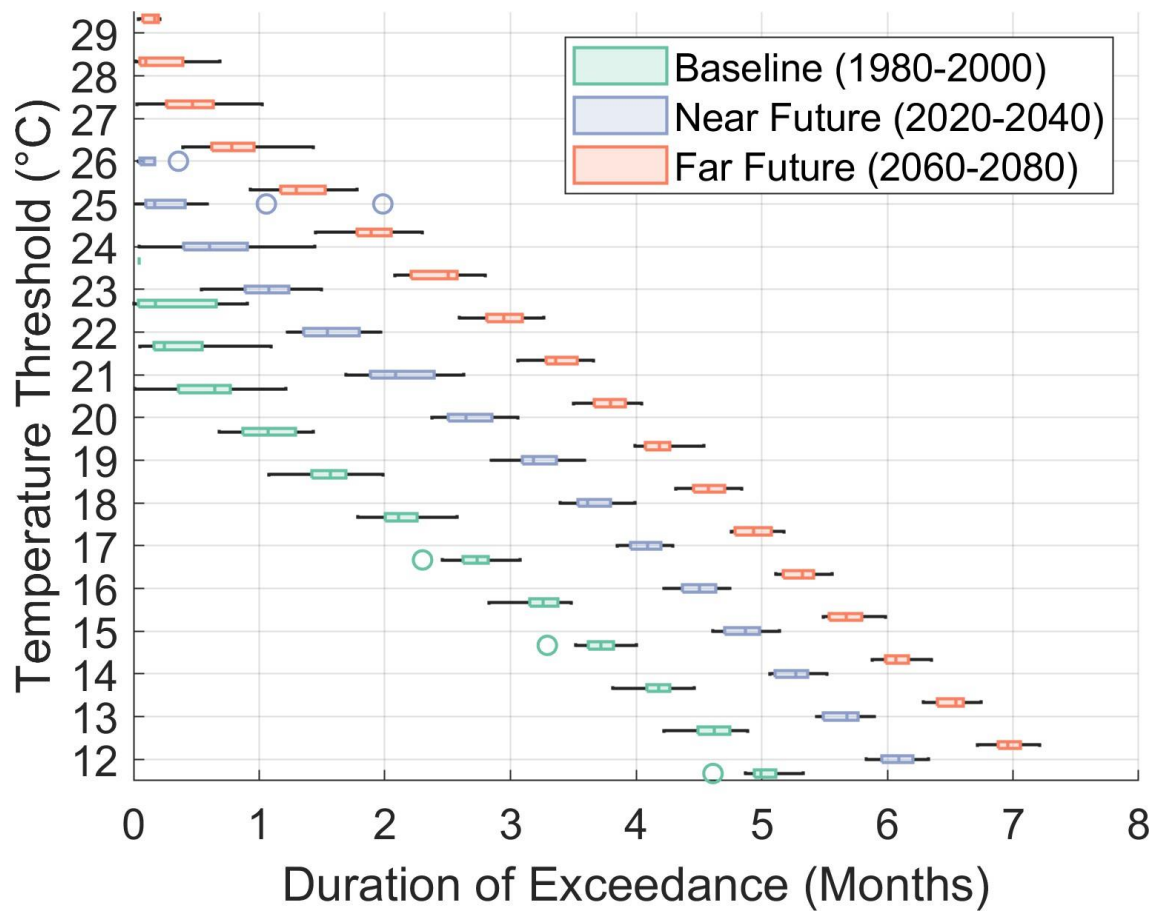
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

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Section 2 - Sea surface salinity changes

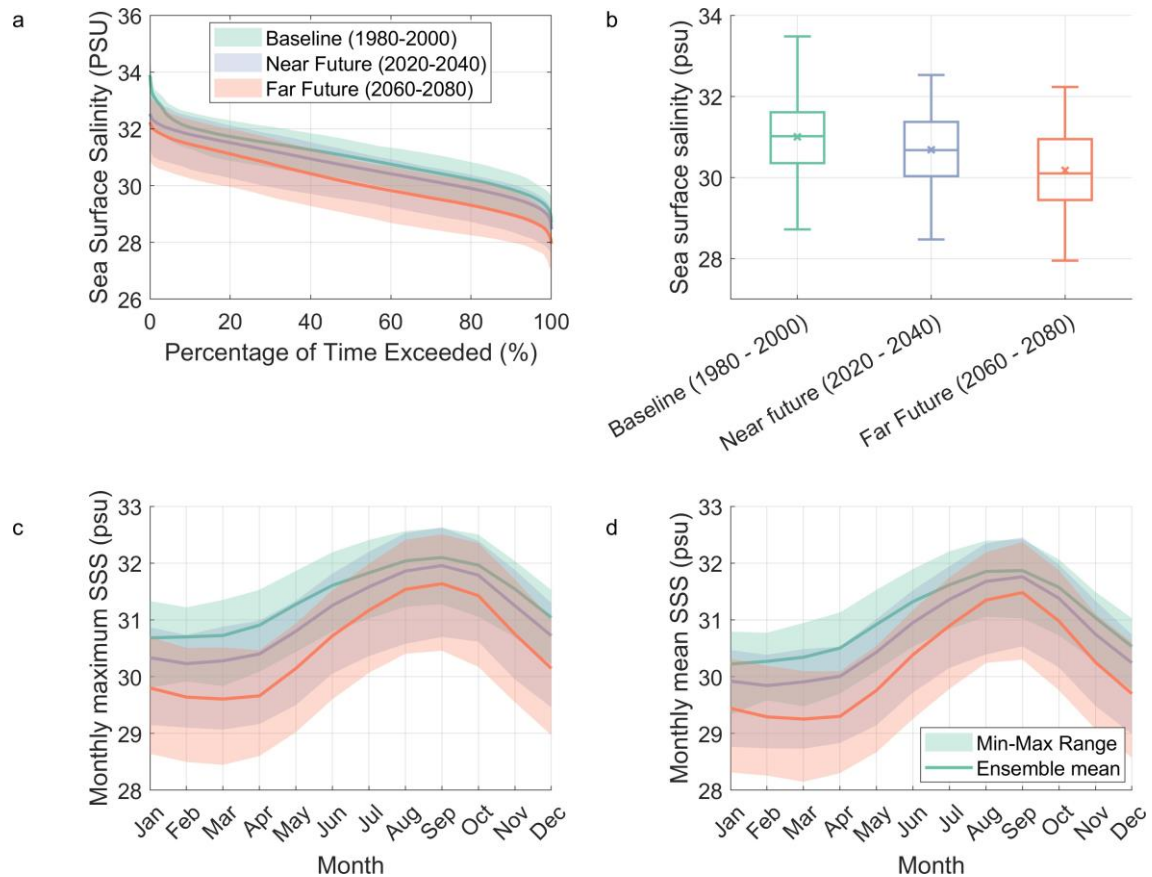


Figure description

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Section 3 - Residual surge changes

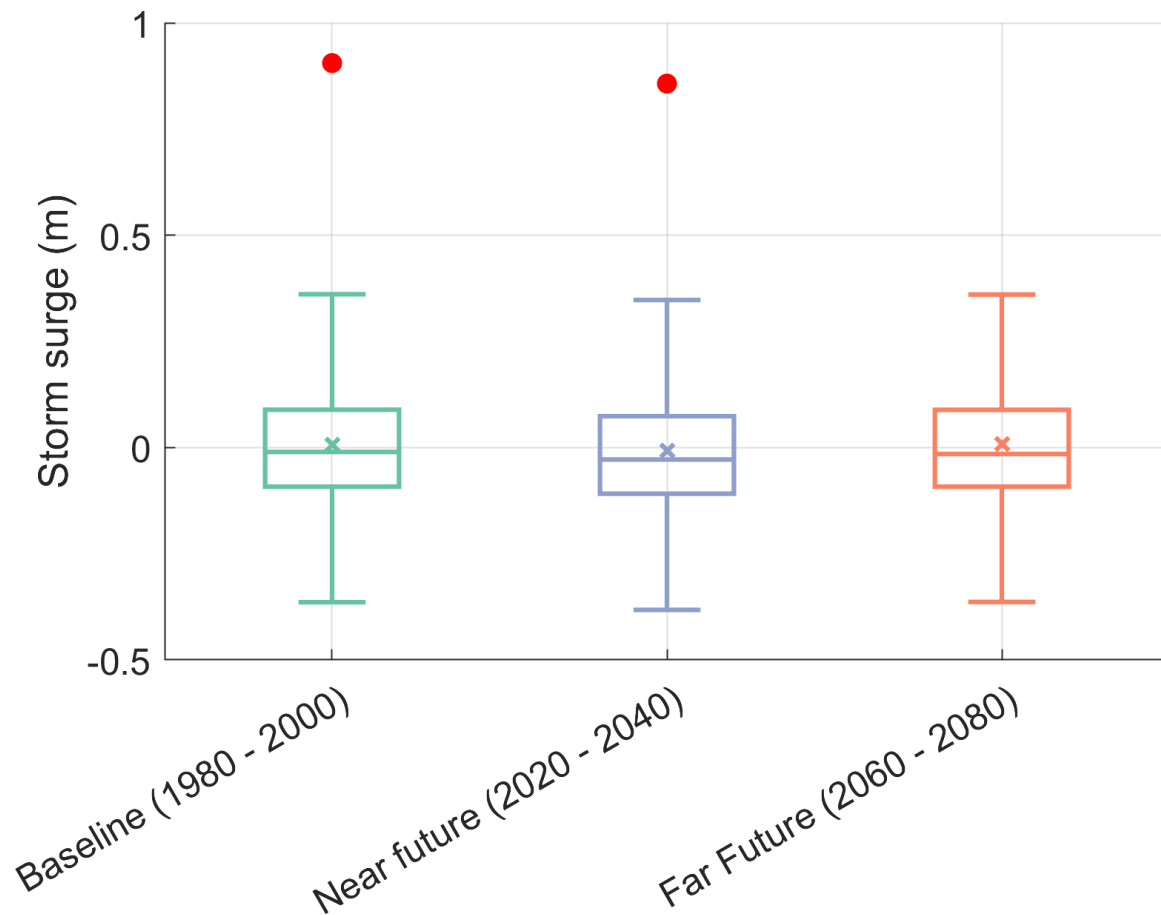


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - River discharge changes

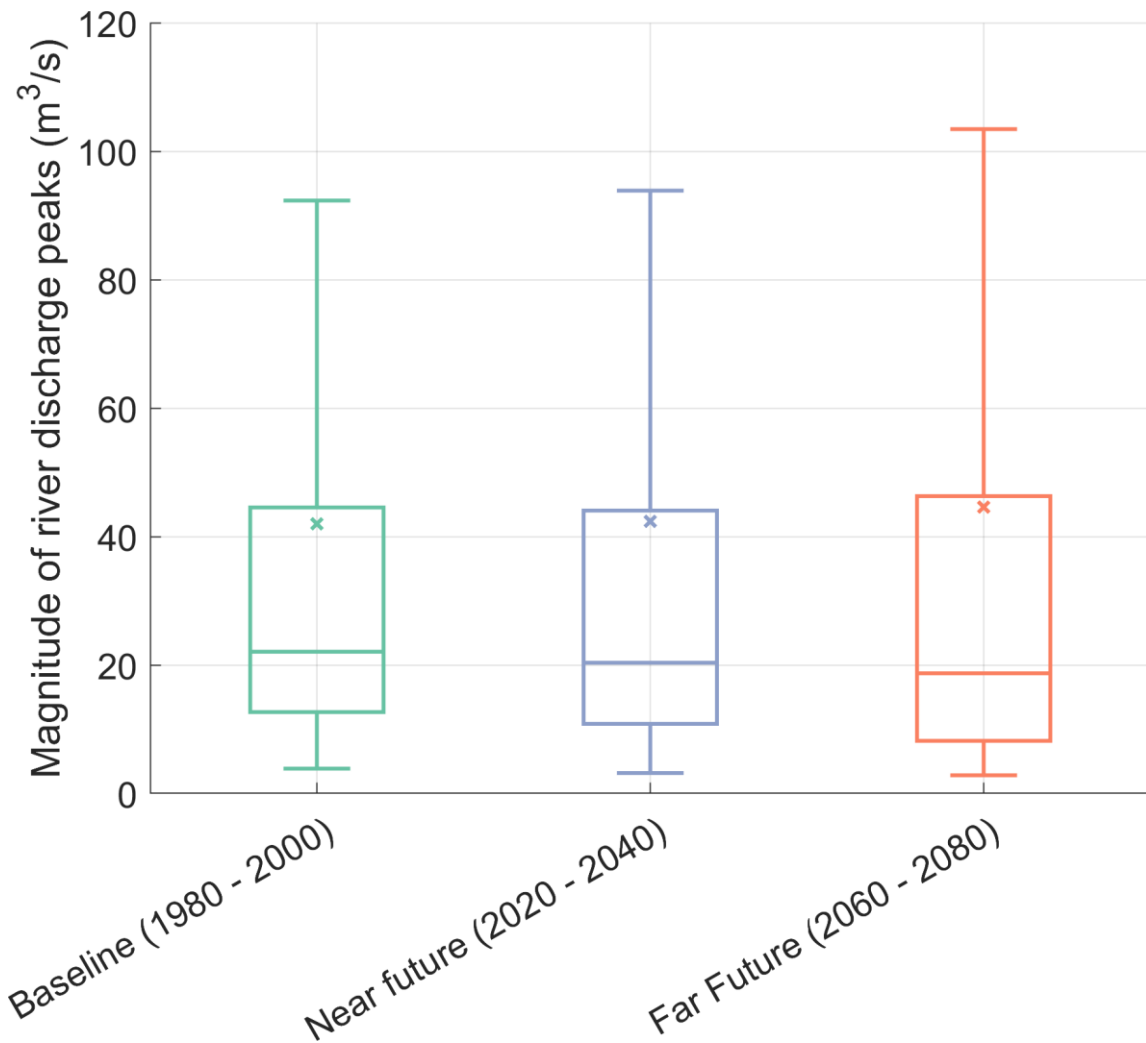


Figure description

Box and whisker plots of discharge percentiles under baseline (1980-2000), near-future (2020-2040) and far-future (2060-2080)

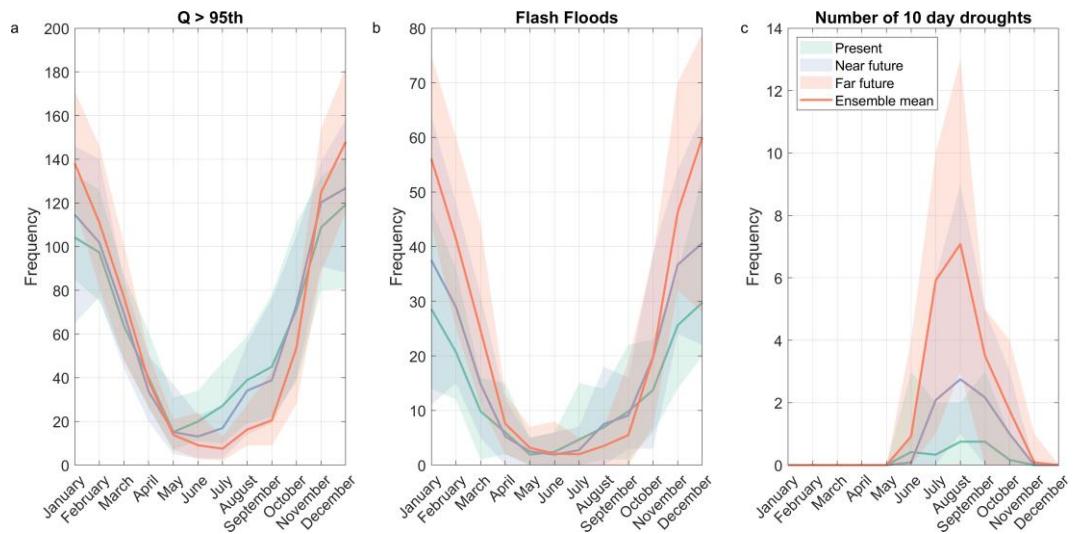


Figure description

Discharge conditions under baseline (1980-2000), near-future (2020-2040) and far-future (2060-2080) showing frequency of (a): Occurrence of high flow (>95th percentile events) per month (hourly resolution), (b): Flash flood events (increase in discharge of >50 m³/s, (c): low flow events lasting longer than 10 days).

Section 5 - Residence times changes

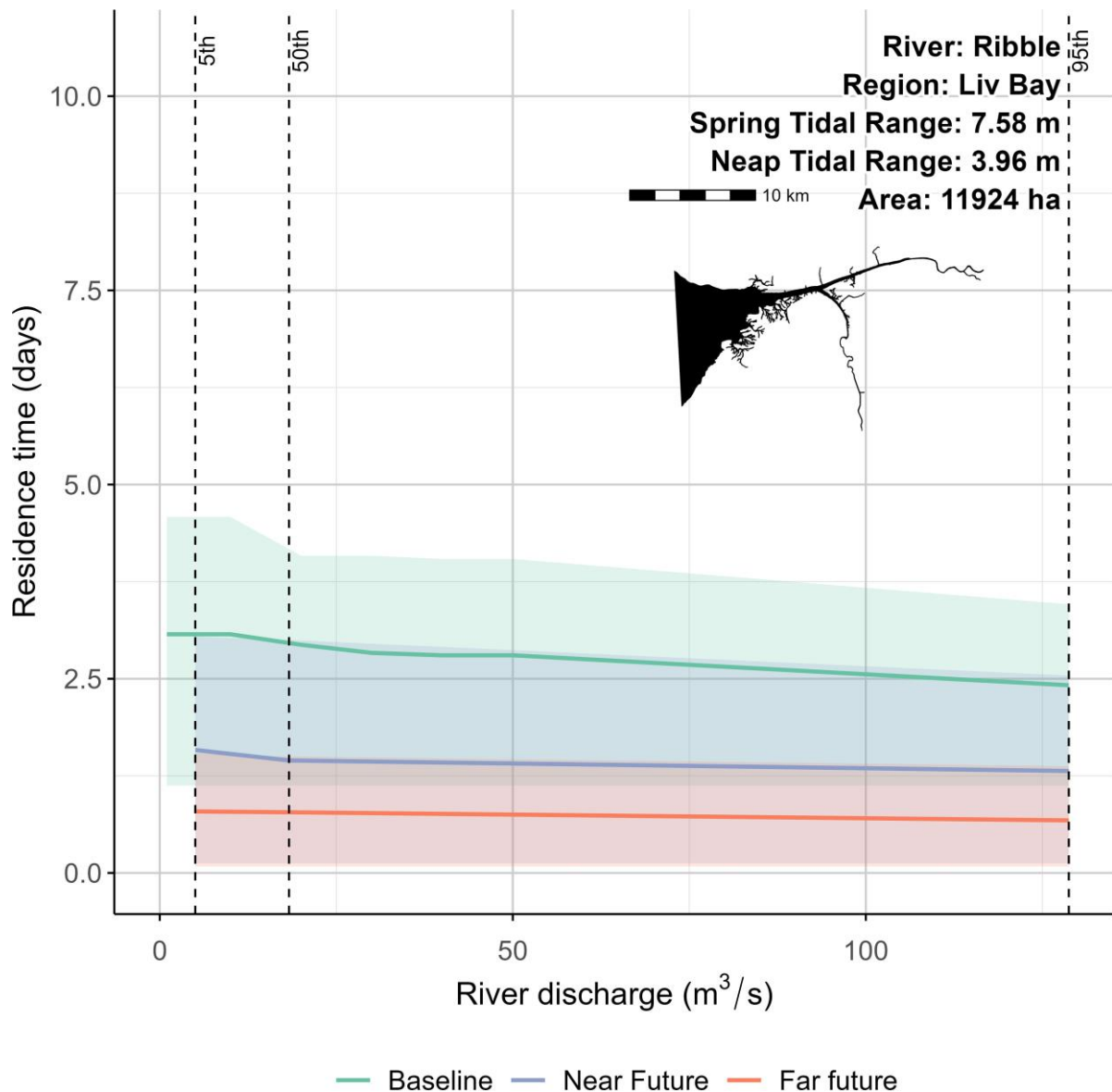


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)
Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Severn

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	51.94873
Longitude	-2.22711
Tidal Range	10.5 m
Gauge Name	Severn at Haw Bridge
Estuary Size	515000000.0 m ²
5th percentile flow	21.1 m ³ /s
50th percentile flow	68.0 m ³ /s
95th percentile flow	377.4 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

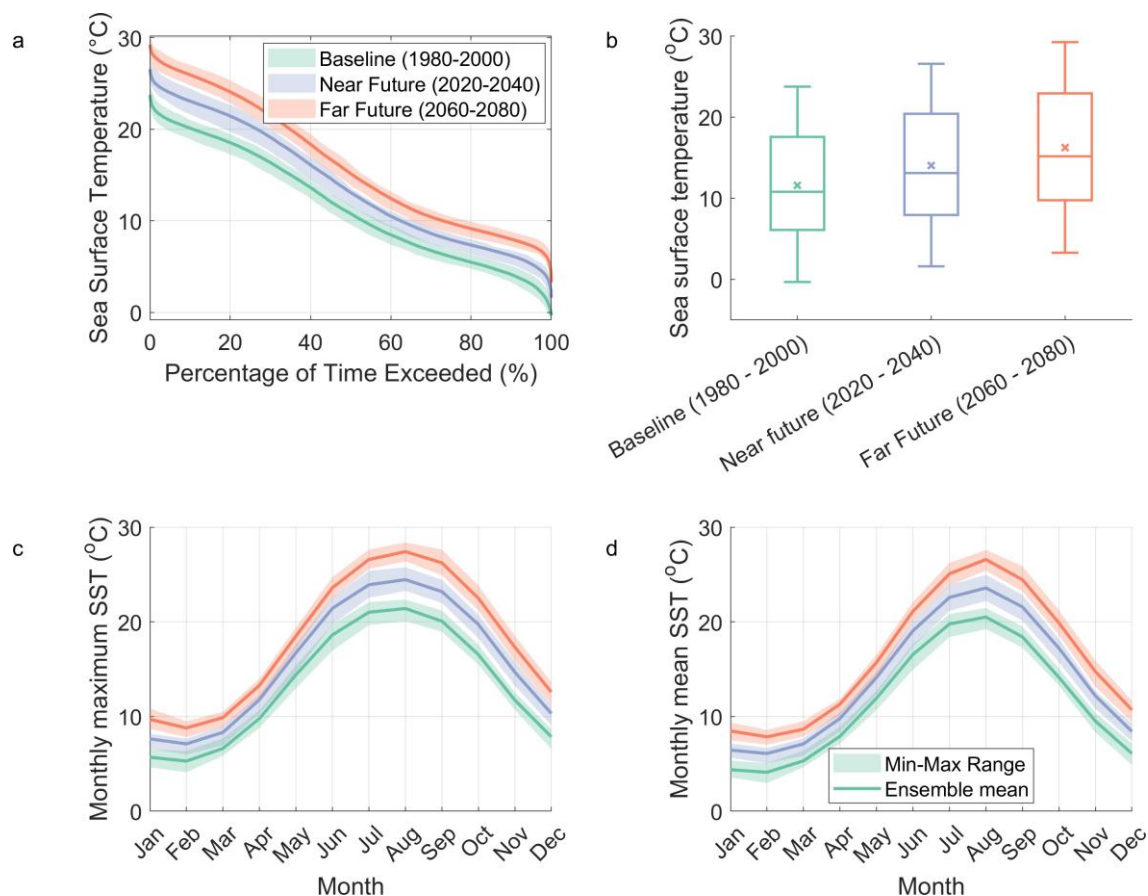
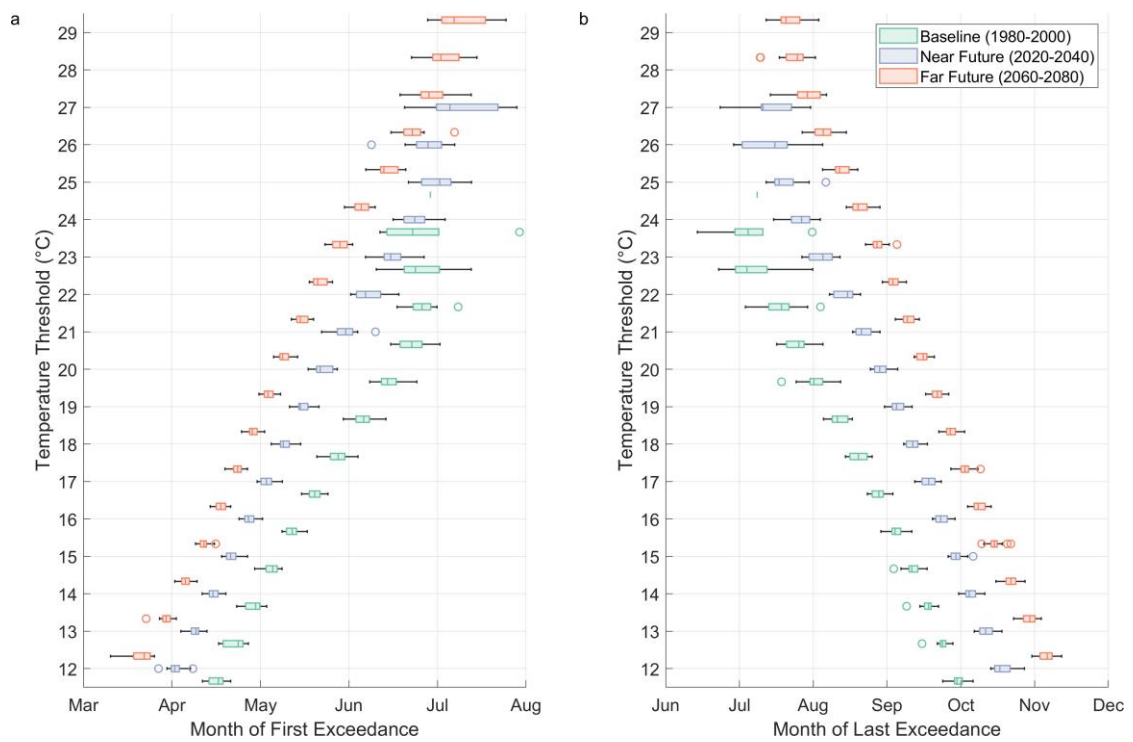


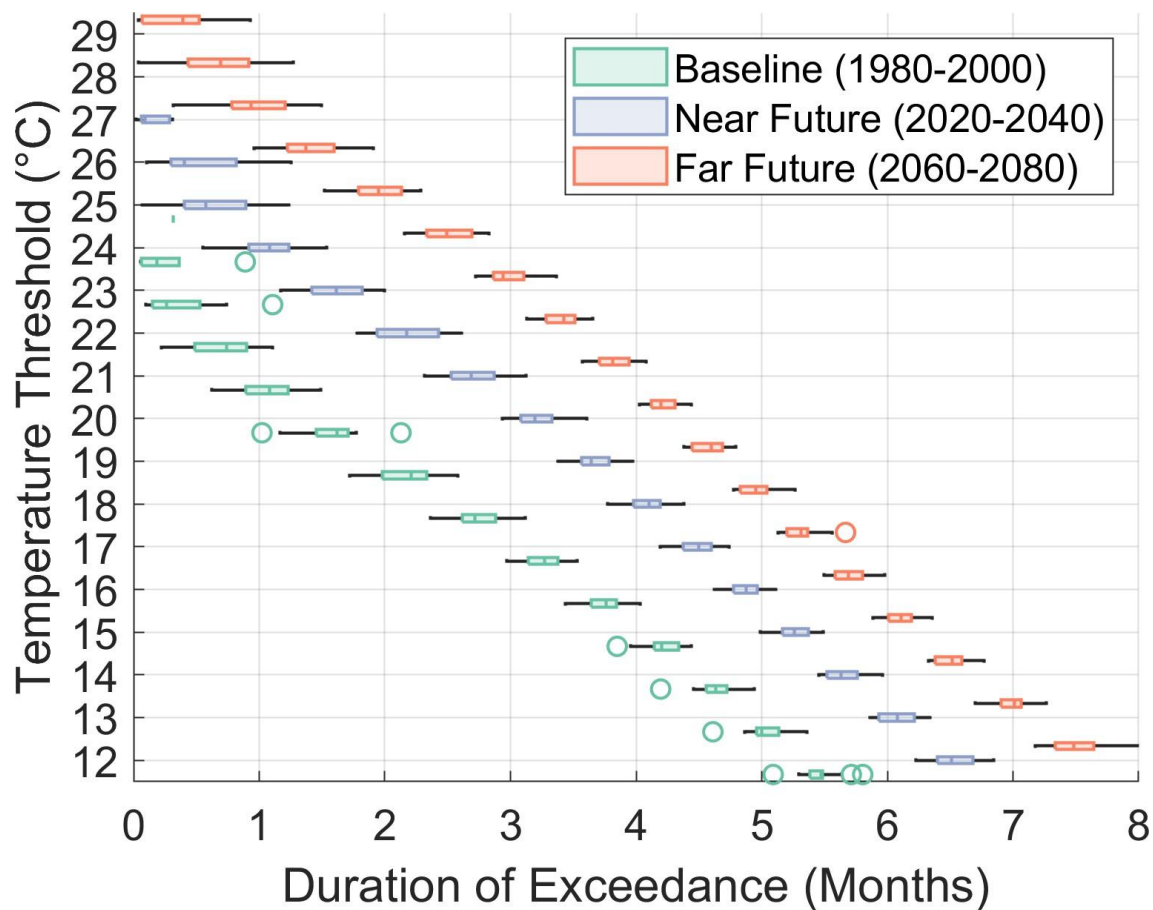
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

- (a) Temperature duration curves represent distribution of SSTs over time to highlight changes in cold and warm extremes.
- (b) Percentile shifts show increasing mean, median, and extremes, indicating prolonged warming over time.
- (c) Rising monthly maximum in every month of the year highlights likelihood of intensified high heat events.
- (d) Rising monthly mean suggests long-term climate-driven warming.



Changes in first and last occurrences of temperature thresholds compared to historical data. Note that these plots are not intended to identify the specific date on which a temperature may occur, rather they indicate the trend in the onset of specific temperature thresholds.



Projected temperature changes under different climate scenarios. Box and whisker plots show the range of different modelled durations of temperatures under the 12 different UKCP 18 ensemble members. Open circles indicate outlier values.

Section 2 - Sea surface salinity changes

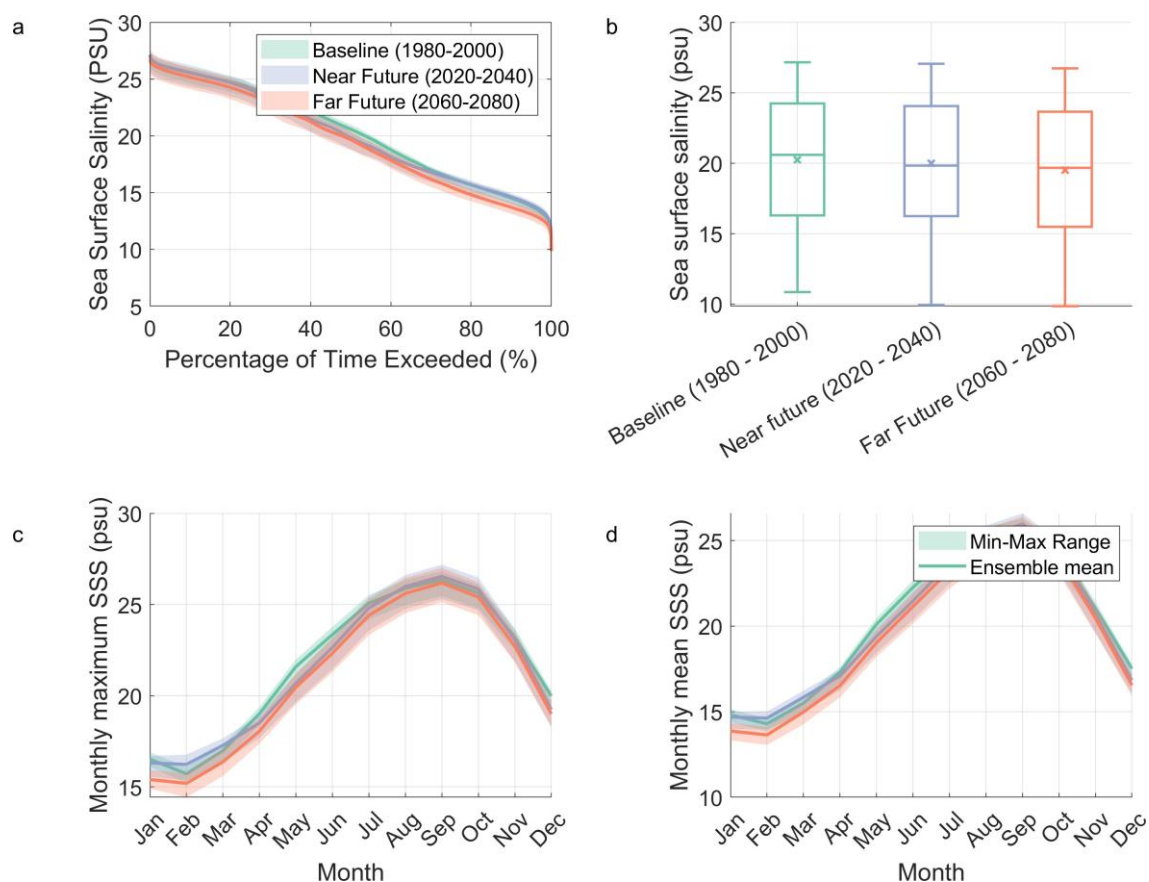


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
- (b) Percentile shifts show decreasing mean, median, and extremes, indicating a trend towards freshening over time.
- (c) Monthly maxima decrease across all months.
- (d) Decreasing monthly means suggest long-term ice-melt driven freshening.

Section 3 - Residual surge changes

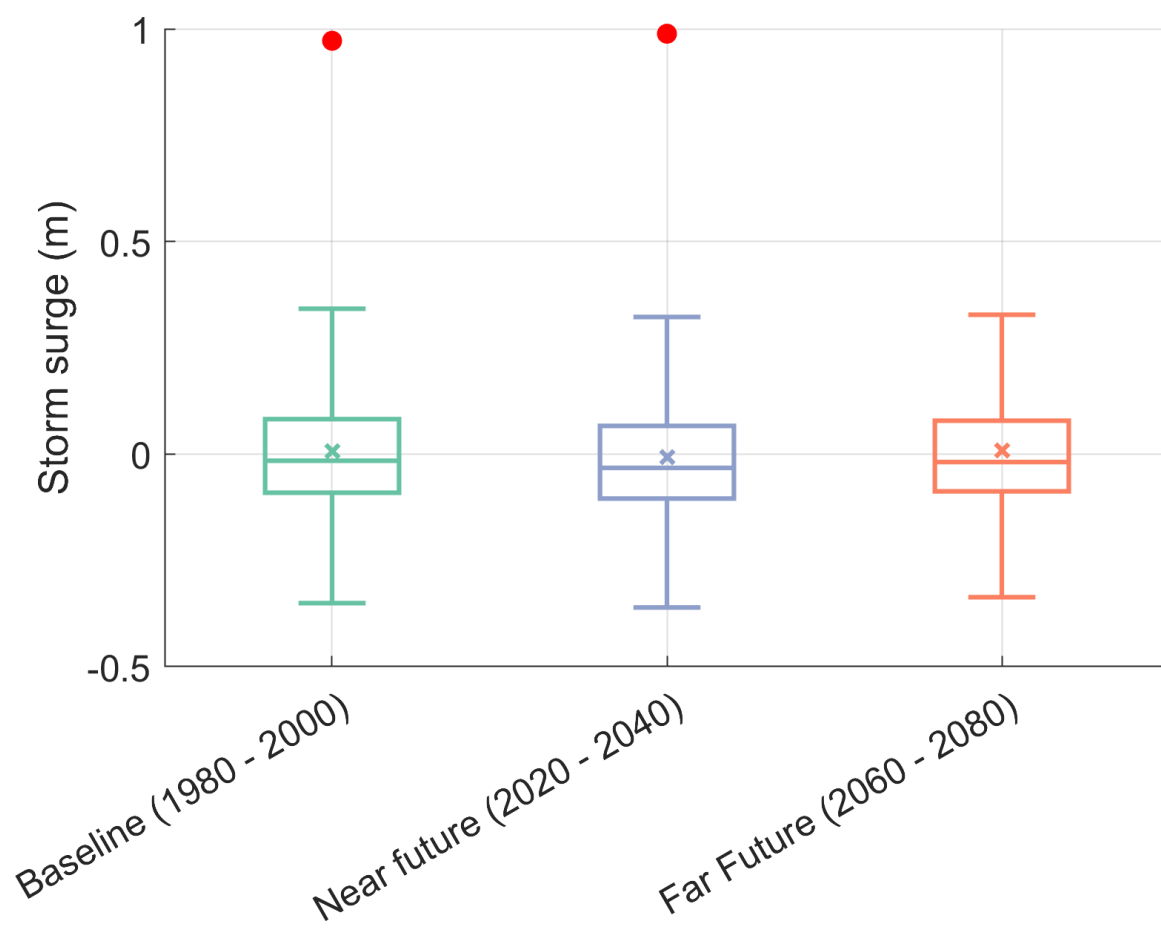


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

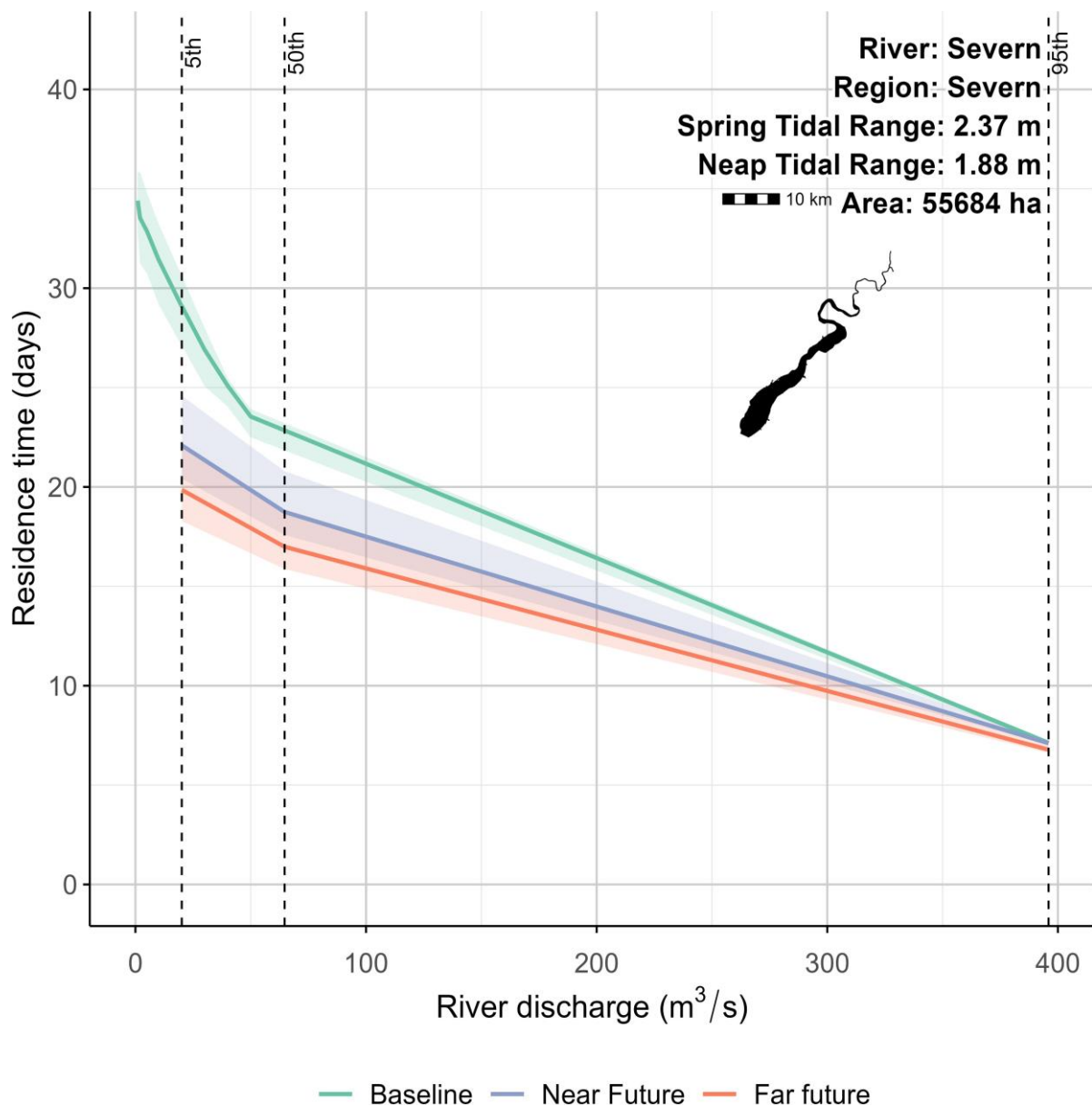


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Southampton_Itchen

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	50.9682
Longitude	-1.4983
Tidal Range	3.7 m
Gauge Name	Test at Broadlands
Estuary Size	24800000.0 m ²
5th percentile flow	5.72 m ³ /s
50th percentile flow	9.811 m ³ /s
95th percentile flow	21.21 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

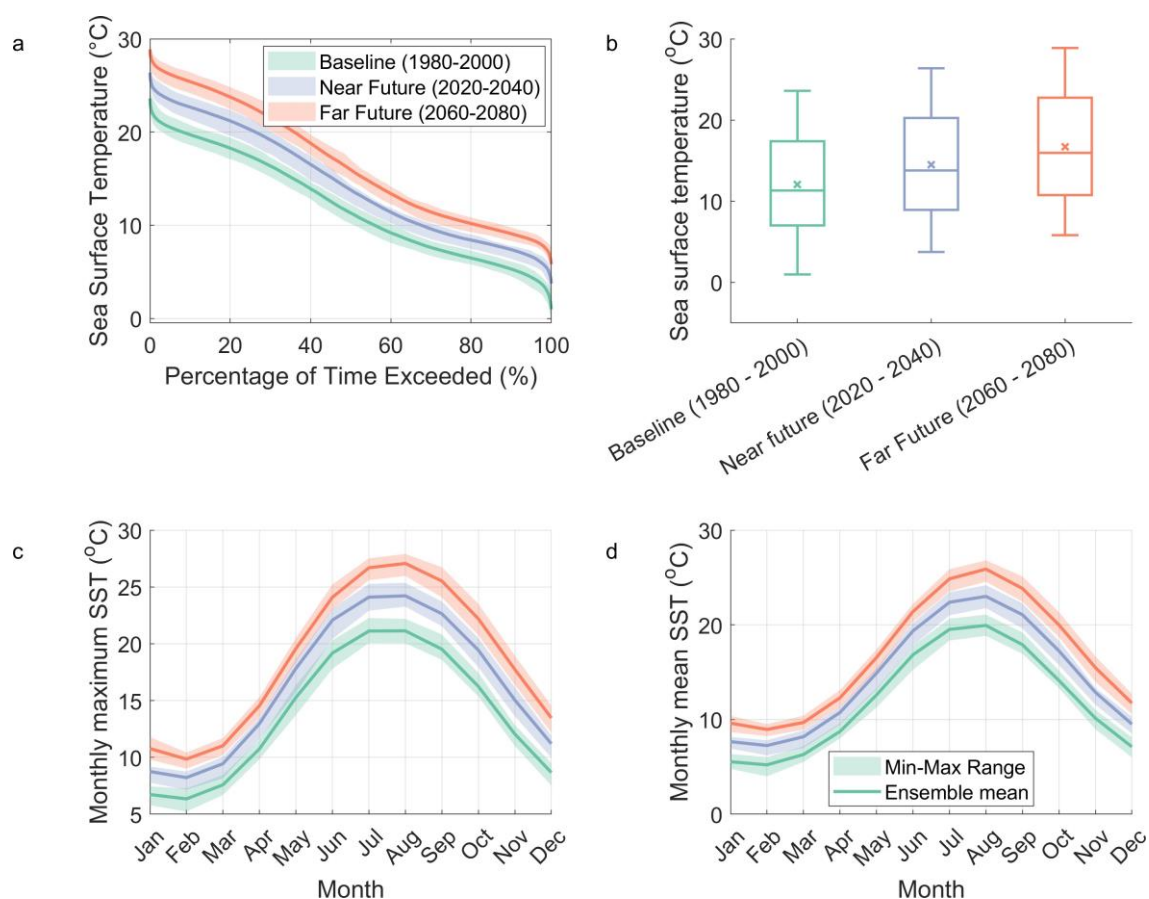
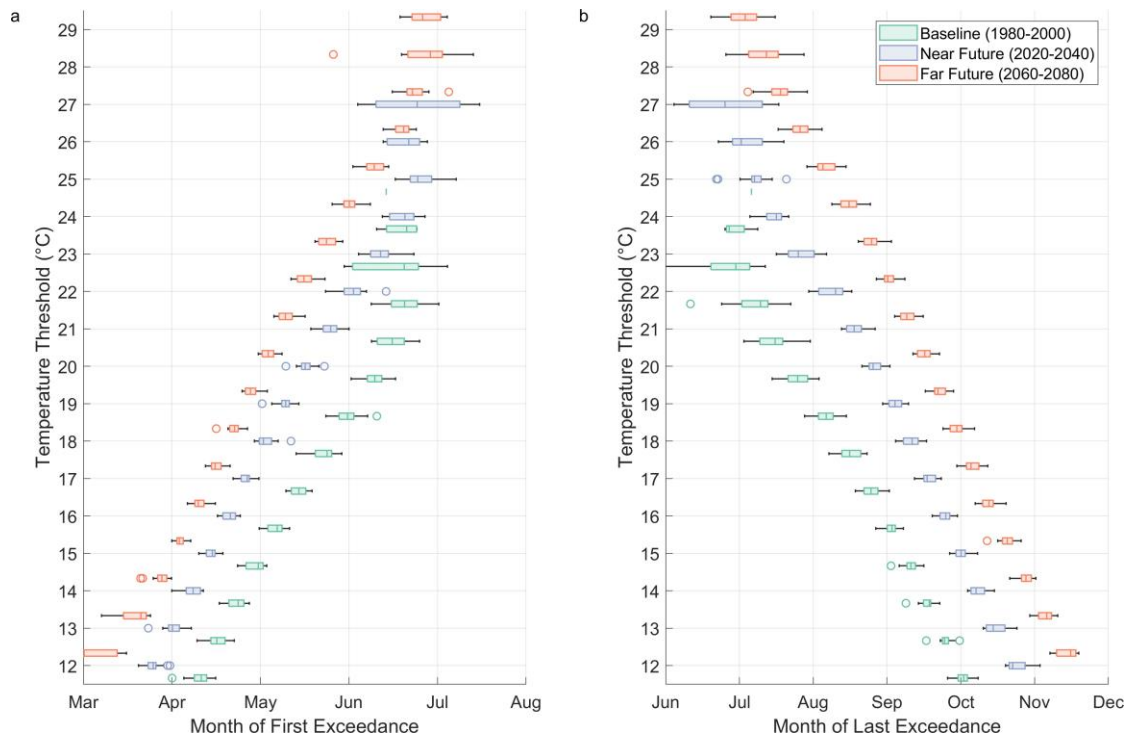


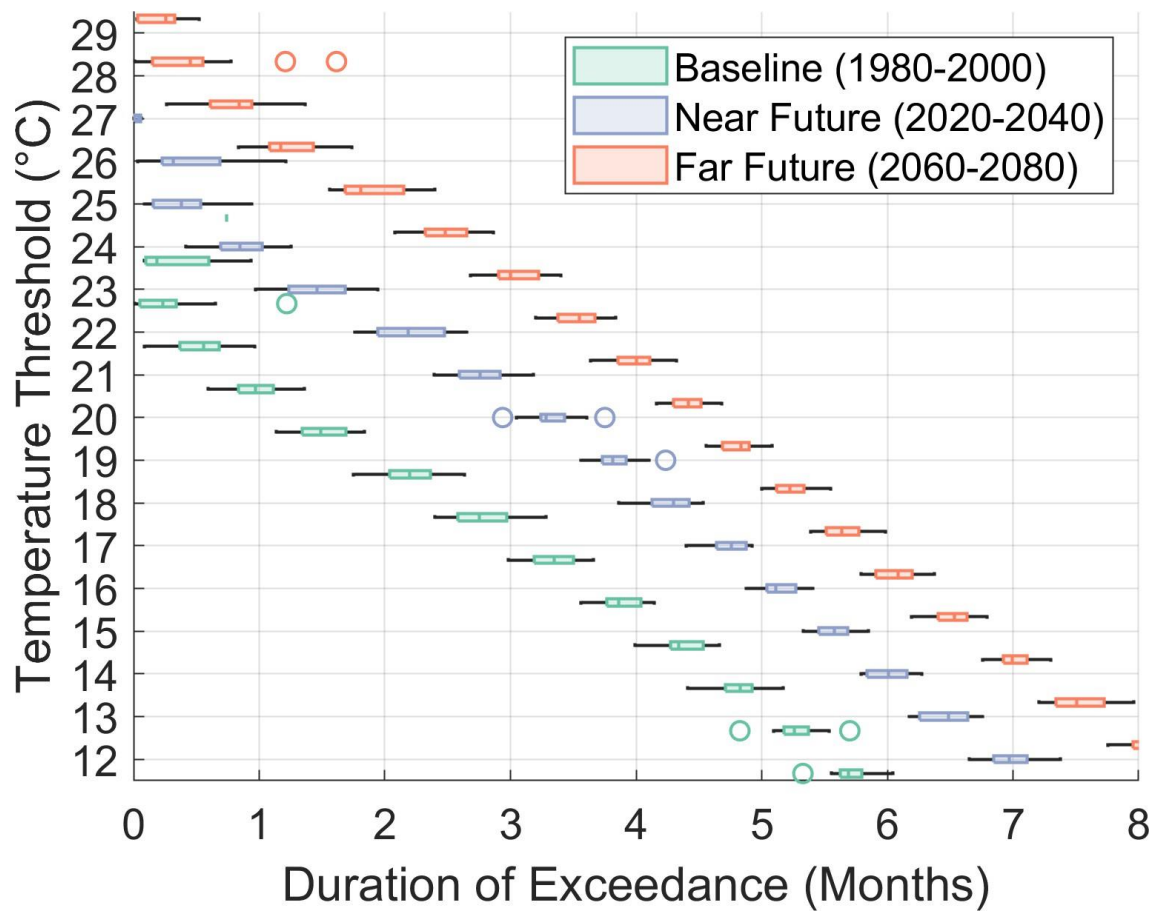
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

- (a) Temperature duration curves represent distribution of SSTs over time to highlight changes in cold and warm extremes.
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Projected temperature changes under different climate scenarios. Box and whisker plots show the range of different modelled durations of temperatures under the 12 different UKCP 18 ensemble members. Open circles indicate outlier values.

Section 2 - Sea surface salinity changes

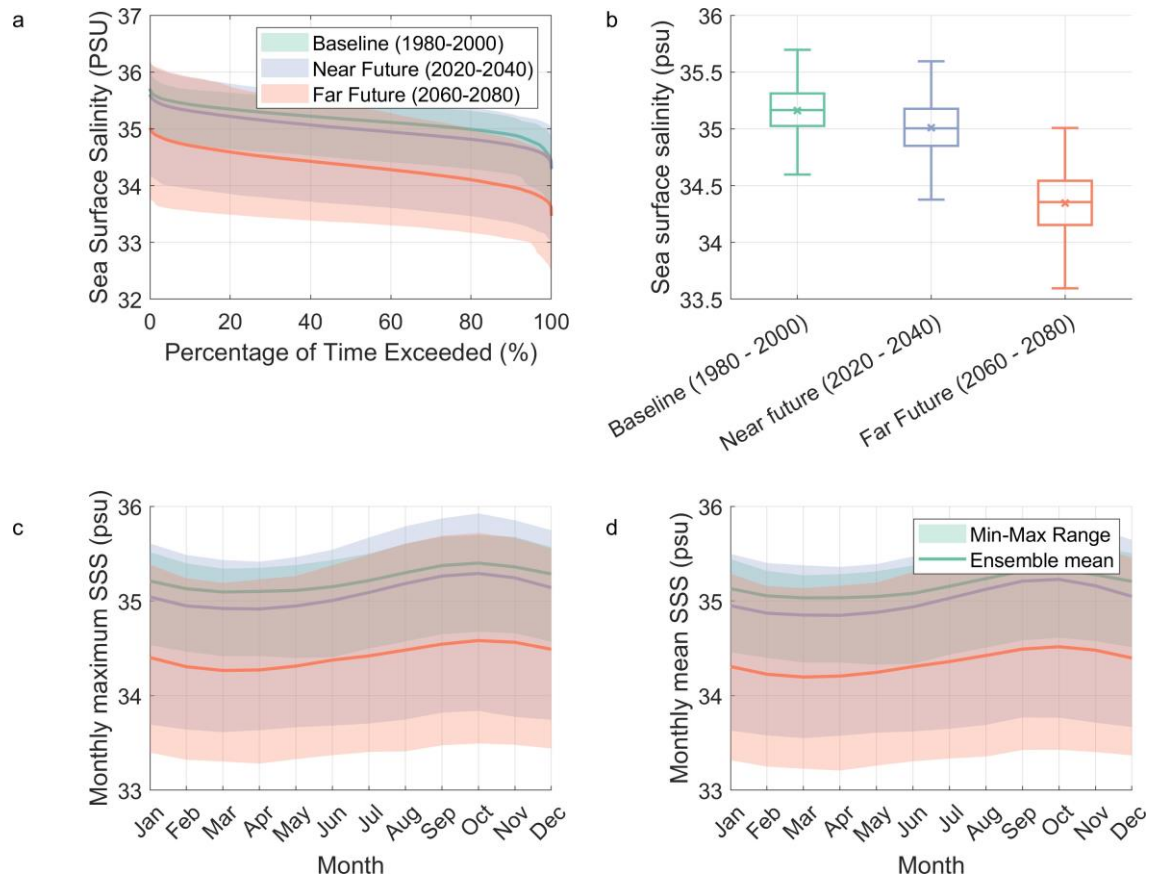


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
- (b) Percentile shifts show decreasing mean, median, and extremes, indicating a trend towards freshening over time.
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- (d) Decreasing monthly means suggest long-term ice-melt driven freshening.

Section 3 - Residual surge changes

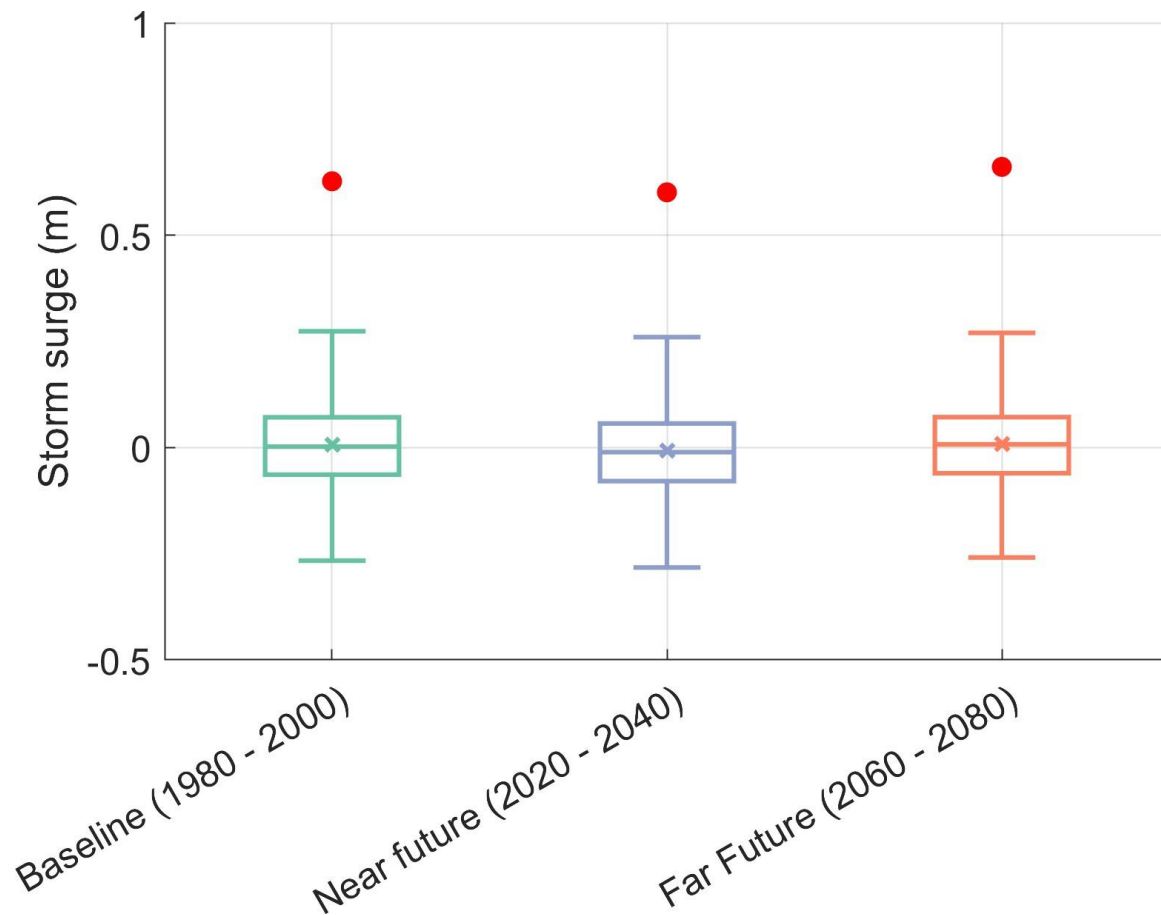


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

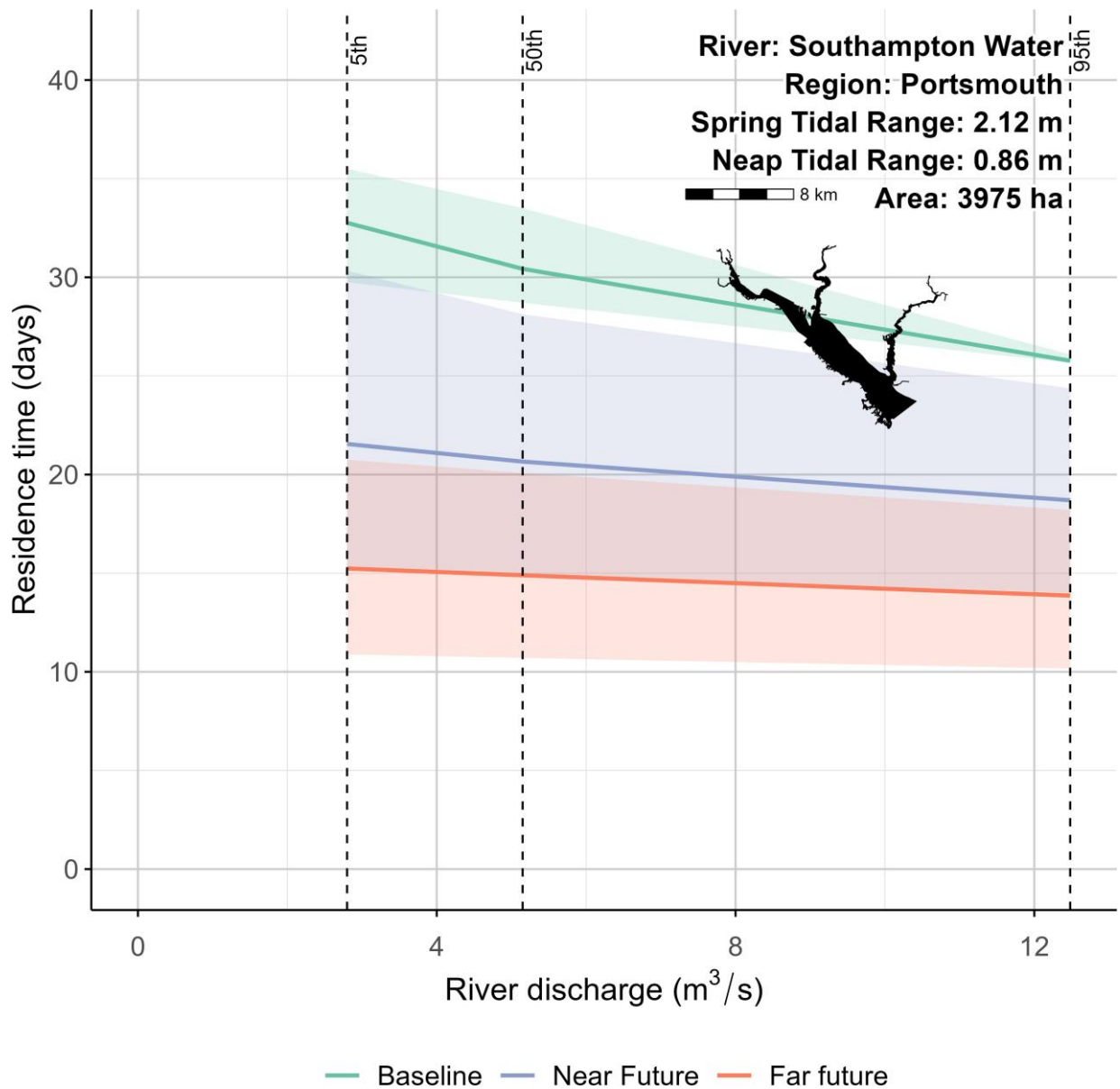


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Stiffkey

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	52.93505
Longitude	0.89211
Tidal Range	5.39 m
Gauge Name	Stiffkey at Warham
Estuary Size	4260000.0 m ²
5th percentile flow	0.145 m ³ /s
50th percentile flow	0.451 m ³ /s
95th percentile flow	1.49 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

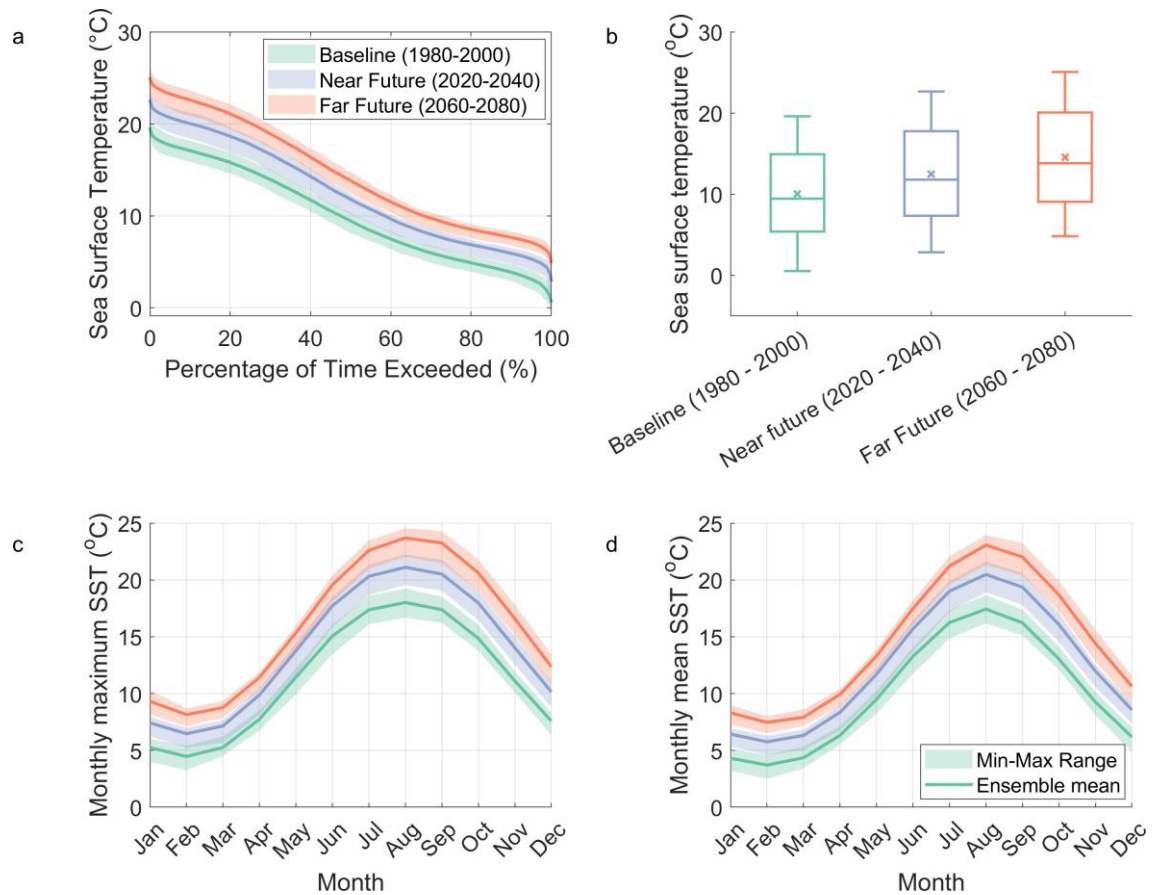
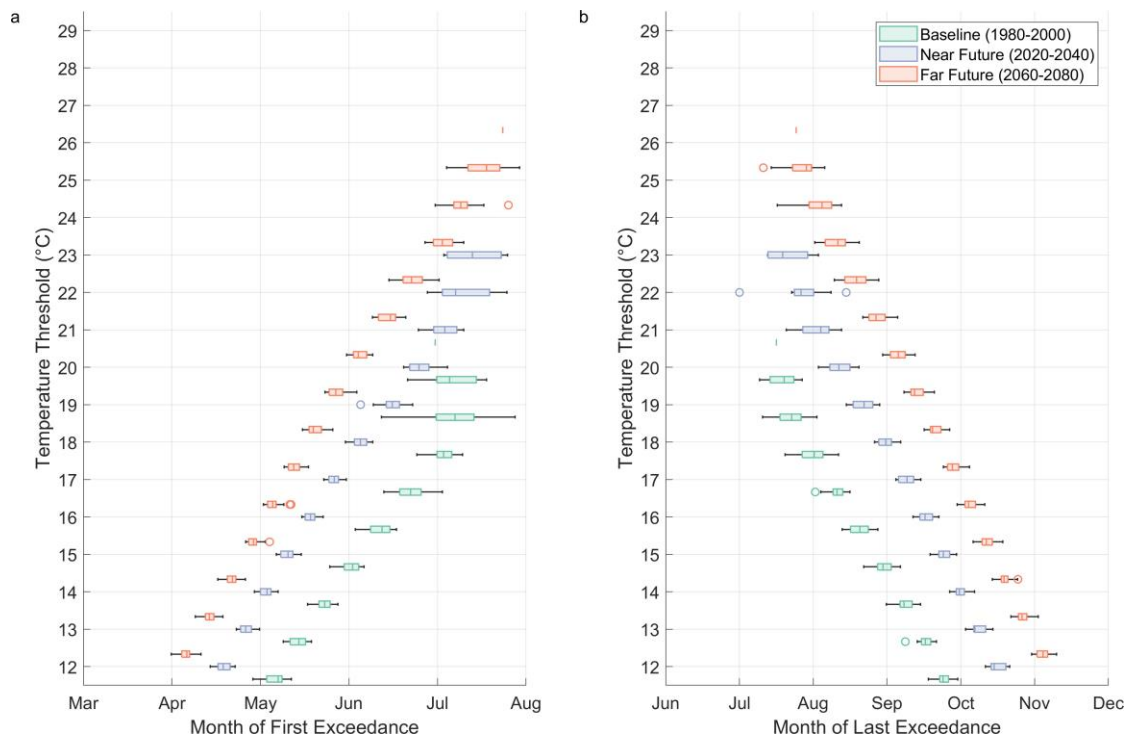


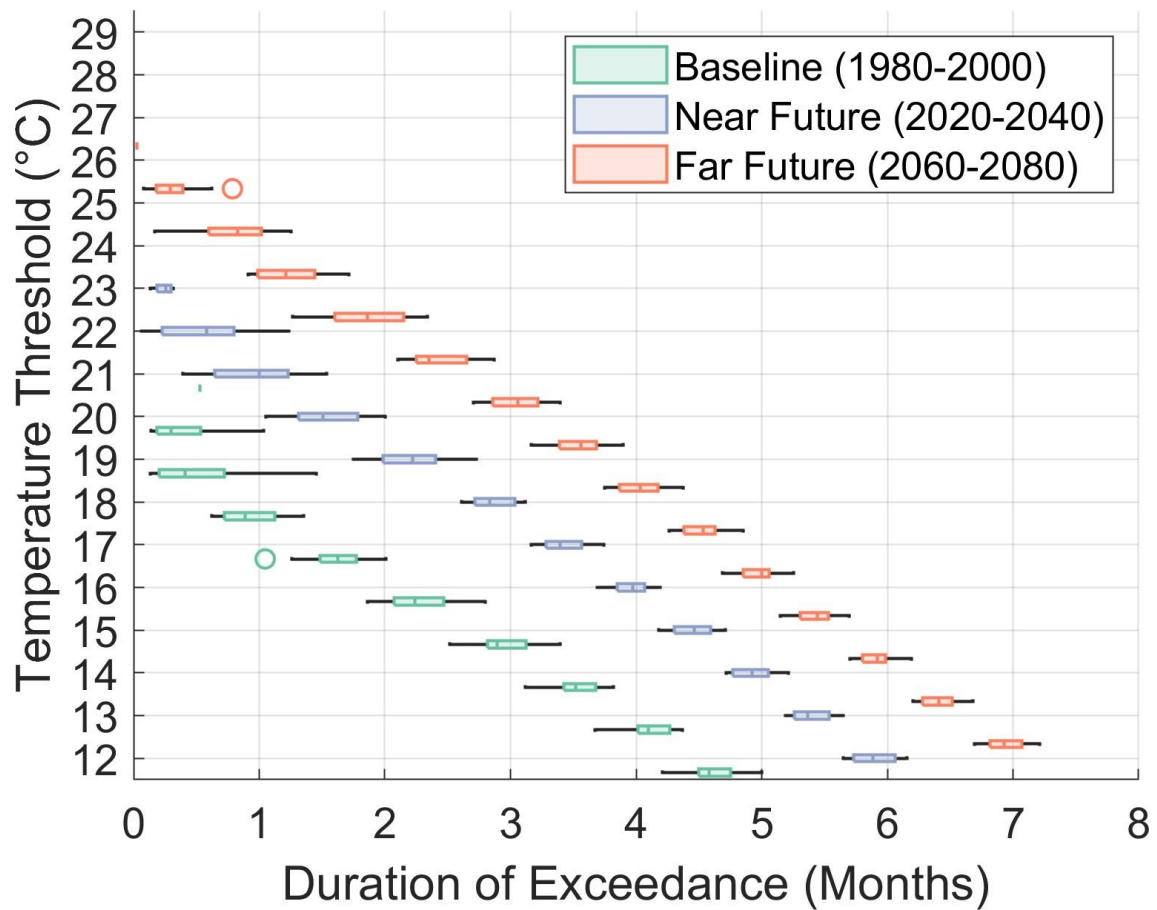
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

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Projected temperature changes under different climate scenarios. Box and whisker plots show the range of different modelled durations of temperatures under the 12 different UKCP 18 ensemble members. Open circles indicate outlier values.

Section 2 - Sea surface salinity changes

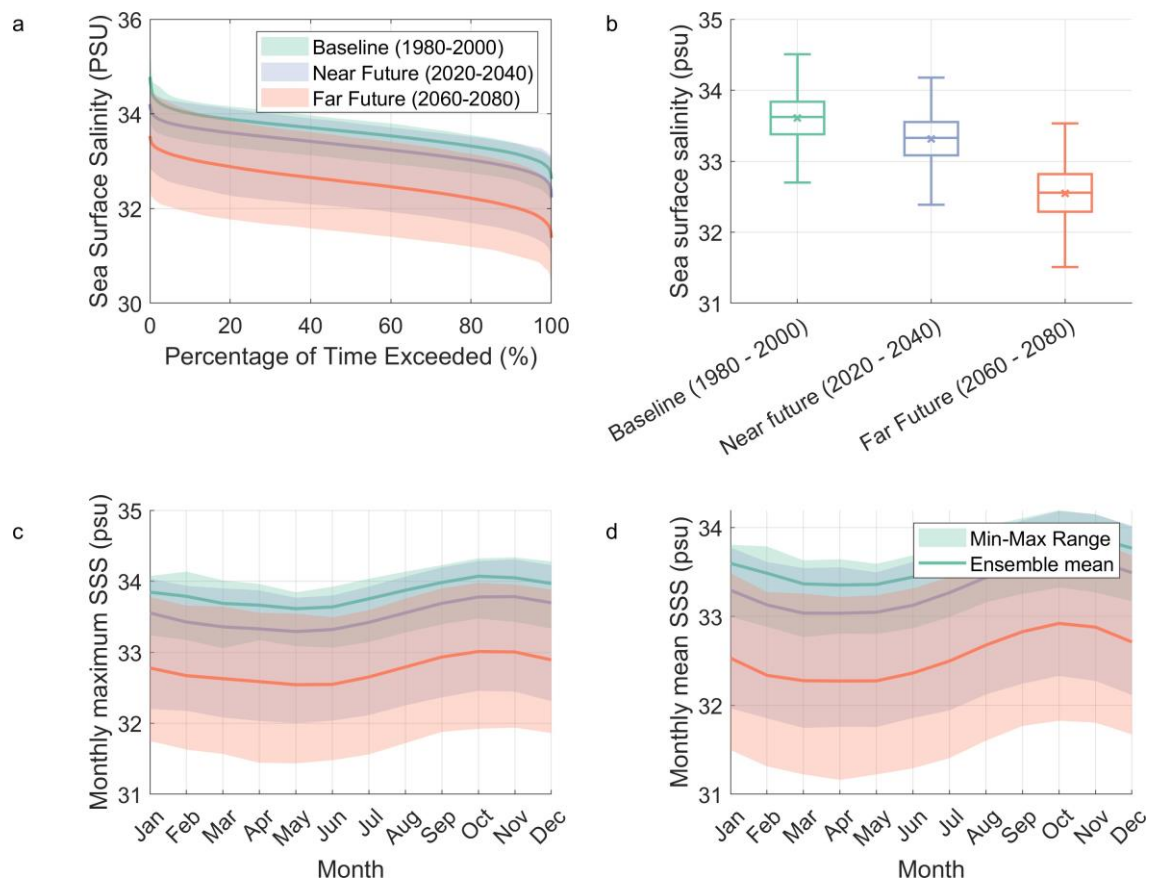


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
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Section 3 - Residual surge changes

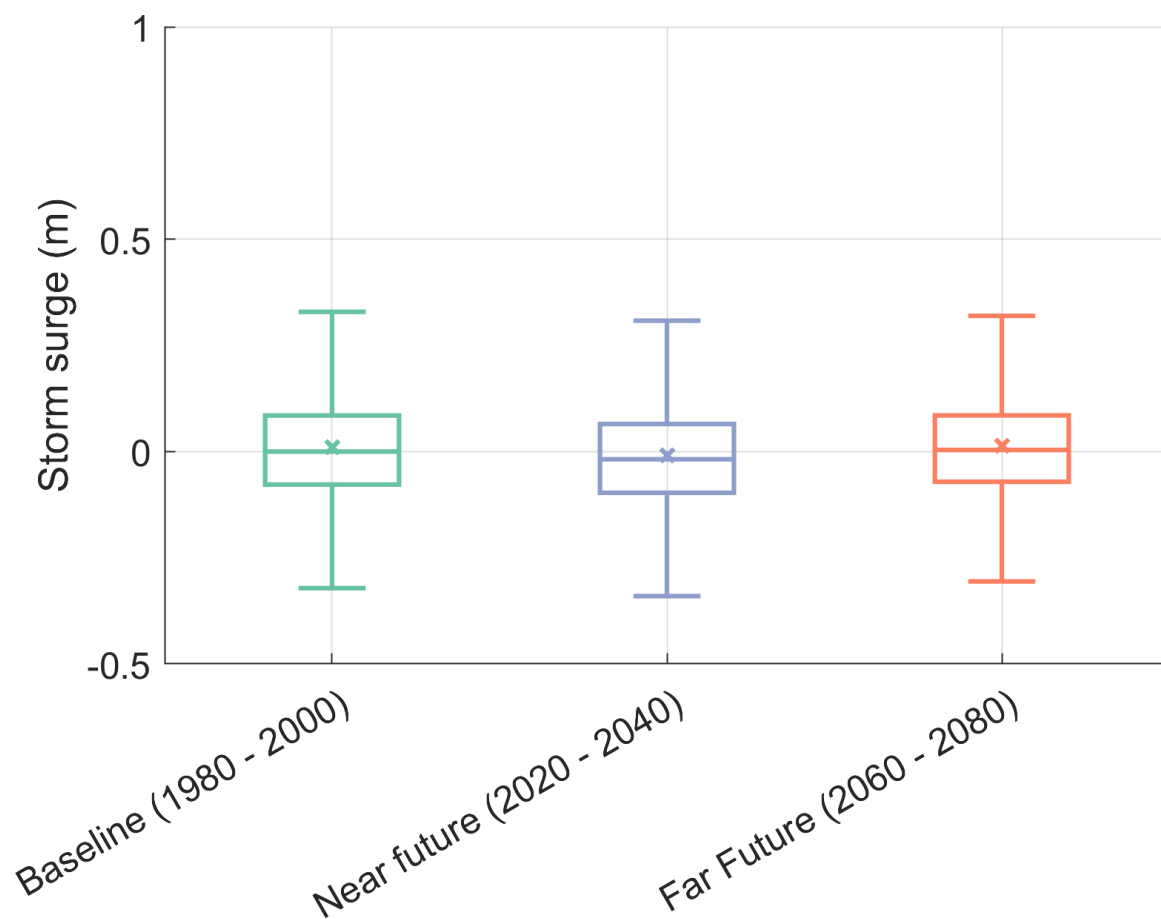


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

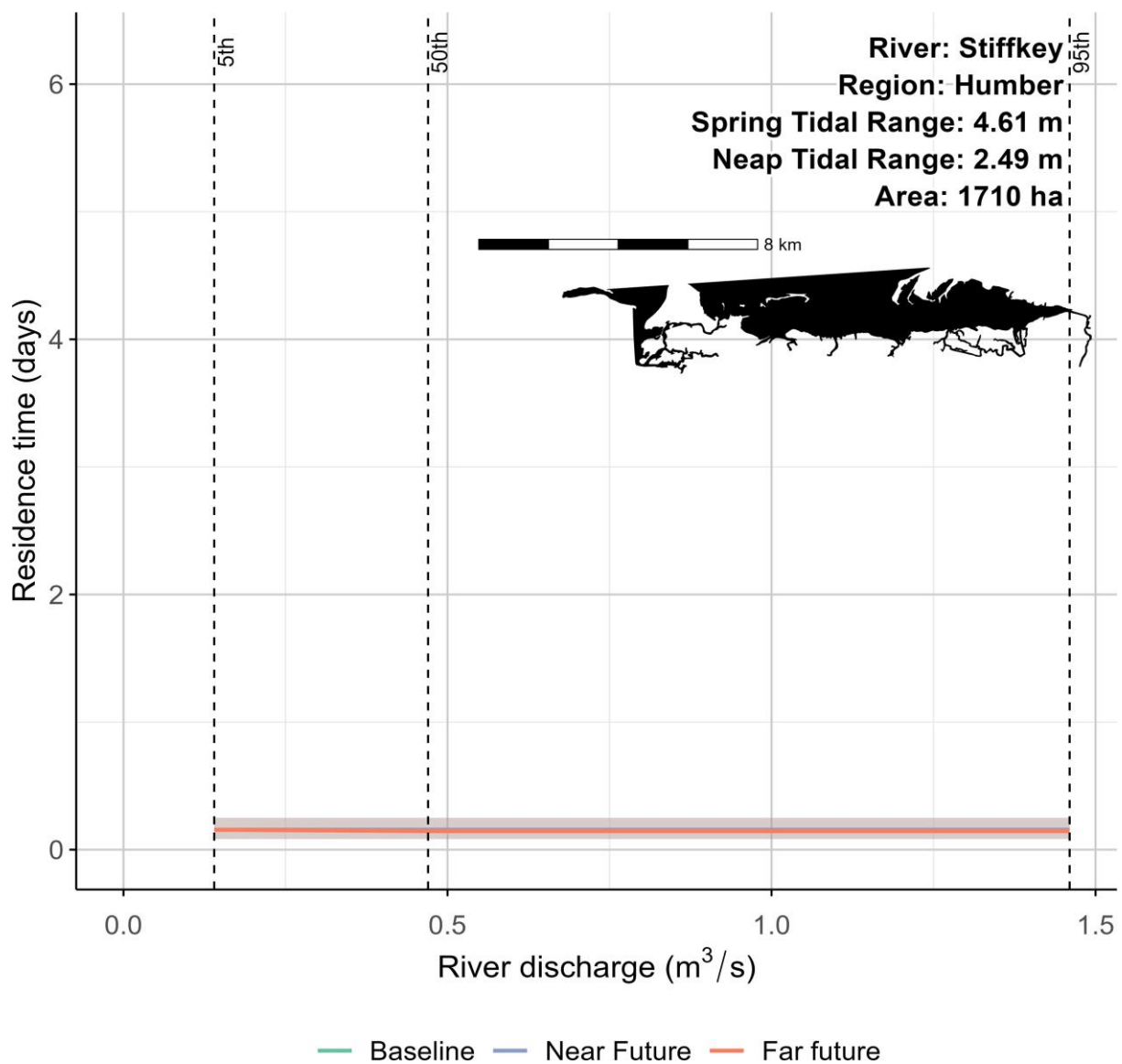


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Stour

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	51.9669
Longitude	0.97126
Tidal Range	3.6 m
Gauge Name	Stour at Stratford St Mary
Estuary Size	20200000.0 m ²
5th percentile flow	0.566 m ³ /s
50th percentile flow	1.523 m ³ /s
95th percentile flow	13.88 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

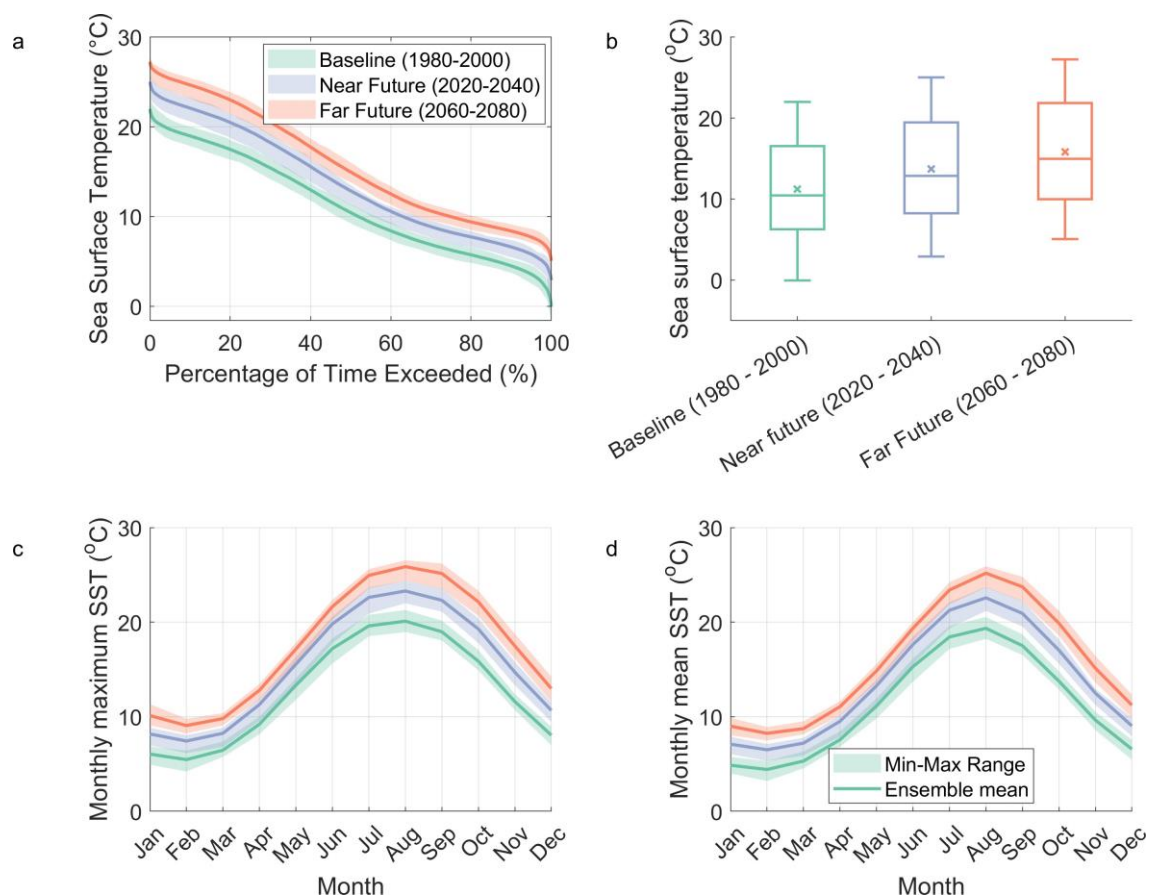
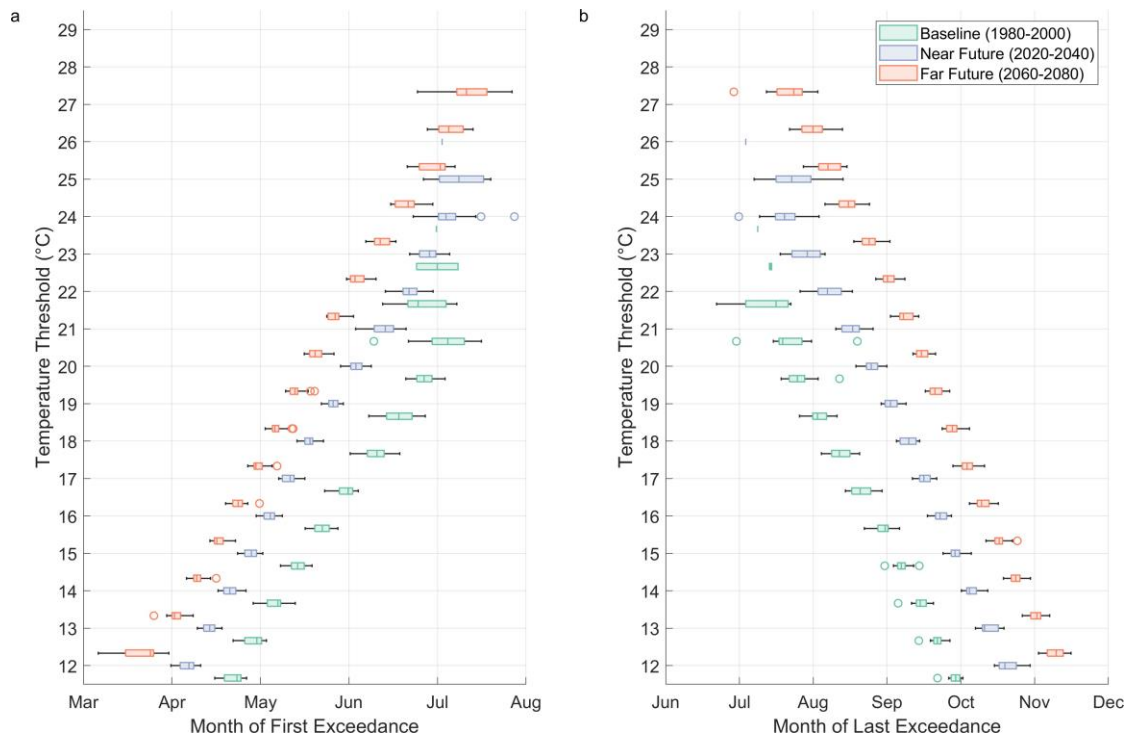


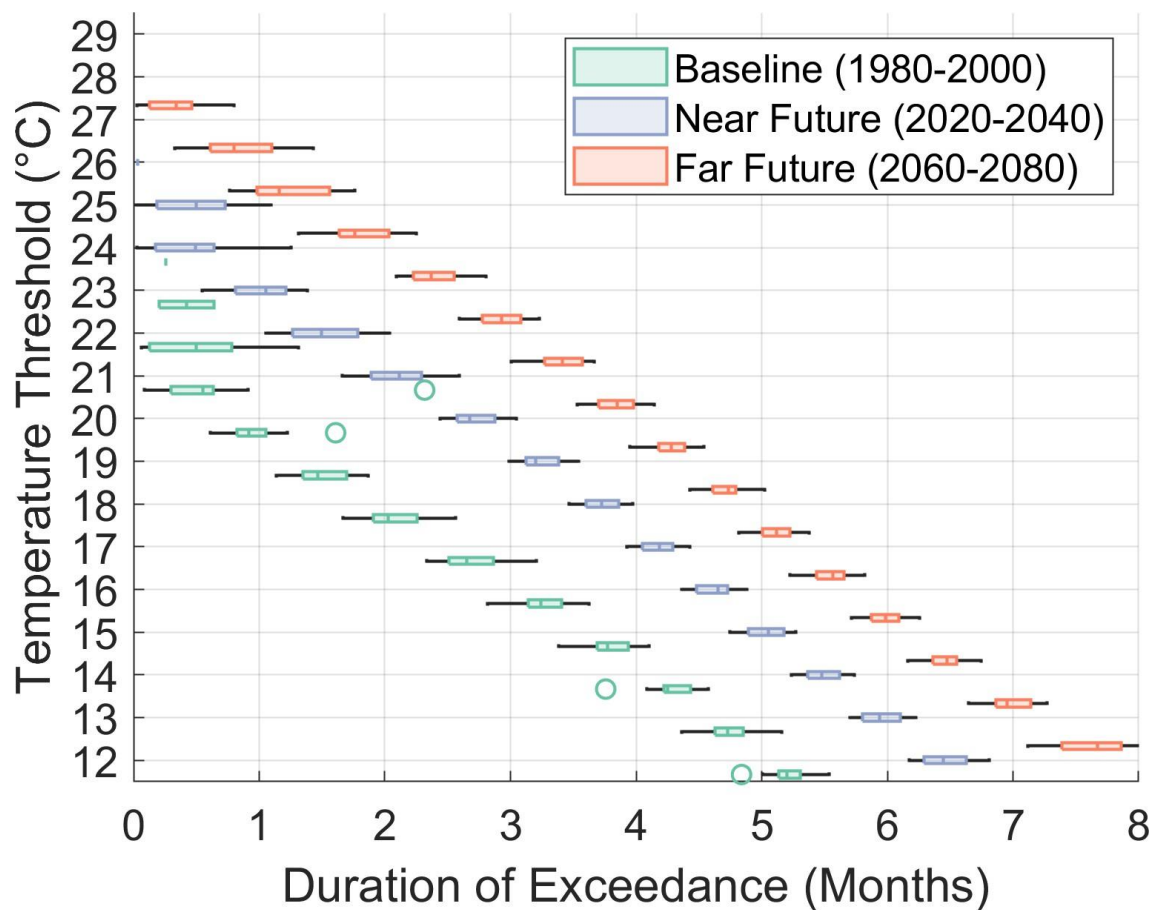
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

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Section 2 - Sea surface salinity changes

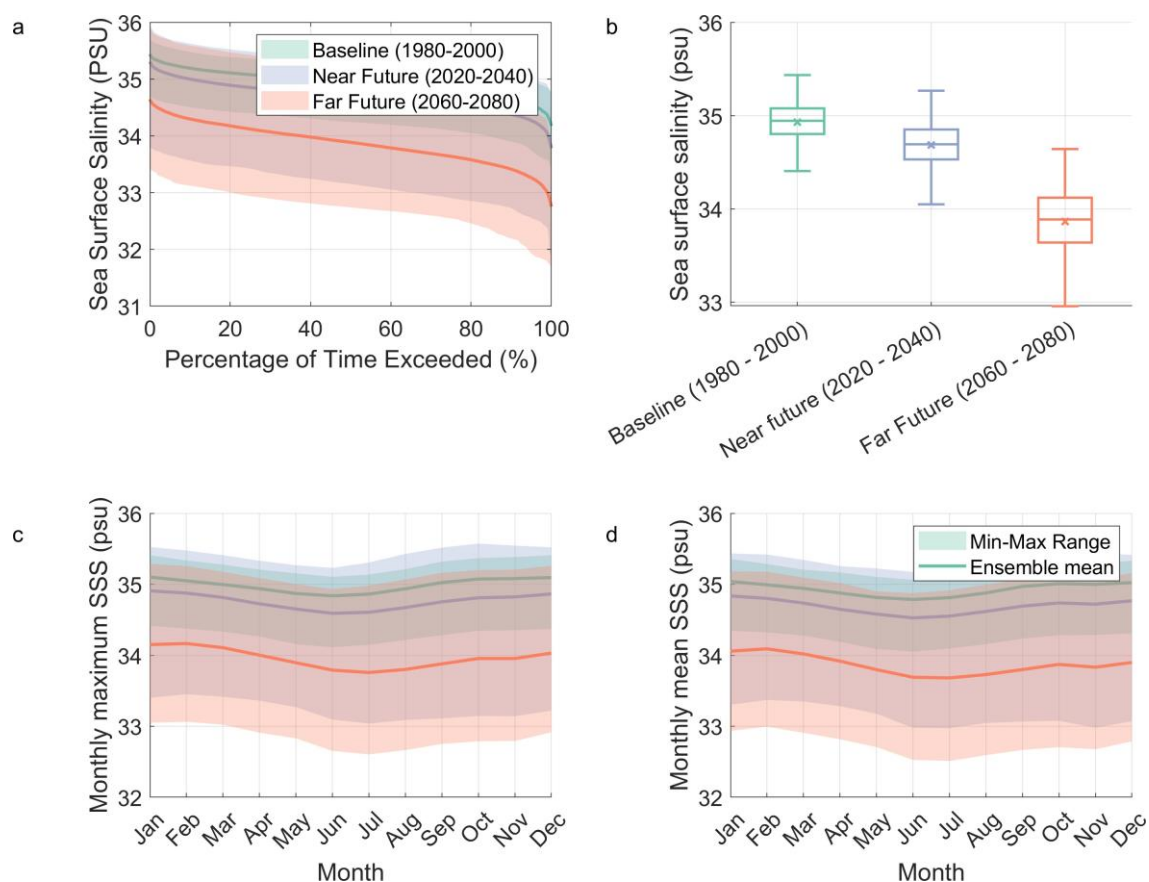


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
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- (d) Decreasing monthly means suggest long-term ice-melt driven freshening.

Section 3 - Residual surge changes

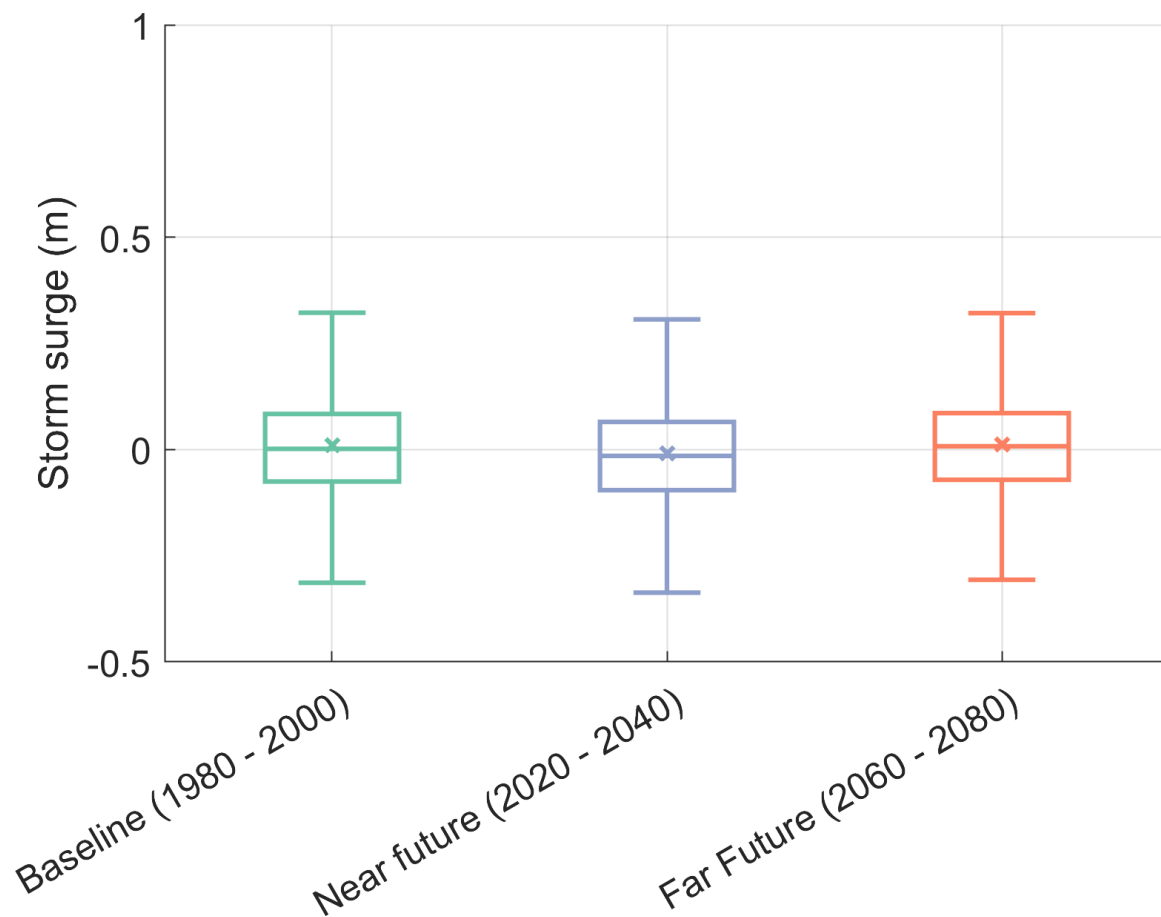


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

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Section 4 - Residence times changes

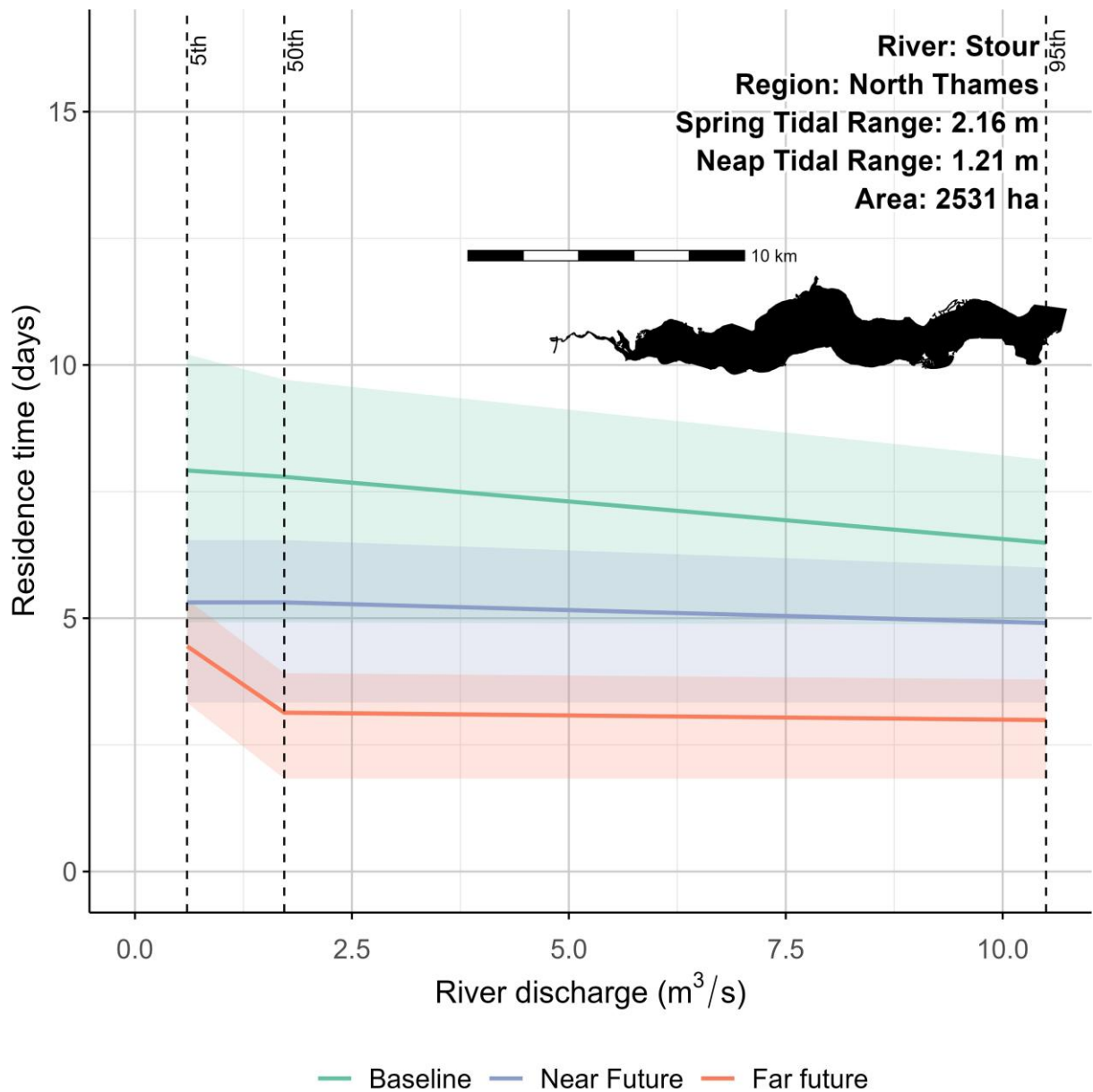


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Taw

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	50.99501
Longitude	-3.98542
Tidal Range	7.3 m
Gauge Name	Taw at Umerleigh
Estuary Size	11300000.0 m ²
5th percentile flow	1.23 m ³ /s
50th percentile flow	8.78 m ³ /s
95th percentile flow	66.0 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

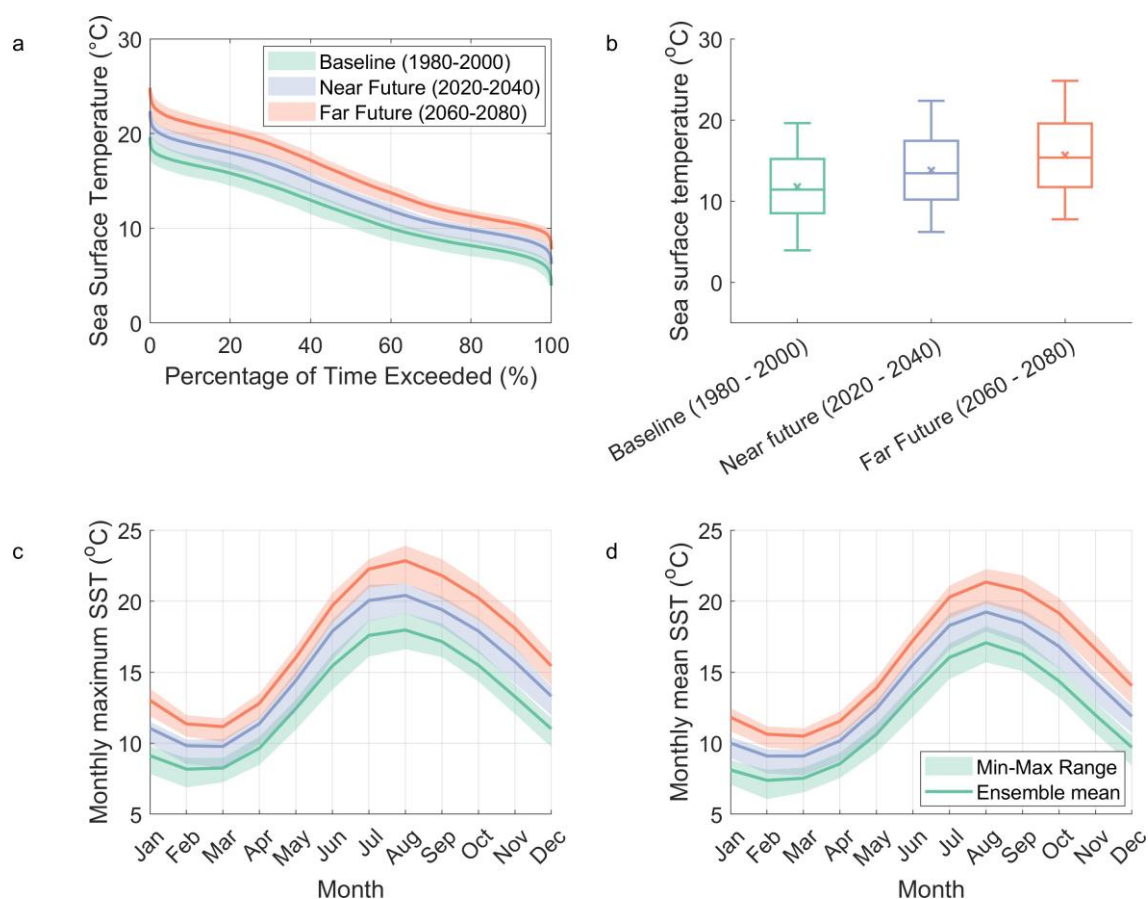
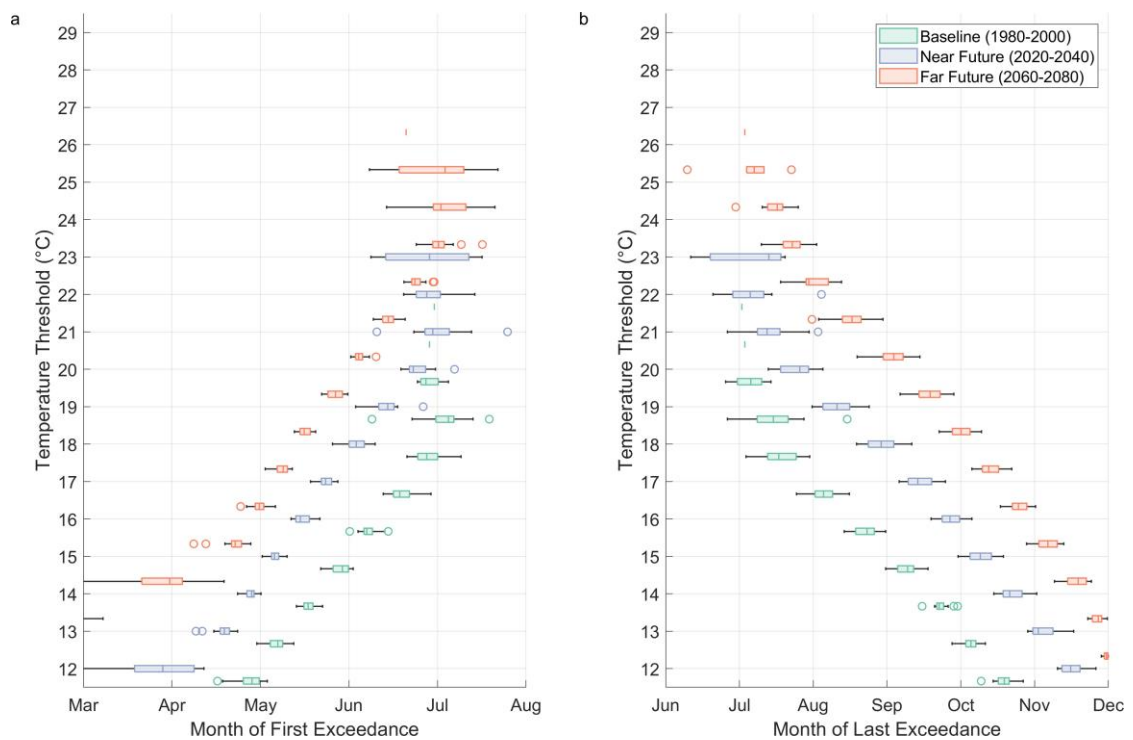


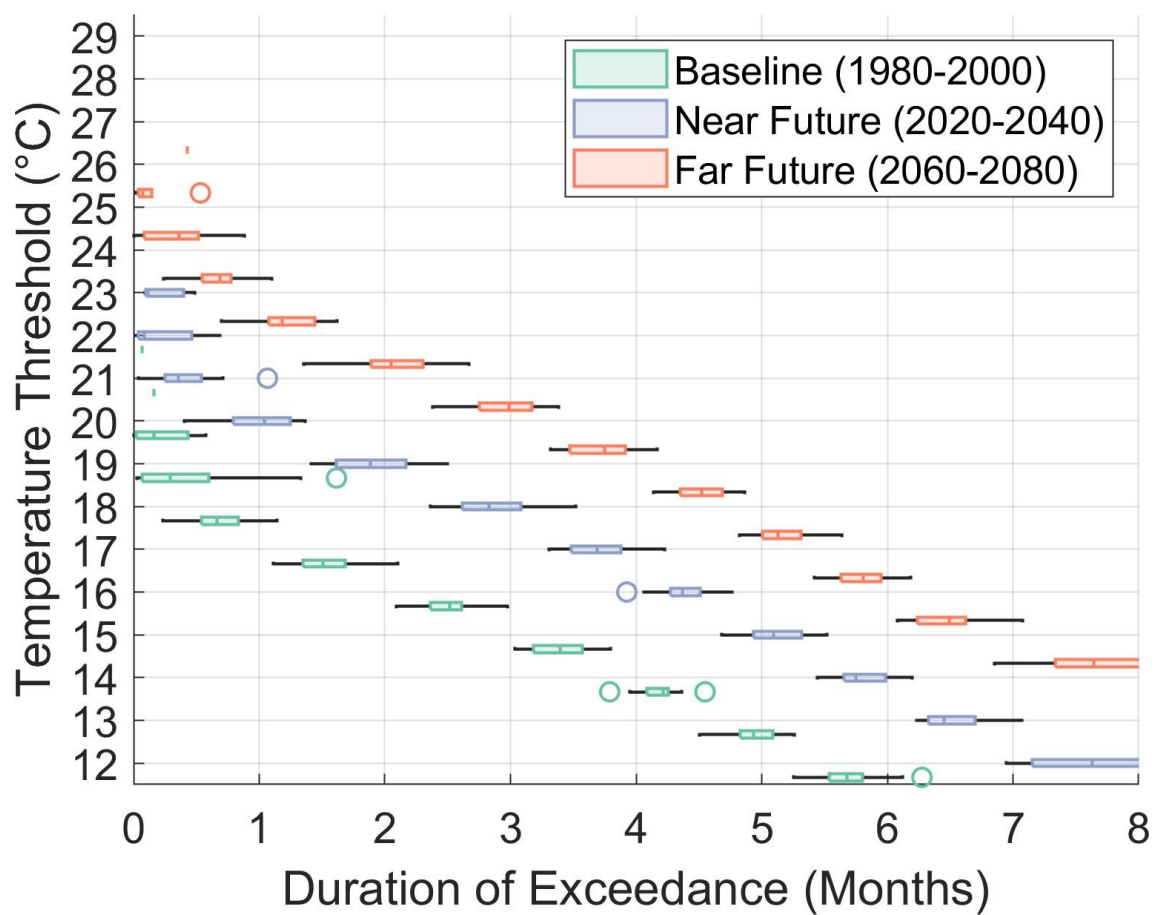
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

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Section 2 - Sea surface salinity changes

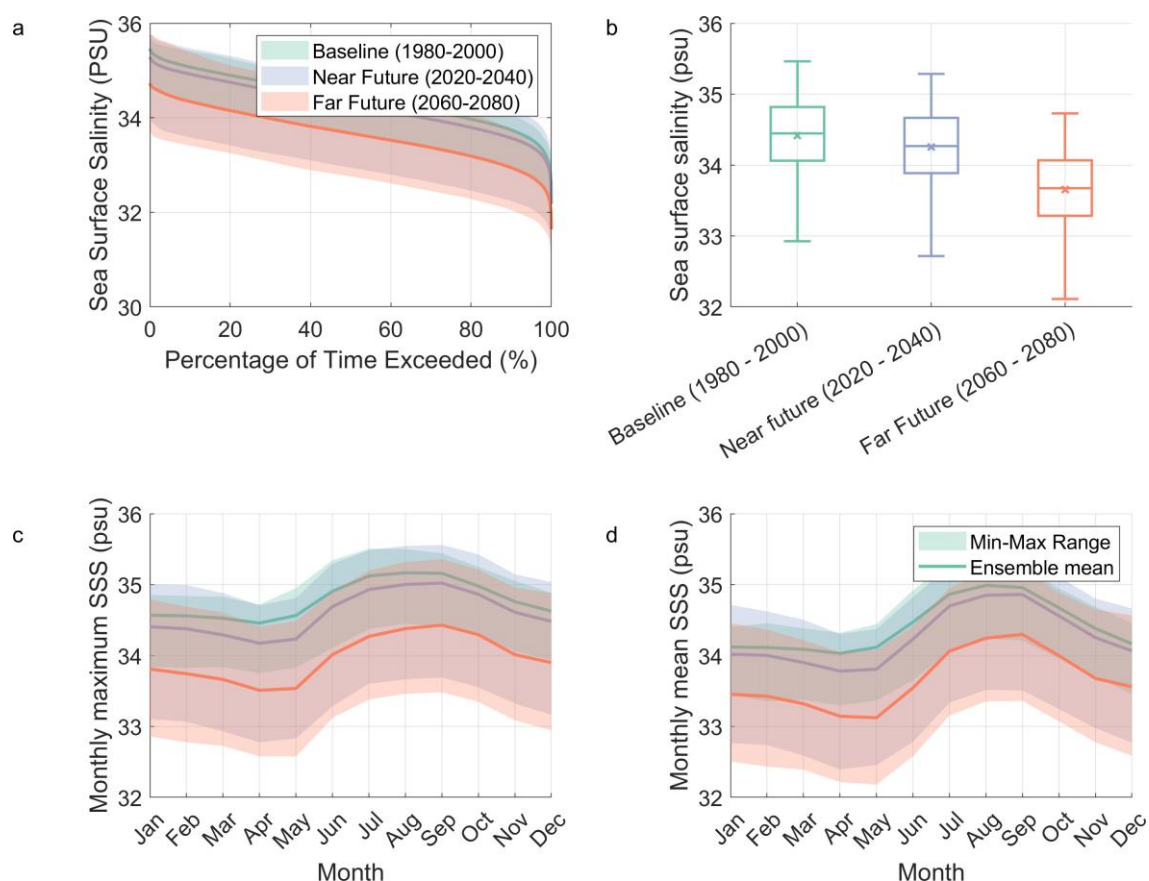


Figure description

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Section 3 - Residual surge changes

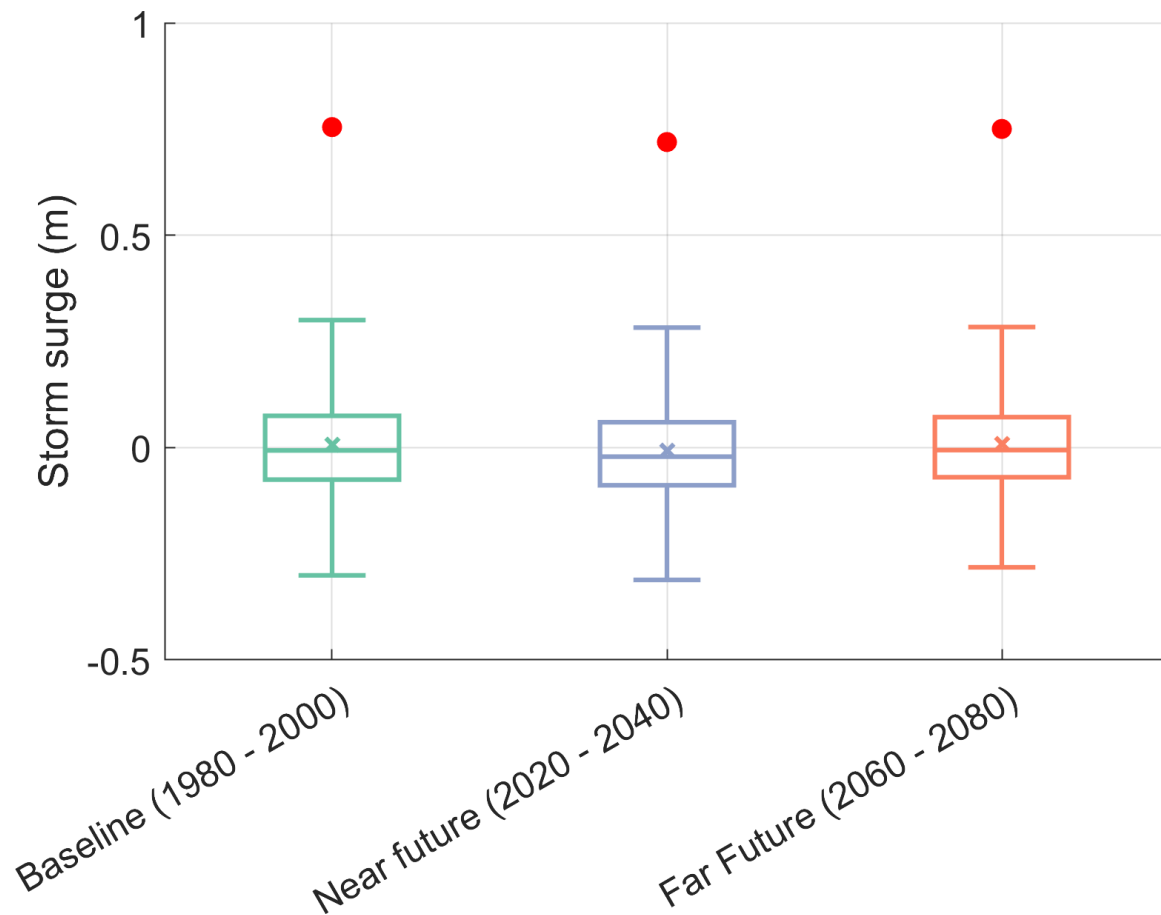


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

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Section 4 - River discharge changes

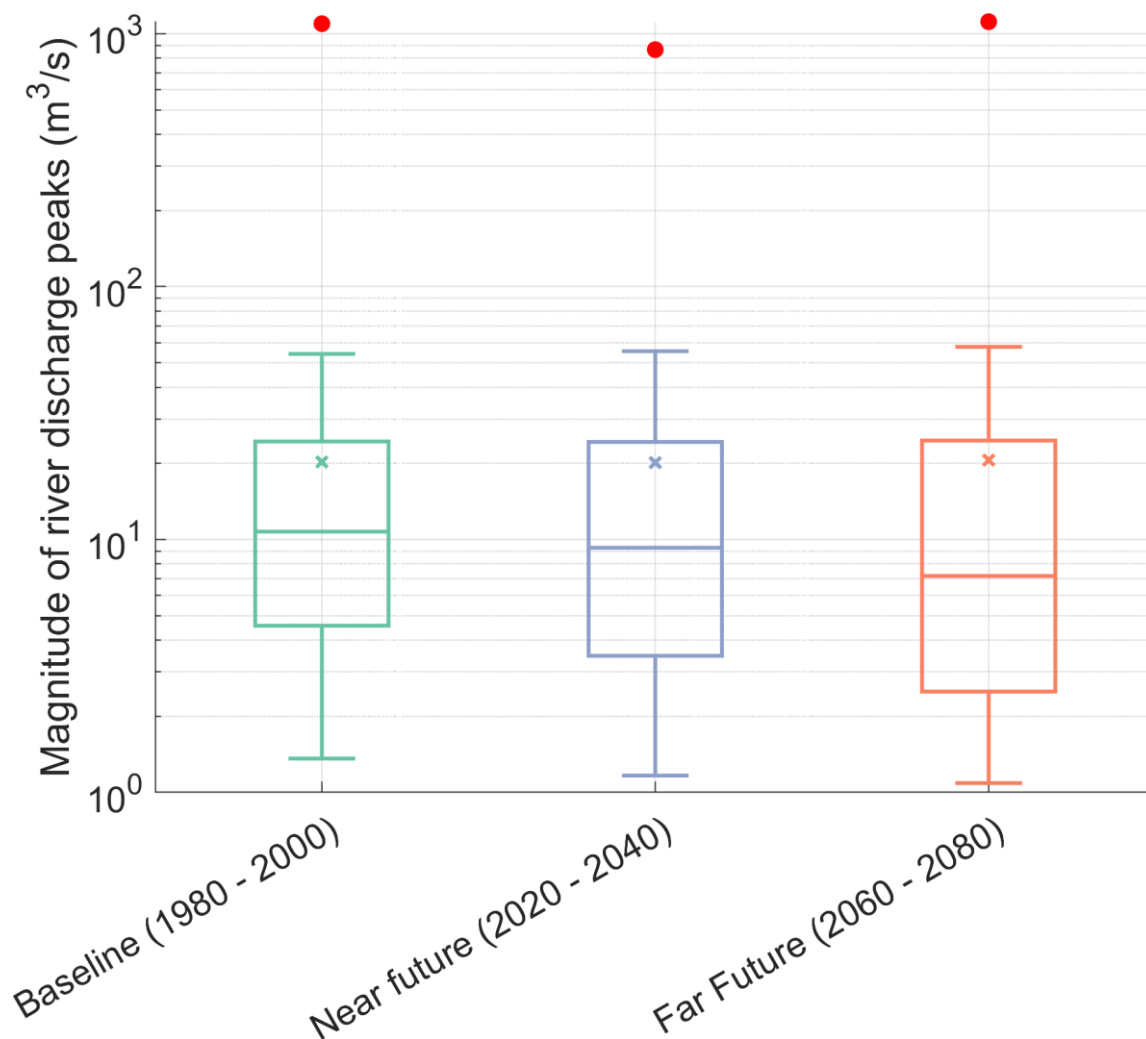


Figure description

Box and whisker plots of discharge percentiles under baseline (1980-2000), near-future (2020-2040) and far-future (2060-2080)

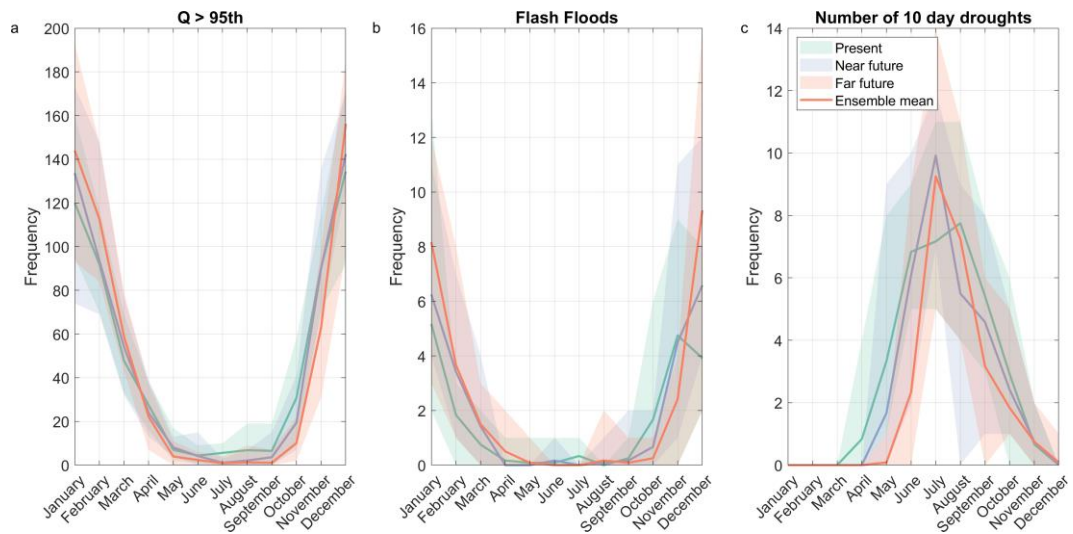


Figure description

Discharge conditions under baseline (1980-2000), near-future (2020-2040) and far-future (2060-2080) showing frequency of (a): Occurrence of high flow (>95th percentile events) per month (hourly resolution), (b): Flash flood events (increase in discharge of >50 m³/s, (c): low flow events lasting longer than 10 days).

Section 5 - Residence times changes

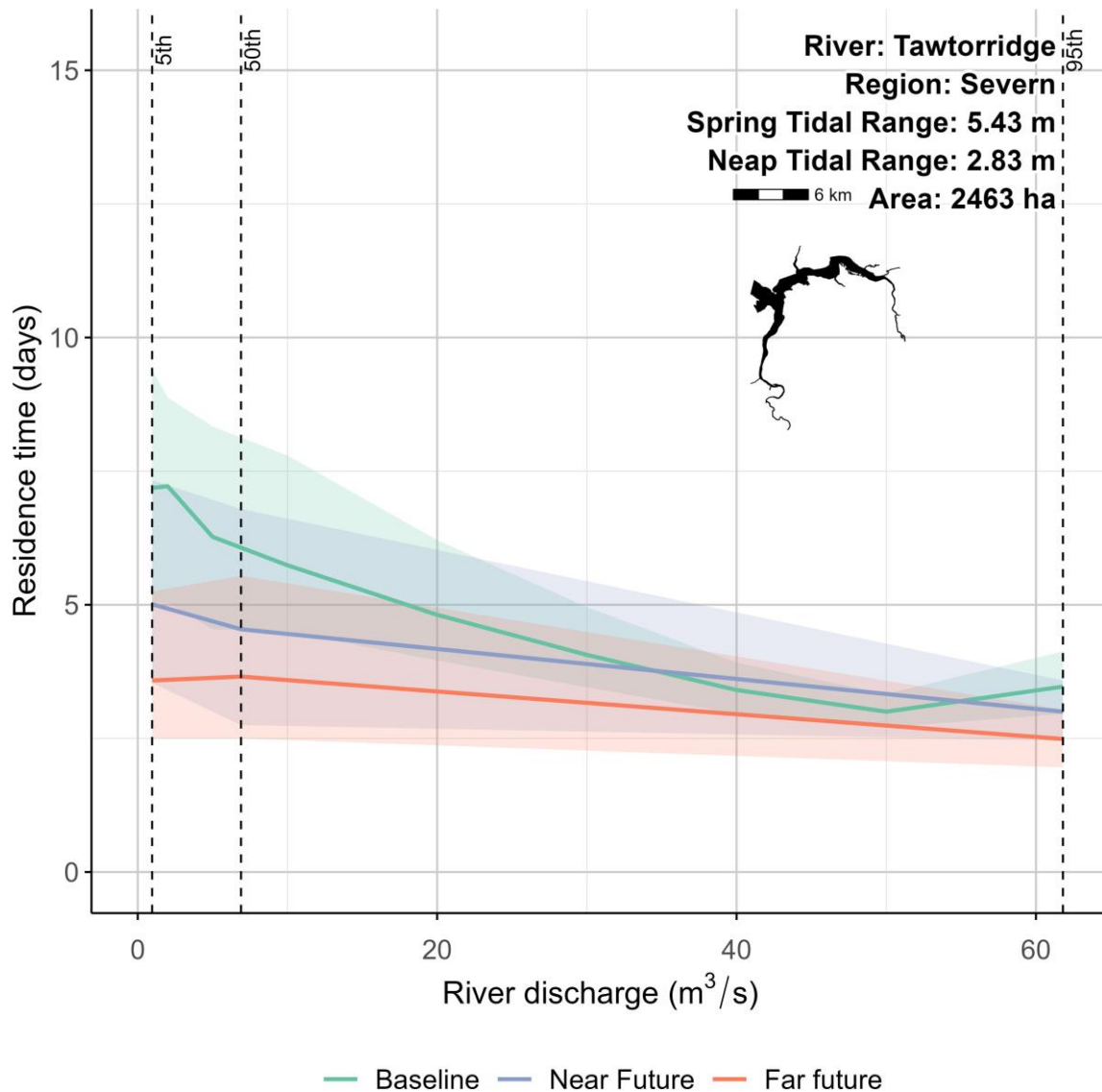


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)
Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Tees

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	54.48908
Longitude	-1.44023
Tidal Range	4.6 m
Gauge Name	Tees at Low Moor
Estuary Size	9420000.0 m ²
5th percentile flow	3.12 m ³ /s
50th percentile flow	11.0 m ³ /s
95th percentile flow	68.7 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

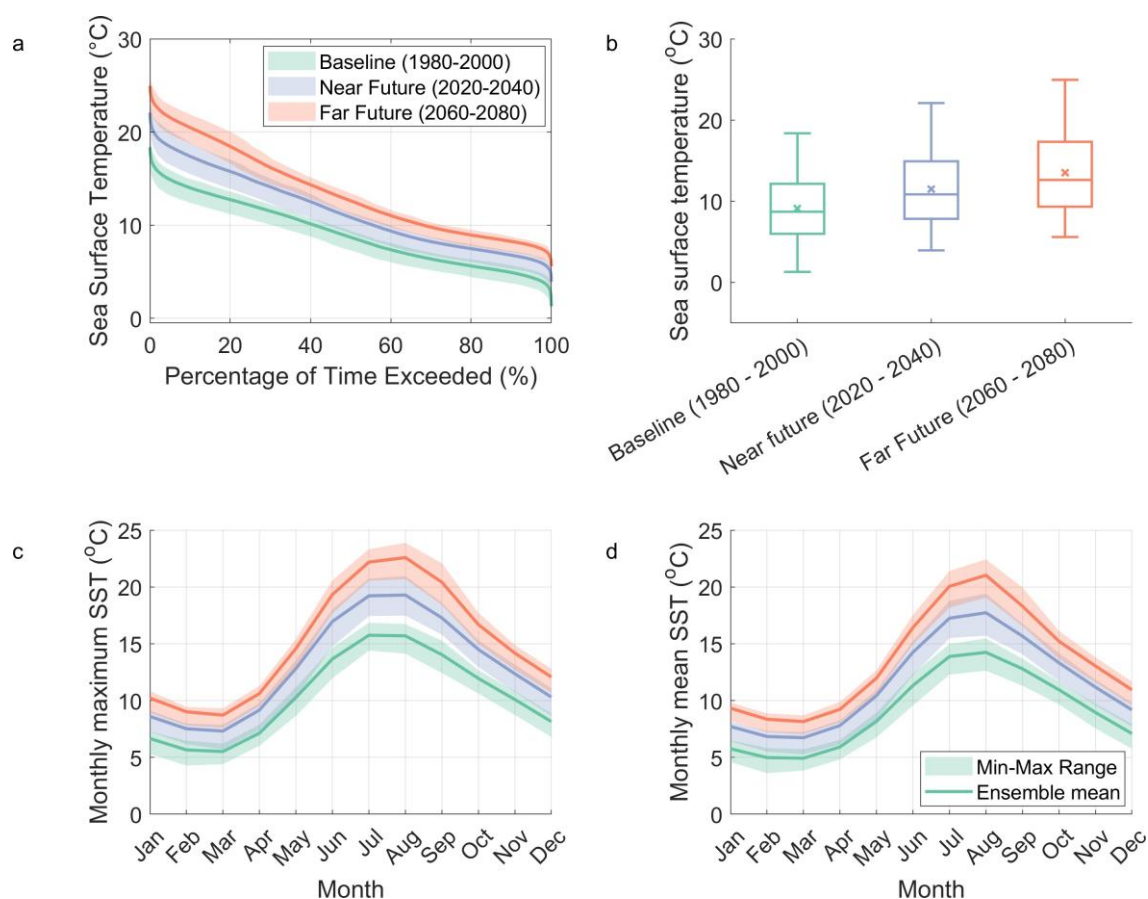
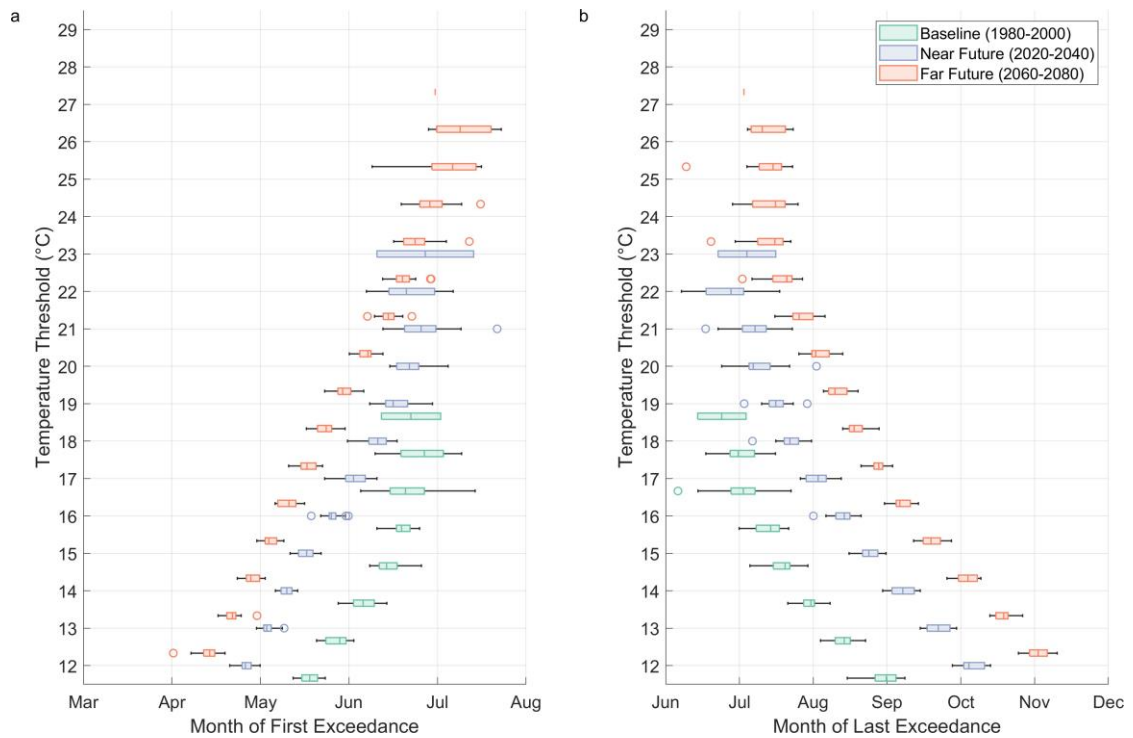


Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

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Section 2 - Sea surface salinity changes

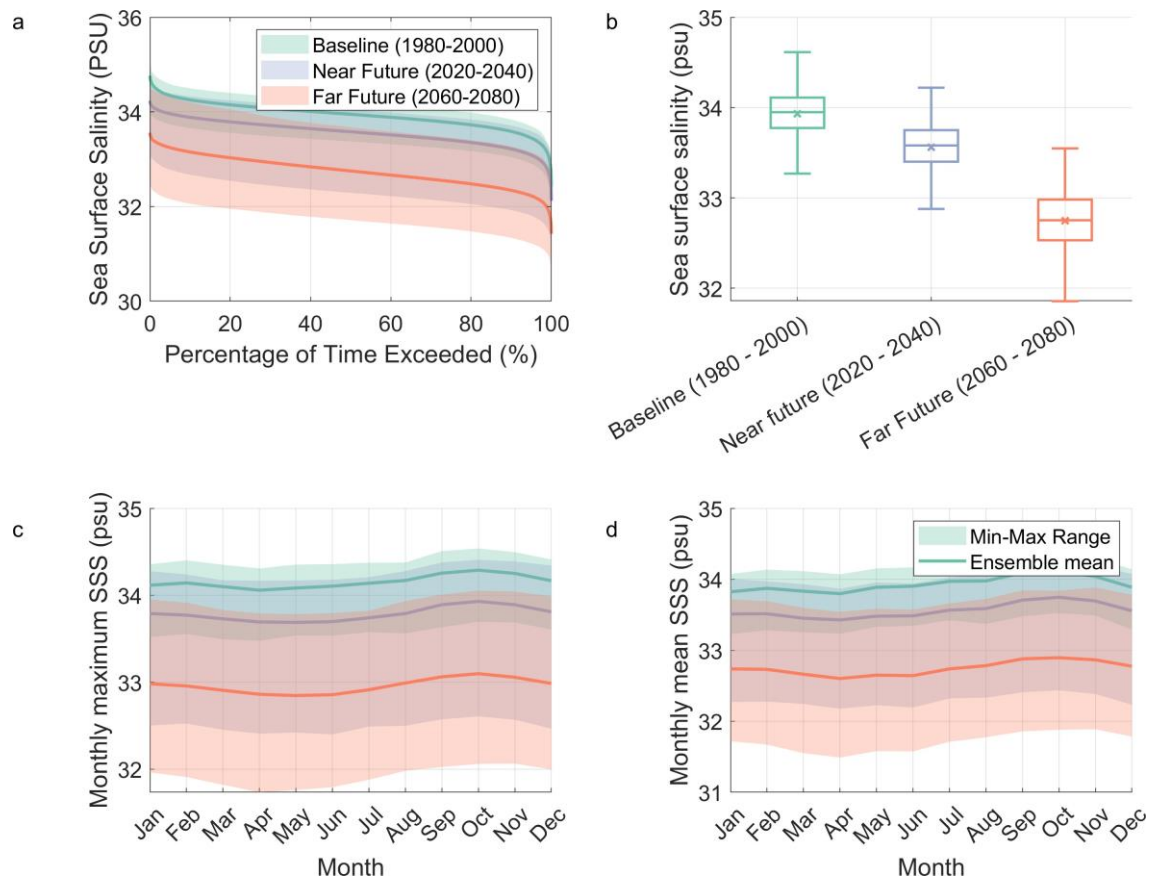


Figure description

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- (b) Percentile shifts show decreasing mean, median, and extremes, indicating a trend towards freshening over time.
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Section 3 - Residual surge changes

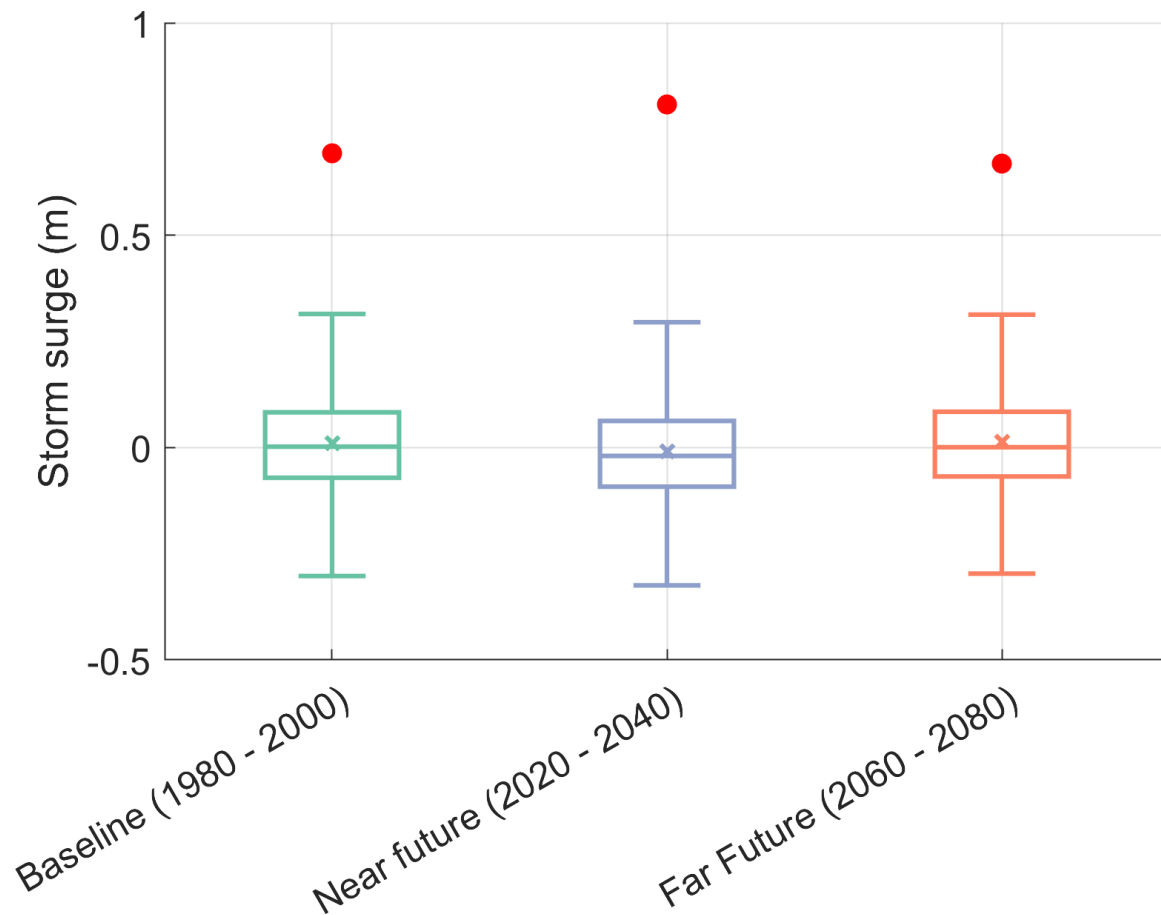


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

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Section 4 - River discharge changes

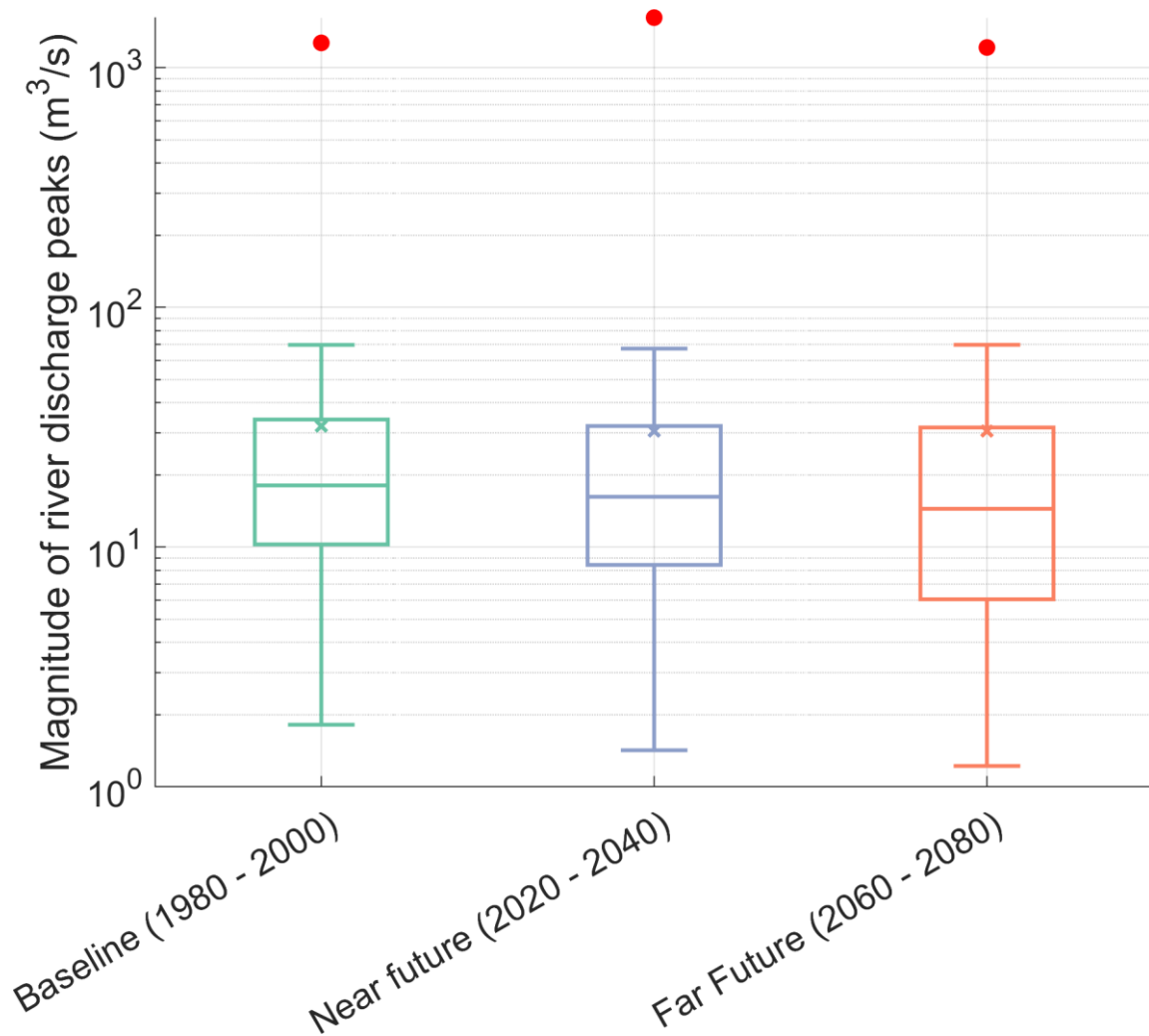


Figure description

Box and whisker plots of discharge percentiles under baseline (1980-2000), near-future (2020-2040) and far-future (2060-2080)

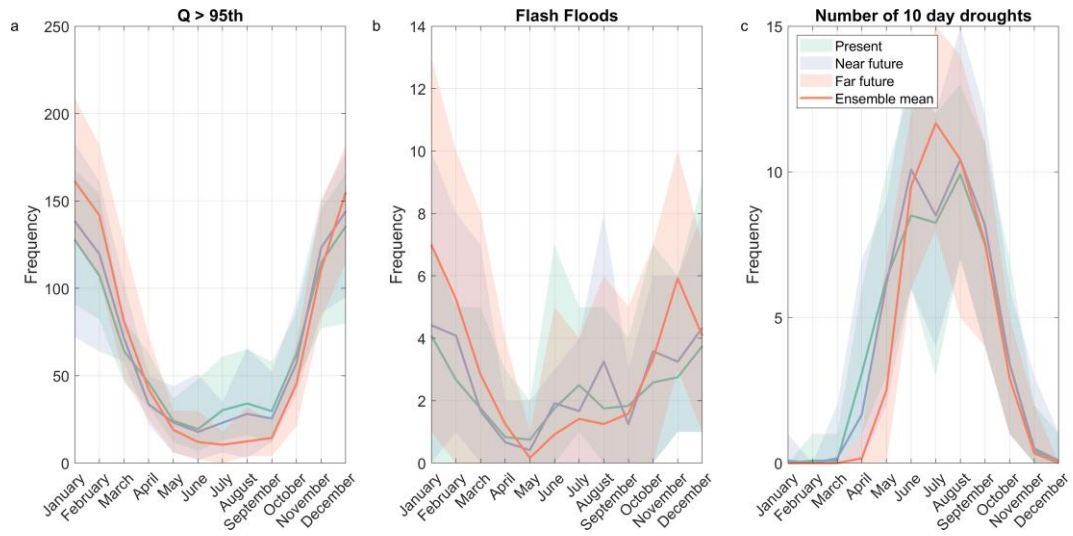


Figure description

Discharge conditions under baseline (1980-2000), near-future (2020-2040) and far-future (2060-2080) showing frequency of (a): Occurrence of high flow (>95th percentile events) per month (hourly resolution), (b): Flash flood events (increase in discharge of >50 m³/s, (c): low flow events lasting longer than 10 days).

Section 5 - Residence times changes

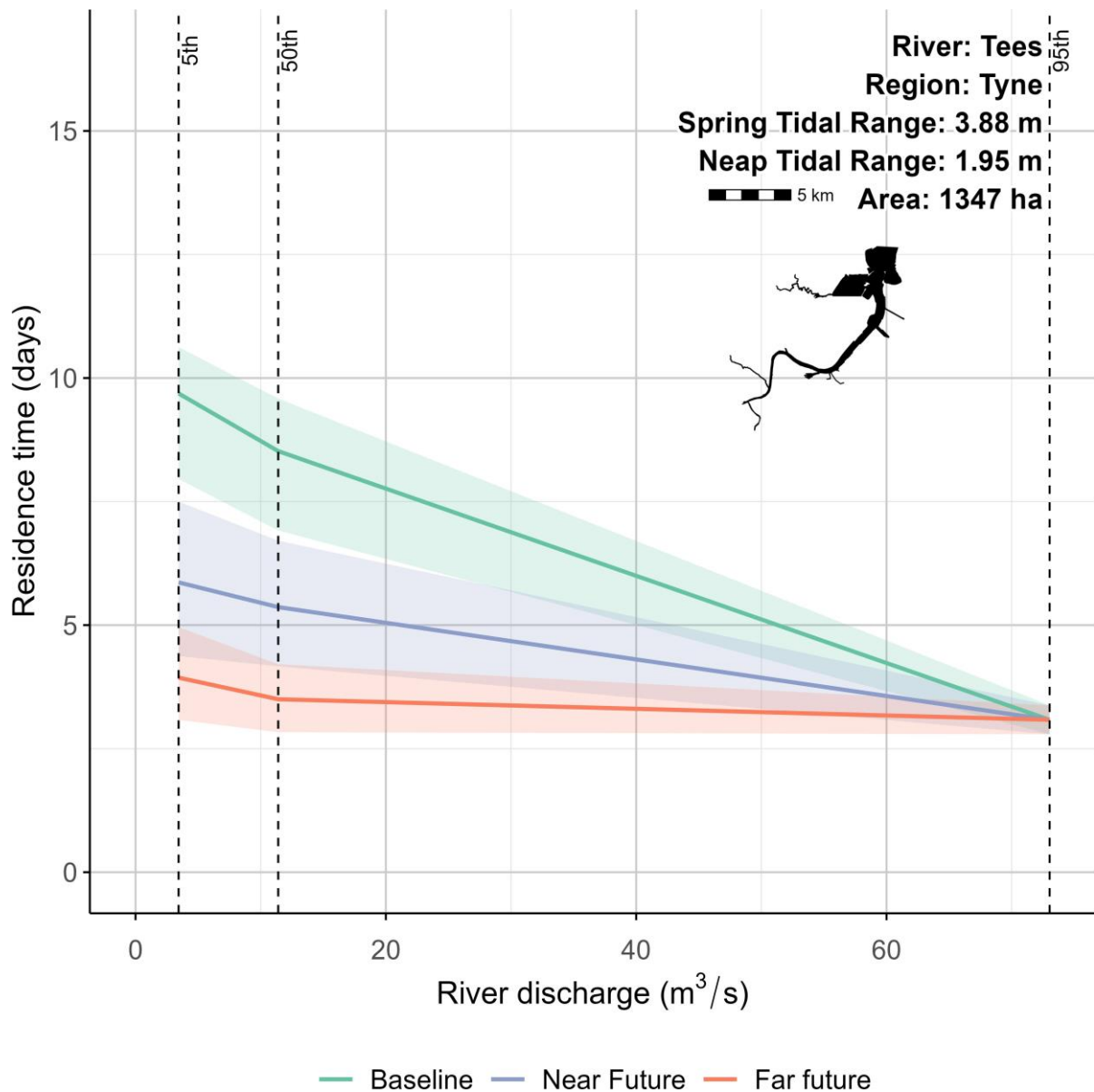


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)
Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Thames

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	51.454549
Longitude	0.434195
Tidal Range	5.4 m
Gauge Name	Kingston
Estuary Size	211000000.0 m ²
5th percentile flow	7.58 m ³ /s
50th percentile flow	40.3 m ³ /s
95th percentile flow	217.4 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

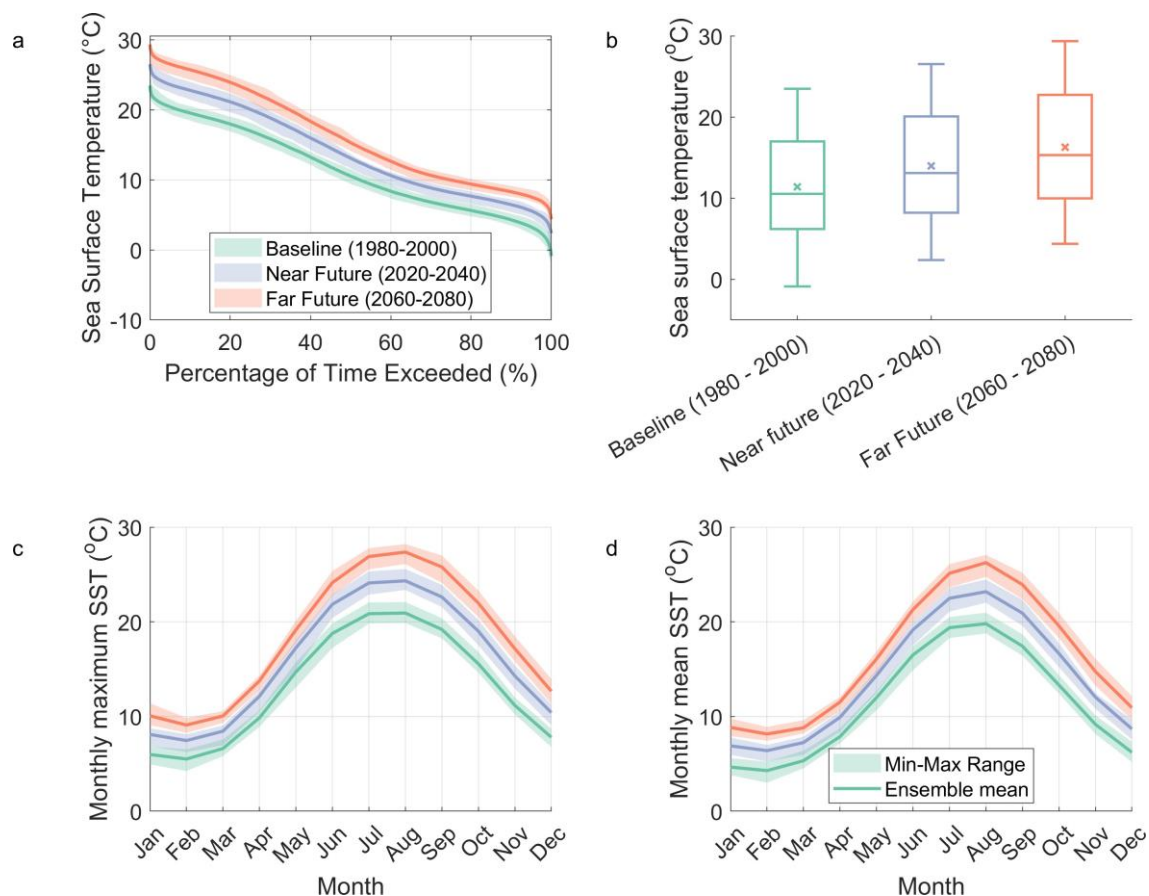
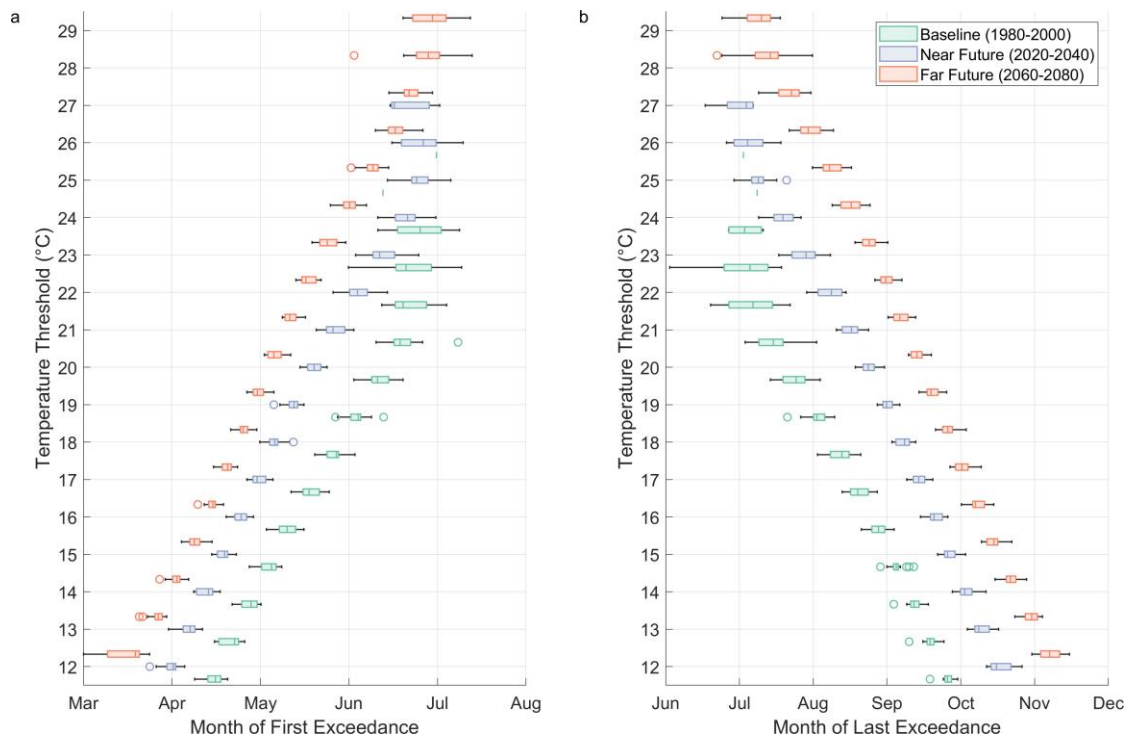


Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

- (a) Temperature duration curves represent distribution of SSTs over time to highlight changes in cold and warm extremes.
- (b) Percentile shifts show increasing mean, median, and extremes, indicating prolonged warming over time.
- (c) Rising monthly maximum in every month of the year highlights likelihood of intensified high heat events.
- (d) Rising monthly mean suggests long-term climate-driven warming.



Changes in first and last occurrences of temperature thresholds compared to historical data. Note that these plots are not intended to identify the specific date on which a temperature may occur, rather they indicate the trend in the onset of specific temperature thresholds.



Projected temperature changes under different climate scenarios. Box and whisker plots show the range of different modelled durations of temperatures under the 12 different UKCP 18 ensemble members. Open circles indicate outlier values.

Section 2 - Sea surface salinity changes

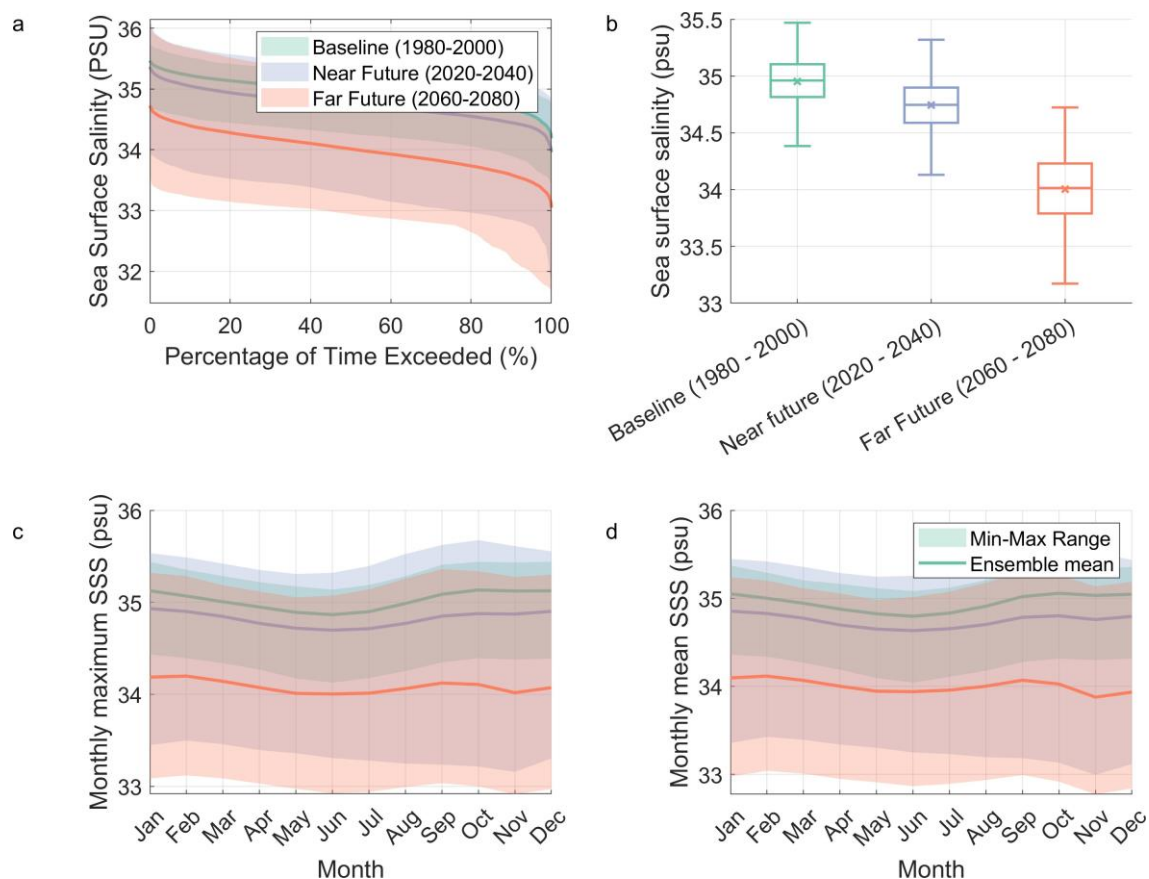


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
- (b) Percentile shifts show decreasing mean, median, and extremes, indicating a trend towards freshening over time.
- (c) Monthly maxima decrease across all months.
- (d) Decreasing monthly means suggest long-term ice-melt driven freshening.

Section 3 - Residual surge changes

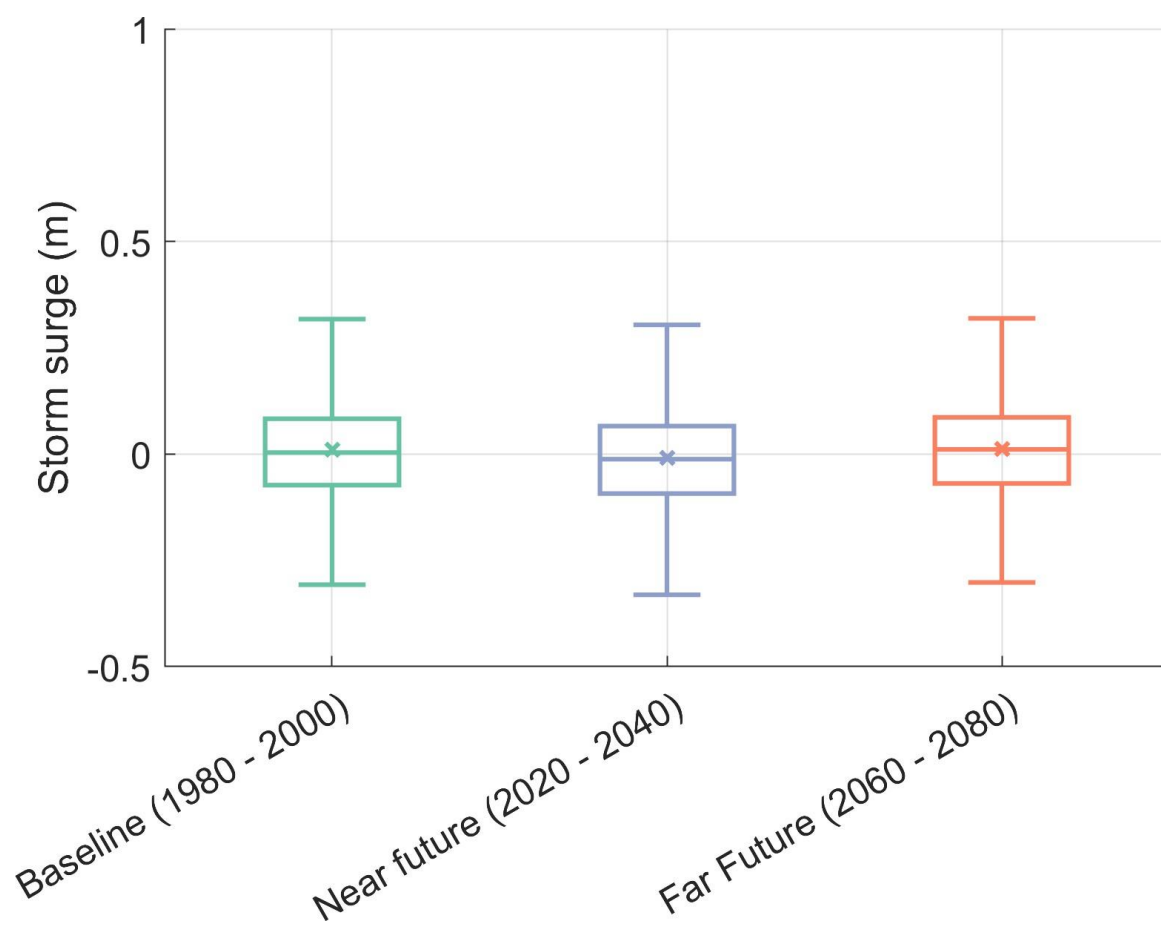


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

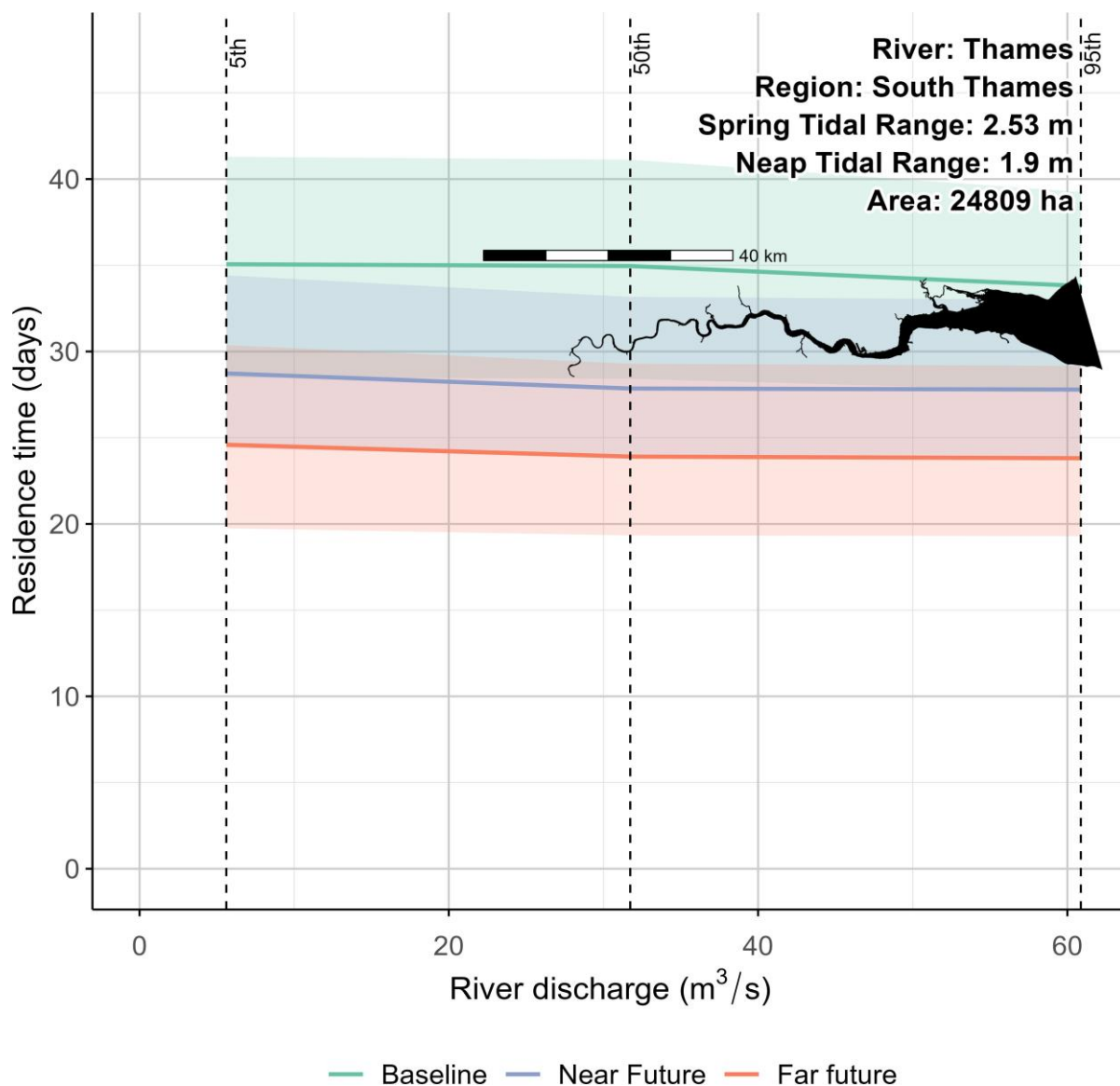


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)
Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Tweed

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	55.72241
Longitude	-2.16344
Tidal Range	4.1 m
Gauge Name	Tweed at Norham
Estuary Size	797000.0 m ²
5th percentile flow	14.34 m ³ /s
50th percentile flow	53.11 m ³ /s
95th percentile flow	245.3 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

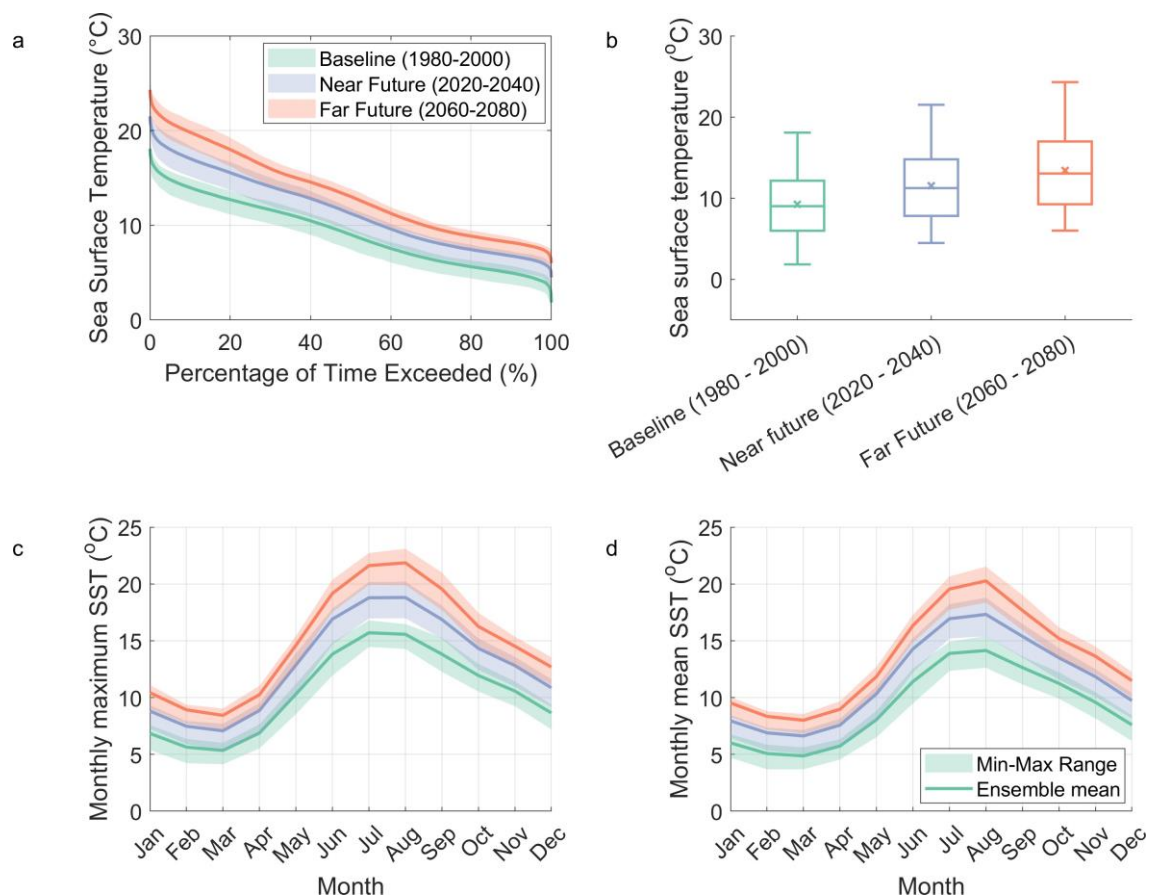
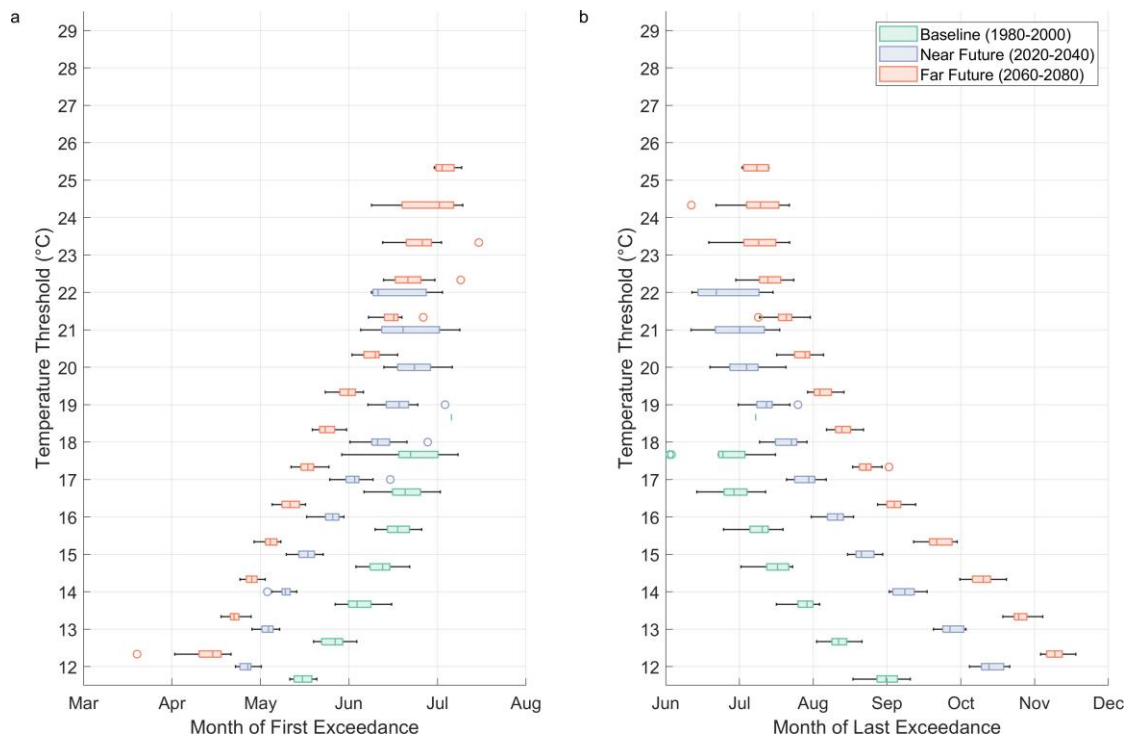


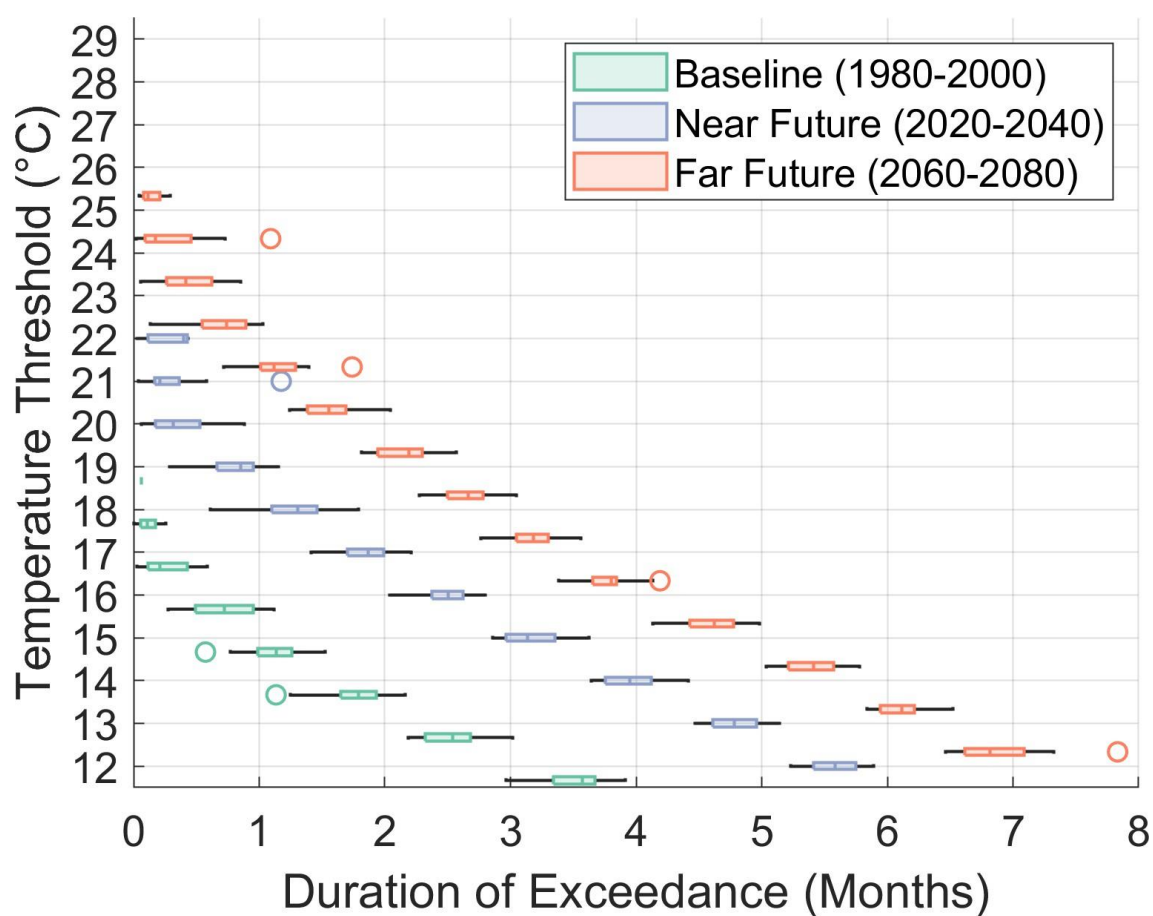
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

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Section 2 - Sea surface salinity changes

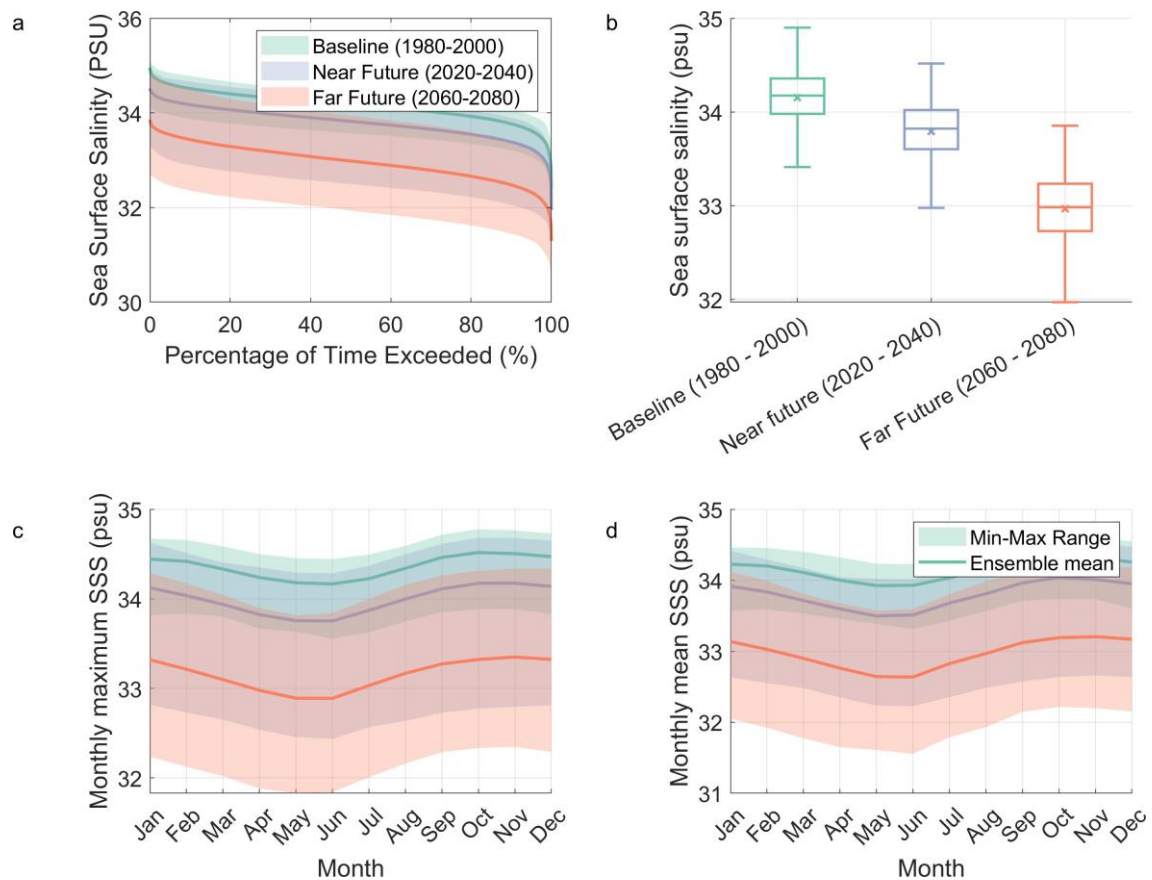


Figure description

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Section 3 - Residual surge changes

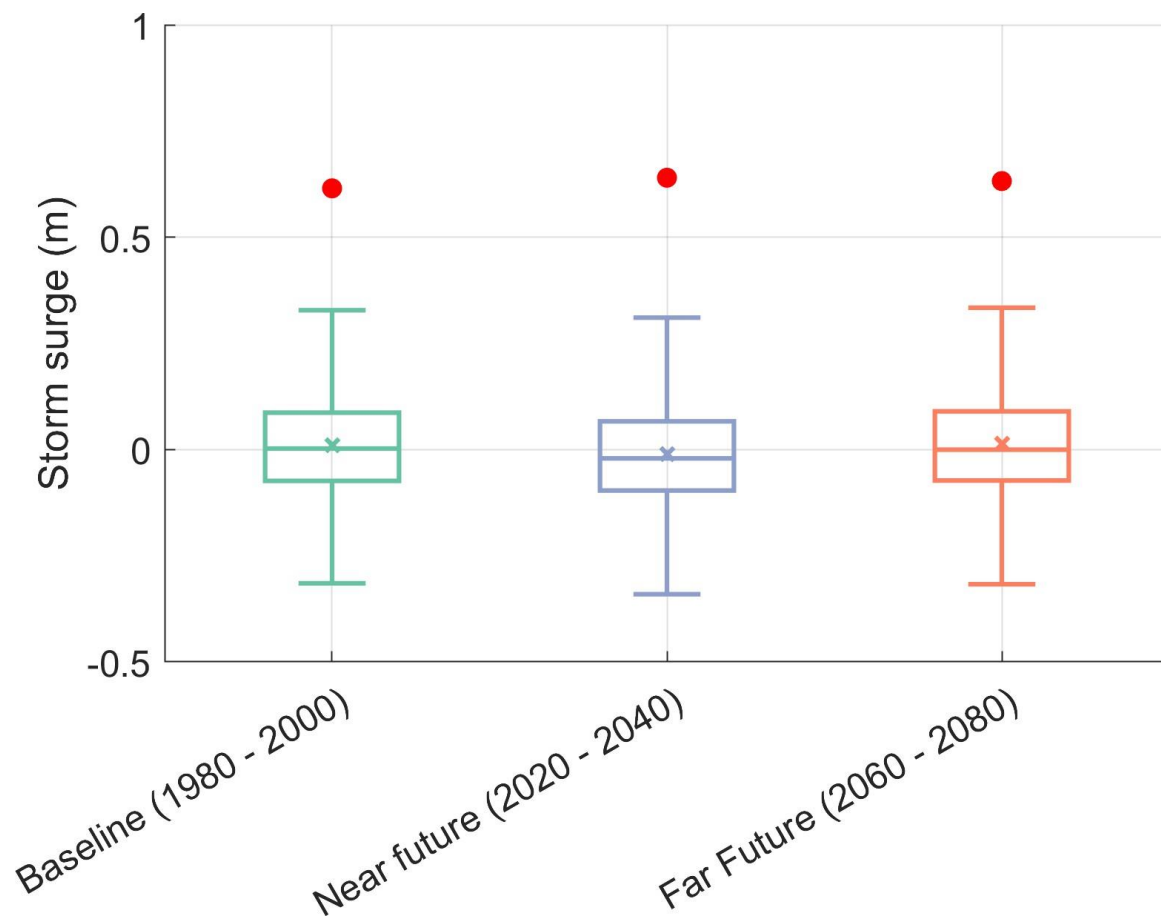


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

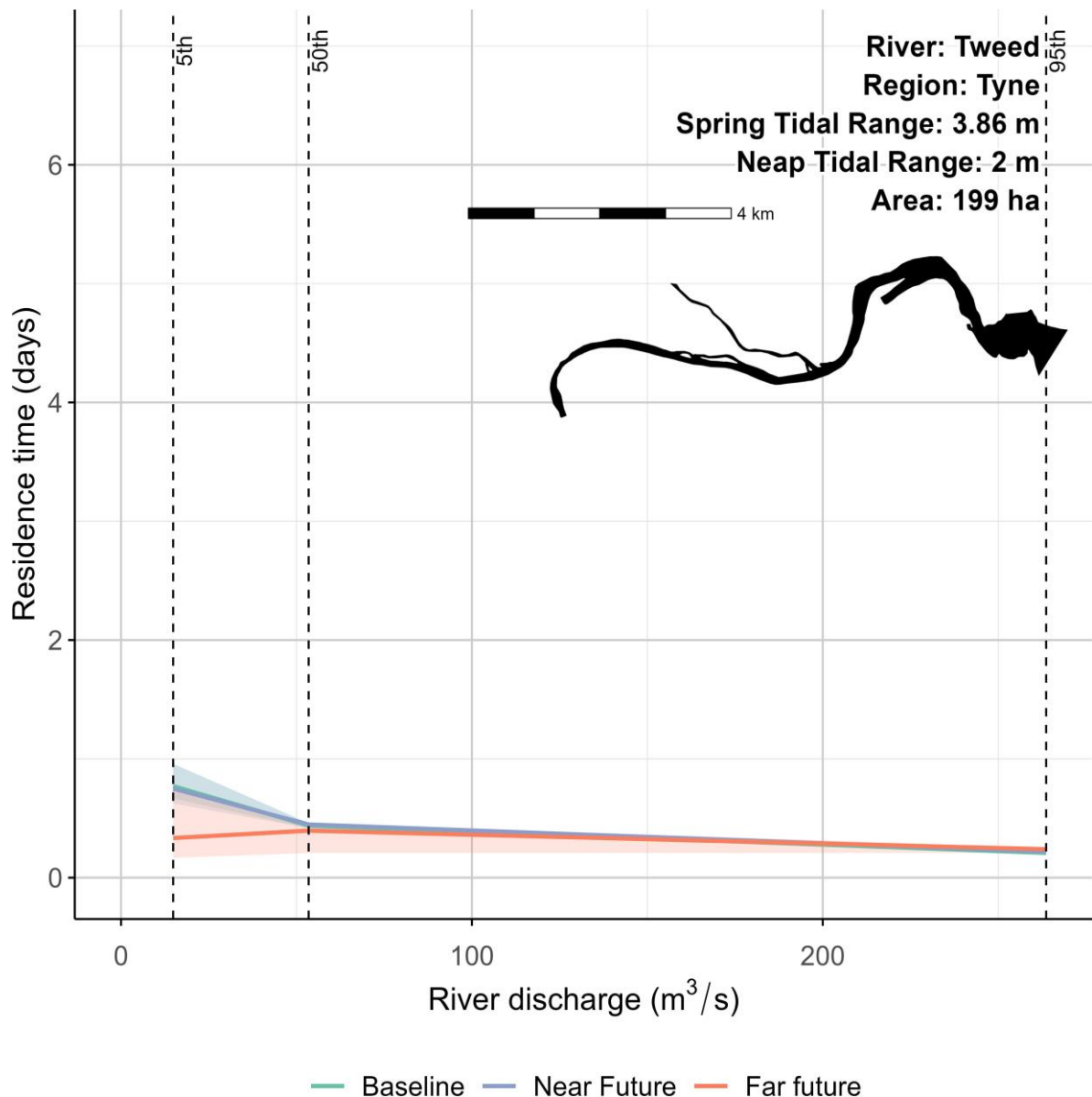


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

Tyne

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	54.95112
Longitude	-1.94082
Tidal Range	4.3 m
Gauge Name	Tyne at Bywell
Estuary Size	7440000.0 m ²
5th percentile flow	6.102 m ³ /s
50th percentile flow	25.7 m ³ /s
95th percentile flow	152.0 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

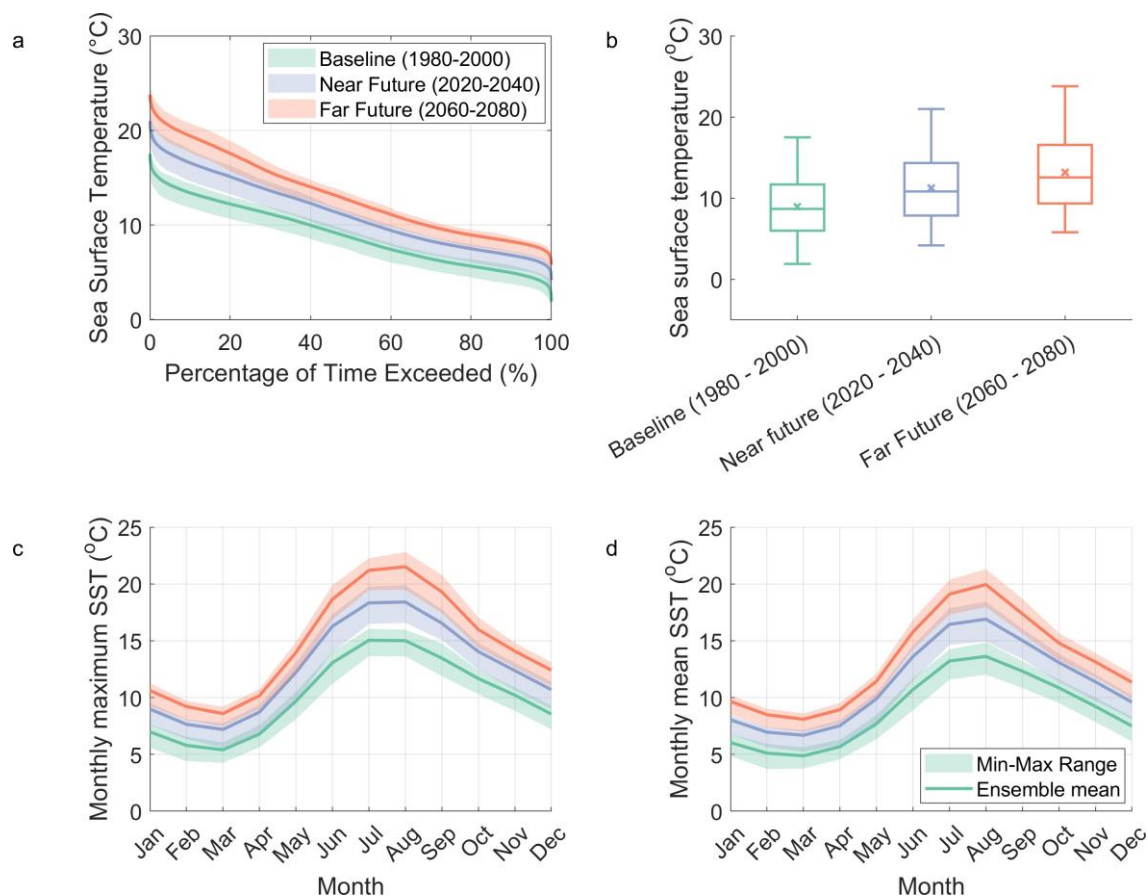
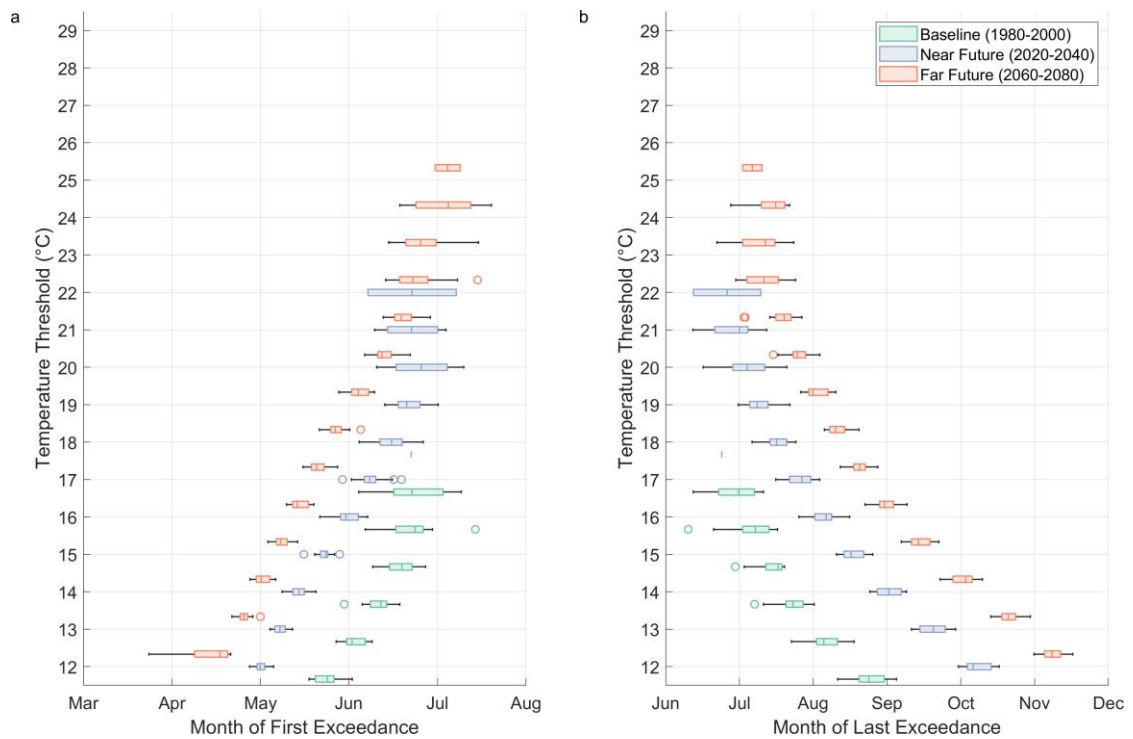


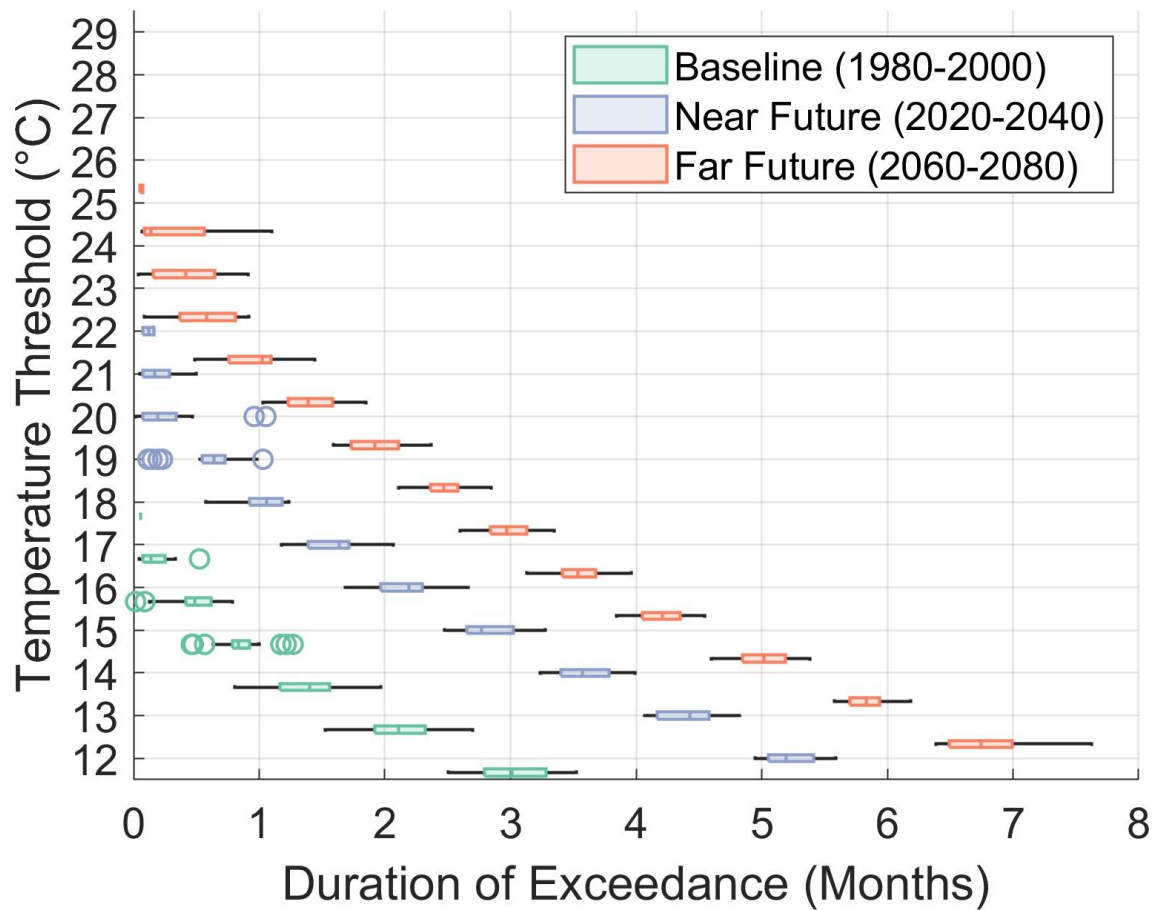
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

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Section 2 - Sea surface salinity changes

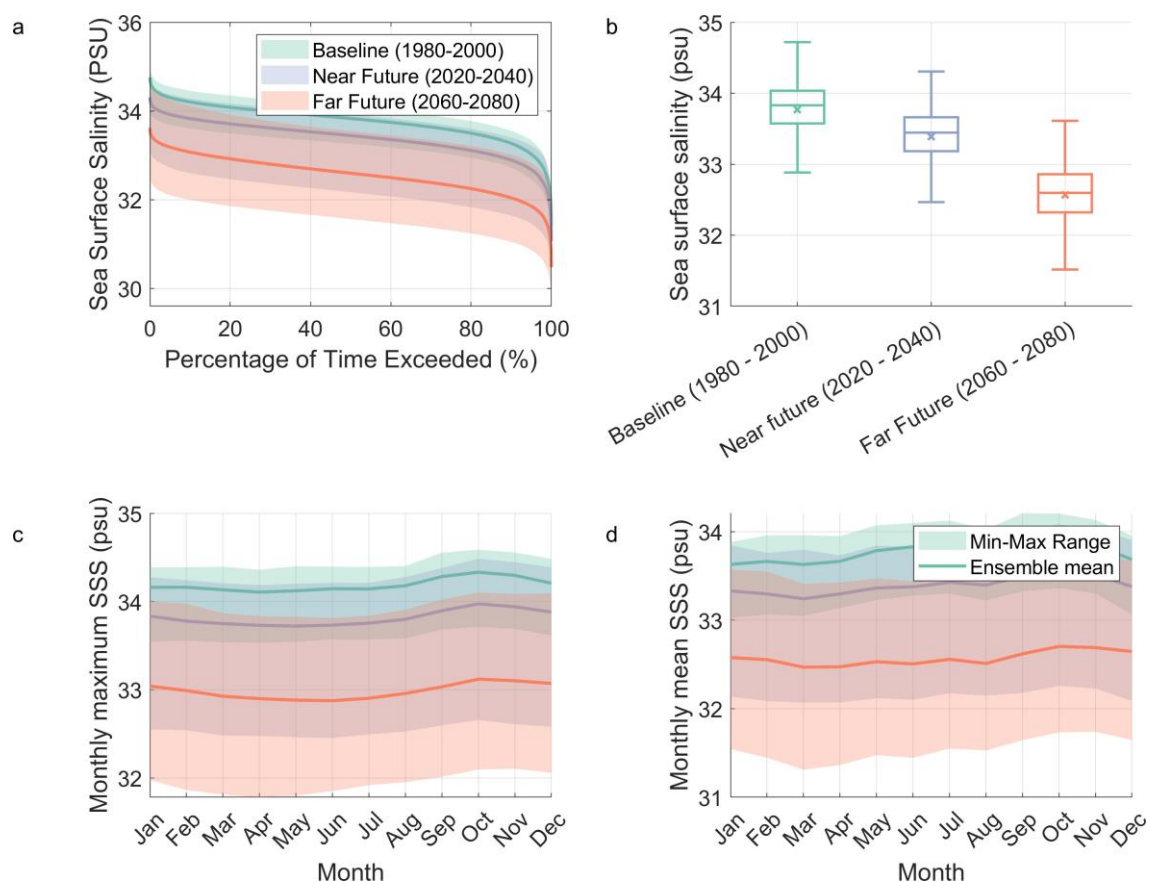


Figure description

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Section 3 - Residual surge changes

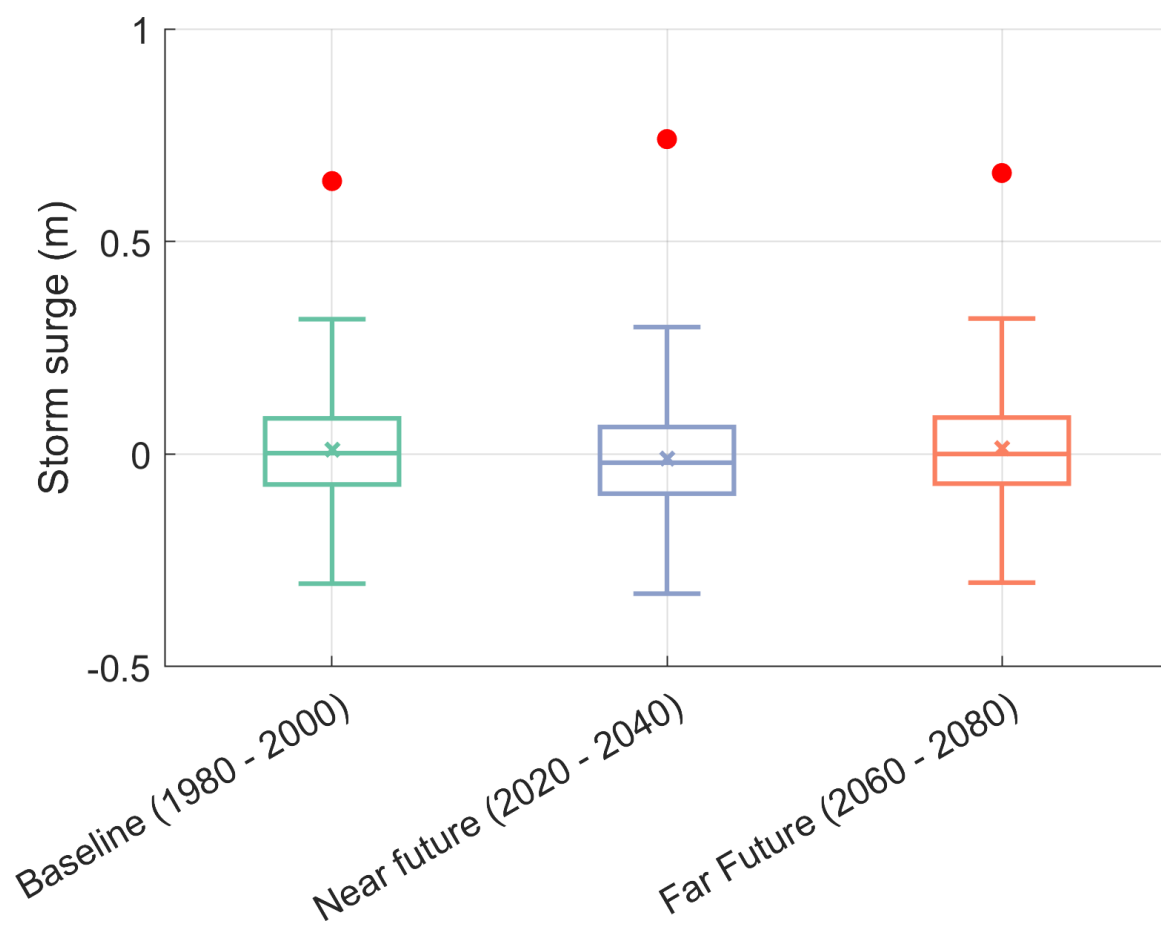


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

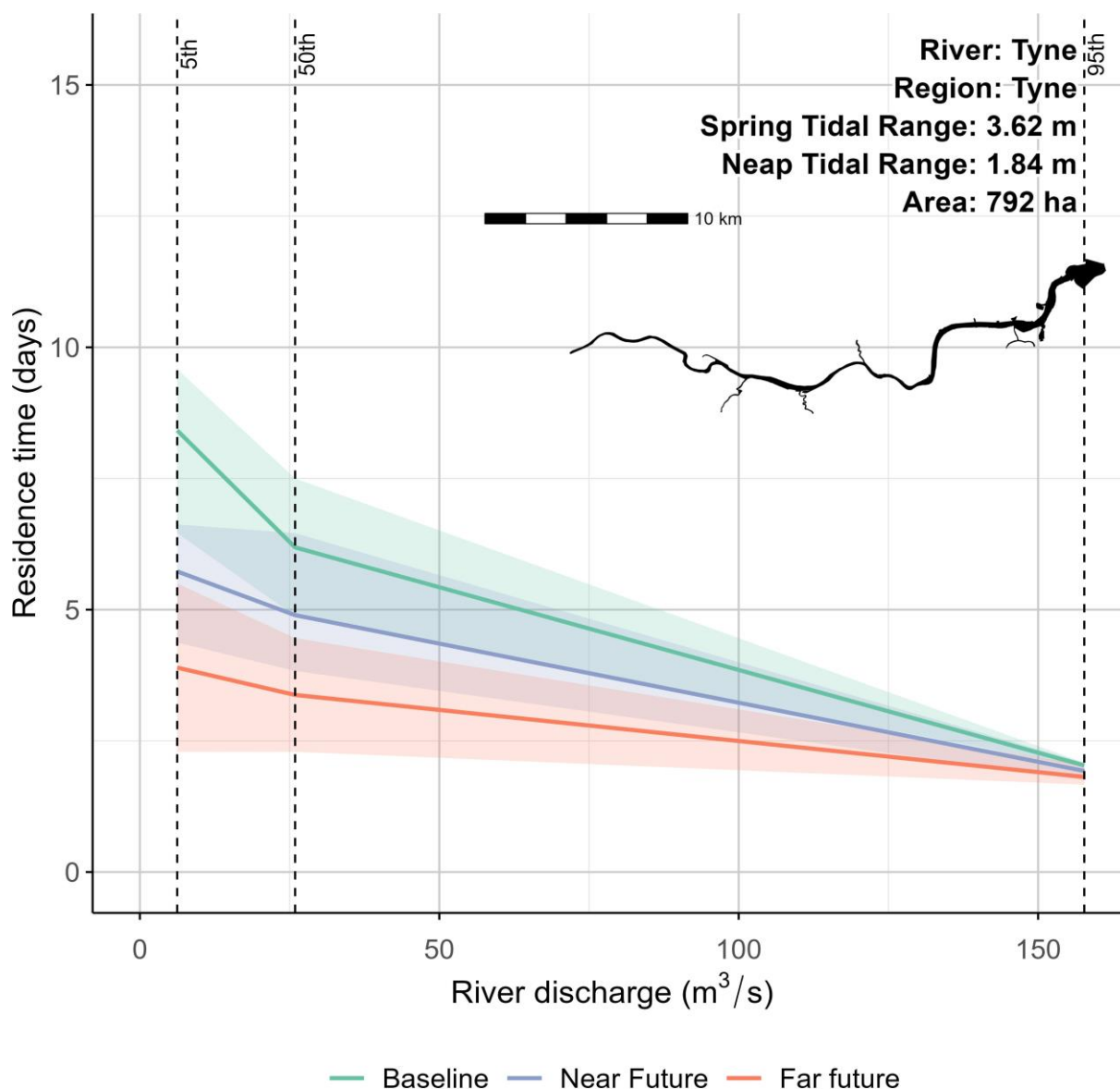


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

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Wansbeck

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	55.16614
Longitude	-1.72768
Tidal Range	4.2 m
Gauge Name	Wansbeck at Mitford
Estuary Size	45200.0 m ²
5th percentile flow	0.238 m ³ /s
50th percentile flow	1.3 m ³ /s
95th percentile flow	11.8 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

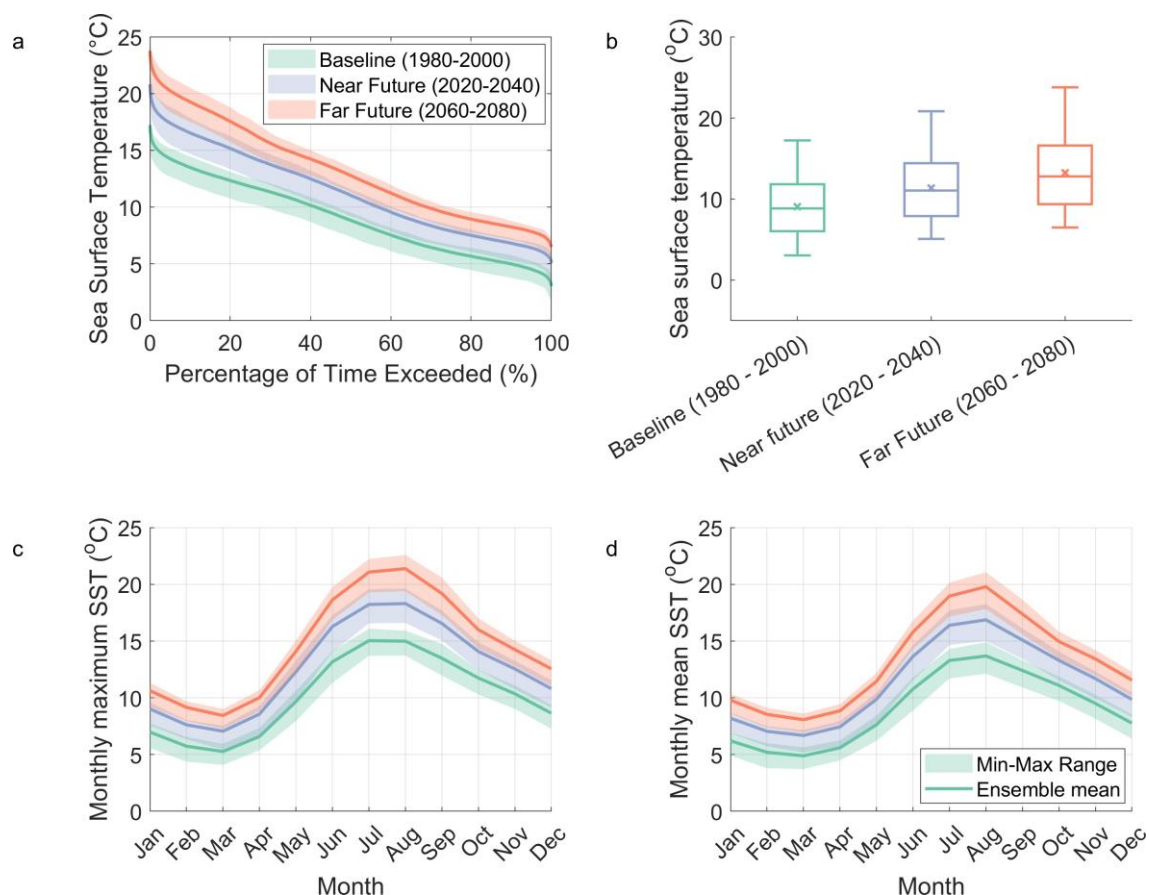
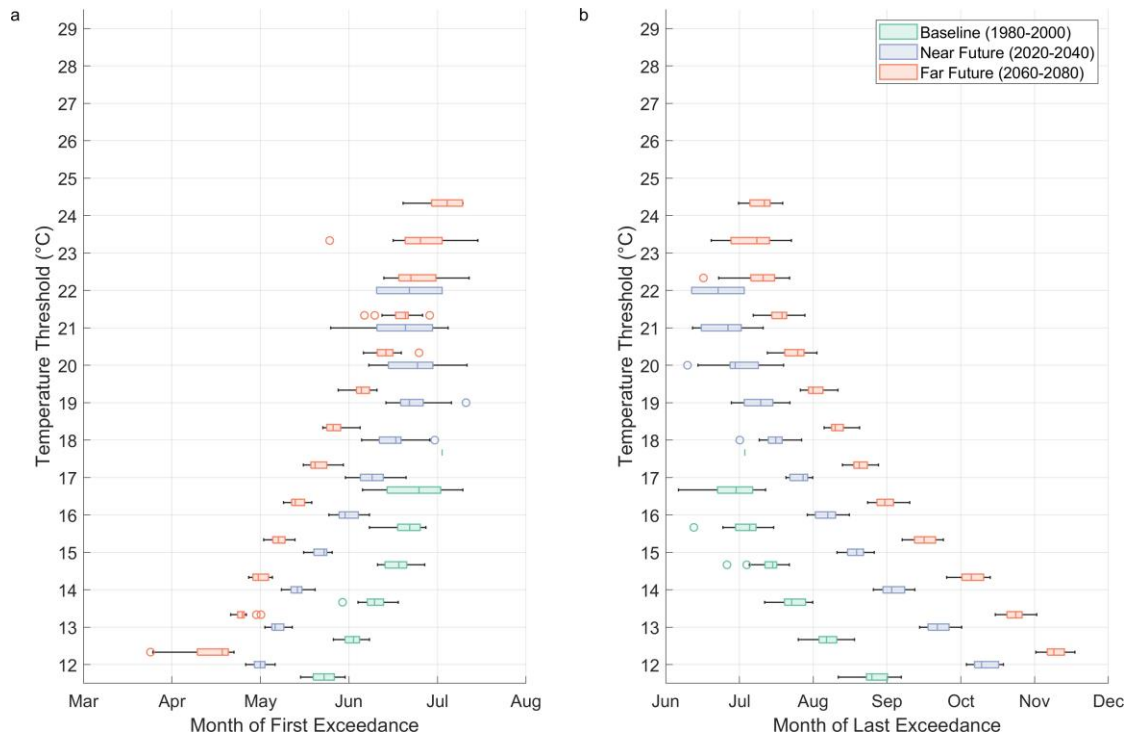


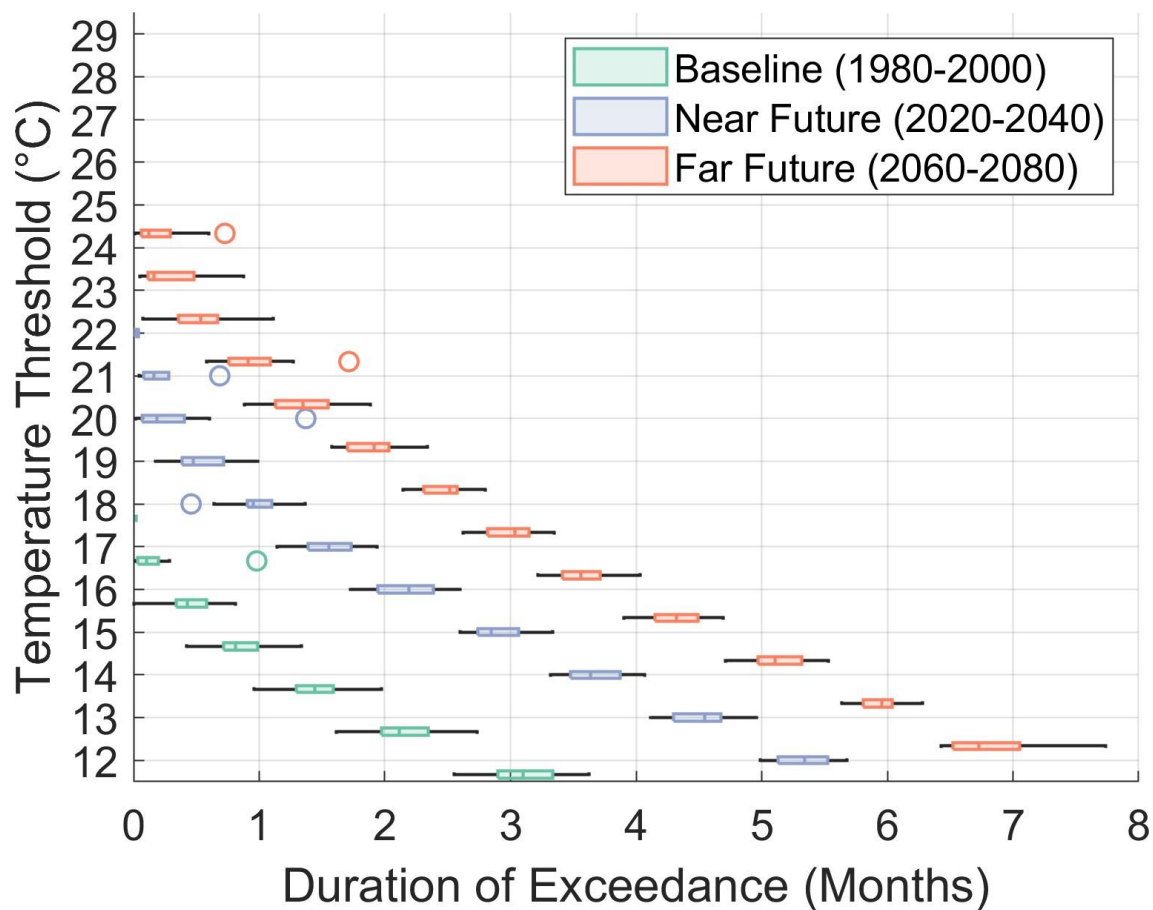
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

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Section 2 - Sea surface salinity changes

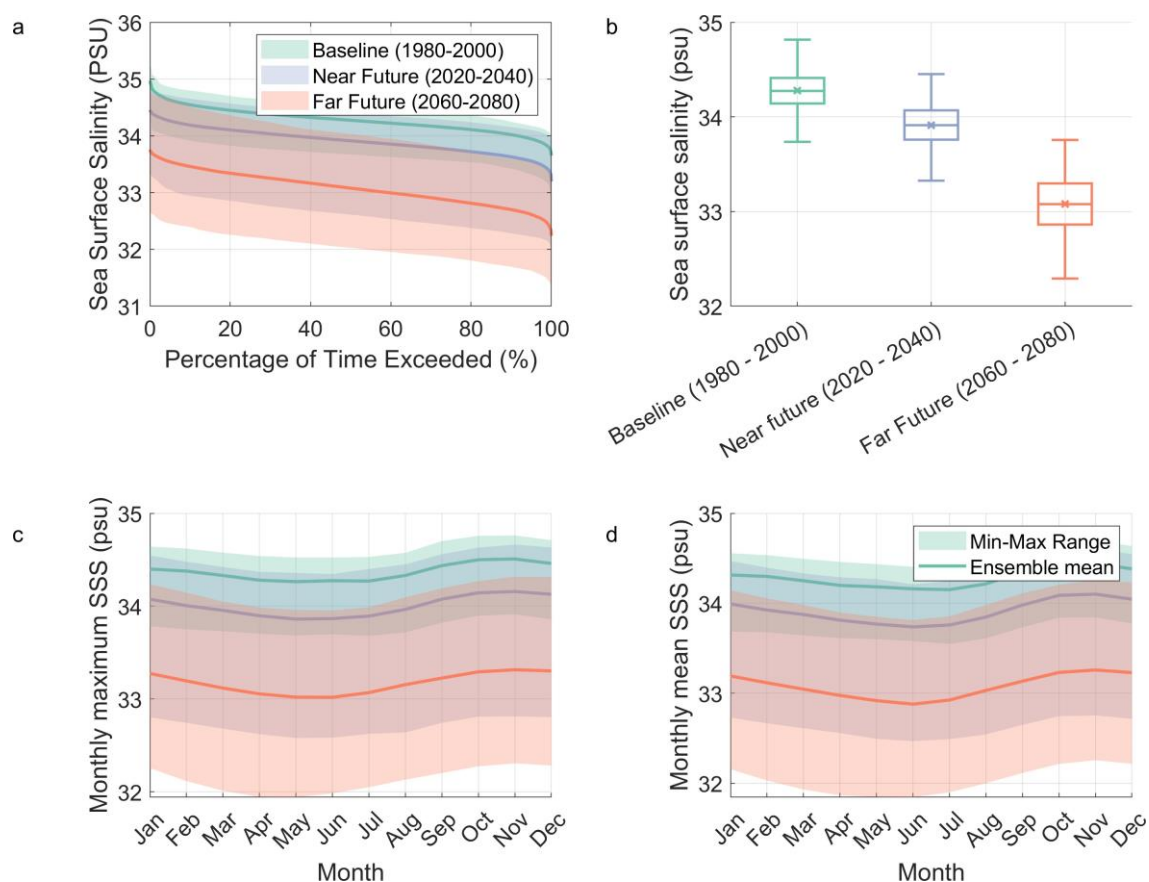


Figure description

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Section 3 - Residual surge changes

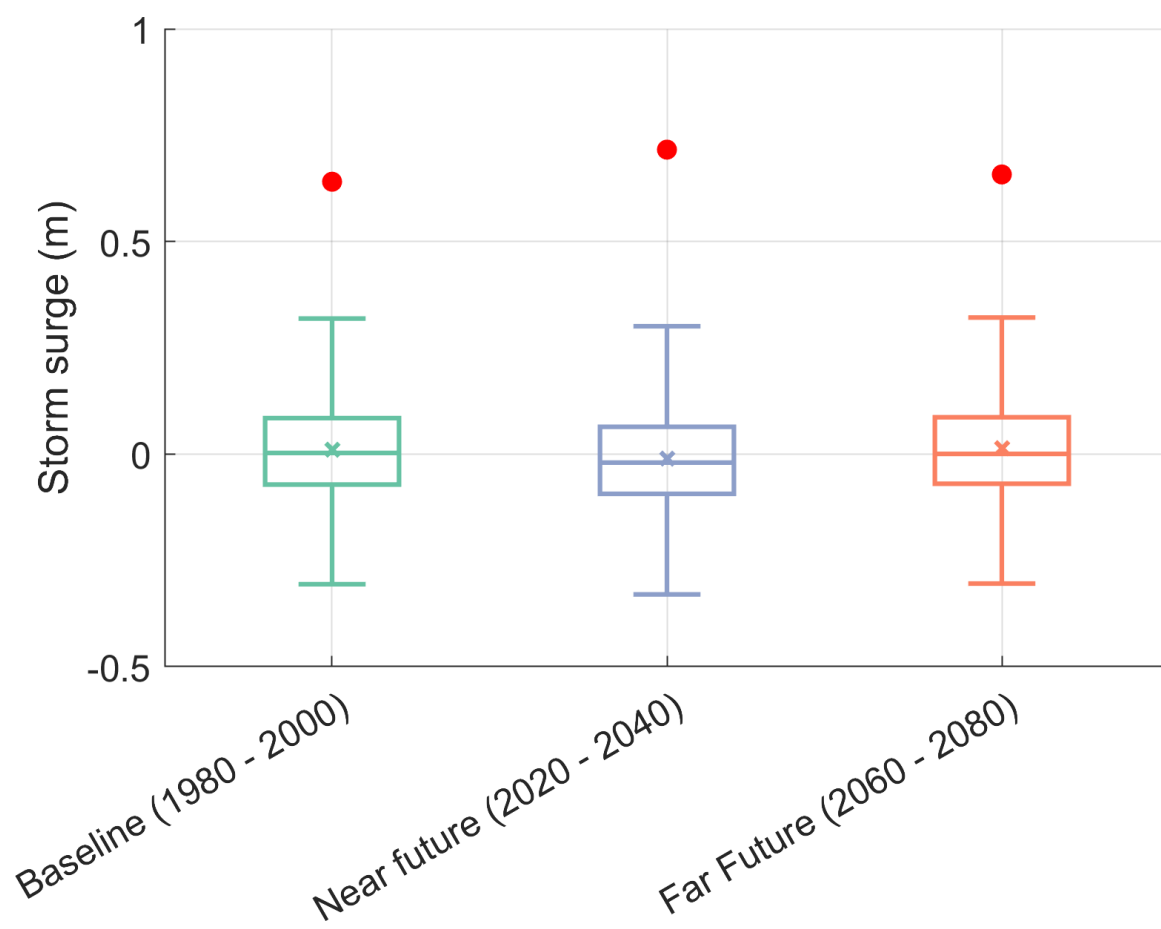


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

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Section 4 - Residence times changes

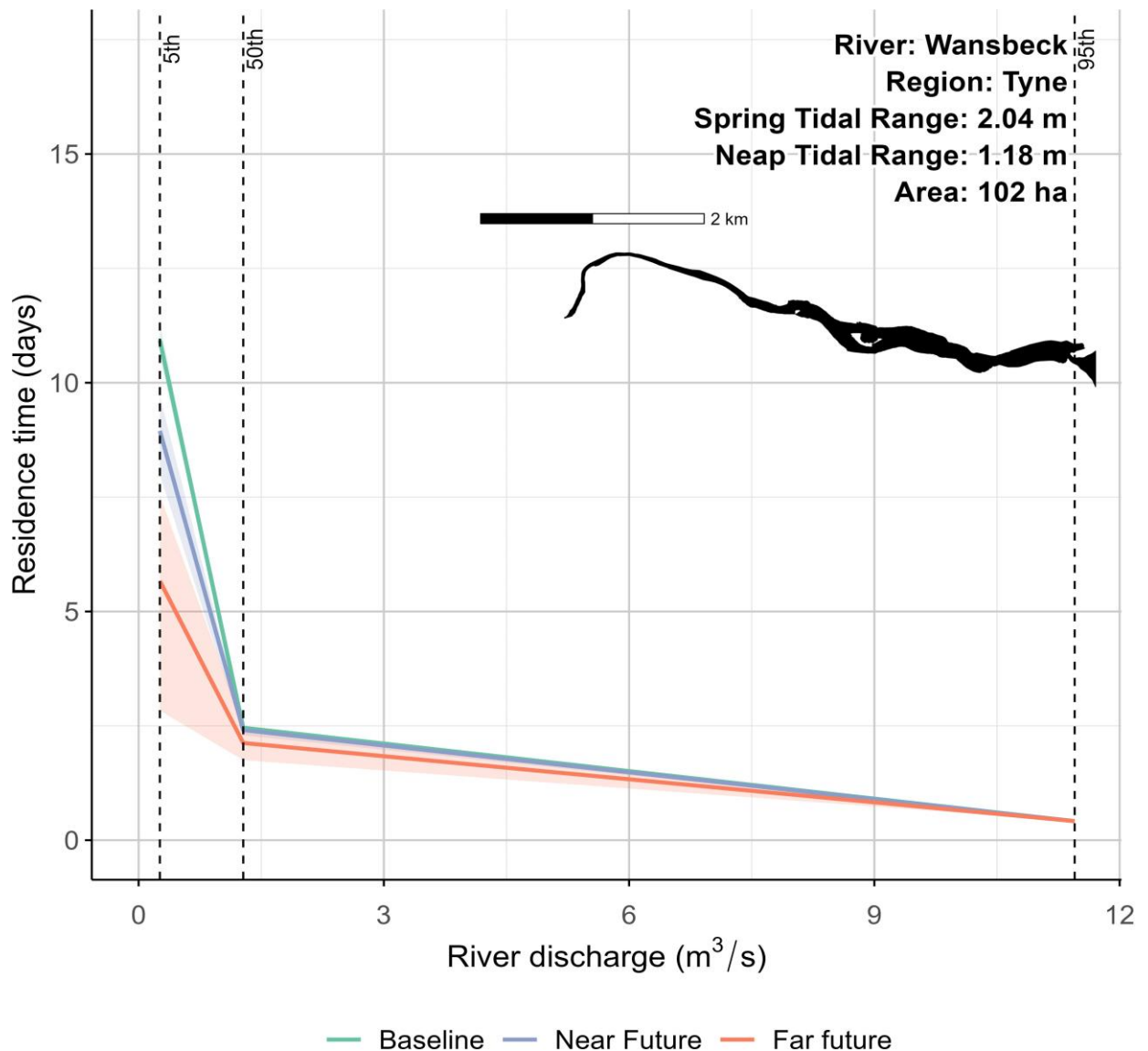


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

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Wear

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	54.85448
Longitude	-1.5608
Tidal Range	4.4 m
Gauge Name	Wear at Chester le Street
Estuary Size	1900000.0 m ²
5th percentile flow	3.152 m ³ /s
50th percentile flow	7.98 m ³ /s
95th percentile flow	49.16 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

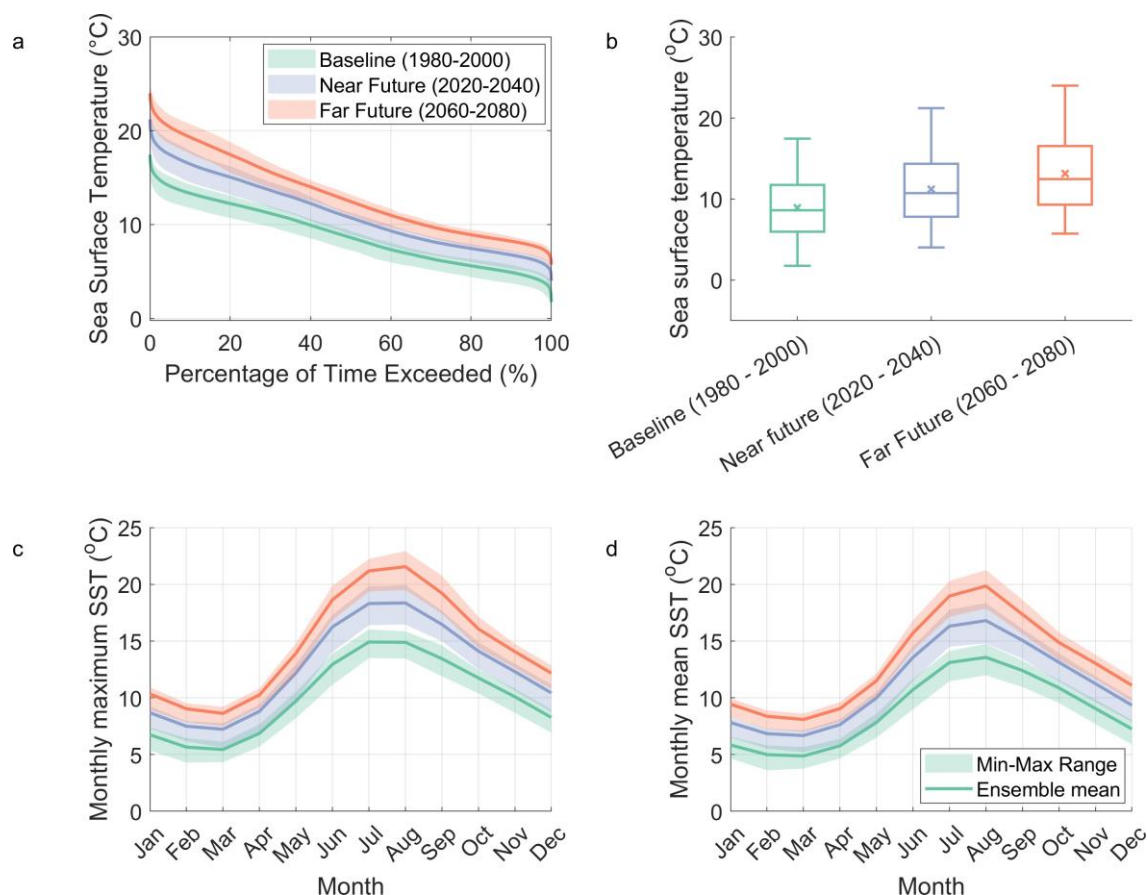
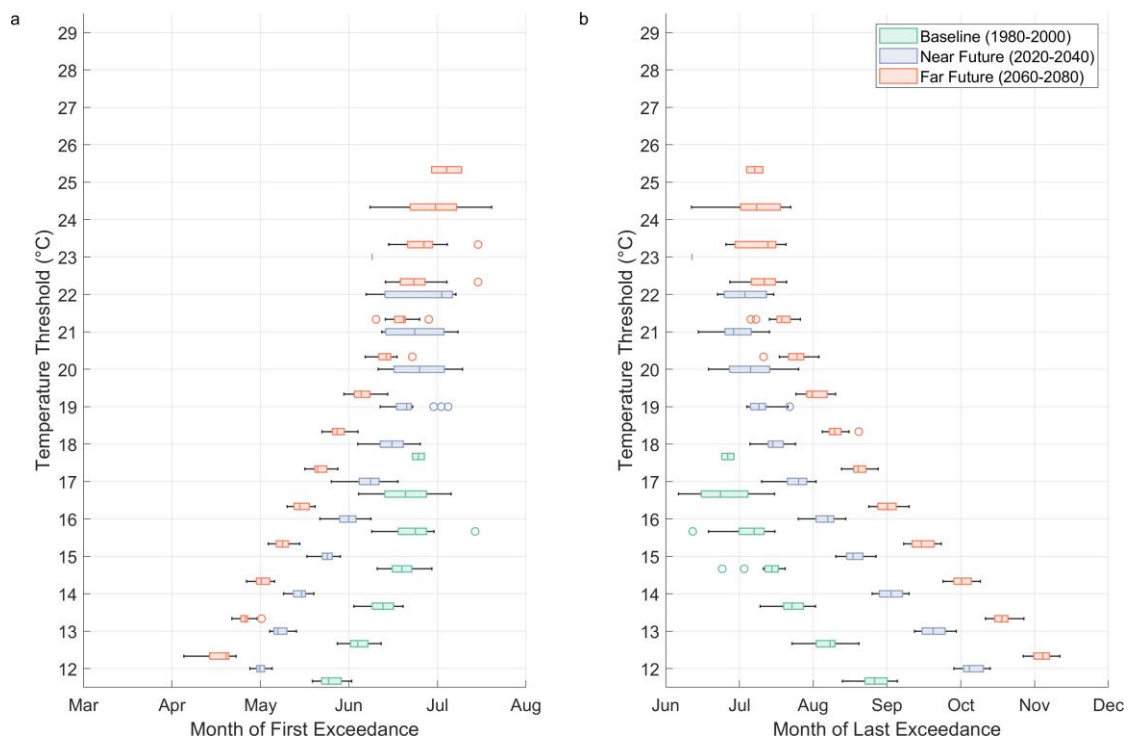


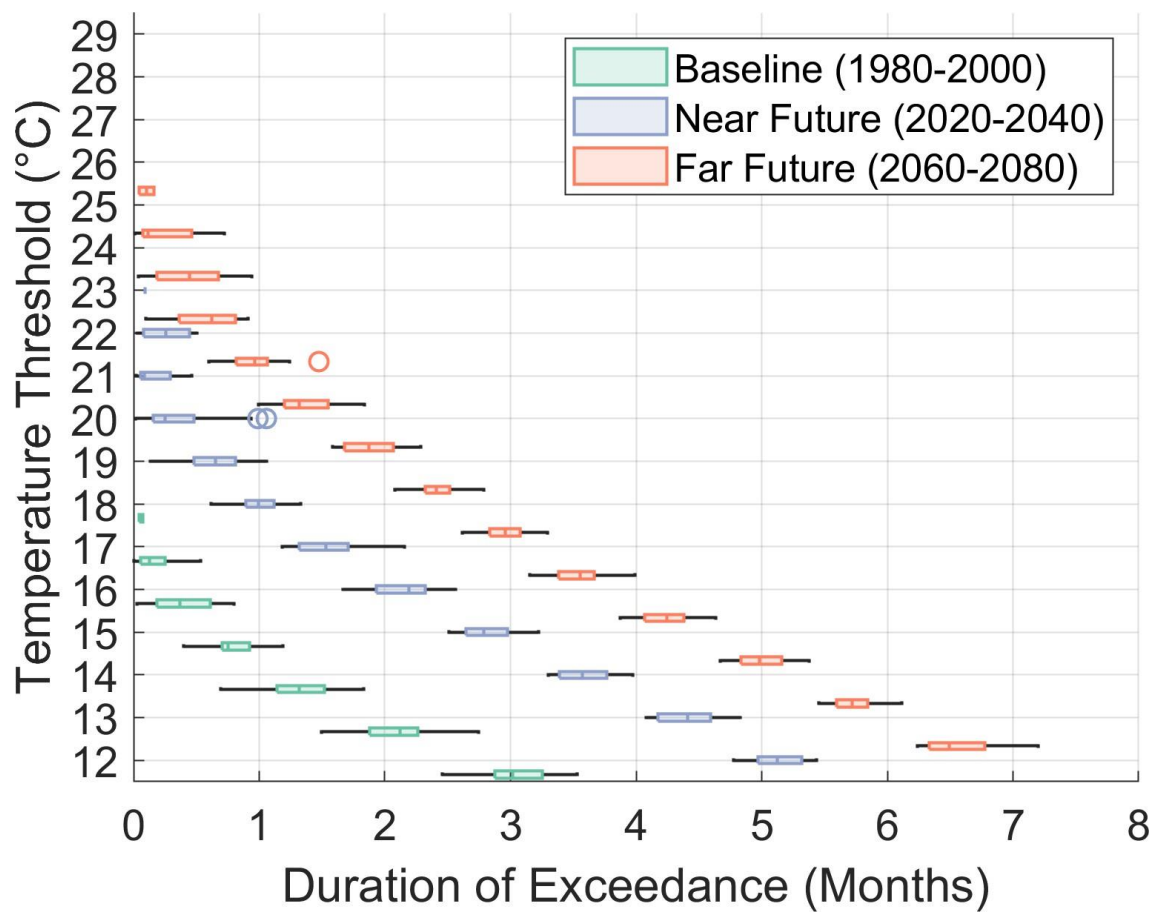
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Section 2 - Sea surface salinity changes

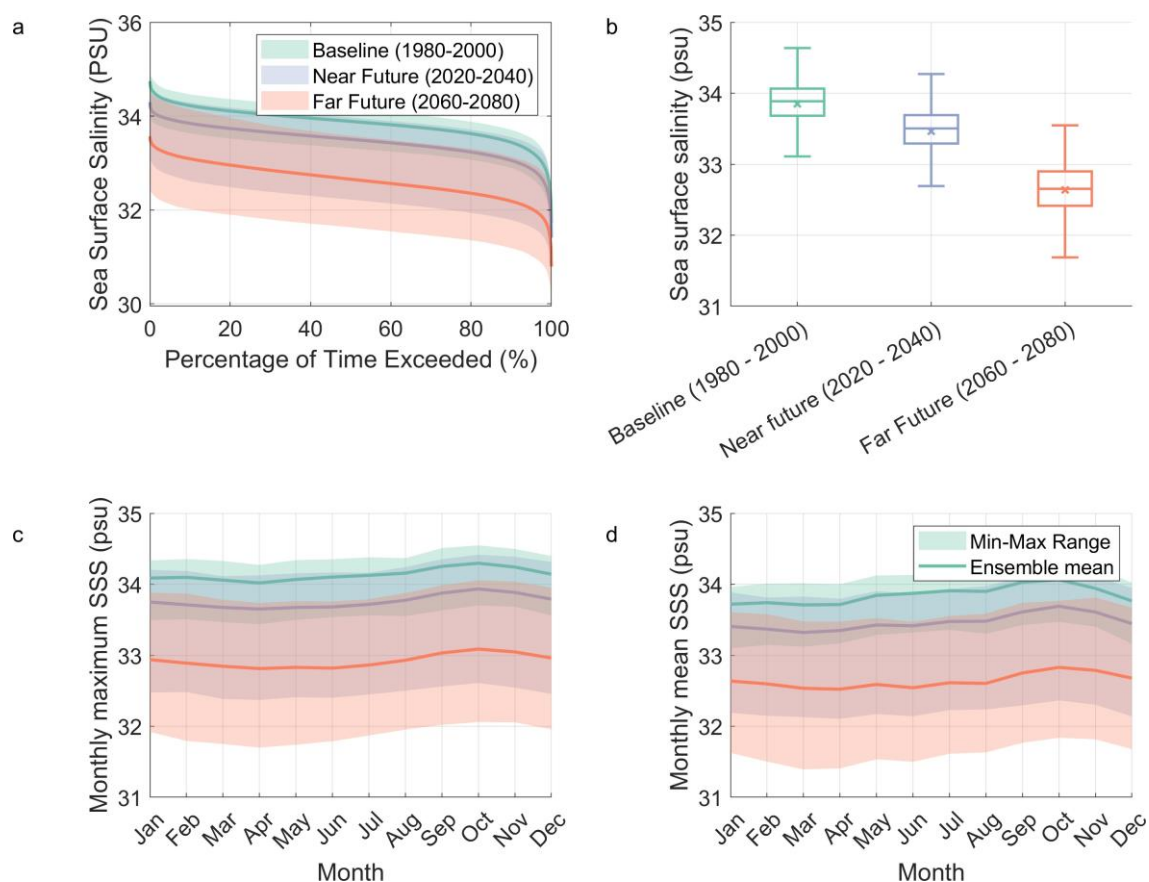


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Section 3 - Residual surge changes

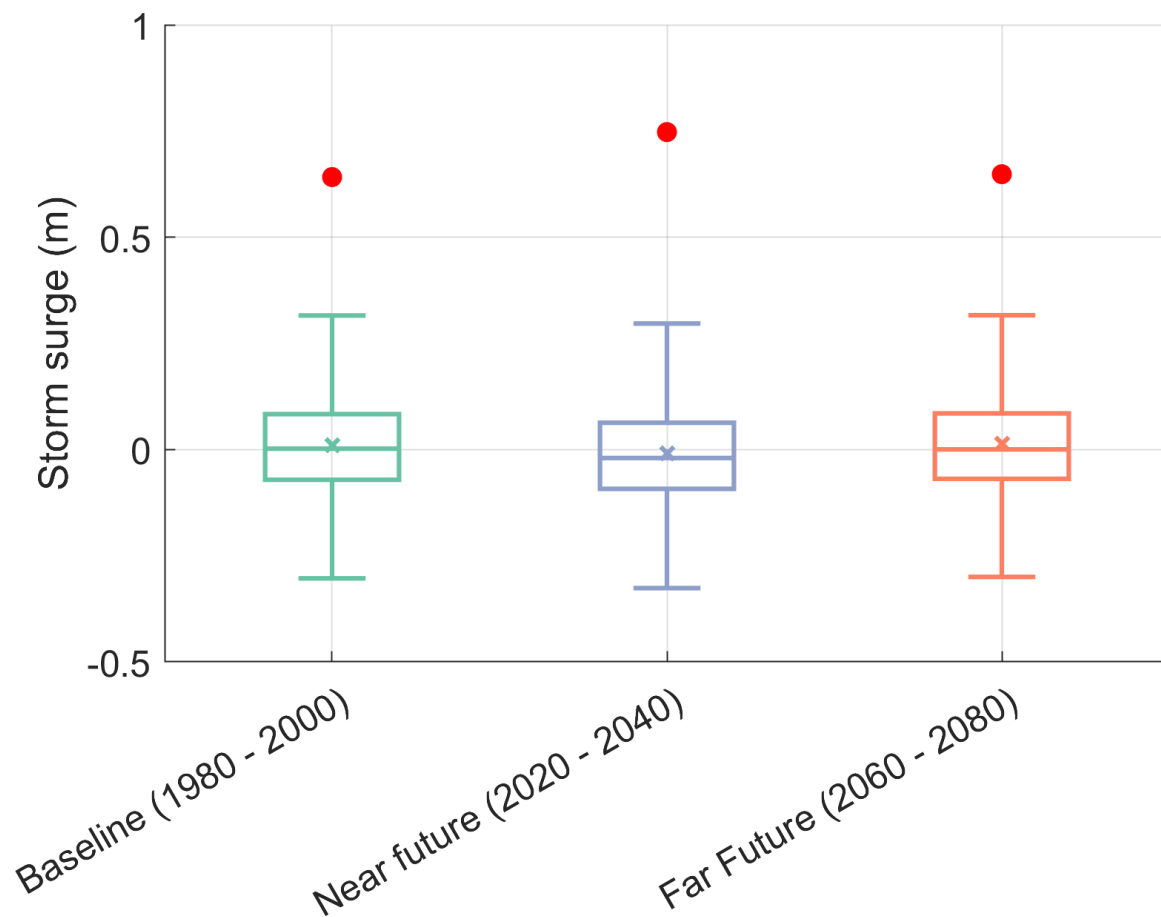


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

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Section 4 - Residence times changes

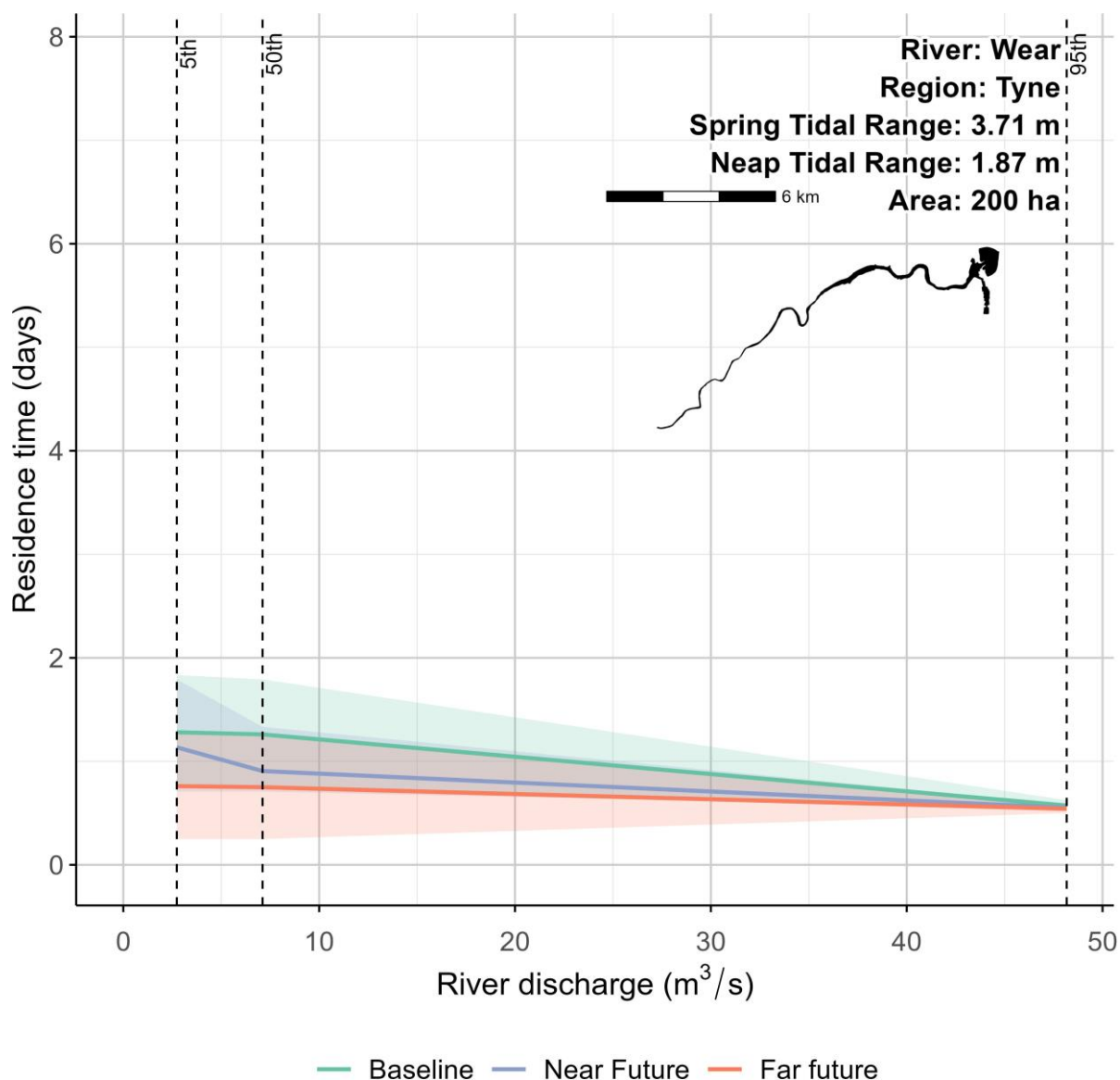


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Wensum

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	52.66837
Longitude	1.21906
Tidal Range	nan m
Gauge Name	Wensum at Costessey Mill
Estuary Size	nan m ²
5th percentile flow	1.36 m ³ /s
50th percentile flow	3.26 m ³ /s
95th percentile flow	9.65 m ³ /s
Notes	Not Listed on Estuarine Database Viewer

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

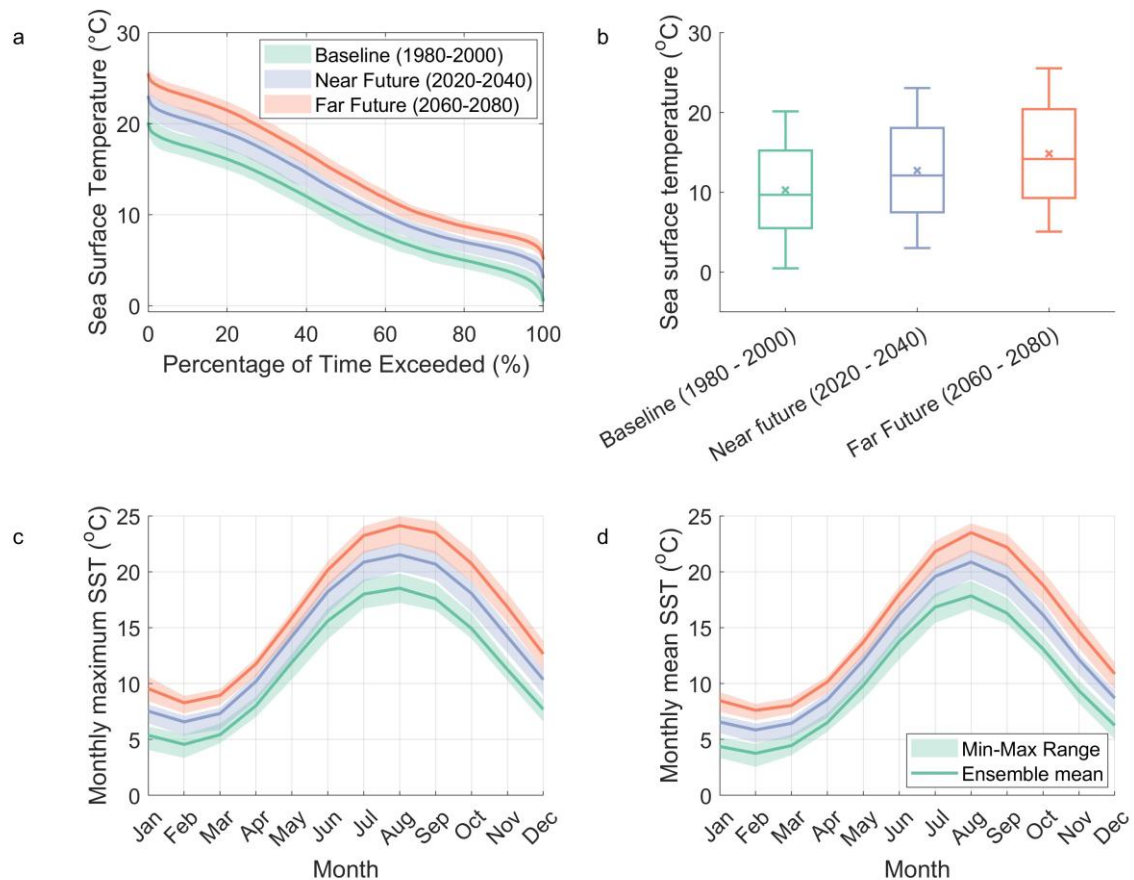
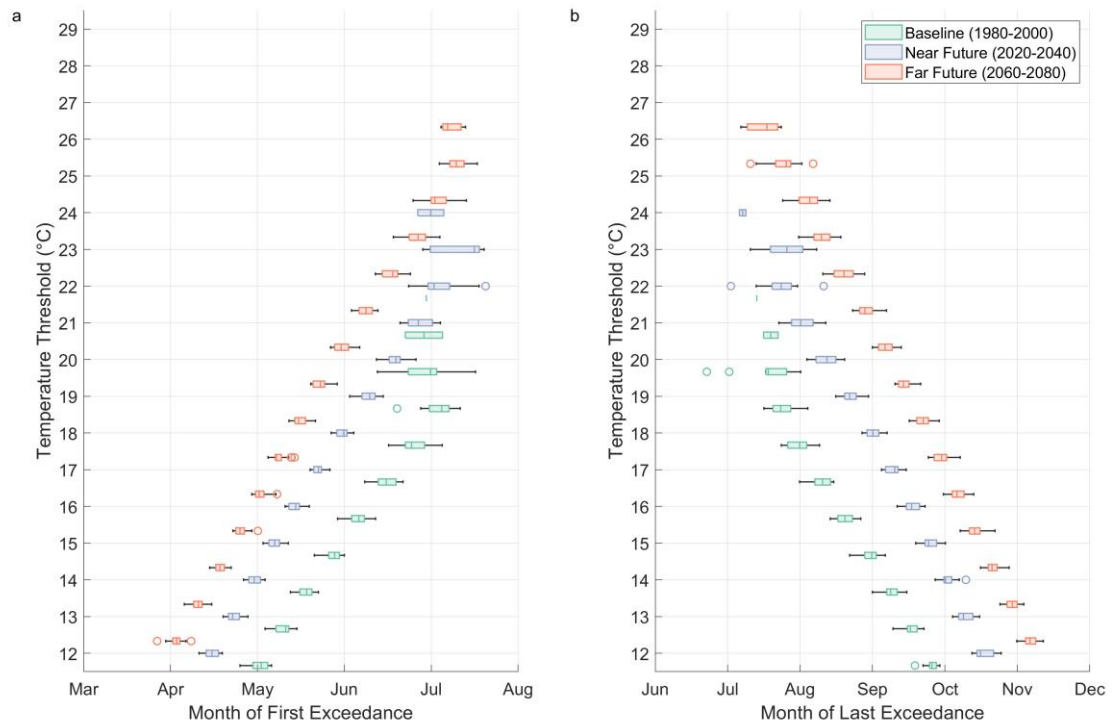


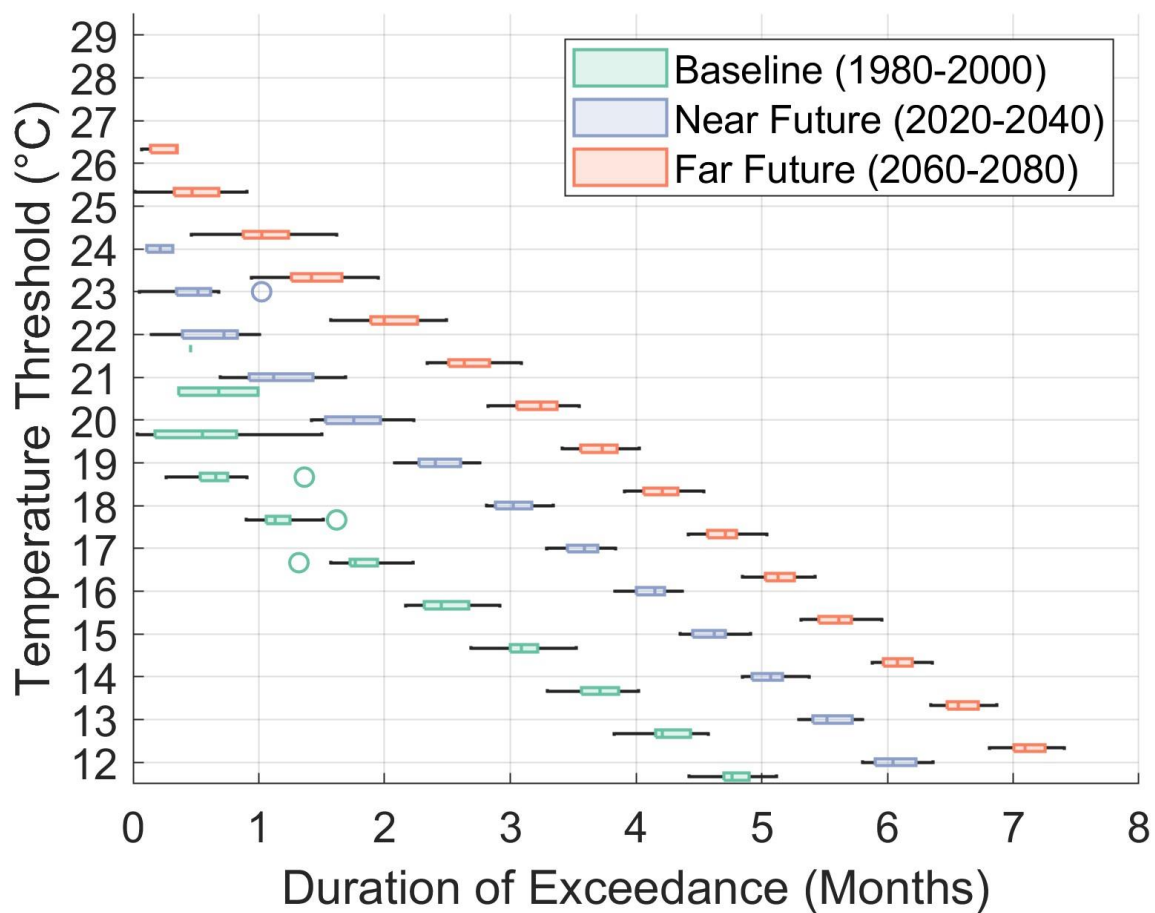
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Section 2 - Sea surface salinity changes

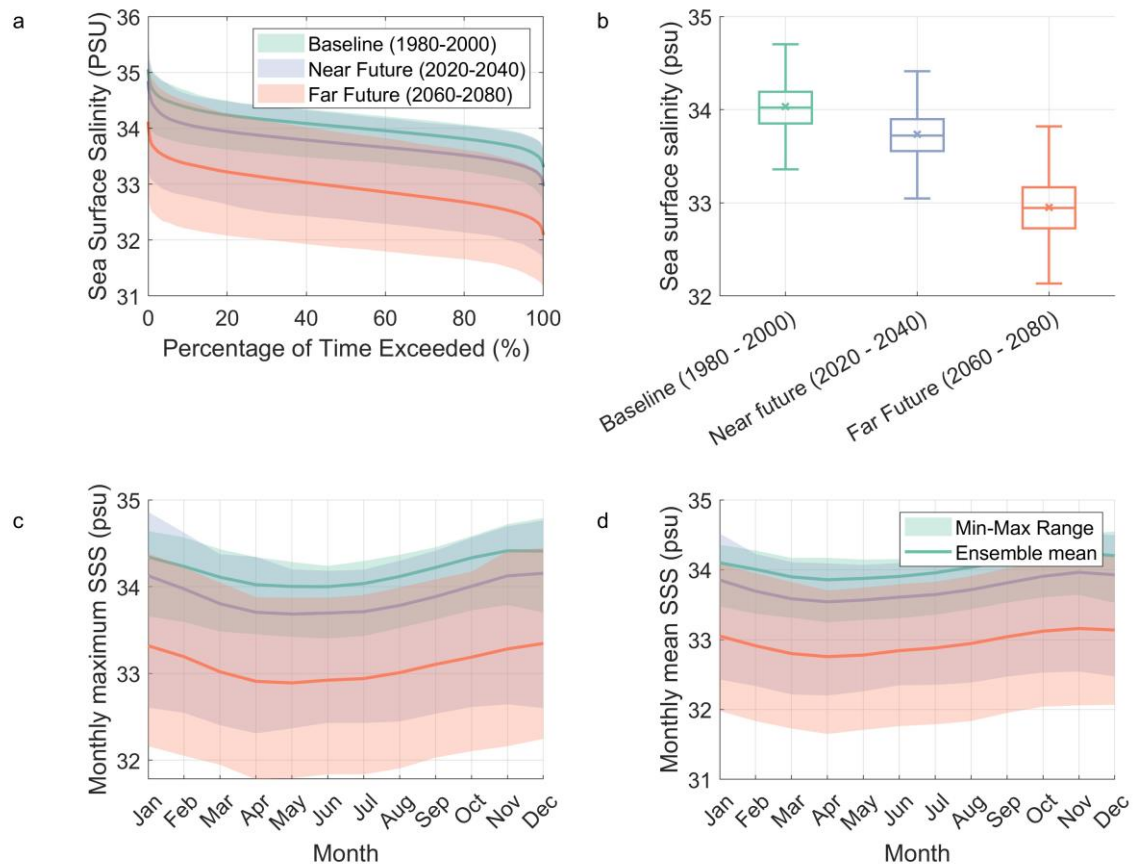


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Section 3 - Residual surge changes

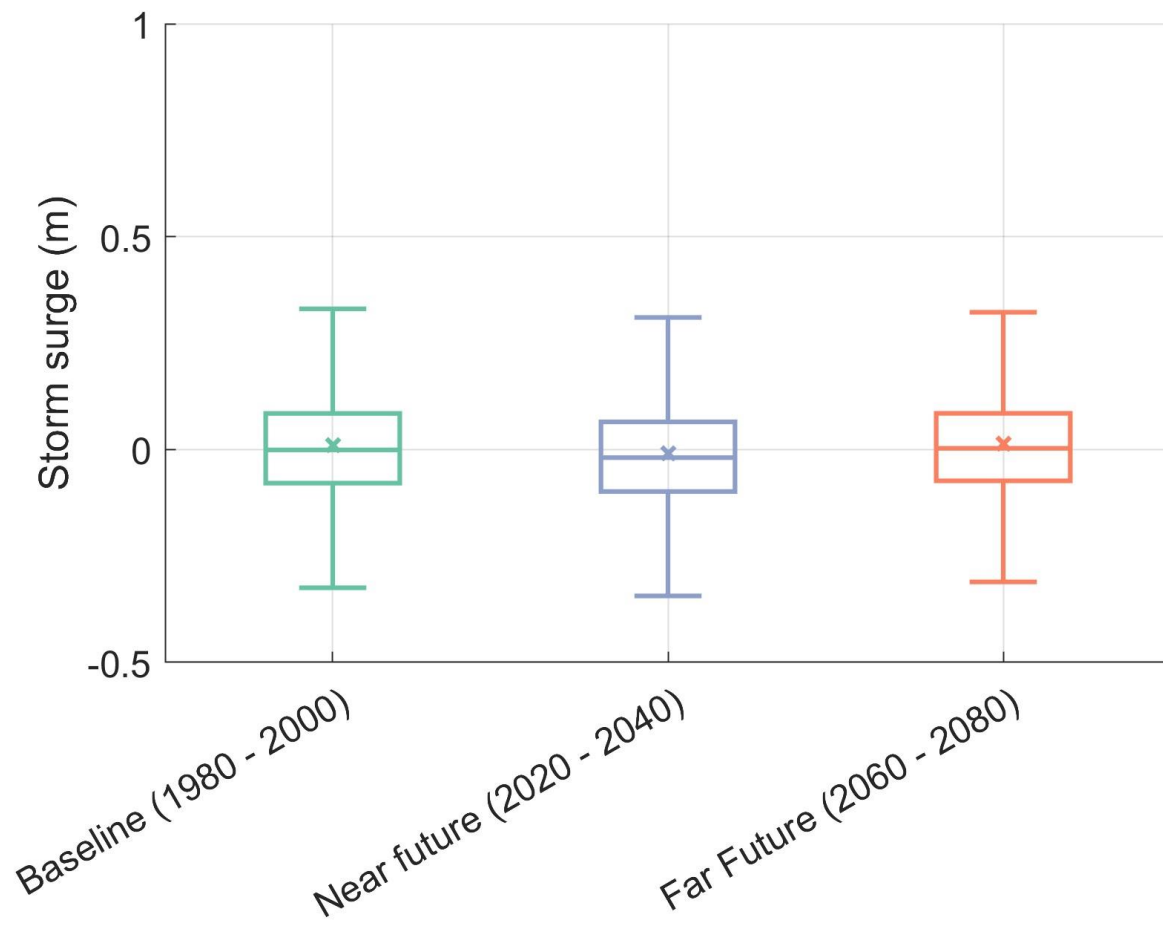


Figure description

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Section 4 - Residence times changes

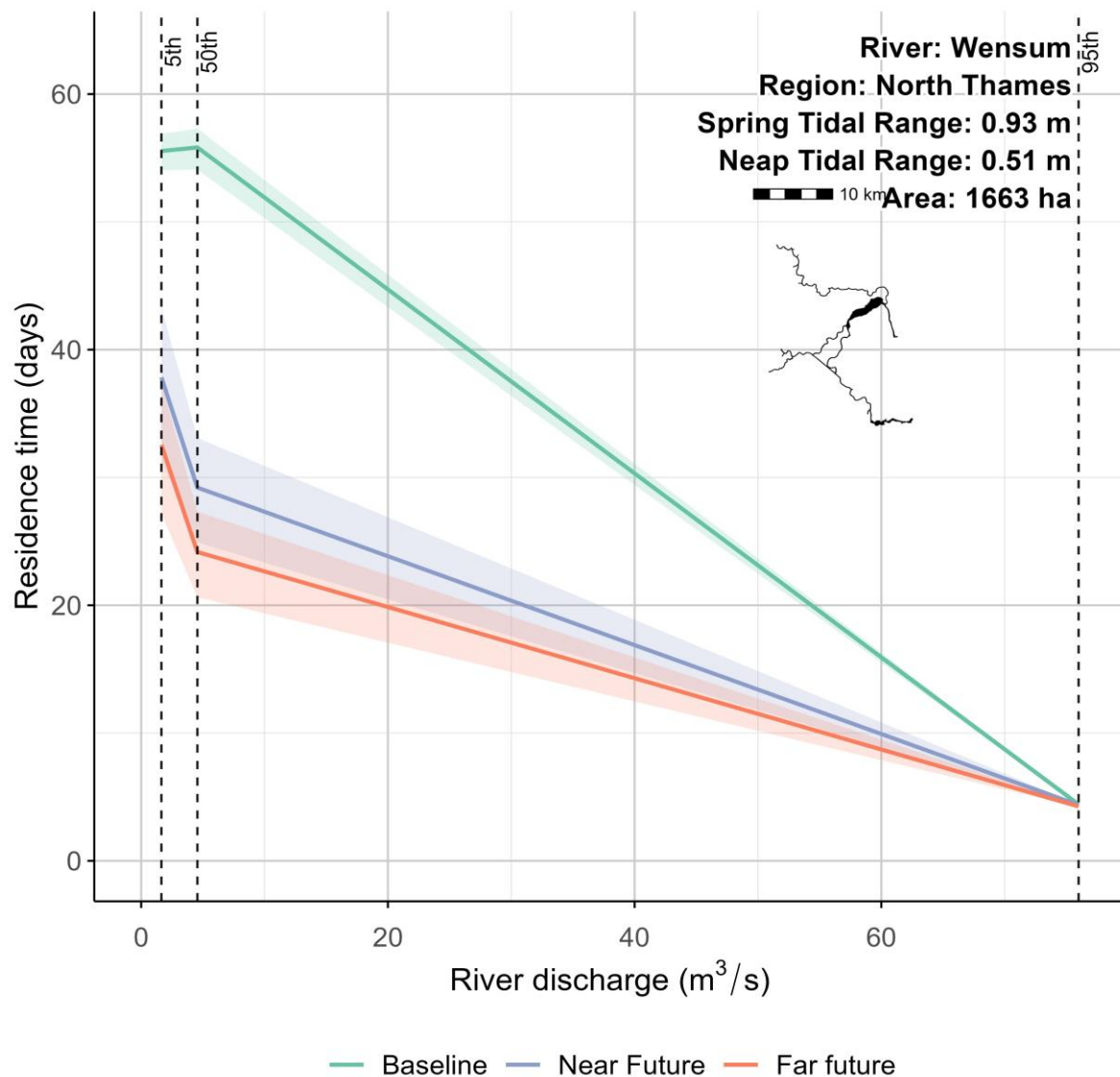


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Wyre

Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	53.8636
Longitude	-2.81739
Tidal Range	7.9 m
Gauge Name	Wyre at St Michaels
Estuary Size	333000000.0 m²
5th percentile flow	0.632 m³/s
50th percentile flow	3.09 m³/s
95th percentile flow	26.39 m³/s
Notes	Tidal Range and Volume for Morecombe Bay

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

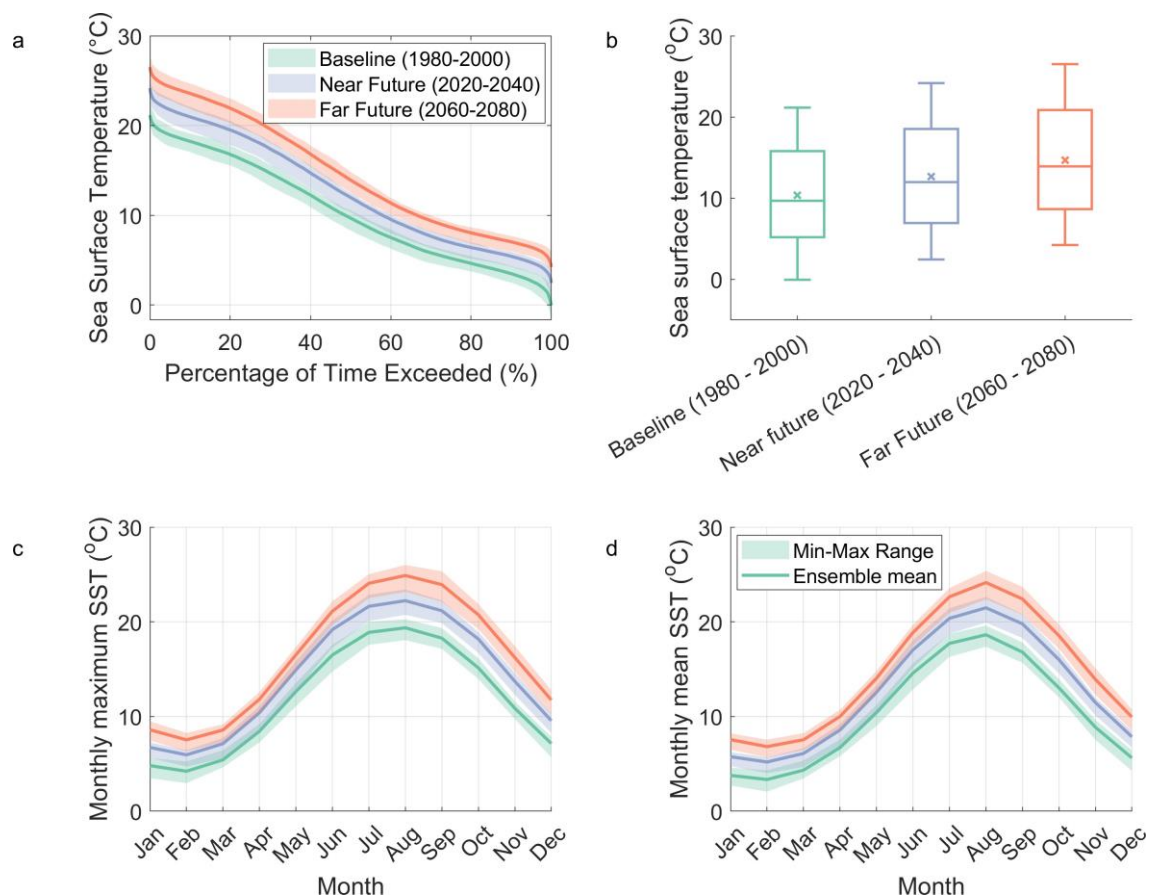
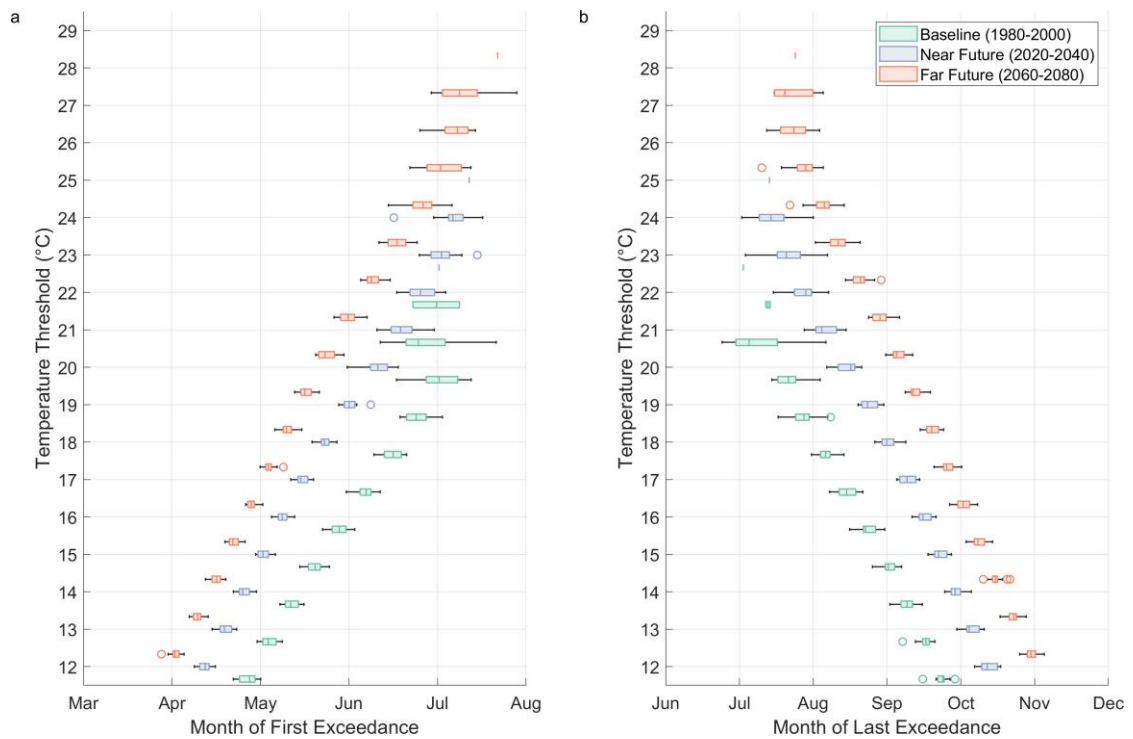


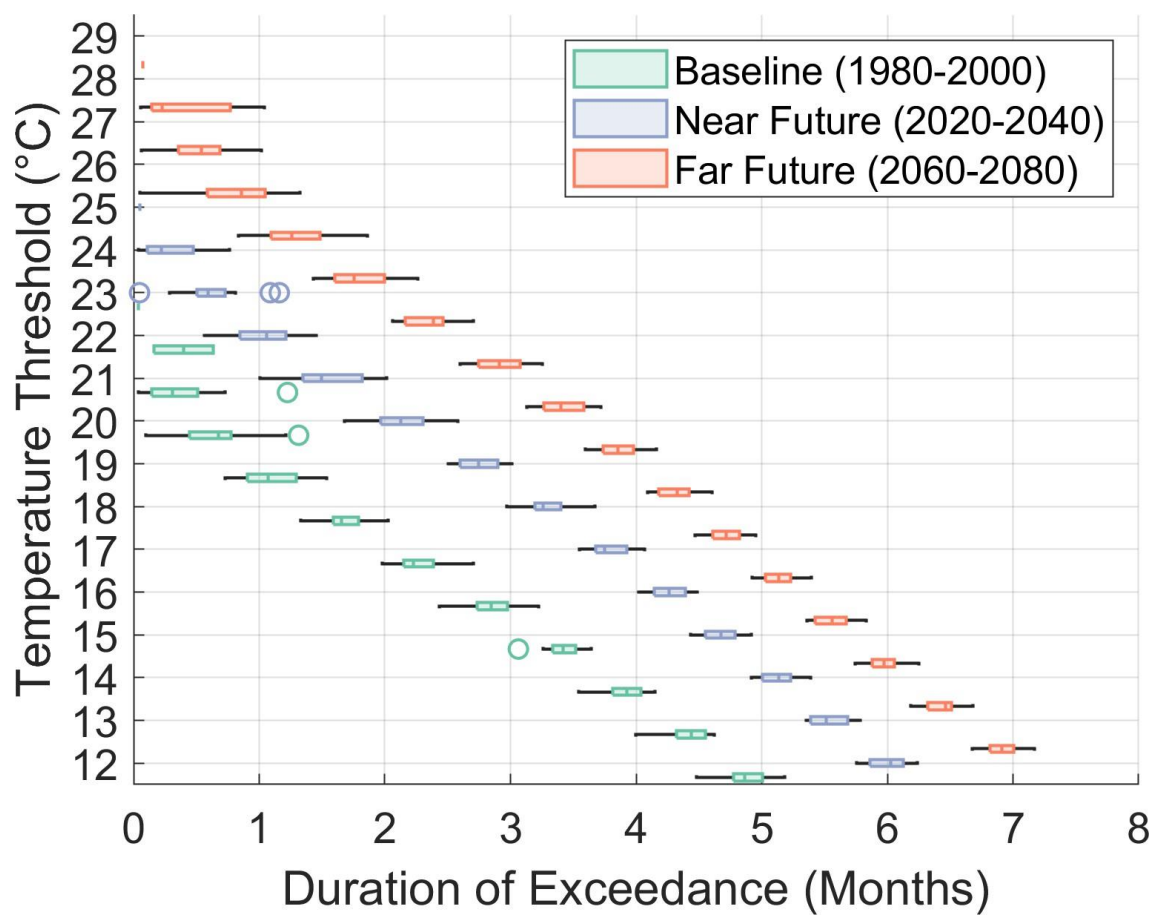
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Section 2 - Sea surface salinity changes

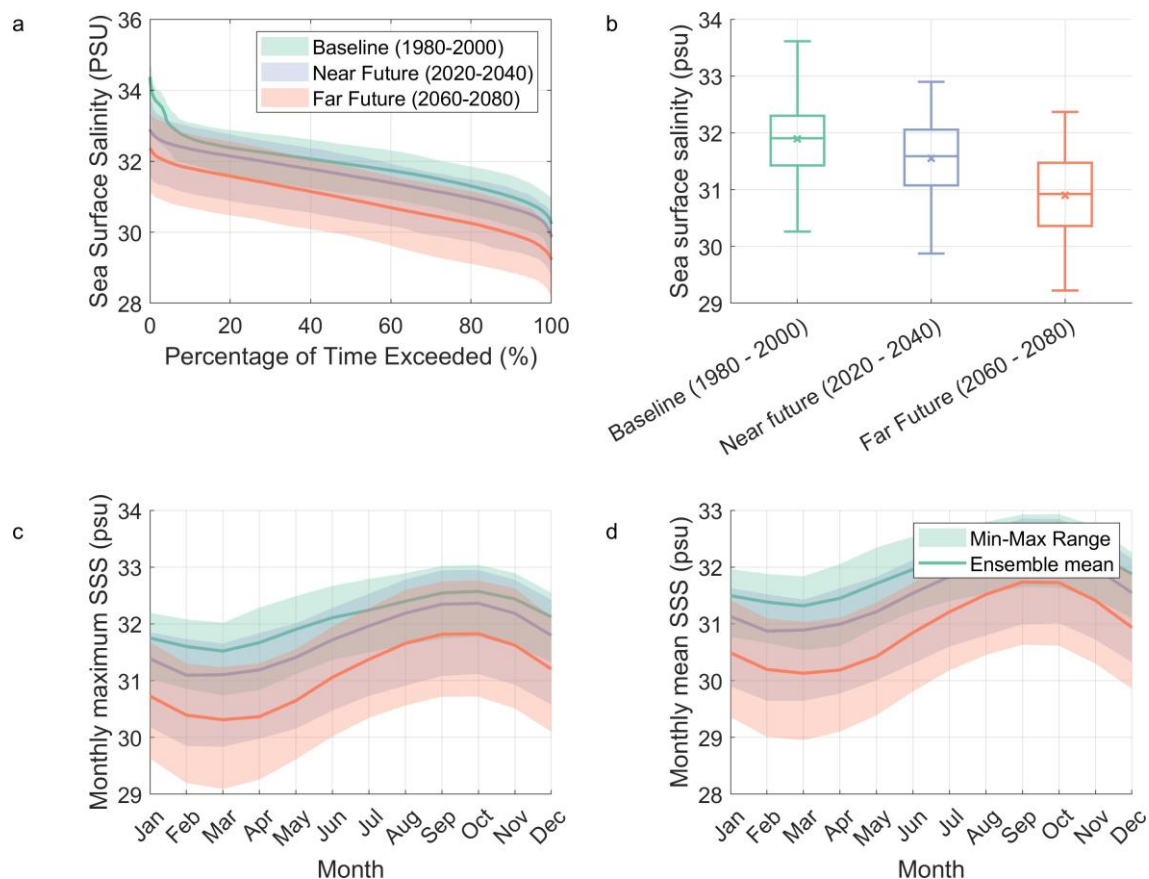


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Section 3 - Residual surge changes

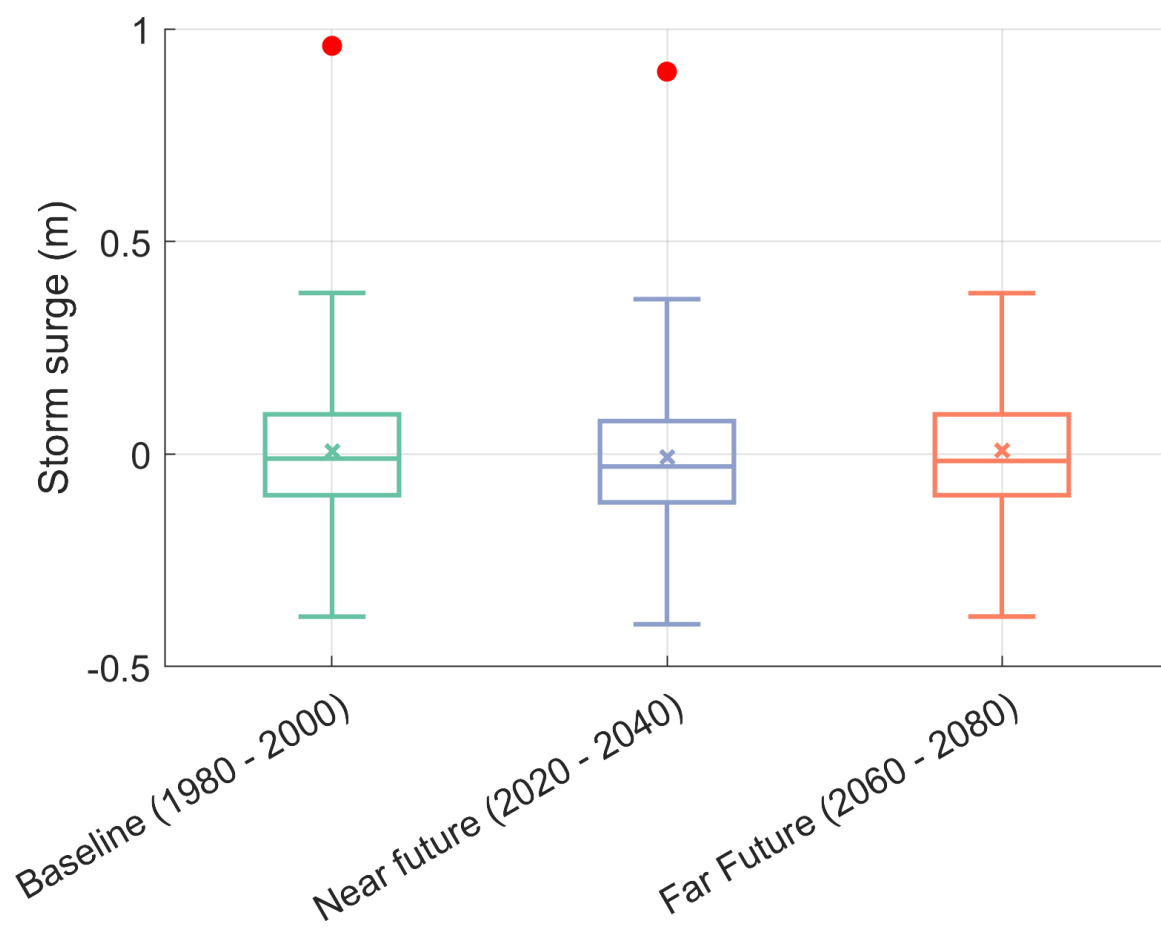


Figure description

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Section 4 - Residence times changes

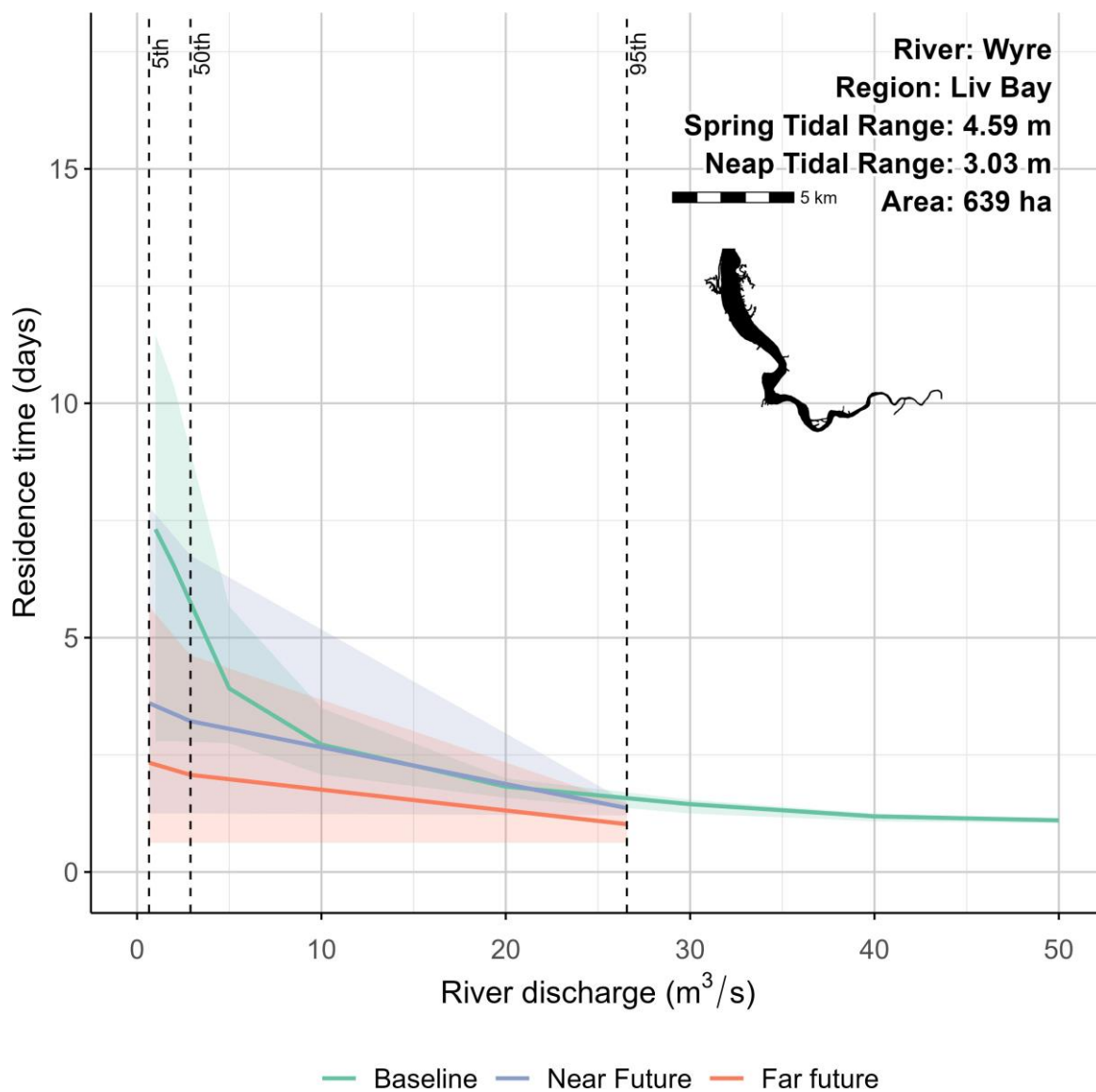


Figure description

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Climate Change Impacts on Water Quality

Report generated: 19-01-2026

Attribute	Value
Latitude	50.34265
Longitude	-4.00563
Tidal Range	4.7 m
Gauge Name	Yealm at Puslinch
Estuary Size	1070000.0 m ²
5th percentile flow	0.247 m ³ /s
50th percentile flow	1.11 m ³ /s
95th percentile flow	5.373 m ³ /s
Notes	nan

Table 1: Summary of estuary characteristics and hydrological data.

Section 1 - Sea surface temperature changes

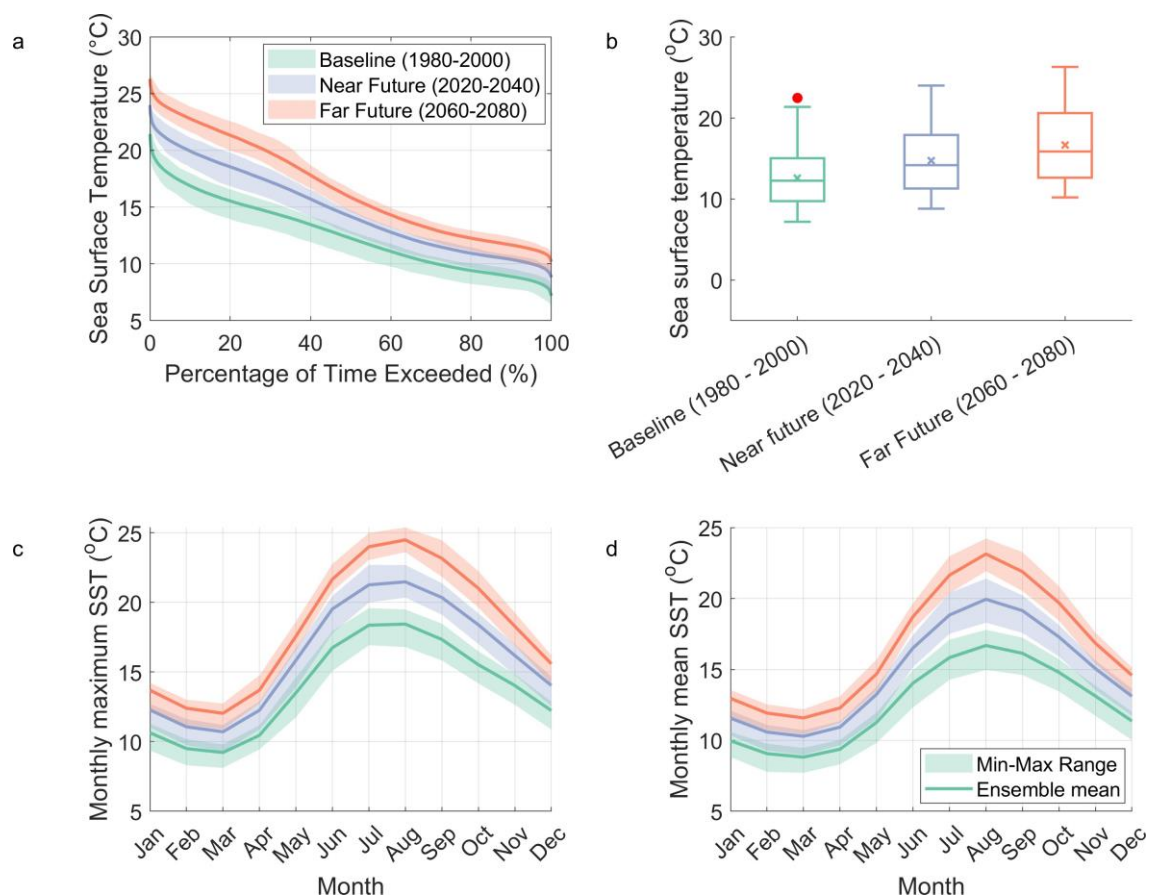
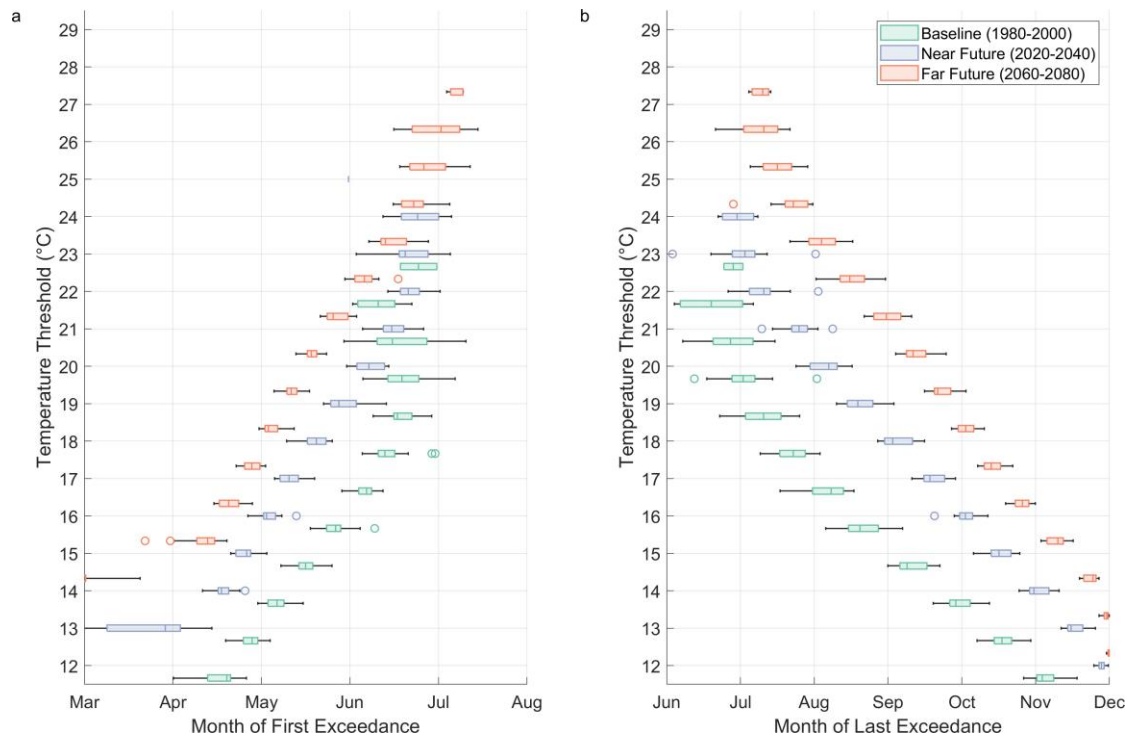


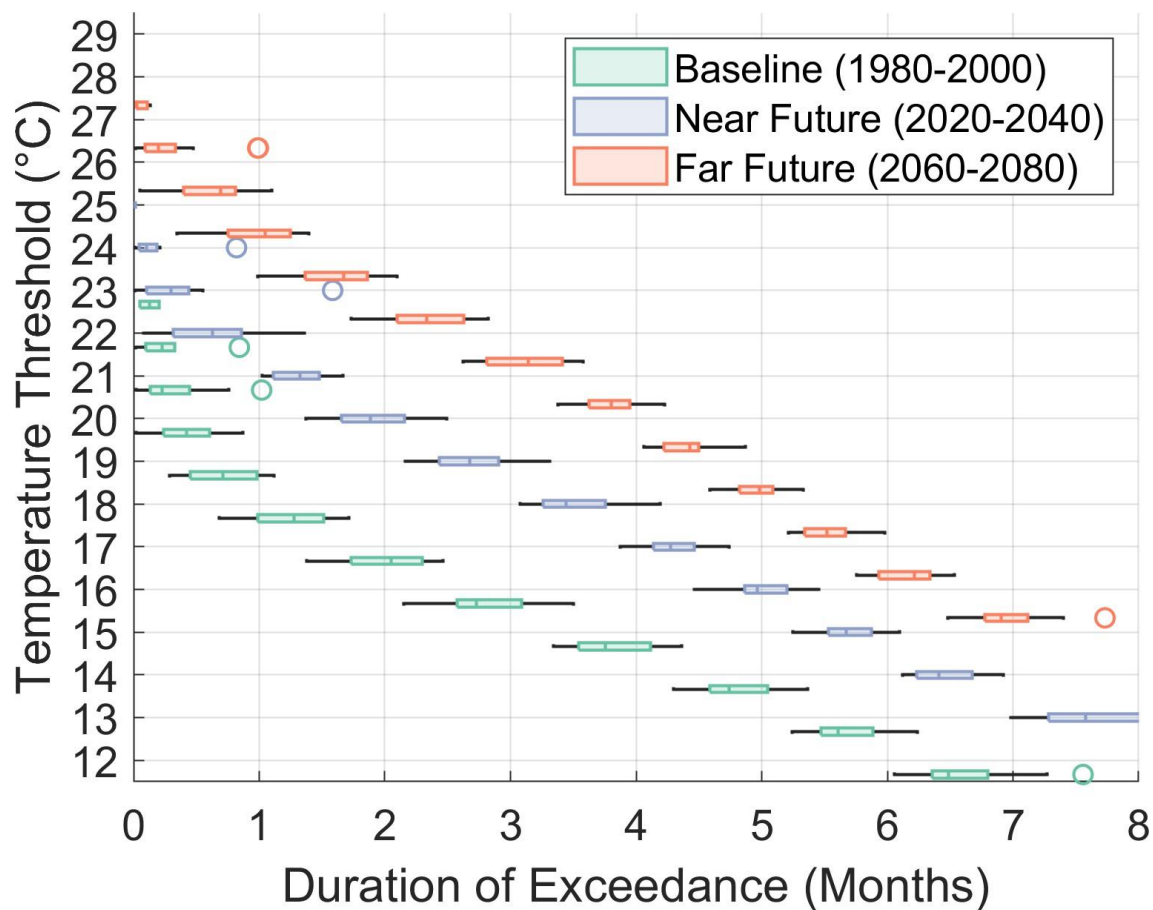
Figure description

Summary statistics of sea surface temperature changes as predicted using NEMO 4.04 (downscaled from the 12 member ensemble UKCP18 GCM-PPE). Solid line indicates ensemble mean and shaded area provides ensemble range.

- (a) Temperature duration curves represent distribution of SSTs over time to highlight changes in cold and warm extremes.
- (b) Percentile shifts show increasing mean, median, and extremes, indicating prolonged warming over time.
- (c) Rising monthly maximum in every month of the year highlights likelihood of intensified high heat events.
- (d) Rising monthly mean suggests long-term climate-driven warming.



Changes in first and last occurrences of temperature thresholds compared to historical data. Note that these plots are not intended to identify the specific date on which a temperature may occur, rather they indicate the trend in the onset of specific temperature thresholds.



Projected temperature changes under different climate scenarios. Box and whisker plots show the range of different modelled durations of temperatures under the 12 different UKCP 18 ensemble members. Open circles indicate outlier values.

Section 2 - Sea surface salinity changes

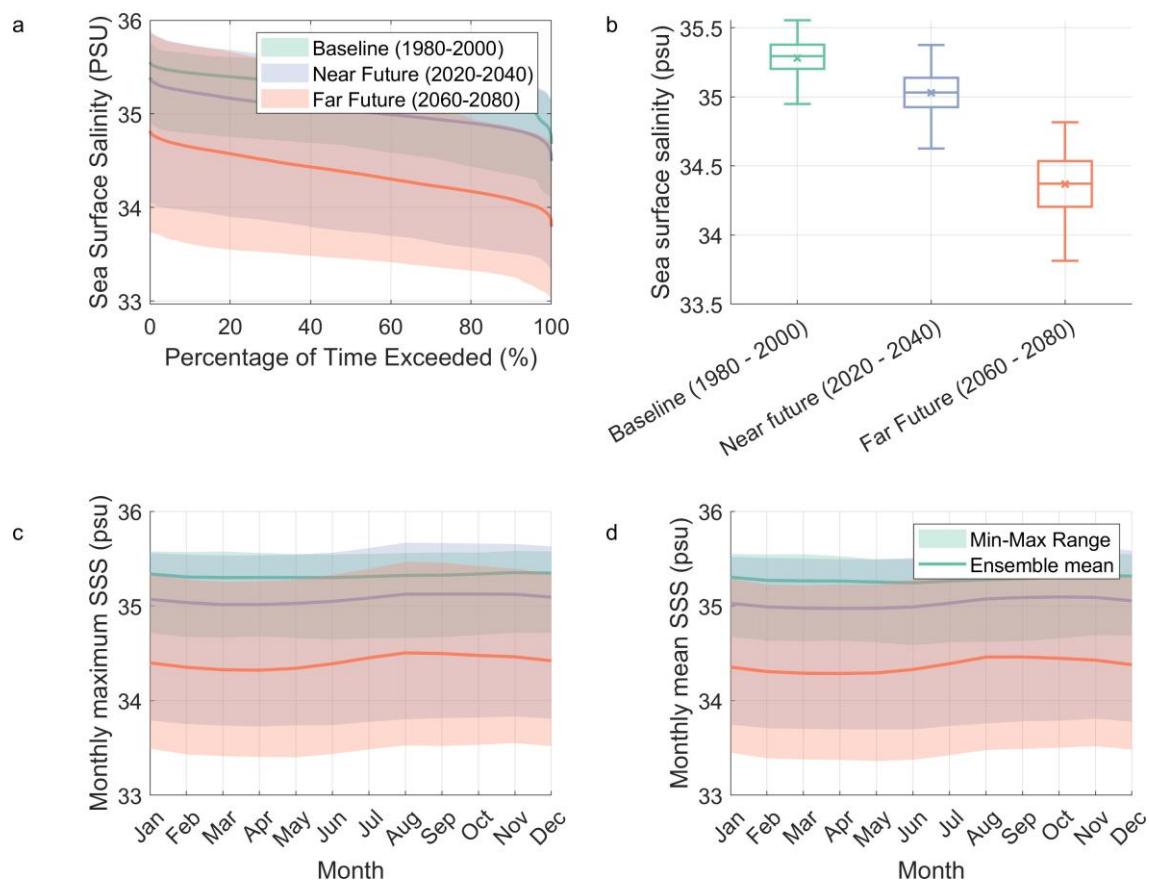


Figure description

- (a) Sea Surface Salinity duration curves represent distribution of SSSs over time to highlight changes in extremes.
- (b) Percentile shifts show decreasing mean, median, and extremes, indicating a trend towards freshening over time.
- (c) Monthly maxima decrease across all months.
- (d) Decreasing monthly means suggest long-term ice-melt driven freshening.

Section 3 - Residual surge changes

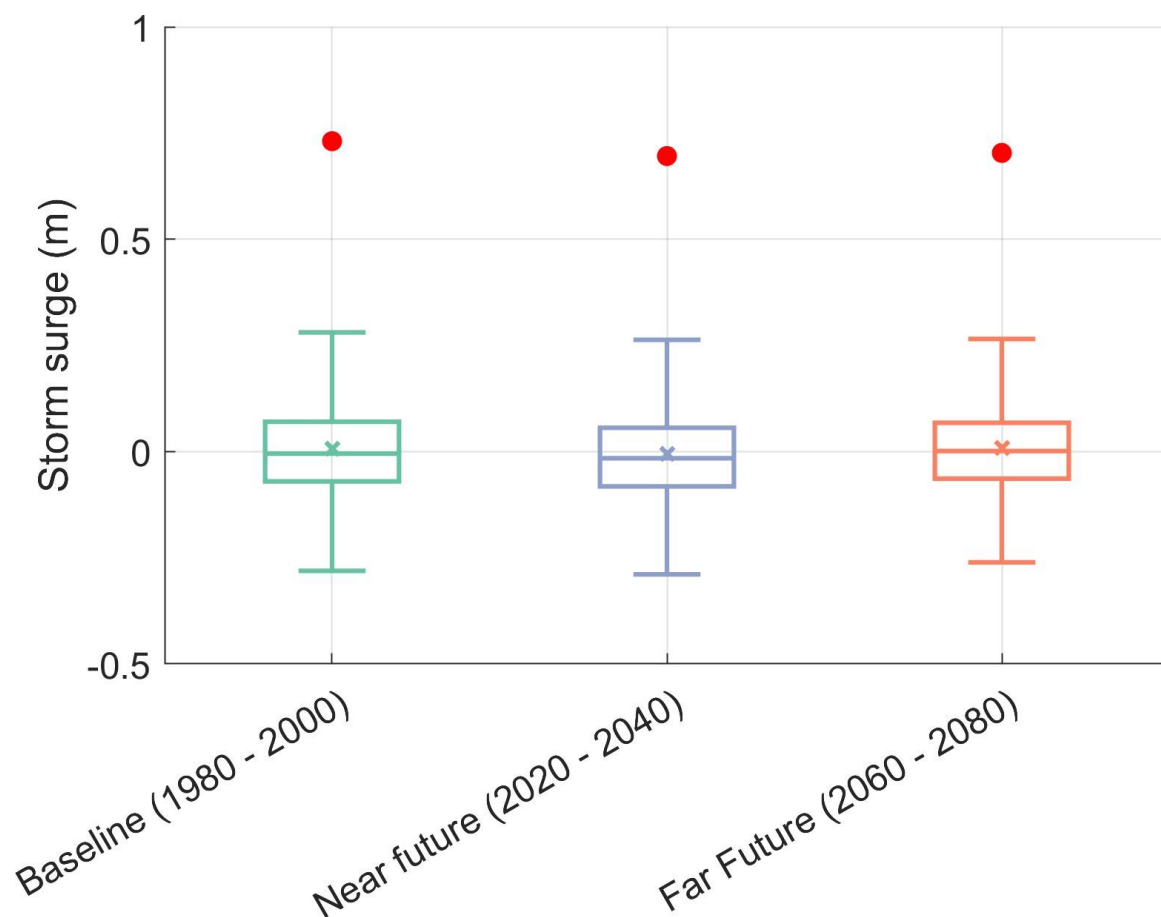


Figure description

Box and whisker plots for residual surge. Residual surge is the difference between 'observed' sea levels and the sea level which would be expected based upon astronomical tides and underlying sea level rise.

Residual surge is used as an indicator of weather-driven surge, such as those associated with stormy conditions.

Section 4 - Residence times changes

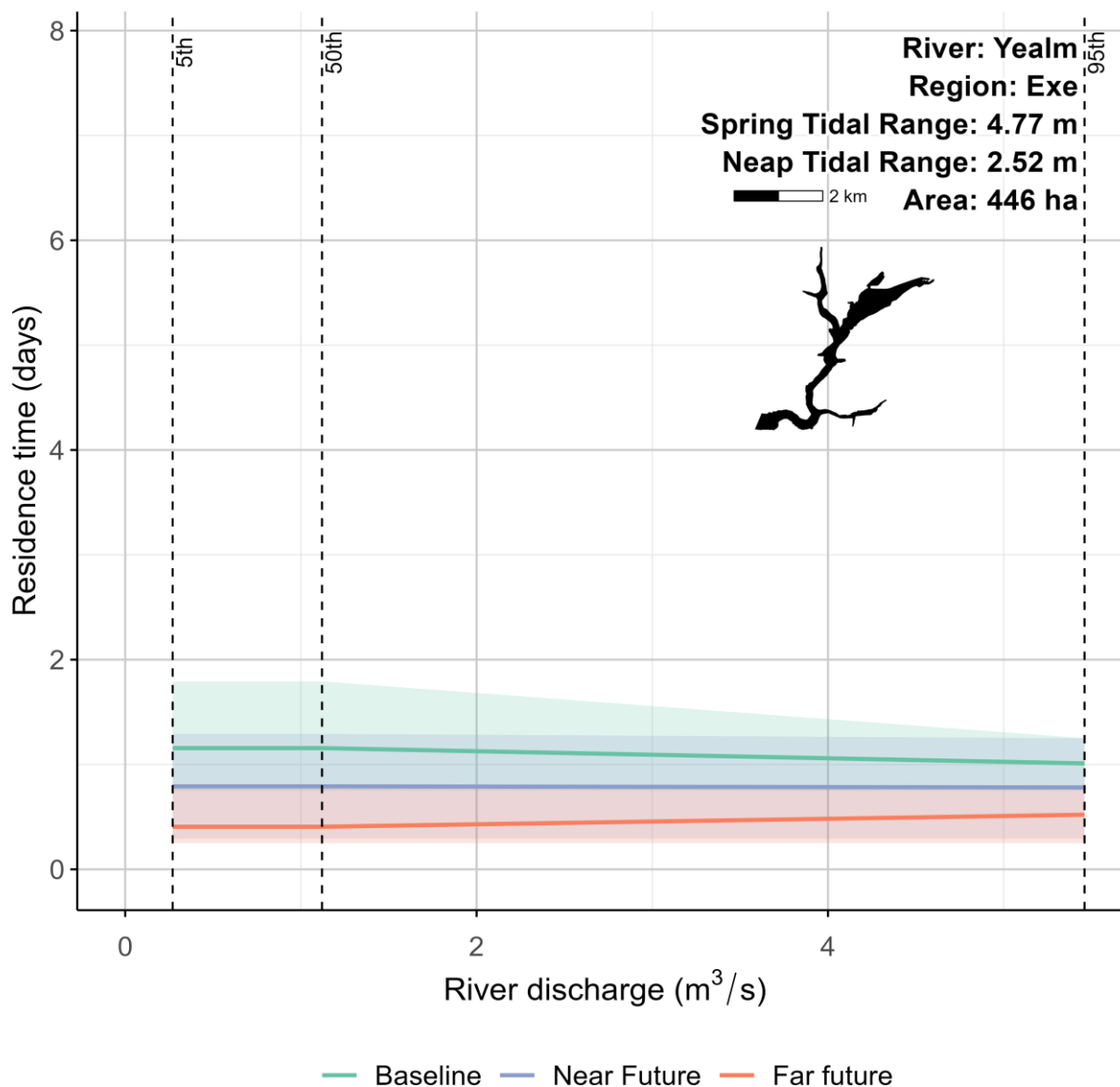


Figure description

Baseline (1980-2000), Near Future (2020-2040), and Far Future (2060-2080)

Residence Times Residence times reflect how long water persists within an estuary and can be an important indicator of potential water quality issues, with longer residence times associated with greater retention of pollutants. Residence times (as calculated in this study) represent the time taken for a conservative tracer (i.e. unreactive) to decay to 37% of its original concentration.

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