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Scottish Ocean Climate Status Report 2016

Scottish Marine and Freshwater Science Vol 9 No 4

S L Hughes, J Hindson, B Berx, A Gallego and W R Turrell

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Marine Scotland is the directorate of the Scottish Government responsible for the integrated management of Scotland's seas. Marine Scotland Science (formerly Fisheries Research Services) provides expert scientific and technical advice on marine and fisheries issues. Scottish Marine and Freshwater Science is a series of reports that publishes results of research and monitoring carried out by Marine Scotland Science. It also publishes the results of marine and freshwater scientific work that has been carried out for Marine Scotland under external commission. These reports are not subject to formal external peer-review.

This report presents the results of marine and freshwater scientific work carried out by Marine Scotland Science.

Executive Summary

In this report we have described the status of the physical conditions in the seas around Scotland in 2016 and examined the variability and trends in the last decade, and further into the past.

Although the global climate trend is one of warming, when examining data at a regional level, there are many different drivers which introduce variability at multi-decadal and decadal timescales. Because of the complex linkages between ocean conditions and the atmosphere, multi-decadal variability can be observed not just in air and sea temperatures, but also in long-term rainfall and sunshine trends. The long-term pattern of variability in North Atlantic temperatures makes it quite difficult to separate observed changes caused by Global Climate Change from changes caused by natural variability, particularly in cases where observations only extend back 30 years or less.

Change observed at a regional level can be more extreme and more variable than the smoothed trend we see in the global average temperature trend. Despite the long-term warming trend, it is likely that Scotland's seas will experience periods of enhanced warming, periods of reduced warming, and even periods of cooling. Nevertheless, climate change induced by human activities will cause a warming trend on global and long-term time scales.

Both air and sea temperatures around Scotland have warmed at a similar rate to the global pattern of century-scale warming as reported by the IPCC in 2014. At a multi-decadal scale, during the 1970-1980 to 2010 warming episode, air and sea temperatures across Scotland warmed at a rate faster than the global average. Regional variations, and variations on shorter time-scales, to these general observations can be found in the many time-series within this report.

The main observations described in this report are as follows.

Weather

- The meteorological data sets presented here cover the time period from 1981 to present day, although there are some gaps in the coverage, in particular for the sunshine data.
- 2016 was a warm year overall, but not as warm as 2014. Annual average air temperatures in 2016 were reduced by cooler conditions during April and November. However, December was unusually warm.
- 2016 was drier than normal, with October 2016 being an unusually dry month.
- The decade 2006–2015 was characterised by mean air temperatures that were higher than normal. However, 2010 was an unusually cold year and in contrast 2014 was the warmest on record for most stations.
- As well as being cold, 2010 was a dry year, with most of the stations having much lower than normal rainfall. 2013 also had very low rainfall in the north and east of Scotland.
- In the Clyde region, the last decade has been sunnier than normal, whereas in recent years in the Shetland Isles and Forth & Tay regions there has been less sunshine than normal.
- The long-term trend (1910 – 2016) is one of increasing air temperature and rainfall over Scotland.

River Flow

- The spatial pattern of riverine input to Scotland's seas is highly variable.
- 2016 showed slightly greater than average river flow across all Scottish Marine Regions.
- River flow in 2016 increased despite the decrease in rainfall recorded in 2016.
- The decade 2006-2016 had greater than normal river flow.
- There is a general trend of increasing river flow between 1971 and 2016.

Coastal Waters

- Sea temperature has a strong seasonal cycle with maxima in August or September, and minimum values observed in February or March.
- Salinity has a much weaker seasonal cycle, but is most pronounced at the Stonehaven monitoring site, with maxima in July to September.
- 2016 was a relatively warm year, with average sea surface temperatures in all regions higher than the long-term average.
- The period of 2006 to 2016 was, on average, warmer than normal in Scottish coastal waters, with sea surface temperatures between 0.2 and 0.4 °C warmer than the long-term average (1981–2010).

- The gridded sea surface temperature dataset, Hadley Centre Sea Ice and Sea Surface Temperature (HadISST), prepared by the UK Meteorological Office, shows that 2014 was the warmest year on record for almost all of the Scottish Marine Regions, and the warmest year overall for Scottish coastal waters.

- In-situ data from coastal observations suggest that, although sea temperatures in 2014 were warm, they did not exceed those observed in 2003.

- Salinity data from selected Scottish Coastal Observatory (SCObs) sites show that in the surface layers 2016 was a fresh year. At all SCObs sites, the years since 2013 have been significantly fresher than any others.

Offshore and Oceanic Waters

- Temperatures in the shallower Northern North Sea show a more rapid rate of warming (0.4 - 0.5 °C per decade) than those in deeper oceanic regions. Multidecadal variability is more marked in the Atlantic NW Approaches region, where a period of warmer temperatures was observed in the late 1950s, and more recently from the end of the 1990s up to the early 2010s.

- The story of the decade is that, superimposed upon a background of higher than normal temperatures, the decade was also quite variable with periods of very low and very high temperatures. This variability is thought to be strongly linked to the atmospheric conditions affecting the NW European Continental Shelf region, which was sometimes dominated by oceanic conditions where prevailing winds bring warmer and wetter conditions, and at other times dominated by blocking highs, which allowed colder airmasses from continental Europe or the Arctic to dominate.

- The temperature and salinity of Atlantic Waters to the west of Scotland increased in the period between the end of the 1990s and the mid 2000s. In more recent years, cooler temperatures and fresher salinities have emerged.

- The changes in temperature recorded in Atlantic Waters to the west of Scotland follow a similar pattern to those in the wider North Atlantic, which is to be expected, as the observations in the Faroe-Shetland Channel (FSC) are on one of the main oceanic pathways from the Atlantic Ocean to the Nordic Seas.

- Although temperatures in recent years have reached record high values, salinity has been higher in the past. There was also a notable warm and salty period in the eastern North Atlantic Ocean near the end of the 1950s.

- Along the pathway of the North Atlantic Current, the decadal trend is one of reducing temperature and salinity since around 2010.

Global and North Atlantic Indices

- Globally, 2016 was extremely warm, and the third year in a row where global temperatures reached new record highs.

- The surface of the North Atlantic remains in a warm phase, with average temperatures being warmer than normal in the last decade.

- The strength of the Sub-Polar Gyre has continued to weaken in the last decade, although there are early indications of the Sub-Polar Gyre strengthening again.
- In 2016, the North Atlantic Oscillation (NAO) Index was positive (0.98), while over the last decade the NAO has been very variable.

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Introduction

This report presents a summary of the conditions in the seas around Scotland using data collected by Marine Scotland (MS), as well as data from other organisations within Scotland and further afield. The underlying themes of this report are trends and variability, particularly those indicative of climate change. The focus of the report is on physical measurements made in the atmosphere and the seas around Scotland. This summary builds on contributions MS staff have made to the Marine Climate Change Impacts Partnership (MCCIP) and ICES Report on Ocean Climate (IROC) in recent years (*MCCIP*, 2017; *Larsen et al.*, 2016).

This report focuses on observations during 2016, and comparing these to conditions observed in the preceding decade, as well as describing longer term changes, where data are available. At the time of writing, 2016 was the most recent complete year of observations for inclusion. Future addenda and updates will provide an overview of conditions in subsequent years.

The first section of this report examines changes that have been observed in the weather at selected stations around Scotland. As the weather has an influence on ocean conditions, this helps put the variability observed in the marine environment into context.

In the second section, data from rivers around Scotland are described: freshwater inputs from rivers are important as these have an influence on the coastal environment.

The report then continues to describe oceanographic data collected in the coastal, offshore and oceanic regions around Scotland.

The final section of this report provides some context for the Scottish climate by describing the changes in climate that have been observed at a global level. We describe changes that have been observed over the whole of the North Atlantic, and how this fits in with the patterns that we are seeing in Scotland.

Although some of the time series presented in this report are relatively short, comparing them to longer time series allows us to put the observations into the context of longer-term change. Examining many single datasets together also helps to develop an understanding of the wider regional patterns of change. By bringing together observations from a number of different sources and presenting them in a variety of ways, we can get a clearer picture of what changes are happening in the Scottish marine environment.

Changes in the physical marine environment affect the marine ecosystem and have an impact on the health and diversity of the marine ecosystem and its productivity. For example, changes in climate can affect the distribution and abundance of plankton, which then influences distribution and abundance of fish stocks. As the marine ecosystem is complex, these changes are not always easy to understand. MS is committed to monitoring the impacts of climate variability on the seas around Scotland. It has an active programme of research that aims at developing a better understanding of the impacts of past, and potential future, change on the marine ecosystem.

Data Presentation

The different datasets used in this report are presented as far as possible in a standard format, and analysis of variability and trends has been undertaken in a standardised way. Where data are presented in summary tables and figures, normalised anomalies have been provided to allow better comparison of trends in the data between different regions and between parameters. Each dataset has been visualised in a number of ways, reflecting the broad range in background knowledge in the target audience for this report.

Guide to Tables and Figures

Statistical Summaries
In this table format (see, for example, Table 1.1), statistical summaries of the data within each region are presented: firstly for each month, then for each season (winter = Jan, Feb, Mar, spring = Apr, May, Jun; summer = Jul, Aug, Sep; autumn = Oct, Nov, Dec), and finally for the year on average. Values for the whole dataset, up to and including the most recent year, are also presented. Secondly values calculated for a common base period, or climatological period, are presented. For most of the records included in this report, the 30-year climatological period, 1981–2000, has been chosen as the base period. Using a common base period makes it easier to compare different datasets. In order to examine more recent conditions, averages from the last 10-years, or decade, are also presented, as well as a summary for the latest year.

Statistical Box Plots
In this figure format (see, for example, Figure 1.1), a statistical analysis of the data within each region is presented. Using all monthly values for the 30-year climatological period (1981-2000) the band at the centre of the box shows the average (mean) value, and the bottom and top of the box show the first and third quartiles, respectively. In statistical terms, we expect 25% of the data to be lower than the range indicated by the box, and 25% of data to be higher than the range indicated by the box. The dashed lines (whiskers) show the range to the lowest value still within 1.5 times the inter-quartile range from the lower quartile, and the highest value still within 1.5 times the inter-quartile range from the upper quartile. This range is equivalent to approximately 2.7 standard deviations. Outside of this range, there should be very few values: these would be defined as extreme, and the values are shown as crosses on the boxplot. [1]

[1] `https://en.wikipedia.org/wiki/Box_plot`

Decadal and Monthly Anomalies
In this figure format (see, for example, Figure 2.1), the left image illustrates how conditions have varied over the last 10 years. The right figure shows how conditions have varied, month by month, over the latest year. In these figures, data from all regions are presented together and this shows how similar (or different) the patterns of variability are between each region.

Summary for the Year
In this figure format (see, for example, Figure 3.11), a central map shows the marine regions used to analyse the data. The surrounding figures show the monthly values for the latest year in comparison to the average values calculated for the last decade, and the 30-year climatological period (1981–2010). Using this figure, it is possible to see exactly what conditions were like in a particular month, and how they compare to those that have been observed in the past. Maximum and minimum values exclude the latest year, so extreme values can be seen on this figure.

Long-Term Trends
In this figure format (see, for example, Figure 4.4), a central map shows the marine regions used to analyse the data. The surrounding figures show annual values for the entire dataset. Using this figure, it is possible to see exactly how conditions have changed over time, and appreciate what the long-term trends in each dataset are.

What is normal?

When trying to understand changes in climate, we tend to be interested mainly in long-term trends, i.e. those changes that occur over periods of five years or longer. When examining data for such trends, it is standard practice to remove both seasonal variability and the long-term average values. The data are then described as anomalies and they show us the difference between the observed value and the ”normal” or average values. In truth, the climate is always changing to some extent, so there is no real definition of ”normal”. However, to help us compare different datasets we have chosen a common base period, which is then used to define ”normal” conditions. For most of the datasets in this report, the base period is calculated as the average of measurements made between between 1981 and 2010 (i.e. a 30-year base period). For shorter time series, where this is not possible, a 10-year base period is used.

In many of the figures shown in this report, data are plotted not as absolute values but as anomalies (for example see Figures 1.2 or 3.18). Sometimes it is difficult to compare data from different regions, as these have different patterns of natural variability. For example, in a coastal location such as Loch Ewe, where salinity values can vary between 30 and 34.5, a value of 1 or 2 above normal is not significant. But in a region where the variability in salinity is low, for example the North Atlantic Water mass, the observed salinity range is closer to 0.1, and so a value of 1 or 2 above normal would be extremely significant. What we really wish to know is ”how unusual” are the changes that we are seeing. To do this, we present the anomalies not as parameter units but as units of standard deviation. This process is referred to as normalisation. For example, a value of 3 means the observation was three standard deviations above normal and a value of -1 means the observation was one standard deviation lower than normal. In this report, normalised anomalies are regularly used when comparing different datasets side by side. More information on the calculation of anomalies and normalised anomalies can be found in Appendix G.

Spatial Patterns

Within this report, the coastal, meteorological and river chapters are all presented by Scottish Marine Region (SMR). In 2010 the Marine (Scotland) Act introduced a new framework for the management of Scotland’s seas to balance the protection and enhancement of the marine environment with boosting economic investment and growth in areas such as marine renewables. The resulting National Marine Plan (*Scottish Government*, 2015) outlines the wider context for planning within Scotland, including the creation of regional marine plans, for which 11 SMRs have been described. These are Argyll, Clyde, Forth & Tay, Moray Firth, North Coast, North East, Outer Hebrides, Orkney Islands, Shetland Isles, Solway and West Highlands (Figure F.1a). These SMRs extend out to 12 nautical miles, and each region will develop their own regional marine plan through a Marine Planning Partnership comprised of marine stakeholders reflecting interests in their region, allowing more local ownership and decision making.

Datasets focused on conditions further offshore use the Charting Progress 2 (CP2) regions, which divide coastal and offshore areas around the UK into 8 subregions. These were presented in the Charting Progress 2 report (*DEFRA*, 2005). The regions were defined taking bio-geographic and physical features into account, and therefore reasonably define different hydrographic regions of the UK (Figure F.1b).

1 Weather

Overview

Short term changes in the atmosphere, or the ”weather”, can affect conditions in the sea in many complex ways. Sunshine warms the sea and, in some circumstances, the warmth held by the sea can be released back to the atmosphere at a different time or in a different place. Sunlight also penetrates into the upper layers of the ocean, where it is utilised by phytoplankton, the small plant life that lives in the sea. Rainfall reduces the saltiness of the sea directly by adding fresh water to the surface, but more significantly there is an indirect effect from freshwater runoff from land and rivers. Winds stir the surface waters by creating waves and they also drive currents around our coasts. Surface winds can also lead to cooling of the ocean surface and drive evaporation, which makes the surface waters more salty.

Here, we present a summary of the weather conditions (monthly average air temperature (°C), monthly total rainfall (mm) and monthly total sunshine (h)) experienced at ten maritime locations around Scotland (for station descriptions, see Appendix A). The sites have been chosen to represent, as far as possible, the weather within each of the Scottish Marine Regions (Appendix F).

Analysis

Meteorological data have been analysed by Scottish Marine Region using data from the UK Meteorological Office. Recent conditions are referenced to a climatological average period calculated over the thirty years between 1981 and 2010. More information on the datasets can be found in Appendix A.

1.1 Spatial Patterns

Average air temperatures in coastal regions are generally warmer than both inland and mountainous regions (*UK Meteorological Office*, 2009). Annual average air temperatures across Scotland tend to be highest on the west coast, e.g. Dunstaffnage and Tiree (9.3 °C), where the moderating influence of the ocean keeps winter temperatures warmer (Table 1.1 and Figure 1.1a). The coldest average coastal air temperatures are found in the northernmost region of Scotland (Lerwick, 7.4 °C), whilst the highest summer temperatures are found at stations on the east coast of Scotland (Nairn and Leuchars), and also at the more southerly stations on the west coast (Paisley and Newton Rigg).

Table 1.1: Tables of monthly average air temperature (°C) calculated over different time periods. The trends in the table are in °C per decade over the indicated time period. See also Figure A.1 and Appendix G.4

Dataset Average 1971-2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. (SOLWAY) NEWTONRIGG	3.3	3.6	5.2	7.3	10.2	12.9	15.0	14.5	12.2	9.2	5.8	3.8	4.0	10.1	13.9	6.3	8.6	0.15
02. (CLYDE) BALLYPATRICK	4.3	4.3	5.4	7.0	9.3	11.8	13.7	13.5	11.9	9.5	6.5	4.9	4.6	9.4	13.1	7.0	8.5	n. s.
02. (CLYDE) PAISLEY	4.2	4.5	6.1	8.6	11.4	14.0	15.8	15.4	13.0	9.8	6.6	4.6	5.0	11.3	14.7	7.0	9.5	0.17
03. (ARGYLL) DUNSTAFFNAGE	4.6	4.8	6.0	8.0	10.6	12.8	14.5	14.4	12.6	10.1	7.1	5.4	5.2	10.5	13.8	7.5	9.2	n. s.
03. (ARGYLL) TIREE	5.6	5.4	6.2	7.7	9.9	12.0	13.7	13.8	12.5	10.3	7.8	6.2	5.7	9.9	13.3	8.1	9.3	0.19
05. (OUTER HEBRIDES) STORNOWAY	4.7	4.6	5.5	7.0	9.2	11.4	13.3	13.3	11.6	9.3	6.6	5.2	5.0	9.2	12.7	7.0	8.5	0.27
06. (NORTH COAST) WICK	3.7	3.7	5.0	6.5	8.5	11.0	12.9	13.0	11.4	9.0	6.1	4.2	4.1	8.7	12.4	6.4	7.9	0.19
08. (SHETLAND ISLES) LERWICK	3.8	3.6	4.3	5.7	7.9	10.0	11.9	12.3	10.6	8.4	5.8	4.3	3.9	7.9	11.6	6.2	7.4	0.25
09. (MORAY FIRTH) NAIRN	3.6	3.8	5.4	7.3	9.9	12.5	14.6	14.3	12.1	9.2	6.0	3.9	4.3	9.9	13.6	6.4	8.5	n. s.
11. (FORTH AND TAY) LEUCHARS	3.5	3.9	5.5	7.4	9.8	12.8	14.9	14.7	12.6	9.5	6.0	4.0	4.3	10.0	14.0	6.5	8.7	0.22

Climatological Average 1981-2010	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. (SOLWAY) NEWTONRIGG	3.4	3.6	5.4	7.4	10.4	13.0	15.1	14.6	12.2	9.1	5.9	3.4	4.1	10.3	14.0	6.1	8.6	n. s.
02. (CLYDE) BALLYPATRICK	4.4	4.4	5.5	7.1	9.5	12.0	13.8	13.7	12.0	9.4	6.6	4.7	4.8	9.5	13.2	6.9	8.6	n. s.
02. (CLYDE) PAISLEY	4.3	4.6	6.3	8.7	11.6	14.1	15.9	15.5	13.0	9.7	6.7	4.3	5.1	11.5	14.8	6.9	9.6	0.35
03. (ARGYLL) DUNSTAFFNAGE	4.7	4.8	6.1	8.1	10.8	12.9	14.6	14.5	12.7	10.0	7.1	5.2	5.2	10.6	13.9	7.5	9.3	0.34
03. (ARGYLL) TIREE	5.6	5.4	6.3	7.8	10.0	12.1	13.8	13.9	12.5	10.3	7.8	6.1	5.8	10.0	13.4	8.1	9.3	0.33
05. (OUTER HEBRIDES) STORNOWAY	4.8	4.7	5.6	7.1	9.3	11.5	13.4	13.5	11.8	9.3	6.8	5.1	5.0	9.3	12.9	7.1	8.6	0.41
06. (NORTH COAST) WICK	3.7	3.6	4.9	6.6	8.6	11.0	13.0	13.1	11.4	8.9	6.1	4.0	4.1	8.7	12.5	6.3	7.9	0.32
08. (SHETLAND ISLES) LERWICK	3.8	3.5	4.3	5.8	7.9	10.1	12.1	12.4	10.7	8.3	5.9	4.2	3.9	7.9	11.7	6.1	7.4	0.35
09. (MORAY FIRTH) NAIRN	3.7	3.9	5.6	7.5	10.0	12.5	14.7	14.4	12.1	9.2	6.1	3.6	4.4	10.0	13.7	6.3	8.6	n. s.
11. (FORTH AND TAY) LEUCHARS	3.6	4.0	5.7	7.5	10.0	12.9	15.0	14.8	12.7	9.5	6.1	3.6	4.4	10.1	14.2	6.4	8.8	0.31

Decadal Average 2006-2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. (SOLWAY) NEWTONRIGG	3.5	3.8	5.1	7.8	10.2	13.0	15.1	14.2	12.5	9.6	6.4	3.5	4.1	10.3	13.9	6.5	8.7	n. s.
02. (CLYDE) BALLYPATRICK	4.5	4.8	5.5	7.8	9.9	12.3	14.1	13.6	12.6	10.1	7.0	4.8	4.9	10.0	13.4	7.3	8.9	n. s.
02. (CLYDE) PAISLEY	4.4	4.9	6.2	9.1	11.4	14.3	16.0	15.1	13.3	10.3	6.9	4.3	5.2	11.6	14.8	7.1	9.7	n. s.
03. (ARGYLL) DUNSTAFFNAGE	4.9	5.0	6.2	8.5	10.8	13.2	15.0	14.4	13.2	10.6	7.5	5.1	5.4	10.8	14.2	7.8	9.5	n. s.
03. (ARGYLL) TIREE	5.8	5.8	6.4	8.2	10.1	12.4	13.9	13.8	12.9	10.7	8.1	6.1	6.0	10.2	13.5	8.3	9.5	n. s.
05. (OUTER HEBRIDES) STORNOWAY	5.1	5.2	5.9	7.7	9.4	12.0	13.9	13.5	12.3	9.8	7.1	5.1	5.4	9.7	13.2	7.3	8.9	n. s.
06. (NORTH COAST) WICK	4.1	4.3	5.3	7.2	8.7	11.3	13.3	13.3	12.0	9.5	6.6	4.0	4.6	9.1	12.9	6.7	8.3	n. s.
08. (SHETLAND ISLES) LERWICK	4.1	4.1	4.7	6.3	8.1	10.4	12.5	12.7	11.2	8.8	6.4	4.4	4.3	8.3	12.1	6.5	7.8	n. s.
09. (MORAY FIRTH) NAIRN	3.8	4.2	5.7	8.1	9.9	12.6	15.0	14.4	12.7	9.8	6.3	3.6	4.6	10.2	14.0	6.6	8.8	n. s.
11. (FORTH AND TAY) LEUCHARS	3.7	4.3	5.7	8.1	10.1	13.1	15.2	14.7	13.1	10.0	6.4	3.6	4.6	10.5	14.3	6.6	9.0	n. s.

Data for Year 2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. (SOLWAY) NEWTONRIGG	4.5	3.4	5.1	6.1	11.4	14.3	14.9	14.7	14.3	9.2	3.5	5.8	4.3	10.6	14.6	6.2	8.9	
02. (CLYDE) BALLYPATRICK	5.2	4.0	6.0	5.8	10.4	13.3	13.6	14.3	13.7	10.2	5.5	7.1	5.1	9.8	13.9	7.6	9.1	
02. (CLYDE) PAISLEY	4.7	4.0	6.5	7.4	12.1	14.9	15.2	15.4	14.4	10.2	4.5	6.8	5.0	11.5	15.0	7.1	9.7	
03. (ARGYLL) DUNSTAFFNAGE	5.5	4.5	6.4	7.2	11.9	14.7	14.4	15.3	14.3	10.8	5.6	8.0	5.4	11.2	14.6	8.1	9.8	
03. (ARGYLL) TIREE	6.0	5.0	6.7	6.8	10.9	13.4	13.4	14.4	13.6	11.2	7.2	8.3	5.9	10.4	13.8	8.9	9.7	
05. (OUTER HEBRIDES) STORNOWAY	5.3	3.8	6.0	6.5	9.7	12.4	13.3	13.7	13.0	10.2	6.0	7.6	5.0	9.5	13.3	7.9	8.9	
06. (NORTH COAST) WICK	4.0	3.3	5.5	5.8	9.2	11.3	13.5	13.4	13.4	10.1	5.0	6.8	4.3	8.8	13.4	7.3	8.4	
08. (SHETLAND ISLES) LERWICK	3.3	2.8	5.5	5.3	8.3	10.7	12.4	12.3	12.4	9.3	5.6	7.0	3.9	8.1	12.4	7.3	7.9	
09. (MORAY FIRTH) NAIRN	4.0	3.0	6.0	6.1	10.8	12.9	14.5	14.5	13.9	9.0	4.2	6.5	4.4	9.9	14.3	6.6	8.8	
11. (FORTH AND TAY) LEUCHARS	4.0	3.4	5.8	6.4	10.8	12.6	15.2	15.1	14.7	9.8	4.3	6.3	4.4	9.9	15.0	6.8	9.0	

Table 1.2: Tables of monthly total rainfall (mm) calculated over different time periods. The trends in the table are in mm per decade over the indicated time period. See also Figure A.1 and Appendix G.4

Dataset Average 1971-2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. (SOLWAY) NEWTONRIGG	103	71	71	49	58	59	68	73	74	102	106	114	82	56	72	107	79	n. s.
02. (CLYDE) BALLYPATRICK	130	108	97	87	82	88	90	104	99	149	146	146	112	86	98	147	111	n. s.
02. (CLYDE) PAISLEY	142	99	105	61	65	65	71	89	110	132	131	131	115	64	90	131	100	n. s.
03. (ARGYLL) DUNSTAFFNAGE	195	131	144	87	85	88	102	123	152	188	183	199	156	87	126	190	140	n. s.
03. (ARGYLL) TIREE	139	98	97	69	62	65	81	98	112	142	138	138	111	65	97	140	103	3.2
05. (OUTER HEBRIDES) STORNOWAY	142	100	106	72	65	63	73	85	108	134	137	138	116	66	89	136	102	n. s.
06. (NORTH COAST) WICK	74	60	61	49	48	51	59	67	71	86	92	74	65	49	66	84	66	n. s.
08. (SHETLAND ISLES) LERWICK	144	112	112	70	57	59	62	84	110	131	151	146	123	62	85	143	103	n. s.
09. (MORAY FIRTH) NAIRN	49	39	41	39	46	53	54	63	58	63	57	54	43	46	58	58	51	n. s.
11. (FORTH AND TAY) LEUCHARS	67	46	48	43	51	56	58	60	58	74	61	65	54	50	58	67	57	3.3
Climatological Average 1981-2010	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. (SOLWAY) NEWTONRIGG	100	74	76	52	56	59	70	70	76	107	102	105	83	56	72	105	79	n. s.
02. (CLYDE) BALLYPATRICK	126	102	101	92	76	82	86	103	100	143	147	135	110	83	96	142	108	n. s.
02. (CLYDE) PAISLEY	148	105	112	64	67	66	73	93	112	143	126	135	122	66	93	135	104	n. s.
03. (ARGYLL) DUNSTAFFNAGE	197	137	156	89	78	88	105	130	153	198	172	186	163	85	129	185	141	n. s.
03. (ARGYLL) TIREE	137	101	104	73	59	65	81	107	112	149	136	132	114	66	100	139	105	n. s.
05. (OUTER HEBRIDES) STORNOWAY	148	108	117	74	63	62	75	90	110	139	131	129	124	66	91	133	104	n. s.
06. (NORTH COAST) WICK	72	64	66	50	49	53	61	65	74	95	90	75	67	51	67	87	68	n. s.
08. (SHETLAND ISLES) LERWICK	143	121	125	70	53	58	67	84	106	141	146	140	129	61	86	143	105	n. s.
09. (MORAY FIRTH) NAIRN	51	43	45	39	47	54	53	59	63	67	54	51	47	47	58	58	52	4.4
11. (FORTH AND TAY) LEUCHARS	67	42	51	45	49	57	55	58	65	78	65	62	53	50	59	68	58	n. s.
Decadal Average 2006-2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. (SOLWAY) NEWTONRIGG	102	60	61	42	71	65	97	82	63	102	119	147	74	59	81	123	84	n. s.
02. (CLYDE) BALLYPATRICK	150	113	111	68	95	98	117	137	110	160	156	152	124	87	122	156	122	n. s.
02. (CLYDE) PAISLEY	144	96	107	58	67	60	100	115	96	127	162	134	115	62	104	141	106	n. s.
03. (ARGYLL) DUNSTAFFNAGE	197	129	118	99	132	80	106	136	128	206	202	233	148	104	123	214	147	n. s.
03. (ARGYLL) TIREE	134	103	83	70	89	66	92	106	89	149	146	166	107	75	95	154	108	n. s.
05. (OUTER HEBRIDES) STORNOWAY	143	89	101	76	90	52	77	99	92	137	130	163	111	73	89	143	104	n. s.
06. (NORTH COAST) WICK	72	55	49	45	53	44	62	91	62	95	85	66	59	47	72	82	65	n. s.
08. (SHETLAND ISLES) LERWICK	165	126	91	63	67	47	80	109	101	134	152	145	127	59	97	144	107	n. s.
09. (MORAY FIRTH) NAIRN	27	41	40	41	54	63	69	83	61	74	54	72	36	53	71	67	56	n. s.
11. (FORTH AND TAY) LEUCHARS	64	44	46	36	59	63	92	84	56	75	73	67	51	53	77	72	63	n. s.
Data for Year 2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. (SOLWAY) NEWTONRIGG	161	99	58	66	88	108	73	97	86	37	95	66	106	87	85	66	86	
02. (CLYDE) BALLYPATRICK	229	116	68	91	48	71	106	99	73	60	109	80	137	70	93	83	96	
02. (CLYDE) PAISLEY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
03. (ARGYLL) DUNSTAFFNAGE	300	186	108	93	98	65	155	164	230	66	128	179	198	85	183	124	148	
03. (ARGYLL) TIREE	186	154	92	77	60	55	145	124	137	37	117	131	144	64	136	95	110	
05. (OUTER HEBRIDES) STORNOWAY	143	146	86	55	63	83	143	92	141	38	98	112	125	67	125	83	100	
06. (NORTH COAST) WICK	142	76	34	64	35	39	105	-	-	45	53	59	84	46	-	52	-	
08. (SHETLAND ISLES) LERWICK	187	118	79	57	46	48	115	108	110	56	133	159	128	50	111	116	102	
09. (MORAY FIRTH) NAIRN	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
11. (FORTH AND TAY) LEUCHARS	158	35	24	83	19	90	57	32	40	51	35	45	72	64	43	43	56	

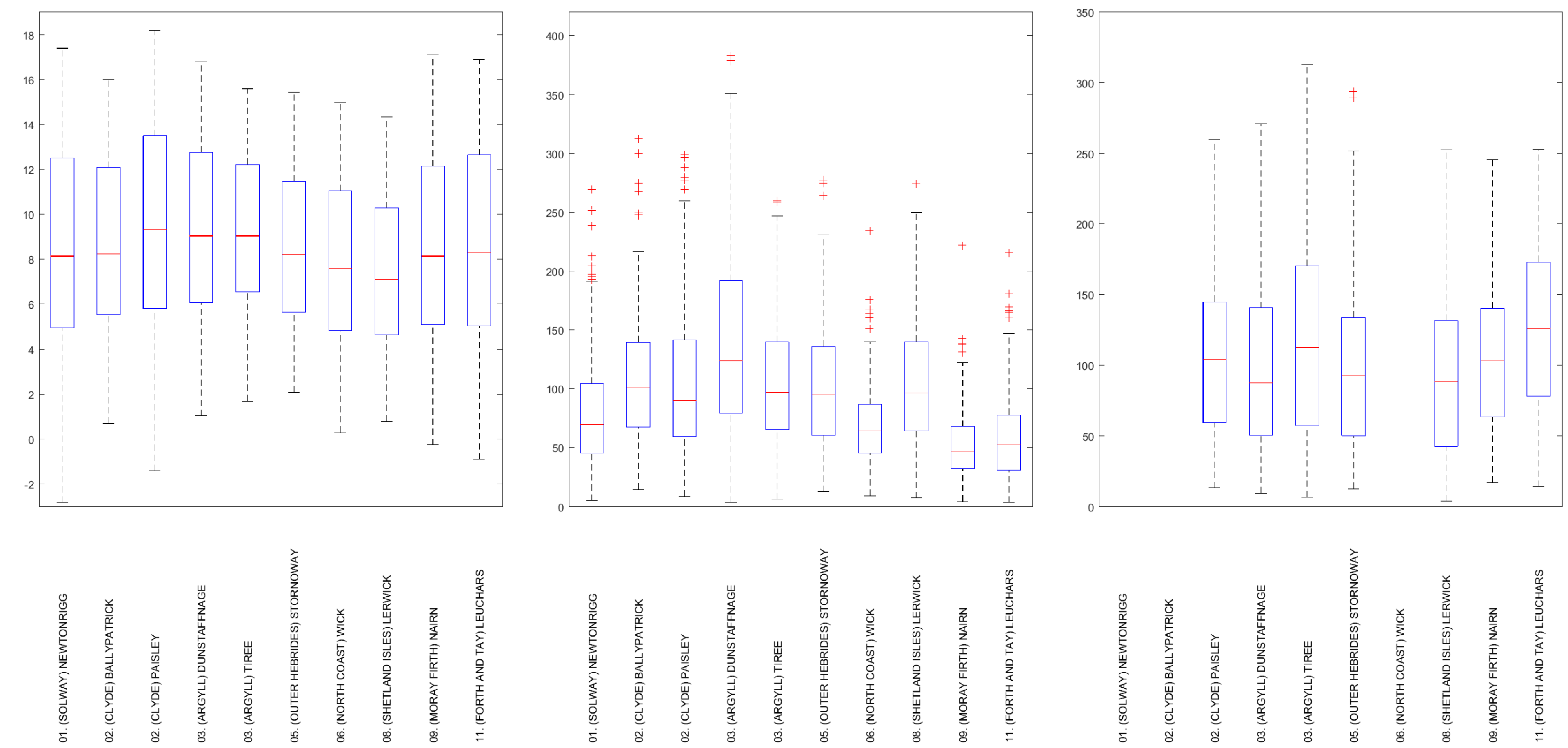
Table 1.3: Tables of monthly total sunshine (hours) calculated over different time periods. The trends in the table are in hours per decade over the indicated time period. See also Figure A.1 and Appendix G.4

Dataset Average 1971-2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. (SOLWAY) NEWTONRIGG	35	58	91	134	190	183	165	150	112	84	53	34	61	169	142	57	108	n. s.
02. (CLYDE) BALLYPATRICK	42	67	93	158	195	166	145	139	109	86	54	31	67	173	131	57	107	n. s.
02. (CLYDE) PAISLEY	37	63	97	140	181	165	163	147	116	83	53	32	66	162	142	56	106	3.4
03. (ARGYLL) DUNSTAFFNAGE	34	55	82	135	196	169	142	141	101	74	45	33	57	167	128	51	101	n. s.
03. (ARGYLL) TIREE	38	65	111	173	220	192	163	156	121	84	46	32	71	195	147	54	117	n. s.
05. (OUTER HEBRIDES) STORNOWAY	32	60	101	146	193	157	128	126	104	79	41	26	65	165	120	49	99	n. s.
06. (NORTH COAST) WICK	42	71	103	129	176	154	134	136	113	87	50	30	72	153	128	56	102	n. s.
08. (SHETLAND ISLES) LERWICK	25	54	92	131	171	142	119	125	98	67	34	17	57	148	114	39	90	n. s.
09. (MORAY FIRTH) NAIRN	46	76	107	138	180	153	152	144	115	87	56	35	76	157	137	59	107	n. s.
11. (FORTH AND TAY) LEUCHARS	59	80	122	157	195	182	182	166	132	102	78	51	87	178	160	77	125	n. s.

Climatological Average 1981-2010	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. (SOLWAY) NEWTONRIGG	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	n. s.
02. (CLYDE) BALLYPATRICK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	n. s.
02. (CLYDE) PAISLEY	38	67	99	135	180	159	154	147	115	85	54	33	68	158	139	57	105	4.4
03. (ARGYLL) DUNSTAFFNAGE	34	55	82	135	196	169	142	141	101	74	45	33	57	167	128	51	101	n. s.
03. (ARGYLL) TIREE	38	67	108	170	230	196	166	157	123	85	46	35	71	198	149	55	118	n. s.
05. (OUTER HEBRIDES) STORNOWAY	33	58	96	143	196	158	127	124	102	78	41	28	62	166	117	49	99	n. s.
06. (NORTH COAST) WICK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	n. s.
08. (SHETLAND ISLES) LERWICK	27	55	93	131	179	144	122	126	100	68	33	18	58	151	116	40	91	5.5
09. (MORAY FIRTH) NAIRN	45	75	102	138	183	153	150	142	112	85	54	35	74	158	135	58	106	n. s.
11. (FORTH AND TAY) LEUCHARS	62	84	124	156	199	183	184	172	136	106	78	51	90	179	164	79	128	n. s.

Decadal Average 2006-2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. (SOLWAY) NEWTONRIGG	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	n. s.
02. (CLYDE) BALLYPATRICK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	n. s.
02. (CLYDE) PAISLEY	40	65	107	168	186	170	186	148	121	89	57	34	71	174	152	60	114	14.6
03. (ARGYLL) DUNSTAFFNAGE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	n. s.
03. (ARGYLL) TIREE	40	67	122	199	209	197	167	142	112	91	45	34	76	202	140	57	119	n. s.
05. (OUTER HEBRIDES) STORNOWAY	32	53	103	156	188	155	136	103	93	71	37	23	63	166	111	44	96	n. s.
06. (NORTH COAST) WICK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	n. s.
08. (SHETLAND ISLES) LERWICK	27	51	100	135	186	124	112	119	86	67	35	20	59	148	105	41	88	-24.6
09. (MORAY FIRTH) NAIRN	53	74	117	157	188	143	160	134	115	89	59	40	82	163	136	63	111	n. s.
11. (FORTH AND TAY) LEUCHARS	57	79	127	170	191	148	161	145	130	94	78	52	88	170	145	74	119	n. s.

Data for Year 2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. (SOLWAY) NEWTONRIGG	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
02. (CLYDE) BALLYPATRICK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
02. (CLYDE) PAISLEY	26	81	127	157	251	153	118	140	94	107	79	19	78	187	117	68	113	
03. (ARGYLL) DUNSTAFFNAGE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
03. (ARGYLL) TIREE	18	87	104	199	269	196	120	145	76	98	51	18	70	221	113	56	115	
05. (OUTER HEBRIDES) STORNOWAY	20	83	116	143	212	133	76	126	94	107	57	24	73	163	99	62	99	
06. (NORTH COAST) WICK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
08. (SHETLAND ISLES) LERWICK	35	87	84	157	183	199	81	92	107	127	48	12	68	180	93	62	101	
09. (MORAY FIRTH) NAIRN	46	72	118	141	196	134	122	191	127	132	77	39	78	157	147	83	116	
11. (FORTH AND TAY) LEUCHARS	30	90	111	143	197	141	166	158	114	95	96	29	77	160	146	73	114	



(a) Air Temperature (°C)

(b) Rainfall (mm)

(c) Sunshine (hours)

Figure 1.1: Statistical Boxplots of (a) monthly average air temperature (°C), (b) monthly total rainfall (mm) and (c) monthly total sunshine (h) for the climatological period 1981–2010 at selected locations in each Scottish Marine Region (Figure A.1). For this dataset, no data are available in the West Highlands, Orkney Islands or North East regions. Note that due to a shorter rainfall records at Ballypatrick, data are referenced to the base period of 1989–2010. For sunshine data, there were not enough data at Newton Rigg, Ballypatrick or Wick stations to present a climatological summary. Label numbers and names in parenthesis refer to the Scottish Marine Region that each station lies within.

Moist air from the Atlantic Ocean arrives first on the high ground along the west coast of Scotland. For this reason, the west coast experiences much more rain than the east coast. There are large areas of western Scotland that have an annual total rainfall of greater that 2000 mm, whereas on the east coast of Scotland annual rainfall totals are typically less than 1000 mm (*Jenkins et al.*, 2007; *UK Meteorological Office*, 2009). The amount of rain falling on Scotland each year is the highest in the UK and one of the highest in Europe (*European Environment Agency*, 2009).

The station with the highest average monthly rainfall is in the Argyll region (141 mm at Dunstaffnage, Figure1.1b and Table 1.2), and the most extreme monthly rainfalls observed, with more than 417 mm falling in December 2011 (dotted line in Figure 1.5). The lowest average monthly rainfall, observed in the Moray Firth region, was less than half of that, at 52 mm (Table 1.2).

Although it might be assumed that the driest places are the sunniest due to the lack of clouds, sunshine and rainfall are not exactly correlated, as cloud or fog can obscure the sun without leading to rainfall. Sunshine hours tend to be highest in May at all stations across Scotland (Table 1.3). Therefore, while it can be rainy on the west coast there is also quite a lot of sunshine at some sites: Tiree, in the Argyll region (Figure 1.1c), has similar average sunshine to Leuchars, in the Forth & Tay region, at around 120 hours per month (h mo^{-1}). The lowest monthly sunshine totals (91 h mo^{-1}) are found in the northernmost site, Lerwick, in the Shetland Isles region (Table 1.3).

There are no weather records presented for the West Highlands or North East regions (Figure A.1), as there are no data records available in this dataset for these regions. However, there are common trends across regions which make it likely that the weather patterns in the West Highlands region will be similar to the adjacent regions of Argyll and Outer Hebrides. The patterns and trends for the weather in the North East region are also likely to be similar to the neighbouring Moray Firth and Forth & Tay regions. Air temperature, in particular, shows a very consistent pattern across all of the Scottish Marine Regions. The rainfall data indicate that rainfall patterns can show more local variability but there are still some consistent patterns and trends with similarities between adjacent regions. The most variable of the meteorological datasets presented here is the sunshine data, for which there is poorer spatial cover. From the ten stations chosen here, only six of them have sunshine data collected in the last decade.

1.2 Conditions Observed during 2016

2016 was, overall, a warm year, with average temperatures remaining above, but close to, normal (Figure 1.2a). The warmest regions in 2016 were Argyll and the northern regions of the North Coast and the Shetland Isles. Annual mean air temperatures at both Dunstaffnage and Wick were 0.5 °C higher than normal (Table 1.1).

Overall, the latter part of the year was the warmest period, as February and April were cold months (Figure 1.2b). However, there was also a cold snap in November 2016 which brought some unusually cold conditions to most of the southern regions (between 1.1 °C and 2.3 °C lower than normal, Table 1.1 and Figure 1.3). In contrast, December 2016 was extremely warm, with temperatures between 2.1 °C and 2.9 °C above the climatological average for this month.

Rainfall for 2016 was generally less than, but close to, normal (Figure 1.4a), so overall 2016 was a dry year. The station with the lowest rainfall anomaly in 2016 was Ballypatrick, in the Clyde region, where the average rainfall for that year was 96 mm per month (mm mo^{-1}), 12 mm mo^{-1} less than the climatological average (Table 1.2).

Examining the month by month pattern of rainfall (Figure 1.5), it is clear that the low annual rainfall in 2016 was due to the latter half of the year being dry, with October in particular being an extremely dry month. Stations on the west coast received around 100 mm less in October 2016 than expected (Table 1.2). In contrast, January was wetter than normal, as was July, particularly in the north-west and northern regions.

The data for sunshine are more sparse and variable than either air temperature or rainfall. However, the data for 2016 show that almost all stations experienced more sunshine than normal (Figure 1.6a). The station at Leuchars, in the Forth & Tay region, was a key exception to this; sunshine values in 2016 being much lower than normal at this station, with an average of 14 hours less sunshine per month (Table 1.3). Examining the month by month pattern of sunshine (Figure 1.6b), it is clear that the spring and autumn were sunny across all of the regions. Record high sunshine anomalies were seen at Lerwick, in the Shetland Isles, in October 2016, with almost 60 hours more sunshine than normal (Table 1.3) and the Moray Firth region was also extremely sunny (Figure 1.7) in October 2016.

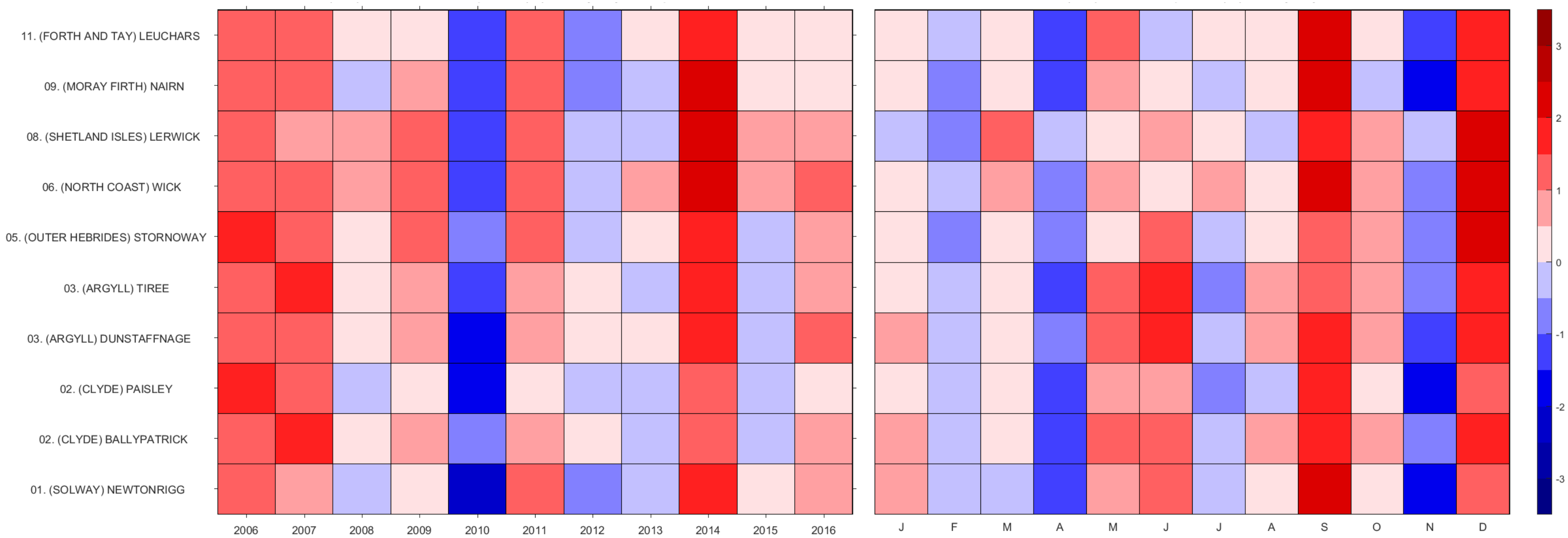
1.3 Trends and Variability over the period 2006-2016

Examining the data from all ten meteorological stations around Scotland over the last 10 years is useful in order to reveal common trends (Figure 1.2a). Since 2006, there has been much more variablity than was observed previously (not shown). Annual mean air temperatures were extremely low at all stations in 2010. The years 2012, 2013 and 2015 were also cooler than normal, although not to the same extent as in 2010.

Annual mean air temperatures in 2014 were unusually high at all stations. This year was the warmest year on record in all of the regions except the Clyde, and constitutes an extreme event. Although the warmest year on average was 2014, none of the individual months in that year were particularly extreme (Figure 1.2a). April 2011, March 2012 and May 2008 were notably warm individual months in the past decade.

Very low air temperature values were observed in December 2010 at a number of stations. In the Argyll region, at Dunstaffnage, a record low monthly average temperature of 1 °C was measured, which is 4.2 °C lower than average, and in the Forth & Tay region, at Leuchars, a record low monthly average temperature of -0.9 °C was measured, which is 4.5 °C lower than the climatological average.

Rainfall varies from year to year and there is a high degree of variability between sites, as well as between years. Over the last decade, average annual rainfall was at its highest during 2015 (Figure 1.4a). Record high rainfall was recorded at



(a) Decade 2006–2016

(b) Monthly for 2016

Figure 1.2: Normalised anomalies (σ) of monthly average air temperature (°C) for (a) the years 2006–2016 and (b) the months in 2016 (all plotted relative to 1981–2010 base period). Anomalies are presented for selected stations within the Scottish Marine Regions. The anomalies are normalised with respect to the standard deviation of each time series (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds = positive/warm; blues = negative/cool. For this dataset, no data are available in the West Highlands, Orkney Islands or North East regions.

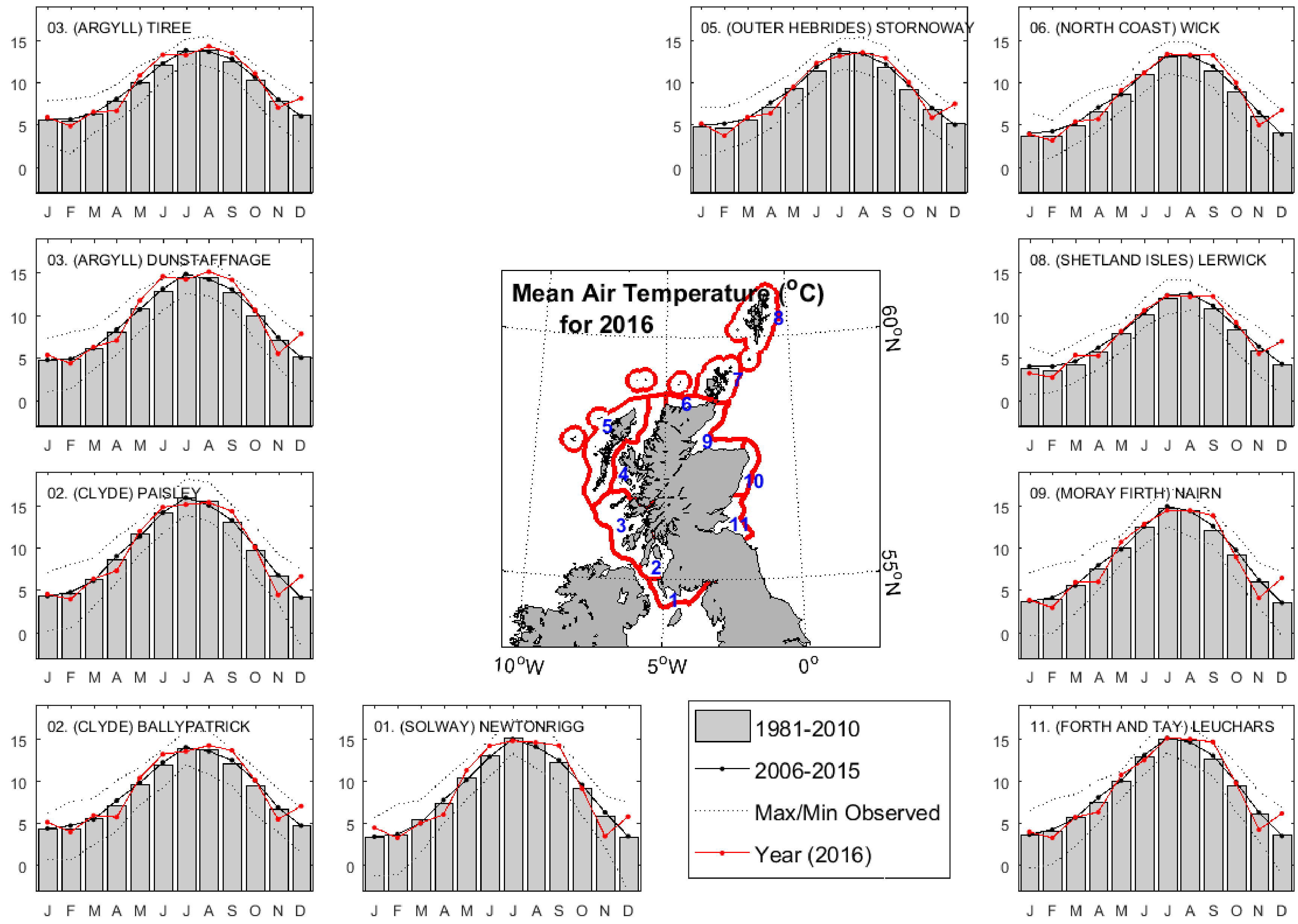
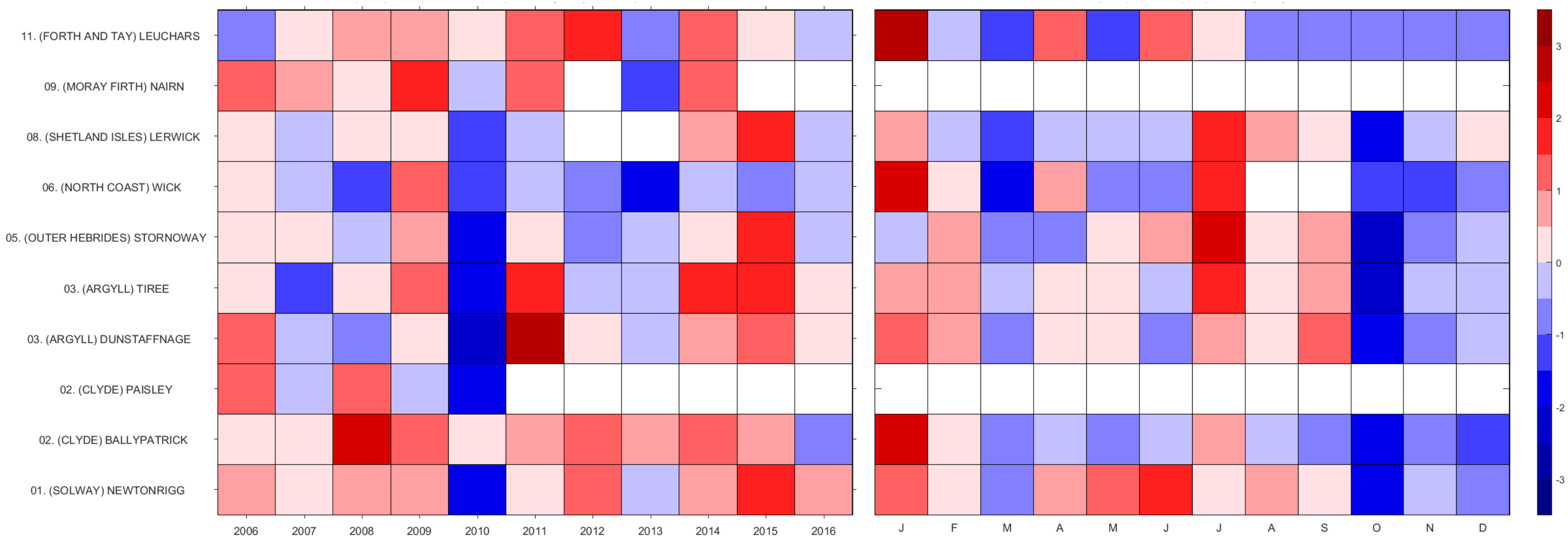


Figure 1.3: Summary of monthly average air temperature (°C) for 2016, by Scottish Marine Region. Plots show air temperature during 2016 compared to the long-term average pattern (calculated for the period 1981–2010) and the average over the last decade (2006–2015). X-axis of each graph is month. Central map shows the Scottish Marine Regions. For this dataset, no data are available in the West Highlands, Orkney Islands or North East regions.



(a) Decade 2006–2016

(b) Monthly for 2016

Figure 1.4: Normalised anomalies (σ) of monthly total rainfall (mm) for (a) the years 2006–2016 and (b) the months in 2016 (all plotted relative to 1981–2010 base period). Anomalies are presented for selected stations within the Scottish Marine Regions. The anomalies are normalised with respect to the standard deviation of each time series (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds = positive/wet; blues = negative/dry. For this dataset, no data are available in the West Highlands, Orkney Islands or North East regions. Note that, due to a shorter rainfall record at Ballypatrick, data are referenced to the base period of 1989–2010.

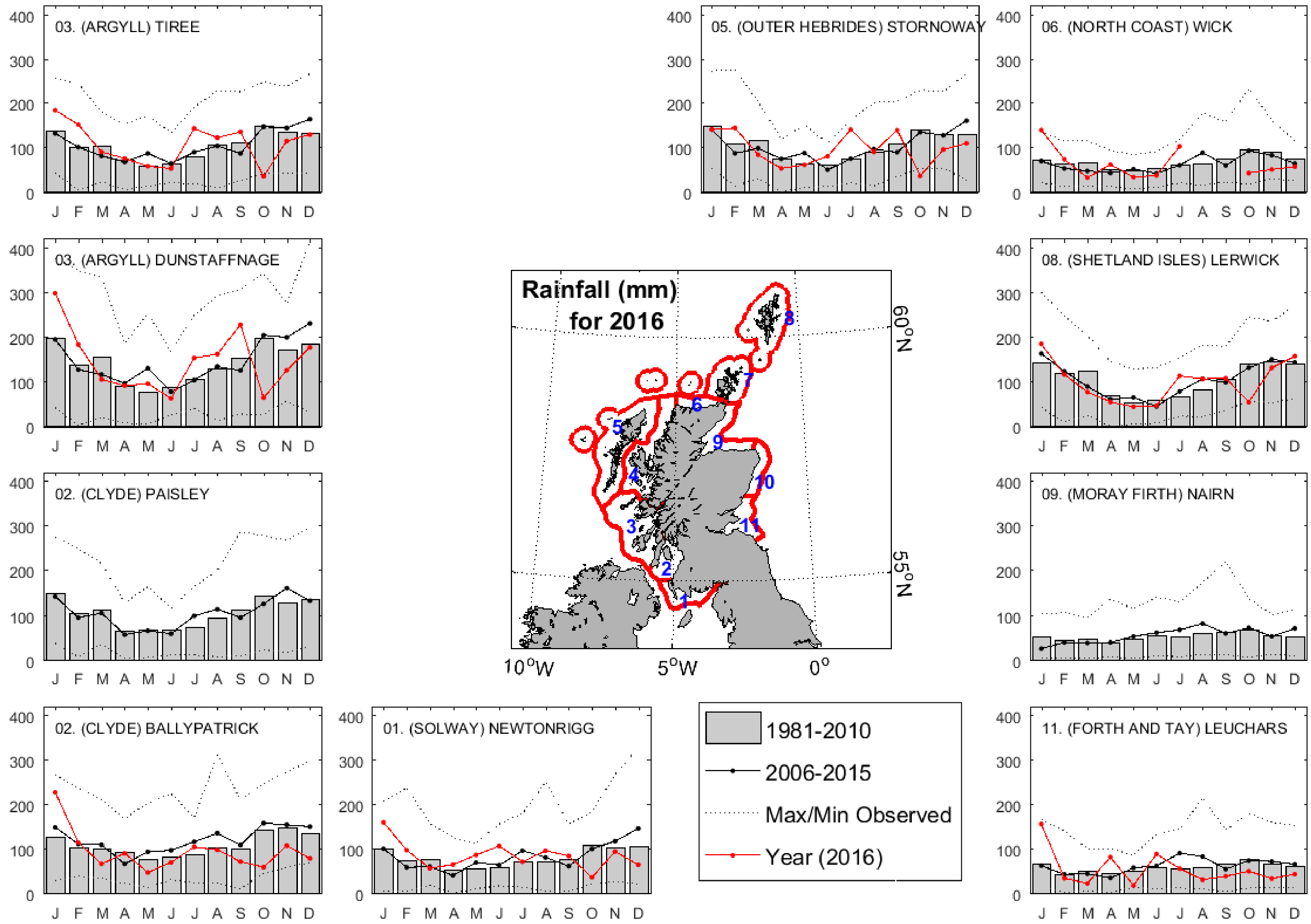
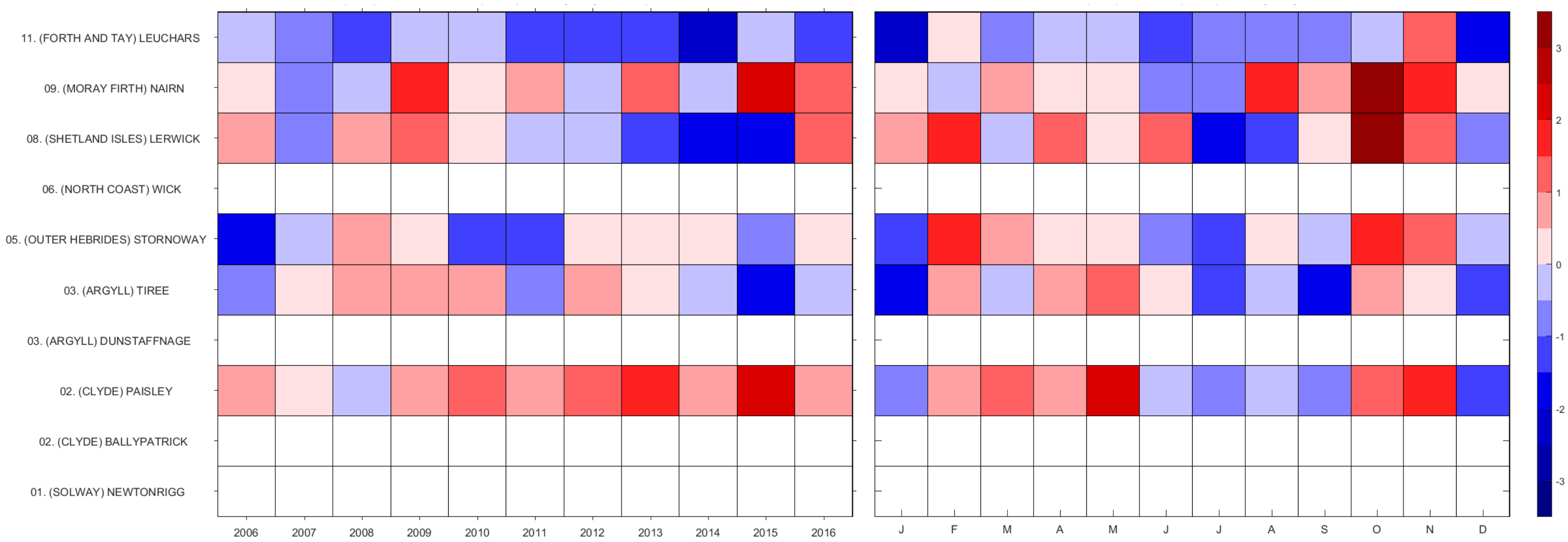


Figure 1.5: Summary of monthly total rainfall (mm) for 2016, by Scottish Marine Region. Plots show rainfall during 2016 compared to the long-term average pattern (calculated for the period 1981–2010) and the average over the last decade (2006–2015). X-axis of each graph is month. Central map shows the extent of each of the Scottish Marine Regions. For this dataset, no data are available in the West Highlands, Orkney Islands or North East regions. Note that, due to a shorter rainfall record at Ballypatrick, data are referenced to the base period of 1989–2010.



(a) Decade 2006–2016

(b) Monthly for 2016

Figure 1.6: Normalised anomalies (σ) of monthly total sunshine (hours) for (a) the years 2006–2016 and (b) the months in 2016 (all plotted relative to 1981–2010 base period). Anomalies are presented for selected stations within the Scottish Marine Regions. The anomalies are normalised with respect to the standard deviation of each time series (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds = positive/warm; blues = negative/cool. For this dataset, no data are available in the West Highlands, Orkney Islands or North East regions. For sunshine data, there were not enough data at Newton Rigg, Ballypatrick or Wick to present a climatological summary. At Dunstaffnage, although climatological records are calculated, there were no recent sunshine data.

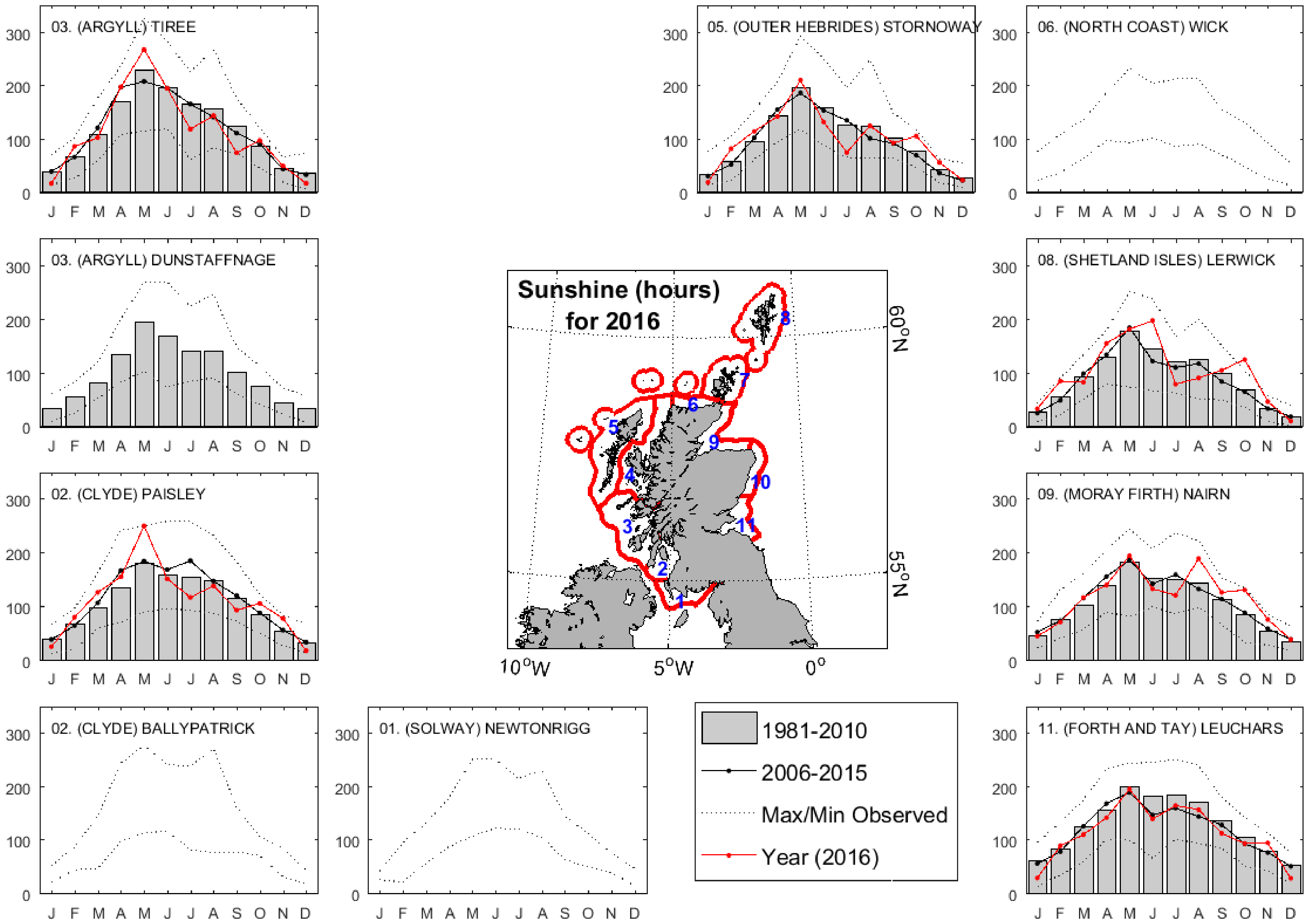


Figure 1.7: Summary of monthly total sunshine (hours) for 2016, by Scottish Marine Region. Plots show sunshine during 2016 compared to the long-term average pattern (calculated for the period 1981–2010) and the average over the last decade (2006–2015). X-axis of each graph is month. Central map shows the extent of each of the Scottish Marine Regions. For this dataset, no data are available in the West Highlands, Orkney Islands or North East regions. Sunshine records at Newton Rigg, Ballypatrick, Dunstaffnage and Wick were too short to be included.

Dunstaffnage in December 2011: 239 mm more rain fell than normal (418 mm in total). The most unusual rainfall occurred in the Solway region in December 2015, when the monthly rainfall at Newton Rigg was 329 mm, more than three times the average for December (105 mm). 2010, as well as being the coldest, was also the driest year in the last 10 years, with much lower rainfall than normal at most stations.

The sunniest year of the last decade was 2009, with Lerwick and Nairn being the sunniest stations in this year (Figure 1.6a). During the last decade, the station with highest sunshine hours was Nairn, with 246 hours recorded in the month of May 2009. In April 2015, Paisley was also unusually sunny, with 243 monthly sunshine hours; more than 100 hours of sunshine above that expected.

The conditions observed at the Scottish meteorological stations presented here are consistent with the pattern observed across the UK. 2016 was a warm year, but not exceptional, with rainfall values slightly below average and sunshine just above average (*UK Meteorological Office*, 2017a). Over the UK as a whole, 2010 was the twelfth-coldest year in the last 100 years and the coldest since 1986 (*UK Meteorological Office*, 2013). The low annual average is a result of having a sequence of cold winters, so there was cold weather in January and February of 2010 and then again at the end of the year in late November, finishing with the record low temperatures in December 2010.

1.4 Long-Term Trends

UK Met Office data (*UK Meteorological Office*, 2017b) show that, on average across the whole of Scotland, both temperature and rainfall have been increasing, whereas sunshine data are more variable and show no long-term trend (Figure 1.8). The warming trend for the period 1910–2016 is 0.06 °C per decade (*UK Meteorological Office*, 2017b). This is consistent with the long-term trends that are seen in global temperatures. The time series also shows a multidecadal pattern of variability, with average temperatures decreasing from 1910 to 1920, warming from 1920 to 1950, cooling 1950 to 1980, and then subsequent warming. Since 1981 the average temperature of Scotland has been warming at the slightly higher rate of 0.2 °C per decade.

The Central England Temperature (CET) time series is the longest instrumental record of temperature in the world (*Parker et al.*, 1992). The data cover an area in a region of the southern UK between Bristol, Lancashire and London and records began in 1659. This dataset, up to and including the year 2016, shows that the warmest year on record was 2014 (Figure 1.9), and the years 2006 and 2011 are among the top 10 warmest years on record. The linear trend in CET is 0.03 °C per decade since records began, and for the period 1981–2016 the trend has been at the higher rate of 0.2 °C per decade. As the CET time series extends back as far as 1659, this dataset provides very strong evidence that the observations presented in this report were made at a time of exceptionally high temperatures.

The data from within each of the Scottish Marine Regions (Figure 1.10) show that there is some variability between regions. For example, 2014 was not the warmest year on record in the Clyde (Figure 1.10). All of the datasets show that there was a

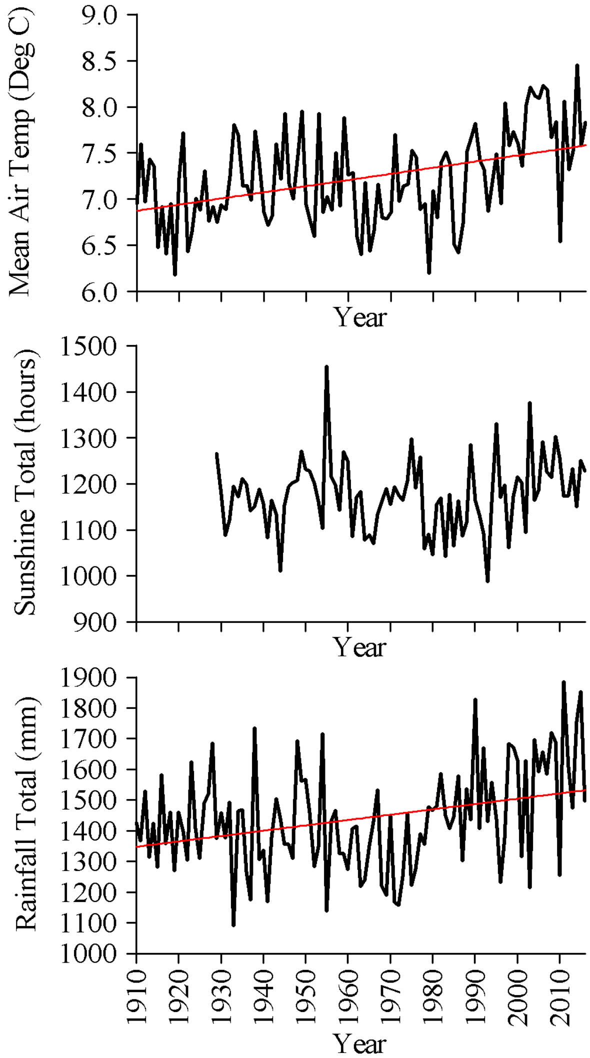


Figure 1.8: Time series of annual mean air temperature (°C), annual total sunshine (hrs) and rainfall (mm) since 1910, averaged for Scotland. Source UK Meteorological Office (*UK Meteorological Office*, 2017b).

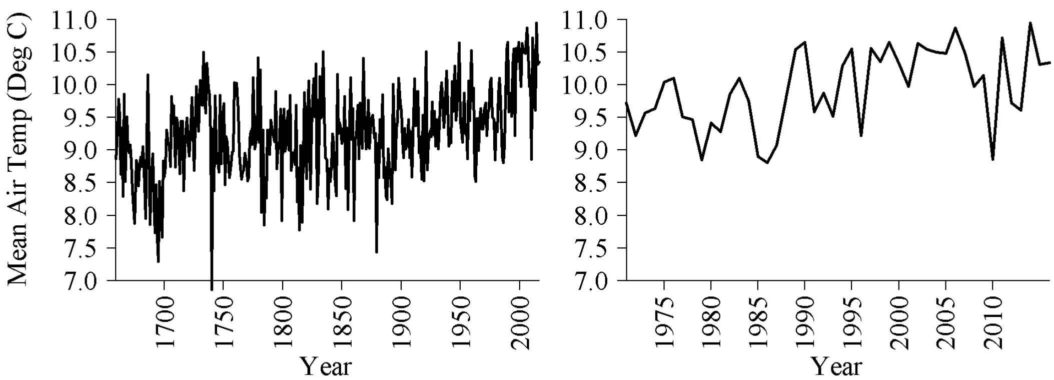


Figure 1.9: Time series of Central England Air Temperature (°C; *Parker et al.*, 1992) since records began in 1659 (left panel) and since 1971 (right panel). Data Source: Mean Central England Temperature provided by the UK Meteorological Office, Hadley Centre for Climate Change, UK (*Hadley Centre for Climate Change*, 2017).

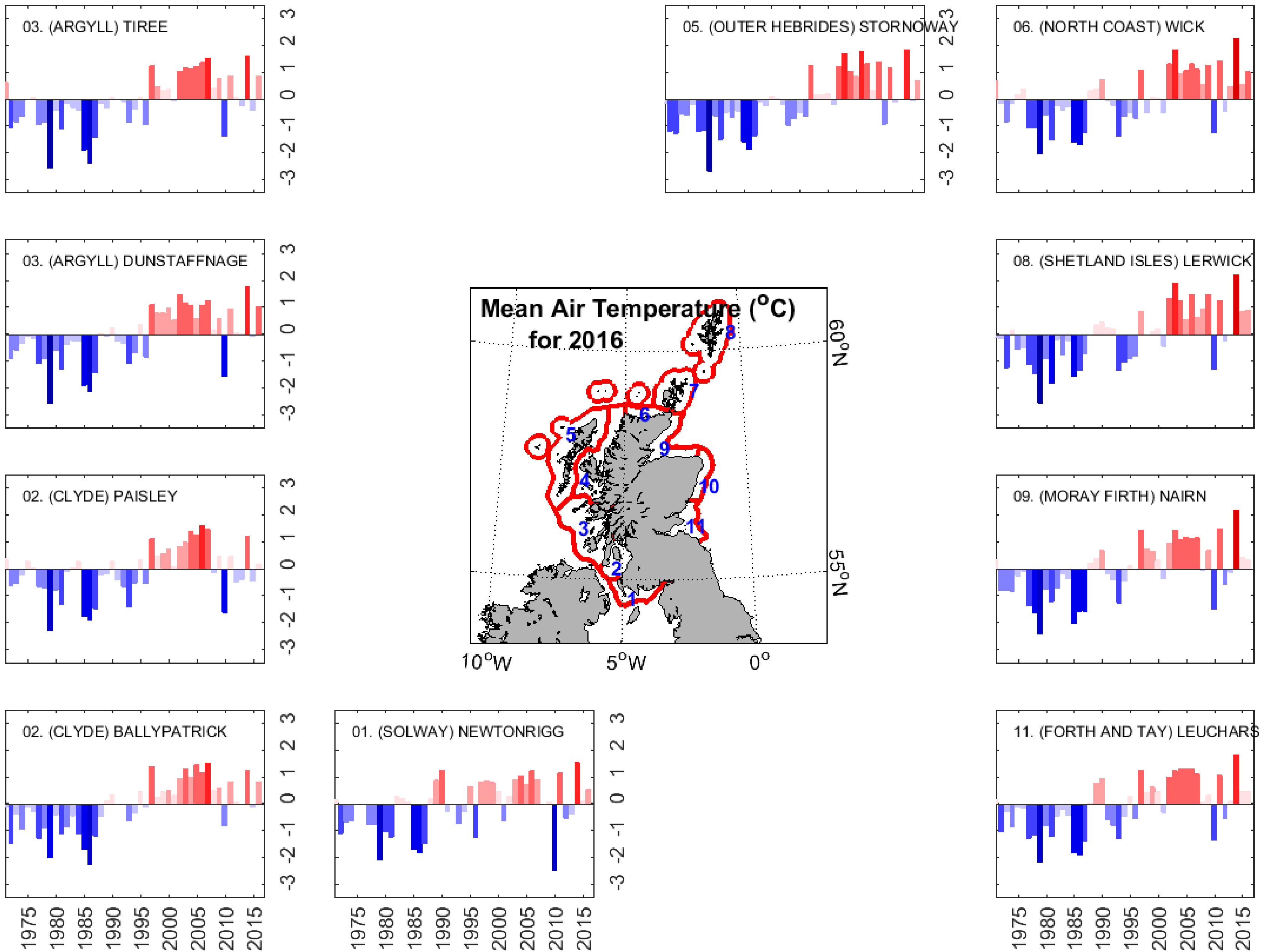


Figure 1.10: Time series of normalised annual anomalies (σ) of monthly average air temperature (°C) up to 2016 (relative to 1981–2010 base period) for ten of the Scottish Marine Regions. X-axis of each plot is year. The anomalies are normalised with respect to the standard deviation (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds = positive/warm; blues = negative/cool. Central map shows the extent of each of the Scottish Marine Regions. For this dataset, no data are available in the West Highlands, Orkney Islands or North East regions.

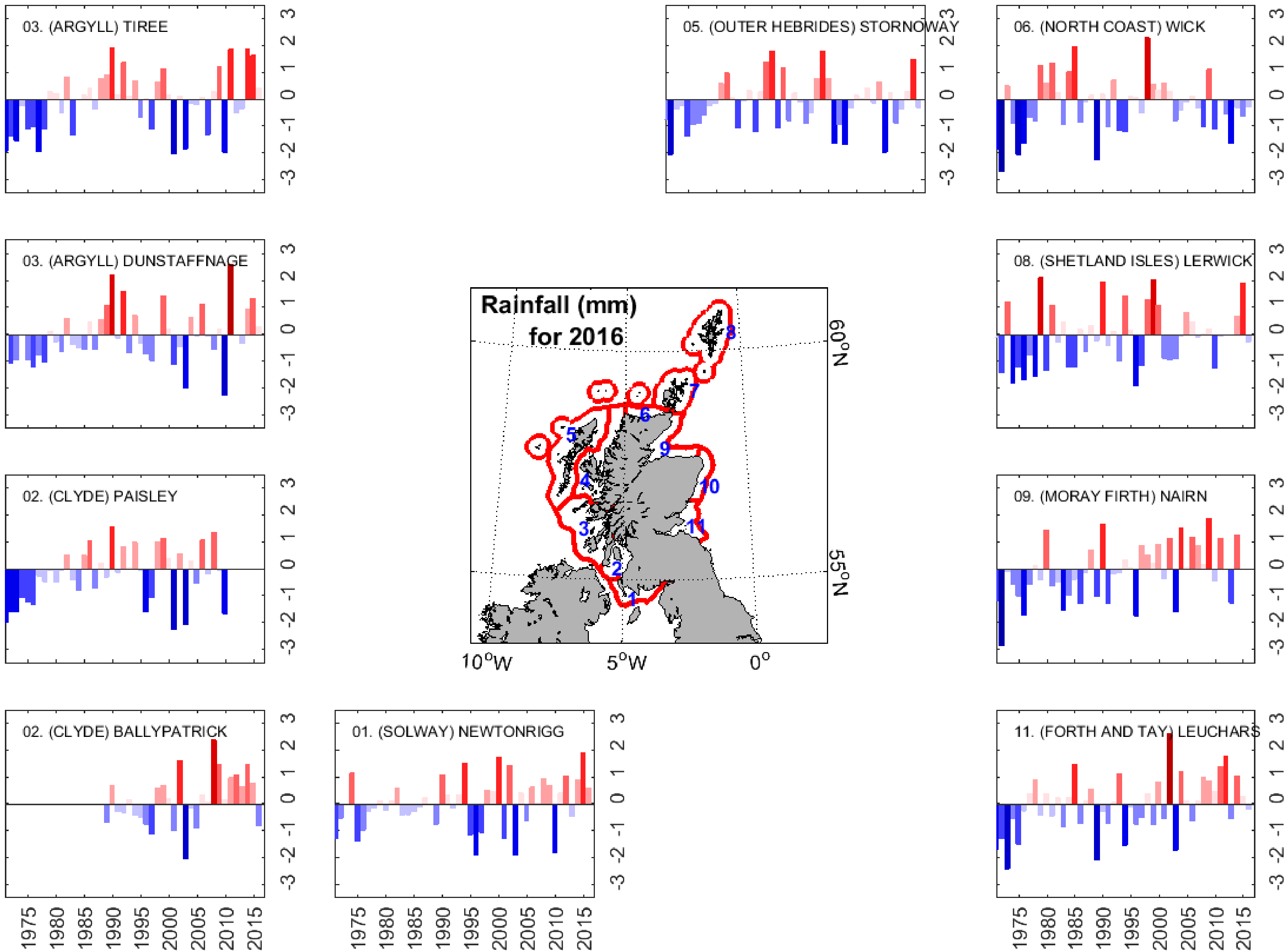


Figure 1.11: Time series of normalised annual anomalies (σ) of monthly total rainfall (mm) up to 2016 (relative to 1981–2010 base period) for ten of the Scottish Marine Regions. X-axis of each plot is year. The anomalies are normalised with respect to the standard deviation (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds = positive/wet; blues = negative/dry. Central map shows the extent of each of the Scottish Marine Regions. For this dataset, no data are available in the West Highlands, Orkney Islands or North East regions. Note that rainfall records at Ballypatrick began in 1989.

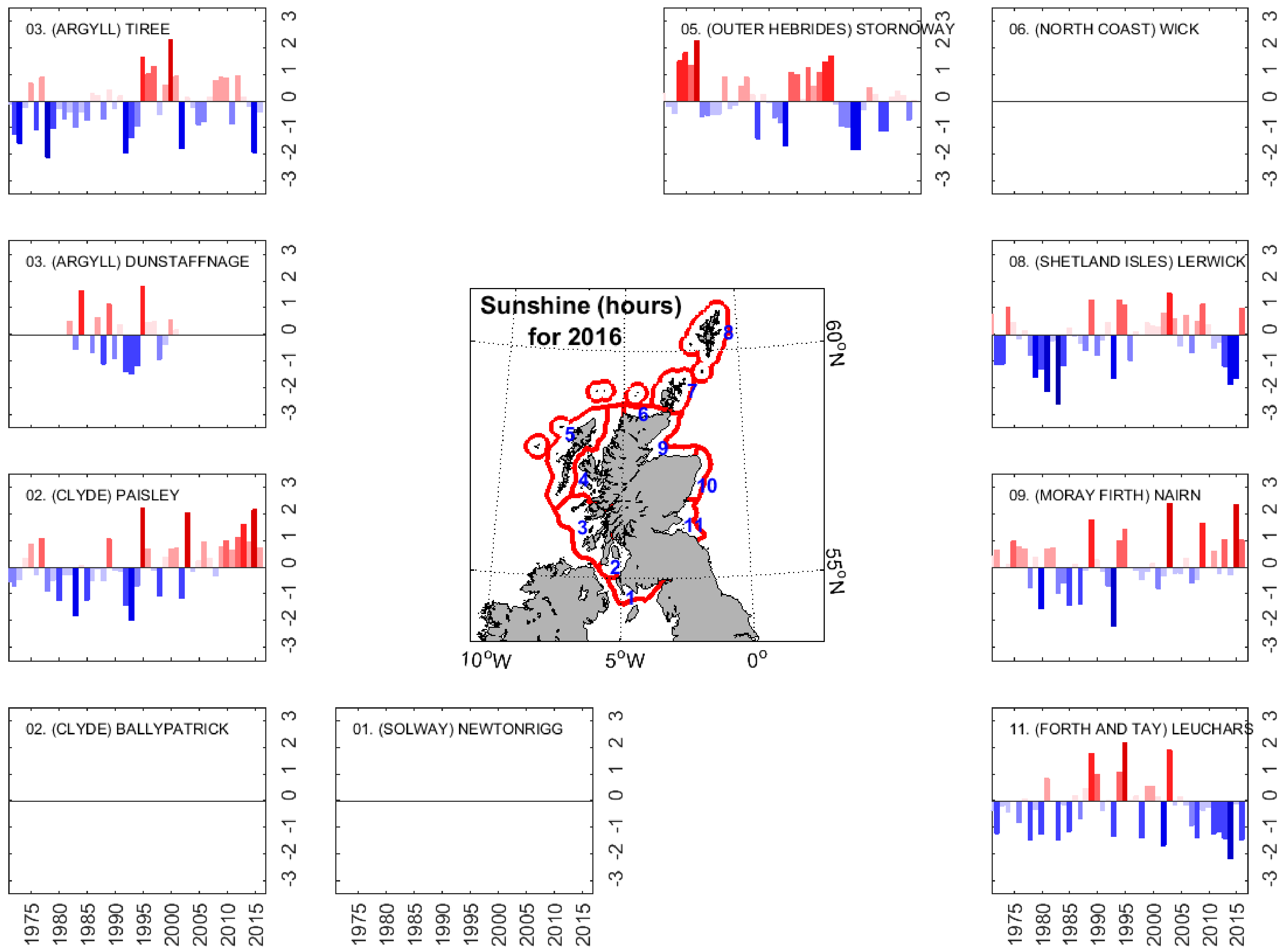


Figure 1.12: Time series of normalised annual anomalies (σ) of monthly total sunshine (hours) up to 2016 (relative to 1981–2010 base period) for ten of the Scottish Marine Regions. X-axis of each plot is year. The anomalies are normalised with respect to the standard deviation (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds = positive/sunny; blues = negative/less sunny. Central map shows the extent of each of the Scottish Marine Regions. For this dataset, no data are available in the West Highlands, Orkney Islands or North East regions. Sunshine records at Newton Rigg, Ballypatrick, Dunstaffnage and Wick were too short to be included in these figures.

warming trend in air temperatures for the period of observation. For those where a significant trend can be calculated, the warming over the observational period has been at rate of between 0.15 and 0.27 °C per decade (Table 1.1).

Annual total rainfall for Scotland also shows similar multidecadal variability to that of air temperature (Figure 1.8). The long-term trend in annual total rainfall is an increase at a rate of 17 mm per decade, but since 1970 there has been a more rapid increase at a rate of approximately 78 mm per decade (Figure 1.8). This is equivalent to an increase of 6.5 mm per decade for monthly rainfall values. However, within the rainfall dataset analysed within this report, there are only a few significant trends in annual total rainfall, with the one significant trend noted in the 1981-2010 climatology showing an increase of 4.4 mm per decade at Nairn, in the Moray Firth region (Table 1.2).

On the whole for Scotland, for the last 5 years, sunshine hours have been slightly higher than the 1981–2010 normal (*UK Meteorological Office*, 2017b). Sunshine hours recorded in each of the Scottish Marine Regions are very variable throughout the period, with few significant trends (Table 1.3) and with some marked differences between stations (Figure 1.12). Some stations, for example Leuchars in the Forth & Tay region, have shown a pattern of fewer sunshine hours than normal over the last decade, whereas others, such as Paisley in the Clyde region, have shown the opposite, with sunshine hours consistently above normal, in the last decade. The only station with a significant trend in sunshine hours for the period 1971–2010, was Paisley, where there has been an increase in monthly sunshine of 3.4 hours per decade.

Summary

- **Monthly mean values of air temperature, sunshine hours and rainfall are presented for 10 meteorological stations around Scotland, analysed by Scottish Marine Region.**
- **The meteorological data sets presented here cover the time period from 1981 to present day, although there are some gaps in the coverage, in particular for the sunshine data.**
- **2016 was a warm year overall, but not as warm as 2014. Annual average air temperatures in 2016 were reduced by cooler conditions during April and November. However, December was unusually warm.**
- **2016 was drier than normal, with October 2016 being an unusually dry month.**
- **The decade 2006–2015 was characterised by mean air temperatures that were higher than normal. However, 2010 was an unusually cold year and in contrast 2014 was the warmest on record for most stations.**
- **As well as being cold, 2010 was a dry year, with most of the stations having much lower than normal rainfall. 2013 also had very low rainfall in the north and east of Scotland.**

- **In the Clyde region, the last decade has been sunnier than normal, whereas in recent years in the Shetland Isles and Forth & Tay regions there has been less sunshine than normal.**
- **The long-term trend (1910 – 2016) is one of increasing air temperature and rainfall over Scotland.**

2 River Flow

Overview

The runoff of fresh water from the land into the sea via rivers can reduce the salinity of coastal waters. This in turn can affect mixing and circulation, and therefore must be considered in the context of variability within Scottish Seas.

Here, we present a summary of river flow from a network of gauged rivers across Scotland. The rivers chosen give reasonable spatial coverage and capture the largest and most representative river flows.

Analysis

River flow data have been analysed by Scottish Marine Region using data from the National River Flow Archive (NRFA) dataset. Recent conditions are referenced to a climatological average period calculated over the thirty years between 1981 and 2010. More information on the datasets can be found in Appendix B.

2.1 Spatial Patterns

In examining the river flow data, it is essential to be aware of the limited amount of monitoring. As detailed in Appendix B, only a small percentage of the flow into Scotland's seas is actually measured. Comparison with model data (*Cole et al.*, 2014) shows that the gauged network does catch the major riverine inputs, and that the variability in these monitored rivers is thought to be representative of the true variability.

Gauged river flow provides one estimate of freshwater input into the coastal zone. However, a large proportion of total freshwater flow into Scottish waters is not gauged. The ungauged proportion is more significant on the west coast of Scotland than on the east coast, and this is partly due to the remote nature of the region and the distribution of the freshwater discharge across a greater number of smaller rivers (Figure B.2).

It is estimated that only 36 % of the runoff from the major rivers on the west coast of Scotland is gauged, which represents approximately 20 % of the total estimated runoff in the west coast region. This is due to land runoff also being a major contributor to freshwater in put on the west coast. On the east coast the gauging of river flow is much more complete. There are 17 rivers with an annual mean flow

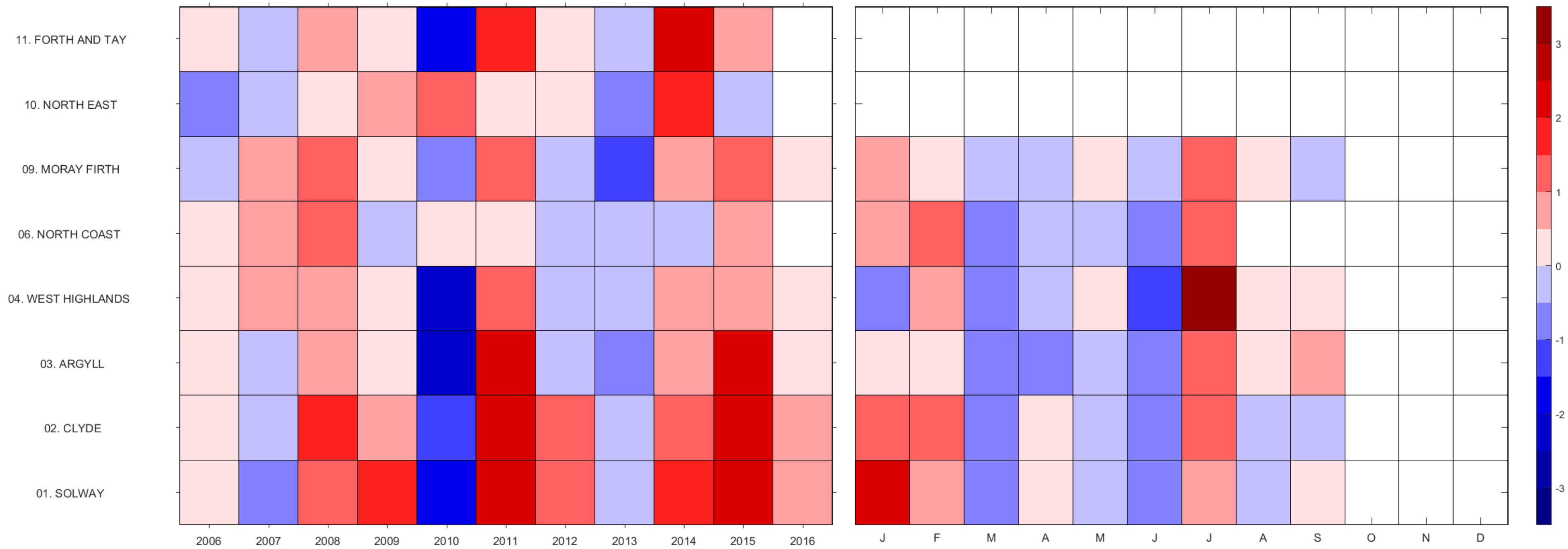
Table 2.1: Tables of monthly average gauged river flow ($m^3\ s^{-1}$) calculated from NRFA data over different time periods. The trends in the table are in $m^3\ s^{-1}$ per decade over the indicated time period. See also Figure F.1a and Appendix G.4

Dataset Average 1971-2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. SOLWAY	129	101	85	53	39	30	31	49	58	98	118	128	105	41	46	115	77	5.1
02. CLYDE	186	148	129	80	55	43	45	63	82	129	160	175	154	59	63	155	108	7.2
03. ARGYLL	38	30	29	14	10	8	10	13	23	30	32	36	33	11	15	33	23	n. s.
04. WEST HIGHLANDS	92	81	73	45	35	29	31	39	61	72	89	91	82	36	43	84	61	n. s.
06. NORTH COAST	27	22	21	11	8	6	6	7	13	21	26	25	23	8	9	24	16	n. s.
09. MORAY FIRTH	385	325	325	243	176	133	120	135	180	267	330	354	345	184	145	317	248	10.3
10. NORTH EAST	96	85	87	81	56	39	34	37	43	79	90	93	90	59	38	87	68	n. s.
11. FORTH AND TAY	405	329	312	221	157	110	99	123	162	275	330	355	349	163	128	320	240	13.2

Climatological Average 1981-2010	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. SOLWAY	129	99	92	56	40	29	32	52	58	103	117	122	107	41	47	114	77	n. s.
02. CLYDE	190	150	137	83	54	41	44	66	82	135	159	165	159	59	64	153	109	n. s.
03. ARGYLL	41	30	30	13	10	8	10	13	21	30	30	33	34	11	15	31	22	n. s.
04. WEST HIGHLANDS	94	86	78	45	32	29	32	39	61	74	88	85	86	35	44	82	62	n. s.
06. NORTH COAST	28	23	23	12	7	6	6	7	13	22	25	23	24	8	8	23	16	n. s.
09. MORAY FIRTH	401	344	351	244	169	135	121	133	188	286	335	338	365	183	147	320	254	n. s.
10. NORTH EAST	97	82	90	82	55	40	35	35	47	84	97	90	90	59	39	90	70	n. s.
11. FORTH AND TAY	414	334	330	229	158	110	97	122	175	294	336	342	359	166	131	324	245	n. s.

Decadal Average 2006-2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. SOLWAY	145	100	81	50	44	34	47	71	58	103	147	156	109	43	59	135	86	n. s.
02. CLYDE	211	146	131	79	69	50	63	82	90	133	195	221	162	66	78	183	122	n. s.
03. ARGYLL	40	29	24	15	15	7	9	14	20	30	36	46	31	12	14	37	24	n. s.
04. WEST HIGHLANDS	91	77	76	48	45	26	28	46	61	71	91	100	81	40	45	87	63	n. s.
06. NORTH COAST	28	20	19	12	9	6	6	10	13	21	25	32	22	9	10	26	17	n. s.
09. MORAY FIRTH	396	313	315	252	190	136	149	181	190	263	344	433	341	192	173	347	263	n. s.
10. NORTH EAST	103	94	80	73	51	41	47	54	46	74	101	103	92	55	49	93	72	n. s.
11. FORTH AND TAY	444	329	288	205	163	112	143	178	174	275	395	418	354	160	165	363	260	n. s.

Data for Year 2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. SOLWAY	212	150	71	67	32	16	52	39	66	-	-	-	144	38	52	-	-	
02. CLYDE	272	252	105	89	53	27	74	49	72	-	-	-	210	56	65	-	-	
03. ARGYLL	45	35	17	8	9	5	17	18	32	-	-	-	32	7	22	-	-	
04. WEST HIGHLANDS	76	105	58	38	38	14	64	47	63	-	-	-	80	30	58	-	-	
06. NORTH COAST	35	35	16	11	6	2	12	-	-	-	-	-	29	7	-	-	-	
09. MORAY FIRTH	483	414	293	219	188	126	174	139	169	-	-	-	397	177	161	-	-	
10. NORTH EAST	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
11. FORTH AND TAY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	



(a) Decade 2006–2016

(b) Monthly for 2016 (note no data beyond September)

Figure 2.1: Normalised anomalies (σ) of monthly gauged river flow (m^3 s^{-1}) for (a) the years 2006–2016 (up until Sep 2016) and (b) the months in 2016 (all plotted relative to 1981–2010 base period), from the NRFA dataset, by Scottish Marine Region. The anomalies are normalised with respect to the standard deviation of each time series (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds = positive/more flow; blues = negative/less flow. For this dataset, data are restricted to the mainland of Scotland; data are available in the Outer Hebrides, Orkney Islands or Shetland Isles regions.

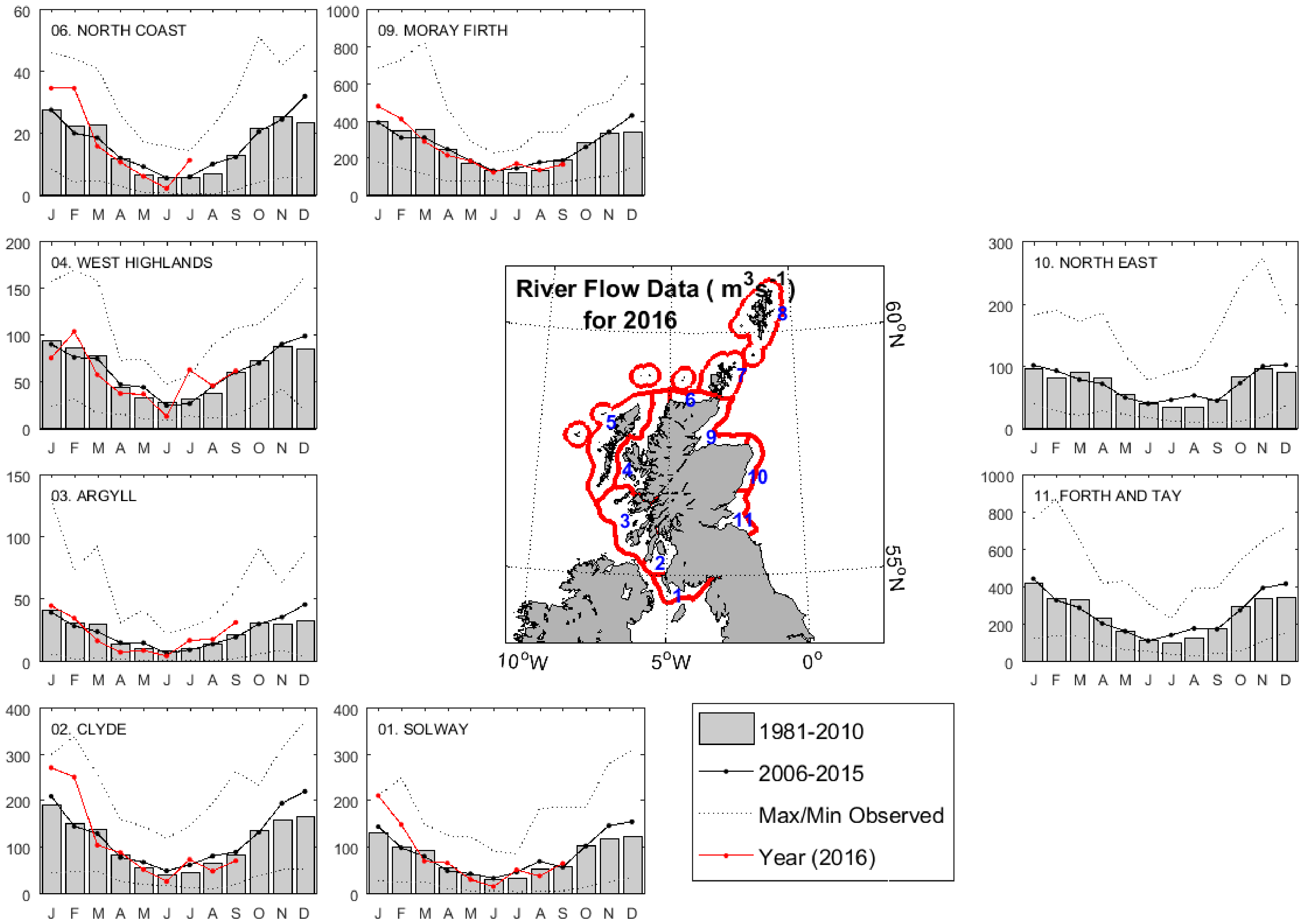


Figure 2.2: Summary of monthly gauged river flow (m^3 s^{-1}) for 2016, from the NRFA dataset, by Scottish Marine Region. Plots show monthly river flow during Jan-Sep 2016 compared to the long-term average pattern (calculated for the period 1981–2010) and the average over the last decade (2006–2015). X-axis of each graph is month. Central map shows the extent of each of the Scottish Marine Regions. For this dataset, no data are available in the outer isles (Outer Hebrides, Orkney Islands, Shetland Isles).

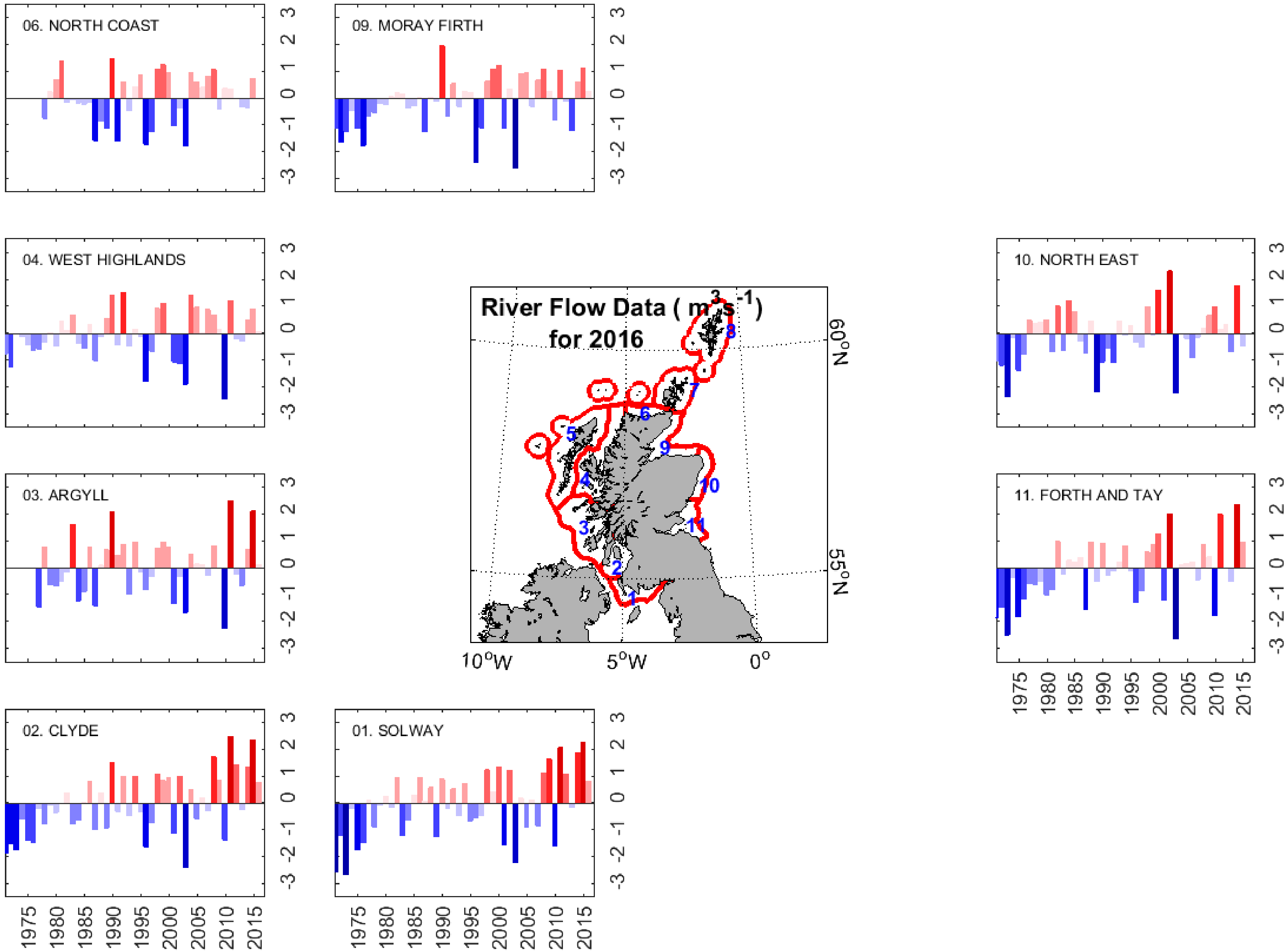


Figure 2.3: Time series of normalised annual anomalies (σ) of gauged river flow (m^3 s^{-1}) up to September 2016 (relative to 1981–2010 base period), from the NRFA dataset, for selected Scottish Marine Regions. X-axis of each plot is year. The anomalies are normalised with respect to the standard deviation (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds = positive/more flow; blues = negative/less flow. Central map shows the extent of each of the Scottish Marine Regions. For this dataset, data are restricted to the mainland of Scotland; no data are available in the Outer Hebrides, Orkney Islands or Shetland Isles regions. Note that the North East and Forth & Tay regions do not have data in 2016.

greater than 13 $m^3 s^{-1}$, and data from 12 of these rivers is available. These rivers represent a much higher percentage of the total estimated freshwater flow, with more than 75 % of the largest rivers being represented in the gauged data. The gauged flow, however, still represents only 60% of the total runoff to the coastal waters on the east coast (*Bresnan et al.*, 2016).

It is the gauged river flow (rather than the modelled flow) that is analysed and presented in this report. However, we expect a high correlation between total flows and gauged flows. *Marsh et al.* (2015) showed that, taken over the whole of Scotland, there was a correlation of 0.993 between gauged and modelled river flow. Within this report we are interested in the patterns seen, rather than absolute values.

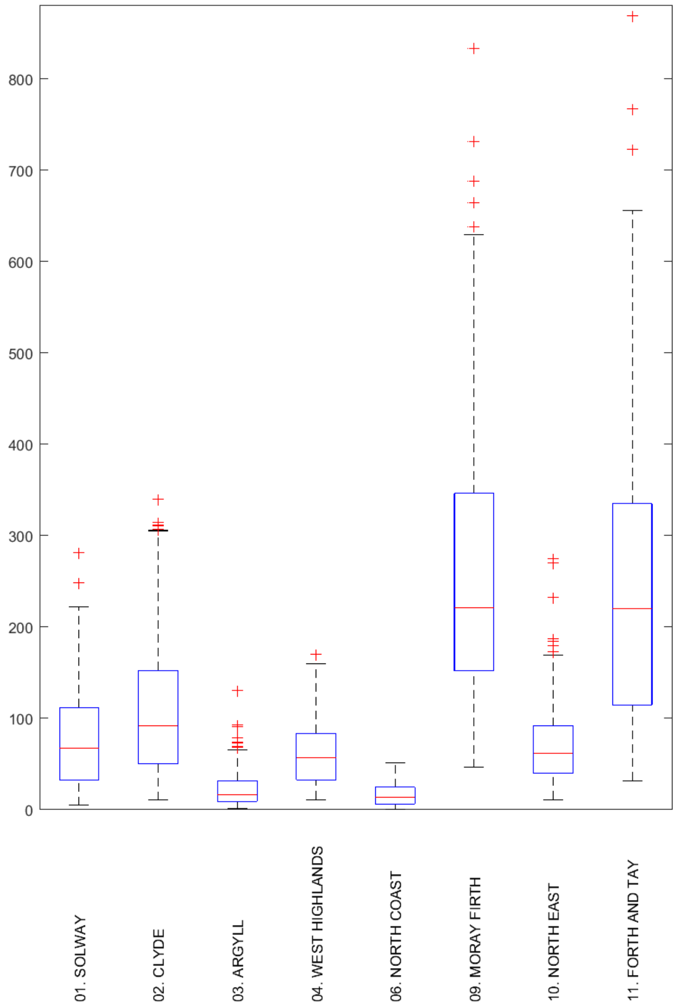


Figure 2.4: Statistical Boxplots of the total monthly average gauged river flow ($m^3\ s^{-1}$) into each SMR for the climatological period 1981–2010. Note that due to the limitations of the monitoring network, the gauged river flow is just a proportion of the true river flow. See Figure B.1 and Table B.1 for more details about the location of the stations in this figure. For this dataset, data are restricted to the mainland of Scotland and so no data are available in the Outer Hebrides, Orkney Islands or Shetland Isles regions. Label numbers and names in parenthesis refer to the Scottish Marine Region.

The spatial pattern of riverine input to Scotland's seas is highly variable (Figure 2.4). The Outer Hebrides has a relatively small landmass and, although the riverine input is larger than the Orkney Islands and Shetland Isles, there are no major rivers and hence the freshwater input is diffuse. On the west coast, riverine input is highest into the Solway and the Clyde regions. The largest riverine input on the west coast occurs in the Argyll region, and this is water flowing through the Loch Linnhe system. It should be noted that technically this input falls into both the Argyll and the West Highlands Scottish Marine Region, but here the boundary of the Argyll region has been taken to cross the mouth of Loch Linnhe.

On the west coast a large number of small rivers lead to a large and diffuse freshwater inflow. However, Scotland cannot be considered in isolation from surrounding regions, and the water flowing northward along the coast from the Irish Sea is already relatively fresh as a result of all of the riverine input from English, Welsh and Irish rivers.

2.2 Conditions Observed during 2016

River flow data are collated and analysed following a ’river year’ which runs from September to September. As a result, for comparative studies, river data become available with a yearly delay compared to oceanographic data. For this reason no data were available beyond September 2016 at the time of preparing this report. Note that Table 2.1 and Figures 2.2 and 2.1b present data for the latest river year, which ends September 2016.

2016 shows a trend across all Scottish Marine Regions of slightly greater than average gauged river flow (Figure 2.1a), although there is variability with fluctuations about the average on a monthly basis. At the start of the year all regions, with the exception of West Highlands, had a greater than average river flow, but in both March and June there is a drop to below normal at all stations, followed by a greater than average gauged river flow at all stations in July. This observation of “slightly greater than average river flow” is despite a trend of slightly lower than average rainfall across Scotland in 2016 (as discussed in Section 1.2).

Between the regions there appears to be good consistency, with most regions following the same patterns. The West Highlands region is the area that shows the most divergence from the general trend, with the January anomaly as the only negative anomaly in any region, and in June and July the anomalies are stronger than average in the negative and positive direction respectively (Figure 2.1b).

2.3 Trends and Variability over the period 2006-2016

Looking at gauged river flow data from each of the Scottish Marine Regions can reveal trends and variability across Scotland throughout the last decade. The lowest gauged river flow measured between 2006 and 2016 occurred in 2010 (Figure 2.1a), which was also a notably dry year (Figure 1.4). 2011, 2014 and 2015 were all years of high river flow and, correspondingly, high rainfall across the Scottish Marine Regions.

Overall, the decade had greater than normal gauged river flow. The region with the greatest increase was in the Forth & Tay region, where the decadal average was 15

m^3 s^{-1} greater than the climatological average, whilst the smallest increase of 1 m^3 s^{-1} was seen in both the West Highlands and North Coast regions (Table 2.1).

2.4 Long-Term Trends

On a longer timescale, looking at data back to the early 1970s, there is a general trend for an increase in gauged river flow (Figure 2.3). This is particularly noticeable in the more southern regions such as the Clyde and Solway, as well as the Moray Firth and Forth & Tay regions. There were significant trends in these regions, ranging between 5.1 m^3 s^{-1} and 13.2 m^3 s^{-1} per decade, when looking at the 1971-2016 dataset (Table 2.1). All regions show a 2006 – 2015 decadal average greater than the climatological average (Table 2.1), thus supporting this trend. This increasing trend is related to the long-term trend of increased rainfall (Figure 1.8).

It is noticeable that in all regions at the start of the datasets (in the 1970s), they show negative anomalies, which then fluctuate until the mid 2000s, at which point they tend to show increasingly positive anomalies (Figure 2.3).

Summary

- **In this report, gauged river flow data from the NRFA is presented, analysed by Scottish Marine Region.**
- **The spatial pattern of riverine input to Scotland's seas is highly variable.**
- **2016 showed slightly greater than average river flow across all Scottish Marine Regions.**
- **River flow in 2016 increased despite the decrease in rainfall recorded in 2016.**
- **The decade 2006-2016 had greater than normal river flow.**
- **There is a general trend of increasing river flow between 1971 and 2016.**

3 Oceanographic Conditions in Coastal Waters

Overview

Staff at Marine Scotland manage a network of monitoring stations around the Scottish coast. Although there are many coastal meteorological stations across Scotland that offer long records of meteorological conditions, there are only a few monitoring stations where conditions in the sea have been recorded for a long time. There are three locations in Scotland (Fair Isle, Millport and Peterhead), where records of coastal sea surface temperature extend back more than 30 years (referred to here as Scotland's Long Coastal Temperature Time series).

The Scottish Coastal Observatory (SCObs) was started in 1997 (*Bresnan et al.*, 2016), and as a result of this there are now a number of stations where sea temperature, and sometimes salinity, have been recorded for 10 years or more. Each of these stations lies within one of the Scottish Marine Regions and data from the station can be taken to be illustrative of conditions in the region. Coastal sea temperature is recorded at hourly or daily frequency at eleven separate sites around Scotland. These data constitute the SCObs coastal temperature dataset, and are presented in this chapter, along with salinity where it is available.

Although there are a limited number of monitoring stations, there are other sources of coastal temperature data, for example, measurements recorded as part of short-term projects or measurements made from ships and satellites. These records can be sparse in space and, or, time, but techniques are available to combine the information from these sparse datasets into more useful gridded datasets. The Hadley Centre Sea Ice and Sea Surface Temperature (HadISST), for example, combines all of the available data on sea surface temperatures and creates a regular gridded dataset from the sparse observations (See Appendix C.2). Using this dataset, it is possible to calculate average surface temperature in each of the Scottish Marine Regions, with a long dataset extending back to the late 1800's.

Although new satellite technology is in development, there is currently no routine way to monitor salinity in coastal waters except by in-situ instrumentation or direct sampling of water. As a result, there are very few locations where long-term continuous observations of salinity have been made. However, salinity data are recorded during weekly sampling at four of the SCObs sites; these are: Loch Ewe, in the Argyll region, Scapa in the Orkney Islands region, Scalloway in the Shetland Isles region, and Stonehaven in the North East region. At two of these sites (Loch Ewe and Stonehaven), measurements are made through the water column, giving both surface and nearbed temperature and salinity measurements.

In a similar way to the HadISST dataset, sparsely distributed temperature and salinity data from around the coastal waters of Scotland, since 1971, have been analysed

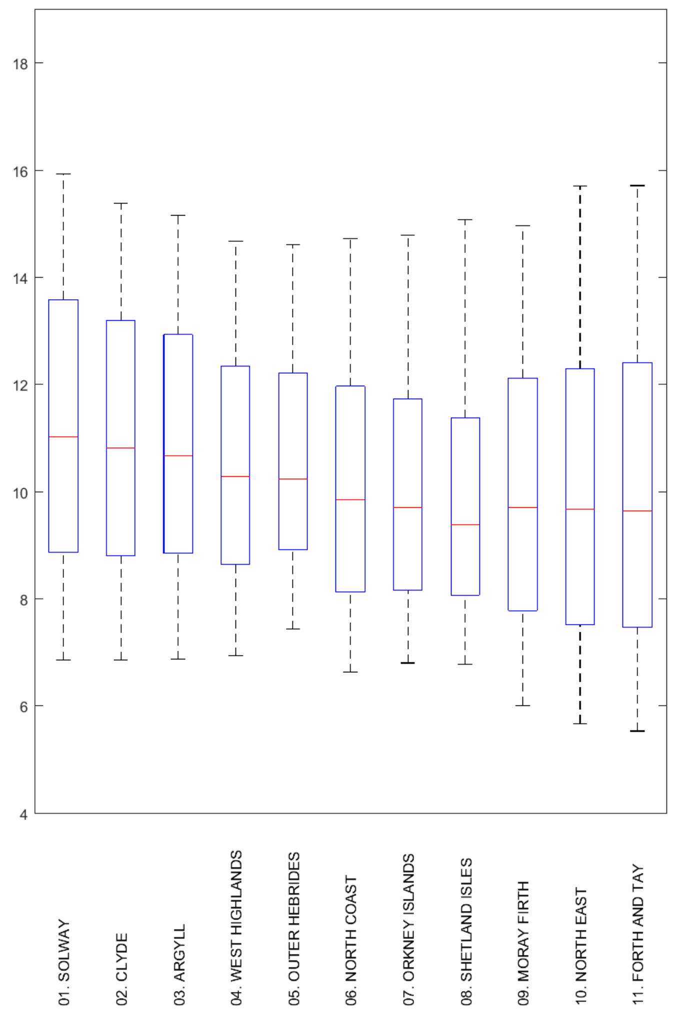


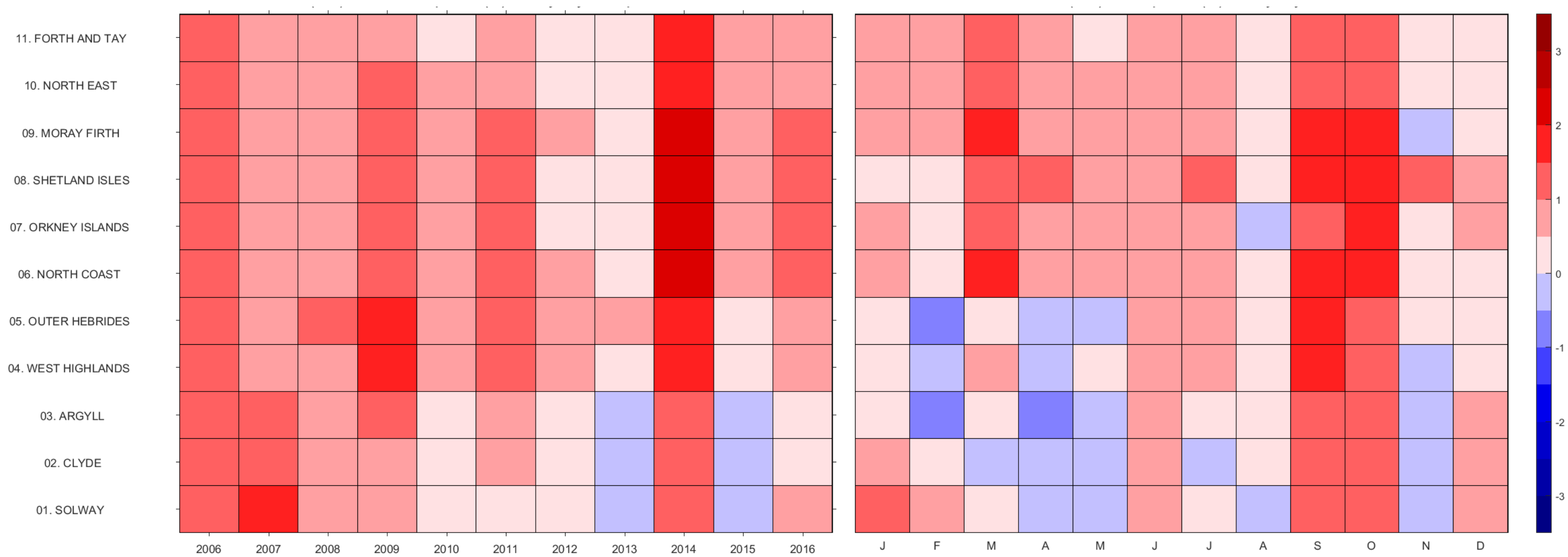
Figure 3.1: Statistical Boxplots of sea surface temperature (°C), from the HadISST dataset, by Scottish Marine Region. See Figure F.1a for a description of the Scottish Marine Regions.

with the newly created Ocean Data Tool (ODaT) dataset (see Appendix C.3). From these combined data, regional summaries of both temperature and salinity at the surface and seabed have been created. Gridded and combined datasets such as HadISST and ODaT are very useful to complement existing in-situ monitoring. However, due consideration should be given to the confidence that can be placed on such datasets, particularly in areas, and during time periods, where the underlying data is sparse (*Hughes et al.*, 2009).

From the combination of these different datasets, surface temperature observations are presented for all of the Scottish Marine Regions and salinity observations for all of the regions, except for the Solway, Clyde and North Coast regions. By bringing together evidence from a combination of different datasets, and examining them with an understanding of the individual strengths and weaknesses, it is possible to build a more complete picture of the status and trends in Scottish coastal waters than is possible from examining a single dataset.

Table 3.1: Statistical summary of sea surface temperature (°C) from the HadISST Dataset, in each of the 11 Scottish Marine Regions. The trends in the table are in °C per decade over the indicated time period. See also Figure F.1a and Appendix G.4.

Dataset Average 1893-2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. SOLWAY	8.9	8.1	7.7	8.4	9.8	11.8	13.4	14.5	14.2	13.3	11.7	10.2	8.2	10.0	14.0	11.7	11.0	0.05
02. CLYDE	8.9	8.1	7.8	8.4	9.6	11.6	13.1	14.1	13.7	12.9	11.4	10.1	8.3	9.9	13.7	11.5	10.8	0.05
03. ARGYLL	8.9	8.3	7.9	8.5	9.6	11.6	13.0	13.9	13.4	12.5	11.2	10.0	8.4	9.9	13.4	11.2	10.7	0.05
04. WEST HIGHLANDS	8.6	8.1	7.8	8.2	9.3	11.2	12.6	13.4	12.7	11.8	10.6	9.6	8.2	9.6	12.9	10.7	10.3	0.05
05. OUTER HEBRIDES	8.9	8.5	8.2	8.6	9.5	11.3	12.6	13.3	12.6	11.7	10.5	9.7	8.5	9.8	12.8	10.6	10.4	0.05
06. NORTH COAST	8.0	7.5	7.3	7.8	8.9	10.8	12.3	13.1	12.3	11.4	10.1	9.0	7.6	9.2	12.6	10.2	9.9	0.06
07. ORKNEY ISLANDS	8.0	7.5	7.3	7.7	8.8	10.6	12.1	12.8	12.0	11.1	9.9	8.9	7.6	9.0	12.3	10.0	9.7	0.06
08. SHETLAND ISLES	7.9	7.4	7.3	7.6	8.6	10.4	12.0	12.7	11.8	10.7	9.5	8.7	7.5	8.9	12.2	9.6	9.5	0.06
09. MORAY FIRTH	7.6	6.9	6.8	7.4	8.8	10.9	12.4	13.2	12.4	11.5	10.0	8.7	7.1	9.0	12.7	10.1	9.7	0.06
10. NORTH EAST	7.3	6.5	6.4	7.0	8.6	11.0	12.7	13.5	12.6	11.5	10.0	8.5	6.7	8.9	13.0	10.0	9.6	0.07
11. FORTH AND TAY	7.1	6.4	6.2	7.0	8.7	11.1	12.9	13.6	12.7	11.6	10.0	8.4	6.6	8.9	13.1	10.0	9.6	0.07
Climatological Average 1981-2010	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. SOLWAY	9.1	8.2	7.9	8.6	10.0	12.1	13.8	14.9	14.5	13.5	11.8	10.3	8.4	10.3	14.4	11.9	11.2	0.31
02. CLYDE	9.0	8.3	7.9	8.6	9.9	11.8	13.4	14.5	14.0	13.0	11.6	10.2	8.4	10.1	14.0	11.6	11.0	0.25
03. ARGYLL	9.0	8.4	8.0	8.6	9.8	11.8	13.3	14.2	13.6	12.6	11.3	10.1	8.5	10.1	13.7	11.3	10.9	0.20
04. WEST HIGHLANDS	8.8	8.3	7.9	8.4	9.5	11.3	12.9	13.7	12.9	12.0	10.8	9.8	8.3	9.7	13.2	10.9	10.5	0.22
05. OUTER HEBRIDES	9.0	8.6	8.3	8.7	9.7	11.4	12.9	13.6	12.8	11.8	10.6	9.8	8.6	10.0	13.1	10.8	10.6	0.21
06. NORTH COAST	8.3	7.7	7.5	8.0	9.1	11.0	12.6	13.4	12.5	11.6	10.3	9.3	7.8	9.4	12.8	10.4	10.1	0.28
07. ORKNEY ISLANDS	8.2	7.8	7.5	8.0	9.0	10.8	12.3	13.2	12.3	11.3	10.1	9.2	7.8	9.3	12.6	10.2	10.0	0.29
08. SHETLAND ISLES	8.1	7.6	7.4	7.8	8.9	10.6	12.2	13.1	12.0	10.8	9.7	8.9	7.7	9.1	12.5	9.8	9.8	0.33
09. MORAY FIRTH	7.9	7.2	7.0	7.6	9.0	11.0	12.8	13.6	12.7	11.7	10.3	9.0	7.4	9.2	13.0	10.4	10.0	0.32
10. NORTH EAST	7.6	6.9	6.7	7.3	8.9	11.3	13.1	14.0	12.9	11.8	10.3	8.9	7.1	9.2	13.3	10.3	10.0	0.40
11. FORTH AND TAY	7.5	6.7	6.5	7.3	9.0	11.4	13.3	14.1	13.0	11.9	10.3	8.8	6.9	9.2	13.5	10.3	10.0	0.38
Decadal Average 2006-2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. SOLWAY	9.2	8.2	8.0	8.9	10.3	12.4	14.0	15.0	14.7	13.8	12.3	10.5	8.5	10.5	14.6	12.2	11.4	-0.50
02. CLYDE	9.2	8.2	8.1	8.8	10.1	12.1	13.6	14.5	14.2	13.4	12.0	10.4	8.5	10.3	14.1	12.0	11.2	-0.39
03. ARGYLL	9.2	8.4	8.2	8.9	10.1	12.0	13.5	14.3	13.8	13.0	11.7	10.4	8.6	10.3	13.8	11.7	11.1	-0.32
04. WEST HIGHLANDS	9.1	8.4	8.2	8.8	9.8	11.7	13.1	13.8	13.1	12.3	11.2	10.0	8.6	10.1	13.3	11.2	10.8	n. s.
05. OUTER HEBRIDES	9.3	8.8	8.6	9.2	10.0	11.8	13.1	13.8	13.0	12.1	11.0	10.1	8.9	10.3	13.3	11.1	10.9	n. s.
06. NORTH COAST	8.6	7.9	7.8	8.4	9.6	11.3	12.8	13.7	12.8	12.0	10.8	9.6	8.1	9.7	13.1	10.8	10.4	n. s.
07. ORKNEY ISLANDS	8.6	7.9	7.8	8.3	9.4	11.1	12.6	13.5	12.6	11.8	10.6	9.5	8.1	9.6	12.9	10.6	10.3	n. s.
08. SHETLAND ISLES	8.3	7.8	7.7	8.1	9.2	11.1	12.7	13.6	12.4	11.4	10.2	9.2	7.9	9.5	12.9	10.2	10.1	n. s.
09. MORAY FIRTH	8.3	7.4	7.4	8.1	9.5	11.3	13.0	13.9	13.0	12.2	10.9	9.4	7.7	9.6	13.3	10.8	10.4	n. s.
10. NORTH EAST	8.0	7.1	7.1	7.7	9.3	11.6	13.6	14.4	13.2	12.3	10.8	9.3	7.4	9.5	13.7	10.8	10.4	n. s.
11. FORTH AND TAY	7.9	6.9	6.9	7.7	9.3	11.7	13.7	14.5	13.3	12.4	10.8	9.0	7.2	9.6	13.8	10.7	10.3	n. s.
Data for Year 2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. SOLWAY	9.6	8.6	7.9	8.4	9.9	12.6	13.8	14.7	15.2	14.0	11.8	10.7	8.7	10.3	14.6	12.2	11.4	
02. CLYDE	9.3	8.3	7.9	8.3	9.8	12.2	13.4	14.5	14.7	13.5	11.5	10.6	8.5	10.1	14.2	11.9	11.2	
03. ARGYLL	9.1	8.1	8.1	8.4	9.7	12.1	13.4	14.3	14.3	13.1	11.2	10.4	8.5	10.1	14.0	11.6	11.0	
04. WEST HIGHLANDS	9.0	8.2	8.2	8.4	9.5	11.6	13.3	13.8	13.8	12.6	10.7	10.0	8.4	9.8	13.6	11.1	10.8	
05. OUTER HEBRIDES	9.2	8.5	8.5	8.6	9.6	11.7	13.4	13.8	13.6	12.3	10.7	10.0	8.7	10.0	13.6	11.0	10.8	
06. NORTH COAST	8.5	7.9	8.0	8.2	9.4	11.4	13.0	13.5	13.3	12.4	10.4	9.5	8.2	9.6	13.3	10.7	10.5	
07. ORKNEY ISLANDS	8.5	7.9	8.0	8.3	9.3	11.2	12.8	13.2	13.0	12.1	10.3	9.5	8.2	9.6	13.0	10.6	10.3	
08. SHETLAND ISLES	8.2	7.6	7.9	8.3	9.2	11.1	12.9	13.2	12.9	11.7	10.1	9.3	7.9	9.5	13.0	10.4	10.2	
09. MORAY FIRTH	8.2	7.5	7.8	7.9	9.3	11.5	13.3	13.8	13.5	12.5	10.3	9.2	7.8	9.6	13.5	10.7	10.4	
10. NORTH EAST	8.0	7.2	7.3	7.7	9.3	11.6	13.7	14.1	13.8	12.4	10.3	9.1	7.5	9.5	13.9	10.6	10.4	
11. FORTH AND TAY	7.9	7.0	7.2	7.6	9.3	11.7	13.8	14.3	13.9	12.4	10.3	9.0	7.3	9.5	14.0	10.6	10.4	



(a) Decade 2006–2016

(b) Monthly for 2016

Figure 3.2: Normalised anomalies (σ) of monthly average sea surface temperature (°C) for (a) the years 2006–2016 and (b) the months in 2016 (all plotted relative to 1981–2010 base period), from the HadISST dataset, by Scottish Marine Region. The anomalies are normalised with respect to the standard deviation of each time-series (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds = positive/warmer; blues = negative/cooler. For this dataset, average values have been calculated in each area

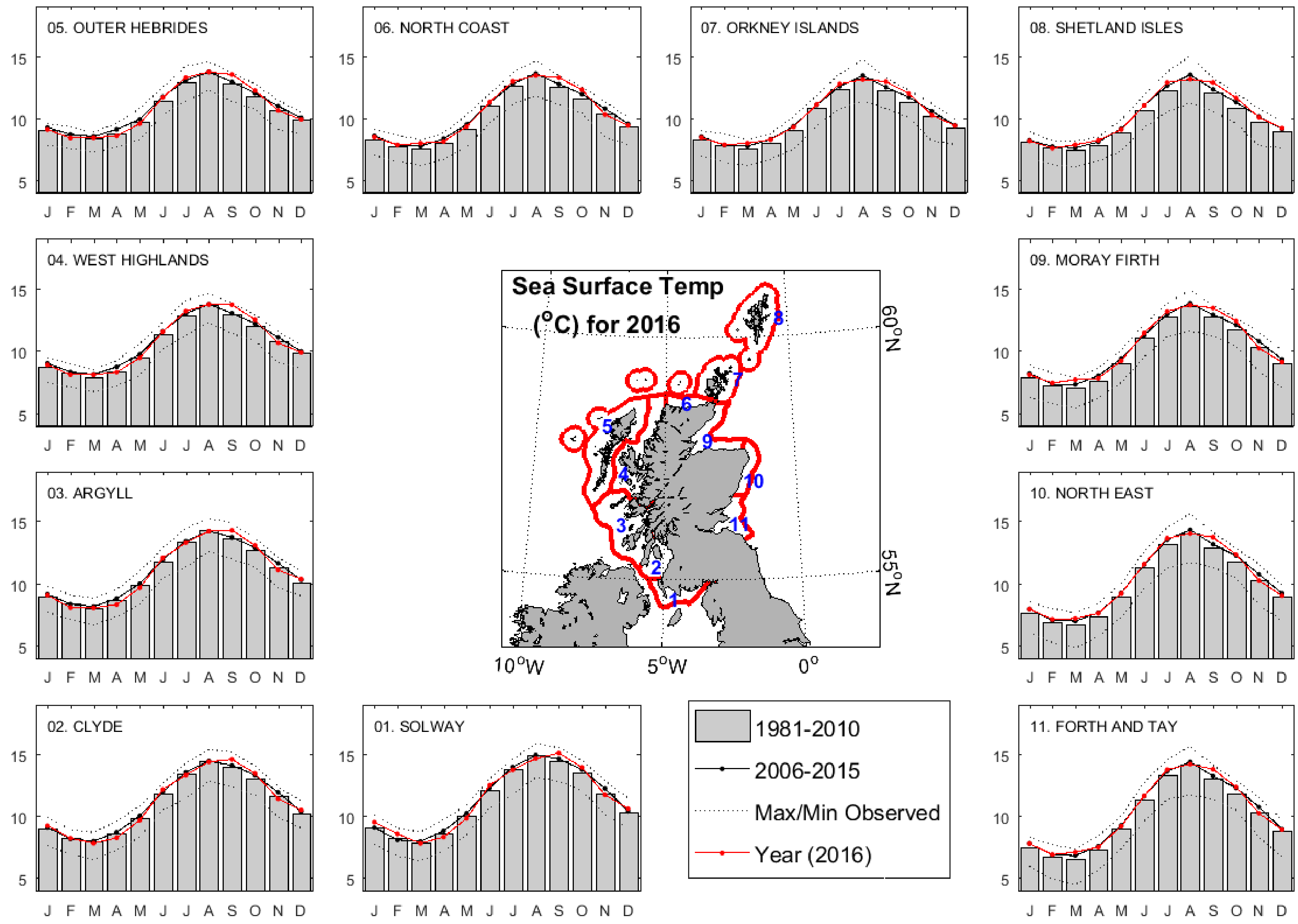


Figure 3.3: Summary of monthly sea surface temperature (°C) for 2016, from the HadISST dataset, by Scottish Marine Region. Plots show monthly values of sea surface temperature during 2016 compared to the long-term average pattern (calculated for the period 1981–2010) and the average over the last decade (2006–2016). X-axis of each graph is month. Central map shows the extent of each of the Scottish Marine Regions.

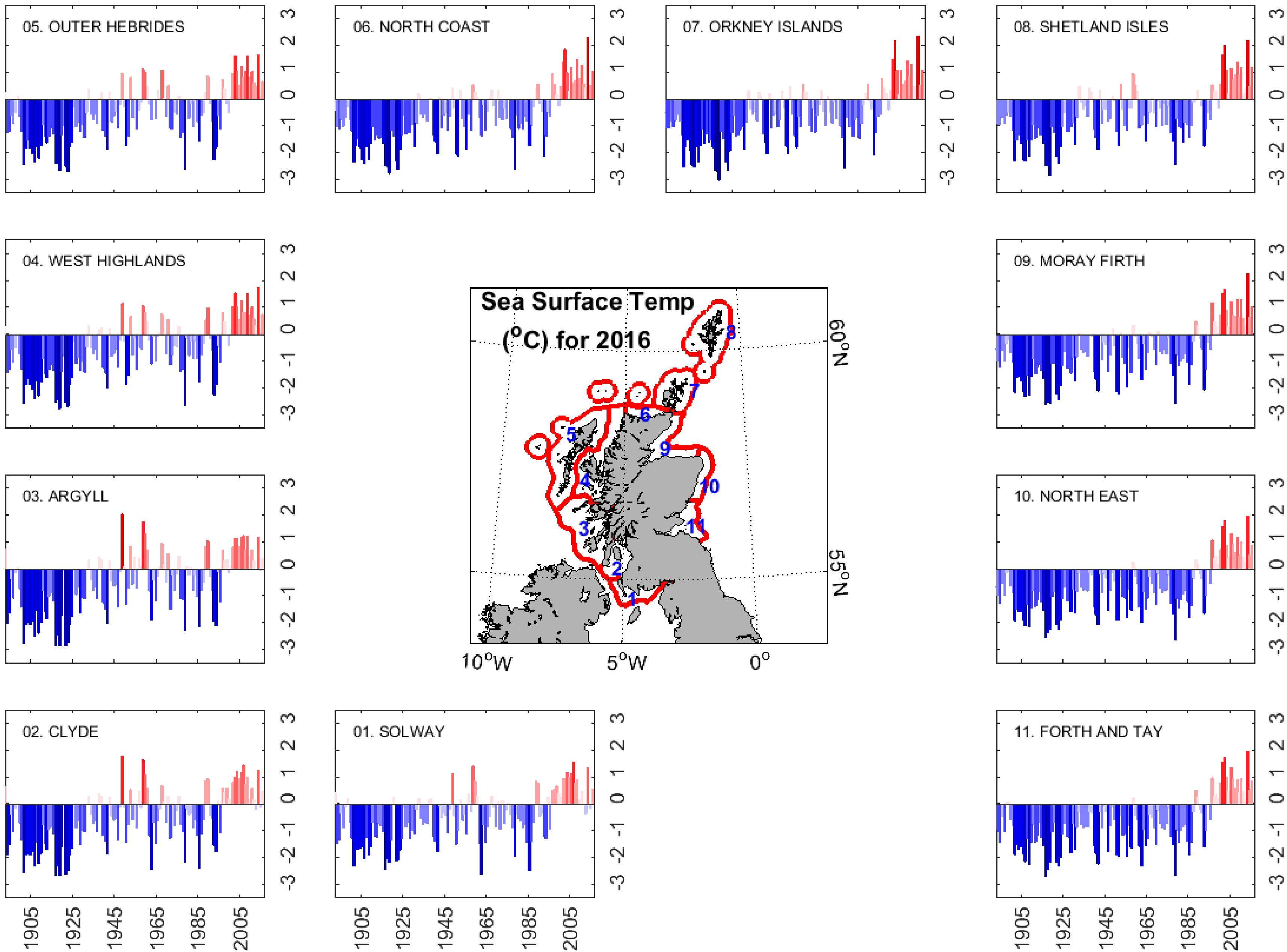


Figure 3.4: Time series of normalised annual anomalies (σ) of sea surface temperature (°C) up to 2016 (relative to 1981-2010 base period), from the HadISST dataset, averaged by Scottish Marine Region. X-axis of each plot is year. The anomalies are normalised with respect to the standard deviation (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds = positive/warmer; blues = negative/cooler. Central map shows the extent of each of the Scottish Marine Regions.

Table 3.2: (a) Statistical Summary of sea surface temperature (°C) from the ODaT Dataset, in each of the 11 Scottish Marine Regions. The trends in the table are in °C per decade over the indicated time period. See also Figure F.1a and Appendix G.4.

Dataset Average 1971-2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. SOLWAY	8.4	7.5	6.5	7.3	8.5	10.1	12.5	13.4	13.0	12.7	11.1	9.8	7.5	8.6	13.0	11.2	10.1	-
02. CLYDE	8.0	7.0	7.0	7.2	8.7	10.7	12.3	13.1	12.7	12.3	11.0	9.6	7.3	8.9	12.7	11.0	10.0	-
03. ARGYLL	8.8	8.0	7.9	8.2	9.0	10.9	12.5	13.7	13.4	13.3	11.5	10.7	8.2	9.4	13.2	11.8	10.7	n. s.
04. WEST HIGHLANDS	8.8	7.6	7.7	7.8	8.7	10.7	12.0	13.1	12.8	12.6	11.3	10.6	8.0	9.1	12.7	11.5	10.3	n. s.
05. OUTER HEBRIDES	8.9	8.1	7.9	8.3	9.3	11.1	12.3	13.3	13.0	12.3	11.2	10.5	8.3	9.6	12.8	11.3	10.5	n. s.
06. NORTH COAST	8.5	7.4	7.4	7.0	7.9	11.0	11.9	12.5	12.3	12.3	10.8	10.4	7.8	8.6	12.2	11.2	10.0	-
07. ORKNEY ISLANDS	7.9	7.3	7.0	7.4	8.3	9.9	11.2	12.6	12.5	11.9	10.6	9.4	7.4	8.6	12.1	10.7	9.7	n. s.
08. SHETLAND ISLES	8.3	7.7	7.3	8.0	8.7	9.7	11.6	12.3	11.9	11.1	10.1	9.4	7.8	8.8	11.9	10.2	9.7	n. s.
09. MORAY FIRTH	7.0	6.5	5.0	7.3	8.6	11.6	12.4	13.5	12.4	11.9	10.1	8.4	6.2	9.1	12.8	10.1	9.5	n. s.
10. NORTH EAST	7.0	6.2	5.7	6.4	8.2	10.4	12.1	13.2	12.5	12.2	10.3	9.3	6.3	8.3	12.6	10.6	9.4	n. s.
11. FORTH AND TAY	6.7	6.0	5.8	6.4	8.4	10.7	12.4	13.9	13.2	12.0	9.6	8.6	6.2	8.5	13.2	10.1	9.5	n. s.
Climatological Average 1981-2010	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. SOLWAY	-	-	6.4	7.2	8.4	10.1	12.7	13.6	-	-	11.2	9.8	-	8.6	-	-	-	-
02. CLYDE	8.1	-	6.9	7.3	8.5	10.9	-	-	12.6	12.4	11.3	9.9	-	8.9	-	11.2	-	-
03. ARGYLL	8.7	8.0	8.0	8.3	8.9	10.9	12.7	13.9	13.3	13.1	11.4	10.7	8.2	9.4	13.3	11.7	10.7	0.36
04. WEST HIGHLANDS	8.8	7.6	7.8	7.8	8.6	10.9	12.0	13.3	12.9	12.4	11.2	10.6	8.1	9.1	12.8	11.4	10.3	0.30
05. OUTER HEBRIDES	9.0	7.9	8.0	8.4	9.2	11.1	12.4	13.5	13.0	12.1	11.3	10.6	8.3	9.6	13.0	11.3	10.5	0.20
06. NORTH COAST	-	-	7.4	-	-	-	-	12.7	12.2	-	11.1	10.4	-	-	-	-	-	-
07. ORKNEY ISLANDS	8.0	7.3	7.1	7.5	8.4	10.0	11.3	12.7	12.6	12.0	10.6	9.7	7.4	8.6	12.2	10.8	9.8	0.45
08. SHETLAND ISLES	8.4	7.8	7.5	8.0	8.7	9.9	11.7	12.4	12.0	11.2	10.2	9.4	7.9	8.9	12.0	10.3	9.8	0.35
09. MORAY FIRTH	7.1	6.6	4.8	7.2	8.4	11.8	12.7	13.8	12.4	12.0	10.3	8.6	6.2	9.2	13.0	10.3	9.7	0.40
10. NORTH EAST	7.1	6.2	6.0	6.6	8.6	10.5	12.1	13.4	12.6	12.4	10.3	9.5	6.4	8.6	12.7	10.7	9.6	0.34
11. FORTH AND TAY	6.9	6.0	6.1	6.4	8.3	10.8	12.0	14.0	13.4	12.2	9.7	8.8	6.3	8.5	13.2	10.2	9.6	0.28
Decadal Average 2006-2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. SOLWAY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
02. CLYDE	-	-	7.3	-	-	-	-	-	-	-	11.1	-	-	-	-	-	-	-
03. ARGYLL	9.0	-	8.1	-	9.6	11.2	12.2	-	-	13.7	11.4	-	-	-	-	-	-	n. s.
04. WEST HIGHLANDS	9.2	7.8	7.7	-	8.9	-	12.6	13.2	-	12.5	11.7	10.9	8.2	-	-	11.7	-	-0.48
05. OUTER HEBRIDES	9.1	8.3	8.0	-	9.5	11.5	12.5	-	-	-	11.3	10.9	8.5	-	-	-	-	n. s.
06. NORTH COAST	-	-	7.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
07. ORKNEY ISLANDS	8.0	7.6	7.9	7.8	8.7	10.4	11.6	12.9	12.7	12.5	11.1	9.7	7.8	9.0	12.4	11.1	10.1	-0.42
08. SHETLAND ISLES	8.2	8.0	-	8.3	9.2	-	11.9	12.6	12.2	11.6	10.4	9.6	-	-	12.2	10.5	-	-0.64
09. MORAY FIRTH	7.3	6.9	-	-	-	-	12.5	13.6	-	-	-	-	-	-	-	-	-	-0.51
10. NORTH EAST	6.9	6.4	5.7	-	-	10.9	12.5	13.6	12.6	-	-	9.4	6.3	-	12.9	-	-	-0.44
11. FORTH AND TAY	6.7	6.3	5.9	-	-	11.0	13.0	13.6	-	-	-	-	6.3	-	-	-	-	n. s.
Data for Year 2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. SOLWAY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
02. CLYDE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
03. ARGYLL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
04. WEST HIGHLANDS	-	8.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
05. OUTER HEBRIDES	-	8.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
06. NORTH COAST	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
07. ORKNEY ISLANDS	8.2	7.7	7.4	7.7	-	-	-	-	-	-	-	-	7.7	-	-	-	-	
08. SHETLAND ISLES	8.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
09. MORAY FIRTH	7.4	6.9	5.1	7.5	-	-	-	-	-	-	-	-	6.5	-	-	-	-	
10. NORTH EAST	-	7.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
11. FORTH AND TAY	-	6.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

(cont.) Table 3.2: (b) Statistical Summary of sea bottom temperature (°C) from the ODaT Dataset, in each of the 11 Scottish Marine Regions. The trends in the table are in °C per decade over the indicated time period. See also Figure F.1a and Appendix G.4.

Dataset Average 1971-2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. SOLWAY	8.5	7.9	6.5	6.8	8.1	9.4	11.8	12.3	12.8	12.9	11.4	10.2	7.6	8.1	12.3	11.5	9.9	-
02. CLYDE	8.1	7.4	7.1	6.9	7.9	9.2	11.3	11.6	12.1	12.7	11.7	9.9	7.5	8.0	11.7	11.4	9.6	-
03. ARGYLL	9.0	8.3	8.2	8.0	8.7	9.7	10.9	12.0	11.4	12.4	11.4	10.9	8.5	8.8	11.4	11.6	10.1	n. s.
04. WEST HIGHLANDS	8.9	7.9	7.8	7.6	8.3	9.5	10.0	11.4	11.6	12.5	11.4	10.7	8.2	8.5	11.0	11.5	9.8	n. s.
05. OUTER HEBRIDES	9.2	8.3	8.1	8.4	8.6	9.4	9.7	10.2	11.2	11.8	11.1	10.6	8.5	8.8	10.4	11.2	9.7	n. s.
06. NORTH COAST	8.2	7.6	7.5	7.0	7.9	10.1	10.3	11.8	12.2	12.3	11.0	10.5	7.8	8.3	11.4	11.3	9.7	-
07. ORKNEY ISLANDS	8.0	7.3	7.1	7.5	8.2	9.3	10.9	11.7	12.4	11.9	10.7	9.5	7.4	8.3	11.6	10.7	9.5	n. s.
08. SHETLAND ISLES	8.2	7.6	7.3	7.7	8.0	8.4	9.5	10.4	10.9	10.9	10.1	9.4	7.7	8.1	10.3	10.1	9.0	n. s.
09. MORAY FIRTH	7.3	6.6	5.2	6.7	7.3	8.5	10.0	11.5	12.0	11.9	10.1	8.6	6.4	7.5	11.2	10.2	8.8	n. s.
10. NORTH EAST	7.2	6.3	5.5	6.1	7.4	8.8	10.5	11.5	12.2	12.1	10.4	9.4	6.3	7.5	11.4	10.7	9.0	n. s.
11. FORTH AND TAY	6.9	6.2	5.7	5.6	7.0	8.7	9.9	11.8	12.4	12.1	10.0	8.8	6.3	7.1	11.4	10.3	8.8	n. s.

Climatological Average 1981-2010	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. SOLWAY	-	-	6.4	6.6	8.0	9.4	12.2	12.6	-	-	11.5	10.2	-	8.0	-	-	-	-
02. CLYDE	8.2	-	7.1	6.9	7.9	9.2	-	-	-	12.6	11.8	10.3	-	8.0	-	11.5	-	-
03. ARGYLL	9.1	8.3	8.3	8.1	8.7	10.0	10.8	12.0	12.0	12.2	11.5	10.9	8.5	8.9	11.6	11.5	10.2	0.42
04. WEST HIGHLANDS	8.9	8.0	7.9	7.7	8.3	9.9	10.1	11.3	11.7	12.5	11.3	10.7	8.3	8.6	11.0	11.5	9.9	0.22
05. OUTER HEBRIDES	9.2	8.2	8.2	8.4	8.6	9.3	9.8	10.3	11.5	12.0	11.3	10.7	8.5	8.8	10.5	11.3	9.8	0.19
06. NORTH COAST	-	-	7.5	-	-	-	-	11.7	12.1	-	11.2	10.5	-	-	-	-	-	-
07. ORKNEY ISLANDS	8.0	7.4	7.1	7.5	8.2	9.3	11.0	11.9	12.5	12.0	10.7	9.7	7.5	8.3	11.8	10.8	9.6	0.45
08. SHETLAND ISLES	8.4	7.8	7.3	7.8	8.0	8.5	9.6	10.5	11.0	11.0	10.2	9.5	7.8	8.1	10.4	10.2	9.1	0.34
09. MORAY FIRTH	7.5	6.7	5.0	6.7	7.3	8.3	10.3	11.7	12.1	12.1	10.4	8.8	6.4	7.4	11.4	10.4	8.9	0.31
10. NORTH EAST	7.3	6.3	5.8	6.3	7.5	9.0	10.4	11.6	12.4	12.4	10.4	9.7	6.5	7.6	11.5	10.8	9.1	0.33
11. FORTH AND TAY	7.2	6.3	6.0	5.9	7.2	8.8	9.7	11.7	12.7	12.2	9.8	9.0	6.5	7.3	11.4	10.3	8.9	0.35

Decadal Average 2006-2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. SOLWAY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
02. CLYDE	-	-	7.5	-	-	-	-	-	-	-	11.7	-	-	-	-	-	-	-
03. ARGYLL	9.2	-	8.5	-	8.8	9.6	11.2	-	-	12.8	11.4	-	-	-	-	-	-	-0.44
04. WEST HIGHLANDS	9.2	8.3	7.9	-	8.3	-	10.1	11.5	-	-	11.7	11.0	8.5	-	-	-	-	-0.12
05. OUTER HEBRIDES	9.5	8.4	8.1	-	8.8	9.7	10.1	-	-	-	11.2	11.2	8.7	-	-	-	-	n. s.
06. NORTH COAST	-	-	7.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
07. ORKNEY ISLANDS	8.0	7.7	7.9	7.8	8.5	9.4	11.1	11.6	12.4	12.5	11.2	9.7	7.9	8.6	11.7	11.1	9.8	-0.67
08. SHETLAND ISLES	8.3	7.9	-	8.1	8.5	-	10.0	10.5	11.1	11.3	10.5	9.6	-	-	10.6	10.5	-	-0.55
09. MORAY FIRTH	7.5	7.0	-	-	-	-	10.2	11.6	-	-	-	-	-	-	-	-	-	-0.64
10. NORTH EAST	7.0	6.5	5.7	-	-	9.5	11.0	11.6	12.6	-	-	9.4	6.4	-	11.8	-	-	n. s.
11. FORTH AND TAY	6.9	6.5	5.9	-	-	8.9	10.1	11.9	-	-	-	-	6.4	-	-	-	-	-0.37

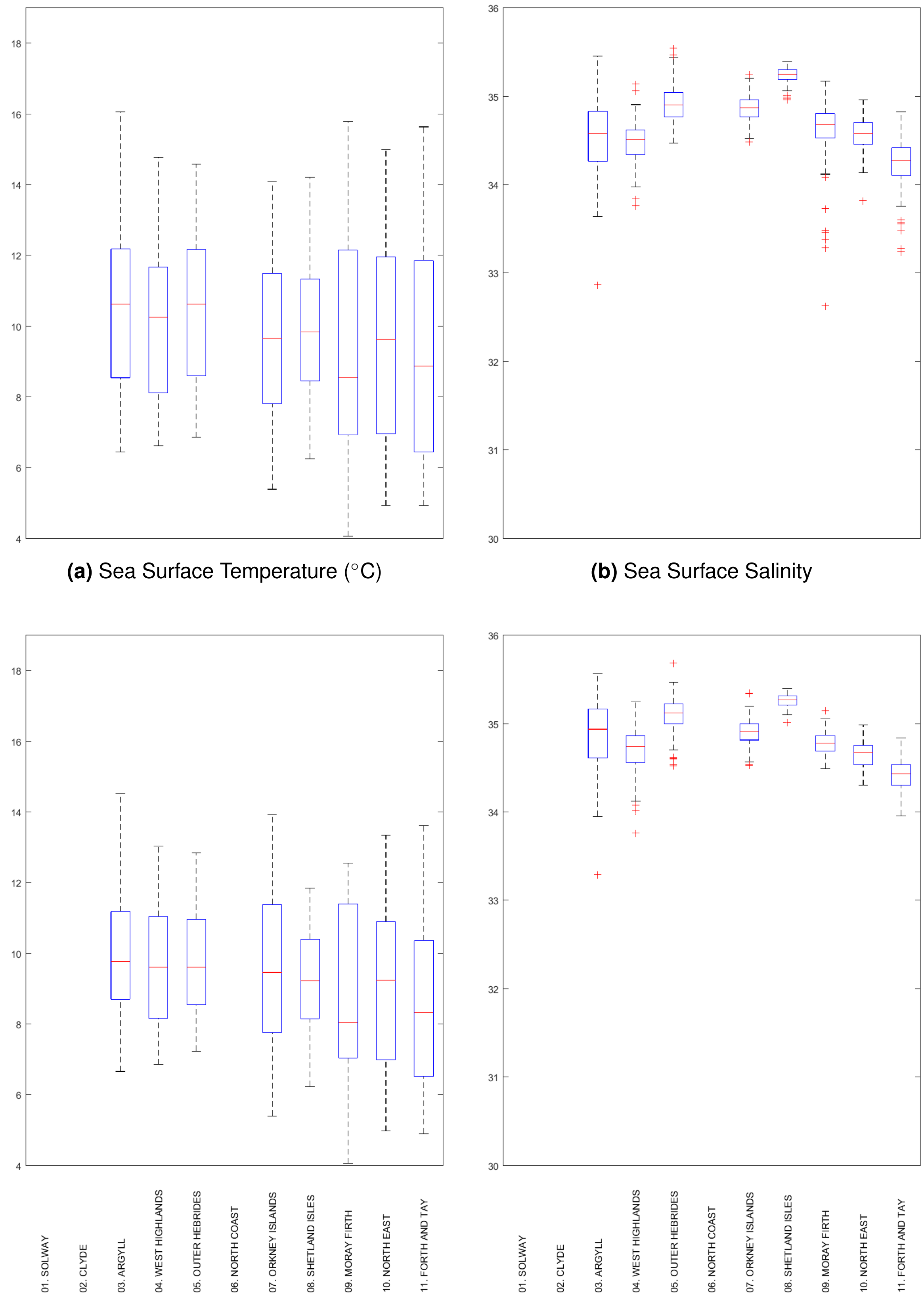
Data for Year 2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. SOLWAY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
02. CLYDE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
03. ARGYLL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
04. WEST HIGHLANDS	-	9.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
05. OUTER HEBRIDES	-	9.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
06. NORTH COAST	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
07. ORKNEY ISLANDS	8.2	7.7	7.5	7.8	-	-	-	-	-	-	-	-	7.8	-	-	-	-	
08. SHETLAND ISLES	8.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
09. MORAY FIRTH	7.6	7.0	5.5	7.5	-	-	-	-	-	-	-	-	6.7	-	-	-	-	
10. NORTH EAST	-	7.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
11. FORTH AND TAY	-	7.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

(cont.) Table 3.2: (c) Statistical Summary of sea surface salinity from the ODaT Dataset, in each of the 11 Scottish Marine Regions. The trends in the table are per decade over the indicated time period. See also Figure F.1a and Appendix G.4.

Dataset Average 1971-2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. SOLWAY	33.75	34.04	33.46	33.82	33.64	33.99	33.82	33.96	33.74	34.01	33.58	33.78	33.75	33.81	33.84	33.79	33.80	-
02. CLYDE	33.28	33.08	33.01	33.06	32.90	32.95	33.27	33.43	33.27	33.63	33.21	33.21	33.13	32.97	33.32	33.35	33.19	-
03. ARGYLL	34.50	34.74	34.70	34.57	34.50	34.30	34.45	34.46	34.73	34.61	34.61	34.59	34.65	34.46	34.55	34.60	34.56	n. s.
04. WEST HIGHLANDS	34.45	34.53	34.47	34.44	34.40	34.46	34.51	34.57	34.55	34.27	34.54	34.59	34.48	34.43	34.54	34.47	34.48	n. s.
05. OUTER HEBRIDES	34.77	34.97	34.82	34.94	34.99	34.97	34.89	34.84	34.87	34.87	34.92	34.96	34.85	34.97	34.87	34.92	34.90	n. s.
06. NORTH COAST	34.49	34.60	34.60	34.75	34.54	34.62	34.85	34.74	34.63	34.74	34.75	34.74	34.56	34.64	34.74	34.74	34.67	-
07. ORKNEY ISLANDS	34.80	34.82	34.87	34.87	34.86	34.85	34.83	34.88	34.93	34.91	34.87	34.87	34.83	34.86	34.88	34.89	34.86	n. s.
08. SHETLAND ISLES	35.22	35.24	35.23	35.30	35.29	35.24	35.23	35.20	35.21	35.21	35.22	35.24	35.23	35.28	35.21	35.22	35.24	n. s.
09. MORAY FIRTH	34.27	34.66	34.50	34.14	34.40	34.61	34.79	34.78	34.78	34.75	34.75	34.75	34.47	34.39	34.79	34.75	34.60	n. s.
10. NORTH EAST	34.53	34.56	34.45	34.47	34.45	34.44	34.63	34.58	34.77	34.82	34.66	34.64	34.52	34.45	34.66	34.71	34.58	n. s.
11. FORTH AND TAY	34.26	34.26	34.08	33.97	33.93	34.17	34.17	34.31	34.36	34.17	34.20	34.51	34.20	34.02	34.28	34.29	34.20	n. s.
Climatological Average 1981-2010	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. SOLWAY	-	-	33.51	33.98	33.81	33.99	33.85	33.90	-	-	33.57	33.78	-	33.93	-	-	-	-
02. CLYDE	33.32	-	33.03	33.04	32.93	32.93	-	-	32.63	33.59	33.25	33.29	-	32.97	-	33.38	-	-
03. ARGYLL	34.51	34.73	34.81	34.56	34.46	34.23	34.46	34.33	34.61	34.63	34.57	34.53	34.69	34.42	34.47	34.58	34.54	0.127
04. WEST HIGHLANDS	34.44	34.50	34.48	34.40	34.38	34.54	34.47	34.44	34.49	34.35	34.58	34.62	34.47	34.44	34.47	34.51	34.47	0.082
05. OUTER HEBRIDES	34.76	34.94	34.91	34.97	35.02	35.03	34.83	34.72	34.86	34.88	34.90	34.92	34.87	35.01	34.80	34.90	34.90	n. s.
06. NORTH COAST	-	-	34.61	-	-	-	-	34.69	34.53	-	34.74	34.74	-	-	-	-	-	-
07. ORKNEY ISLANDS	34.81	34.82	34.87	34.84	34.85	34.86	34.83	34.90	34.92	34.91	34.86	34.88	34.83	34.85	34.88	34.88	34.86	0.051
08. SHETLAND ISLES	35.21	35.26	35.26	35.32	35.29	35.24	35.23	35.21	35.22	35.22	35.22	35.25	35.24	35.28	35.22	35.23	35.25	0.026
09. MORAY FIRTH	34.19	34.65	34.66	34.16	34.46	34.55	34.78	34.75	34.78	34.70	34.76	34.81	34.50	34.39	34.77	34.76	34.60	0.091
10. NORTH EAST	34.57	34.58	34.40	34.43	34.40	34.35	34.61	34.53	34.73	34.77	34.65	34.63	34.52	34.40	34.62	34.68	34.55	0.039
11. FORTH AND TAY	34.27	34.31	34.05	33.85	34.04	34.15	34.25	34.36	34.34	34.17	34.33	34.61	34.21	34.02	34.32	34.37	34.23	0.077
Decadal Average 2006-2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. SOLWAY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
02. CLYDE	-	-	32.96	-	-	-	-	-	-	-	32.97	-	-	-	-	-	-	-
03. ARGYLL	34.55	-	34.68	-	34.67	34.24	34.35	-	-	34.77	34.67	-	-	-	-	-	-	n. s.
04. WEST HIGHLANDS	34.56	34.52	34.54	-	34.48	-	34.55	34.52	-	34.44	34.38	34.48	34.54	-	-	34.43	-	-0.219
05. OUTER HEBRIDES	34.66	35.00	34.79	-	34.97	34.98	34.97	-	-	-	35.00	34.96	34.82	-	-	-	-	n. s.
06. NORTH COAST	-	-	34.63	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
07. ORKNEY ISLANDS	34.88	34.87	35.03	34.87	34.84	34.95	34.89	34.88	34.90	34.89	34.85	34.88	34.93	34.89	34.89	34.87	34.90	-0.139
08. SHETLAND ISLES	35.23	35.28	-	35.33	35.31	-	35.27	35.20	35.23	35.20	35.22	35.27	-	-	35.23	35.23	-	-0.100
09. MORAY FIRTH	34.45	34.72	-	-	-	-	34.83	34.80	-	-	-	-	-	-	-	-	-	n. s.
10. NORTH EAST	34.47	34.44	34.42	-	-	34.56	34.60	34.53	34.78	-	-	34.71	34.44	-	34.64	-	-	n. s.
11. FORTH AND TAY	34.21	34.28	34.22	-	-	34.23	34.06	34.29	-	-	-	-	34.24	-	-	-	-	-0.417
Data for Year 2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. SOLWAY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
02. CLYDE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
03. ARGYLL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
04. WEST HIGHLANDS	-	34.58	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
05. OUTER HEBRIDES	-	34.77	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
06. NORTH COAST	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
07. ORKNEY ISLANDS	34.79	34.68	34.73	34.70	-	-	-	-	-	-	-	-	34.73	-	-	-	-	
08. SHETLAND ISLES	35.13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
09. MORAY FIRTH	34.68	34.56	34.74	34.42	-	-	-	-	-	-	-	-	34.66	-	-	-	-	
10. NORTH EAST	-	35.09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
11. FORTH AND TAY	-	34.13	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

(cont.) Table 3.2: (d) Statistical Summary of sea bottom salinity from the ODaT Dataset, in each of the 11 Scottish Marine Regions. The trends in the table are per decade over the indicated time period. See also Figure F.1a and Appendix G.4.

Dataset Average 1971-2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. SOLWAY	33.82	34.26	33.58	33.76	33.88	34.09	33.93	34.10	33.74	33.98	33.71	33.96	33.88	33.91	33.92	33.88	33.90	-
02. CLYDE	33.71	33.74	33.67	33.65	33.60	33.64	33.78	33.80	33.46	34.00	33.67	33.54	33.71	33.63	33.68	33.73	33.69	-
03. ARGYLL	34.90	34.92	34.92	34.95	34.86	34.71	34.83	34.70	35.01	34.91	34.81	34.80	34.91	34.84	34.85	34.84	34.86	n. s.
04. WEST HIGHLANDS	34.57	34.75	34.64	34.69	34.68	34.67	34.72	34.72	34.85	34.65	34.68	34.76	34.65	34.68	34.76	34.70	34.70	n. s.
05. OUTER HEBRIDES	34.93	35.11	35.00	35.19	35.22	35.19	35.15	35.14	35.09	34.95	35.07	35.10	35.02	35.20	35.13	35.04	35.09	n. s.
06. NORTH COAST	34.70	34.78	34.78	34.92	34.61	34.65	34.89	34.82	34.77	34.85	34.84	34.79	34.75	34.73	34.83	34.83	34.78	-
07. ORKNEY ISLANDS	34.84	34.86	34.92	34.89	34.91	34.93	34.89	34.95	34.97	34.93	34.92	34.89	34.87	34.91	34.94	34.91	34.91	n. s.
08. SHETLAND ISLES	35.23	35.25	35.23	35.30	35.29	35.25	35.27	35.24	35.24	35.25	35.23	35.26	35.24	35.28	35.25	35.24	35.25	n. s.
09. MORAY FIRTH	34.72	34.71	34.68	34.70	34.75	34.85	34.89	34.85	34.85	34.88	34.79	34.83	34.71	34.77	34.86	34.83	34.79	n. s.
10. NORTH EAST	34.58	34.63	34.49	34.54	34.55	34.59	34.71	34.70	34.80	34.85	34.72	34.73	34.57	34.56	34.74	34.77	34.66	n. s.
11. FORTH AND TAY	34.47	34.47	34.30	34.29	34.30	34.39	34.36	34.47	34.57	34.44	34.38	34.66	34.41	34.33	34.47	34.49	34.42	n. s.
Climatological Average 1981-2010	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. SOLWAY	-	-	33.58	33.91	34.04	34.09	33.88	34.04	-	-	33.71	33.96	-	34.02	-	-	-	-
02. CLYDE	33.72	-	33.73	33.71	33.63	33.59	-	-	-	33.94	33.67	33.54	-	33.64	-	33.71	-	-
03. ARGYLL	34.99	34.93	34.99	35.00	34.84	34.58	34.96	34.72	34.94	34.96	34.79	34.76	34.97	34.81	34.88	34.84	34.87	0.101
04. WEST HIGHLANDS	34.56	34.75	34.71	34.67	34.67	34.70	34.77	34.62	34.83	34.65	34.71	34.76	34.67	34.68	34.74	34.71	34.70	0.084
05. OUTER HEBRIDES	34.90	35.09	35.04	35.21	35.23	35.27	35.14	35.16	35.07	34.92	35.06	35.05	35.01	35.24	35.13	35.01	35.10	n. s.
06. NORTH COAST	-	-	34.80	-	-	-	-	34.81	34.72	-	34.82	34.79	-	-	-	-	-	-
07. ORKNEY ISLANDS	34.83	34.86	34.93	34.86	34.91	34.95	34.88	34.97	34.97	34.93	34.92	34.91	34.87	34.90	34.94	34.92	34.91	0.049
08. SHETLAND ISLES	35.23	35.26	35.27	35.31	35.29	35.25	35.28	35.26	35.25	35.25	35.23	35.26	35.25	35.29	35.26	35.25	35.26	0.028
09. MORAY FIRTH	34.73	34.70	34.73	34.65	34.74	34.78	34.89	34.84	34.84	34.89	34.81	34.87	34.72	34.72	34.85	34.86	34.79	0.053
10. NORTH EAST	34.60	34.66	34.38	34.54	34.53	34.55	34.71	34.64	34.77	34.78	34.71	34.75	34.55	34.54	34.71	34.75	34.63	0.021
11. FORTH AND TAY	34.49	34.46	34.31	34.22	34.26	34.38	34.37	34.50	34.59	34.43	34.41	34.74	34.42	34.28	34.49	34.53	34.43	0.030
Decadal Average 2006-2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. SOLWAY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
02. CLYDE	-	-	33.68	-	-	-	-	-	-	-	33.67	-	-	-	-	-	-	-
03. ARGYLL	34.92	-	34.99	-	35.03	34.70	34.61	-	-	34.97	34.89	-	-	-	-	-	-	n. s.
04. WEST HIGHLANDS	34.66	34.84	34.69	-	34.69	-	34.70	34.71	-	-	34.64	34.69	34.73	-	-	-	-	-0.141
05. OUTER HEBRIDES	34.87	35.12	34.90	-	35.16	35.14	35.14	-	-	-	35.18	35.21	34.97	-	-	-	-	n. s.
06. NORTH COAST	-	-	34.78	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
07. ORKNEY ISLANDS	34.94	34.94	35.05	34.88	34.90	35.08	34.95	34.95	34.96	34.90	34.91	34.90	34.98	34.95	34.95	34.91	34.95	-0.119
08. SHETLAND ISLES	35.27	35.28	-	35.33	35.32	-	35.30	35.25	35.24	35.25	35.23	35.28	-	-	35.26	35.25	-	-0.088
09. MORAY FIRTH	34.73	34.74	-	-	-	-	34.87	34.87	-	-	-	-	-	-	-	-	-	n. s.
10. NORTH EAST	34.52	34.49	34.49	-	-	34.66	34.68	34.70	34.80	-	-	34.72	34.50	-	34.73	-	-	n. s.
11. FORTH AND TAY	34.45	34.46	34.38	-	-	34.44	34.31	34.53	-	-	-	-	34.43	-	-	-	-	-0.173
Data for Year 2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. SOLWAY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
02. CLYDE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
03. ARGYLL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
04. WEST HIGHLANDS	-	35.25	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
05. OUTER HEBRIDES	-	35.26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
06. NORTH COAST	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
07. ORKNEY ISLANDS	34.80	34.70	34.78	34.71	-	-	-	-	-	-	-	-	34.76	-	-	-	-	
08. SHETLAND ISLES	35.15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
09. MORAY FIRTH	34.74	34.61	34.60	34.47	-	-	-	-	-	-	-	-	34.65	-	-	-	-	
10. NORTH EAST	-	35.09	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
11. FORTH AND TAY	-	34.44	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	



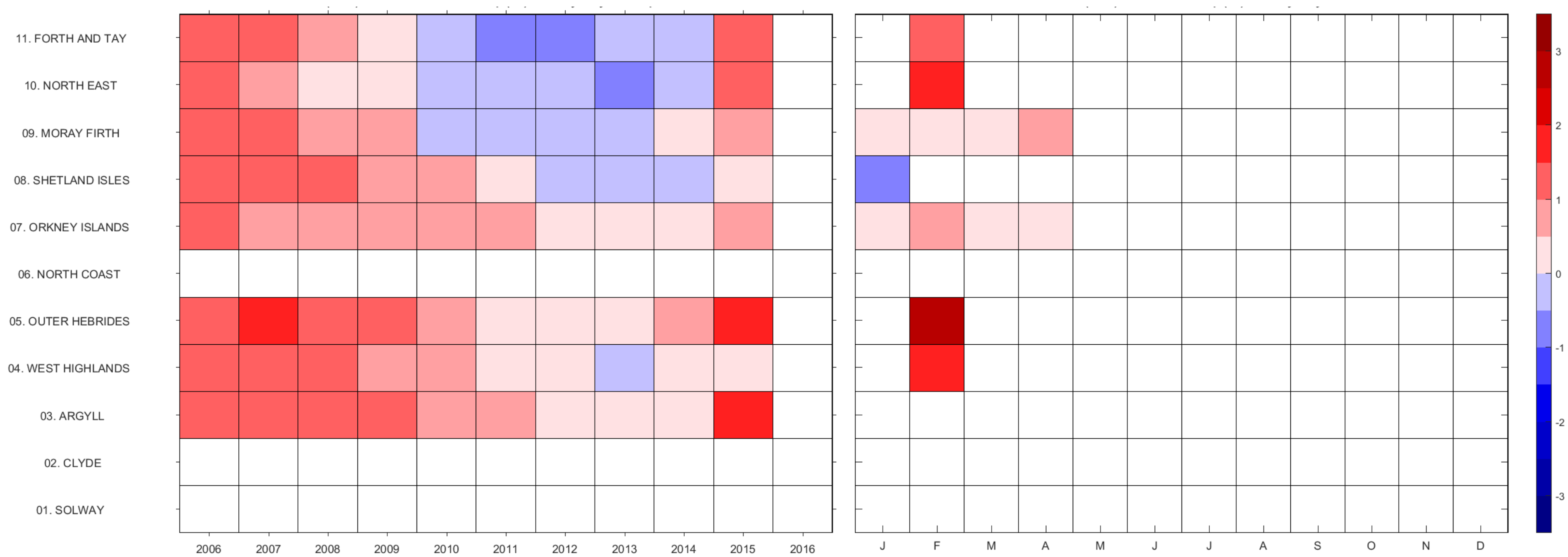
(a) Sea Surface Temperature (°C)

(b) Sea Surface Salinity

(c) Sea Bottom Temperature (°C)

(d) Sea Bottom Salinity

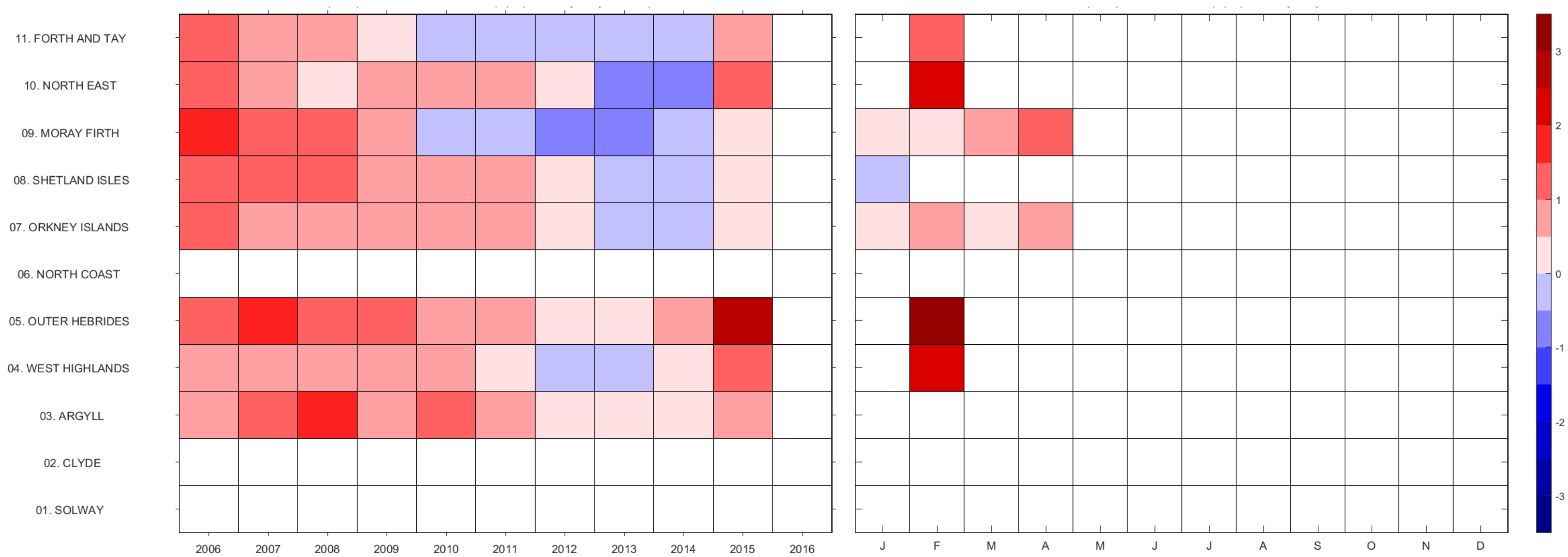
Figure 3.5: Statistical Boxplots of (a) sea surface temperature (°C), (b) sea surface salinity, (c) sea bottom temperature (°C), (d) sea bottom salinity for the climatological period 1981–2010, from the ODaT dataset, in each Scottish Marine Region (see also Figure F.1a). For this dataset, not enough data are available in the Solway, Clyde or North Coast regions to make an analysis of the long-term trend.



(a) Decade 2006–2016

(b) Monthly for 2016

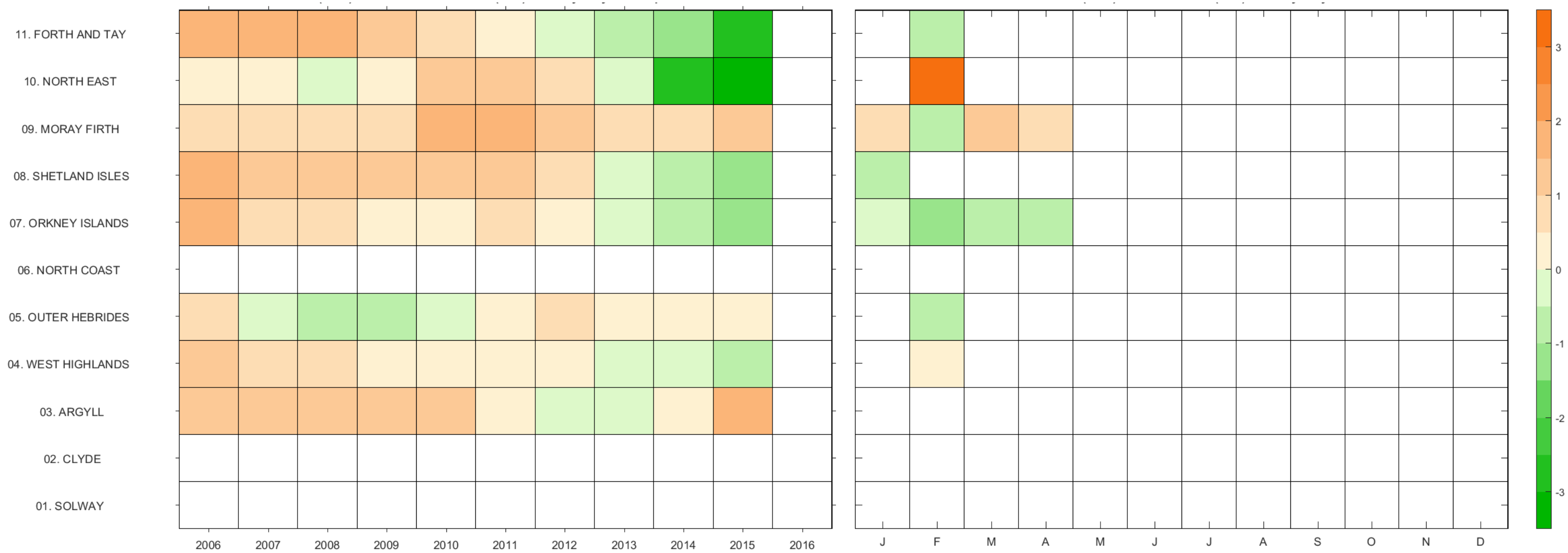
Figure 3.6: Normalised anomalies (σ) of monthly average sea surface temperature (°C) for (a) the years 2006–2016 and (b) the months in 2016 (all plotted relative to 1981–2010 base period), from the ODaT dataset, by Scottish Marine Region. The anomalies are normalised with respect to the standard deviation of each time-series (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds = positive/warmer; blues = negative/cooler. For this dataset, not enough data are available in the Solway, Clyde or North Coast regions to make an analysis of the long-term trend.



(c) Decade 2006–2016

(d) Monthly for 2016

(cont.) Figure 3.6: Normalised anomalies (σ) of monthly average sea bottom temperature (°C) for (c) the years 2006–2016 and (d) the months in 2016 (all plotted relative to 1981–2010 base period), from the ODaT dataset, by Scottish Marine Region. The anomalies are normalised with respect to the standard deviation of each time-series (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds = positive/warmer; blues = negative/cooler. For this dataset, not enough data are available in the Solway, Clyde or North Coast regions to make an analysis of the long-term trend.

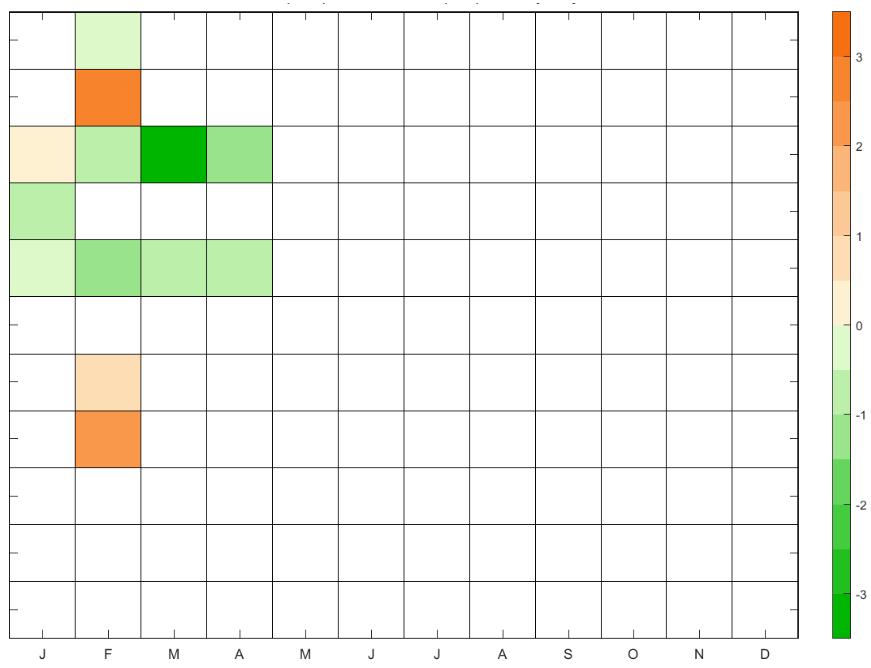


(e) Decade 2006–2016

(f) Monthly for 2016

(cont.) Figure 3.6: Normalised anomalies (σ) of monthly average sea surface surface salinity for (e) the years 2006–2016 and (f) the months in 2016 (all plotted relative to 1981–2010 base period), from the ODaT dataset, by Scottish Marine Region. The anomalies are normalised with respect to the standard deviation of each time-series (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; oranges = positive/saltier; greens = negative/fresher. For this dataset, not enough data are available in the Solway, Clyde or North Coast regions to make an analysis of the long-term trend.

(g) Decade 2006–2016



(h) Monthly for 2016

(cont.) Figure 3.6: Normalised anomalies (σ) of monthly average sea bottom salinity for (g) the years 2006–2016 and (h) the months in 2016 (all plotted relative to 1981–2010 base period), from the ODaT dataset, by Scottish Marine Region. The anomalies are normalised with respect to the standard deviation of each time-series (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; oranges = positive/saltier; greens = negative/fresher. For this dataset, not enough data are available in the Solway, Clyde or North Coast regions to make an analysis of the long-term trend.

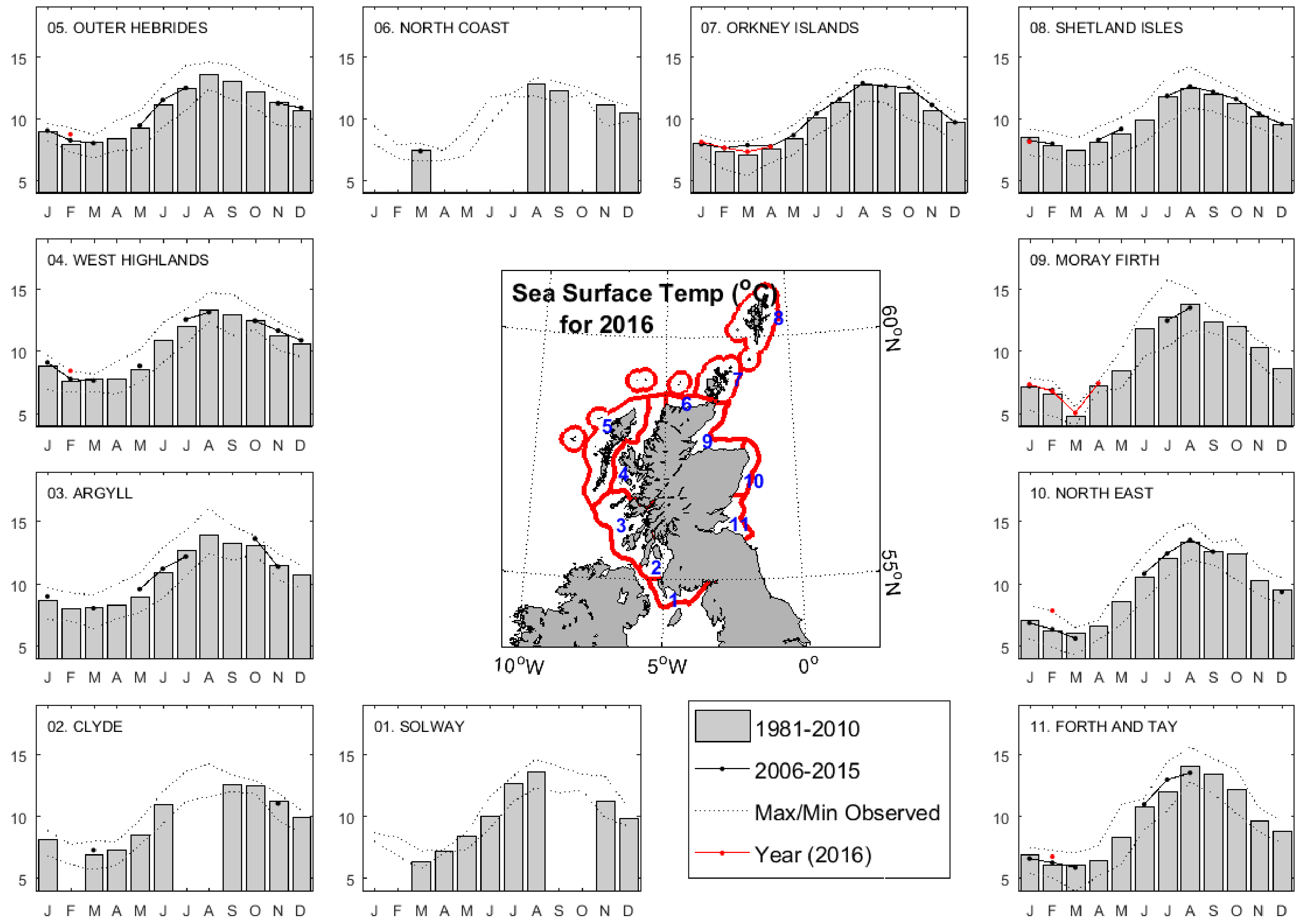
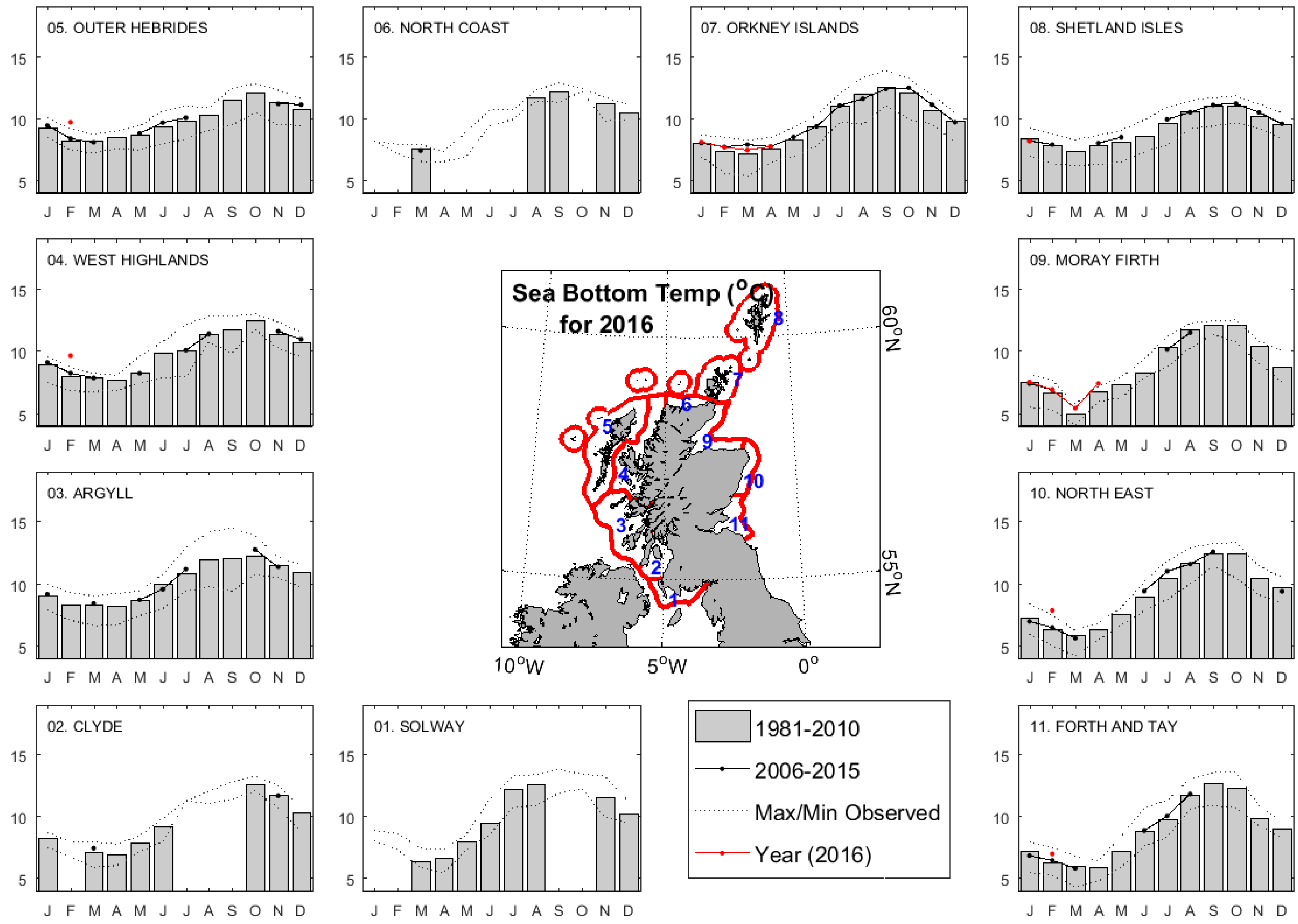
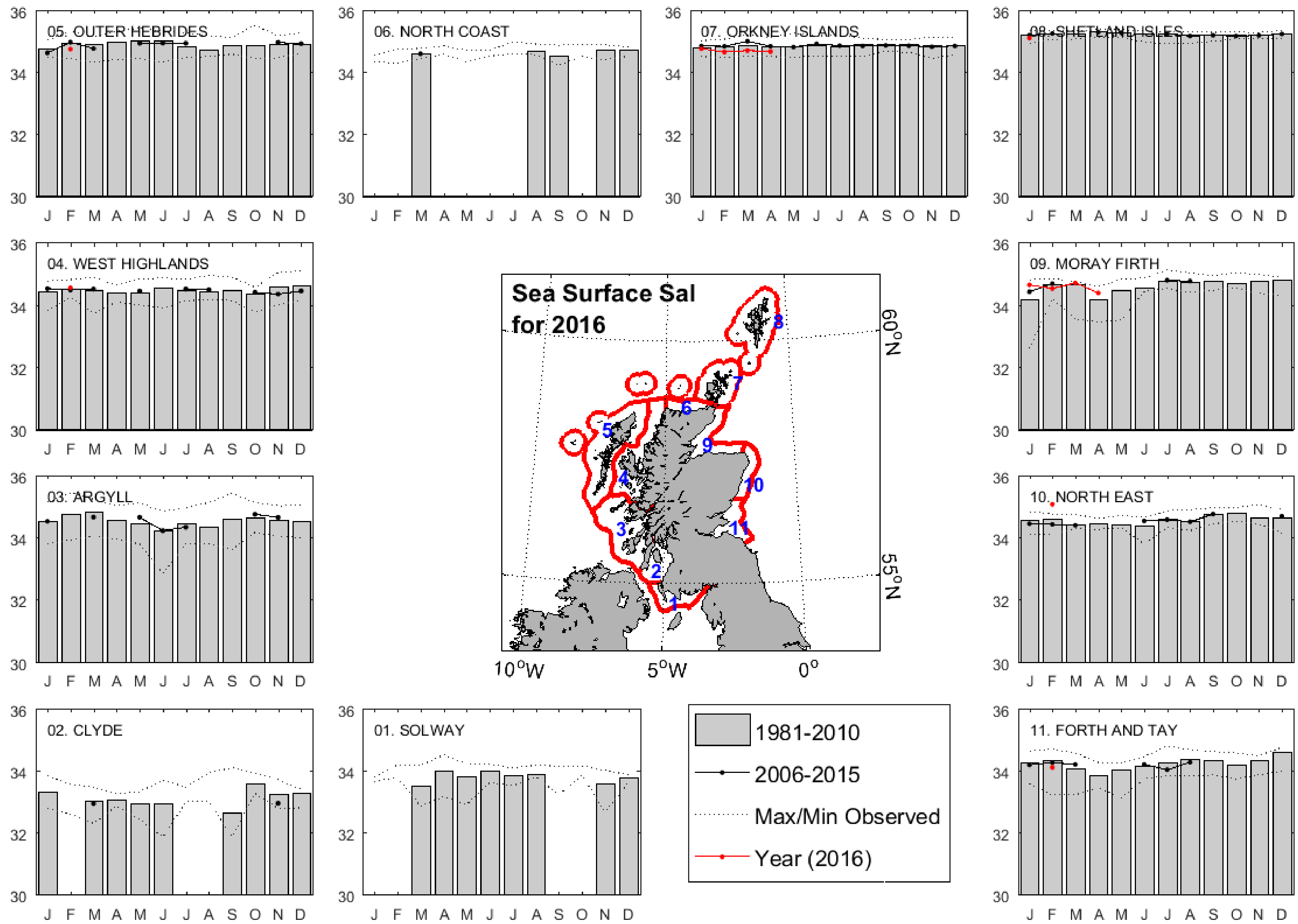


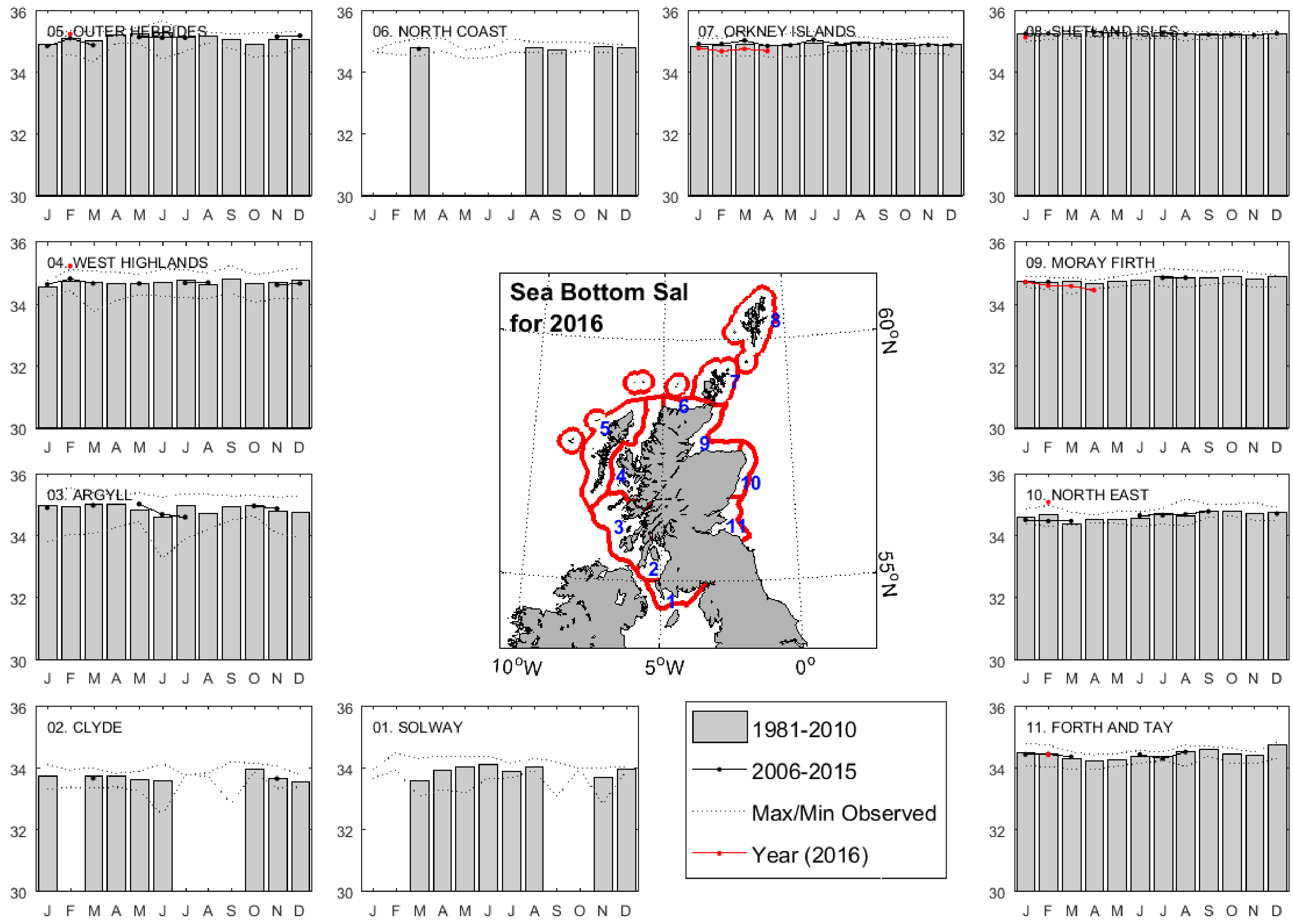
Figure 3.7: (a) Summary of monthly sea surface temperature (°C) for 2016, from the ODaT dataset, by Scottish Marine Region. Plots show monthly values of sea surface temperature during 2016 compared to the long-term average pattern (calculated for the period 1981–2010) and the average over the last decade (2006–2016). X-axis of each graph is month. Central map shows the extent of each of the Scottish Marine Regions.



(cont.) Figure 3.7: (b) Summary of monthly sea bottom temperature (°C) for 2016, from the ODaT dataset, by Scottish Marine Region. Plots show monthly values of sea bottom temperature during 2016 compared to the long-term average pattern (calculated for the period 1981–2010) and the average over the last decade (2006–2016). X-axis of each graph is month. Central map shows the extent of each of the Scottish Marine Regions.



(cont.) Figure 3.7: (c) Summary of monthly sea surface salinity for 2016, from the ODaT dataset, by Scottish Marine Region. Plots show monthly values of sea surface salinity during 2016 compared to the long-term average pattern (calculated for the period 1981–2010) and the average over the last decade (2006–2016). X-axis of each graph is month. Central map shows the extent of each of the Scottish Marine Regions.



(cont.) Figure 3.7: (d) Summary of monthly sea bottom salinity for 2016, from the ODaT dataset, by Scottish Marine Region. Plots show monthly values of sea bottom salinity during 2016 compared to the long-term average pattern (calculated for the period 1981–2010) and the average over the last decade (2006–2016). X-axis of each graph is month. Central map shows the extent of each of the Scottish Marine Regions.

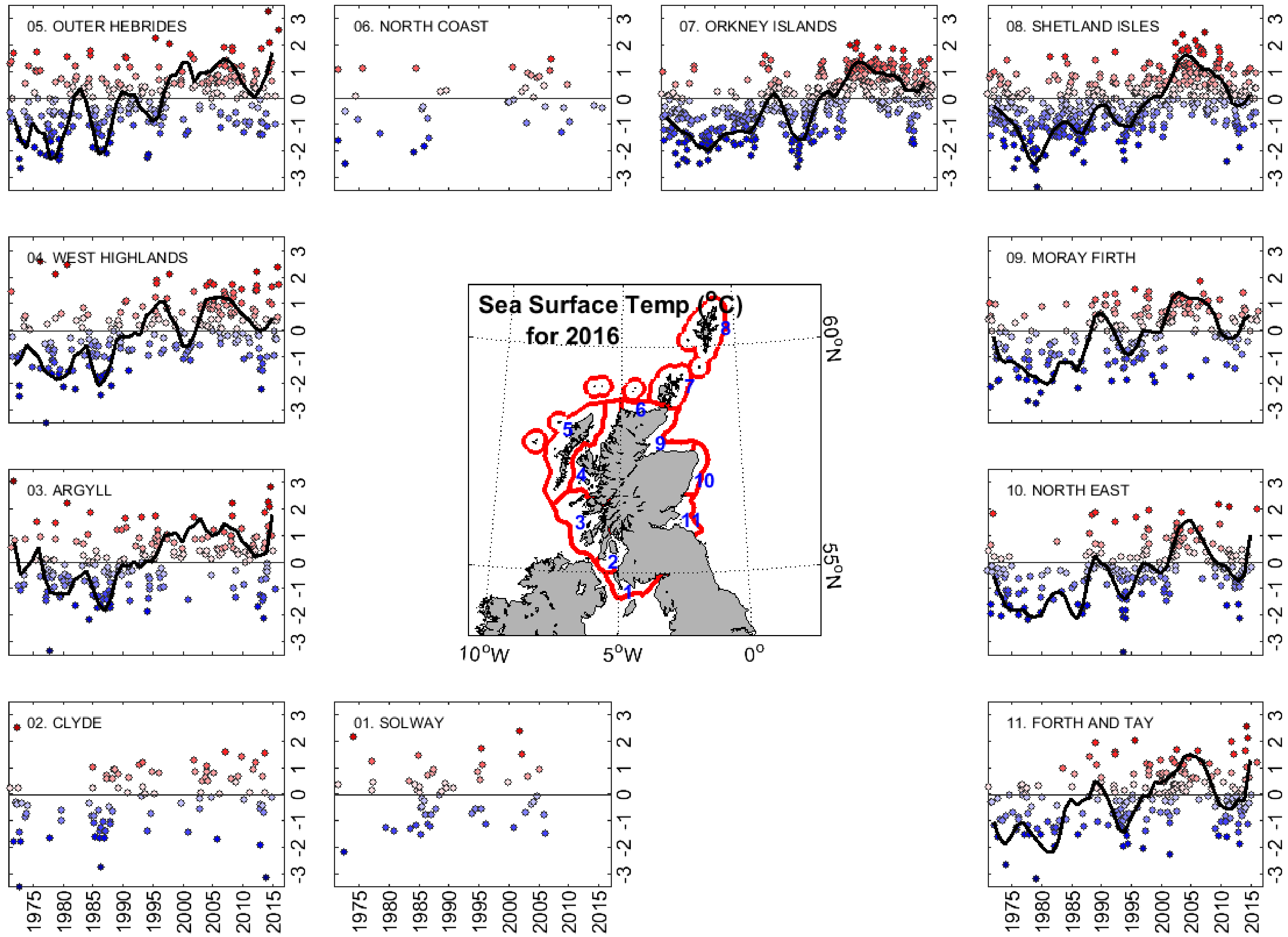
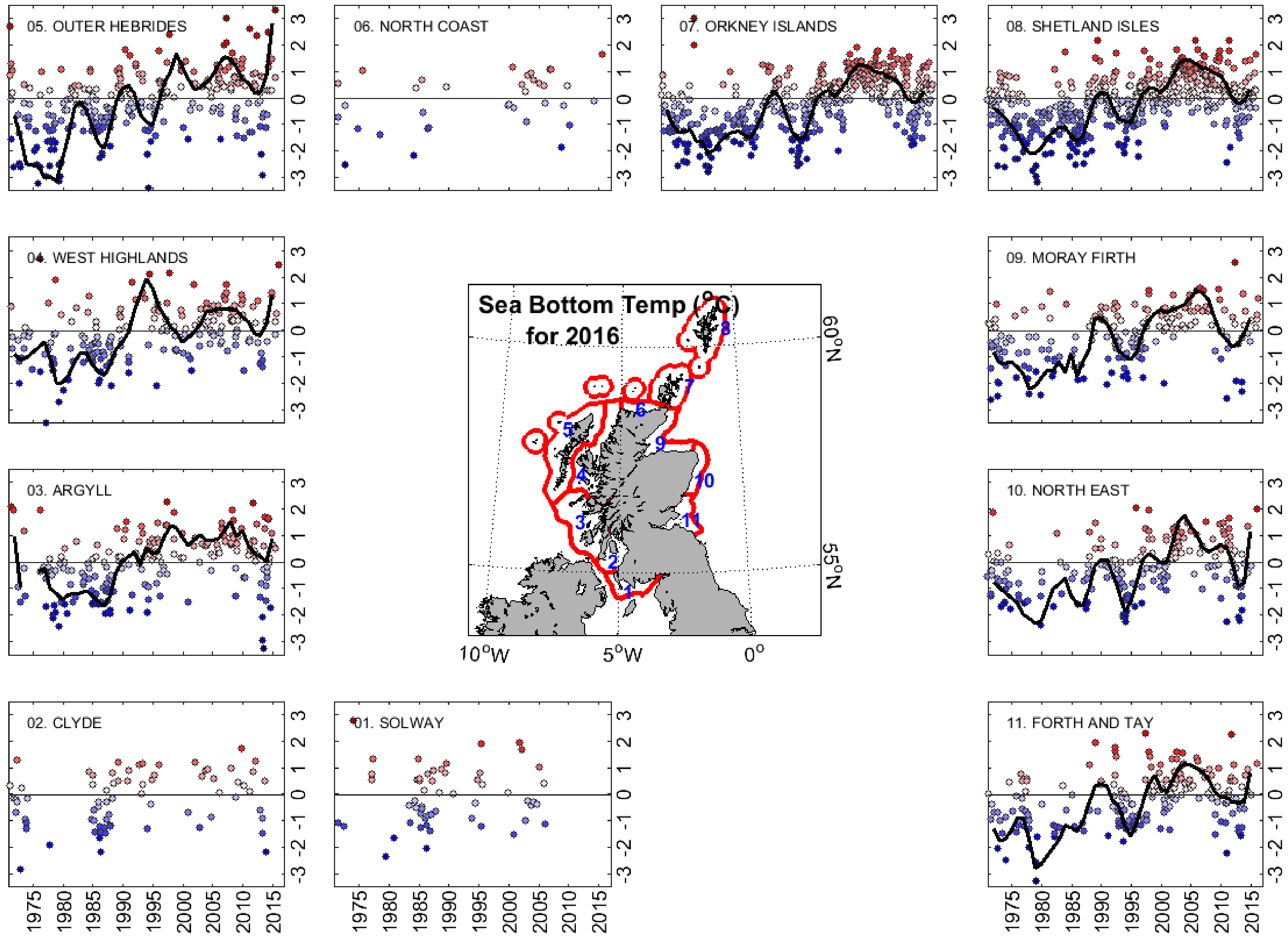
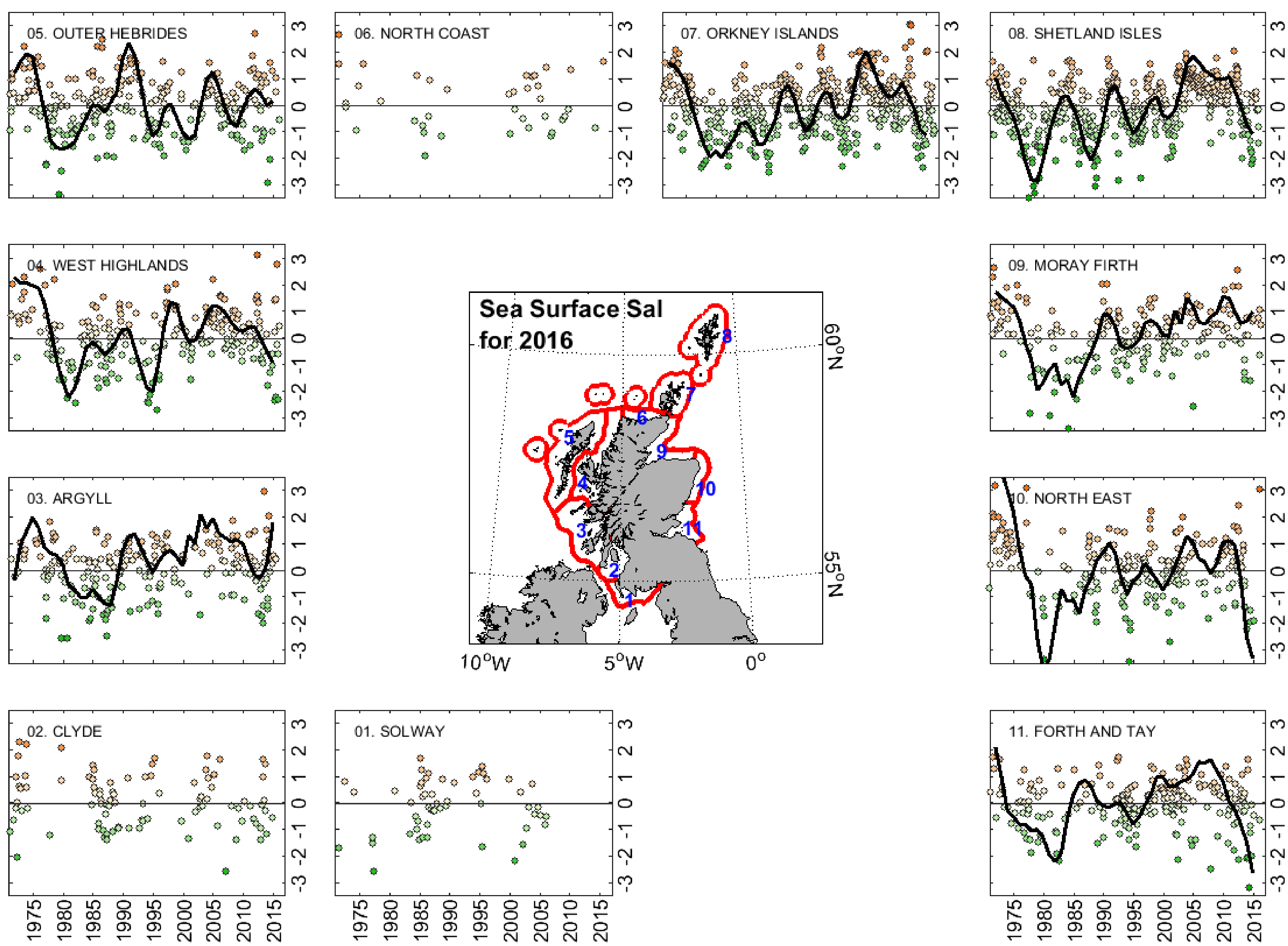


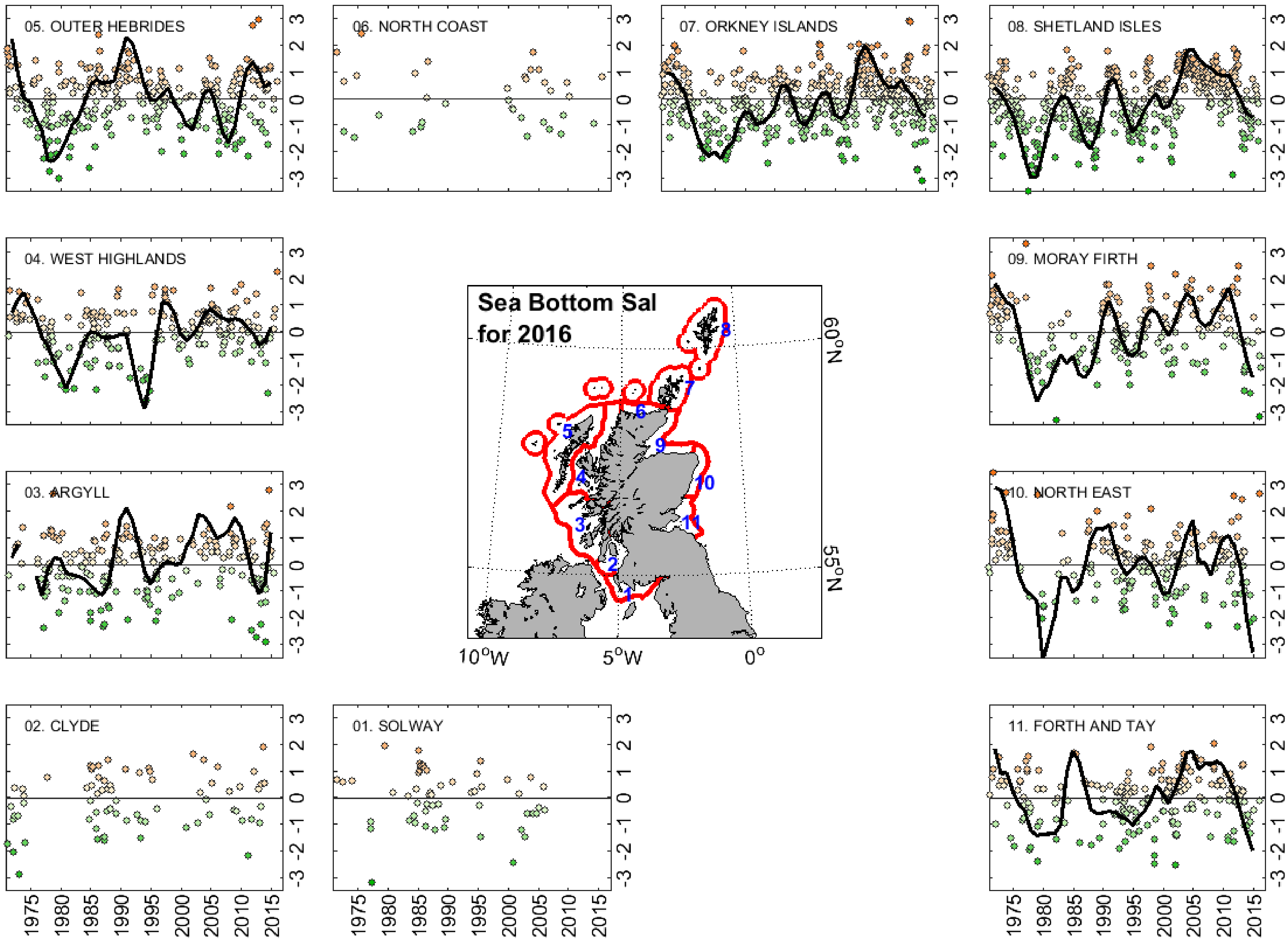
Figure 3.8: (a) Time series of normalised annual anomalies (σ) of sea surface temperature (°C) up to 2016 (relative to 1981-2010 base period), from the ODaT dataset, by Scottish Marine Region. X-axis of each plot is year. The anomalies are normalised with respect to the standard deviation (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds = positive/warmer; blues = negative/cooler. Central map shows the extent of each of the Scottish Marine Regions.



(cont.) Figure 3.8: (b) Time series of normalised annual anomalies (σ) of sea bottom temperature (°C) up to 2016 (relative to 1981-2010 base period), from the ODaT dataset, by Scottish Marine Region. X-axis of each plot is year. The anomalies are normalised with respect to the standard deviation (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds = positive/warmer; blues = negative/cooler. Central map shows the extent of each of the Scottish Marine Regions.



(cont.) Figure 3.8: (c) Time series of normalised annual anomalies (σ) of sea surface salinity up to 2016 (relative to 1981-2010 base period), from the ODaT dataset, by Scottish Marine Region. X-axis of each plot is year. The anomalies are normalised with respect to the standard deviation (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; oranges = positive/saltier; greens = negative/fresher. Central map shows the extent of each of the Scottish Marine Regions.



(cont.) Figure 3.8: (d) Time series of normalised annual anomalies (σ) of sea bottom salinity up to 2016 (relative to 1981-2010 base period), from the ODaT dataset, by Scottish Marine Region. X-axis of each plot is year. The anomalies are normalised with respect to the standard deviation (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; oranges = positive/saltier; greens = negative/fresher. Central map shows the extent of each of the Scottish Marine Regions.

Table 3.3: Statistical Summary of sea surface temperature (°C) from SCObs, in each of the Scottish Marine Region. The trends in the table are in °C per decade over the indicated time period. See also Figure C.1 and Appendix G.4.

Dataset Average 1997-2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
02. (CLYDE) MILLPORT	8.0	7.5	7.5	8.5	10.1	12.1	14.0	14.7	13.9	12.5	11.1	9.6	7.7	10.3	14.2	11.0	10.8	-0.38
03. (ARGYLL) TIREE	8.7	8.0	7.6	8.0	9.6	11.1	12.5	13.7	14.0	13.3	11.9	10.1	8.1	9.6	13.4	11.8	10.7	n. s.
04. (WEST HIGHLANDS) ARDTOE	8.1	7.5	7.5	8.5	10.2	12.0	13.5	14.3	14.0	12.7	11.1	9.3	7.7	10.2	13.9	11.0	10.7	n. s.
04. (WEST HIGHLANDS) MALLAIG	8.3	7.5	7.5	8.4	9.9	11.8	13.4	14.2	13.9	12.8	11.3	9.7	7.8	10.0	13.8	11.3	10.7	n. s.
04. (WEST HIGHLANDS) LOCH EWE	8.3	7.5	7.4	8.1	9.4	10.9	12.6	13.4	13.1	12.1	10.8	9.4	7.7	9.5	13.0	10.8	10.3	n. s.
05. (OUTER HEBRIDES) LOCH MADDY	8.8	7.8	7.7	8.5	9.9	11.4	12.5	13.3	13.1	12.2	10.9	9.9	8.1	9.9	13.0	11.0	10.5	n. s.
07. (ORKNEY ISLANDS) SCAPA	6.6	6.1	6.5	7.8	9.4	11.1	12.6	13.5	13.0	11.4	9.6	7.7	6.4	9.4	13.0	9.6	9.6	n. s.
08. (SHETLAND ISLES) FAIR ISLE	8.0	7.3	7.4	7.7	8.8	10.1	11.4	12.3	12.1	11.3	10.2	8.8	7.6	8.9	12.0	10.1	9.6	n. s.
08. (SHETLAND ISLES) SCALLOWAY	6.4	6.0	6.3	7.6	9.4	11.2	12.7	13.2	12.3	10.7	8.9	7.3	6.2	9.4	12.7	9.0	9.3	n. s.
09. (MORAY FIRTH) CROMARTY	5.9	5.5	5.9	7.5	9.6	12.2	14.0	14.2	13.2	11.5	9.3	7.1	5.8	9.8	13.8	9.3	9.7	n. s.
10. (NORTH EAST) EAST COAST	7.1	6.2	6.1	6.9	8.5	10.5	12.3	13.2	13.0	12.1	10.5	8.7	6.5	8.7	12.9	10.5	9.6	n. s.

Climatological Average 2000-2010	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
02. (CLYDE) MILLPORT	8.3	7.7	7.6	8.6	10.2	12.4	14.0	14.8	14.1	12.5	11.2	9.7	7.9	10.4	14.3	11.1	10.9	n. s.
03. (ARGYLL) TIREE	8.9	8.2	7.8	8.3	9.6	11.1	12.6	13.8	14.1	13.4	12.0	10.3	8.3	9.7	13.5	11.9	10.8	n. s.
04. (WEST HIGHLANDS) ARDTOE	8.1	7.4	7.4	8.4	10.2	12.0	13.5	14.3	14.0	12.8	11.1	9.2	7.6	10.2	13.9	11.0	10.7	n. s.
04. (WEST HIGHLANDS) MALLAIG	8.4	7.7	7.6	8.4	10.1	11.9	13.5	14.4	14.0	12.9	11.4	9.8	7.9	10.1	14.0	11.4	10.8	n. s.
04. (WEST HIGHLANDS) LOCH EWE	8.3	7.6	7.4	8.2	9.6	11.3	12.8	13.6	13.3	12.2	10.7	9.4	7.8	9.7	13.2	10.8	10.4	n. s.
05. (OUTER HEBRIDES) LOCH MADDY	8.8	8.0	7.7	8.6	10.1	11.6	12.8	13.5	13.2	12.3	11.0	9.9	8.2	10.1	13.2	11.1	10.6	n. s.
07. (ORKNEY ISLANDS) SCAPA	6.8	6.2	6.5	7.8	9.6	11.3	12.7	13.6	13.1	11.4	9.5	7.8	6.5	9.6	13.1	9.6	9.7	n. s.
08. (SHETLAND ISLES) FAIR ISLE	8.0	7.3	7.1	7.6	8.9	10.1	11.3	12.3	12.1	11.3	10.1	8.9	7.5	8.9	11.9	10.1	9.6	n. s.
08. (SHETLAND ISLES) SCALLOWAY	6.6	6.0	6.3	7.6	9.6	11.3	12.9	13.2	12.4	10.7	8.9	7.4	6.3	9.5	12.8	9.0	9.4	n. s.
09. (MORAY FIRTH) CROMARTY	6.1	5.7	5.8	7.4	9.8	12.5	13.9	14.5	13.5	11.7	9.4	7.2	5.9	9.9	14.0	9.4	9.8	n. s.
10. (NORTH EAST) EAST COAST	7.2	6.3	6.1	6.9	8.5	10.7	12.5	13.4	13.2	12.2	10.7	8.7	6.5	8.7	13.0	10.5	9.7	n. s.

Decadal Average 2006-2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
02. (CLYDE) MILLPORT	7.8	7.3	7.3	8.3	9.8	11.9	14.0	14.6	13.7	12.5	11.0	9.2	7.5	10.0	14.1	10.9	10.6	-0.79
03. (ARGYLL) TIREE	8.7	7.9	7.5	7.8	9.6	11.1	12.5	13.6	13.9	13.3	11.8	9.9	8.0	9.5	13.4	11.7	10.7	n. s.
04. (WEST HIGHLANDS) ARDTOE	8.1	7.4	7.5	8.5	10.0	12.1	13.6	14.2	13.9	12.8	11.2	9.2	7.7	10.2	13.9	11.1	10.7	n. s.
04. (WEST HIGHLANDS) MALLAIG	8.2	7.5	7.4	8.4	9.8	11.7	13.5	14.1	13.7	12.8	11.3	9.6	7.7	10.0	13.8	11.2	10.7	-0.68
04. (WEST HIGHLANDS) LOCH EWE	8.3	7.5	7.4	8.0	9.1	10.6	12.3	13.2	13.1	12.2	10.9	9.4	7.7	9.2	12.8	10.8	10.2	-0.77
05. (OUTER HEBRIDES) LOCH MADDY	8.7	7.8	7.7	8.5	10.0	11.4	12.5	13.1	13.0	12.1	10.8	9.8	8.1	10.0	12.9	10.9	10.5	n. s.
07. (ORKNEY ISLANDS) SCAPA	6.5	6.1	6.5	7.7	9.4	10.9	12.6	13.5	12.8	11.3	9.5	7.5	6.4	9.3	13.0	9.4	9.5	n. s.
08. (SHETLAND ISLES) FAIR ISLE	7.8	7.2	7.1	7.5	8.6	10.0	11.2	11.9	11.7	11.0	9.8	8.6	7.4	8.7	11.6	9.8	9.4	n. s.
08. (SHETLAND ISLES) SCALLOWAY	6.3	6.0	6.3	7.7	9.4	11.2	12.7	13.2	12.2	10.7	8.9	7.0	6.2	9.4	12.7	8.9	9.3	n. s.
09. (MORAY FIRTH) CROMARTY	5.9	5.5	6.0	7.5	9.6	12.3	14.1	14.1	13.2	11.5	9.3	7.0	5.8	9.8	13.8	9.3	9.7	n. s.
10. (NORTH EAST) EAST COAST	7.0	6.1	6.0	6.9	8.5	10.4	12.3	13.1	13.0	12.2	10.6	8.6	6.4	8.6	12.8	10.5	9.6	n. s.

Data for Year 2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
02. (CLYDE) MILLPORT	8.2	7.2	7.8	8.4	10.0	12.2	14.1	14.2	14.3	12.8	11.4	10.1	7.7	10.2	14.2	11.5	10.9	
03. (ARGYLL) TIREE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
04. (WEST HIGHLANDS) ARDTOE	8.1	7.2	7.7	8.3	10.5	12.8	13.4	14.1	14.5	12.8	10.5	10.0	7.7	10.5	14.0	11.1	10.8	
04. (WEST HIGHLANDS) MALLAIG	8.6	7.6	7.9	8.4	10.0	11.8	13.2	13.8	14.4	13.3	11.5	10.1	8.0	10.1	13.8	11.6	10.9	
04. (WEST HIGHLANDS) LOCH EWE	8.7	7.7	7.7	8.1	9.0	10.7	12.0	12.8	13.2	12.4	11.0	9.8	8.0	9.3	12.7	11.1	10.2	
05. (OUTER HEBRIDES) LOCH MADDY	-	-	-	-	-	-	-	12.9	13.3	12.8	11.2	10.3	-	-	-	11.4	-	
07. (ORKNEY ISLANDS) SCAPA	6.5	6.0	6.5	7.4	8.8	11.0	13.3	13.6	13.8	11.9	9.6	8.5	6.3	9.1	13.6	10.0	9.8	
08. (SHETLAND ISLES) FAIR ISLE	7.8	7.2	7.3	7.8	8.7	10.2	11.1	12.3	12.5	11.9	10.3	9.6	7.4	8.9	12.0	10.6	9.7	
08. (SHETLAND ISLES) SCALLOWAY	6.2	5.9	6.7	7.5	9.2	11.2	13.2	12.6	12.9	10.9	8.9	8.0	6.2	9.3	12.9	9.3	9.4	
09. (MORAY FIRTH) CROMARTY	6.5	5.6	6.0	7.3	10.0	-	-	-	-	-	-	-	6.0	-	-	-	-	
10. (NORTH EAST) EAST COAST	7.3	6.1	6.1	7.0	9.0	10.9	12.3	13.3	13.3	12.2	9.7	8.5	6.5	9.0	12.9	10.1	9.6	

Table 3.4: Statistical Summary of sea surface temperature (°C) from Scotland's Long Coastal Temperature Time series. The trends in the table are in °C per decade over the indicated time period. See also Figure C.1 and Appendix G.4.

Dataset Average 1900-2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
02. (CLYDE) MILLPORT	7.7	6.9	7.0	7.8	9.3	11.2	13.0	13.8	13.2	11.9	10.4	9.0	7.2	9.4	13.3	10.4	10.1	n. s.
08. (SHETLAND ISLES) FAIRISLE	7.5	6.8	6.8	7.5	8.6	10.2	11.2	12.0	11.9	11.1	9.7	8.5	7.0	8.8	11.7	9.7	9.3	n. s.
10. (NORTH EAST) PETERHEAD	6.5	5.9	6.1	7.1	8.8	10.8	12.2	13.3	13.0	11.7	9.8	8.1	6.2	8.9	12.8	9.9	9.4	n. s.
Climatological Average 1981-2010	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
02. (CLYDE) MILLPORT	7.8	7.0	7.2	8.1	9.8	11.8	13.6	14.4	13.7	12.3	10.9	9.5	7.3	9.9	13.9	10.9	10.5	0.50
08. (SHETLAND ISLES) FAIRISLE	7.5	6.8	6.8	7.5	8.7	10.2	11.2	12.1	12.0	11.1	9.7	8.5	7.0	8.8	11.8	9.8	9.3	0.29
10. (NORTH EAST) PETERHEAD	6.6	5.9	6.1	7.1	8.8	10.7	12.2	13.3	13.0	11.8	10.0	8.3	6.2	8.9	12.8	10.0	9.5	0.26
Decadal Average 2006-2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
02. (CLYDE) MILLPORT	7.8	7.3	7.3	8.3	9.9	12.0	13.9	14.4	13.7	12.4	11.0	9.1	7.5	10.1	14.0	10.8	10.6	-0.76
08. (SHETLAND ISLES) FAIRISLE	7.9	7.3	7.3	7.6	8.5	10.0	11.3	11.8	11.6	11.1	9.7	8.6	7.5	8.7	11.6	9.8	9.4	n. s.
10. (NORTH EAST) PETERHEAD	6.8	6.5	6.3	7.2	9.0	10.9	12.5	13.7	13.5	11.7	10.0	8.0	6.6	9.0	13.2	9.9	9.7	n. s.
Data for Year 2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
02. (CLYDE) MILLPORT	8.2	7.2	7.8	8.4	10.0	12.2	14.1	14.2	14.3	12.8	11.4	10.1	7.7	10.2	14.2	11.5	10.9	
08. (SHETLAND ISLES) FAIRISLE	7.8	7.2	7.3	7.8	8.7	10.2	11.1	-	12.5	11.9	10.3	9.6	7.4	8.9	-	10.6	-	
10. (NORTH EAST) PETERHEAD	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

Table 3.5: (a) Statistical Summary of sea surface temperature (°C) from selected stations in the SCObs dataset. The trends in the table are in °C per decade over the indicated time period. See also Figure C.1 and Appendix G.4.

Dataset Average 1997-2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
04. (WEST HIGHLANDS) LOCHEWE	8.0	7.4	7.3	8.1	9.3	11.4	12.8	13.5	13.1	11.9	10.5	9.2	7.6	9.6	13.1	10.5	10.2	n. s.
07. (ORKNEY ISLANDS) SCAPA	6.6	6.2	6.4	7.9	9.4	11.0	12.6	13.5	12.9	11.4	9.6	7.9	6.4	9.4	13.0	9.6	9.6	n. s.
08. (SHETLAND ISLES) SCALLOWAY	6.3	6.1	6.3	7.7	9.3	10.9	12.6	13.2	12.3	10.8	8.8	7.4	6.2	9.3	12.7	9.0	9.3	n. s.
10. (NORTH EAST) STONEHAVEN	7.2	6.2	6.1	6.8	8.6	10.7	12.4	13.2	13.0	12.1	10.6	8.8	6.5	8.7	12.9	10.5	9.6	n. s.
Climatological Average 2000-2010	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
04. (WEST HIGHLANDS) LOCHEWE	8.2	7.5	7.3	8.2	9.4	11.6	13.0	13.6	13.2	11.9	10.4	9.3	7.7	9.7	13.2	10.6	10.3	n. s.
07. (ORKNEY ISLANDS) SCAPA	6.8	6.3	6.4	8.0	9.5	11.3	12.7	13.6	13.1	11.3	9.6	7.9	6.5	9.6	13.1	9.6	9.7	n. s.
08. (SHETLAND ISLES) SCALLOWAY	6.5	6.2	6.2	7.6	9.5	11.2	12.8	13.1	12.5	10.8	8.7	7.5	6.3	9.4	12.8	9.0	9.4	n. s.
10. (NORTH EAST) STONEHAVEN	7.2	6.3	6.0	6.8	8.5	10.8	12.5	13.3	13.2	12.2	10.6	8.7	6.5	8.7	13.0	10.5	9.7	n. s.
Decadal Average 2006-2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
04. (WEST HIGHLANDS) LOCHEWE	7.9	7.3	7.2	8.1	9.3	11.3	12.8	13.3	13.1	11.9	10.4	9.0	7.5	9.6	13.1	10.4	10.1	n. s.
07. (ORKNEY ISLANDS) SCAPA	6.5	6.1	6.3	7.9	9.3	10.8	12.7	13.4	12.8	11.4	9.6	7.7	6.3	9.3	13.0	9.6	9.5	n. s.
08. (SHETLAND ISLES) SCALLOWAY	6.2	6.0	6.3	7.6	9.3	10.9	12.7	13.2	12.2	10.7	8.7	7.1	6.2	9.3	12.7	8.9	9.2	n. s.
10. (NORTH EAST) STONEHAVEN	7.0	6.1	6.1	6.8	8.6	10.7	12.4	13.1	13.0	12.3	10.8	8.8	6.4	8.7	12.9	10.6	9.7	n. s.
Data for Year 2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
04. (WEST HIGHLANDS) LOCHEWE	8.0	7.0	7.7	8.0	9.5	12.5	12.6	13.5	13.3	11.9	9.9	-	7.6	10.0	13.1	-	-	
07. (ORKNEY ISLANDS) SCAPA	6.8	6.1	6.3	7.3	8.7	11.4	12.9	12.9	-	-	-	-	6.4	9.1	-	-	-	
08. (SHETLAND ISLES) SCALLOWAY	6.2	6.0	6.8	7.6	9.6	11.5	12.8	12.5	12.9	10.8	8.9	-	6.3	9.6	12.7	-	-	
10. (NORTH EAST) STONEHAVEN	7.4	6.5	6.0	6.9	8.6	10.2	12.1	13.1	13.1	12.3	10.4	9.8	6.6	8.6	12.8	10.8	9.7	

(cont.) Table 3.5: (b) Statistical Summary of sea bottom temperature (°C) from selected stations in the SCObs dataset. The trends in the table are in °C per decade over the indicated time period. See also Figure C.1 and Appendix G.4.

Dataset Average 1997-2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
04. (WEST HIGHLANDS) LOCHEWE	8.7	7.9	7.6	8.0	8.8	10.1	11.7	12.8	13.0	12.4	11.2	9.9	8.1	9.0	12.5	11.2	10.2	n. s.
07. (ORKNEY ISLANDS) SCAPA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
08. (SHETLAND ISLES) SCALLOWAY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10. (NORTH EAST) STONEHAVEN	7.2	6.3	6.1	6.7	8.0	9.8	11.5	12.6	13.0	12.3	10.8	9.1	6.5	8.2	12.4	10.7	9.4	n. s.
Climatological Average 2000-2010	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
04. (WEST HIGHLANDS) LOCHEWE	8.9	8.1	7.6	8.0	8.9	10.3	11.8	12.9	13.1	12.4	11.3	10.0	8.2	9.1	12.6	11.2	10.3	n. s.
07. (ORKNEY ISLANDS) SCAPA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
08. (SHETLAND ISLES) SCALLOWAY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10. (NORTH EAST) STONEHAVEN	7.3	6.5	6.1	6.7	8.0	9.9	11.8	12.8	13.2	12.3	10.9	9.1	6.6	8.2	12.6	10.8	9.6	n. s.
Decadal Average 2006-2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
04. (WEST HIGHLANDS) LOCHEWE	8.6	7.9	7.5	7.9	8.7	9.9	11.6	12.7	12.9	12.3	11.2	9.8	8.0	8.9	12.4	11.1	10.1	-0.49
07. (ORKNEY ISLANDS) SCAPA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
08. (SHETLAND ISLES) SCALLOWAY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10. (NORTH EAST) STONEHAVEN	7.0	6.3	6.1	6.7	8.0	10.0	11.6	12.5	13.0	12.4	10.9	9.1	6.5	8.2	12.4	10.8	9.5	n. s.
Data for Year 2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
04. (WEST HIGHLANDS) LOCHEWE	8.8	7.8	7.8	8.0	8.7	9.9	11.5	12.6	13.3	12.5	11.1	-	8.1	8.9	12.5	-	-	
07. (ORKNEY ISLANDS) SCAPA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
08. (SHETLAND ISLES) SCALLOWAY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
10. (NORTH EAST) STONEHAVEN	8.0	6.6	6.0	6.8	8.1	10.1	11.1	12.4	13.1	12.4	10.5	9.9	6.9	8.3	12.2	10.9	9.6	

(cont.) Table 3.5: (c) Statistical Summary of sea surface salinity from selected stations in the SCObs dataset. The trends in the table are per decade over the indicated time period. See also Figure C.1 and Appendix G.4.

Dataset Average 1997-2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
04. (WEST HIGHLANDS) LOCHEWE	32.76	33.27	33.18	33.42	33.65	33.75	33.90	33.72	33.42	33.27	32.91	32.59	33.07	33.61	33.68	32.92	33.32	n. s.
07. (ORKNEY ISLANDS) SCAPA	34.12	34.36	34.41	34.61	34.69	34.74	34.77	34.80	34.66	34.63	34.56	34.40	34.30	34.68	34.74	34.53	34.56	n. s.
08. (SHETLAND ISLES) SCALLOWAY	34.27	34.29	34.49	34.89	34.96	35.12	35.15	35.08	34.95	34.79	34.49	34.59	34.35	34.99	35.06	34.62	34.76	n. s.
10. (NORTH EAST) STONEHAVEN	34.40	34.31	34.31	34.29	34.33	34.41	34.48	34.56	34.62	34.59	34.54	34.44	34.34	34.34	34.55	34.52	34.44	n. s.
Climatological Average 2000-2010	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
04. (WEST HIGHLANDS) LOCHEWE	33.20	33.48	33.42	33.72	34.02	33.96	34.00	34.08	33.69	33.39	33.09	33.52	33.37	33.90	33.92	33.33	33.63	n. s.
07. (ORKNEY ISLANDS) SCAPA	34.12	34.37	34.36	34.64	34.73	34.79	34.80	34.83	34.77	34.66	34.57	34.46	34.28	34.72	34.80	34.57	34.59	n. s.
08. (SHETLAND ISLES) SCALLOWAY	34.47	34.34	34.42	34.96	35.14	35.14	35.14	35.11	35.01	34.82	34.53	34.68	34.41	35.08	35.09	34.68	34.81	n. s.
10. (NORTH EAST) STONEHAVEN	34.39	34.28	34.31	34.27	34.37	34.46	34.56	34.61	34.65	34.58	34.50	34.43	34.33	34.37	34.61	34.50	34.45	n. s.
Decadal Average 2006-2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
04. (WEST HIGHLANDS) LOCHEWE	32.64	33.18	33.07	33.24	33.52	33.71	33.81	33.55	33.35	33.28	32.81	32.26	32.96	33.49	33.57	32.78	33.20	-1.199
07. (ORKNEY ISLANDS) SCAPA	34.09	34.41	34.36	34.58	34.67	34.72	34.75	34.79	34.60	34.56	34.47	34.35	34.29	34.65	34.71	34.46	34.53	n. s.
08. (SHETLAND ISLES) SCALLOWAY	34.07	34.26	34.40	34.83	34.90	35.17	35.17	35.07	34.93	34.77	34.38	34.45	34.24	34.97	35.05	34.53	34.70	n. s.
10. (NORTH EAST) STONEHAVEN	34.39	34.24	34.30	34.28	34.33	34.42	34.46	34.51	34.58	34.60	34.52	34.43	34.31	34.34	34.52	34.52	34.42	n. s.
Data for Year 2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
04. (WEST HIGHLANDS) LOCHEWE	33.31	32.56	30.69	32.44	32.32	33.40	31.98	31.60	33.71	30.47	-	-	32.19	32.72	32.43	-	-	
07. (ORKNEY ISLANDS) SCAPA	34.57	34.42	34.40	34.48	34.52	34.68	34.57	34.42	-	-	-	-	34.46	34.56	-	-	-	
08. (SHETLAND ISLES) SCALLOWAY	33.11	33.99	34.61	34.66	34.96	35.00	34.96	34.79	-	-	-	-	33.91	34.87	-	-	-	
10. (NORTH EAST) STONEHAVEN	33.98	34.33	34.17	34.15	34.25	34.22	34.14	34.40	34.59	34.55	34.41	-	34.16	34.20	34.38	-	-	

(cont.) Table 3.5: (d) Statistical Summary of sea bottom salinity from selected stations in the SCObs dataset. The trends in the table are in per decade over the indicated time period. See also Figure C.1 and Appendix G.4.

Dataset Average 1997-2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
04. (WEST HIGHLANDS) LOCHEWE	34.14	34.17	34.15	34.26	34.36	34.42	34.47	34.46	34.35	34.24	34.12	34.12	34.15	34.35	34.43	34.16	34.27	n. s.
07. (ORKNEY ISLANDS) SCAPA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
08. (SHETLAND ISLES) SCALLOWAY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10. (NORTH EAST) STONEHAVEN	34.46	34.39	34.39	34.39	34.44	34.51	34.60	34.63	34.66	34.64	34.61	34.56	34.41	34.44	34.63	34.60	34.52	n. s.
Climatological Average 2000-2010	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
04. (WEST HIGHLANDS) LOCHEWE	34.18	34.24	34.25	34.38	34.44	34.49	34.53	34.54	34.39	34.26	34.15	34.23	34.22	34.43	34.48	34.21	34.34	n. s.
07. (ORKNEY ISLANDS) SCAPA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
08. (SHETLAND ISLES) SCALLOWAY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10. (NORTH EAST) STONEHAVEN	34.45	34.38	34.37	34.39	34.47	34.56	34.65	34.68	34.68	34.65	34.60	34.54	34.40	34.47	34.67	34.60	34.53	n. s.
Decadal Average 2006-2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
04. (WEST HIGHLANDS) LOCHEWE	34.11	34.13	34.08	34.19	34.31	34.40	34.45	34.41	34.33	34.23	34.10	34.03	34.11	34.30	34.40	34.12	34.23	n. s.
07. (ORKNEY ISLANDS) SCAPA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
08. (SHETLAND ISLES) SCALLOWAY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10. (NORTH EAST) STONEHAVEN	34.41	34.36	34.39	34.39	34.44	34.50	34.59	34.60	34.62	34.61	34.57	34.56	34.39	34.45	34.60	34.58	34.50	n. s.
Data for Year 2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
04. (WEST HIGHLANDS) LOCHEWE	33.98	33.63	33.75	33.96	34.13	34.28	34.26	34.11	33.96	33.94	-	-	33.79	34.12	34.11	-	-	
07. (ORKNEY ISLANDS) SCAPA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
08. (SHETLAND ISLES) SCALLOWAY	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
10. (NORTH EAST) STONEHAVEN	34.42	34.35	34.26	34.24	34.34	34.42	34.39	34.45	34.60	34.55	34.42	-	34.34	34.33	34.48	-	-	

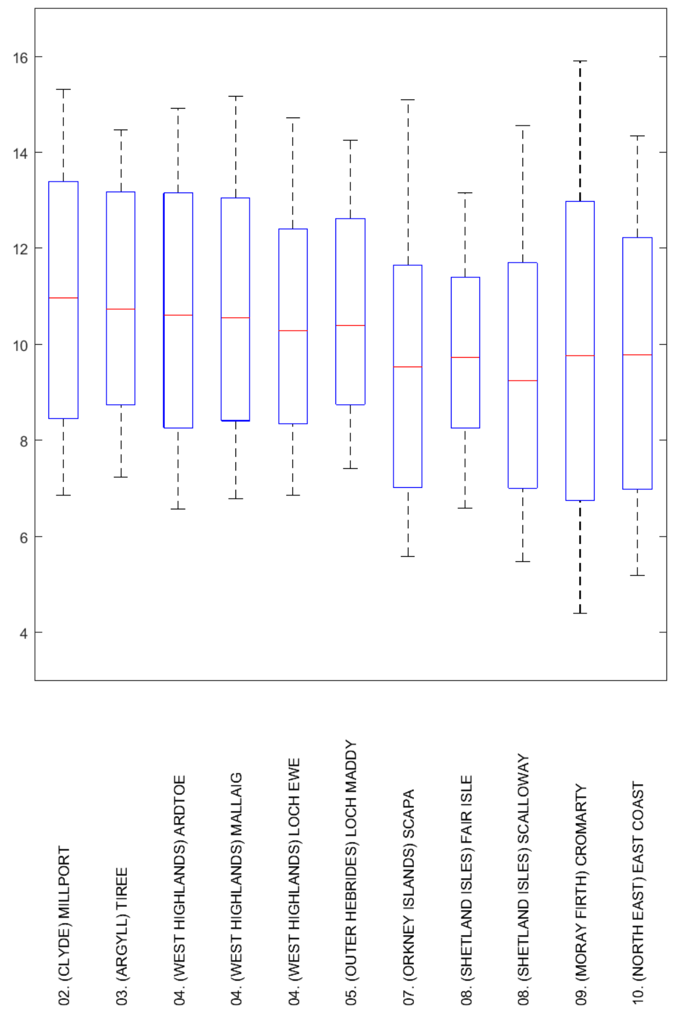
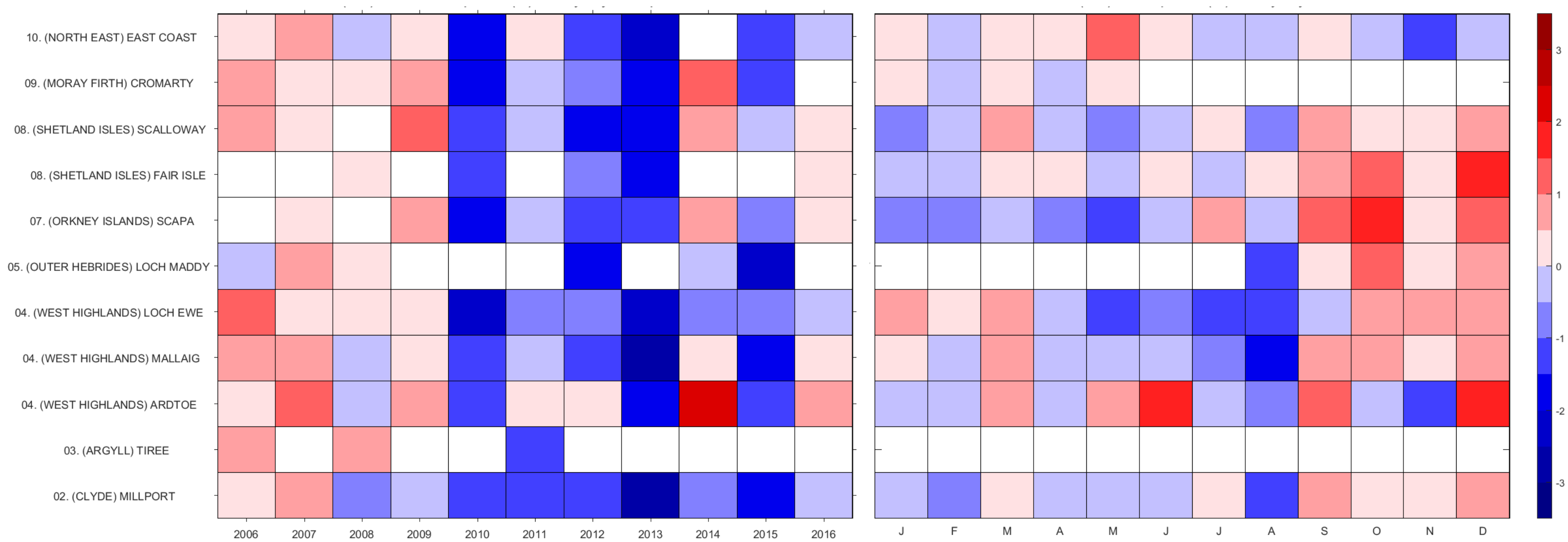


Figure 3.9: Statistical boxplots of coastal sea temperature (°C) from SCObs sites, by Scottish Marine Region. See Figure C.1 for a map supplying more details about the regions in this figure. For this dataset, no data are available in the Solway, North Coast or Forth & Tay regions.



(a) Decade 2006–2016

(b) Monthly for 2016

Figure 3.10: Normalised anomalies (σ) of monthly average coastal sea surface temperature (°C), collected at SCObs sites, from (a) the years 2005–2016 and (b) the months in 2016 (all plotted relative to 2000–2010 base period). Anomalies are presented for each of the Scottish Marine Regions. The anomalies are normalised with respect to the standard deviation of each time-series (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds = positive/warmer; blues = negative/cooler. For this dataset, no data are available in the Solway, North Coast or Forth & Tay regions.

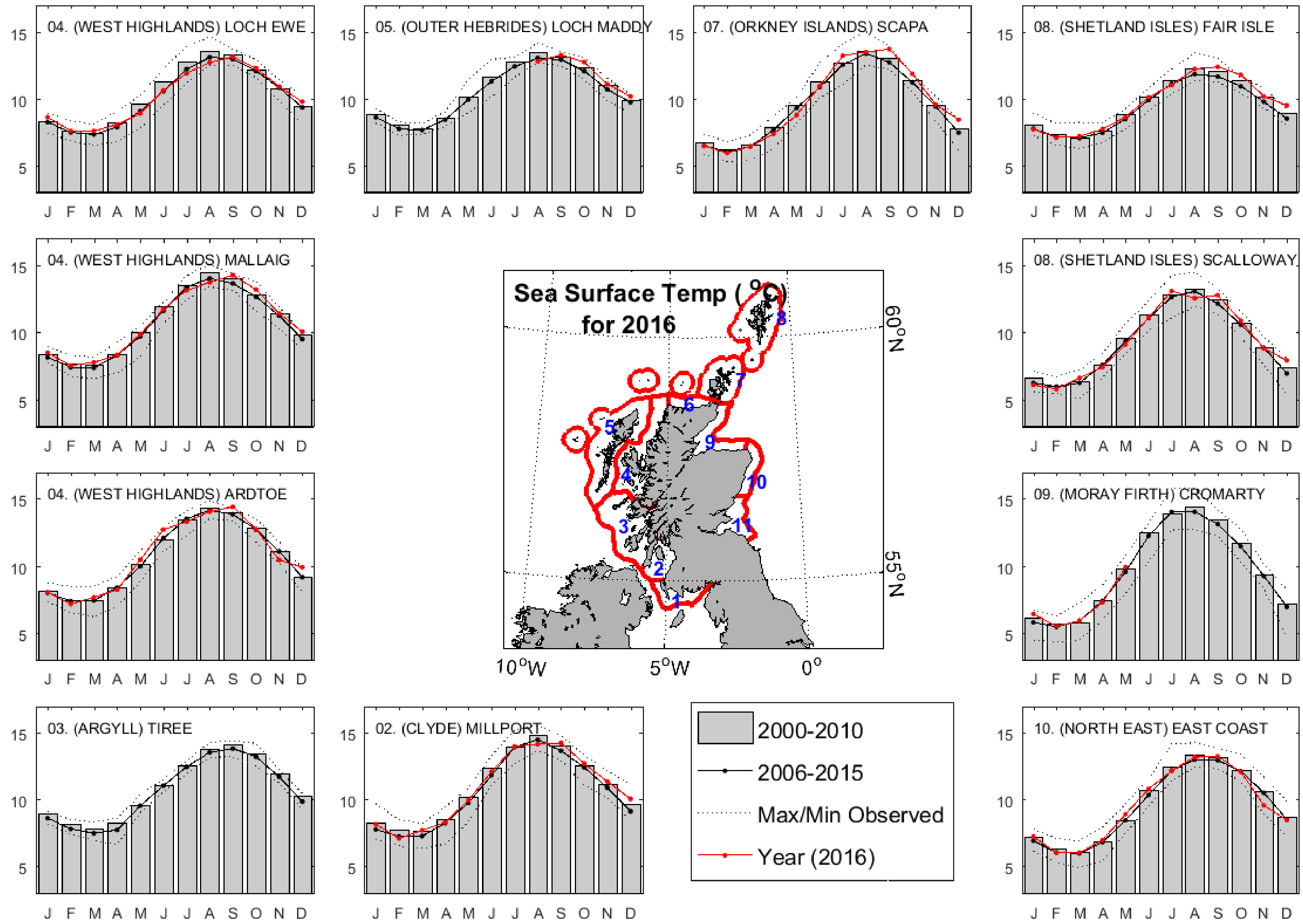


Figure 3.11: Summary of monthly coastal sea surface temperature (°C) for 2016, collected at SCObs sites, by Scottish Marine Region. Plots show monthly values of sea surface temperature during 2016 compared to the long-term average pattern (calculated for the period 2000–2010) and the average over the last decade (2006–2016). X-axis of each graph is month. Central map shows the extent of each of the Scottish Marine Regions. For this dataset, no data are available in the Solway, North Coast or Forth & Tay regions.

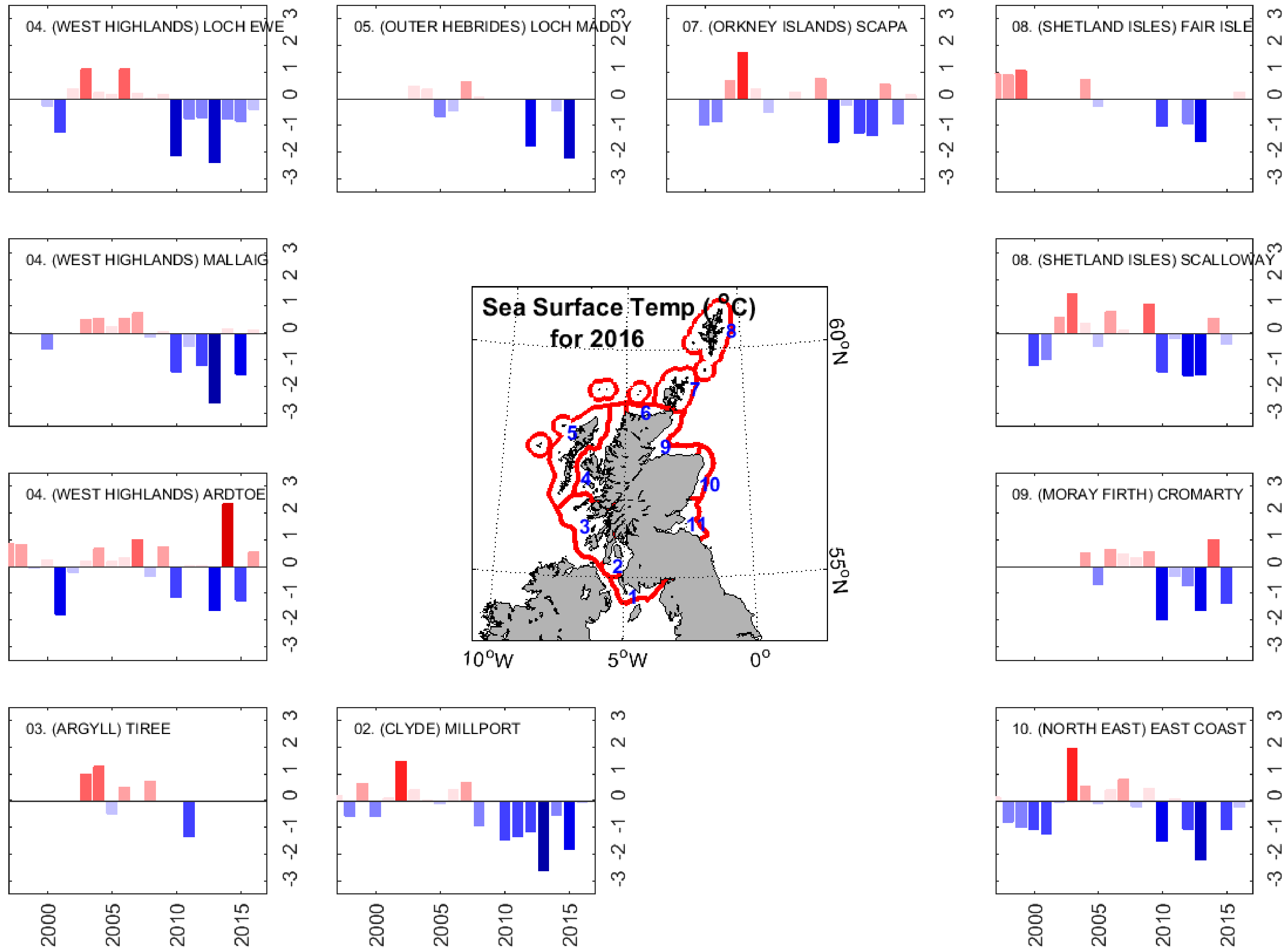


Figure 3.12: Time series of normalised annual anomalies (σ) of sea surface temperature (°C), up to 2016 (relative to 2000-2010 base period), collected at SCObs sites, by Scottish Marine Region. X-axis of each plot is year. The anomalies are normalised with respect to the standard deviation (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds = positive/warmer; blues = negative/cooler. Central map shows the extent of each of the Scottish Marine Regions. For this dataset, no data are available in the Solway, North Coast or Forth & Tay regions.

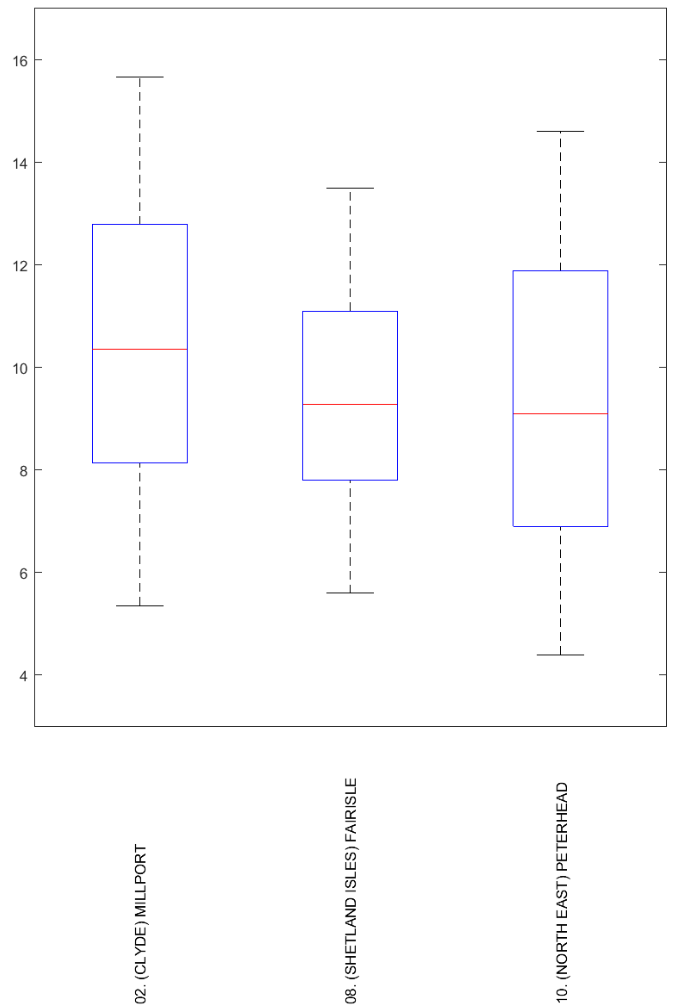
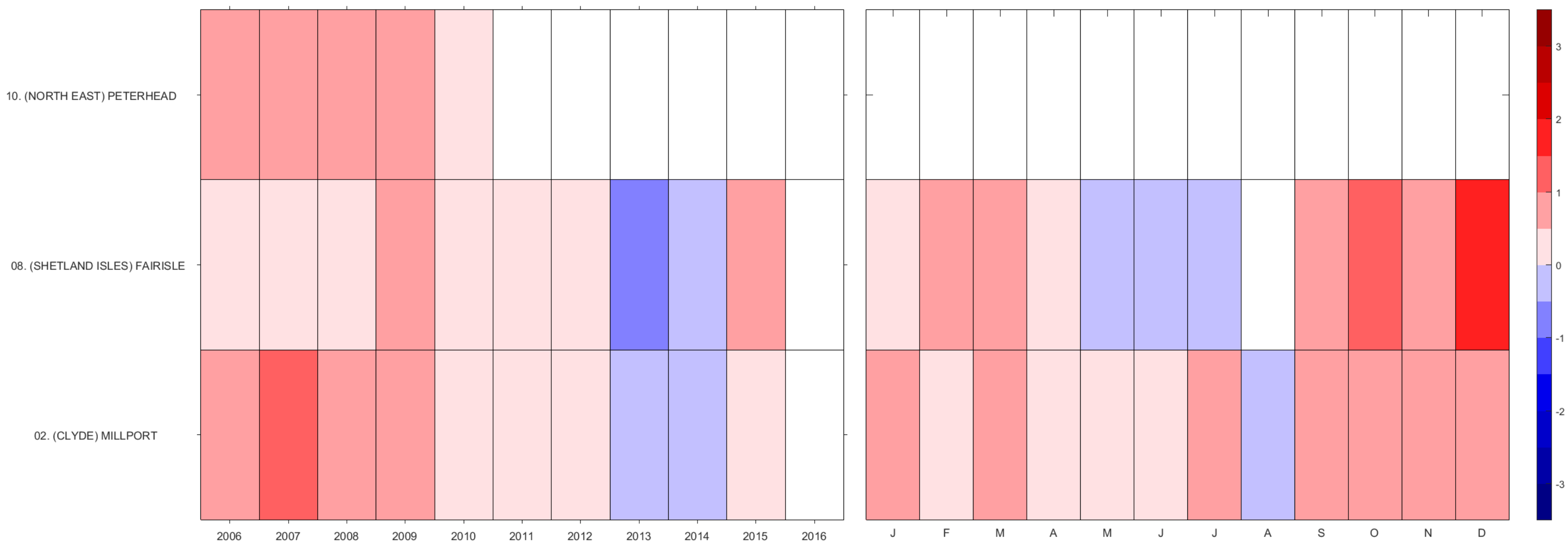


Figure 3.13: Statistical Boxplots of sea surface temperature (°C) for Scotland's Long Coastal Temperature Time series. See Figure C.1 for a map supplying more details about the regions in this figure.



(a) Decade 2006–2016 **(b)** Monthly for 2016

Figure 3.14: Normalised anomalies (σ) of monthly average sea surface temperature (°C), for (a) the years 2005–2016 and (b) the months in 2016 (all plotted relative to 1981–2010 base period), for Scotland's Long Coastal Temperature Time series. The anomalies are normalised with respect to the standard deviation of each time-series (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds = positive/warmer; blues = negative/cooler. Note that the Peterhead time series has not been updated since 2010. For this dataset, data are only available in the Clyde, Orkney Islands and North East regions.

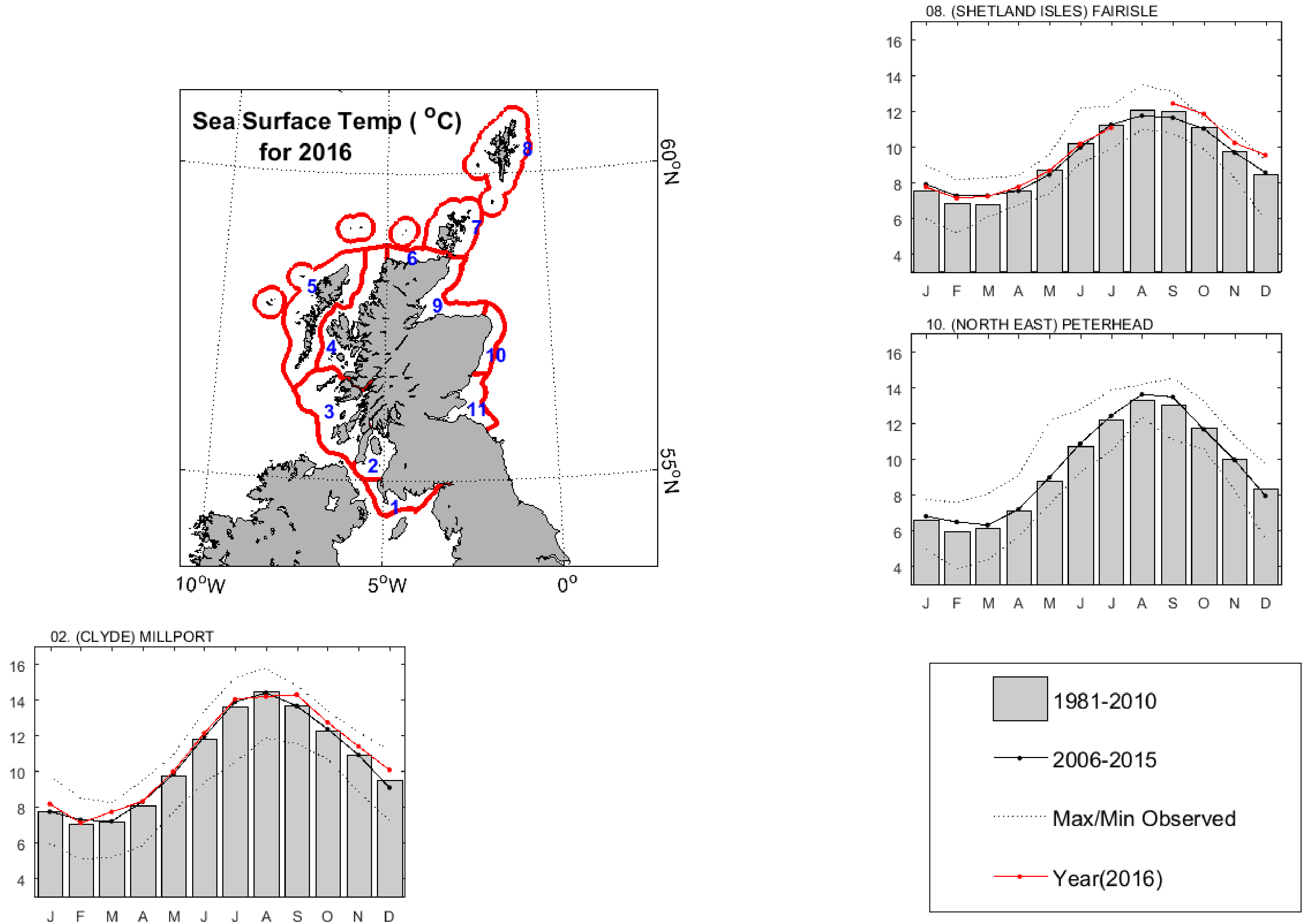


Figure 3.15: Summary of monthly average sea surface temperature (°C), during 2016 compared to the long-term average pattern (calculated for the period 2000–2010) and the average over the last decade (2006–2016) for Scotland's Long Coastal Temperature Time series. X-axis of each graph is month. Central map shows the extent of each of the Scottish Marine Regions. Note that the Peterhead time series has not been updated since 2010. For this dataset, data are only available in the Clyde, Orkney Islands and North East regions.

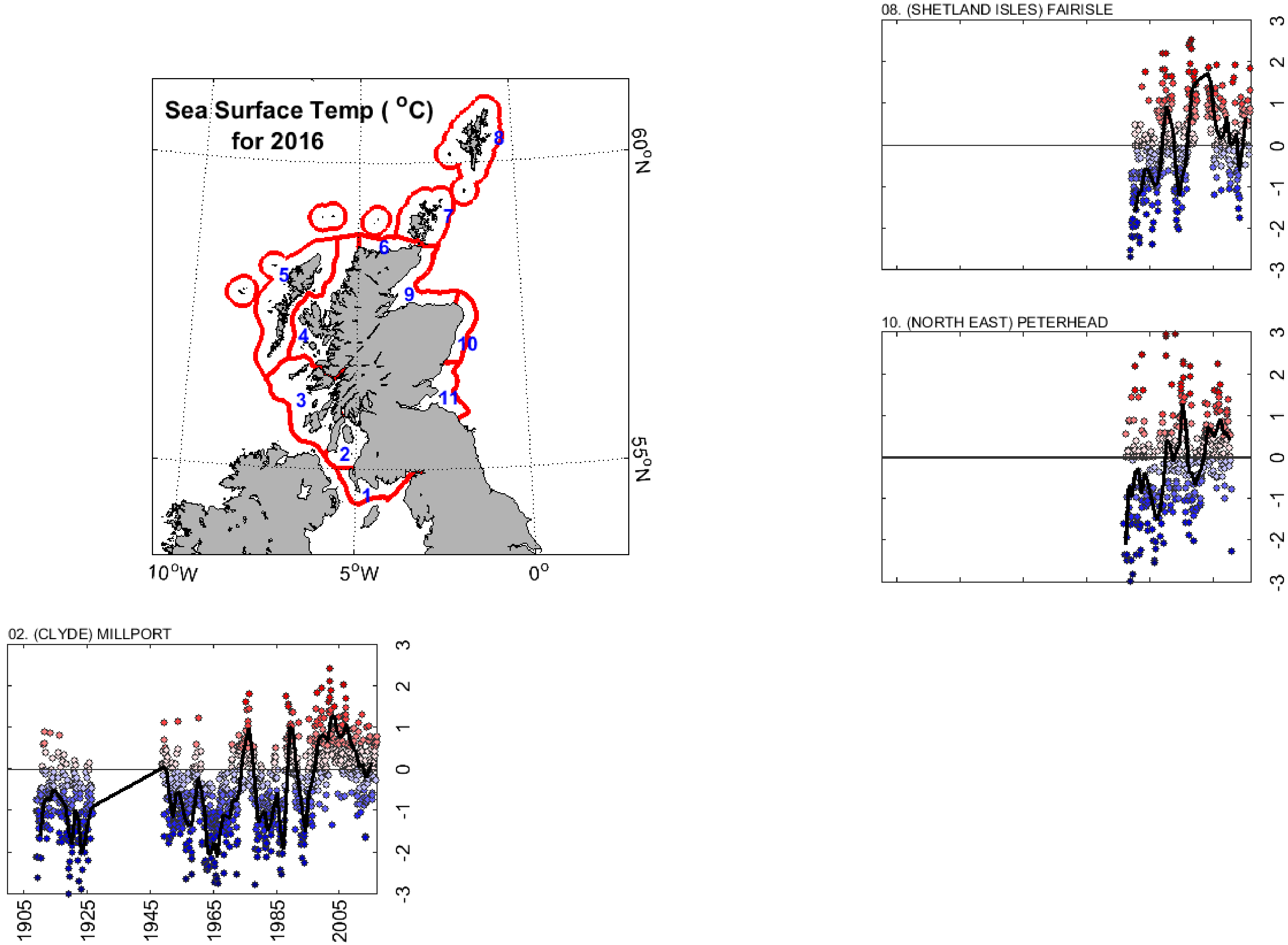


Figure 3.16: Time series plots show normalised annual anomalies (σ) of sea surface temperature (°C), up to 2016 (relative to 2000-2010 base period), for Scotland's Long Coastal Temperature Time series. X-axis of each plot is year. The anomalies are normalised with respect to the standard deviation (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds = positive/warmer; blues = negative/cooler. Central map shows the extent of each of the Scottish Marine Regions. Note that the Peterhead time series has not been updated since 2010. For this dataset, data are only available in the Clyde, Orkney Islands and North East regions.

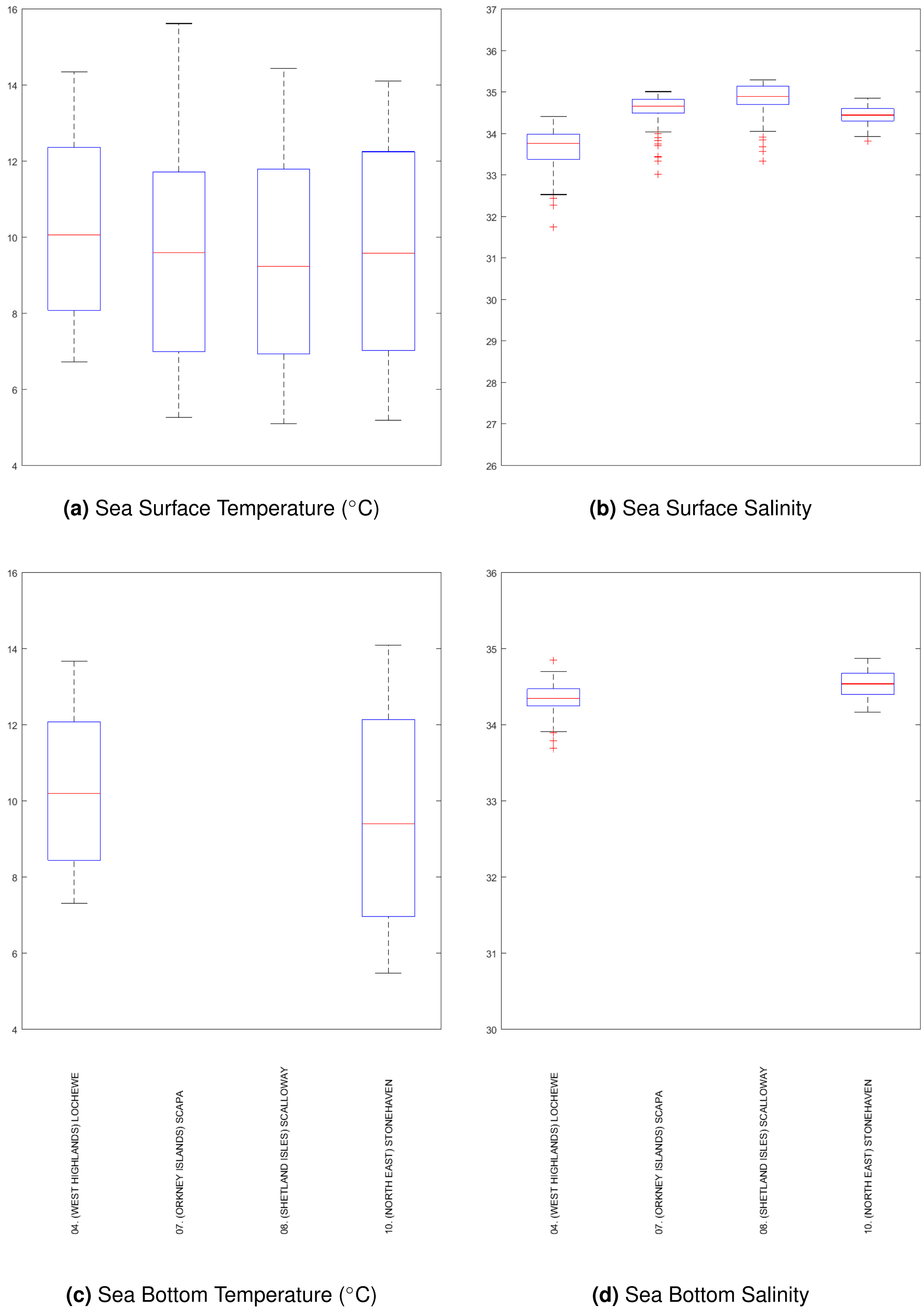
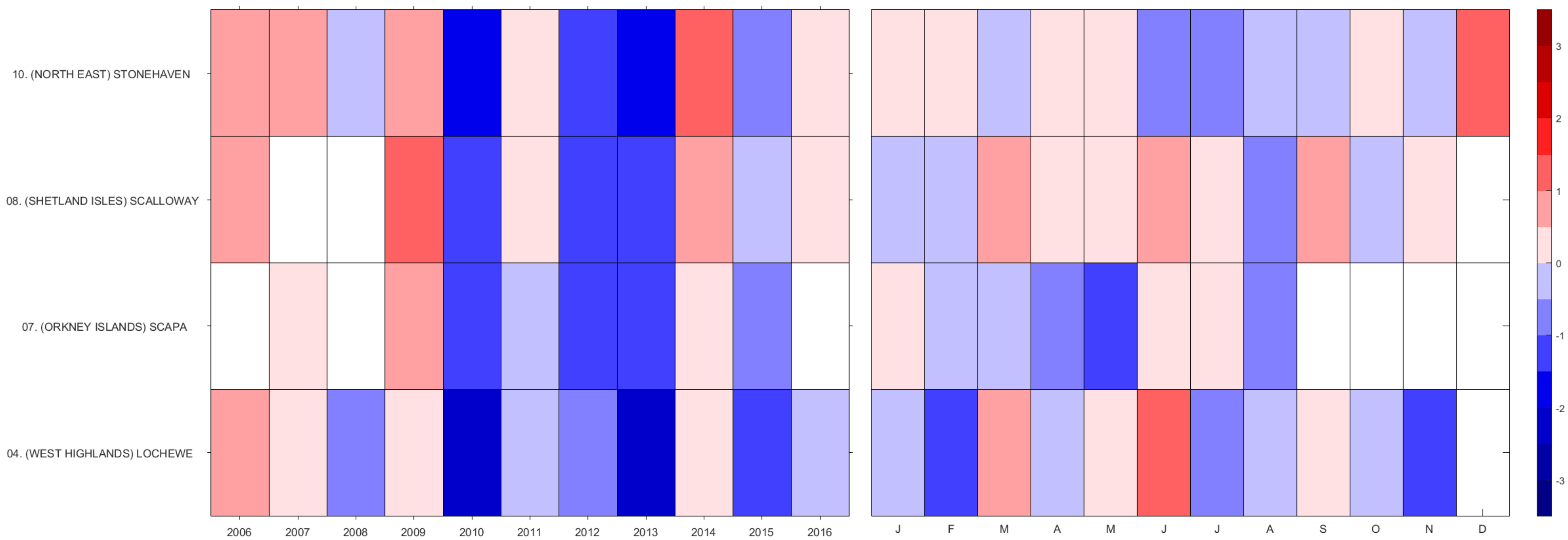


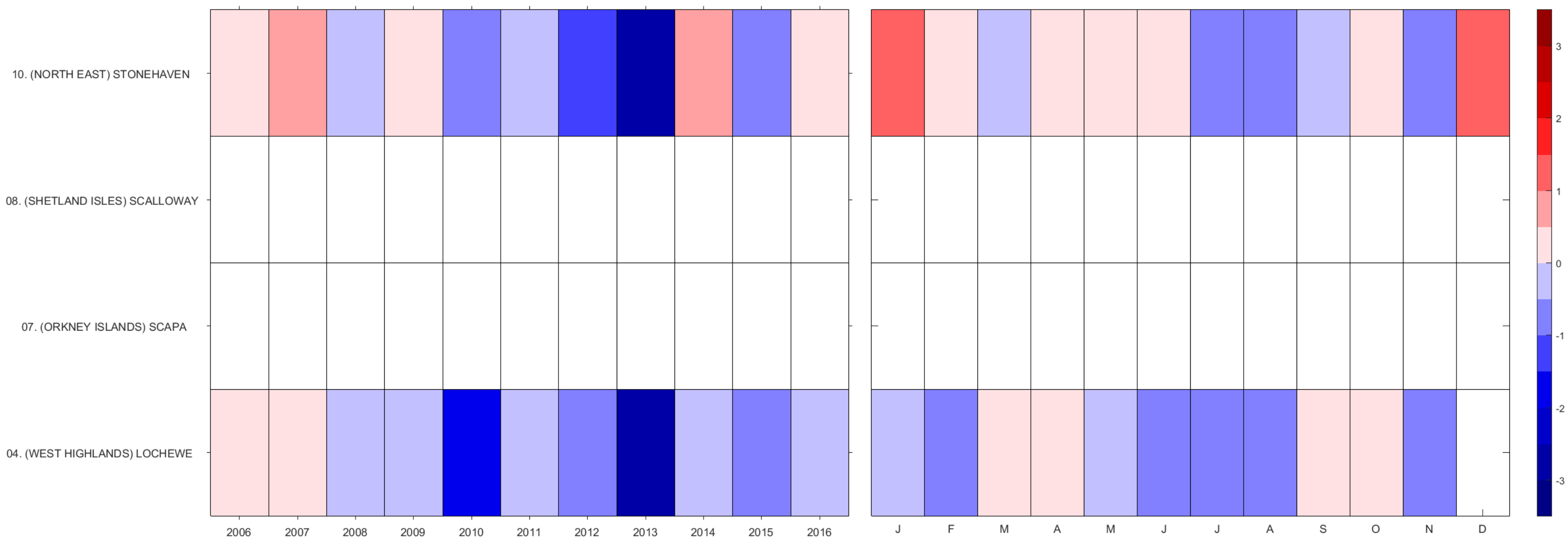
Figure 3.17: Statistical Boxplots of (a) sea surface temperature (°C), (b) sea surface salinity, (c) sea bottom temperature (°C), (d) sea bottom salinity for the climatological period 2000-2010 from selected sites of the SCObs, by Scottish Marine Region (Figure C.1). For this dataset, data are only available in the West Highlands, Orkney Islands, Shetland Isles and North East regions.



(a) Decade 2006–2016

(b) Monthly for 2016

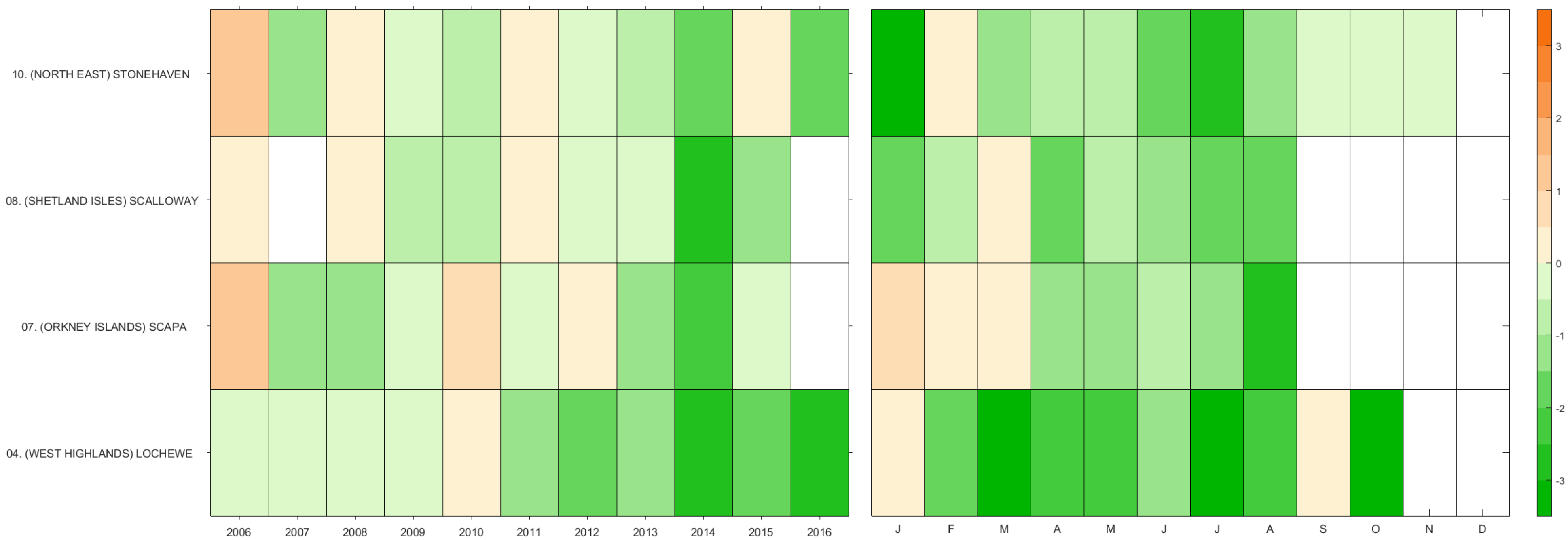
Figure 3.18: Normalised anomalies (σ) of monthly average sea surface temperature (°C) for (a) the years 2005–2016 and (b) the months in 2016 (all plotted relative to 2000-2010 base period), from selected sites in the SCObs dataset, by Scottish Marine Region. The anomalies are normalised with respect to the standard deviation of each time-series (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds = positive/warmer; blues = negative/cooler. For this dataset, data are only available in the West Highlands, Orkney Islands, Shetland Isles and North East regions.



(c) Decade 2006–2016

(d) Monthly for 2016

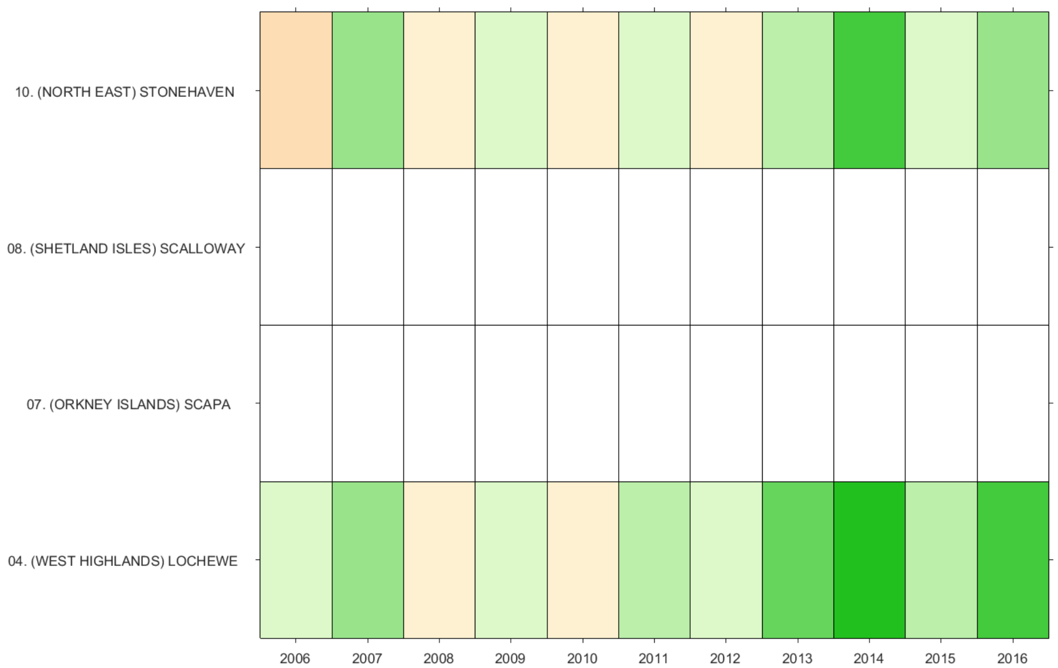
(cont.) Figure 3.18: Normalised anomalies (σ) of monthly average sea bottom temperature (°C) for (c) the years 2006–2016 and (d) the months in 2016 (all plotted relative to 2000-2010 base period), from selected stations in the SCObs dataset, by Scottish Marine Region. The anomalies are normalised with respect to the standard deviation of each time-series (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds = positive/warmer; blues = negative/cooler. For this dataset, data are only available in the West Highlands and North East regions.



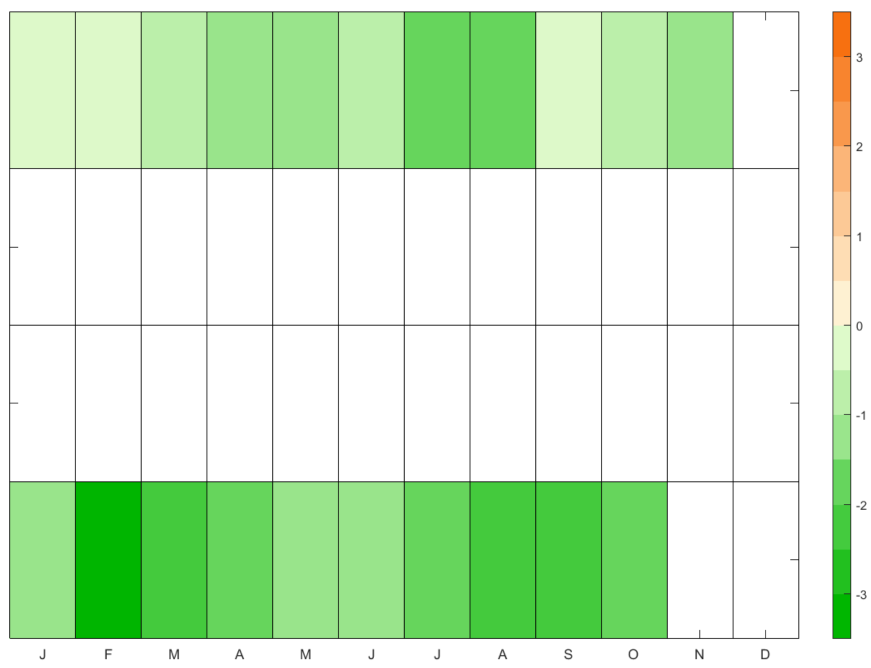
(e) Decade 2006–2016

(f) Monthly for 2016

(cont.) Figure 3.18: Normalised anomalies of monthly average sea surface surface salinity for (e) the years 2006–2016 and (f) the months in 2016 (all plotted relative to 2000-2010 base period, from selected sites in the SCObs dataset, by Scottish Marine Region. The anomalies are normalised with respect to the standard deviation of each time-series (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; oranges = positive/saltier; greens = negative/fresher. For this dataset, data are only available in the West Highlands, Orkney Islands, Shetland Isles and North East regions.



(g) Decade 2006–2016



(h) Monthly for 2016

(cont.) Figure 3.18: Normalised anomalies (σ) of monthly average sea bottom salinity for (g) the years 2005–2016 and (h) the months in 2016 (all plotted relative to 2000-2010 base period), from selected sites in the SCObs dataset, by Scottish Marine Region. The anomalies are normalised with respect to the standard deviation of each time-series (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds = positive/saltier; greens = negative/fresher. For this dataset, data are only available in the West Highlands and North East regions.

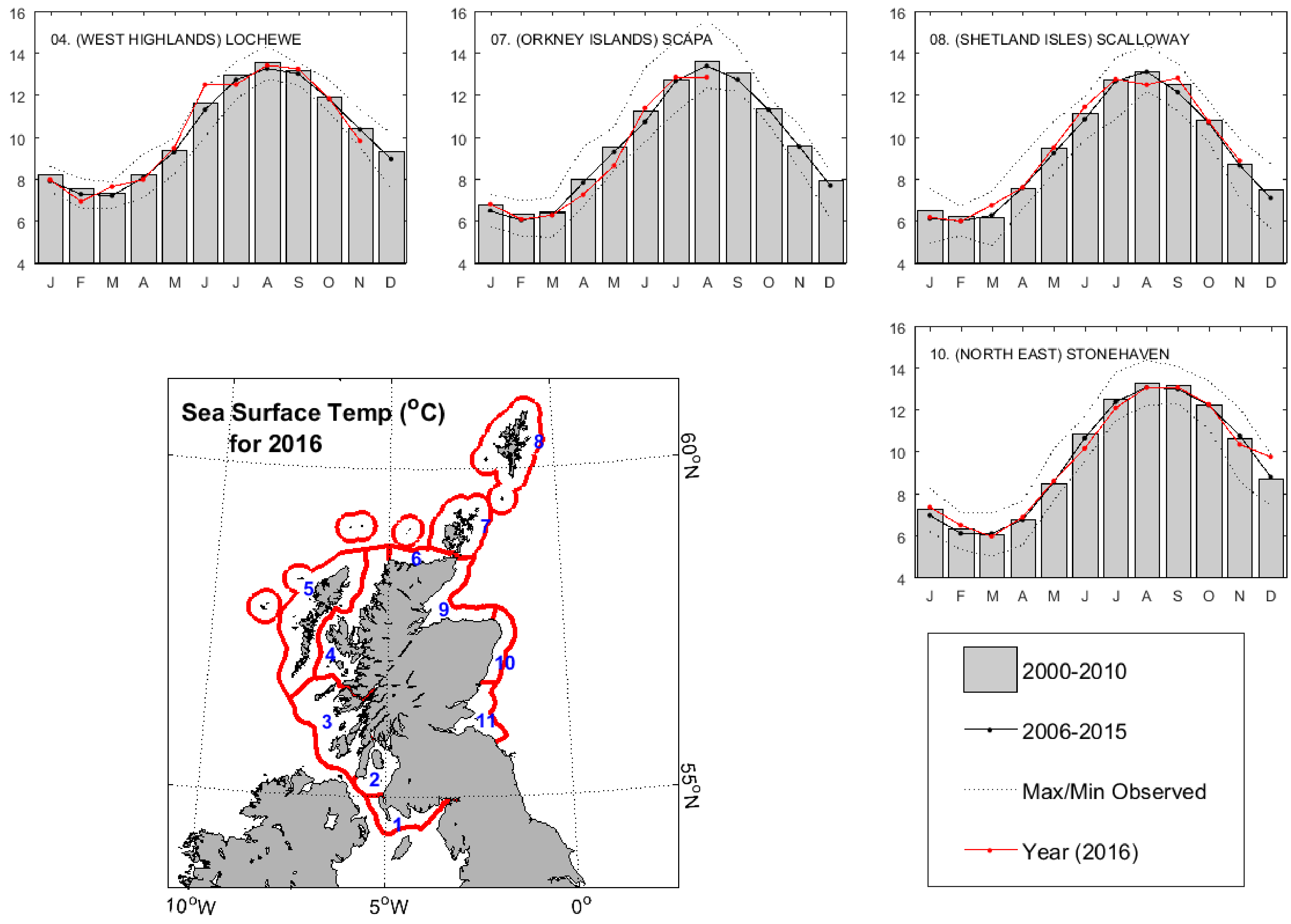
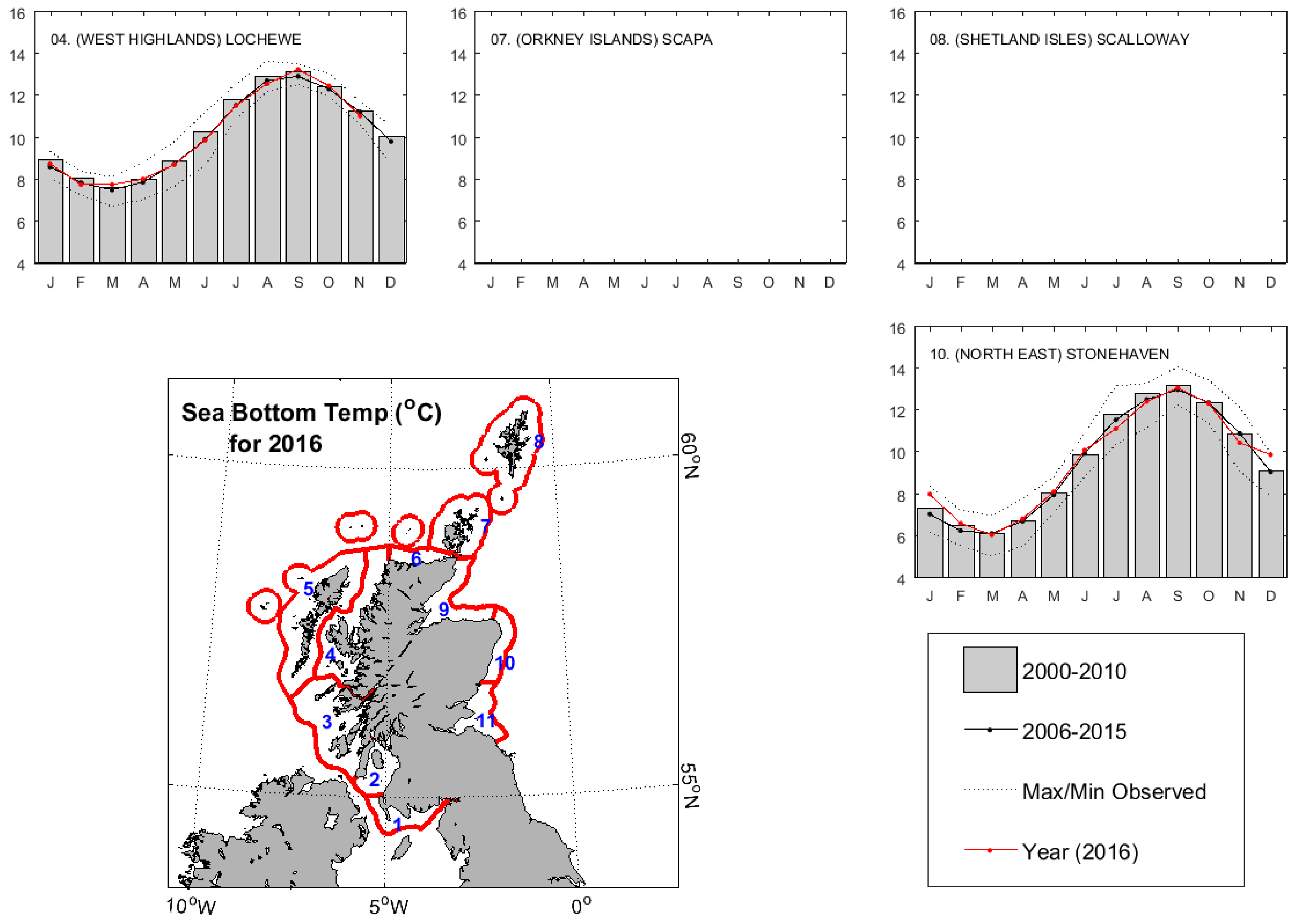
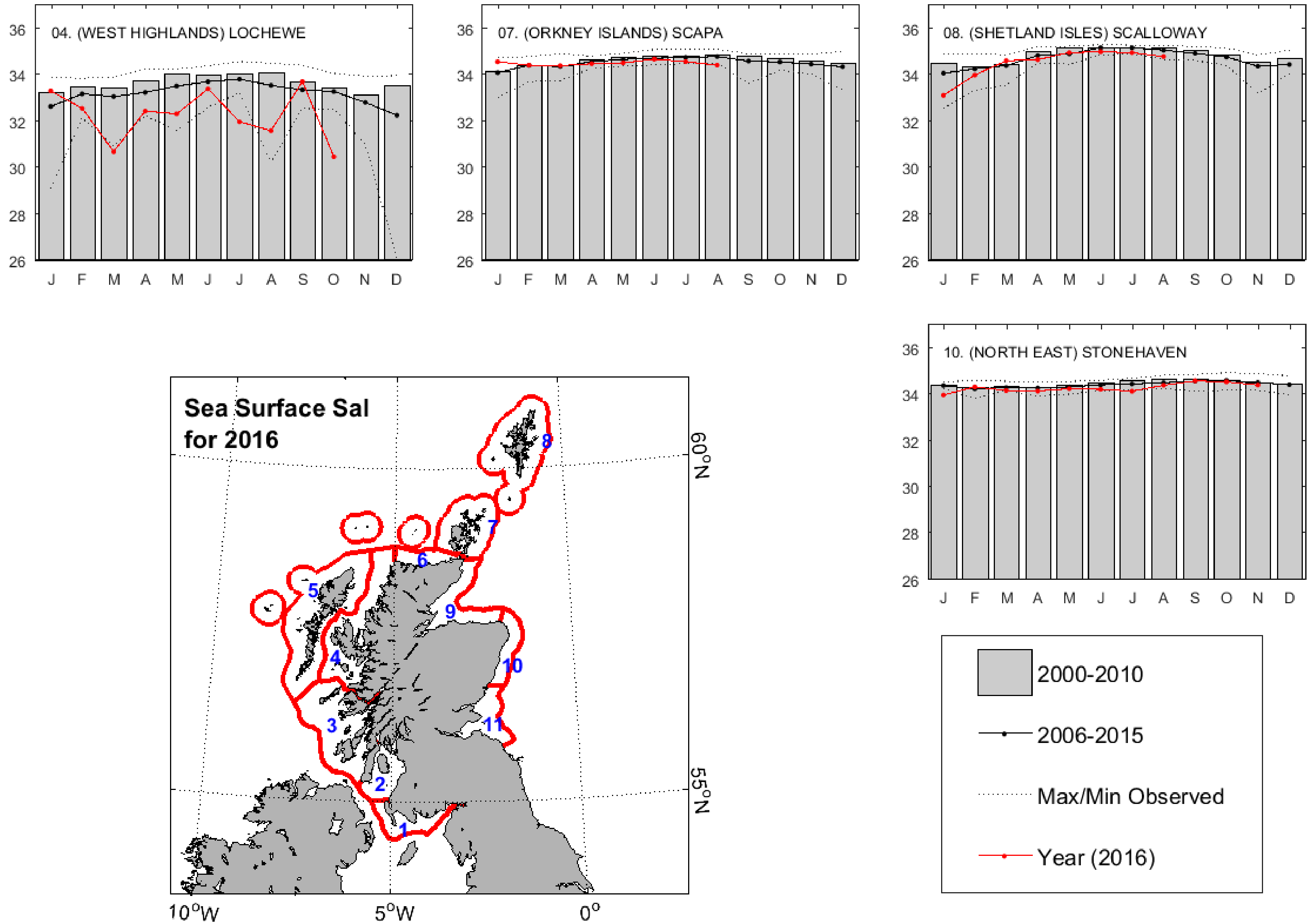


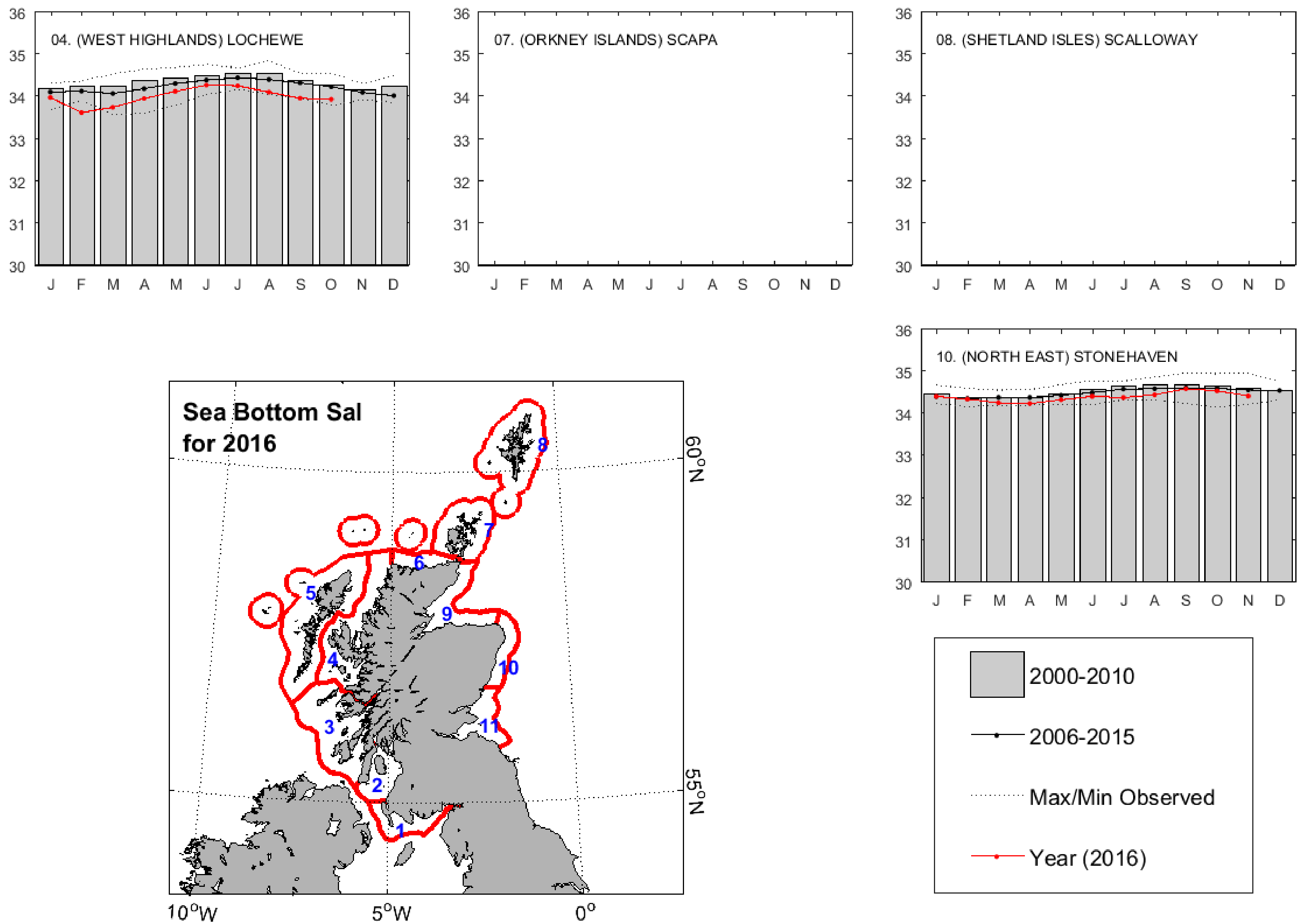
Figure 3.19: (a) Summary of monthly sea surface temperature (°C) for 2016 from selected sites in the SCObs dataset, by Scottish Marine Region. Plots show monthly values of sea surface temperature during 2016 compared to the long-term average pattern (calculated for the period 2000-2010) and the average over the last decade (2006–2016). X-axis of each graph is month. Central map shows the extent of each of the Scottish Marine Regions.



(cont.) Figure 3.19: (b) Summary of monthly sea bottom temperature (°C) for 2016 from selected sites in the SCObs dataset, by Scottish Marine Region. Plots show monthly values of sea bottom temperature during 2016 compared to the long-term average pattern (calculated for the period 2000-2010) and the average over the last decade (2006–2016). X-axis of each graph is month. Central map shows the extent of each of the Scottish Marine Regions.



(cont.) Figure 3.19: (c) Summary of monthly sea surface salinity for 2016 from selected sites in the SCObs dataset, by Scottish Marine Region. Plots show monthly values of sea surface salinity during 2016 compared to the long-term average pattern (calculated for the period 2000-2010) and the average over the last decade (2006–2016). X-axis of each graph is month. Central map shows the extent of each of the Scottish Marine Regions.



(cont.) Figure 3.19: (d) Summary of monthly sea bottom salinity for 2016 from selected sites in the SCObs dataset, by Scottish Marine Region. Plots show monthly values of sea bottom salinity during 2016 compared to the long-term average pattern (calculated for the period 2000-2010) and the average over the last decade (2006–2016). X-axis of each graph is month. Central map shows the extent of each of the Scottish Marine Regions.

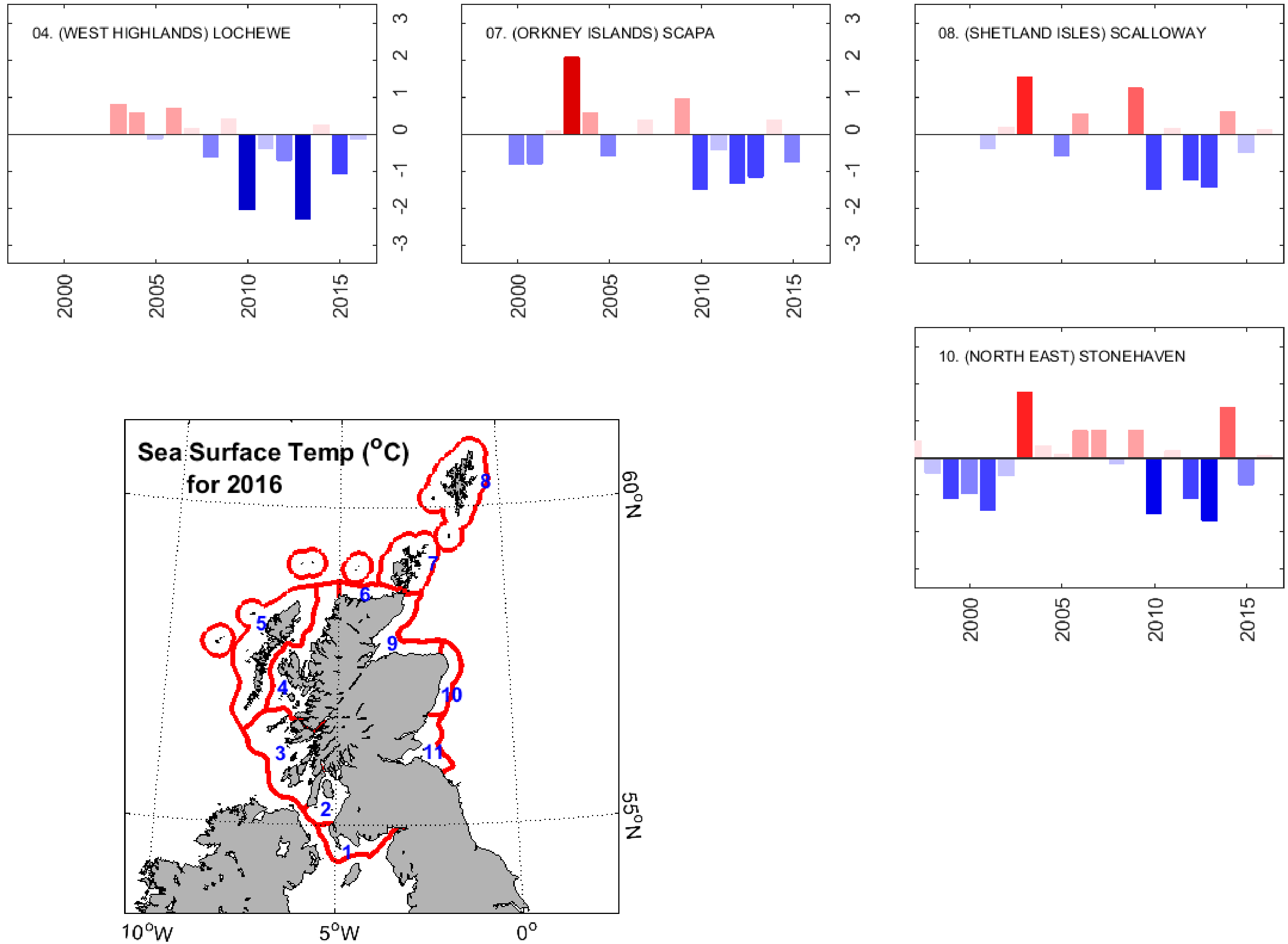
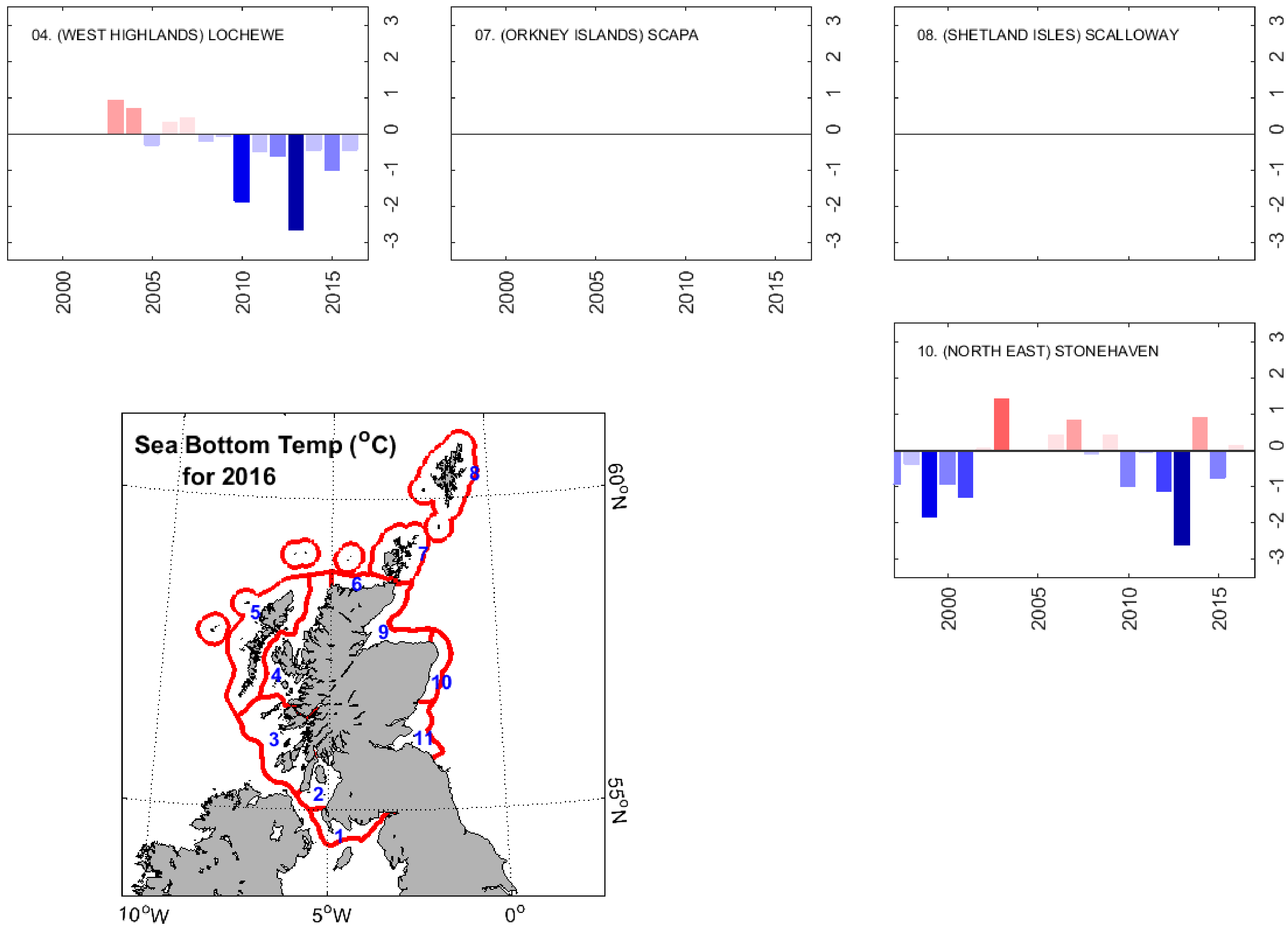
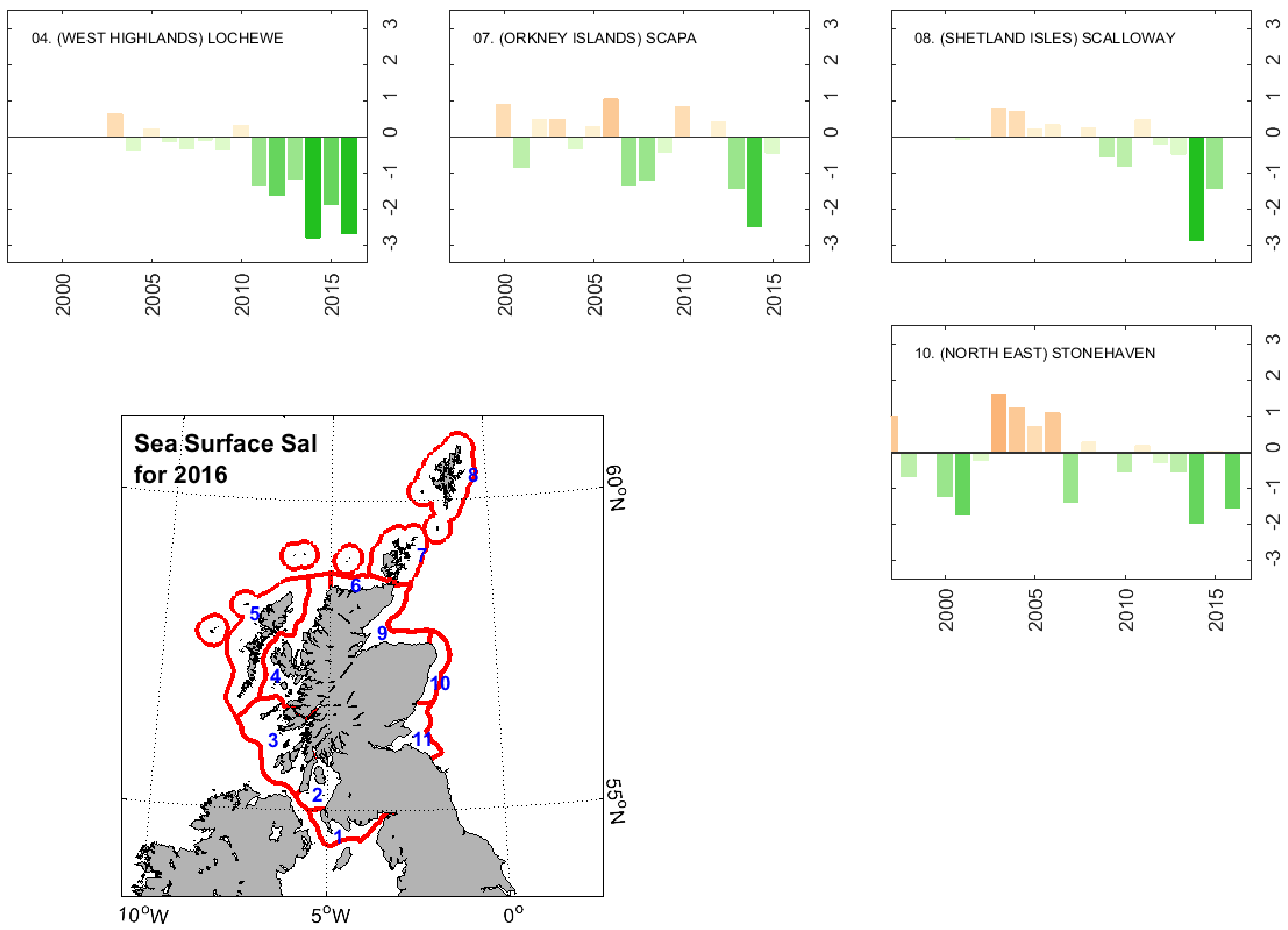


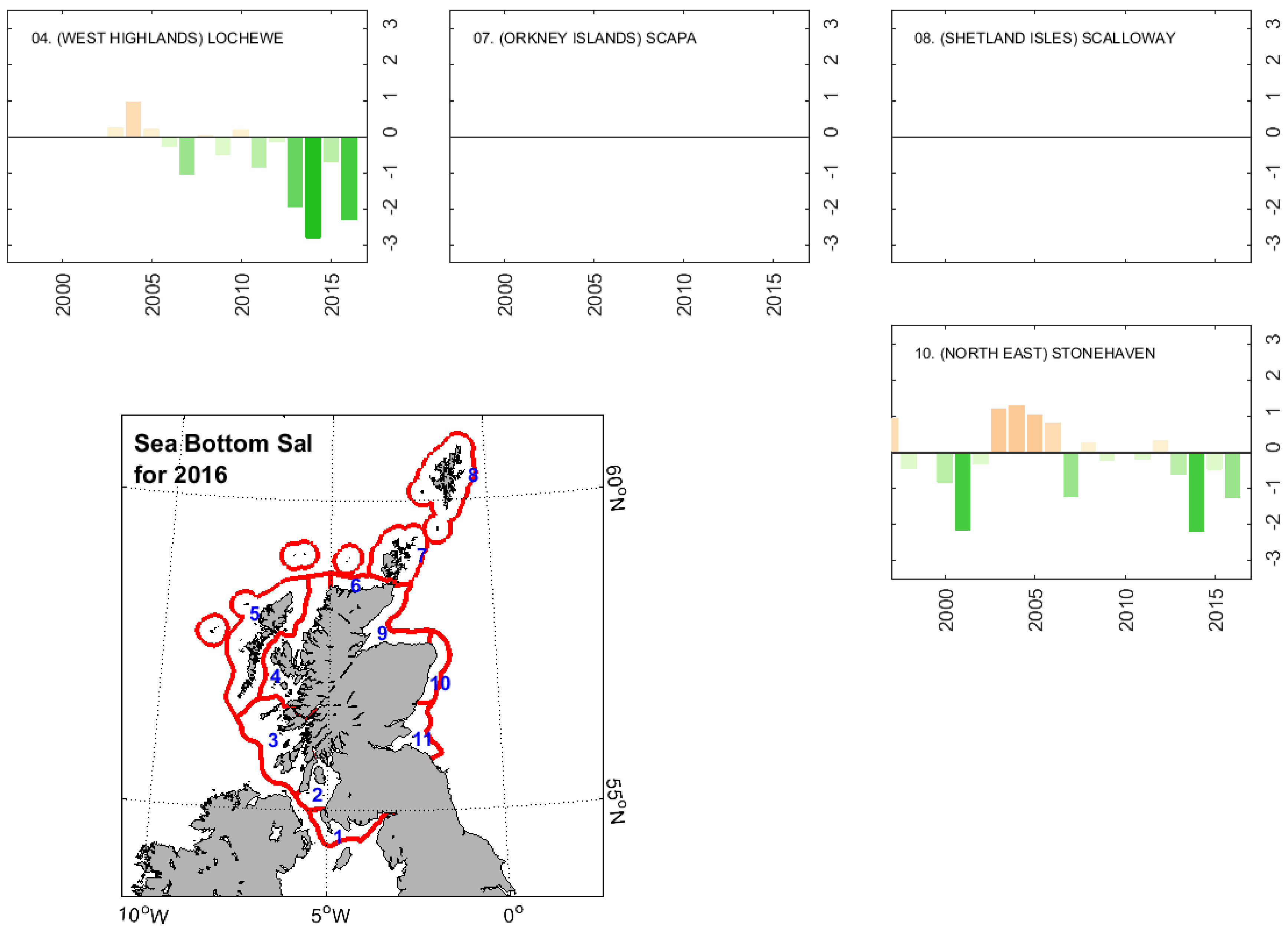
Figure 3.20: **(a)** Time series of normalised annual anomalies (σ) of sea surface temperature (°C) up to 2016 (relative to 2000-2010 base period) from selected sites in the SCObs dataset. X-axis of each plot is year. The anomalies are normalised with respect to the standard deviation (σ; e.g. a value of +2 indicates 2σ. above normal). Colour intervals 0.5σ; reds = positive/warmer; blues = negative/cooler. Central map shows the extent of each of the Scottish Marine Regions.



(cont.) Figure 3.20: (b) Time series of normalised annual anomalies (σ) of sea bottom temperature (°C) up to 2016 (relative to 2000-2010 base period) from selected sites in the SCObs dataset, by Scottish Marine Region. X-axis of each plot is year. The anomalies are normalised with respect to the standard deviation (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds = positive/warmer; blues = negative/cooler. Central map shows the extent of each of the Scottish Marine Regions.



(cont.) Figure 3.20: (c) Time series of normalised annual anomalies (σ) of sea surface salinity up to 2016 (relative to 2000-2010 base period) from selected sites in the SCObs dataset, by Scottish Marine Region. X-axis of each plot is year. The anomalies are normalised with respect to the standard deviation (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; greens = negative/fresher; oranges = positive/saltier. Central map shows the extent of each of the Scottish Marine Regions.



(cont.) Figure 3.20: (d) Time series of normalised annual anomalies (σ) of sea bottom salinity up to 2016 (relative to 2000-2010 base period) from selected sites in the SCObs dataset, by Scottish Marine Region. X-axis of each plot is year. The anomalies are normalised with respect to the standard deviation (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; greens = negative/fresher; oranges = positive/saltier. Central map shows the extent of each of the Scottish Marine Regions.

3.1 Coastal Temperature

Analysis

Coastal temperatures have been analysed by Scottish Marine Region using data from HadISST, ODaT, and the MS SCObs datasets. Recent conditions are referenced to a climatological average period calculated over the thirty years between 1981 and 2010. More information on the datasets can be found in Appendix C.

3.1.1 Spatial Patterns

The seasonal patterns of temperature in Scottish waters are well described in *Hughes et al.* (2012) and *Berx and Hughes* (2009). Other useful datasets that provide information about conditions in Scottish Marine Regions are *Slesser and Turrell* (2013) and *Hughes et al.* (2017).

The pattern observed in sea surface temperature across each Scottish Marine Region is affected by both latitude and the proximity of each region to the warming influence of the North Atlantic. The effect of latitude can be seen in the pattern of average temperature for each region. For example, on the west coast of Scotland, winter sea surface temperatures tend to remain higher than in the north of Scotland or in the North Sea: average winter (Jan-Mar) temperatures in the Argyll region, at 8.5 °C, are almost 1.5 °C higher than average winter temperatures in the North East region (7.1 °C, Table 3.1).

Average sea surface temperatures decrease slowly between the Solway region, where the average temperature of 11.2 °C is observed and the Shetland Isles, where the average temperature is 9.8 °C (Table 3.1). This pattern of decreasing temperature with latitude is not as clear in the eastern regions of Scotland. In the Forth & Tay region, the annual average temperature (10 °C) is almost one degree lower than that of the Argyll region, which sits at a similar latitude on the west coast of Scotland. Another difference between east coast and west coast regions is the difference in annual temperature range (maximum - minimum). On the shallower east coast, away from the moderating influence of the North Atlantic, the annual range of temperatures is greater, with similar summer temperatures but colder winters, than those observed on the west coast (Table 3.1).

Near surface temperatures in Scottish waters have a typical seasonal pattern, similar to that of air temperature, with maximum temperatures occurring in late summer, August or September, and minimum temperatures at the end of winter, February or March (Figures 3.3 and 3.7 a). Near bottom temperature can, however, show a different pattern, as during the summer months, stratification isolates the nearbed water masses from those at the surface, and they tend to warm much more slowly than the waters of the upper layers. In bottom waters, the maximum temperature often occurs later than those of the surface waters. For example in the Outer Hebrides and Argyll regions, maximum nearbed temperature occurs in October whereas maximum surface temperature occurs in September (Figures 3.7 a and b).

3.1.2 Conditions Observed during 2016

2016 was a relatively warm year, with average sea surface temperatures in all regions higher than the long-term average value (1981–2010). Regions on the east coast of Scotland were between 0.3 °C and 0.4 °C warmer than average, whilst those on the west coast were 0.1 °C to 0.2 °C warmer than average. The most unusually warm region in 2016 was the Shetland Isles region, which was almost 0.5 °C above average.

Although regions of the east coast of Scotland tended to remain warmer than average all year round, in regions on the west of Scotland the earlier part of the year was cooler than normal (Table 3.1 and Figure 3.2b). Autumn was the warmest period with temperatures in September and October above normal, and some stations reaching 0.9 °C higher than expected at this time of year (Figure 3.2b). After this rather warm period, temperatures at almost half of all sites in November were lower than normal.

Due to the methods used to analyse the ODaT data, not enough data were available during 2016 to use this dataset to examine conditions in 2016. Due to the relatively short duration of the SCObs dataset, conditions at each of the monitoring sites can only be compared to more recent observations. Following similar patterns to those shown by HadISST, these data show that, in 2016, conditions were warmer in the latter part of the year at most sites, but that August was a relatively cool month (Figure 3.10b).

3.1.3 Trends and Variability over the period 2006-2016

During the decade of 2006-2016, although sea surface temperatures were overall between 0.2 °C and 0.4 °C warmer than the long-term average, there has been no significant trend in sea surface temperature. Temperatures remained above the long-term average in all of the Scottish Marine Regions in all years, except for 2013 and 2015, when temperatures were lower than average in the Solway, Clyde and Argyll regions (Figure 3.2a). 2014 was the warmest year of the decade, with an average temperature of 10.95 °C across all Scottish Marine Regions. 2014 was overall 0.35 °C warmer than average, and was also the warmest year on record (since 1870) for the northern and eastern Scottish Marine Regions.

The ODaT dataset shows that both surface and bottom temperatures have followed similar trends over the last decade (Figure 3.6 a and c). This is to be expected, as in shallow regions the water column becomes well mixed every winter. Conditions in 2006 were warmer than normal in all regions. Both surface and bottom temperatures cooled towards the end of the decade. 2015, in contrast to the years proceeding it, was warmer than normal.

A comparison of the annual variability in coastal sea surface temperatures (Figure 3.14) demonstrates a similar pattern to that observed across the Scottish Marine Regions (Figure 3.2a). Warmer temperatures were observed in the early part of the decade and have generally reduced since then. The SCObs sea temperature data also show that, on average, in 2016 conditions were warmer than had been seen in the years 2010-2015, but not as warm as in the earlier part of the decade (Figure 3.10a).

Following a pattern seen at most of the measurement sites, 2010 and 2013 were notably cold years. In both of these years, temperatures in all months and at all levels were below average (Figure 3.18 a and c).

3.1.4 Long-Term Trends

In all but one of the Scottish Marine Regions, 2014 was the warmest year in the HadISST dataset record, which extends back to 1870 (Figure 3.3 and Table 3.1). The long-term trend (1893–2016) in all of the regions is one of warming at a rate of between 0.05 and 0.07 °C per decade (Table 3.1). This rate is consistent with the observed global surface temperature warming. For the period 1981–2010, sea surface temperatures in Scottish Marine Regions warmed at a rate of between 0.20 and 0.40 °C per decade, a rate of warming which is higher than the long-term trend. Using evidence from the Millport coastal temperature time series, for example (Figure 3.16), we know that since the early 2000s, average coastal sea temperatures tended to be above the long-term mean as a result of a long-term trend of rising temperatures. It is clear from the long-term record that conditions in the last decade can mostly be characterised as warmer than normal, particularly in the first part of the decade. Therefore, in the context of long-term climate change, the last decade can be considered to be unusually warm. The long-term trend in coastal temperature at Millport is also consistent with evidence from average UK coastal temperatures (*Dye et al.*, 2013a).

3.2 Coastal Salinity

Analysis

Coastal salinities have been analysed by Scottish Marine Region using data from HadISST, ODaT, and the Marine Scotland SCObs datasets. Recent conditions are referenced to a climatological average period calculated over the thirty years between 1981 and 2010. More information on the datasets can be found in Appendix C.

3.2.1 Spatial Patterns

Examining the evidence from the whole of the ODaT time series (1971-2016) reveals that the region with the highest average surface salinity was the Shetland Isles region (35.24) and the region with the lowest average surface salinity was the Clyde region (33.21; Table 3.2c). This is a pattern to be expected as Shetland has very little freshwater input, and the coastal regions of Shetland mix with the highly saline North Atlantic Water that flows along the edge of the Scottish continental shelf. In contrast, the Clyde region has a large amount of freshwater directly flowing into the region, and is also on the pathway for freshwater advected northward from the Celtic Seas further south. On the east coast, the Forth & Tay region experiences the largest single input of freshwater, that flowing from the River Tay (see Chapter 2 and Appendix B), and as a result average surface salinity in this region is also one of the lowest (34.23; Table

3.2c). Nearbed salinity is always higher than that at the surface, as is to be expected in regions of direct freshwater input.

The data from the SCObs stations show patterns that are typical of those expected from their locations (Tables 3.5 c and d, and Figure 3.17). The annual average salinity at the surface is higher in locations such as Scapa (34.67) and Scalloway (34.88), than Loch Ewe, a west coast sea loch (33.70). The annual average salinity at Stonehaven was 34.46, higher than in the west coast sea loch environment but lower than the North Atlantic influenced island regions of Orkney and Shetland. At both Loch Ewe and Stonehaven, average salinity increases with sampling depth. This is to be expected as any local surface runoff will tend to remain in the upper layers as it is more buoyant than the surrounding water.

The seasonal pattern of salinity at each site also conformed to the expected broad scale patterns (Figure 3.19 c and d). At all sites on the west and north coasts of Scotland, maximum salinity occurs in the summer months (June-July) and lower salinities are observed in autumn/winter months (November, December, January, February). This correlates to the seasonal pattern of river flow and suggests that on seasonal timescales, the coastal freshwater content is locally influenced. At Stonehaven, however, the seasonal pattern of salinity is quite different. Minimum salinity is observed in spring (March) and maximum salinity is observed in September (Tables 3.5 c and d). Salinities remain high during the autumn and early winter when there is high Atlantic inflow, and then begin to decrease in January-February. Rather than simply reflecting the patterns of precipitation and runoff, the seasonal pattern of salinity at Stonehaven is similar to that across the whole of the Northern North Sea, and is thought to be a consequence of varying Atlantic Water influence (*Dye et al.*, 2013b) balanced with the freshwater inputs to the North Sea.

At sites where there are both surface and nearbed salinity records, it was clear that variability in salinity is greater in the surface layers (Figure 3.19 c and d). Salinity at the nearbed level can therefore be assumed to be a more reliable indicator of the coastal water freshwater content and is taken to be more representative of the broader scale changes in coastal waters.

3.2.2 Conditions Observed during 2016

The SCObs dataset offers one of the only records of salinity during 2016. At most sites and in most of the months, the observed salinities in 2016 were below the average, indicating a freshening of the waters in these locations (Figure 3.18 f and h). This below average salinity anomaly is recorded in both the surface and bottom waters. This is in agreement with patterns observed recently in the offshore and oceanic water masses (also see Chapters 4 and 5).

3.2.3 Trends and Variability over the period 2006-2016

The ODaT dataset shows a decadal pattern of salinity that is a little less distinct than that seen in temperature, but there is evidence of a recent freshening trend in the northern and eastern regions. Salinity has decreased since 2003 and has been lower than normal in these regions since 2013 (Figure 3.8 c and d). The same pattern is evident in both surface and bottom salinity, and in line with patterns recently observed in oceanic water masses.

The SCObs data also show a freshening trend at all sites since 2013 (Figure 3.18e). Although the ODaT dataset did not reveal a freshening trend in the West Highlands region (Figure 3.6), overall, the SCObs data from Loch Ewe suggests that in the coastal sea lochs the same freshening trend exists.

3.2.4 Long-Term Trends

Long-term salinity records from the ODaT dataset show multi-decadal variability, with periods of high salinity being observed in the early part of the record and a general trend of increasing salinity during the 1981-2010 period, followed by a general decrease again after this time (Figure 3.8c and d). The drivers of this variability are not well understood but they appear to be related to variability in North Atlantic weather patterns influenced by factors such as the North Atlantic Oscillation (also see Chapter 5). The lowest salinities were observed in the late 1970s and early 1980s, similar to patterns observed in the offshore and oceanic time series (see Chapter 4).

Coastal Waters: Summary

- **In this report, all of the quality controlled physical data (temperature and salinity) from the SCObs is presented.**
- **Temperature recorded at Millport, Peterhead and Fair Isle (the longest coastal temperature observations in Scotland) are examined in order to establish long-term trends.**
- **Salinity and temperature recorded at four selected SCObs sites (Stonehaven, Loch Ewe, Scalloway, Scapa) reveal information about local variability.**
- **To complement the SCObs data, information from different complementary datasets are presented and compared. These are gridded sea surface temperature data from the HadISST, and a first look at a newly created dataset from the ODaT developed by Scottish Association of Marine Science (SAMS).**
- **Sea temperature has a strong seasonal cycle with maxima in August or September, and minimum values observed in February or March.**
- **Salinity has a much weaker seasonal cycle, but is most pronounced at the Stonehaven monitoring site, with maxima in July to September.**
- **2016 was a relatively warm year, with average sea surface temperatures in all regions higher than the long-term average.**

- **The period of 2006 to 2016 was, on average, warmer than normal in Scottish coastal waters, with sea surface temperatures between 0.2 and 0.4 °C warmer than the long-term average (1981–2010).**
- **The gridded sea surface temperature dataset, HadISST, prepared by the UK Meteorological Office, shows that 2014 was the warmest year on record for almost all of the Scottish Marine Regions, and the warmest year overall for Scottish coastal waters.**
- **In-situ data from coastal observations suggest that, although sea temperatures in 2014 were warm, they did not exceed those observed in 2003.**
- **Salinity data from selected SCObs sites show that in the surface layers 2016 was a fresh year. At all SCObs sites, the years since 2013 have been significantly fresher than any others.**

4 Oceanographic Conditions in Offshore and Oceanic Waters

Overview

The coastal temperature time series, described in Chapter 3, give a good indication of changes that are occurring in the Scottish coastal environment. In order to put these changes in a broader context, we can compare the coastal data to those collected further offshore in the seas surrounding the United Kingdom and in the wider North Atlantic.

Figure 4.1 shows the location of key sites where Marine Scotland and other organisations make long-term measurements. These monitoring sites are plotted on a map that also shows a simplified path of the main ocean currents flowing around Scotland.

Using datasets that are collected at a number of different stations and at various depths, the data are analysed to determine the properties of water that travels from the North Atlantic to each of these monitoring points. A brief description for each of these datasets can be found below, and full details of how the water masses are identified, and their properties extracted, can be found in Appendix D. As the Scottish Marine Regions do not cover the entire offshore seas, the analysis here has been done using the Charting Progress 2 regions. More details on these, and how they relate to the Scottish Marine Regions, can be found in Appendix F.

Atlantic Water North of Scotland, North Atlantic Water. Researchers from MS and Faroe Marine Research Institute (FAMRI) monitor a set of stations across the FSC. Data from the Shetland side of the channel are used to represent conditions in the warm Atlantic water that flows along the continental shelf to the north of Scotland. This water is referred to as North Atlantic Water (NAW) and lies within the CP2 Region 7, Scottish Continental Shelf.

Atlantic Water around Faroe, Modified North Atlantic Water. Data from the Faroese side of the FSC are used to represent conditions in Atlantic waters flowing around Faroe, also known as Modified North Atlantic Water (MNAW).

Fair Isle Current, Scottish Coastal Waters. Researchers from MS monitor a set of stations to the east of the Orkney Islands. Here, data from within the Fair Isle Current which flows into the North Sea, have been chosen as an indicator of the properties in Scottish Coastal Waters. These are a mixture of waters from offshore origin and those flowing around the coast of Scotland. These waters are referred to as Fair Isle Current waters (FIC) and lie within the CP2 Region 1, Northern North Sea.

Central North Sea, Cooled Atlantic Waters (CAW). Further out into the North Sea, the monitoring stations enter deeper water. These waters are so deep that only the surface layers get warmed up in the summer, and the deeper bottom layers remain at a similar temperature to that of the winter before. During the late autumn and winter, when strong winds and storms cause a lot of mixing in the Northern North Sea the surface waters cool and mix to an extent with the waters below. These cold and deep bottom waters are referred to as Cooled Atlantic Waters and lie within the CP2 Region 1, Northern North Sea.

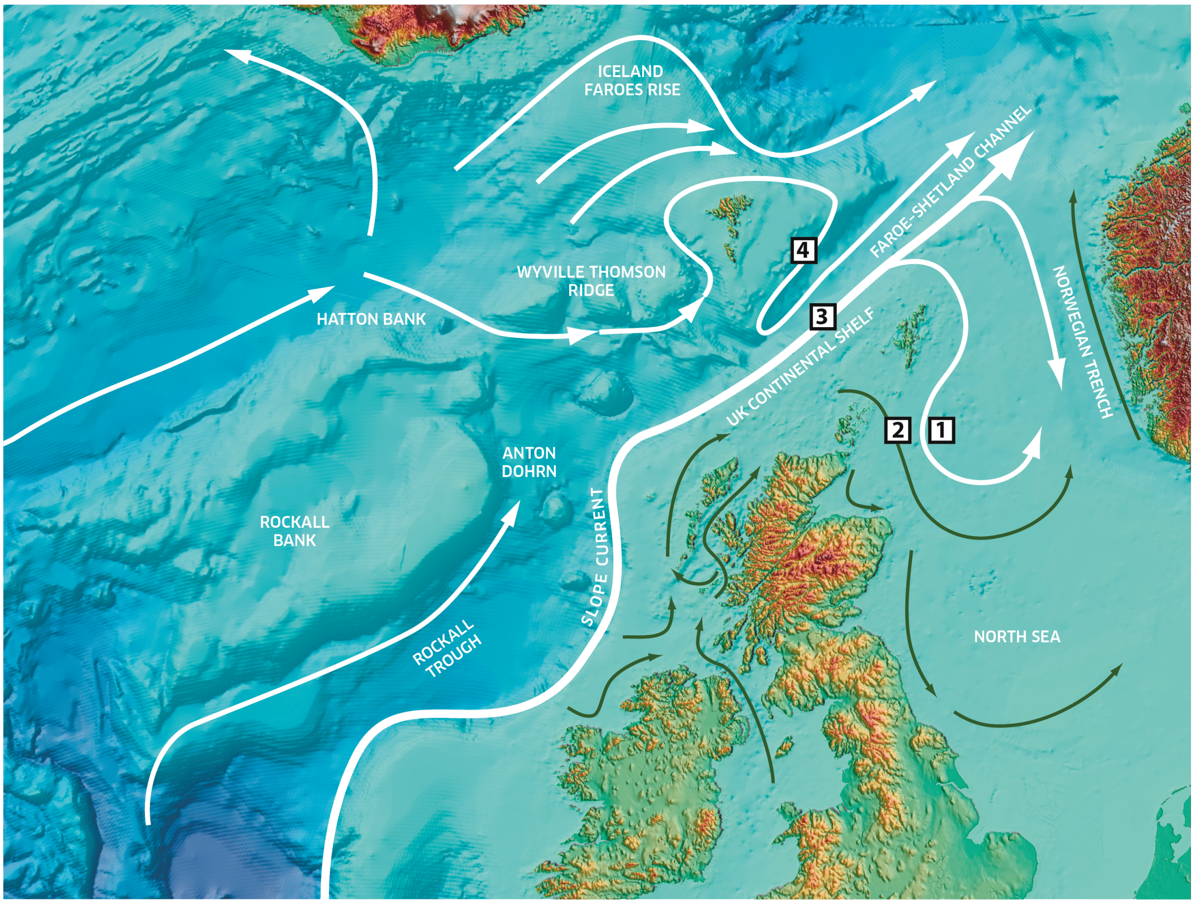


Figure 4.1: Schematic Circulation of Scottish Waters showing location of offshore and oceanic sampling sites (squares) around Scotland where MS and others (see text) make routine oceanographic measurements 2-3 times each year: 1. Atlantic water north of Scotland; 2. The Fair Isle Current, North Sea; 3. Atlantic water west of Scotland; 4. Atlantic water near Faroe. The map also shows the circulation of surface waters around Scotland. White arrows are the flow of warm, salty Atlantic water, green arrows show the flow of coastal waters.

4.1 Offshore Sea Surface Temperatures by CP2 region

Analysis

Sea Surface Temperatures have been analysed by CP2 Regions (see Figure 4.4 and Appendix F) from the HadISST dataset. The HadISST dataset is available from 1870, but here the observational records have been restricted to the period 1893-2015 as this matches the observational limits in Scottish offshore hydrographic datasets. Recent conditions are referenced to a climatological average period calculated over the thirty years between 1981 and 2010. More information on this dataset can be found in Appendix D.

Table 4.1: Statistical Summary of sea surface temperature (°C) from the HadISST Dataset, in each of the CP2 Regions. The trends in the table are in °C per decade over the indicated time period. See also Figure F.1b and Appendix G.4.

Dataset Average 1893-2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
03. EASTERN CHANNEL	9.9	9.0	8.8	9.5	11.2	13.4	15.4	16.5	16.4	15.2	13.2	11.3	9.3	11.4	16.1	13.2	12.5	0.08
04. WESTERN CHANNEL CELTIC SEA	10.6	10.0	9.7	10.3	11.7	14.1	16.1	16.8	16.0	14.5	12.7	11.4	10.1	12.0	16.3	12.9	12.8	0.06
05. IRISH SEA	9.0	8.1	7.8	8.6	10.0	12.1	13.8	14.8	14.6	13.6	11.9	10.3	8.3	10.2	14.4	11.9	11.2	0.05
06. MINCHES WESTERN SCOTLAND	8.8	8.3	8.0	8.5	9.6	11.5	12.9	13.7	13.1	12.3	11.0	9.9	8.4	9.9	13.2	11.0	10.6	0.05
07. SCOTTISH CONTINENTAL SHELF	8.4	8.0	7.9	8.2	9.2	10.9	12.3	13.1	12.2	11.1	10.0	9.2	8.1	9.4	12.5	10.1	10.0	0.05
08. ATLANTIC NW APPROACHES	9.0	8.8	8.7	8.8	9.6	11.0	12.4	13.0	12.2	11.0	9.8	9.3	8.8	9.8	12.5	10.0	10.3	0.02
01. NORTHERN NORTH SEA	7.4	6.7	6.5	7.1	8.6	11.2	13.1	13.9	12.8	11.4	9.8	8.5	6.9	9.0	13.3	9.9	9.8	0.07
02. SOUTHERN NORTH SEA	7.0	6.1	6.0	7.2	9.4	12.4	14.7	15.9	15.1	13.3	10.8	8.7	6.4	9.7	15.2	10.9	10.6	0.09
Climatological Average 1981-2010	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
03. EASTERN CHANNEL	10.2	9.3	9.1	9.9	11.5	13.8	15.9	17.0	16.8	15.5	13.6	11.6	9.5	11.7	16.6	13.6	12.9	0.30
04. WESTERN CHANNEL CELTIC SEA	10.8	10.2	10.0	10.6	12.0	14.4	16.4	17.2	16.3	14.7	13.0	11.7	10.3	12.3	16.7	13.1	13.1	0.23
05. IRISH SEA	9.2	8.3	7.9	8.8	10.3	12.4	14.1	15.3	14.9	13.8	12.1	10.4	8.5	10.5	14.8	12.1	11.4	0.34
06. MINCHES WESTERN SCOTLAND	8.9	8.4	8.1	8.6	9.8	11.6	13.2	14.1	13.3	12.4	11.1	10.0	8.5	10.0	13.5	11.2	10.8	0.20
07. SCOTTISH CONTINENTAL SHELF	8.6	8.2	8.0	8.4	9.4	11.1	12.6	13.4	12.4	11.3	10.1	9.4	8.3	9.6	12.8	10.3	10.2	0.27
08. ATLANTIC NW APPROACHES	9.0	8.8	8.7	8.8	9.6	11.1	12.5	13.2	12.3	11.0	9.9	9.4	8.8	9.8	12.7	10.1	10.4	0.33
01. NORTHERN NORTH SEA	7.7	7.0	6.8	7.4	9.0	11.5	13.6	14.5	13.2	11.7	10.1	8.9	7.2	9.3	13.7	10.2	10.1	0.41
02. SOUTHERN NORTH SEA	7.4	6.5	6.4	7.7	10.0	13.0	15.3	16.6	15.6	13.7	11.2	9.0	6.8	10.2	15.8	11.3	11.0	0.53
Decadal Average 2006-2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
03. EASTERN CHANNEL	10.4	9.5	9.3	10.2	11.9	14.1	16.1	17.0	17.0	16.0	14.1	11.9	9.7	12.1	16.7	14.0	13.1	n. s.
04. WESTERN CHANNEL CELTIC SEA	10.9	10.2	10.0	10.8	12.2	14.6	16.7	17.2	16.4	15.2	13.4	11.9	10.4	12.5	16.8	13.5	13.3	n. s.
05. IRISH SEA	9.3	8.2	8.1	9.0	10.6	12.7	14.5	15.4	15.1	14.2	12.5	10.5	8.5	10.8	15.0	12.4	11.7	-0.53
06. MINCHES WESTERN SCOTLAND	9.2	8.5	8.3	8.9	10.0	11.9	13.4	14.1	13.5	12.7	11.5	10.3	8.7	10.3	13.7	11.5	11.0	n. s.
07. SCOTTISH CONTINENTAL SHELF	8.8	8.3	8.2	8.7	9.7	11.5	12.9	13.7	12.7	11.7	10.6	9.6	8.5	10.0	13.1	10.6	10.5	n. s.
08. ATLANTIC NW APPROACHES	9.3	9.1	8.9	9.1	9.9	11.5	12.8	13.5	12.6	11.4	10.3	9.6	9.1	10.2	13.0	10.4	10.7	n. s.
01. NORTHERN NORTH SEA	8.0	7.2	7.0	7.7	9.3	11.9	14.0	14.9	13.5	12.1	10.6	9.1	7.4	9.6	14.1	10.6	10.4	n. s.
02. SOUTHERN NORTH SEA	7.8	6.8	6.7	8.1	10.4	13.3	15.7	16.9	15.9	14.3	11.9	9.5	7.1	10.6	16.2	11.9	11.4	n. s.
Data for Year 2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
03. EASTERN CHANNEL	10.9	10.1	9.3	10.3	11.7	14.0	15.7	17.1	17.7	16.1	13.2	11.8	10.1	12.0	16.8	13.7	13.2	
04. WESTERN CHANNEL CELTIC SEA	11.5	10.8	10.1	10.5	12.3	15.0	16.6	17.4	17.0	15.1	13.1	12.1	10.8	12.6	17.0	13.4	13.5	
05. IRISH SEA	9.8	8.9	8.0	8.6	10.2	12.9	14.3	15.1	15.6	14.3	12.0	10.9	8.9	10.6	15.0	12.4	11.7	
06. MINCHES WESTERN SCOTLAND	9.1	8.2	8.2	8.4	9.7	12.0	13.4	14.1	14.1	12.9	11.0	10.3	8.5	10.0	13.9	11.4	10.9	
07. SCOTTISH CONTINENTAL SHELF	8.7	8.2	8.3	8.5	9.5	11.5	13.1	13.5	13.2	12.0	10.4	9.6	8.4	9.8	13.3	10.7	10.5	
08. ATLANTIC NW APPROACHES	8.6	8.4	8.5	8.6	9.3	11.5	12.7	13.5	12.7	11.2	9.9	9.7	8.5	9.8	13.0	10.3	10.4	
01. NORTHERN NORTH SEA	8.2	7.3	7.3	7.8	9.3	11.9	14.1	14.6	14.2	12.4	10.3	9.1	7.6	9.6	14.3	10.6	10.5	
02. SOUTHERN NORTH SEA	9.0	7.7	7.3	8.4	10.5	13.8	15.7	17.2	17.2	14.7	11.4	9.7	8.0	10.9	16.7	11.9	11.9	

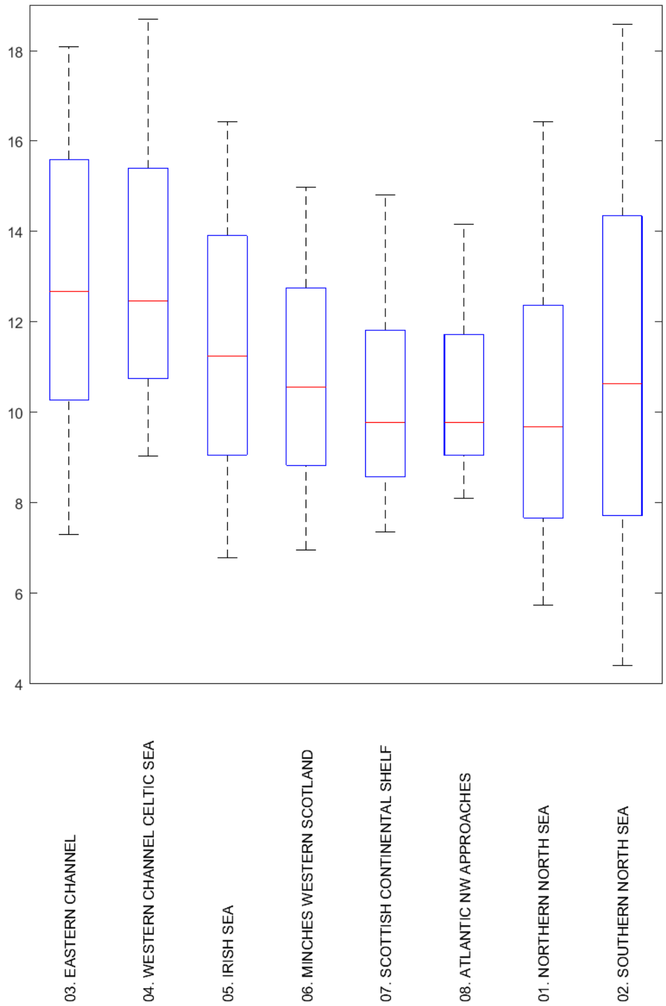


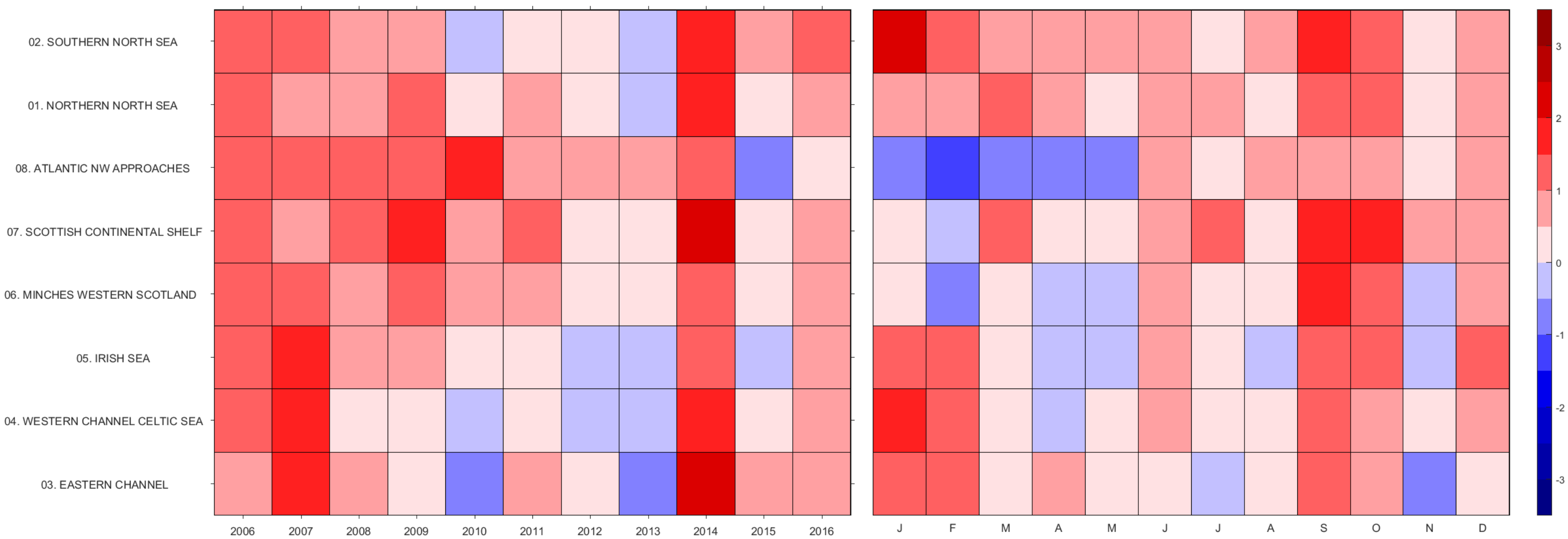
Figure 4.2: Statistical Boxplots of sea surface temperature (°C) by CP2 Region. See Figure F.1b for a description of these

4.1.1 Spatial Patterns

Further analysis of regional variability in the CP2 regions can be found in Appendix F. In general, waters in the shallower areas of the North Sea, which experience more coastal influence, demonstrate a much larger seasonal temperature range and temporal variability in sea surface temperatures (Figure 4.2). As expected, regions with a more northerly latitude tend to have cooler average temperatures than those further south. However, regions within the North Sea, where waters are shallower and air-sea heat fluxes are influenced by nearby continental land and air masses, have lower average temperatures than those in the Western Channel & Celtic Sea region which remain strongly influenced by oceanic water masses.

4.1.2 Conditions Observed during 2016

In common with the long-term trends, conditions differed between the northern regions influenced by Atlantic water masses (region 6, Minches & Western Scotland;



(a) Decade 2006–2016

(b) Monthly for 2016

Figure 4.3: Normalised anomalies (σ) monthly average sea surface temperature (°C) for (a) the years 2005–2016 and (b) the months in 2016 (all plotted relative to 1981–2010 base period), from the HadISST Dataset, by CP2 Regions. The anomalies are normalised with respect to the standard deviation of each time-series (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds = positive/warmer; blues = negative/cooler. For this dataset, average values have been calculated in each area.

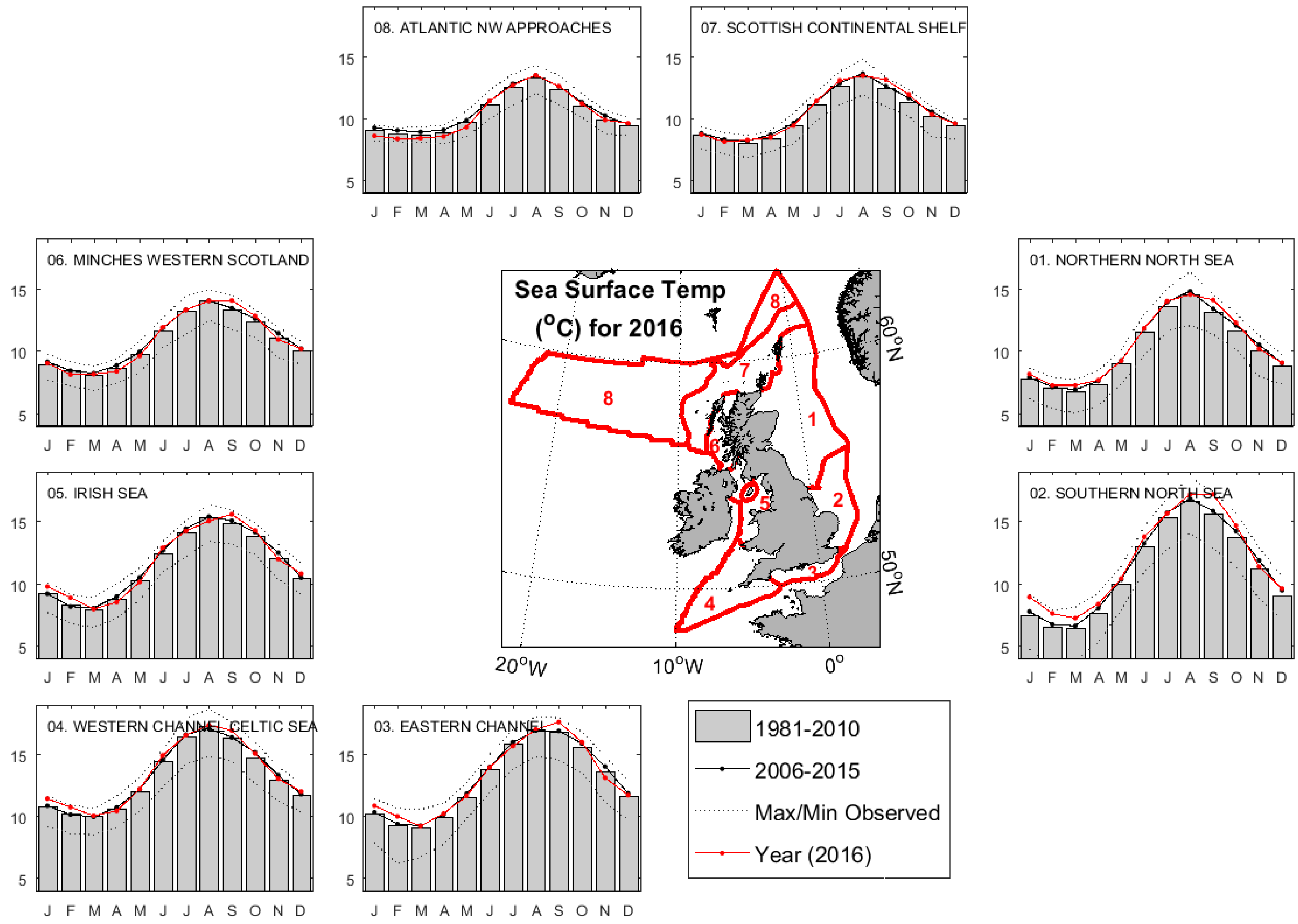


Figure 4.4: Summary of monthly sea surface temperature (°C) for 2016, from the HadISST Dataset, by CP2 Region. Plots show monthly values of sea surface temperature during 2016 compared to the long-term average pattern (calculated for the period 1981–2010) and the average over the last decade (2006–2016). X-axis of each graph is month. Central map shows the extent of each of the CP2 Regions.

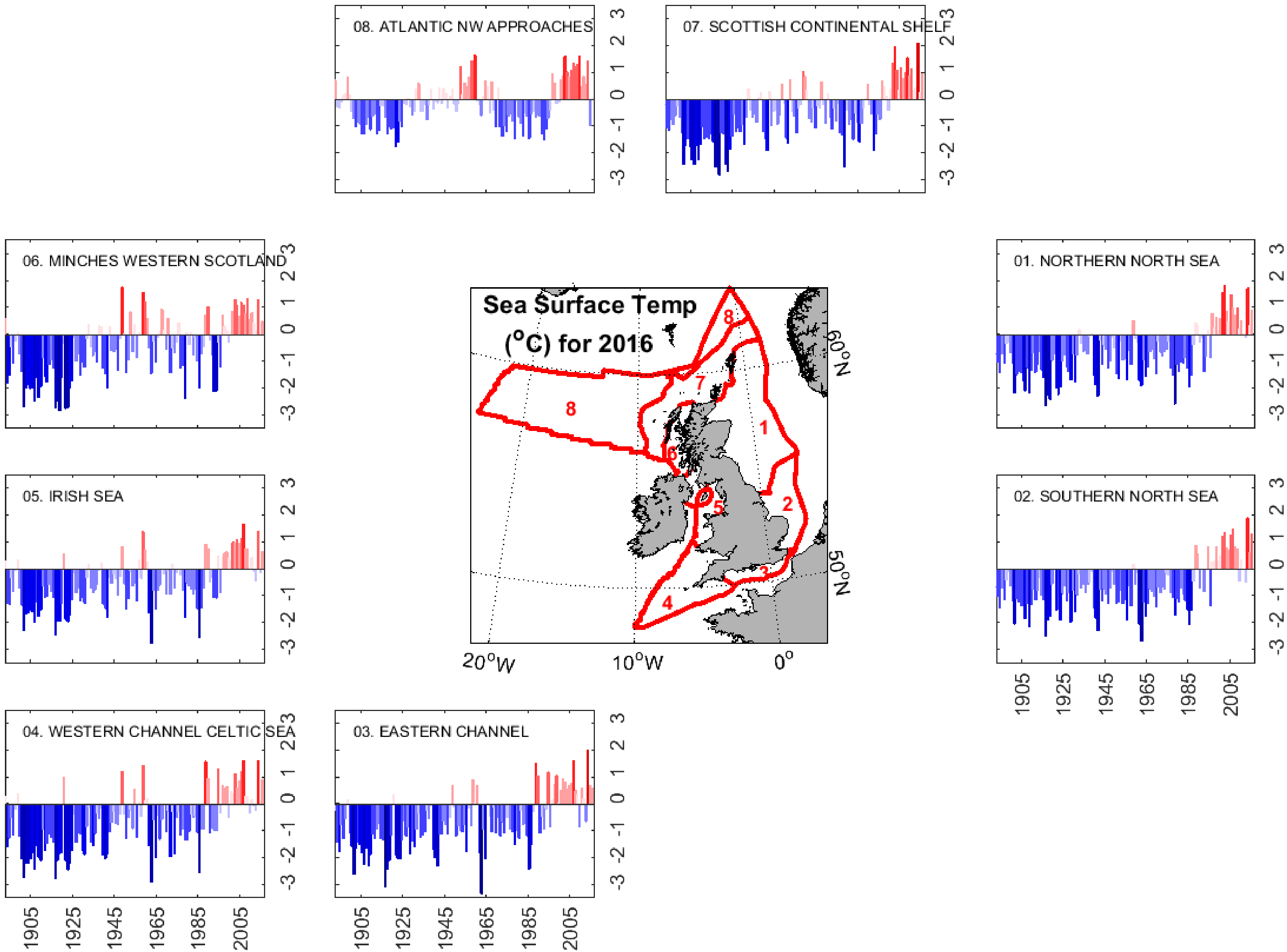


Figure 4.5: Time series of normalised annual anomalies (σ) of sea surface temperature (°C) up to 2016 (relative to 1981-2010 base period), from the HadISST Dataset, averaged over the eight CP2 Regions. X-axis of each plot is year. The anomalies are normalised with respect to the standard deviation (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds = positive/warmer; blues = negative/cooler. Central map shows the extent of each of the CP2 Regions.

region 7, Scottish Continental Shelf; region 8, Atlantic NW Approaches) and those further to the south (Figure 4.4). Winter and spring were cooler than average in region 8, Atlantic NW Approaches and region 6, Minches & Western Scotland (Table 4.1 & Figure 4.3b). Overall, 2016 was warmer than normal in all regions.

4.1.3 Trends and Variability over the period 2006-2016

The regional variability in sea surface temperature over the last decade can be seen in Figure 4.3a. In most regions, the recent decade has, overall, been warmer than the climatological average (Table 4.1). Within this period, 2010 and 2013 were relatively cool years, particularly in the shallower and eastern-most regions, away from the main influence of the North Atlantic. 2014 was the warmest year on record in Region 3, Eastern Channel, on the Scottish Continental Shelf (Region 7) and in the North Sea (Regions 1 and 2). Note that for this dataset, the warmest year in Region 6 occurred in 1949, and in Region 8 in 1960. Prior to 2014, the warmest year was 2007 in Regions 3, 4 and 5.

2014 was much warmer than normal throughout the year, with particularly high temperatures in June and July. The start of the year (Jan-Feb) was a little cooler than normal in western regions of the UK (from region 4, Western Channel & Celtic Sea, through to region 6, Minches & Western Scotland). The annual mean normalised anomaly for 2014 can be seen in Figure 4.3a, the aforementioned seasonal anomalies are not shown here.

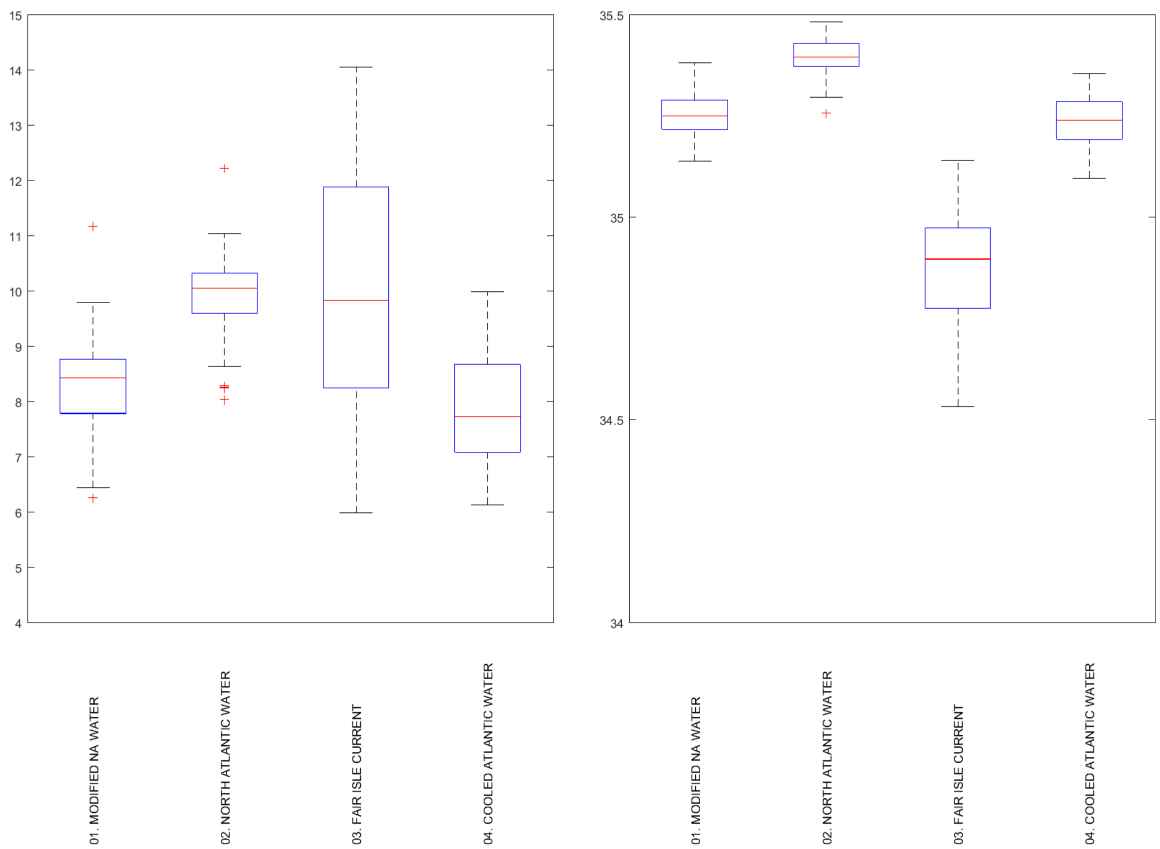
4.1.4 Long-Term Trends

The long-term trend in sea surface temperatures is one of warming at a rate of between 0.02°C and 0.08°C per decade (Table 4.1). The fastest rate of warming occurs in region 2, Southern North Sea, the shallowest of the CP2 regions. However, there is large amount of decadal and multi-decadal variability observed in sea surface temperatures (Figure 4.5), and as a result the warming trend over the 30 year period 1981-2010 was much more pronounced, ranging between 0.18°C and 0.54°C per decade (Table 4.1). Therefore, some regions have experienced a relatively rapid change, up to 1.5°C in 30 years. The more rapid warming trend is not reflective of the long-term trend, but is a consequence of long-term climate change superimposed on a period of warming thought to be driven by changes in ocean circulation in the North Atlantic. During the last decade, most regions showed a non-significant trend, except for Minches & Western Scotland (Region 6), which showed a cooling trend between 2006 and 2015.

4.2 Scotland's Offshore Monitoring Data

Analysis

MS's Offshore Monitoring Programme collects temperature and salinity observations at several key locations in the offshore region (Figure 4.1). More details on how these data were analysed can be found in Appendix D.



(a) Offshore Temperature (°C) **(b)** Offshore Salinity

Figure 4.6: Statistical Boxplots of (a) temperature (°C) and (b) salinity for the climatological period 1981–2010 in each offshore water mass. More detailed water mass descriptions can be found on page 89, Figure 4.1, and in Appendix D.

4.2.1 Spatial Patterns

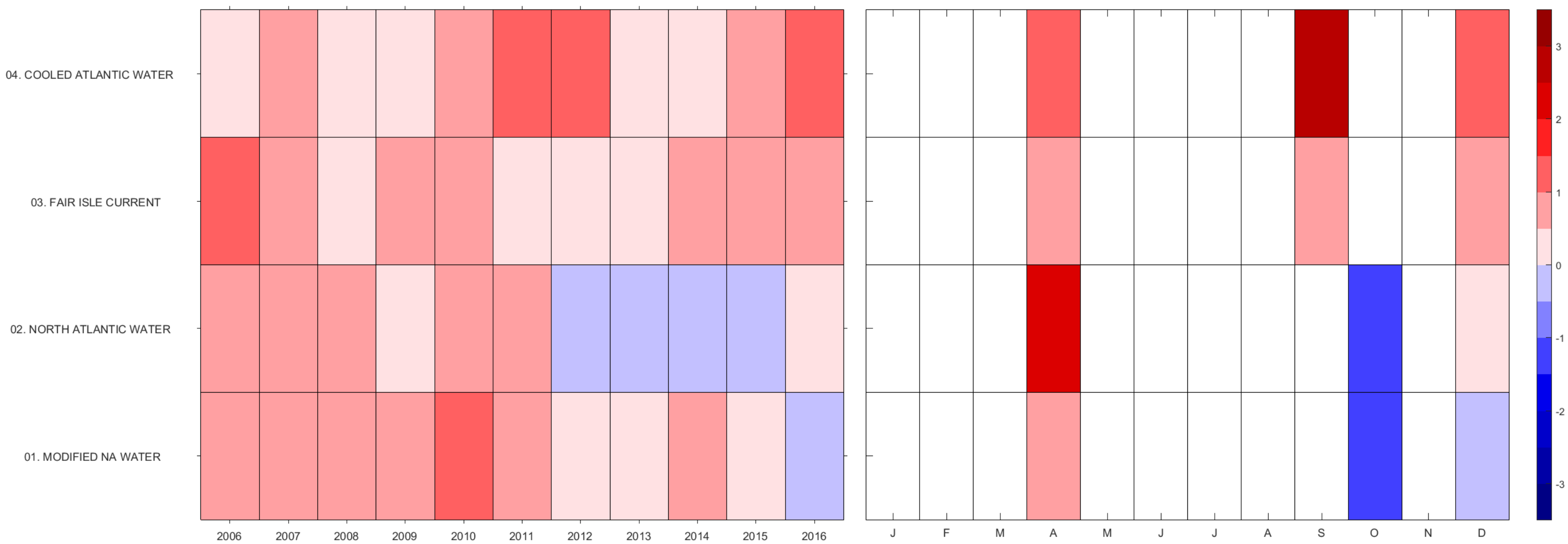
These data represent the properties of particular water masses that are found in Scottish Waters. North Atlantic Water is the saltiest of these water masses, with an average salinity of 35.37 (Table 4.2 & Figure 4.6), and also the warmest on average (9.6°C, Table 4.2). Modified North Atlantic Water has mixed with cooler and fresher waters on its journey through the western North Atlantic and around the Faroe Islands. Therefore, the temperature and salinity of this water mass is slightly lower than those of North Atlantic Water: the average salinity of MNAW is 35.25 and the average temperature is 7.9°C (Table 4.2).

Table 4.2: (a) Statistical Summary of temperature (°C) in each offshore water mass. Abbreviations are: Modified North Atlantic Water (MNAW), North Atlantic Water (NAW), Fair Isle Current (FIC), Cooled Atlantic Water (CAW). The trends in the table are in °C per decade over the indicated time period. Dataset coverage is 1893–2016 for MNAW and NAW; and 1960–2016 for FIC and CAW. See also Appendices D and G.4.

Dataset Average 1893-2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. MODIFIED NA WATER	7.0	7.1	6.7	7.0	7.8	8.7	8.5	8.2	8.5	8.9	8.3	8.4	6.9	7.8	8.4	8.5	7.9	n. s.
02. NORTH ATLANTIC WATER	8.8	8.8	8.0	8.3	9.4	9.6	9.7	9.7	10.3	10.4	10.3	9.9	8.5	9.1	9.9	10.2	9.4	n. s.
03. FAIR ISLE CURRENT	8.0	6.7	7.6	7.4	8.4	9.8	10.6	11.9	12.4	12.2	10.3	9.7	7.4	8.5	11.6	10.7	9.6	n. s.
04. COOLED ATLANTIC WATER	7.2	6.7	6.4	6.9	7.1	7.2	7.0	7.6	8.7	8.7	8.9	8.9	6.8	7.1	7.8	8.9	7.6	n. s.
Climatological Average 1981-2010	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. MODIFIED NA WATER	-	7.3	6.8	7.1	8.5	8.7	8.8	8.2	8.5	8.6	8.3	8.5	-	8.1	8.5	8.5	-	0.48
02. NORTH ATLANTIC WATER	9.1	9.4	9.3	8.3	9.7	10.1	10.1	10.0	10.3	10.3	10.5	10.2	9.3	9.4	10.1	10.3	9.8	0.26
03. FAIR ISLE CURRENT	8.4	6.6	7.6	7.2	8.5	10.1	10.7	12.0	12.8	12.4	10.5	9.8	7.5	8.6	11.8	10.9	9.7	0.41
04. COOLED ATLANTIC WATER	7.2	6.6	7.0	6.8	7.3	7.6	7.0	7.6	8.7	8.6	8.8	9.1	6.9	7.2	7.8	8.8	7.7	0.21
Decadal Average 2006-2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. MODIFIED NA WATER	-	-	-	8.4	8.7	-	-	-	8.8	9.0	-	8.5	-	-	-	-	-	n. s.
02. NORTH ATLANTIC WATER	-	-	-	-	9.8	-	-	-	10.5	10.3	-	10.0	-	-	-	-	-	-0.65
03. FAIR ISLE CURRENT	-	-	-	8.0	8.4	-	-	-	12.5	12.7	-	9.7	-	-	-	-	-	n. s.
04. COOLED ATLANTIC WATER	-	-	-	7.4	7.5	-	-	-	8.7	9.3	-	9.3	-	-	-	-	-	n. s.
Data for Year 2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. MODIFIED NA WATER	-	-	-	7.7	-	-	-	-	-	7.9	-	8.2	-	-	-	-	-	
02. NORTH ATLANTIC WATER	-	-	-	9.3	-	-	-	-	-	9.8	-	10.3	-	-	-	-	-	
03. FAIR ISLE CURRENT	-	-	-	7.8	-	-	-	-	13.2	-	-	10.3	-	-	-	-	-	
04. COOLED ATLANTIC WATER	-	-	-	7.3	-	-	-	-	10.3	-	-	9.7	-	-	-	-	-	

(cont.) Table 4.2: (b) Statistical Summary of salinity in each offshore water mass. Abbreviations are: Modified North Atlantic Water (MNAW), North Atlantic Water (NAW), Fair Isle Current (FIC), Cooled Atlantic Water (CAW). The trends in the table are per decade over the indicated time period. Dataset coverage is 1893–2016 for MNAW and NAW; and 1960–2016 for FIC and CAW. See also Appendices D and G.4.

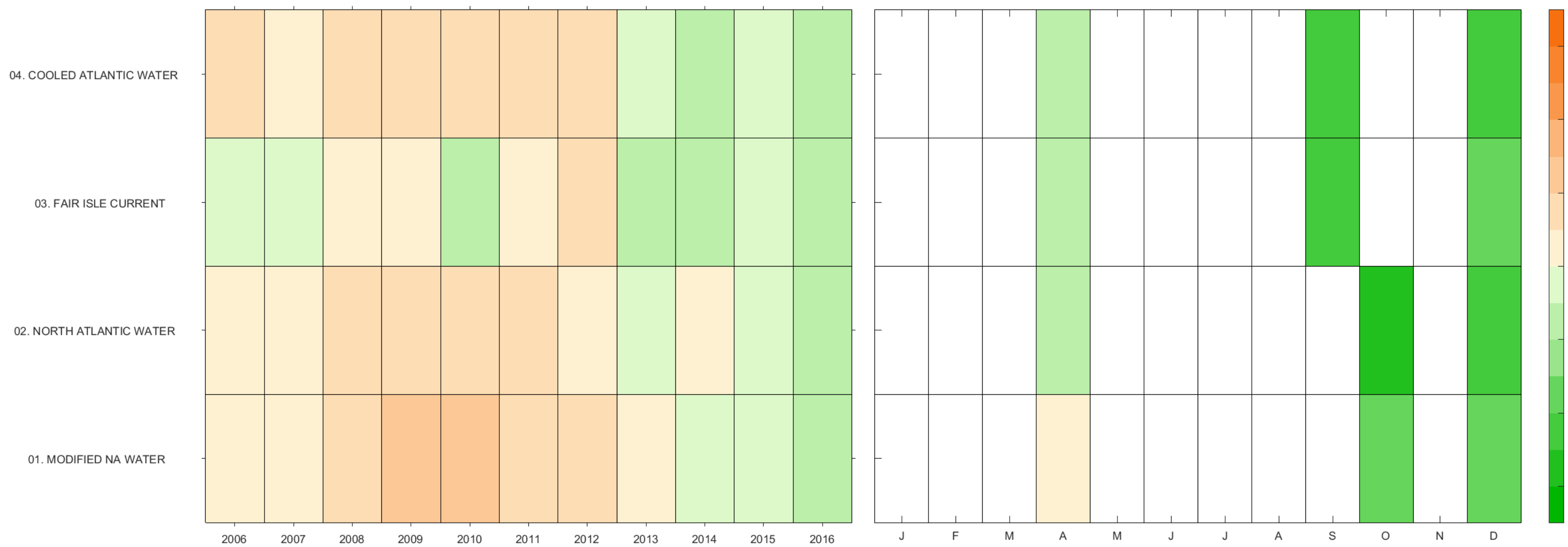
Dataset Average 1893-2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. MODIFIED NA WATER	35.22	35.23	35.19	35.23	35.26	35.27	35.26	35.26	35.27	35.28	35.24	35.25	35.22	35.25	35.26	35.26	35.25	n. s.
02. NORTH ATLANTIC WATER	35.34	35.39	35.35	35.35	35.38	35.38	35.39	35.36	35.38	35.40	35.36	35.37	35.36	35.37	35.37	35.38	35.37	n. s.
03. FAIR ISLE CURRENT	34.70	34.83	34.77	34.82	34.98	34.80	34.85	34.80	34.97	34.88	34.76	34.91	34.77	34.87	34.87	34.85	34.84	n. s.
04. COOLED ATLANTIC WATER	35.15	35.19	35.18	35.23	35.25	35.21	35.20	35.23	35.29	35.26	35.19	35.21	35.18	35.23	35.24	35.22	35.22	n. s.
Climatological Average 1981-2010	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. MODIFIED NA WATER	-	35.22	35.18	35.23	35.27	35.29	35.27	35.26	35.26	35.27	35.25	35.25	-	35.27	35.27	35.26	-	0.028
02. NORTH ATLANTIC WATER	35.34	35.39	35.40	35.35	35.39	35.40	35.41	35.41	35.40	35.43	35.38	35.39	35.38	35.38	35.41	35.40	35.39	0.027
03. FAIR ISLE CURRENT	34.69	34.96	34.77	34.82	34.98	34.83	34.87	34.79	34.99	34.91	34.73	34.92	34.80	34.88	34.88	34.85	34.85	n. s.
04. COOLED ATLANTIC WATER	35.15	35.26	35.19	35.25	35.25	35.26	35.21	35.23	35.28	35.26	35.19	35.24	35.20	35.25	35.24	35.23	35.23	0.024
Decadal Average 2006-2015	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. MODIFIED NA WATER	-	-	-	35.29	35.33	-	-	-	35.28	35.29	-	35.24	-	-	-	-	-	n. s.
02. NORTH ATLANTIC WATER	-	-	-	-	35.42	-	-	-	35.43	35.45	-	35.39	-	-	-	-	-	n. s.
03. FAIR ISLE CURRENT	-	-	-	34.80	34.86	-	-	-	34.96	34.87	-	34.89	-	-	-	-	-	n. s.
04. COOLED ATLANTIC WATER	-	-	-	35.25	35.31	-	-	-	35.32	35.31	-	35.25	-	-	-	-	-	n. s.
Data for Year 2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Wi	Sp	Su	Au	**Avg**	**Trend**
01. MODIFIED NA WATER	-	-	-	35.24	-	-	-	-	-	35.18	-	35.16	-	-	-	-	-	
02. NORTH ATLANTIC WATER	-	-	-	35.33	-	-	-	-	-	35.32	-	35.26	-	-	-	-	-	
03. FAIR ISLE CURRENT	-	-	-	34.70	-	-	-	-	34.71	-	-	34.69	-	-	-	-	-	
04. COOLED ATLANTIC WATER	-	-	-	35.20	-	-	-	-	35.14	-	-	35.12	-	-	-	-	-	



(a) Decade 2006–2016

(b) Monthly for 2016

Figure 4.7: Normalised anomalies (σ) of monthly average sea temperature (°C) for (a) the years 2005–2016 and (b) the months in 2016 (all plotted relative to 1981–2010 base period). Anomalies are presented for each of four water masses (MNAW, NAW, FIC and CAW; see Appendix D for more details). The anomalies are normalised with respect to the standard deviation of each time-series (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds = positive/warmer; blues = negative/cooler. Note that these data are a representation of the properties of the water mass in each location.



(c) Decade 2006–2016

(d) Monthly for 2016

(cont.) Figure 4.7: Normalised anomalies (σ) of monthly average salinity for (c) the years 2005–2016 and (d) the months in 2016 (all plotted relative to 1981–2010 base period). Anomalies are presented for each of four water masses (MNAW, NAW, FIC and CAW; see Appendix D for more details). The anomalies are normalised with respect to the standard deviation of each time-series (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; orange = positive/saltier; greens = negative/fresher. Note that these data are a representation of the properties of the water mass in each location.

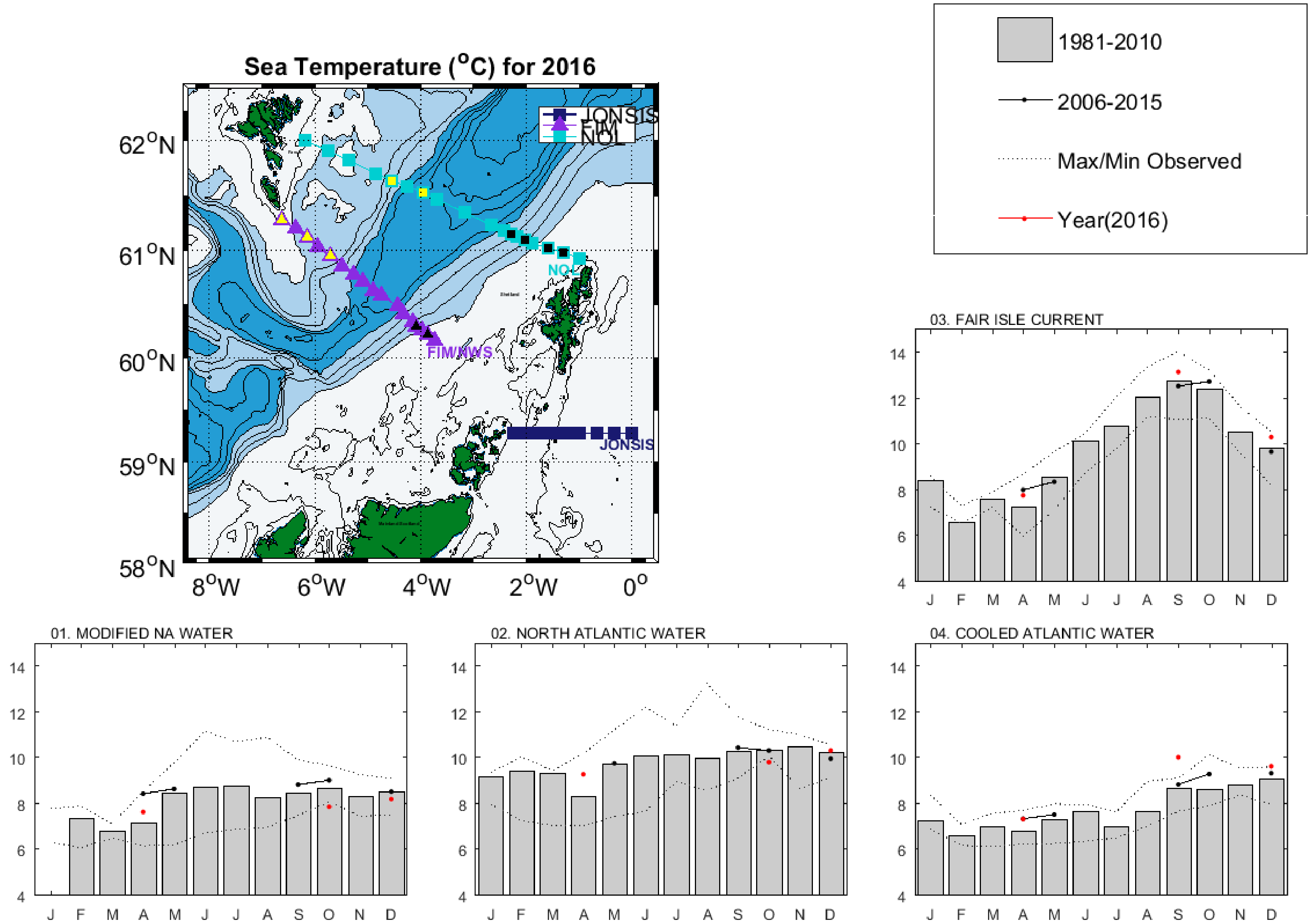
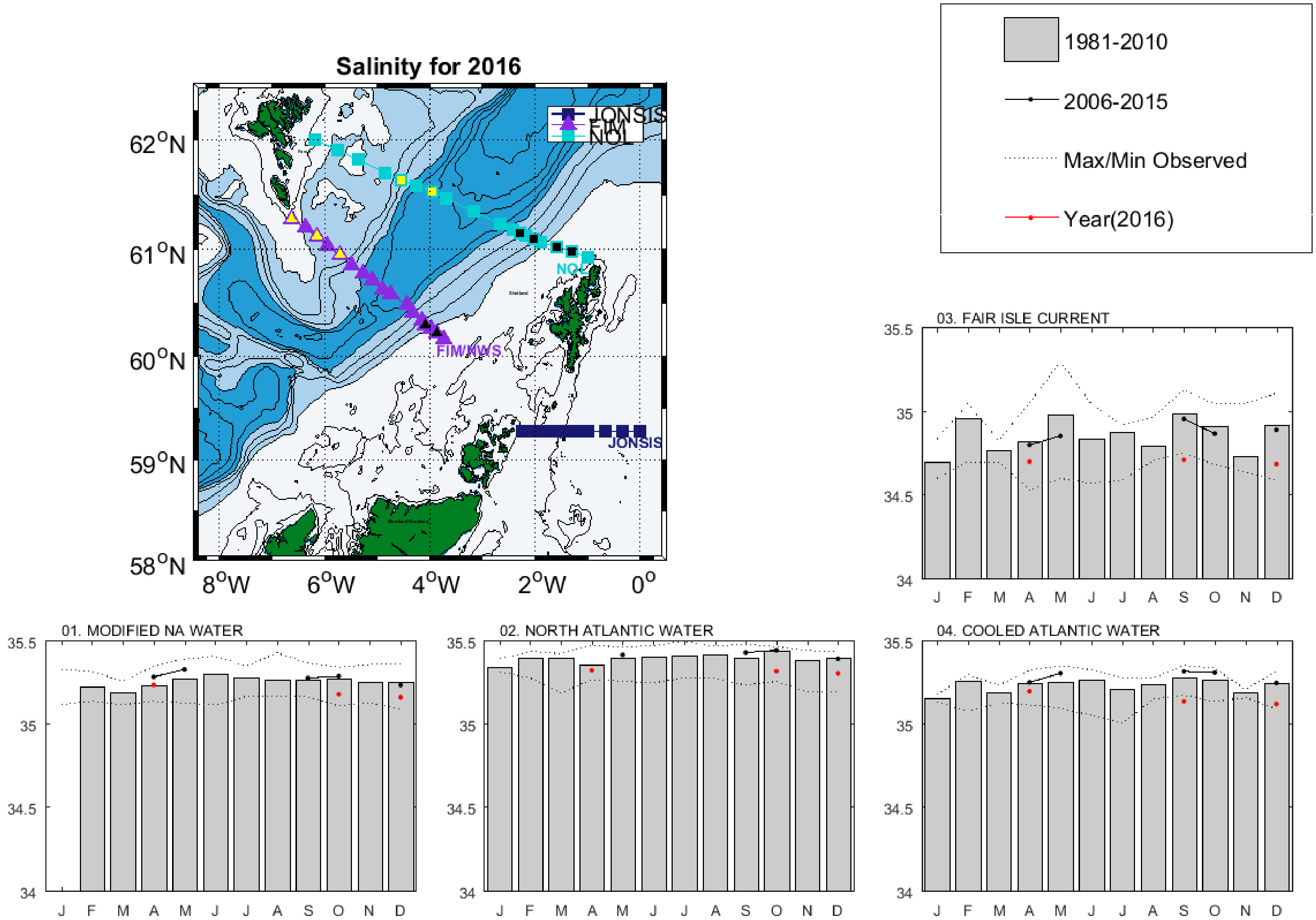


Figure 4.8: Summary of temperature (°C) of offshore water masses during 2016 compared to the long-term average pattern (calculated for the period 1981–2010) and the average over the last decade (2006–2016). X-axis of each graph is month. Map shows the location of Marine Scotland standard monitoring sections used to extract the water mass properties.



(cont.) Figure 4.8: Summary of salinity of offshore water masses during 2016 compared to the long-term average pattern (calculated for the period 1981–2010) and the average over the last decade (2006–2016). X-axis of each graph is month. Map shows the location of Marine Scotland standard monitoring sections used to extract the water mass properties.

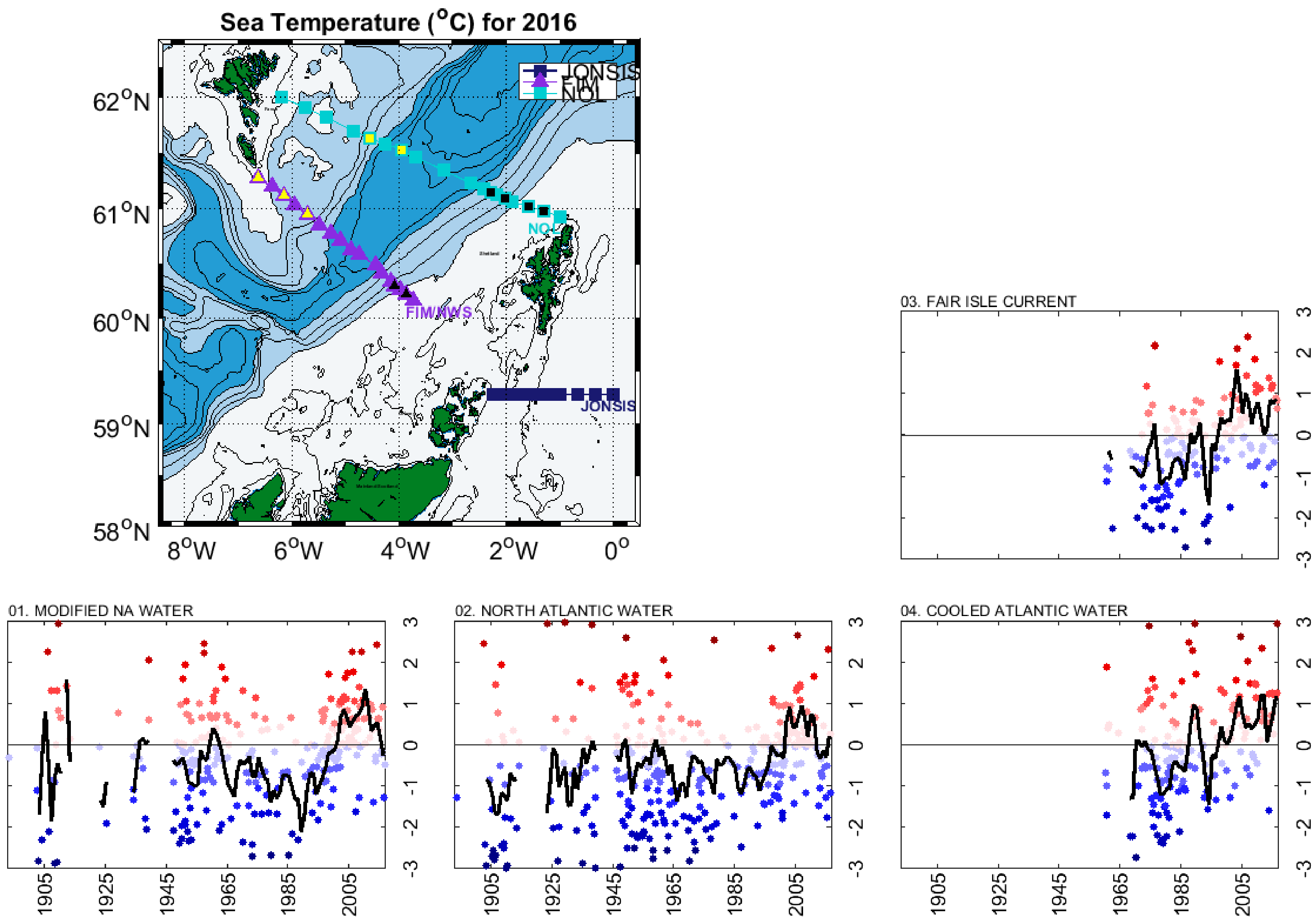
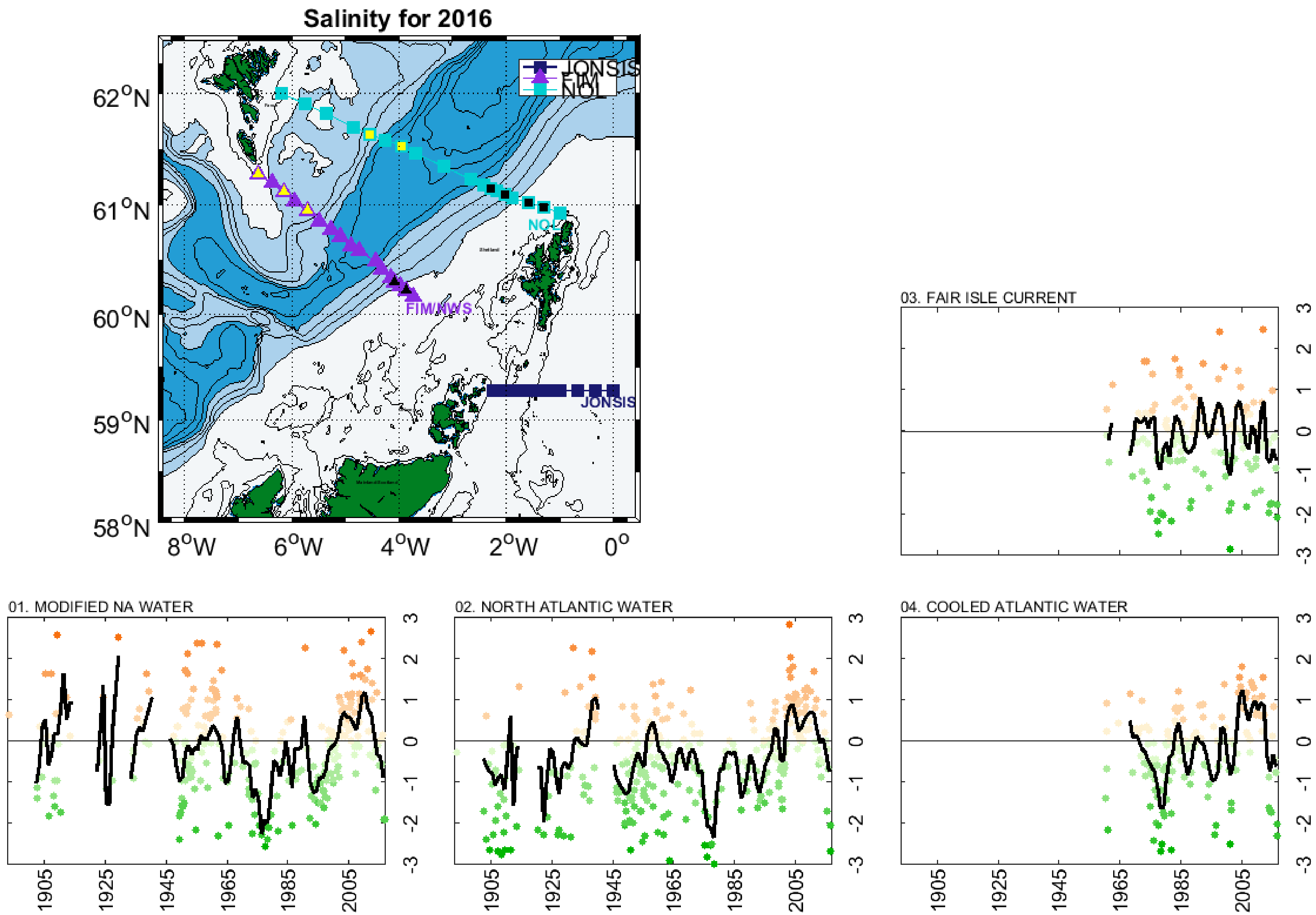


Figure 4.9: Time series of normalised annual anomalies (σ) of sea temperature (°C) up to 2016 (relative to 1981-2010 base period) for each of four water masses (MNAW, NAW, FIC and CAW; see Appendix D for more details). X-axis of each plot is year. The anomalies are normalised with respect to the standard deviation (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds = positive/warmer; blues = negative/cooler. Map shows the location of Marine Scotland standard monitoring sections used to extract the water mass properties.



(cont.) Figure 4.9: Time series of normalised annual anomalies (σ) of salinity up to 2016 (relative to 1981-2010 base period) for each of four water masses (MNAW, NAW, FIC and CAW; see Appendix D for more details). X-axis of each plot is year. The anomalies are normalised with respect to the standard deviation (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; oranges = positive/saltier; greens = negative/fresher. Map shows the location of Marine Scotland standard monitoring sections used to extract the water mass properties.

Fair Isle Current (FIC) Water is the most variable of the water masses presented here and, as a shallow water mass, it also has a marked seasonal cycle in temperature. Over the climatological period 1981–2010, temperatures ranged between a minimum of 6.0°C and a maximum of 14.1°C, with an average temperature of 9.6°C (Table 4.2). The salinity of FIC Water can be as low as 34.53, and as high as 35.30; its average salinity is 34.84 (Table 4.2). In common with the other water masses, the variability in salinity does not have a significant seasonal pattern and the range of salinity recorded reflects year to year variability in the water mass.

The waters found in the deeper part of the Northern North Sea, known as Cooled Atlantic Water, have a higher salinity (35.22) than that of FIC, and a salinity range which is much closer to the other North Atlantic water masses (Figure 4.6). These waters are the coldest of all water masses presented here: average temperatures in CAW during the period 1981–2010 were 7.7°C (Table 4.2).

4.2.2 Conditions Observed during 2016

In the early part of 2016, temperatures of all key water masses were higher than normal (Figure 4.7b & Table 4.2). In the oceanic water masses of MNAW and NAW, temperatures remained higher than normal throughout the year. However, in the Northern North Sea region during October temperatures were below normal, and remained lower than or close to normal at the end of the year (Figures 4.7b and 4.8). The warmer temperatures of the North Atlantic in 2016 were mirrored in coastal regions, where sea surface temperatures had annual averages higher than normal at all locations (see Chapter 3). Atmospheric conditions also align with these data, with 2016 noted as an overall warm year (see Chapter 1).

There was a notable decrease in salinity in all these key water masses towards the end of 2016, and overall 2016 was much fresher than normal (Figures 4.7d & 4.8, & Table 4.2). The fresher period throughout 2016 is in alignment with freshening patterns observed within the coastal regions (see Chapter 3).

4.2.3 Trends and Variability over the period 2006-2016

During the decade of 2006 to 2016, the temperature of all water masses was mostly higher than normal (Figure 4.7a). 2016 was warmer than normal for the Cooled Atlantic Water, Fair Isle Current Water and North Atlantic Water. However, in the Modified NA Water the temperature was below average.

The salinity of the surface layers in the North Atlantic follows a similar pattern of variability to the temperature (Figure 4.7c). Until 2012, as for temperature, the trend has been towards an increase in salinity. Since 2012, however, the salinity of the offshore water masses has been lower than average.

4.2.4 Long-Term Trends

The measurements made in the FSC are one of the longest time series in the world's oceans. The quality and reliability of the data have improved over the years, particularly since the early 1950s, as more sophisticated measuring equipment has been developed, and sampling has occurred on a more frequent and regular basis.

In the North Atlantic waters to the north of Scotland and around Faroe Islands, higher than normal temperatures have been observed in the past around the 1950s to 1960s and then declined to a minimum value by the end of the 1970s (Figure 4.9). Until the late 2010s, as for temperature, the trend has been towards an increase in salinity (Figure 4.9). This is also seen in observations made in the wider North Atlantic (Figure 4.15c).

These data show that temperature and salinity both increased in the period between the end of the 1990s and the mid 2000s (Figure 4.9). There was also a warm and salty period towards the end of the 1950s. During the last decade, annual temperatures in all of the water masses have been higher than normal. Modified North Atlantic Water reached the highest temperature values seen since the 1920s in 2010 and 2007 respectively. For NAW, all of the 10 warmest years have occurred since 2002.

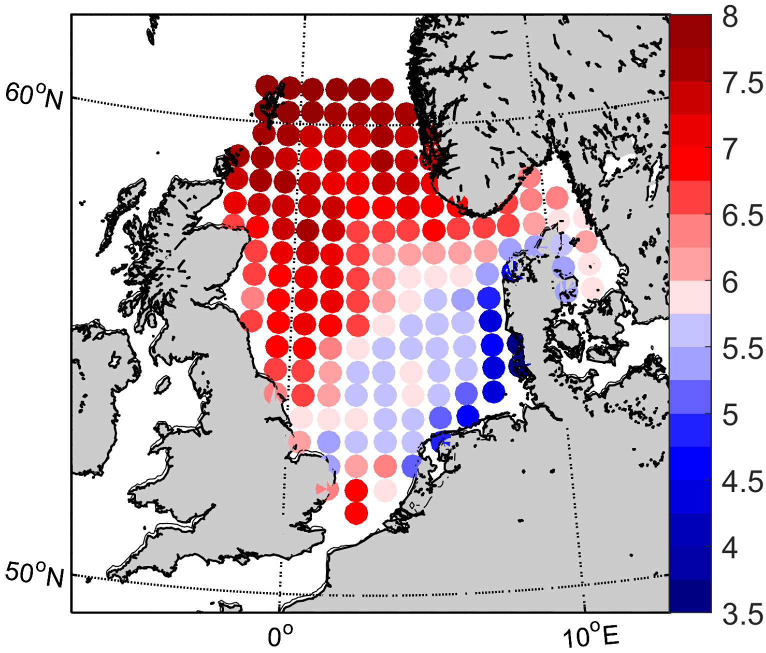
All of the water masses showed a significant trend in temperature between 1981 and 2010, with warming at a rate of between 0.21 and 0.48°C per decade (Table 4.2). There was also an increasing trend in salinity of between 0.03 and 0.02 units per decade in all water masses, except Fair Isle Current Water (Table 4.2).

The salinity of Fair Isle Current Water is very variable and shows no statistically significant long-term trend (Figure 4.9), although as with all the waters described in this report, temperatures have been higher than normal in the last decade. Like NAW, all of the 10 warmest years have occurred since 2002. Long-term trends in Cooled Atlantic Water follow a similar pattern to those of the other Atlantic Water masses, with higher than normal salinities in the last decade. This reflects the influence that these water masses have on conditions in the Northern North Sea.

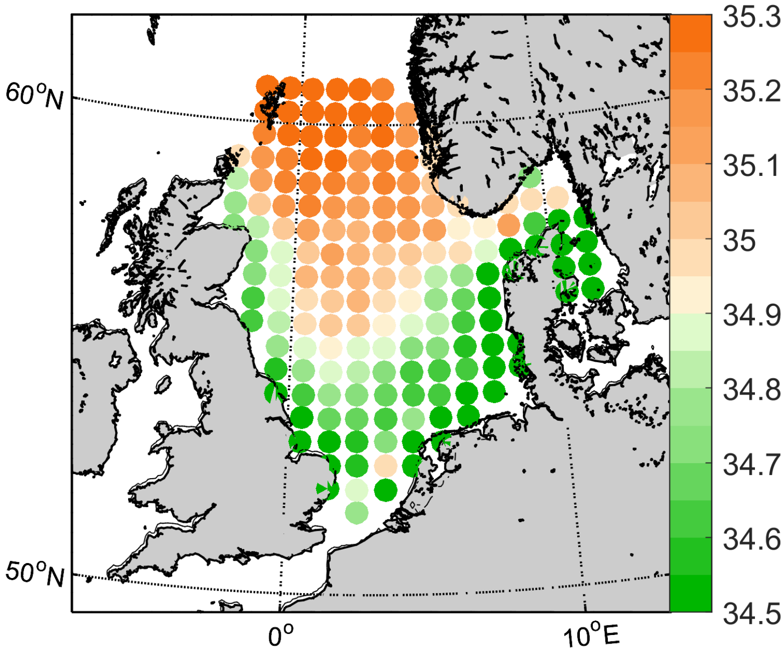
The salinity in the Fair Isle Current appears to vary with a cycle that has a period of around 7 years (Figure 4.9). This is closely linked to changes in the weather patterns over the North Sea and can be explained to some extent by the NAO Index.

4.3 Temperature and Salinity in the North Sea

Each year, fisheries scientists from a number of different countries with an interest in the North Sea collaborate in the International Bottom Trawl Survey (IBTS). The first quarter survey is usually carried out in February, and scientists count the number of young fish in a grid of boxes in the North Sea. In each box, measurements of nearbed temperature and salinity are also recorded to provide information about the conditions in which these young fish are living. This information can also tell us how the winter bottom temperature and salinity of the North Sea have changed over the last 30 years.

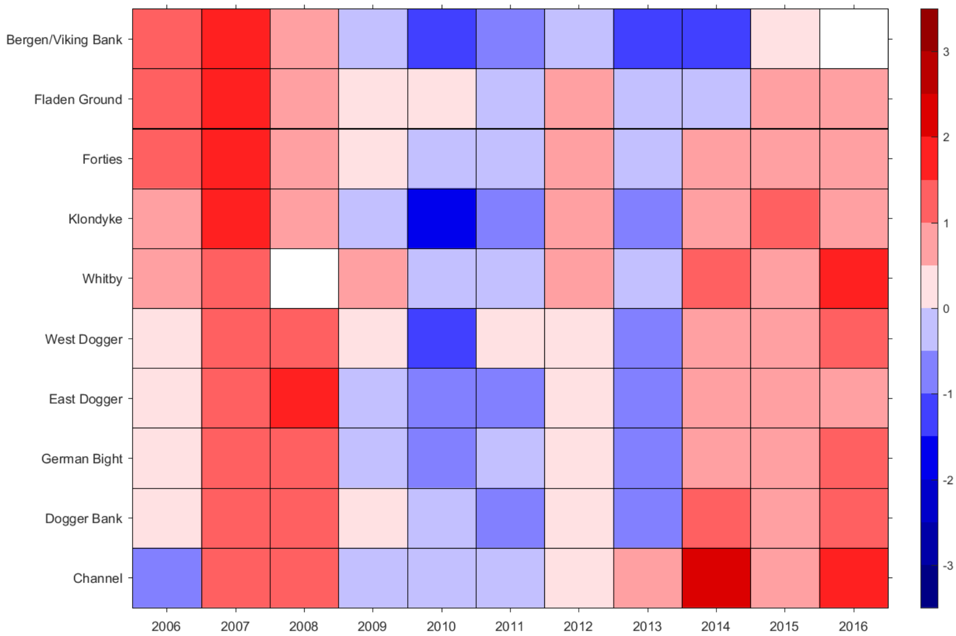


(a) Mean Temperature (°C)

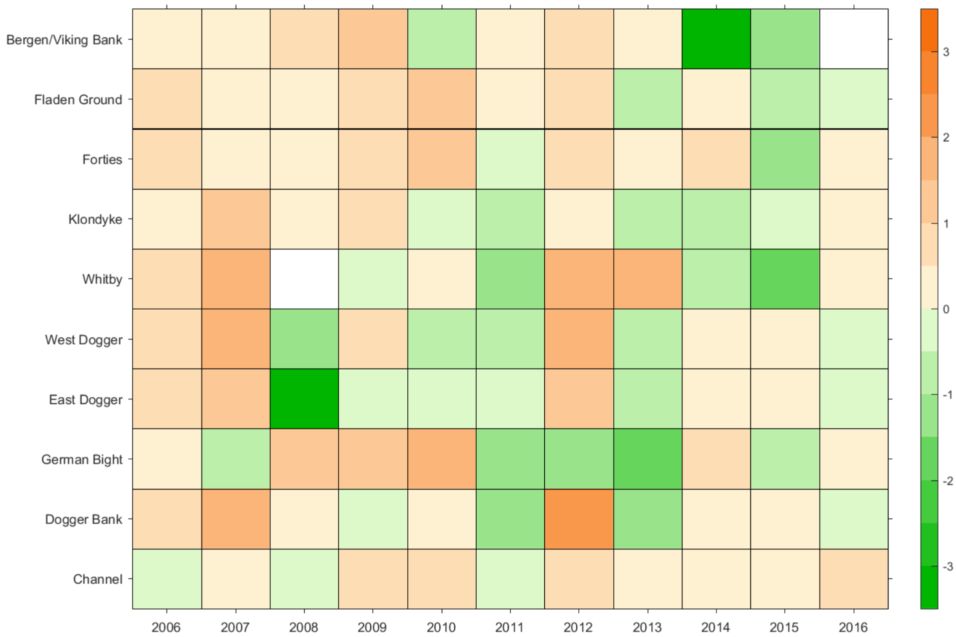


(b) Mean Salinity

Figure 4.10: (a) Average Winter Bottom Temperature (°C) and (b) Salinity, calculated from the ICES International Bottom Trawl Survey Quarter 1 for the climatological period 1981–2010.



(a) Temperature Anomalies



(b) Salinity Anomalies

Figure 4.11: Normalised anomalies (σ) of (a) sea bottom temperature (°C) and (b) sea bottom salinity in winter of 2006–2016 (all plotted relative to 1981–2010 base period). Anomalies are presented for 10 fishing grounds (see Appendix D.3.3). The anomalies are normalised with respect to the standard deviation of each time-series (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds and oranges = positive/warmer/saltier; blues and greens = negative/cooler/fresher.

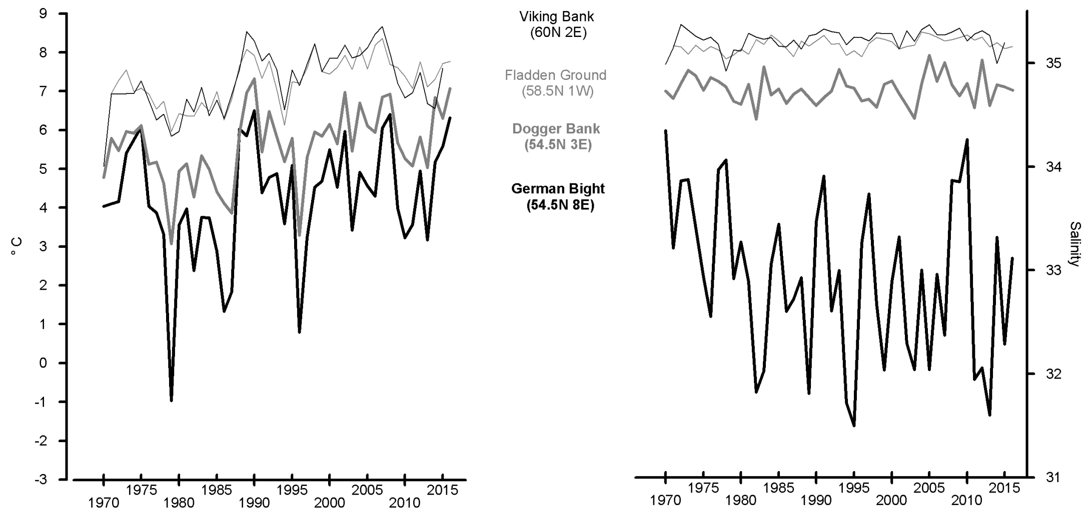


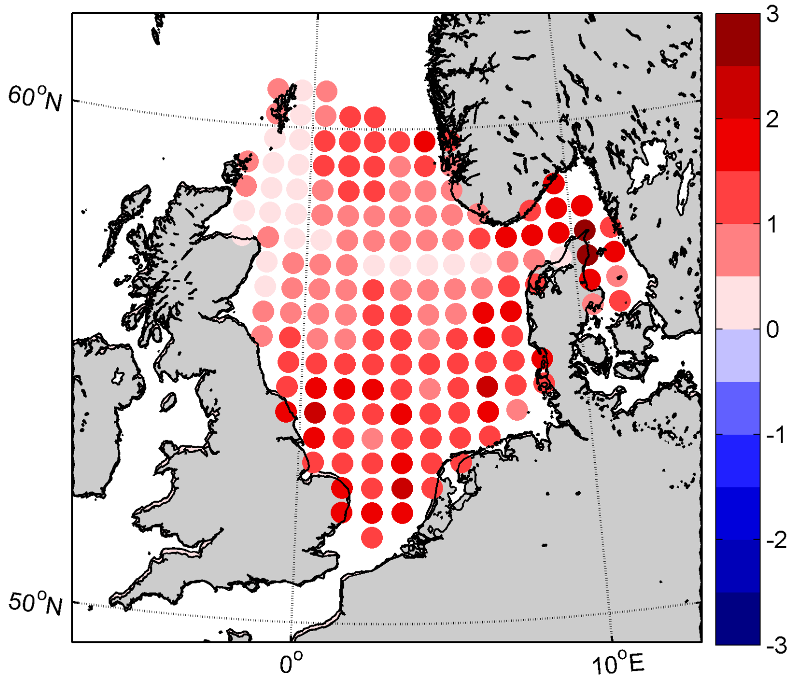
Figure 4.12: Variability of Winter Bottom Temperature (°C; left) and Salinity (right) at selected fishing grounds in the North Sea. Data are extracted from the ICES International Bottom Trawl Survey (IBTS) Quarter 1 data at a central position appropriate to each fishing ground. See Appendix D.3.3 and Figure D.3.

The general circulation of the North Sea is shown in Figure 4.1. As the North Sea is relatively shallow, conditions in the North Sea are strongly influenced by those in the atmosphere, and therefore the sea conditions often reflect the local weather conditions. In the past, this has led to a strong relationship with the NAO Index (see Chapter 5). However, there are a few other factors that have a marked effect. The first is input of freshwater running off land and through rivers around the North Sea. This leads to the lowered salinity values in coastal areas, particularly in the south-east near to the large rivers such as the Rhine and the Elbe. During the winter months, the water flowing into the North Sea from rivers is also colder than the seawater. The largest source of freshwater is the surface outflow from the Baltic, but this does not influence conditions close to the seabed due to the vertical stratification. The second major influence on conditions in the North Sea is the inflow of warmer and saltier water from the North Atlantic. This occurs mainly in the Northern North Sea, although the influence of the Atlantic can also be observed in waters flowing through the English Channel.

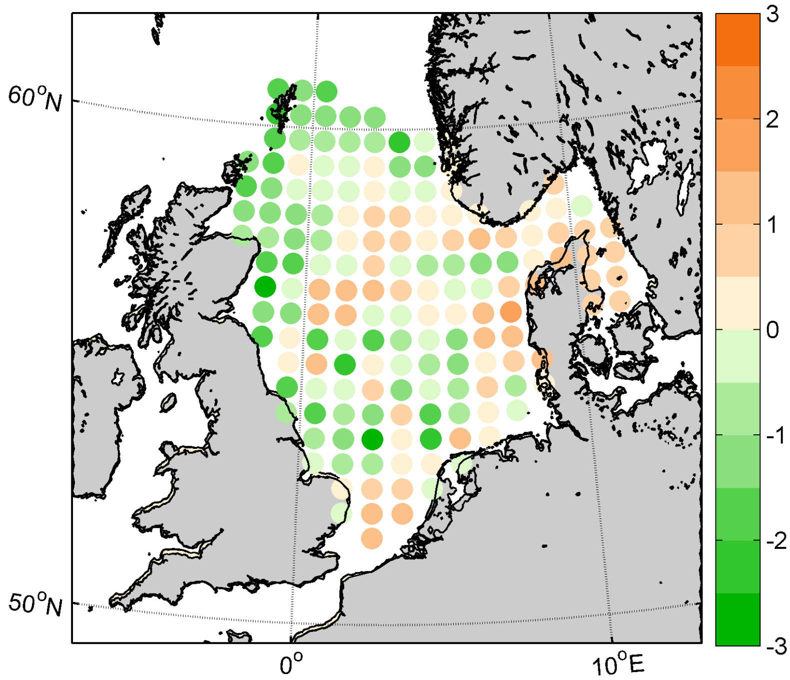
As a result, conditions at the seabed in the Northern North Sea are normally warmer and saltier than those in the Southern North Sea, and they also show less variability from year to year. The average temperature and salinity observed during the Quarter 1 surveys during the period 1981-2010 are shown in Figure 4.10, the influence of the North Atlantic (warmer and saltier) and coastal freshwater input (colder and fresher) can be seen clearly.

Figure 4.11 show the difference in the winter bottom temperatures and salinity of the North Sea at selected fishing grounds during the IBTS surveys between 2006 and 2016, compared to normal conditions. To take into account the variability at each site, normalised anomalies are presented (also see “What is normal?” on page 3 and Appendix G).

During the 2016 surveys, winter bottom salinities were close to normal (generally within 0.5 σ units; Figure 4.13). Winter bottom temperatures in 2016 were higher than

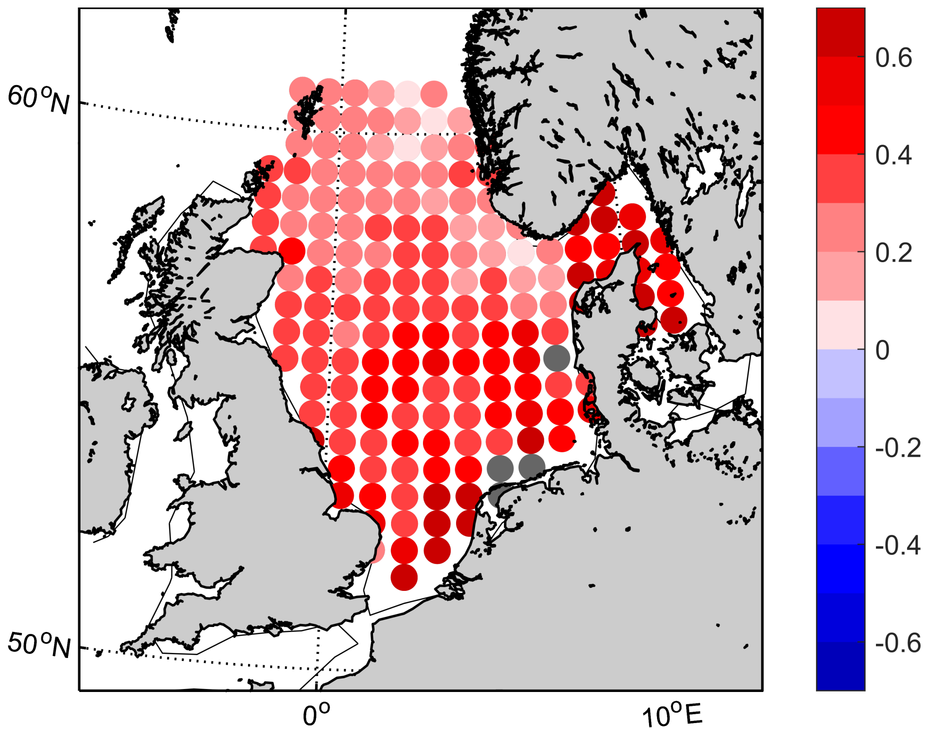


(a) Temperature Anomaly

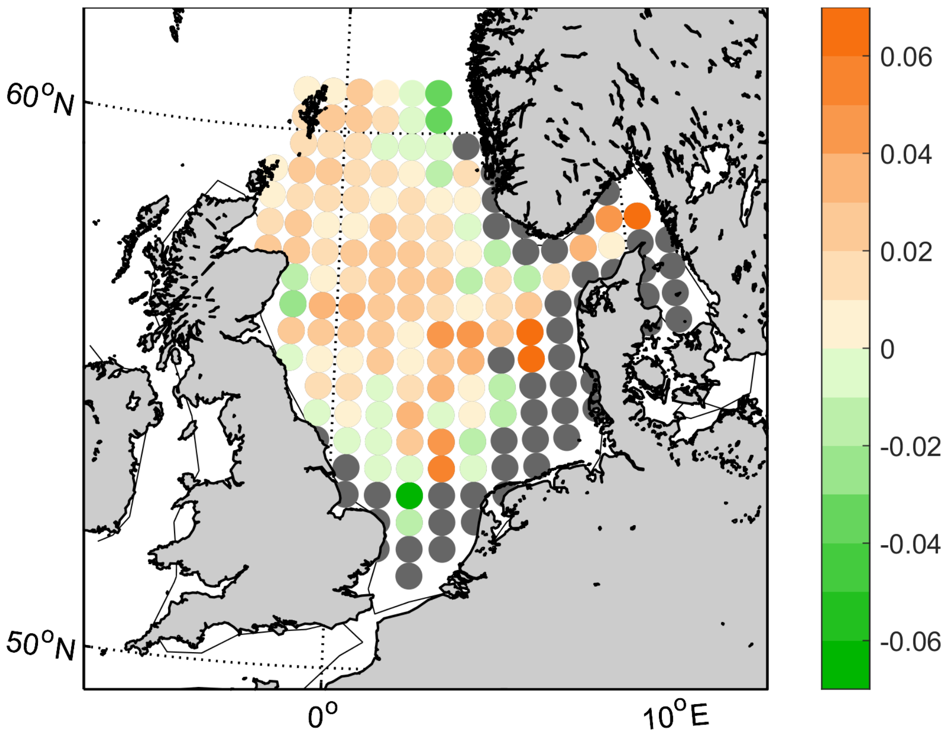


(b) Salinity Anomaly

Figure 4.13: Winter Bottom temperature (°C; upper) and salinity anomalies (lower) calculated from the ICES International Bottom Trawl Survey Quarter 1 during 2016. The anomalies are normalised with respect to the standard deviation of each time-series (σ; e.g. a value of +2 indicates 2σabove normal). Colour intervals 0.5σ; reds and oranges = positive/warmer/saltier; blues and greens = negative/cooler/fresher.



(a) Temperature Trend



(b) Salinity Trend

Figure 4.14: Linear trend (as units per decade) in Winter Bottom Temperature (°C; upper) and Salinity (lower) calculated from the ICES International Bottom Trawl Survey Quarter 1 data for the period 1981–2016. Values calculated from linear fit to data in ICES rectangles. Grey filled circles have a trend which is not significant at the 95% confidence level (alpha=0.05) using Mann-Kendall non-parametric test for a trend. Trends have been calculated for data in each ICES statistical rectangle where there are more than 25 years of data.

normal in most areas, with particularly warmer conditions in southern parts of the North Sea.

The long-term variability in winter bottom temperature and salinity at selected fishing grounds since 1970 are shown in Figure 4.12. They are the Bergen/Viking Bank, the Fladen Ground, the Dogger Bank and the German Bight. Figure D.3 shows the areas used to select data for each of the four fishing grounds. There has been a change to the method used to calculate these time series, and as such the data are slightly different to those published in earlier Climate Status Reports.

These fishing ground data (Figure 4.12) clearly show how the waters of the Northern North Sea are much warmer than those in the south during the winter months. The observed winter temperatures in the northern fishing grounds of the Viking Bank have never fallen below 5°C (1970), while winter temperatures in the more southerly Dogger Bank have been as low as 3°C (1979). In the German Bight area, extremely low temperatures (less than 0°C) were also recorded in 1979. The southern coastal locations show large year to year changes in salinity, as shown for the time series from the German Bight which varies between 34.35 in 1970 and 31.50 in 1995 (Figure 4.12).

In all of the North Sea fishing grounds, the long-term trend in winter bottom temperatures is one of warming as temperatures have been generally rising after a cool period in the late-1970s (Figure 4.14). Winter temperatures at the northern sites such as the Viking Bank and Fladen Ground have been warming at around 0.2-0.3°C per decade. In the Southern North Sea, at Dogger Bank and German Bight, the warming has been at a higher rate of around 0.4°C per decade. Overall, using this IBTS Quarter 1 dataset, a warming trend is observed in all regions of the North Sea with average values of around 0.4°C per decade.

Winter bottom salinities show more variability than temperatures, particularly in coastal regions. In the Northern North Sea, winter bottom salinities have also been increasing since 1970 (Figure 4.14). This reflects the trend across the whole North Atlantic towards higher salinities. Further south, it is more difficult to determine a clear trend. In the German Bight, which is strongly influenced by freshwater runoff, there appears to be a strong decreasing trend in salinity (Figure 4.14). However, the interannual variability in freshwater runoff means that it is difficult to have confidence in trends calculated in the shallow coastal areas. Overall in the Southern North Sea, there is therefore no statistical trend in the salinity data (Figure 4.14).

4.4 Temperature and Salinity in the North Atlantic Ocean

Each year, the International Council for the Exploration of the Seas (ICES) Report on Ocean Climate summarises conditions in the North Atlantic, providing a comprehensive overview (*Larsen et al.*, 2016). The report is prepared by many different researchers from across the North Atlantic region, who compare their own findings from each region. The data collected by Marine Scotland are included in this report, and therefore the data for Scottish Waters can be compared to other similar datasets in adjacent regions.

In 2016, the report shows that air and sea surface temperatures were higher than normal across most of the coastal regions of the North Atlantic region. However, there was an area of cool water in the centre of the North Atlantic.

For 2016, the report showed that salinity in the upper layer of the south-eastern North Atlantic and also the Norwegian Sea has been decreasing since the late 2000s. In 2016, a dramatic freshening and record low values were observed in the Faroe Bank Channel and Iceland Basin. This reduction in salinity was also observed in the Atlantic Waters around the coast of Scotland (Figure 4.9).

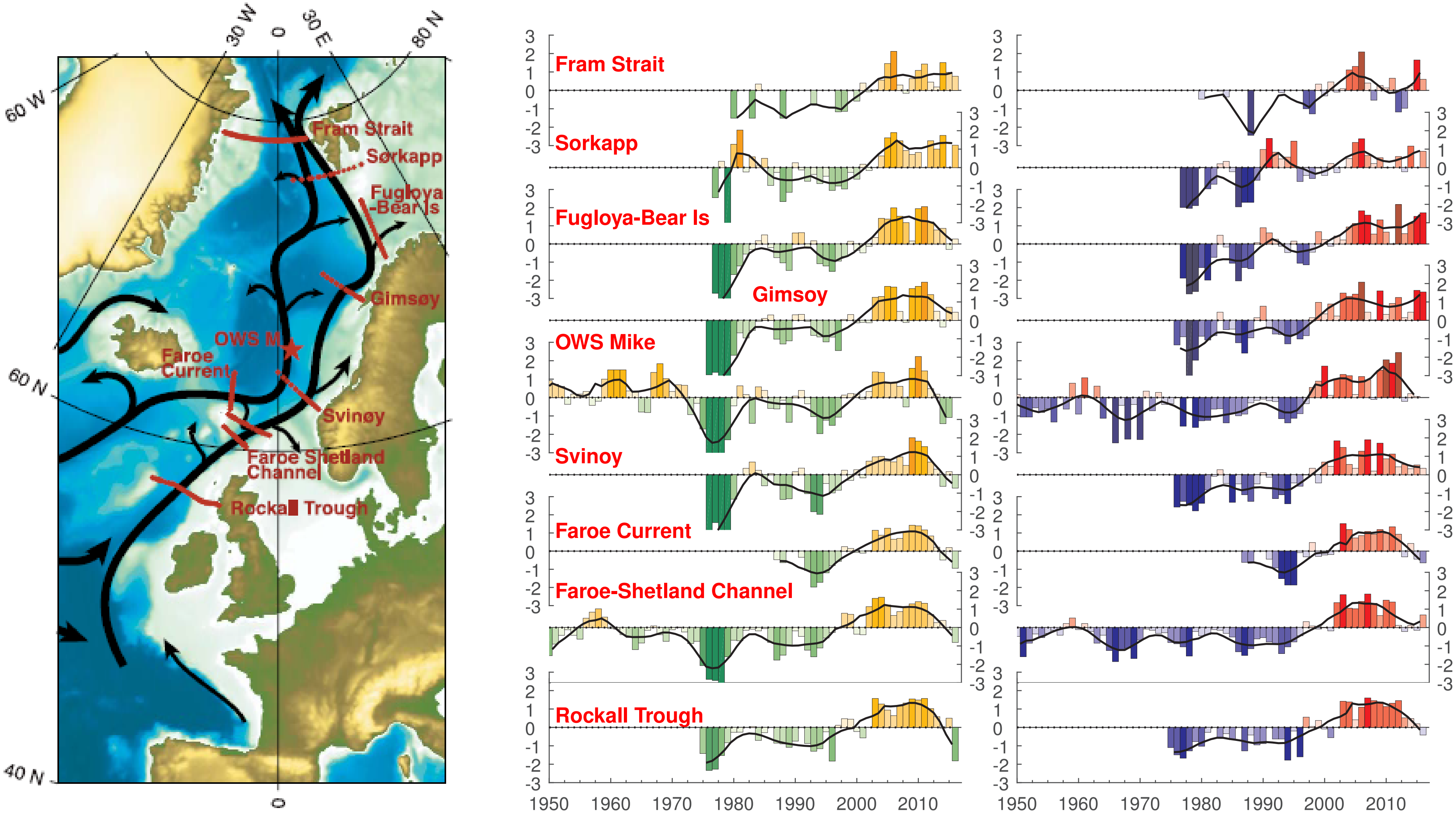
The North Atlantic Current transports Atlantic Water across the north Atlantic and then, following the continental shelf edge, these waters travel poleward through the FSC and onto the Nordic Seas and the Arctic. Coherent patterns of variability have been observed in temperature and salinity at positions along this pathway (*Holliday et al.*, 2008, and Figure 4.15).

In the late 1950s, salinities were at a maximum but then decreased, reaching a minimum in the mid 1970s. This phenomenon of low salinity was observed across the North Atlantic and termed ”The Great Salinity Anomaly”. Values of temperature and salinity then increased up until around 2010.

The updated time series now show that from mid-to-late 2000s a clear decrease in both temperature and salinity is evident at all stations, except the most northern stations. Combined evidence from datasets to the south and north of Scotland shows therefore that the current trend is one of cooling and freshening in North Atlantic water (Figure 4.15b).

Summary

- **Temperature and salinity data in the offshore regions of Scotland's seas are presented from HadISST by CP2 regions, the MS monitoring programme, the International Bottom Trawl Survey, and other relevant data providers.**
- **In the FSC, the data collected by Marine Scotland and colleagues from the Faroe Marine Research Institute form one of the longest time series of regular measurements in the global ocean.**
- **Temperatures in the shallower Northern North Sea show a more rapid rate of warming (0.4 - 0.5 °C per decade) than those in deeper oceanic regions. Multidecadal variability is more marked in the Atlantic NW Approaches region, where a period of warmer temperatures was observed in the late 1950s, and more recently from the end of the 1990s up to the early 2010s.**
- **The story of the decade is that, superimposed upon a background of higher than normal temperatures, the decade was also quite variable with periods of very low and very high temperatures. This variability is thought to be strongly linked to the atmospheric conditions affecting the NW European Continental Shelf region, which was sometimes dominated by**



(a) Section/Station Map **(b)** Upper Ocean Salinity **(c)** Upper Ocean Temperature

Figure 4.15: *updated to extend data to 2016, from original figure printed in Holliday et al. (2008).* left: Schematic of the major Atlantic Water pathways from the eastern subpolar gyre through the Nordic Seas (adapted from *Orvik and Niiler* (2002)). Hydrographic sections and stations that are regularly occupied by oceanographic institutes are shown in red. These data are collated annually and presented in the IROC (*Larsen et al.*, 2016) middle and right: Time series of upper ocean temperature (middle) and salinity (right) anomalies from sustained ocean observations along pathways of Atlantic Inflow from the Rockall Trough to the Fram Strait. Data are presented as normalised anomalies from the long-term mean 1981-2010. (Note that for the Faroe Current and Fram Strait sections, a shorter reference period 1988-2010 is used due to the length of these records).

oceanic conditions where prevailing winds bring warmer and wetter conditions, and at other times dominated by blocking highs, which allowed colder airmasses from continental Europe or the Arctic to dominate.

- **The temperature and salinity of Atlantic Waters to the west of Scotland increased in the period between the end of the 1990s and the mid 2000s. In more recent years, cooler temperatures and fresher salinities have emerged.**
- **The changes in temperature recorded in Atlantic Waters to the west of Scotland follow a similar pattern to those in the wider North Atlantic, which is to be expected, as the observations in the FSC are on one of the main oceanic pathways from the Atlantic Ocean to the Nordic Seas.**
- **Although temperatures in recent years have reached record high values, salinity has been higher in the past. There was also a notable warm and salty period in the eastern North Atlantic Ocean near the end of the 1950s.**
- **Along the pathway of the North Atlantic Current, the decadal trend is one of reducing temperature and salinity since around 2010.**

5 Global and North Atlantic Climate Indices

We can place the changes observed in the seas around Scotland into a much wider global context by relating them to global climate trends and changes in other indicators from the North Atlantic (for data descriptions see Appendix E). Conditions across the globe are being affected by climate change. Taking a more regional perspective, Scottish Seas are affected by the circulation of the ocean and atmosphere in the North Atlantic. The strength of the North Atlantic current and the properties of the water it transports towards Scotland affect conditions in Scottish Waters.

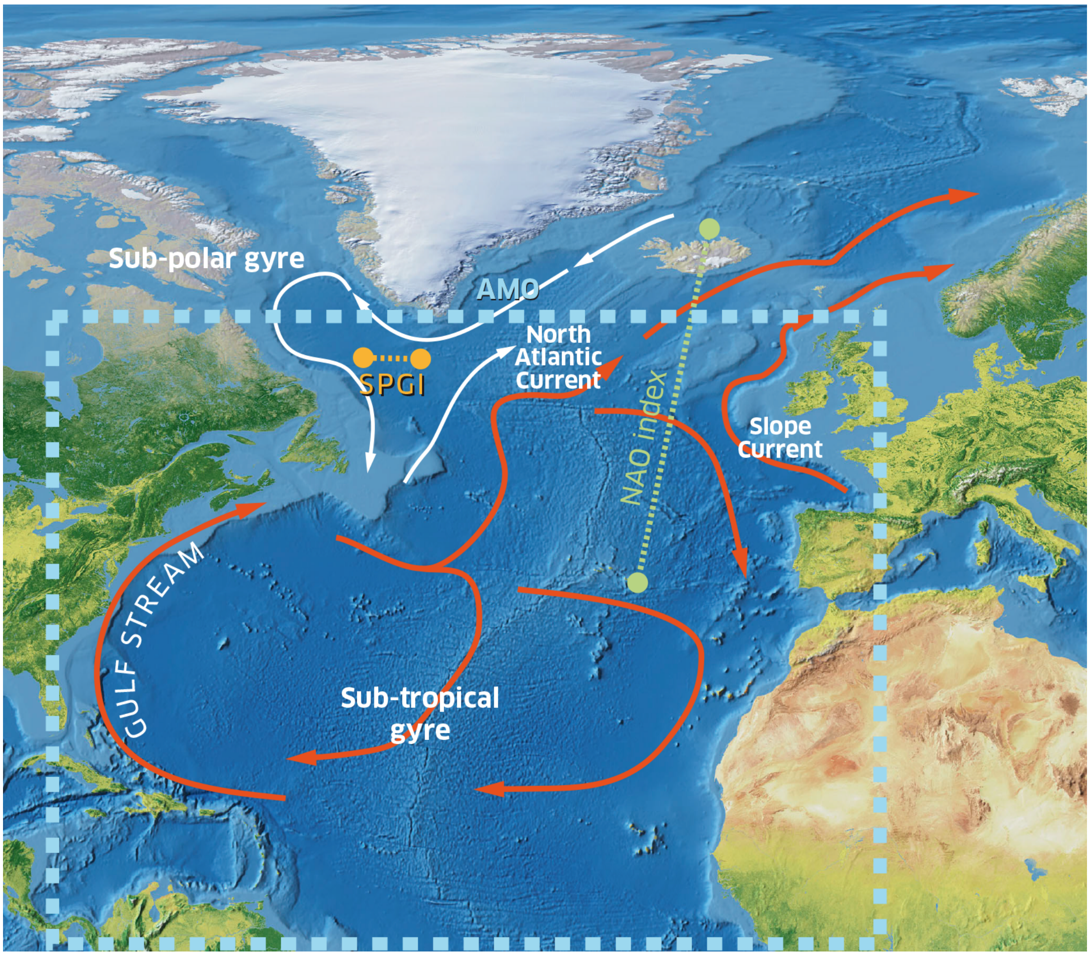


Figure 5.1: North Atlantic circulation, with schematic representation of global indicators

5.1 Global Surface Temperatures

Global climate change is being driven by rising concentrations of greenhouse gases into the atmosphere caused by human activities such as burning of fossil fuels and deforestation (*Bindoff et al.*, 2007). Temperatures over land have warmed at a faster rate than those in the ocean, due to the thermal inertia of the oceans (*Hansen et al.*, 2010).

The latest assessment of global climate change was published in 2014 as the 5th report of the IPCC (IPCC, 2014). This assessment provides the backdrop for the Scottish Ocean Climate Status Report. Summary statements in the global assessment include the following:

- Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems.
- Warming of the climate system is unequivocal, and since the 1950s many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen.
- The globally averaged combined land and ocean surface temperature data as calculated by a linear trend show a warming of 0.85 [0.65 to 1.06]° C over the period 1880 to 2012.

Note that the warming trends stated here are for the period 1880 to 2012, a period of 132 years. The equivalent rates of warming per decade are 0.05 to 0.08° C per decade.

Three commonly used datasets of global surface temperature are those provided by the UK Meteorological Office (*UK Meteorological Office*, 2017c) and the US agencies of NOAA (*National Oceanic and Atmospheric Administration*, 2017a) and NASA (*GISTEMP Team*, 2017). Estimates of global surface temperature trends from each of these datasets can differ slightly (*WMO*, 2017), however, all show the same consistent patterns and long-term trends. Only data from *GISTEMP Team* are shown here.

The IPCC (2014) report notes that ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010. It notes that, on a global scale, the ocean warming is largest near the surface, and the upper 75 m warmed by between 0.09° C and 0.13° C per decade over the period 1971 to 2010.

The last decade (2007–2016) has been the warmest decade on instrumental record and the long-term trend is calculated to have been an increase in global surface temperature of 0.07° C per decade. Global land and sea temperatures in 2016 were 0.98° C above the long-term mean and 0.55° C above the 1981–2010 mean (Figure 5.2a). The year 2016 was the third year in a row where global temperatures set a new record (*National Oceanic and Atmospheric Administration*, 2017b).

5.2 Atlantic Multidecadal Oscillation

As well as having a long-term warming trend, records show that the surface temperature of the North Atlantic Ocean has alternately switched between warmer

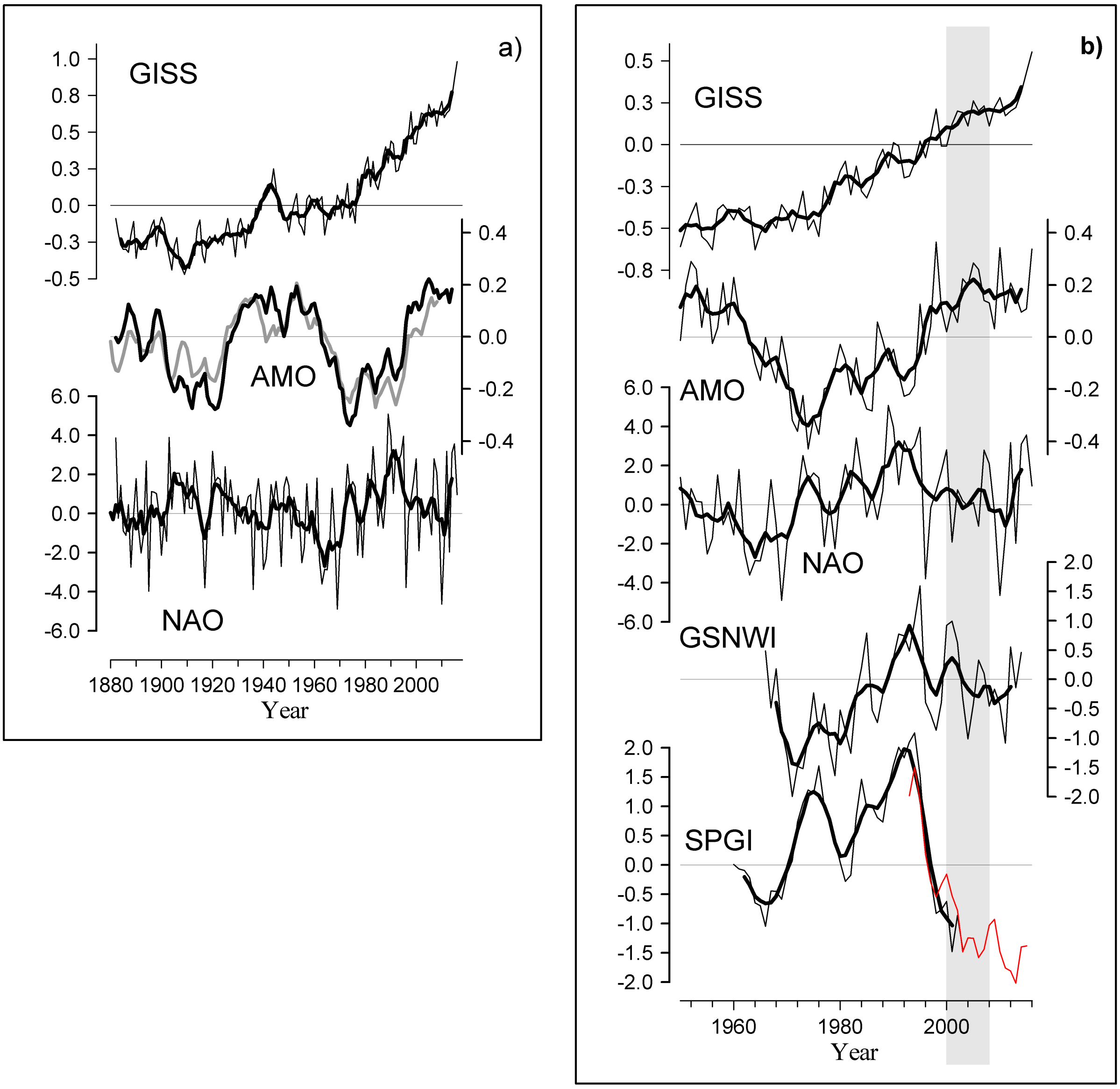


Figure 5.2: Selected indicator time series for the North Atlantic. (a) Data period 1880–2016, with anomalies referenced to the long-term mean, thin lines show the annual values, and thick lines are 5-year running means: upper: Global land and ocean temperature (GISS); middle: the Atlantic Multidecadal Oscillation (AMO) version after *Enfield et al.* (2001) in black and version after *Trenberth and Shea* (2006) in grey; lower: The North Atlantic Oscillation (NAO) Index. (b) Time series over the shorter period 1950–2016: upper: GISS data, as for (a) but with data referenced to the 1981–2010 mean; middle panels: the AMO, the NAO Index, the Gulf Stream North Wall Index (GSNWI) last updated to 2014; lower: The Sub-Polar Gyre (SPGI) last updated to 2015. Black lines show the simulated SPGI normalised to the standard deviation, red lines show the new SPGI from *Berx and Payne* (2017a). For comparison, data are plotted relative to the mean values in the common time period of 1999—2003. The shaded area highlights the decade 2000—2009, the period of interest for *Hughes et al.* (2012). *Figure originally published in Hughes et al. (2012), updated here to 2016.*

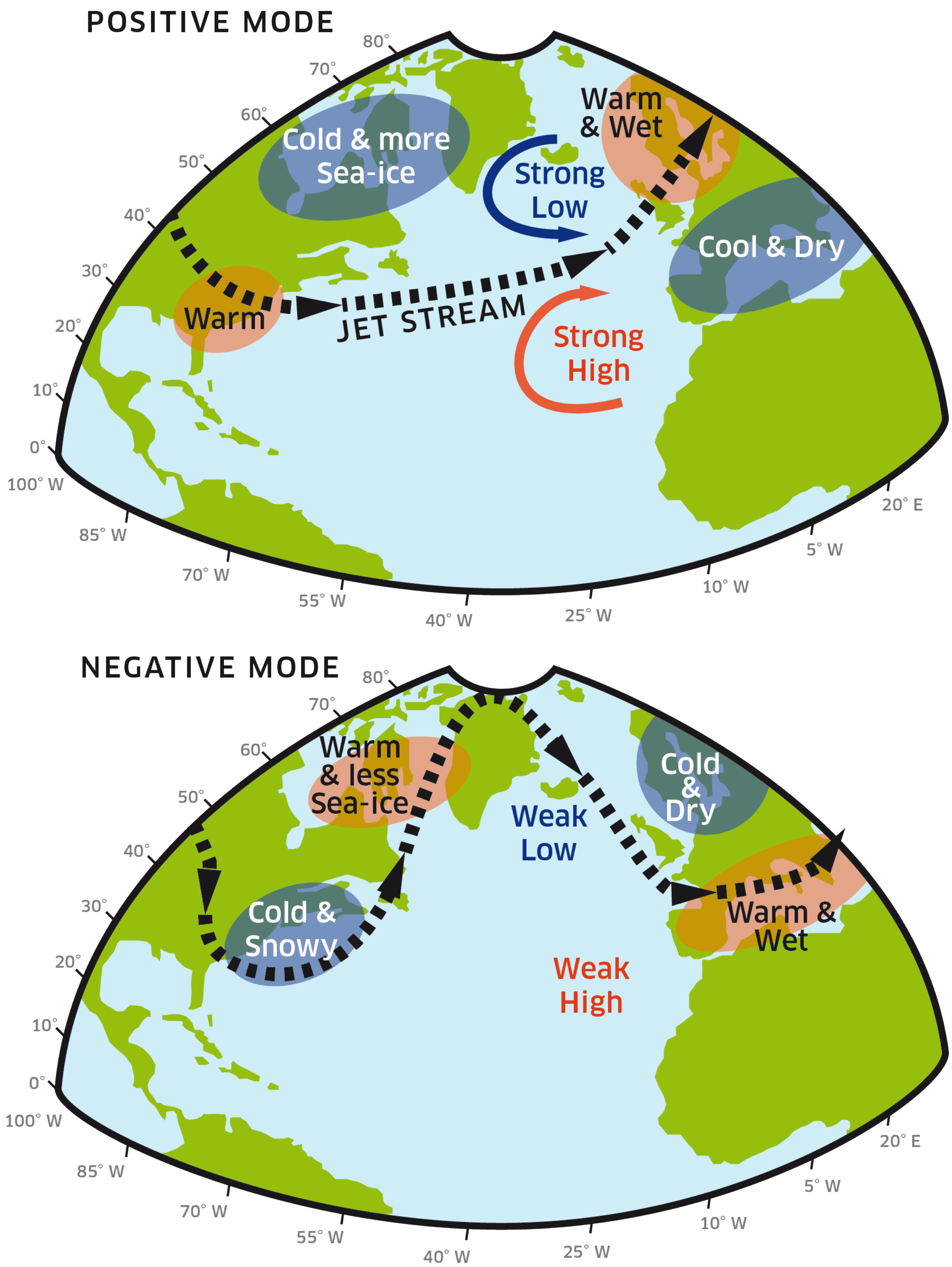


Figure 5.3: Schematic diagram of the positive and negative phases of the North Atlantic Oscillation (NAO), and their associated weather patterns.

and cooler phases that last around 20-40 years (*Kerr*, 2005; *Enfield et al.*, 2001). This oscillation has been called the Atlantic Multidecadal Oscillation (AMO). The AMO Index is a measure of this variability (Figure 5.2a) and shows that the North Atlantic was in a warm phase during the late 1950s, transitioned to a cool phase by the mid 1970s and then back to a warm phase by the 2000s. It is thought that these changes are related to changes in the circulation of the North Atlantic Ocean, making this a natural internally driven phenomenon.

Although the AMO is thought to be a natural process, it is not yet fully understood or

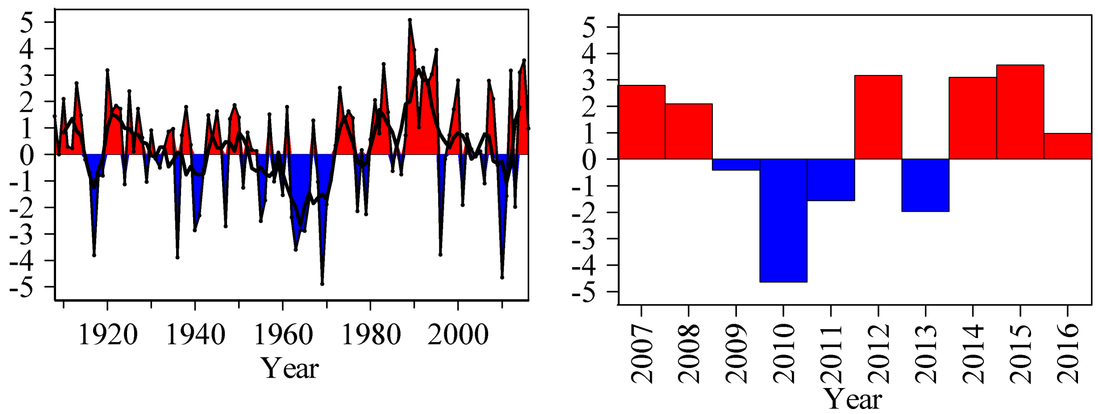


Figure 5.4: The Hurrell winter (DJFM) NAO index for the past 100 years with a two-year running mean applied (left panel) and for the current decade (right panel). Data source: NAO Index Data provided by the Climate Analysis Section, NCAR, Boulder, USA, (*Hurrell and National Center for Atmospheric Research Staff (Eds.)*, 2017)

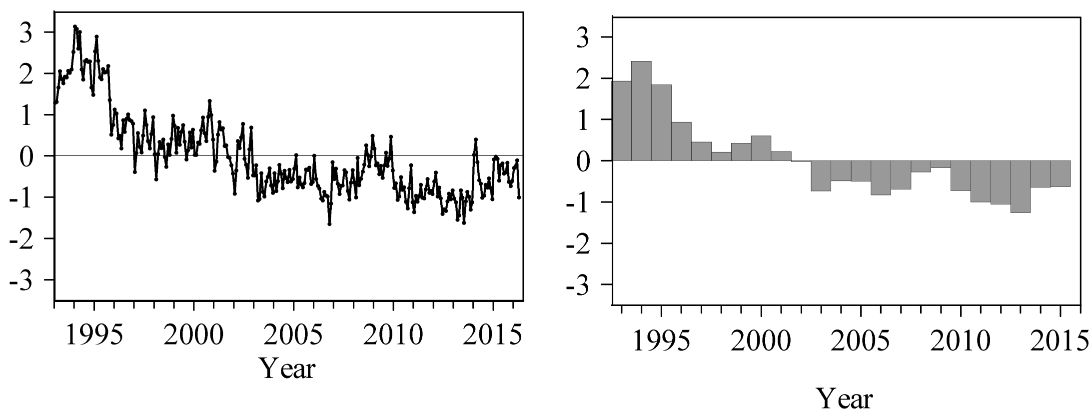


Figure 5.5: The monthly (left) and annual (right) Sub-Polar Gyre Index since 1993. Data source: Sub-Polar Gyre Index provided by Marine Scotland, UK (*Berx and Payne*, 2017a). Note that the last available update is to 2015.

clear whether the patterns of high and low we have seen in the past will continue in the future. Some scientists believe that the AMO might start to decrease, and that this decrease will be large enough to temporarily reduce the observed warming trend. More research is needed to help us understand the internal processes in the ocean that drive AMO variability.

5.3 The North Atlantic Oscillation Index

The NAO is the dominant pattern of variability in atmospheric pressure over the North Atlantic region. The NAO Index is a parameter that contains information on the state of the NAO.

The NAO is related to the strength and direction of westerly winds across the North Atlantic 5.3. Changes in the strength and position of these westerly winds have a significant impact on conditions in the weather and the seas around Scotland.

When the NAO Index is high, the weather conditions in Scotland tend to become warmer and wetter. Conversely when the NAO Index is low, the weather becomes colder and drier. These changes are also reflected by differing conditions in the seas and oceans.

The NAO Index (Figure 5.4) was generally low for a period during the 1960s and early 1970s, and showed an increasing trend until around 1995. During the decade of 2007–2016 the NAO Index was quite variable, with alternating periods of positive and negative NAO. The winter of 2010 was remarkable with a very low NAO index (-4.96). Since 2014, the NAO has been positive and in 2016 it had a value of 0.98.

5.4 Sub-Polar Gyre Index

The Sub-Tropical and Sub-Polar Gyres are the dominant features of the surface circulation of the North Atlantic Ocean. Both are driven by the combination of permanent wind features, heat-input variation with latitude, and the global overturning circulation. In the Atlantic, the Sub-Polar Gyre (SPG) can be considered as a cyclonic gyre encompassing the North Atlantic, East Greenland, and Labrador Currents (Figure 5.1). Changes in the strength and extent of the Sub-Polar Gyre have been linked to changes in the advection of water masses (*Häkkinen and Rhines*, 2004) and changes in their properties (*Holliday et al.*, 2008; *Johnson et al.*, 2013).

When the Sub-Polar Gyre is strong, more water from the cooler and fresher currents mixes with the surface waters of the North Atlantic which are flowing towards Scotland. A strong Sub-Polar Gyre is therefore linked to cooler and fresher conditions in Atlantic Waters approaching the coasts of Scotland. A weaker Sub-Polar Gyre, conversely, can be linked to warmer and saltier waters around Scotland.

The Sub-Polar Gyre Index (SPGI) describes the current state of this complex circulation and has been found to be a useful indicator for understanding ecosystem variability in the Sub-Polar Gyre region and in the wider North Atlantic (*Alheit et al.*, 2014), including potential links with commercially important fish stocks (e.g. *Hátún et al.*, 2016).

The SPGI (*Berx and Payne*, 2017b) was high in the early 1990s, indicating a strong gyre circulation, extending eastward across the Atlantic. Between 1995 and 2005 the Sub-Polar Gyre contracted and the index weakened (Fig. 5.5). Since 2010 the SPGI can be described as weak and variable. The lowest annual value observed in the SPGI time series was in 2013 (-1.26). The annual value of the SPGI in 2015 was -0.63. Similar to the AMO, the SPG is thought to have a natural cycle of variability: based on recent observations, there are early indications that the SPG circulation is strengthening.

Global and North Atlantic Climate Indices: Summary

- **Globally, 2016 was extremely warm, and the third year in a row where global temperatures reached new record highs.**
- **The surface of the North Atlantic remains in a warm phase, with average temperatures being warmer than normal in the last decade.**
- **The strength of the Sub-Polar Gyre has continued to weaken in the last decade, although there are early indications of the Sub-Polar Gyre strengthening again.**
- **In 2016, the NAO Index was positive (0.98), while over the last decade the NAO has been very variable.**

Conclusions & Outlook

Recent Observations

When placed in the context of longer-term trends, the last decade (2006–2016) should be considered warmer than normal, although, there was no overall warming trend. The warmest years occurred around 2007 and the latter part of the measurement period was characterised by more variable and often cooler conditions, with a series of very cold winters in 2010 and 2011. Patterns of atmospheric and ocean temperatures follow similar patterns, but the cold winter air temperatures in 2010 had the most influence on conditions in the shallower coastal areas such as the Clyde and the North Sea, whilst areas influenced by the North Atlantic remained warm.

From data from offshore monitoring sites the year 2010 stands out as a cold year. It is important to note that the cold conditions in 2010 were skewed by a particularly cold winter, and this is shown in the much lower than average air temperatures (and higher than average days of frost, not shown). These conditions were not reflected in offshore areas, showing that the main drivers of this cold year were atmospheric conditions, rather than broader patterns in oceanic circulation.

The highest freshwater flows within the last decade occurred in 2011, and in general the decade had greater than normal river flow. There is little evidence in the data that local freshwater flows influence salinity in the coastal areas, and the interannual variability in salinity appears more closely related to the salinity of oceanic waters. The lowest salinities observed at Stonehaven occurred in 2014 and 2016, and at all SCObs locations the latter half of the decade showed freshening as was also observed in the offshore data.

Future climate and Impacts

In 2013, the Intergovernmental Panel on Climate Change (IPCC) published its latest assessment of global climate change (AR5; *IPCC*, 2013). Based on scientific evidence compiled for AR5, warming of the Earth's climate has now been established unequivocally, with many of the observed changes occurring at unprecedented rates. The role of human activity in driving these changes to the climate system is also well established, and continued emissions of greenhouse gases will cause further warming and related changes in the global climate.

In 2017, the Royal Society published an intermediate "climate update", reviewing some of the key statements from AR5 and updating these with more recent information (*Royal Society*, 2017). This report highlights the importance of observational time series, and particularly long records, in establishing long-term climate trends. Shorter records and regional analyses will differ from the global climate trend, due to year-to-year and decade-to-decade variability in addition to the longer-term trend, as well as regional differences in the oceanic and atmospheric conditions. Globally, 2015 and 2016 were the warmest years on record; future projections estimate a doubling of pre-industrial carbon dioxide concentrations in the atmosphere will lead to a long-term warming of 1.5 to 4.5 °C (although the lower end of this range is less likely).

In the marine environment, a warming climate will stress marine organisms in a number of ways (*IPCC*, 2013; *Royal Society*, 2017), resulting in changes to the biodiversity, species distribution and marine food webs. Climate change is also expected to affect food availability, water resources and human health. More information on socio-economic impacts and adaptation and mitigation for climate change can be found on the IPCC website (`https://www.ipcc.ch/index.htm`).

The Scottish Government has recently renewed its commitment to limiting global temperature rise. As part of the most recent Programme for Government (published in September 2017), the transition to a low carbon economy was highlighted as a priority. More information on the Scottish Government's plans for addressing climate change can be found at `http://www.gov.scot/Topics/Environment/climatechange`.

Revision Schedule

The Scottish Ocean Climate Status Report was first published in 1998, and then subsequently in 1999, 2000, 2003 and 2004 (*Turrell*, 1998, 1999, 2000; *Hughes*, 2003, 2004). This current report revives this series of climate status reports for Scotland. It does so using new techniques which make the preparation of diagrams and text semi-automatic, based on updated data sets.

In the intervening years between 2003 and the present report, Scottish ocean climate assessments have been published as part of the ICES Report on Ocean Climate (see `https://ocean.ices.dk/iroc/`). The Scottish Coastal Observatory data has also been summarised as part of the review by *Bresnan et al.* (2016).

This report highlighted conditions in 2016, as well as the overview of the preceding decade and long-term trends. To revise the entire report annually is a considerable effort when realistically significant changes to statements on trends and variability observed in the decade and longer period are unlikely. Therefore, annual addenda are planned which will provide the overview of the most recent complete year of available data with selected figures (combining Sections 1.2, 2.2, 3.1.2, 3.2.2, 4.1.2 and 4.2.2).

A next major revision of the Scottish Ocean Climate Status Report is planned for publication in mid-2021, and will include an overview of conditions during the year 2020, the decade 2011-2020 and the long-term trends observed.

Acknowledgements

This report has been prepared by collating data and editing text from a wide range of sources from within Marine Scotland and beyond, where relevant appropriate reference has been made.

Marine Scotland would like to thank all of the volunteers who participate in the long-term monitoring programme as well as the staff, both scientific and technical, from the many organisations who have made their data sets available for inclusion into this report. A full list of data providers can be found in Appendix H.

Feedback

If you have comments or suggestions on how the Scottish Ocean Climate Status Report can be improved, please contact Marine Scotland Science.

A Datasets: Meteorological Data

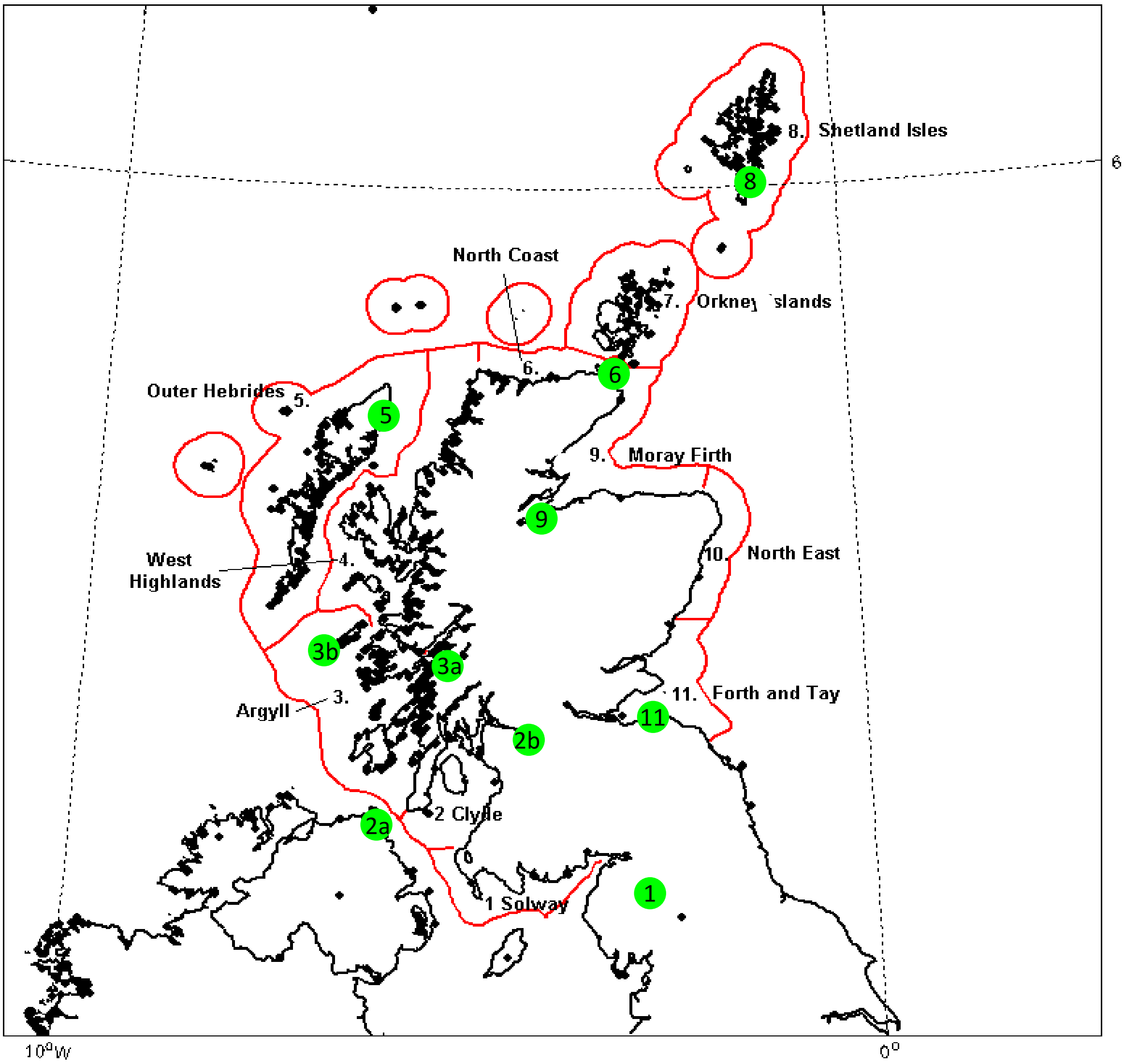


Figure A.1: Position of Meteorological Data Sites at which air temperature (Max and Min), days of Frost, Rainfall and Sunshine have been recorded. Stations are matched to Scottish Marine Region (SMR) as follows: Region 1. Solway: 1 Newton Rigg, Region 2. Clyde: 2a , 2b Paisley, Region 3. Argyll: 3a Dunstaffnage, 3b Tiree, Region 5. Outer Hebrides: 5 Stornoway, Regions 6. North Coast and 7. Orkney Islands: 6/7 Wick. Region 8. Shetland Isles: 8 Lerwick, Region 9. Moray Firth: 9 Nairn, Region 11. Forth & Tay: 11 Leuchars. There are no meteorological data presented for Region 4. West Highlands, Region 7. Orkney Islands or Region 10. North East.

Meteorological data from a number of coastal meteorological stations around the coast of Scotland have been selected, in order to examine weather conditions in each of the Scottish Marine Regions (SMRs). Table A.1 provides details of the meteorological stations chosen and Figure A.1 shows the location of each station in relation to the Scottish Marine Regions (SMRs). It should be noted that the stations at Newton Rigg and Paisley are further inland than the other stations, which will affect the characteristics of the data. There are no meteorological data available from this dataset in the regions of West Highlands or the North East. Sunshine data at the Newton Rigg station were only recorded up to 1985 and therefore have not been included in the analysis.

A.1 Data Source

Meteorological data were obtained from the historic climate datasets prepared by the UK Meteorological Office and downloaded via their website[1]. The data have been collected from long running synoptic stations around Scotland and the data have been quality controlled and processed by the UK Meteorological Office.

The data provided by UK Meteorological Office was as follows: Monthly averages of daily maximum and minimum air temperature (and mean air temperature), recorded over the period 0900-0900 (1000-1000 in summer), days of air frost (not discussed in this report), total daily rainfall and total sunshine duration. Values for mean air temperature were calculated from the average of the mean daily maximum and mean daily minimum air temperature i.e. (tmax+tmin)/2.

A.2 Data Quality Control and Processing

Data from all stations were processed and formatted into a standard data format for use within Marine Scotland and standard quality flags applied. As the data have already been quality controlled by the UK Meteorological Office, all data were given the quality flag 1. Missing data (when there were more than two days missing in a month) were marked as QC9 (see Table G.1). Where estimated data have been provided by the UK Met Office, these have been marked as QC8 in the data file and these data have been incorporated into the analysis without further consideration.

Sunshine data were mainly recorded by a Campbell-Stokes recorder. However, at some sites in more recent years the automated Kipp and Zonen photosensitive detectors have been used. Comparison of the two types of sensor has shown the newer automated sensors to be an improvement on the Campbell-Stokes recorder (*Kerr and Tabony*, 2004; *Legg*, 2014) which is read manually, often requires subjective analysis to remove artefacts in the data and tends to overestimate sunshine hours in summer. In this analysis, data from either sensor have been treated in exactly the same way, with no distinction or correction in the data analysis. No allowances have been made for small site changes or other changes in instrumentation, although these have been noted in Table A.1.

[1] `http://www.metoffice.gov.uk/public/weather/climate-historic`

Table A.1: Details of Meteorological Stations in each Scottish Marine Region (see Figure A.1)

Scottish Marine Region	Station Name	Start Date	Latitude	Longitude	Height (above mean sea level)	Kipp and Zonen[1]
1. Solway	1 Newton Rigg	1959	54.670°N	2.786°W	169m	n/a
2. Clyde	2a BallyPatrick*	1961	55.181°N	6.153°W	156 m	Jun 2009 only
2. Clyde	2b Paisley	1959	55.846°N	4.430°W	32 m	no
3. Argyll	3a Dunstaffnage	1971	56.451°N	5.439°W	3 m	Jun 2009 only
3. Argyll	3b Tiree	1928	56.500°N	6.880°W	12 m	Sep 2001 onwards
5. Outer Hebrides	5 Stornoway	1873	58.214°N	6.318°W	15 m	Sep 2002 onwards
6/7. North Coast and Orkney Isles	6 Wick Airport*	1914	58.454°N	3.088°W	36 m	n/a
8. Shetland Isles	8 Lerwick*	1930	60.139°N	1.183°W	82 m 7	Jun 2008 onwards
9. Moray Firth	9 Nairn	1931[2]	57.593°N	3.821°W	8m[3] /23 m	n/a
11. Forth and Tay	11 Leuchars	1957	56.377°N	2.861°W	10 m	Sep 2005 onwards

Stations marked with * do not lie within a Scottish Marine Region (Figure A.1)
[1] Periods in which an automated Kipp and Zonen sunshine recorder was used, all other records are from a Campbell-Stokes sunshine recorder.
[2] Site changed in 1998 and station height increased
[3] Prior to 1998

B Datasets: River Flow

This section describes the datasets presented in Chapter 2. This appendix provides a brief description of the datasets, along with information on original sources of data and any further quality control or processing.

Table B.1: Details of gauged rivers used to estimate the freshwater input into each Scottish Marine Region. Positions here are the position of the gauging station which may be some distance upstream of the point at which the river discharges into the marine environment. The location of the discharge points can be seen in Figure B.1.

Scottish Marine Region	River Name	Latitude	Longitude	Notes
1. Solway	1a Annan	54.964°N	3.266°W	at Annan
1. Solway	1b Nith	54.955°N	3.537°W	near Glencaple
1. Solway	1c Cree	54.897°N	4.394°W	at Creetown
2. Clyde	2a Ayr	55.470°N	4.644°W	at Ayr
2. Clyde	2b Clyde	55.921°N	4.474°W	This is the head of the Clyde
2. Clyde	2c Leven	55.946°N	4.572°W	flows from Loch Lomond into Clyde Estuary
3. Argyll	3 Orchy	56.444°N	5.226°W	Orchy flows in to Loch Awe which in turn flows via river Awe into Loch Etive
4. West Highlands	4a Shiel	56.776°N	5.824°W	River Shiel flows from Loch Shiel into Loch Moidart
4. West Highlands	4b Carron	57.413°N	5.445°W	River Carron flows into Loch Carron
4. West Highlands	4c Ewe	57.763°N	5.608°W	River Ewe flows into Loch Ewe at Poolewe
6. North Coast	6 Naver	58.522°N	4.225°W	at Bettyhill
9. Moray Firth	9a Conon	57.602°N	4.392°W	flows into Cromarty Firth near Dingwall
9. Moray Firth	9b Ness	57.493°N	4.237°W	flows from Loch Ness into Beauly Firth near Inverness
9. Moray Firth	9c Findhorn	57.633°N	3.635°W	at Findhorn
9. Moray Firth	9d Spey	57.666°N	3.100°W	at Speybay
9. Moray Firth	9e Deveron	57.660°N	2.513°W	at Banff
10. North East	10a Don	57.176°N	2.079°W	at Aberdeen
10. North East	10b Dee	57.141°N	2.069°W	at Aberdeen
11. Forth and Tay	11a North_Esk	56.753°N	2.435°W	St Cyrus
11. Forth and Tay	11b South_Esk	56.700°N	2.451°W	Montrose
11. Forth and Tay	11c Earn	56.352°N	3.304°W	flows into the Tay Estuary
11. Forth and Tay	11d Tay	56.361°N	3.305°W	flows into the Tay Estuary

B.1 Data Source

Variability in river flow was derived by combining data from a number of gauged (measured) rivers across Scotland, which were selected to give reasonable spatial coverage and to capture the largest, and therefore most representative river flows. The river gauging network is maintained by the Scottish Environment Protection Agency (SEPA) and the original data files were downloaded from the National River Flow Archive (NRFA) via their website[1]. Some gauged data held by NRFA not freely

[1] http://nrfa.ceh.ac.uk/data/search

available for public download. Because of the restrictions in obtaining these data, these data have not been used and the data from these stations are treated as if they had not been gauged. Gauged stations with flows of less than 10 $\mathrm{m^3\,s^{-1}}$ were not used in the analysis.

Climatological averages of total river flow across the whole of Scotland for the period 2007-2010 and 1961-2012 were obtained from a Grid-to-Grid model (G2G) dataset (*Cole et al.*, 2014). This model uses rainfall data across Scotland, information about shape of river catchments, and knowledge of land runoff to estimate freshwater input. The model was developed by Centre for Ecology and Hydrology (CEH), and has been tuned and tested against the gauged river flows.

The modelled data has been used to provide estimates of what percentage of the total freshwater inflow to Scottish coastal waters is covered by the gauged rivers presented within this report (Table B.2).

Table B.2: Average total river flow into each of the Scottish Marine Regions (SMRs), calculated from output of Grid-to-Grid model (G2G) for period 1962–2011. The third column shows number of discrete discharge points in each region as assessed by G2G (*Cole et al.*, 2014). The fourth column shows the number of major rivers from which gauged data is summed. The last column presents an estimate of the % of the total flow into each SMR that has been captured in the analysis

Scottish Marine Region	River Flow ($\mathrm{m^3\ s^{-1}}$)	Flow of Largest River ($\mathrm{m^3\ s^{-1}}$)	# of Discharge Points	# of Captured Rivers	% of Flow captured
1 Solway	188	43	40	3	40
2 Clyde	269	68	57	3	40
3 Argyll	325	105	64	1	7
4 West Highlands	363	27	112	1	17
5 Outer Hebrides	64	8	51	0	-
6 North Coast	75	16	26	1	21
7 Orkney Islands	4	2	6	0	-
8 Shetland Isles	4	1	11	0	-
9 Moray Firth	453	87	67	5	55
10 North East	86	47	19	2	79
11 Forth and Tay	354	176	57	4	68

B.2 Data Quality Control and Processing

The daily gauged river flow data ($\mathrm{m^3\,s^{-1}}$) were averaged to calculate monthly mean river flow at each river gauging station. Monthly average data values were only calculated if there was gauged flow available for 15 or more days in that particular month. The total monthly average gauged river flow into each of the Scottish Marine Regions was then calculated using the sum of monthly values from each river in that region. In periods where gauged data was missing from a particular river, climatological average values were used to avoid skewing the totals.

Table B.1 and Figure B.1 show the discharge location for each of the rivers used in this analysis and also the Scottish Marine Region in which each of the rivers lie. While there are some small rivers in the Outer Isles, the freshwater input from these is very small and these have not been included in this analysis. As a result there are no freshwater data for the Outer Hebrides, Orkney Islands or Shetland Isles regions.

Table B.2 summarises the key statistics for river flow by SMR. Each row lists the largest points of freshwater discharge in each SMR determined using climatological averages from the G2G model for the period 1961-2012. Each of these rivers has an average monthly mean flow of greater than 13 $\mathrm{m^3\,s^{-1}}$ and these are referred to as the major rivers in the following text.

B.3 River Network

Although rainfall over Scotland is one of the highest in Europe (*Cole et al.*, 2014), the freshwater inputs to the coastal zone tend to be distributed across many small discharge points rather than in large single rivers. Scotland has a network of more than 125,000 km of rivers. The River Tay, Scotlands biggest, has an annual average discharge of approximately 170 $\mathrm{m^3\,s^{-1}}$. In comparison, the Rhine has a discharge of 2900 $\mathrm{m^3\,s^{-1}}$.

Around 32 (of $\sim$ 508) rivers on mainland Scotland have a mean flow of $>$15 $\mathrm{m^3\,s^{-1}}$ (calculated from G2G, period 1961-2012, *Cole et al.* (2014)). Modelled averages of freshwater flow from mainland Scotland show that input on the east and west coasts (divided by a line at 4° 6′ W) on the northernmost coast of Scotland are very similar. Total annual flow on west coast (1191 $\mathrm{m^3\,s^{-1}}$) is similar to the east coast (1115 $\mathrm{m^3\,s^{-1}}$) (*Bresnan et al.*, 2016).

More details on how representative the gauged rivers are of the freshwater input to Scottish coastal waters is given in Section 2.1.

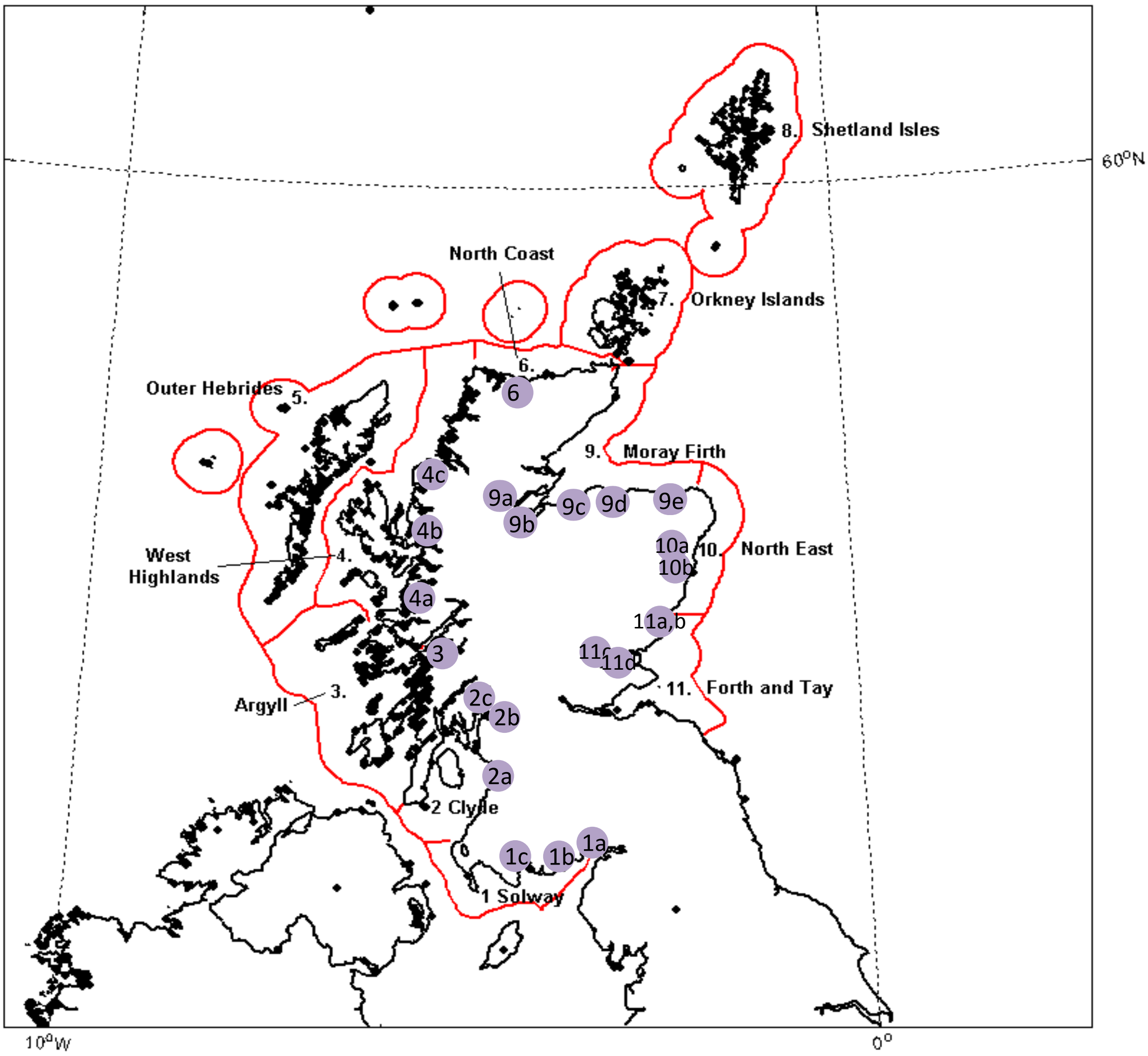


Figure B.1: Map of approximate coastal discharge point of rivers used to calculate flow into each of the Scottish Marine Regions. The actual measurements are made at a monitoring station that may be some way inland/upstream of the actual discharge point (see Table B.1 for actual gauged positions). Rivers are matched to the Scottish Marine Region into which they discharge as follows: Region 1. Solway: 1a Annan, 1b Nith, 1c Cree; Region2. Clyde: 2a Ayr, 2b Clyde, 2c Leven; Region3. Argyll: 3 Orchy; Region 4. West Highlands: 4a Shiel, 4b Carron, 4c Ewe; Region 6. North Coast: 6 Naver; Region 9. Moray Firth: 9a Conon, 9b Ness, 9c Findhorn, 9d Spey, 9e Deveron; Region 10. North East: 10a Dee, 10b Don; Region 11. Forth & Tay: 11a North Esk, 11b South Esk, 11c Tay, 11d Earn. There are no data presented for the island regions (5. Outer Hebrides, 7. Orkney Islands or 8. Shetland Isles), as these land areas have very few rivers and freshwater input is very small.

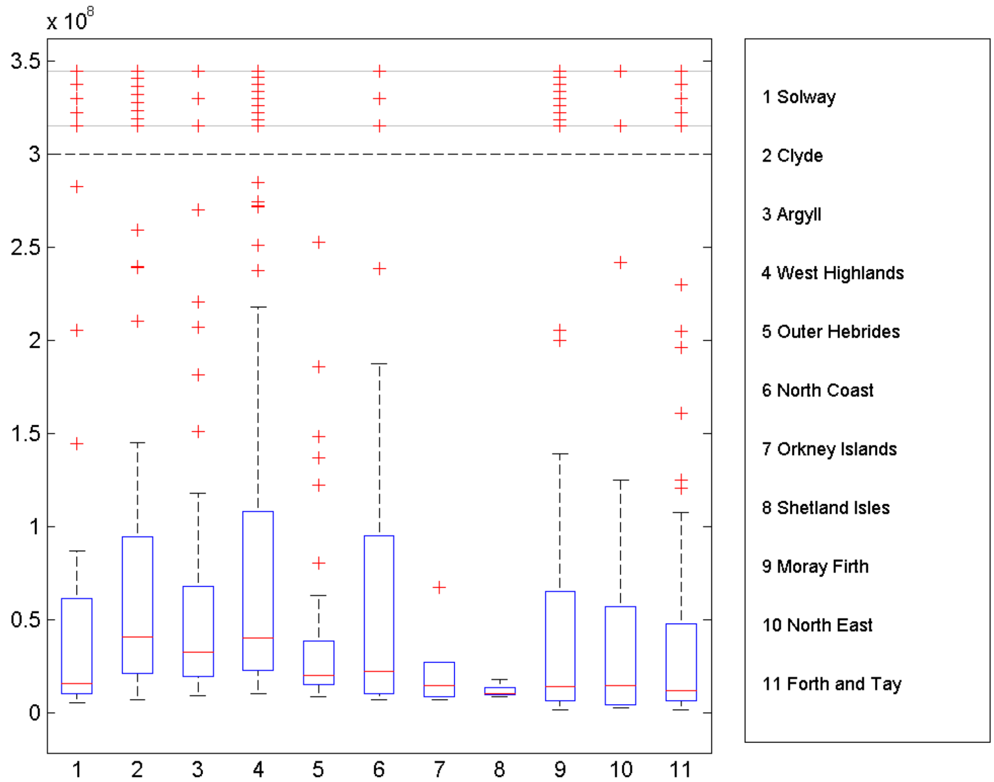


Figure B.2: Statistical Boxplots showing the variability of the average gauged river flow (m^3 s^{-1}) for the period 1962–2011 into each SMR. For each region, this shows the average size of the rivers flowing into this dataset and the range of the river input. Note this figure does not give any indication of the total fiver flow into each SMR, for that refer to Table B.2. Values greater than 3×10^8 m^3 s^{-1} (dashed line) are represented by a single red cross at a nominal value.

C Datasets: Coastal

This section describes the datasets presented in Chapter 3. This appendix provides a brief description of the datasets, along with information on original sources of data and any further quality control or processing.

C.1 The Scottish Coastal Observatory

The Scottish Coastal Observatory (SCObs) consists of a number of sites where coastal sea surface temperature measurements are recorded (*Bresnan et al.*, 2016). Within SCObs, there is a subset of sites at which measurements extend back more than 30 years. These are presented separately as Scotland's Long Coastal Temperature Time series (see section C.1.1). There is also a subset of SCObs sites where additional parameters including salinity and subsurface measurements are available (see section C.1.2). Sampling methodology and parameter sampling frequencies do vary between SCObs sites, which are fully described by *Bresnan et al.* (2016).

The SCObs coastal temperature data are collected automatically using electronic temperature loggers (Vemco miniloggers). The original data are recorded at hourly and half hourly intervals, and are quality controlled using standard procedures to remove outliers and any data affected by instrument malfunctions or external interference. From these quality controlled data, monthly mean values are calculated. Temperature data at Ardtoe and Tiree are collected by separate Scottish marine organisations and remain funded outside the SCObs dataset.

For Scotland's Long Coastal Temperature Time series, yearly and monthly anomalies are calculated in a standard method as described in Appendix G. Anomalies are presented relative to the 1981–2010 climatological base period. However, for the shorter SCObs datasets, the data are presented relative to a 2000–2010 base period, and the standard deviation used for normalisation of monthly and yearly anomalies is calculated using the whole dataset.

C.1.1 Subset: Scotland's Long Coastal Temperature Time series

Each of the long coastal temperature time series in Scotland were started by a different organisation. The history of these data is described below. In 2003, the time series at Millport and Fair Isle were formally adopted by Marine Scotland Science and now form part of SCObs. Temperature data at Peterhead, collected on a private site, remains funded and supported outside the SCObs dataset.

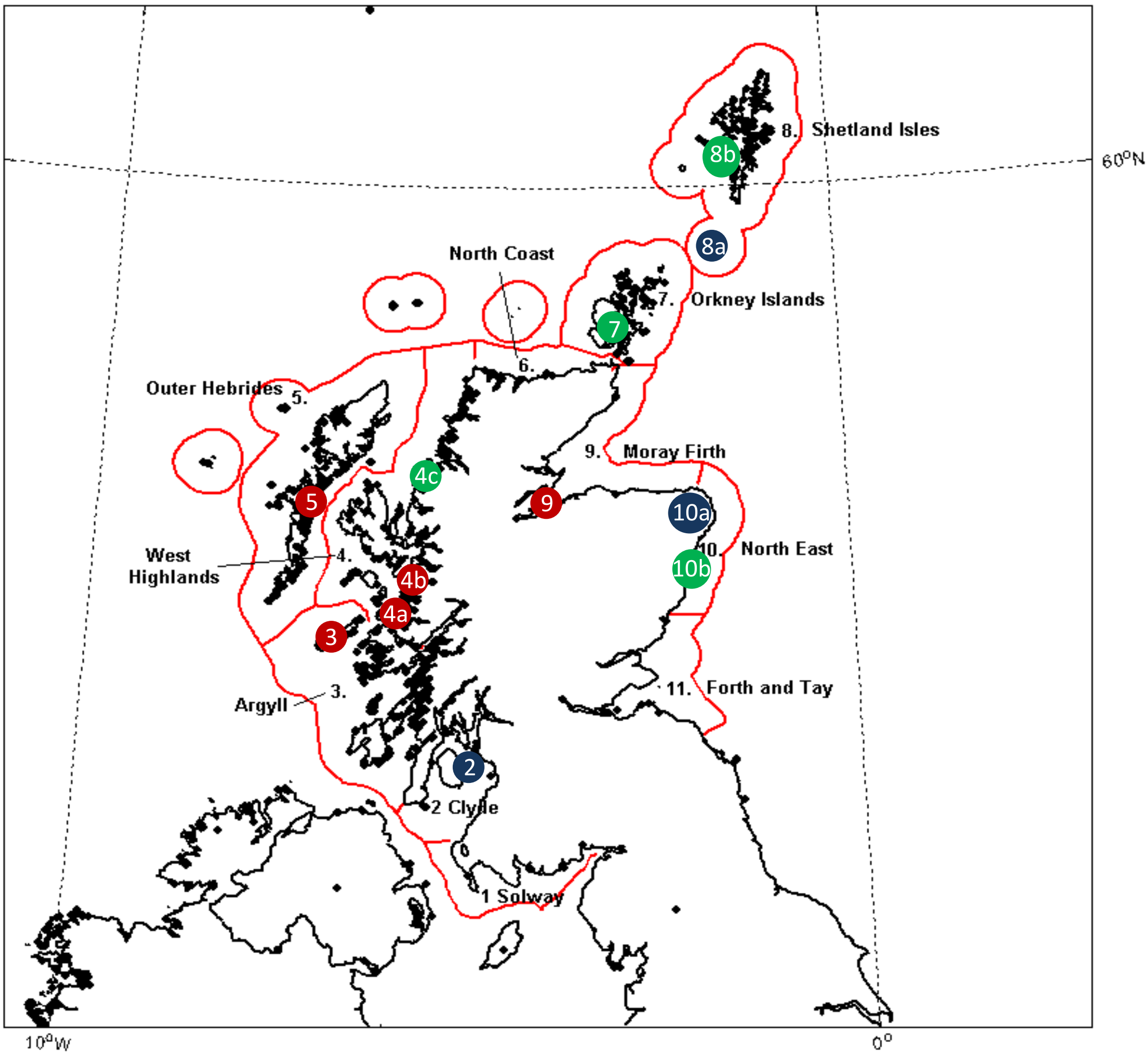


Figure C.1: Map shows approximate position of the stations within the Scottish Coastal Observatory (SCObs) presented in this report. Note that data is collected at some other sites but the time series are too short (<5 years) for inclusion in this report. Red circles show sites of just temperature collection, whilst green circles show sites where both temperature and salinity are recorded; the Ecosystem subset. Blue circles show sites that form the Long Coastal Temperature subset. Sites are matched to the Scottish Marine Region as follows: Region 2. Clyde: 2 Millport, Region 3. Argyll: 3 Tiree, Region 4. West Highlands: 4a Ardtoe, 4b Mallaig, 4c Loch Ewe. Region 5. Outer Hebrides: Loch Maddy. Region 7. Orkney Islands: 7 Scapa. Region 8. Shetland Isles: 8a Fair Isle, 8b Scalloway, Region 9. Moray Firth: 9. Cromarty, Region 10. North East: 10a Peterhead, 10b East Coast/Stonehaven. For this dataset there are no monitoring sites in regions 1. Solway, 6. North Coast and 11. Forth & Tay. Note that the sites at Tiree, Ardtoe and Peterhead are additional sites which are not funded as part of the Scottish Coastal Observatory.

Coastal sea surface temperature data from Millport

The time series at Keppel Pier in Millport started in 1909. Sea surface temperature records were first collected, using a bucket thermometer, at a reported frequency of 'every few days' at the Keppel Pier site. Monthly mean values were calculated and published in annual reports of the Marine Biological Association of the West of Scotland (1909–1913, except 1912), and then the Scottish Marine Biological Association (1914–1926).

After a gap in the data, daily records started again in 1949 and these data were submitted to the UK Meteorological Office (*Barnes*, 1959).

Early records were collected using a thermometer graded in degrees Fahrenheit with a scale that was read to the nearest whole degree. From 1953, a bucket thermometer fitted with a centigrade thermometer was used. This could be read to an accuracy of 0.1 °C (*Barnes*, 1959). The published monthly mean values in degrees Fahrenheit have been converted to degrees Centigrade, but otherwise no other quality control has been applied.

Ownership of the Millport Marine Biological station has since changed, but daily (or near-daily) records continued. The station is currently owned by the Field Studies Council[1], but the sea surface temperature records have been maintained by Dr Peter Barnett. In 2003, MS installed an automatic temperature logger (minilogger) at this site which Dr Barnett helps to maintain.

Since 2003, hourly records have been recorded using a minilogger temperature recorder. Quality control and analysis of these data follow the same procedure as for other minilogger data collected as part of the SCObs dataset.

Coastal sea surface temperature data from Fair Isle

The sea temperature time series at Fair Isle was initiated in 1974 by Dave Wheeler, who also collected meteorological data. Prior to 2003, monthly average values were calculated by Dave Wheeler and then sent to Marine Scotland. In 2003, MS installed an electronic temperature recording device (minilogger) at this site, which Mr Wheeler and later staff at the Fair Isle Bird Observatory continue to maintain. Quality control and analysis of these data follow the same procedure as for other minilogger data collected as part of the SCObs dataset (see Section C.1 for more details). Both the meteorological and sea temperature data are supported by the Fair Isle Marine Environment and Tourism Initiative[2].

Coastal sea surface temperature data from Peterhead

The data at Peterhead have been collected since 1976 from the cooling water intake at Peterhead Power Station[3]. Note that temperatures are measured on the steam

[1] `http://www.field-studies-council.org/centres/scotland/millport.aspx`
[2] `http://www.northisles-weather.co.uk`
[3] `http://www.scottish-southern.co.uk/`

turbine condenser inlet waterbox, and therefore may show some deviations from the sea water temperatures. Daily values of these data are calculated by Scottish and Southern Energy (SSE) staff and are sent to Marine Scotland for further quality control and analysis. The data are checked for any unusual outliers and monthly average values are calculated from the daily records. Monthly averages are only calculated where there are more than 15 days recorded in each month.

C.1.2 Subset: selected SCObs sites

At four of the SCObs sites (Loch Ewe, Scapa, Scalloway and Stonehaven) weekly observations of salinity (and other ecosystem parameters) are taken and at two of the sites (Loch Ewe and Stonehaven), the salinity observations are at both the sea surface and the seabed, which allows for examination of conditions close to the seabed. Data from the surface level are defined as all data collected at a depth of less than 10 m, and data from the seabed level are data within 10 m of the bottom (deeper than 24 m for the site at Loch Ewe and deeper than 37 m for the site at Stonehaven).

These SCObs data are collected at weekly intervals and, before presentation here, monthly median values of each parameter were calculated. In order to eliminate the impact of extreme single values, monthly medians were rejected if they fell outside of an acceptable range, and came from an average of only one or two weekly samples. The acceptable range was calculated using the difference from a smoothed trend line (a 3-month running mean). Data were rejected if the difference was greater than 4 standard deviations from the smoothed trend.

C.2 Gridded Sea Surface Temperature Data (HadISST)

C.2.1 Data Source

Sea surface temperatures in Scottish waters have been obtained from a combined satellite and in situ gridded dataset (Figure C.2). The data used are a subset of the HadISST1.1 data. This dataset is produced on a 1° latitude-longitude grid and is provided by the Meteorological Office, Hadley Centre for Climate Science and Services in the UK (*Rayner et al.*, 2003). The dataset starts in 1870, and incorporates data from the Comprehensive Ocean-Atmosphere Data Set (COADS, now ICOADS) between 1871 and 1995. Gridded fields are constructed using optimal interpolation techniques.

C.2.2 Data Quality Control and Processing

These datasets are quality controlled at source and all data are therefore accepted at QF1. The data are interpolated and gridded, and therefore contain no gaps. None of the regions analysed are affected by sea ice. The HadISST1.1 is not published with its own climatology, therefore the 1981–2010 climatological averages were calculated using the monthly averages in each grid cell.

C.2.3 Regional Averages

A single time series of SST has been prepared in each region by averaging the monthly anomalies in each of the gridded data points whose central position falls within the boundary of the region. In order to provide a better match of the regions within each Scottish Marine Region, the original data were re-sampled onto a finer grid using linear interpolation. As regions are of different sizes the number of data points used to calculate each regional average varies. Table C.1 indicates the number of data points within each of the Scottish Marine Regions.

For the HadISST data, yearly and monthly anomalies are calculated in a standard method as described in Appendix G.

Table C.1: Analysis of HadISST gridded datasets by Scottish Marine Region

Number	Scottish Marine Region	Number of Datapoints
1	Solway	3
2	Clyde	1
3	Argyll	10
4	West Highlands	11
5	Outer Hebrides	14
6	North Coast	2
7	Orkney Islands	6
8	Shetland Islands	10
9	Moray Firth	8
10	North East	4
11	Forth and Tay	2

C.3 The Ocean Data Tool (ODaT)

C.3.1 Data Source

Large amounts of oceanographic data are collected in Scotland's waters by a variety of different institutes. As these data are collected for a variety of reasons and in a number of different formats, they do not form a single data time series, but are instead saved together in large national databases, such as those held at British Oceanographic Data Centre (BODC) and ICES. In 2016-2017, SAMS received funding from the Natural Environment Research Council (NERC) to develop a new data tool allowing these existing data to be interrogated and visualised, and to provide new data products that meet the needs of marine users. As part of this project, time series of monthly average temperature and salinity at the sea surface and the seabed have been calculated for each of the Scottish Marine Regions. Inland and estuarine observations were removed; a mask of 5 km was applied around the coastline to exclude rivers, sea lochs and estuaries from the analysis. Sea surface is defined as being shallower than 12 m and seabed is defined as being within 15 % of the water depth of the seabed. The seabed data were cross-checked against the GEBCO 30 arc-second grid bathymetry (*GEBCO*, 2014), and this comparison led to approximately 20 % of 'bottom' data being rejected as they did not extend close

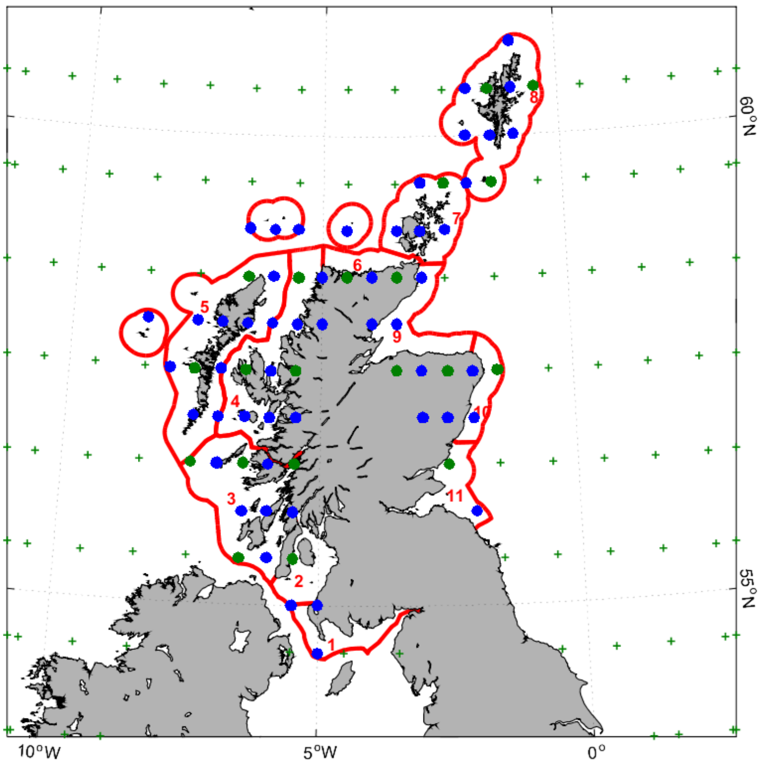


Figure C.2: Position of HadISST1.1 Gridpoints within each of the Scottish Marine Regions. + show all original grid points, ● show original data points with SMR, and ● show data points interpolated onto a 0.5° grid within SMRs. For number of data points within each SMR and full names of each SMR, see Table C.1.

enough to the seabed. Data were isolated for each Scottish Marine Region, and data points were rejected if they fell outside 3 standard deviations of the full time series. Note that temperature and salinity are considered separately as salinity outliers are more likely.

C.3.2 Data Quality Control and Processing

The average time series have been analysed to remove a seasonal cycle, and to calculate anomalies for each of the datasets. In order to examine the long-term trend a LOESS smoother with a 2-year window has been applied to each dataset. This smoother gives similar results to a 2 year running mean, but, as it uses weighted means, the results tend to be smoother and more useful for examining long-term trends. It must be noted that when the underlying dataset is sparse, there can be less confidence attached to the results.

Monthly averages are only calculated if there are data for more than half of the months in the chosen timeperiod. Therefore, for a 30 year average (1981–2010) there would need to be more than 15 valid records in each month. For this reason, there are no climatological averages presented for the Solway, Clyde and North Coast regions.

The most valuable part of the ODaT dataset is the additional information that is provided from inclusion of salinity data as well as temperature. The sparse nature of the underlying data used to create the ODaT dataset means that the confidence we may have in the dataset is less than that of the HadISST gridded dataset or indeed from measurements made directly at sites in coastal waters, for example, those in the SCObs dataset. However, the statistical analysis of surface and bottom temperatures (Figure 3.5) suggests that the ODaT dataset captures the general pattern expected in regional temperatures. For example, average temperatures in western marine regions of Scotland are higher than those of the east, and the seasonal range is less extreme.

D Datasets: Offshore and Oceanic

This section describes the datasets presented in Chapter 5. This appendix provides a brief description of the datasets, along with information on original sources of data and any further quality control or processing.

D.1 Marine Scotland Offshore Hydrographic Datasets

The data from offshore surveys by Marine Scotland (MS) and Faroe Marine Research Institute (FAMRI) in the Faroe-Shetland Channel (FSC) are used to understand the circulation in Scottish waters. Particularly important are the water masses that pass through the FSC to and from the Arctic, and those that exchange with the Northern North Sea.

The FSC, directly north of mainland Scotland, is a region where water masses transported from different locations come together. These may be classified into five types (Table D.1). Whilst this table represents the average properties of each water mass, we can determine how the properties of these waters are changing over time using data from standard monitoring sections in the FSC.

Table D.1: Properties of Water masses in the Faroe-Shetland Channel from (*Hansen and Østerhus*, 2000)

Water Mass	Acronym	Salinity	Temperature (°C)
North Atlantic Water	NAW	35.35-35.45	9.5-10.5
Modified North Atlantic Water	MNAW	35.10-35.30	7-8.5
Modified East Icelandic Water	MEIW	34.70-34.90	1.0-3.0
Norwegian Sea Arctic Intermediate Water	NSAIW	34.87-34.90	-0.5-0.5
Norwegian Deep Sea Water	NDSW	34.91	$<$0.5

Data from a further survey on the Joint North Sea Information Systems (JONSIS) line in the Northern North Sea (NNS) is used to understand changes in circulation in this important region. This hydrographic section measures the water mass properties of two key currents in the NNS: the Fair Isle Current (FIC) and the East Shetland Atlantic Inflow (ESAI), represented by the FIC water mass and Cooled Atlantic Water (CAW), respectively.

D.1.1 Analysis Description

Marine Scotland undertakes regular monitoring of the seas around Scotland, occupying 3 standard sections in Scottish waters (Figure D.1). Data from these

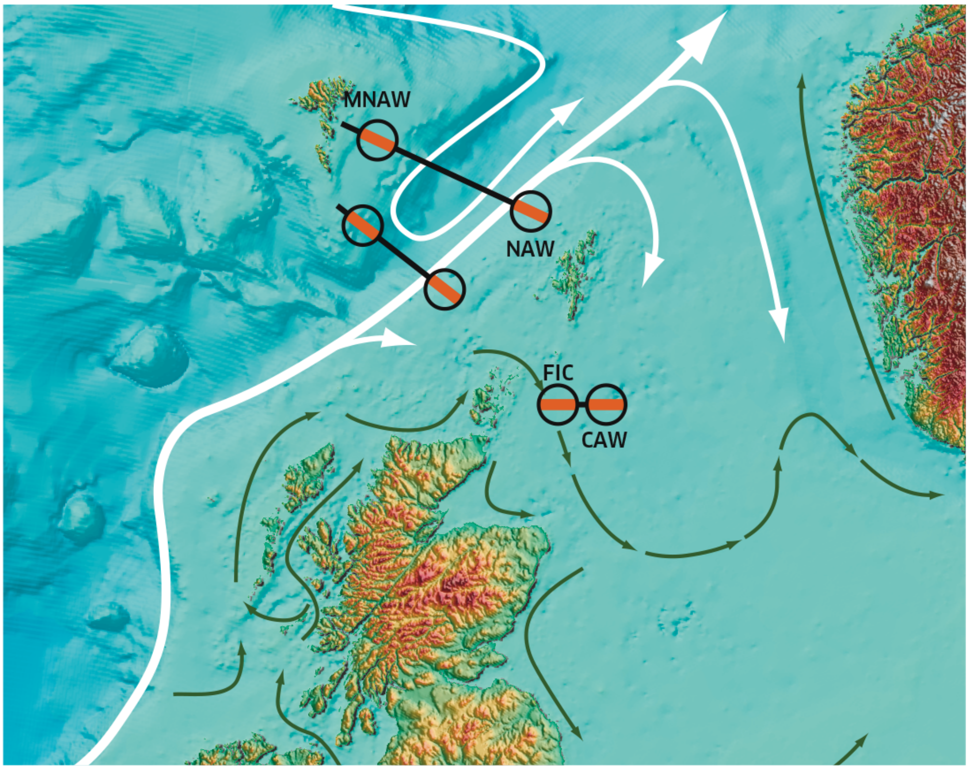


Figure D.1: Circulation diagram of surface waters around Scotland, showing the position of Marine Scotland Standard Monitoring Sections in the Northern North Sea (NNS) (JONSIS section) and Faroe-Shetland Channel (FSC) (Fair Isle-Munken and Nolso-Flugga sections). Black circles with red highlighting show water mass definition regions.

sections are carefully quality controlled and sub-sampled before being stored in a central archive. The archive is supplemented by additional observations that have been made along the same sections. These additional data were sourced from the ICES database and other sources as described by *Turrell* (1995).

In order to examine long-term variability from these complex datasets, water mass indices that describe conditions in key regions are extracted from the records. These indices are widely published and reported at least annually (e.g. *Larsen et al.*, 2016; *MCCIP*, 2017).

Calculation of the data for the indices requires the reduction of observed data to anomalies, removing the mean and seasonal cycle. This requires an accurate analysis of the data in order to derive a seasonal cycle. Since the initial work of *Turrell* (1995), the database has been transferred from a VAX system to a PC based system, and the original FORTRAN code has been re-written into Matlab scripts.

An examination of the seasonal cycle calculated at each station and depth, particularly that of salinity, has resulted in a re-evaluation and update of the methodology used. This report compares three different evaluation methods and examines the results from the new analysis.

The Marine Scotland long-term monitoring database holds data at standard stations and at standard depths (*Turrell*, 1995). Prior to the 1980s, data were collected at discrete depths using hydrographic water bottles fixed with reversing thermometers. Since then, the development of electronic instrumentation means that the actual data are now collected at a much higher vertical sampling frequency (with depth) and therefore the data held in the archive are actually a subsample of the recorded data.

In 1989, during a specific project investigating the migration of pelagic fish along the continental shelf (Shelf Edge Fisheries Oceanography Study, SEFOS), additional sampling stations were added to the sections. Whilst these have been maintained, they are not treated separately in the long-term monitoring archive and are combined with the original nearby stations.

Sections in the FSC (FIM and NOL) have been occupied regularly since the first expedition in 1893. Currently, MS survey the FSC & NNS three times per year: in April-May, September-October and December. These occupations are supplemented by additional occupations from other oceanographic institutes. FAMRI occupies part of the FIM & NOL sections approximately three times each year.

The JONSIS section in the NNS was first occupied in 1969 and then regularly from 1974, developed as part of an ICES Joint North Sea Project. The Institute of Marine Research, Norway (IMR) occupies this section approximately three times each year.

Whilst occupation of the sections currently occurs regularly (with exceptions for bad weather), the record of occupation of the sections and individual stations within sections is variable. Notable gaps can be seen in the earlier years when sections in the FSC may consist of only one or a few stations. Large gaps also occur during the war years and in the late 1980s, when funding cuts reduced the occupation frequency.

D.1.2 Data Source

Data are sourced from the three hydrographic sections shown in Figure D.1. These are regularly observed by MS, FAMRI, and IMR.

D.1.3 Data Quality Control and Processing

Key water mass properties are extracted from the data and described below. The quality control of this data is done by each of the data providers, and all data is therefore considered as ’QF1’.

North Atlantic Water (NAW)

This time series represents conditions (temperature and salinity) from an oceanic site to the north of Scotland. This site lies within the Charting Progress region 7, Scottish Continental Shelf (Figure D.1).

Full Definition: The temperature and salinity at the standard pressure level which exhibits the maximum salinity within an individual survey of the most south-easterly two stations, on both FIM & NOL standard sections, on the Scottish side of the FSC. The criteria were designed to produce the characteristics of the North Atlantic Water lying within the Slope Current at the Scottish shelf edge. North Atlantic Water is typified by a salinity maximum on a θ-S diagram. This water most probably originates west of the UK, in the Rockall Trough, and hence may be most closely related to North East Atlantic Water (NEAW).

Modified North Atlantic Water (MNAW)

This time series represents conditions (temperature and salinity) from an oceanic site on the Faroe Shelf. This site lies outwith the Charting progress regions but has value as an indicator of conditions in Charting Progress region 8, Atlantic NW Approaches (Figure D.1).

Full Definition: The temperature and salinity at the standard depth which exhibits the maximum salinity within an individual survey of the first two stations, on both FIM & NOL standard sections, on the Faroese side of the FSC. These criteria were defined in order to characterise Modified North Atlantic Water, the water mass which composes much of the surface waters of the FSC, and encompasses the anti-cyclonic flow of warm, surface water around the Faroe plateau. These waters most probably originate in the sub-tropical gyre, west of Rockall, and hence may be more representative of conditions in areas influenced by the North Atlantic Current. This water again is identified on a θ-S diagram as a salinity maximum for waters on the Faroese side of the Channel.

Fair Isle Current (FIC)

Temperature and salinity data from an offshore site, in the Fair Isle Current. This water is an indicator of conditions in Charting Progress region 1, Northern North Sea (Figure D.1).

Full Definition: The mean temperature and salinity at all standard pressures, averaged over the first two stations at the western end of the JONSIS standard section. This criteria captures the characteristics of water entering the North Sea through the Fair Isle Channel. This water originates west of Scotland, and is a mixture of coastal water and Atlantic water that has come onto the shelf from the Slope Current.

Cooled Atlantic Water (CAW)

Temperature and salinity data from an offshore site, in the central North Sea. This water is an indicator of conditions in Charting Progress region 1, Northern North Sea (Figure D.1).

Full Definition: The mean temperature and salinity at all standard pressures below 50 decibar, averaged over the first six stations at the eastern end of the JONSIS standard section. This criteria is designed to examine the characteristics of the cool dense lens of Atlantic water which forms in the centre of the North Sea during the summer months. During periods of vertical stratification in the NNS, this water mass retains the characteristics of the mixed North Sea during the previous winter, until the dense lower layer is eventually eroded through autumnal wind mixing, and again takes on the properties of the NNS as a whole. Thus, it generally represents water of Atlantic origin, modified by mixture with North Sea coastal waters to a varying extent.

D.2 Gridded SST Data

D.2.1 Data Source

Sea surface temperatures in Scottish waters have been obtained from a combined satellite and in situ gridded dataset. The data used are a subset of the HadISST1.1 data. This dataset is produced on a 1° latitude-longitude grid and is provided by the Meteorological Office, Hadley Centre for Climate Science and Services in the UK (*Rayner et al.*, 2003). The dataset starts in 1870, and incorporates data from the Comprehensive Ocean-Atmosphere Data Set (COADS) (now ICOADS) between 1871 and 1995. Gridded fields are constructed using optimal interpolation techniques.

Table D.2: Analysis of HadISST gridded datasets by Charting Progress Region

Number	Charting Progress Region	Number of Datapoints
3	Eastern Channel	5
4	Western Channel and Celtic Sea	15
5	Irish Sea	9
6	Minches and Western Scotland	6
7	Scottish Continental Shelf	7
8	Atlantic North West Approaches including Rockall Trough and Faroe-Shetland Channel	29
1	Northern North Sea	22
2	Southern North Sea	51

D.2.2 Data Quality Control and Processing

These datasets are quality controlled by the data provider, and all data are therefore accepted at QF1. The data are interpolated and gridded and therefore contain no gaps. None of the regions analysed are affected by sea ice. The HadISST1.1 is not published with its own climatology, therefore the 1981–2010 climatological averages were calculated using the monthly averages in each grid cell.

D.2.3 Regional Averages

A single time series of SST has been prepared in each CP2 region by averaging the monthly anomalies in each of the gridded datapoints whose central position falls within the boundary of the region. As regions differ in size, the number of datapoints used to calculate each regional average varies. Table D.2 indicates the number of datapoints within each of the CP2 regions.

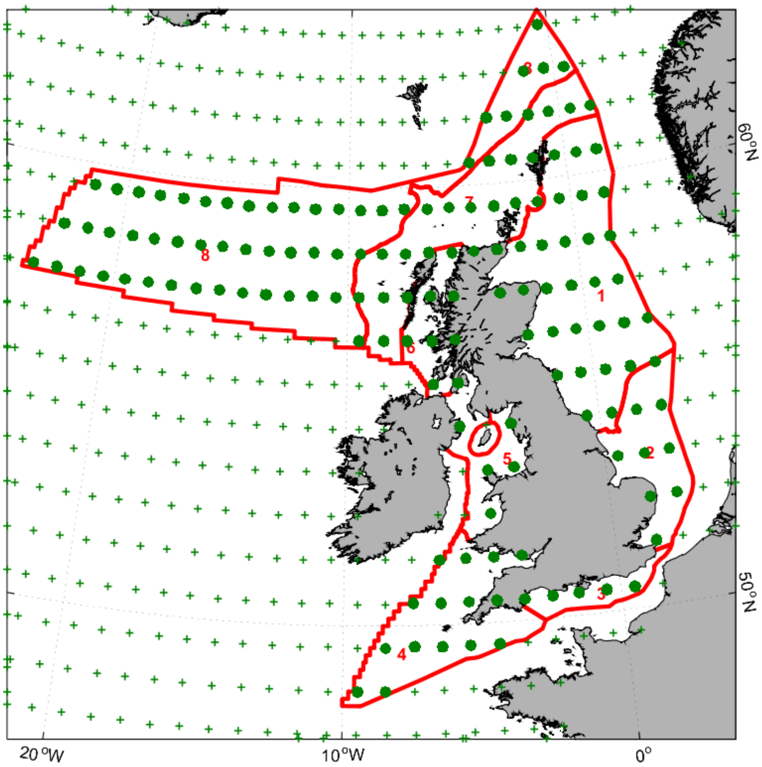


Figure D.2: Position of HadISST1.1 Gridpoints within each of the Charting Progress 2 Regions. + show all original grid points, ● show data points with CP2 Region. For number of data points within each CP2 Region and full names of each region, see Table D.2.

D.3 International Bottom Trawl Survey (IBTS)

D.3.1 Data Source

Each year, fisheries scientists from a number of different countries with an interest in the North Sea collaborate in the International Bottom Trawl Survey (IBTS). The first quarter survey is usually carried out in February. Observations in each ICES Statistical Rectangle (30' latitude and 1° longitude)[1] are assigned the central coordinate within the rectangle.

D.3.2 Data Quality Control and Processing

Mean values are calculated for the period 1981–2010 (inclusive) and anomalies relative to these values are calculated. To allow for comparison between regions where variability is much higher (e.g. coastal regions), these anomalies are normalised by the standard deviation in each grid box.

[1] http://www.ices.dk/marine-data/maps/Pages/ICES-statistical-rectangles.aspx

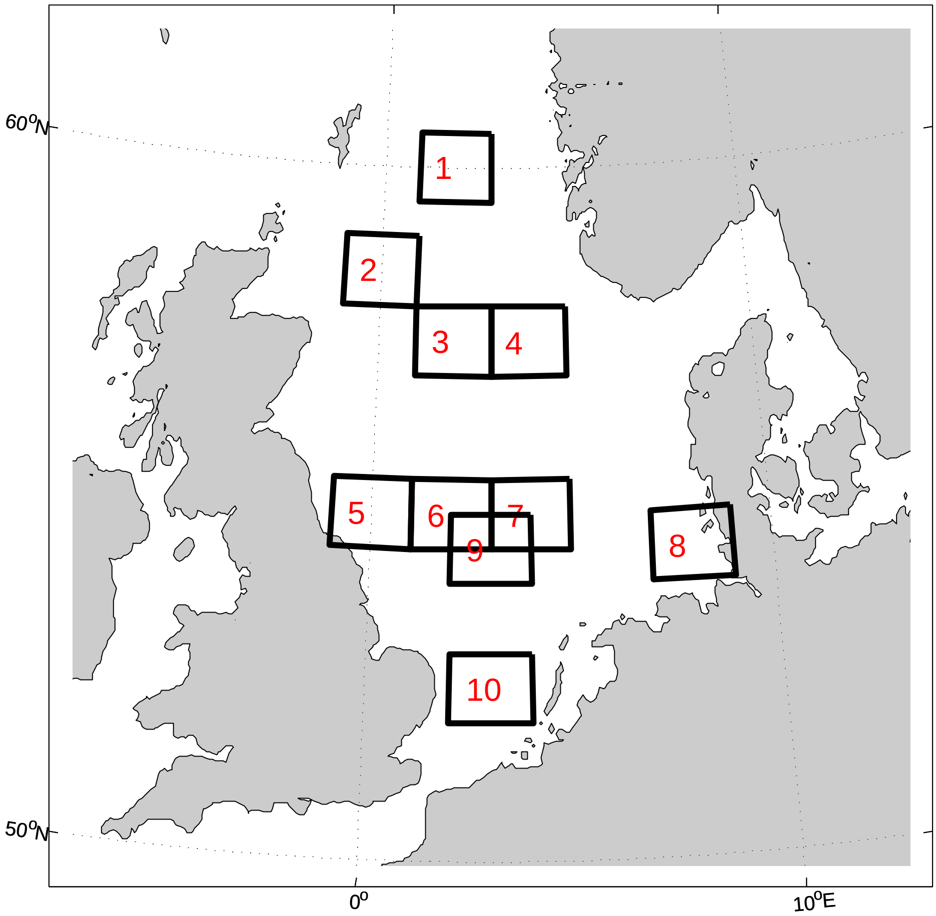


Figure D.3: Position of selected fishing grounds (1-10; see also Table D.3). The fishing banks labelled as 1 (Bergen/Viking Bank), 2 (Fladen Ground), 9 (Dogger Bank) and 8 (German Bight) are also selected for presentation as time series. Fishing ground properties are calculated from the average of data in the 4 ICES statistical rectangles (1° latitude x 2° longitude) surrounding the central location of the fishing ground.

D.3.3 Averages for key fishing grounds

Several key fishing grounds have been defined according to Table D.3 and D.3. Within the report, these fishing grounds are identified by their common name (final column Table D.3). For each of these grounds, the temperature and salinity observed during the IBTS within the four ICES Statistical Rectangles surrounding the central location has been used to represent temperature and salinity conditions of the fishing ground.

Table D.3: IBTS Fishing Grounds (see also Figure D.3)

Number	Latitude	Longitude	Fishing Ground
1	60.0N	2.0E	Bergen/Viking Bank
2	58.5N	0.0E	Fladen Ground
3	57.5N	2.0E	Forties
4	57.5N	4.0E	Klondyke
5	55.0N	0.0E	Whitby
6	55.0N	2.0E	W Dogger
7	55.0N	4.0E	E Dogger
8	54.5N	8.0E	German Bight
9	54.5N	3.0E	Dogger Bank
10	52.5N	3.0E	Channel

E Datasets: Global and North Atlantic Climate Indices

This section describes the datasets presented in Chapter 5. A brief description of each dataset, along with information on the original sources of data and any further quality control or data processing follows.

E.1 Global Surface Temperature

There are a number of different sources of global temperature data, as described in Section 5.1. In this report global surface temperature data provided by the Goddard Institute for Space Studies (GISS), National Aeronautics and Space Administration (NASA) in the United States of America (*GISTEMP Team*, 2017). The data are an estimate of global surface (land and ocean combined) temperature compiled from a combination of meteorological and oceanographic datasets as described in *Hansen et al.* (2010). Data are provided relative to the long-term mean calculated for the period 1951-1980.

Quality control of this dataset is done at the source, so no further checks are necessary. For comparison with other datasets, a version of the data relative to the average values between 1981–2010 has been plotted in Figure 5.2.

E.2 Atlantic Multidecadal Oscillation (AMO)

The Atlantic Multidecadal Oscillation (AMO) is a mode of natural variability occurring in the North Atlantic Ocean, which has its principle expression in the sea surface temperature (SST) field. Here we present annual values of the AMO (*NOAA*, 2017) using the method proposed by *Enfield et al.* (2001). This is defined as the detrended (using a linear trend) annual mean area-averaged SST anomalies over the North Atlantic basin (0N-70N), using the Kaplan dataset (*National Oceanic and Atmospheric Administration*, 2017c) for the period 1856 to present day.

Quality control of this dataset is done at the source, so no further checks are necessary.

E.3 North Atlantic Oscillation (NAO) Index

There are several slightly different versions of the NAO index calculated by climate scientists. The Hurrell winter (December/January/February/March, or DJFM) NAO index (*Hurrell et al.*, 2003) is used here. Note that although we may think of the winter as coming at the end of the year, here the 'winter season' spans an annual boundary and precedes the year of interest, so the winter of December 2014 to March 2015 set up conditions for the summer of 2015.

Here we use the station based index (*Hurrell and National Center for Atmospheric Research Staff (Eds.)*, 2017; *Hurrell et al.*, 2003), calculated from the difference of normalised sea level pressure (SLP) between Lisbon (Portugal) and Stykkisholmur/Reykjavik (Iceland). The SLP values at each station were normalised by removing the long-term mean and by dividing by the long-term standard deviation. Both the long-term means and standard deviations are based on the period 1864–1983.

Quality control of this dataset is done at the source, so no further checks are necessary.

E.4 Sub-Polar Gyre Index (SPGI)

In 2005, *Hátún et al.* (2005) calculated a hindcast of the long-term variability of the Sub-Polar Gyre Index (SPGI) using data from an ocean circulation model. Since 1993, sea surface height data from satellite altimeters has been available, offering the opportunity to create an observation based SPGI. The method was devised by *Häkkinen and Rhines* (2004), and *Berx and Payne* (2017b) have prepared a version of the SPGI, which is made available online and intended for use in the oceanographic and fisheries scientific communities. The index presented here (*Berx and Payne*, 2017a) was last updated in 2015.

Quality control of this dataset is done at the source, so no further checks are necessary.

F Regional Analysis

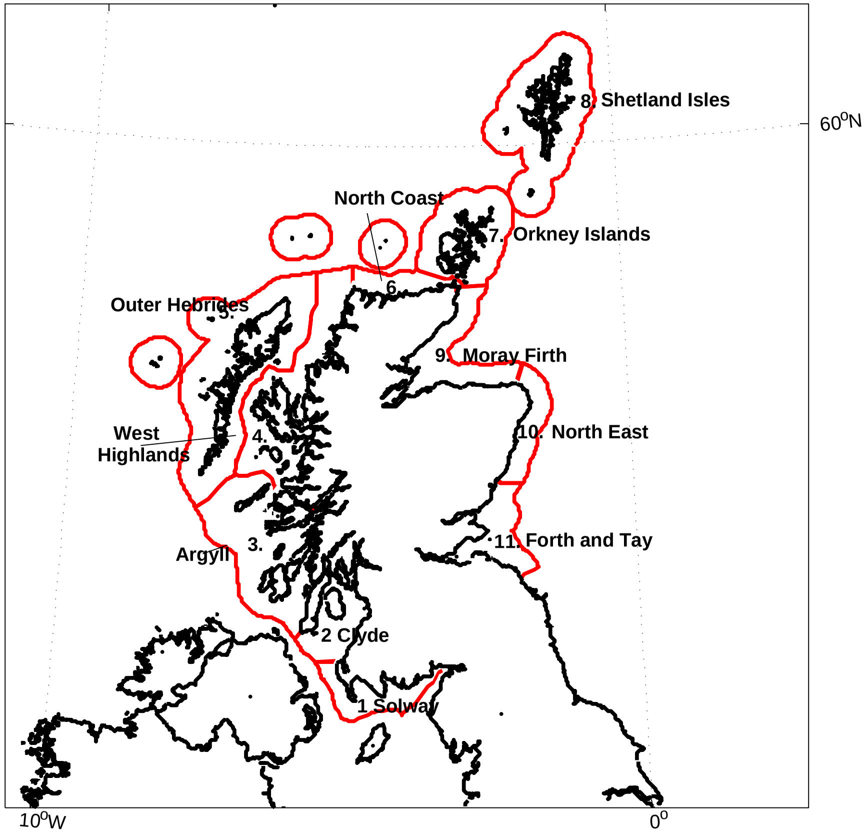
In order to summarise the spatial variability in climate change, conditions have been assessed within smaller subregions. It is assumed that within each subregion, there will be a common variability which can be captured by presenting a regional average. In the Scottish Ocean Climate Status Report, data are presented using a regional analysis approach. To provide a UK wide context, which incorporates offshore data, Charting Progress 2 (CP2) regions have been used. To examine the variability in coastal areas around Scottish waters, the smaller Scottish Marine Region (SMR) have been used. When gridded datasets are available, these datasets have been averaged within each region. Where data are more sparse, then it is only possible to offer one or two time series from within that region. It should be noted that, depending on the nature of the parameter being presented, individual time series will not necessarily be representative of average conditions across the entire region.

F.1 Scottish Marine Region (SMR)

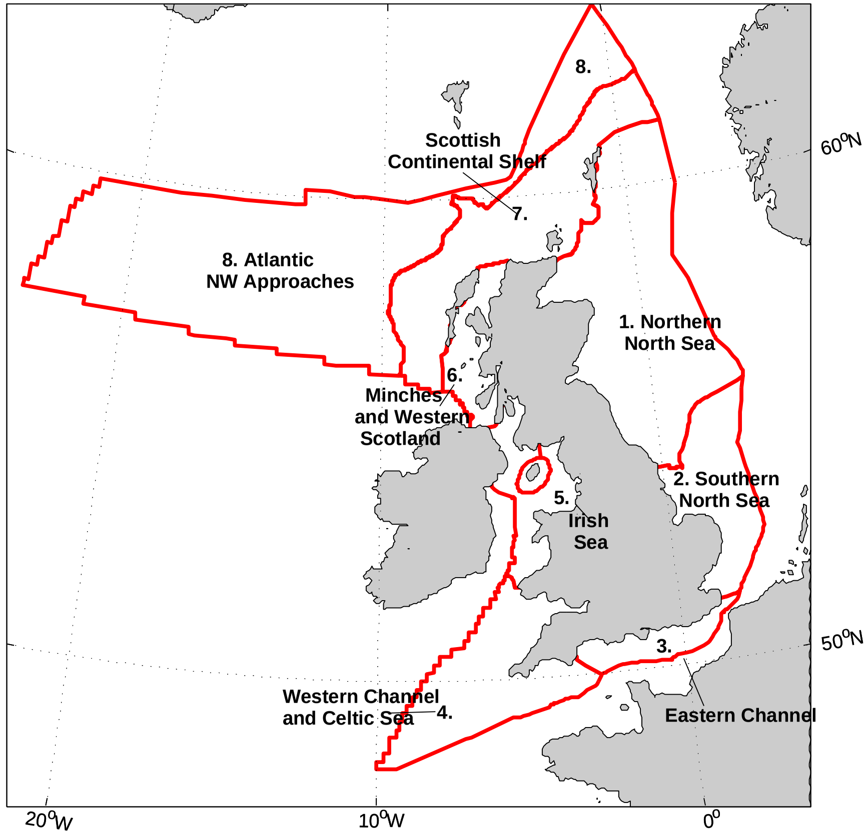
The SMR divide Scottish Waters up to the 12 nautical miles or adjacent waters limits (Scotland's Territorial Seas) into 11 subregions (Figure F.1a). The regions were defined in the Scottish Marine Regions Order 2015 for marine planning purposes. The regions were designed to take account of the physical properties of marine waters but some boundaries are also set by socio-economic features.

F.2 Charting Progress 2 (CP2) Regions

The CP2 regions divide coastal and offshore areas around the UK into 8 subregions and were presented in the Charting Progress 2 report (*DEFRA*, 2005). The regions were defined taking bio-geographic and physical features into account, and therefore reasonably define different hydrographic regions of the UK (Figure F.1b). The CP2 regions are also used for other UK National Assessments, such as the assessments made by MCCIP (*MCCIP*, 2017).



(a) Scottish Marine Regions



(b) Charting Progress 2 Regions

Figure F.1: (a) Map of the eleven Scottish Marine Regions. 1. Solway, 2. Clyde, 3. Argyll, 4. West Highlands, 5. Outer Hebrides, 6. North Coast, 7. Orkney Islands, 8. Shetland Isles, 9. Moray Firth, 10. North East, 11. Forth & Tay
(b) Map of the eight Charting Progress 2 Regions (in anti-clockwise order around the UK): 3. Eastern Channel, 4. Western Channel & Celtic Sea, 5. Irish Sea, 6. Minches & Western Scotland, 7. Scottish Continental Shelf, 8. Atlantic NW Approaches, 1. Northern North Sea, 2. Southern North Sea

G Data Analysis

G.1 Quality Flags

Where datasets have been quality controlled within Marine Scotland Science, the data quality is indicated within each file using a set of quality flags. Table G.1 describes the flags used in this project; these are adapted from SEADATA (*SEADATANET*, 2010). Datasets imported from external sources are assigned appropriate quality flags based on the descriptors provided with each dataset.

Table G.1: Quality Flags

Flag	Name	Explanation of protocol used in this dataset
QF0	No Quality Control Applied	This is the initial status for all data values in the file. Note that for chemical parameters subject to UKAS accreditation these values will have passed the initial analytical tests.
QF1	Good Data	These data have passed all appropriate analytical tests without question. These data have passed all environmental and statistical range tests without question
QF2	Probably Good Data	These data have failed an initial analytical test or been flagged as unusual during environmental and statistical range tests. Following review, and using available evidence from associated parameters they have been determined to be good
QF3	Probably Bad Data	These data have failed an initial analytical test or been flagged as unusual during environmental and statistical range tests. Following review, and using available evidence from associated parameters they have been determined to be bad
QF4	Bad Data	Obviously erroneous values. These data may have failed repeated analytical tests and are therefore flagged as bad. Or these data have been flagged as out of expected range during environmental and statistical range tests. Following review, and using evidence from associated parameters no evidence can be found to show they are good.
QF5	Changed Value	Data value has been adjusted during quality control. These are generally limited to metadata information where evidence of a misstype has been found in paper records.
QF6	Below limit of detection	The level of the measured phenomenon was too small to be quantified by the technique employed to measure it
QF7	Above limit of detection	The level of the measured phenomenon was too large to be quantified by the technique employed to measure it
QF8	Estimated/Interpolated	Estimated Data, the value has been derived by interpolation from other values in the data object.
QF9	Missing data	A survey was made on this date, but no data is available for this particular parameter either because it was not measured or the sample was lost or spoilt. Any accompanying value will be a magic number representing absent data,typically a number $<=$ -99
QF10	Repeated Bad Flag	Internal QF flag, used to assist with repeated flagging, has the same meaning as QF4

G.2 Trends

Long-term trends have been calculated from annual mean datasets using a simple linear regression. To ensure that the trends quoted are significant the non-parametric Mann-Kendall test for a trend (*Mann*, 1945) has been applied.

G.3 Descriptors, Anomalies and Normalisation

When comparing time series from different areas, common patterns and trends are easier to discover if the data are scaled to the local variability. Examining annual data from a particular location, we can discover the average value and also the range of variability, which can be measured using the statistical parameter of standard deviation, σ. We expect data with no external drivers, to demonstrate a normal distribution, and so 68% of the dataset should lie within $\pm 1\sigma$ of the mean, and 97.8% of data within $\pm 3\sigma$ of the mean (Figure G.1).

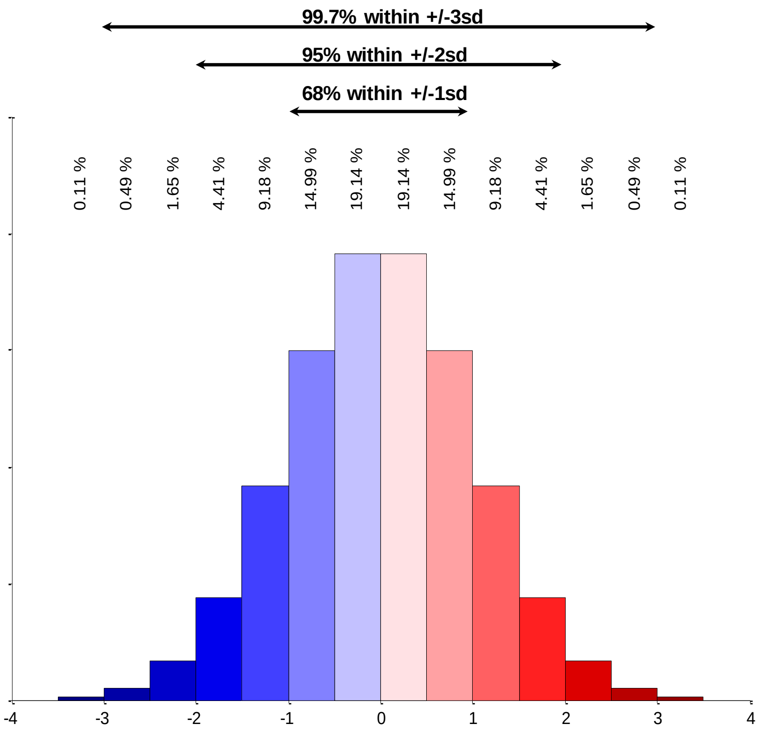


Figure G.1: Demonstration of normally distributed data. The bar chart demonstrates the relative frequency of data within each standard deviation boundary. This helps to define how extreme data values are in relation to that expected. A value that exceeds $\pm 3\sigma$ from mean would be described as extreme conditions. A value that exceeds $\pm 2\sigma$ from the mean would be referred to as very unusual or much higher than normal or very high. A value that exceeds $\pm 1\sigma$ from the mean would be referred to as unusual or higher than normal. Data within 1σ of the mean would be described as being usual or close to normal.

Table G.2: Descriptive terms for variation about the mean

Descriptive terms	Standard Deviation (σ)	% data
Exceptionally high, very extreme	$>$=3.5	0.0005%
Extremely high, extreme	$>$=3	0.15%
Much higher than normal, Very high, very unusual	$>$=2	2.5%
Higher than normal, unusual	$>$= 1	16%
Usual, close to normal, close to average	within 1σ	68%
Lower than normal, unusual	$<$1	16%
Much lower than normal, Very low, very unusual	$<$2	2.5%
Extremely low, extreme	$<$3	0.15%
Exceptionally low, very extreme	$<$3.5	0.0005%

Therefore, rather than seeing that one site might vary more than the other, we can see whether each site varies to the same order. If one site naturally varies by 5 °C from year to year, and another site naturally varies by only 1 °C from year to year, comparing the amount of variability can be misleading. This helps us clearly answer the question, how different were conditions to normal? The answer, rather than *x* units above normal, would be *x* standard deviations more than normal. This comparison is most easily done by looking at normalised anomalies (see below).

Anomalies are the differences between an individual measurement and the average values of a parameter at each location. Positive anomalies in temperature, for example, mean warmer than normal conditions; negative anomalies mean colder than normal conditions.

G.3.1 Monthly Calculations

For many of the datasets, monthly averages are already calculated as described in the orginator's dataset. Where monthly average data are not already calculated, and where raw data are of higher than monthly frequency, monthly averages are calculated for all months where there are more than 15 days of valid data within the month.

Monthly anomalies

Monthly anomalies are calculated by removing the average over the base period for that month.

$$A_{MY} = P_{MY} - P_{MBP} \tag{G.1}$$

Where A_{MY} is the monthly anomaly for month M in year Y and P_{MY} is the average of parameter P in month M and year Y and P_{MBP} is the average of parameter P, for all of the months M over the base period (30 years where possible).

Normalised monthly anomalies

Monthly anomalies are normalised using the mean and standard deviation of observations in that month over the base period.

$$NA_{MY} = A_{MY}/\sigma_{MBP} \tag{G.2}$$

Where NA_{MY} is the normalised monthly anomaly for month M in year Y and A_{MY} is the monthly anomaly for month M in year Y and σ_{MBP} is the standard deviation of parameter P, for all of the months M over the base period (30 years where possible).

G.3.2 Annual Calculations

Annual average values are calculated taking into account any missing monthly values. To help reduce data gaps, single missing months are interpolated by linear interpolation from the months prior and following. The interpolated monthly anomaly will therefore be the average of the anomalies prior and following. After gap filling, the number of valid months in a year are then determined. Where, after gap filling, there are still less than 9 valid months in a year, no average is calculated. Where there are more than 9 valid months in a year, the missing months are filled using the climatological average values. Climatological anomalies are of course zero, and therefore annual anomalies are unaffected by this calculation.

Averages are the simple arithmetic mean as follows:

$$P_Y = \Sigma P_{MY}/nval \tag{G.3}$$

$$A_Y = \Sigma A_{MY}/nval \tag{G.4}$$

Where, ΣP_Y is the sum of all the valid monthly values in year Y and $nval$ is the number of months with valid data in that year. A_Y is the annual mean of the monthly anomalies.

Normalised annual anomalies

Annual anomalies are normalised using the standard deviation of all the annual values within the base period.

$$NA_Y = A_Y/\sigma_{YBP} \tag{G.5}$$

Where NA_Y is the normalised annual anomaly for year Y, A_Y is the annual anomaly for year Y and σ_{YBP} is the standard deviation of A_Y over the base period (30 years where possible).

G.4 Statistical Summary Tables

Statistical summaries derived from analysis of monthly mean data are presented for each dataset. Note that any gaps of a single month in the record have been filled by linear interpolation. The long-term averages are calculated for each month from the whole dataset. Seasonal averages are calculated as follows: Winter is the average of January-March, Spring is the average of April-June, Summer is the average of July-September and Autumn is the average of October-December. Note that these seasonal definitions are suited to examining ocean conditions and do not match the meteorological definitions normally used for each season.

Annual averages are calculated if all months are available. The long-term trend is calculated form all datasets without gaps, trends which do not pass a Mann-Kendall test for significance are marked as not significant (n.s.).

Climatological averages are calculated by taking the mean value for each month in the climatological period, which is 1981 to 2010 for the longer datasets. Climatological averages are rejected if there are less than 15 monthly values available in the 30-year period. For datasets with a shorter climatological period, averages are rejected if there are less than 3 months available to make the calculation.

Decadal averages are calculated by taking the mean value for each month in the 10 year period prior to the most recent year of analysis. Decadal averages for a particular month are rejected if there are less than 3 months available to make the calculation.

Monthly values for the latest year are also shown in the table. Annual averages for the year are calculated if all months are available.

H Data Providers

Global Temperature Data: GISS Surface Temperature Analysis (GISTEMP). NASA Goddard Institute for Space Studies, USA.

Atlantic Multidecadal Oscillation: Earth System Research Laboratory, Physical sciences Division, NOAA, USA.

North Atlantic Oscillation Index: National Center for Atmospheric Research (NCAR), Boulder, USA.

Weather Data: UK Meteorological Office.

River Flow Data: National River Flow Archive (NRFA).

Gridded Sea Surface Temperature Data: Hadley Centre Sea Ice and Sea Surface Temperature (HadISST).

Regional Temperature and Salinity Data: Ocean Data Tool (ODaT), Scottish Association of Marine Science (SAMS), Oban, UK.

Millport: Staff of the University Marine Biological Station Millport and Staff of the Field Studies Council.

Loch Maddy: The late Dr. John McLeod, Staff of Camann na Mara, and Staff of Loch Duart Salmon.

Loch Ewe: Jane and Willie Grant (Isle Ewe Shellfish), and Phil McLaughlan.

Scapa: Staff of Orkney Islands Council Marine Services.

Scalloway: Staff of the North Atlantic Fisheries College.

Mallaig: Ewen Nicholson.

Cromarty: Tim Barton (Aberdeen University).

Fair Isle: Dave Wheeler, and Staff at the Fair Isle Bird Observatory.

Glossary and Acronyms

Glossary

The conditions in the seas and oceans around Scotland vary in similar ways to those in the atmosphere, with daily, monthly and seasonal patterns, as well as longer term change. Sometimes the terminology used to describe change in weather and climate can be misunderstood or confused. Some common terms and sources of variability are described below:

'Weather'
Weather is used to describe changes that occur over a short period of time (i.e. days). In this report we most commonly use the term weather to describe the short term changes that occur in the atmosphere (such as in Chapter 1), but the term could also be correctly used to describe short term changes that are observed in the seas and oceans.

'Climate'
The climate of a region is described by the average weather. The climate is often calculated as the average weather over a long period of time. In this report the climate of a region is calculated over a long period (usually a 30 year period) and is referred to as normal or average conditions. Elsewhere these average conditions may be referred to as the climatological mean or just the climate.

'Climatology'
The term climatology refers to average values over a long period which give a reasonable estimate of the climate. This is used to compare observations in a particular year. In keeping with standard practice recommended by the World Meteorological Organization (WMO) [1], climatological average values have been most commonly calculated for the 30-year period 1981–2010.

'Climate Variability'
In this report we describe the changes that are observed in conditions in the seas and oceans from month to month and from year to year. These changes, described as climate variability are driven, in part by natural variability and in part by global climate change. Natural variability can be internal to the climate system, like the effect of the oceans; or it can be external, like the effect of changing planetary orbits. Natural variability can be cyclical or intermittent. An example of intermittent climate variability is that caused by large volcanic eruptions.

'Climate Change'
We know that the average global climate is changing over a long period, caused by human activities, sometimes termed as human-induced or anthropogenic climate change. In this report we use the term Global Climate Change to distinguish between

[1] https://www.metoffice.gov.uk/climate/uk/averages/key-features-1981-2010

this and other natural changes or variability in climate.

'Daily Cycle'
The daily cycle of light and dark influences the marine ecosystem, and some plankton migrate in the water column in response to changes in light. As the sea heats up and cools down much more slowly than the atmosphere, daily changes in temperature are only observed in very shallow coastal areas. The semi-diurnal (twice daily) changes in the tide also have a strong influence on the marine ecosystem.

'Seasonal Cycle'
In Scotland, we have four distinct seasons: spring, summer, autumn and winter. This seasonal pattern of variability can also observed in the marine environment. As the sea heats up and cools down more slowly than the atmosphere, we see a lag in the seasonal temperature cycle. Seas are at their warmest during August and September, and at their coolest in February and March. It is sometimes useful to calculate an average seasonal cycle, and then compare monthly data to the average. This can tell us if a particular month was above or below normal. Changes on a month to month basis cannot really be described as climate change or be attributed directly to global climate change, but can nevertheless have a significant impact on the marine ecosystem at that time.

'Long-term variability'
We know that conditions in the seas around Scotland vary from year to year and decade to decade, and that these changes can be linked to changes in patterns of atmospheric pressure in the North Atlantic. This variability can be explained to some extent by the NAO Index (see Section 5.3). If we look at average temperatures in the North Atlantic, we can also see a pattern of variability of between 20-40 years which is described as the Atlantic Multidecadal Oscillation (see Section 5.2), and is thought to be a natural pattern. We also know that the-longer term changes that we see are in part driven by Global Climate Change.

'Anomalies'
Anomalies are the mathematical differences between each individual measurement and the average values of a parameter at each location. For example, positive anomalies in temperature mean warmer than normal conditions; negative anomalies mean colder than normal conditions. Anomalies and their calculation are described in more detail in Section G.3.

'Normalised'
For some figures, it makes sense to present normalised anomalies rather than the raw anomaly values. Normalised anomalies have been normalised by dividing the values by the standard deviation (σ) of the data during 1981–2010 (or the 2000–2010). A value of +2 thus represents data (temperature or salinity) at 2σ higher than normal. Normalisation is described in more detail in Section G.3.

Acronyms

AMO	Atlantic Multidecadal Oscillation
AW	Atlantic Water
BADC	British Atmospheric Data Centre
BODC	British Oceanographic Data Centre
CAW	Cooled Atlantic Water
CEH	Centre for Ecology and Hydrology
CET	Central England Temperature
COADS	Comprehensive Ocean-Atmosphere Data Set
CP2	Charting Progress 2
EC	East Coast
ESAI	East Shetland Atlantic Inflow
FAMRI	Faroe Marine Research Institute
FIC	Fair Isle Current
FIG	Fair Isle Gap
FSC	Faroe-Shetland Channel
G2G	Grid-to-Grid model
GISS	Goddard Institute for Space Studies
HadISST	Hadley Centre Sea Ice and Sea Surface Temperature
IBTS	International Bottom Trawl Survey
ICES	International Council for the Exploration of the Seas
IMR	Institute of Marine Research, Norway
IPCC	Intergovernmental Panel on Climate Change
IROC	ICES Report on Ocean Climate
JONSIS	Joint North Sea Information Systems
MCCIP	Marine Climate Change Impacts Partnership
MIDAS	Meteorological Office Integrated Data Archive System
MNAW	Modified North Atlantic Water
MS	Marine Scotland
MSS	Marine Scotland Science
NAO	North Atlantic Oscillation
NASA	National Aeronautics and Space Administration

NAW	North Atlantic Water
NCAR	National Center for Atmospheric Research
NERC	Natural Environment Research Council
NNS	Northern North Sea
NOCL	National Centre for Oceanography, Liverpool
NOCS	National Centre for Oceanography, Southampton
NOCSv2	National Centre for Oceanography, Southampton (NOCS) Flux Dataset v2.0
NRFA	National River Flow Archive
ODaT	Ocean Data Tool
OSPAR	Oslo Paris Commission for the Protection of the Marine Environment of the North-East Atlantic
SAMS	Scottish Association of Marine Science
SCObs	Scottish Coastal Observatory
SEPA	Scottish Environment Protection Agency
SES	Shelf Edge Study
SLCTT	Scotland's Long Coastal Temperature Time series
SMR	Scottish Marine Region
SNS	Southern North Sea
SOCSR	Scottish Ocean Climate Status Report
SPG	Sub-Polar Gyre
SPGI	Sub-Polar Gyre Index
SSA	Scottish Sea Area
SST	Sea Surface Temperature
WMO	World Meteorological Organization
WODC	World Oceanographic Data Centre

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