MCCIP Marine Climate Change Impacts Partnership

Topic

Sea Temperature

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Executive summary

Sea surface temperatures (SST) in the north east Atlantic and UK coastal waters have been rising since the 1980s, most rapidly in the southern North Sea and the English Channel. Despite a relatively cold winter in UK waters in 2005/2006 anomalously rapid warming in the spring and early summer meant that 2006 became the second warmest year in UK coastal waters since 1870.

The temperature of the upper ocean (0-800m) to the west and north of the UK has been generally increasing since the 1970s. A significant period of warming occurred from 1995 to 2003. The decadal-scale pattern of temperature around the UK reflects the mean conditions of the North Atlantic which has evolved from a maximum in the early 1960s and a minimum in the 1980s and 1990s.

West of the UK the water of the deep ocean (>1000m) comes from the Labrador Sea and has cooled since 1975. North of the UK, the deep water (800 m) flows from the Nordic Seas and shows no long-term trend since 1950.

In the northern North Sea the temperature is most strongly influenced by inflowing North Atlantic water, showing similar decadal variations and a general warming since the mid 1980s. In the southern North Sea, atmospheric forcing is the dominant influence, with ocean temperatures being generally cool from 1970 to 1987 when a "switch" to warm conditions occurred.

The upper 1500 m of the North Atlantic has warmed since 1999 and remains anomalously warm up to the end of 2006, especially in the zone between 50-70°N.

Full review

Sea Surface Temperature

Sea surface temperatures (SST) in the northeast Atlantic and UK coastal waters have been rising in recent decades (Figure 1). The warming has been most rapid in the southern North Sea and the English Channel. Figure 2 shows the annual-average SST in the UK coastal waters between 1870 and 2006. 2006 was nominally the second warmest year in this series, but it was a year of contrasts. The winter of 2005/2006 was colder than many recent winters and UK waters cooled to their lowest temperature in ten years (Figure 3). However, anomalously rapid warming in the spring and early summer meant that by July SSTs in the area had reached record levels. A cooler August followed, but from October to the end of the year SSTs were once again at record levels. Figure 3 also shows the range of monthly-average sea-surface temperatures observed in the past ten years and in the 1961-1990 **climatology period**. Warming is evident in all months, but it is in the latter half of the year that the warming is most marked.

In early 2006 in the wider North Atlantic a characteristic "tripole" SST pattern (anomalously cool tropics, warm mid-latitudes and cool subpolar latitudes) became strongly established and persisted up to May 2006. This SST pattern may have had an influence on winter 2006/07 in the UK, based on recent seasonal forecasting experience (Graham *et al.,* 2006).

Sea-surface temperatures in the North Atlantic have risen faster than the global-average over the past 25 years. The widespread and significant warmth of the North Atlantic over the past decade may be due in part to the **Atlantic Multi-decadal Oscillation (AMO)**, a natural mode of multi-decadal variability (Knight *et al.* 2005). Warming due to **anthropogenic effects** will be overlain on the slow oscillations of the AMO, which previously peaked in the 1940s.

Temperatures of Shelf Seas around the UK

Scotland and the south west of England are most strongly affected by changing oceanic conditions, the influence of which penetrates into the northern North Sea. The east coast of England is affected by conditions in the southern North Sea. Wales and the east coast of Northern Ireland border on the Irish Sea.

In the northern North Sea the temperature is most strongly influenced by inflowing North Atlantic water, showing similar decadal variations and a general warming since the mid 1980s (Figures 4,5).

In the southern North Sea, atmospheric forcing is the dominant influence, with ocean temperatures being generally cool from 1970 to 1987 when a "switch" to warm conditions occurred (Figures 6,7). Temperatures peaked in 2002 (highest area-averaged SST since 1968) and autumn 2006 (ICES, 2007).

Oceanic Temperatures around the UK

Observational evidence for changes in **deep ocean** temperature is relatively sparse. There are few long-term measurements of shelf or deep waters in the North Atlantic, though two of the longest (Faroe to Shetland since 1900, and Rockall Trough since 1948) are maintained by UK agencies. Offshore observations in the North Atlantic and Nordic Seas are summarised annually in the International Council for the Exploration of the Seas (ICES) Report on Ocean Climate (IROC) (ICES, 2007). Coastal and shelf sea monitoring stations are maintained around Scotland by the Fisheries Research Services, Marine Laboratory Aberdeen (FRS, 2007), and the Scottish Association for Marine Science, Oban.

The upper layer of the deep ocean (0-600m) around the UK is presently becoming warmer. Time series are noisy with large-scale, long-term patterns overlain by higher variability related to locally important processes such as changing positions of fronts, passing of eddies, river run-off, the changing inflow of different water masses, and the exchange of heat with the atmosphere. Over the last 50-60 years the large-scale mean temperature of the northern North Atlantic and Nordic Seas has evolved from a maximum in the early 1960s to a minimum in the 1980s and 1990s (IROC 2007). It is presently becoming warmer, exceeding previous measurements in 2003. The mean salinity shows a similar pattern (refer to Holliday et al, 2007, MCCIP Ocean Salinity document). This basin-wide, decadal-scale variability is overlain by shorter time-scale changes and regional patterns.

The surface layer of the ocean (the top 100m) is most heavily influenced by the atmosphere and is more variable than deep temperature. Below the surface, the deep ocean around the UK is strongly influenced by changes in ocean circulation, which in turn is affected by large-scale atmospheric conditions (Holliday, 2003, Hátún *et al*, 2005). Surface conditions in a few key locations remote to the UK, where surface water sinks into the deep ocean, also affect the temperature of UK deep waters (Dickson, *et al,* 2002).

The temperature of the upper ocean (0-600 m) to the west and north of the UK has been increasing since the 1970s (Figures 8, 9). There was a brief maximum in the early 1980s, but in 2003 temperatures reached the highest levels recorded since 1900, surpassing the previous peak in 1960. 2004-2006 have seen slight decreases in upper ocean temperature. The pattern reflects the changing balance of the inflow of subtropical (warm and salty) versus subpolar (cool and fresh) water into the area (Holliday, 2003).

Below 1000 m the deep ocean west of the UK has become cooler since 1975, reflecting a period of cooling in the **Labrador Sea** where the deep water originates (Figure 10). The Labrador Sea has become warmer again since the late 1990s, and we expect the deep water west of the UK will also increase in temperature over the next few years. There is some evidence to suggest that warming began in 2006. North of the UK, the deep water (800 m) flows from the Nordic Seas and shows no long-term trend since 1950 (Figure 11).

North Atlantic Ocean Temperatures

Analysis of data from profiling **Argo floats** has shown that the upper 1500m of the North Atlantic warmed throughout the period 1999 to 2005 (Ivchenko *et al* 2006). Warming was strongest in the zone 50-70°N but there is a complex variation in changes in heat content both with latitude and with depth. The North Atlantic remained anomalously warm, relative to long-term climatology, during 2006 (Johnson *et al.,* 2007).

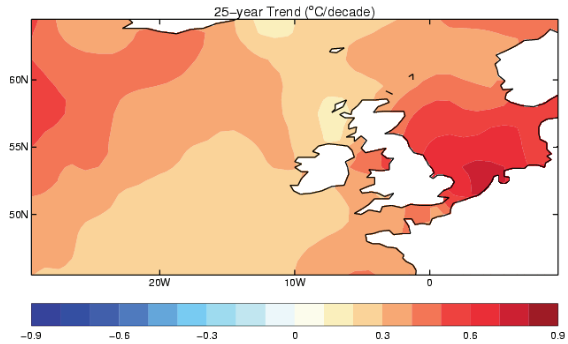

Figure 1: 25-year trend in sea-surface temperature (˚C decade^{-1}, 1982-2006) for the north east Atlantic. Data are from the HadISST data set (Rayner *et al.* 2003).

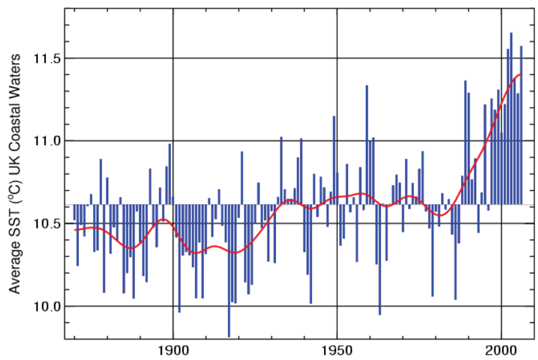

Figure 2: Time series of annual-average sea-surface temperature for UK Coastal Waters (7˚W-3˚E, 50˚N-60˚N) 1870-2006 from the HadISST data set (Rayner et al. 2003). The blue bars show the deviations of the annual averages from the 1961-1990 average and the red line shows the annual averages after smoothing with a **21-point binomial filter**, thus highlighting the decadal variability in the series.

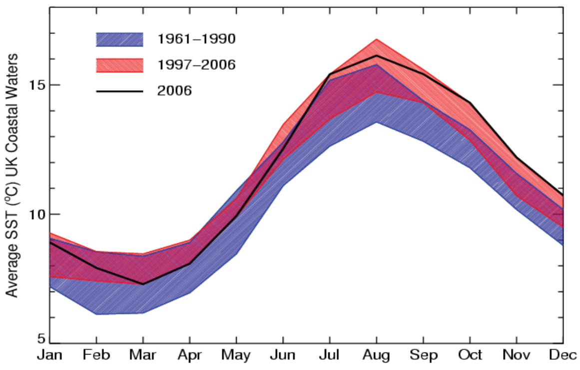

Figure 3: Seasonal cycle of monthly-average SST in UK Coastal Waters (7˚W-3˚E, 50˚N-60˚N) for 2006 (˚C, black). The blue shaded area shows the range of monthly-average SSTs from the 1961-1990 period. The red shaded area shows the range of monthly-average SSTs for the past ten years. Data are from HadISST (Rayner *et al.* 2003).

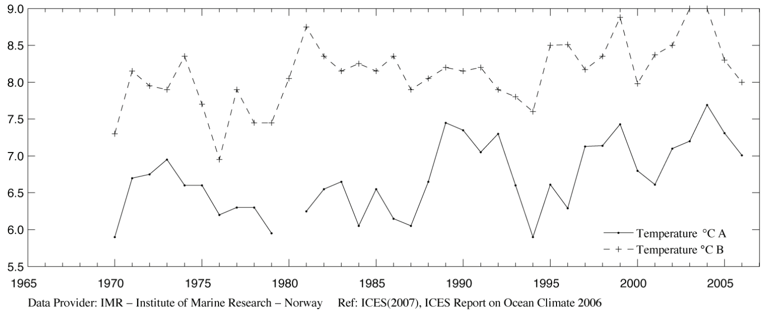

Figure 4: Northern North Sea. Temperature near the sea-floor in the northwestern part of the North Sea (A) and in the core of Atlantic Water at the western shelf edge of the Norwegian Trench (B) during the summers of 1975- 2006.

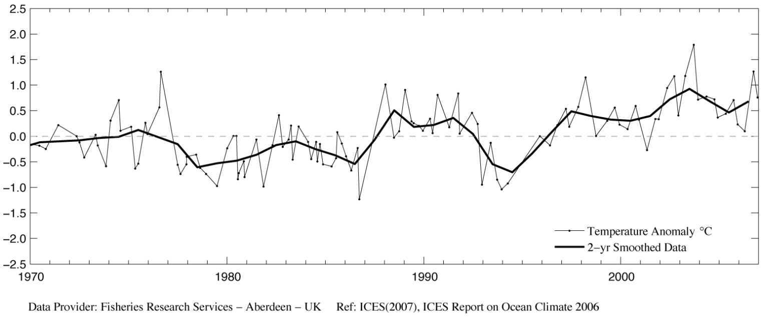

Figure 5: Northern North Sea. Temperature anomaly in the Fair Isle current entering the North Sea from the North Atlantic.

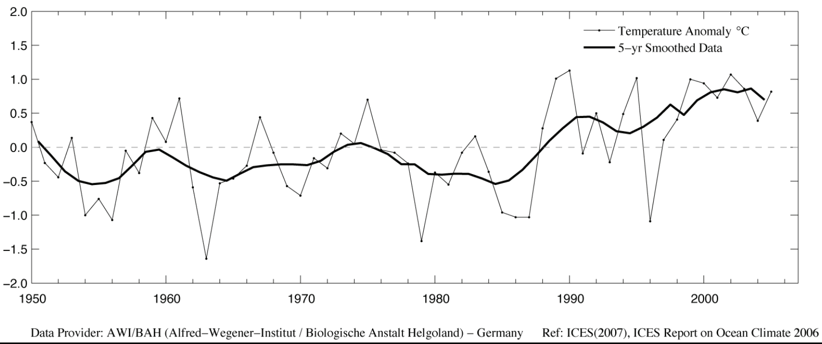

Figure 6: Southern North Sea. Annual mean surface temperature anomaly at Station Helgoland Roads.

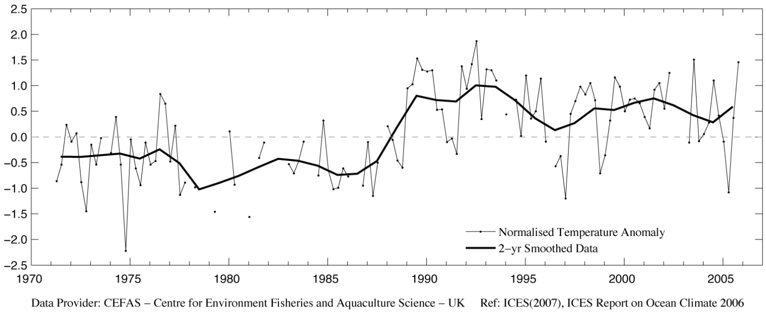

Figure 7: Southern North Sea. Normalised sea surface temperature anomaly relative to the period 1971-2000 measured along 52°N, a regular ferry at six standard stations. The time series show the seasonal section average (DJF, MAM, JJA, SON) of the normalised variable. The normalised value is the anomaly divided by the standard deviation.

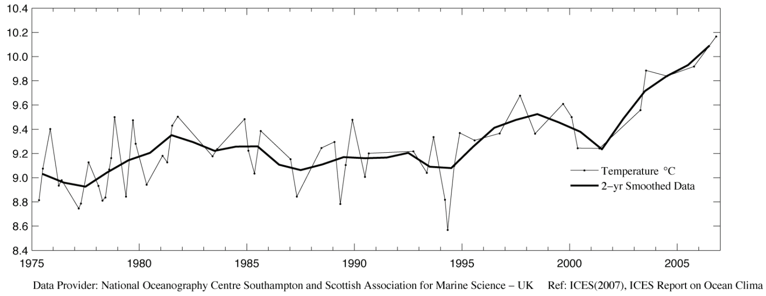

Figure 8: Rockall Trough. Temperature for the upper ocean (0–800 m).

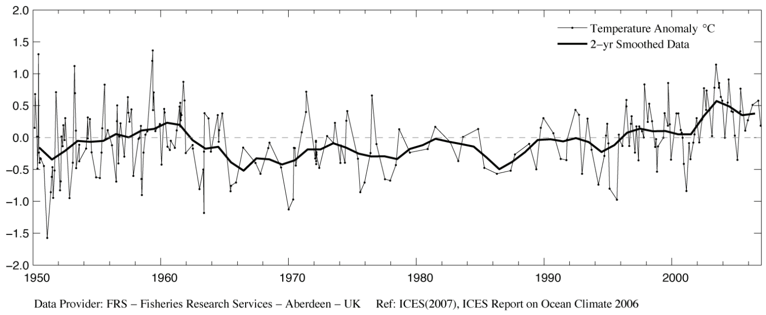

Figure 9: Faroe Shetland Channel. Temperature anomaly in the Atlantic Water in the Slope Current.

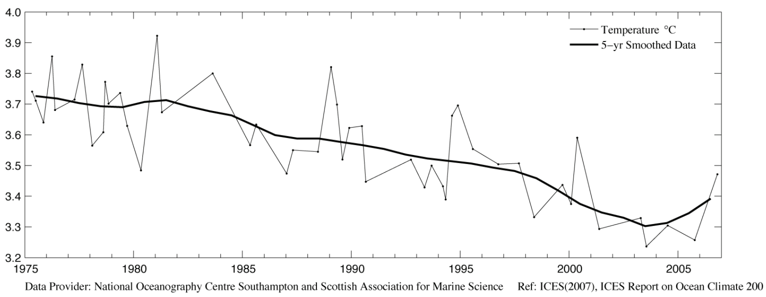

Figure 10: Rockall Trough. Temperature of Labrador Sea Water (depth 1800 - 2000m).

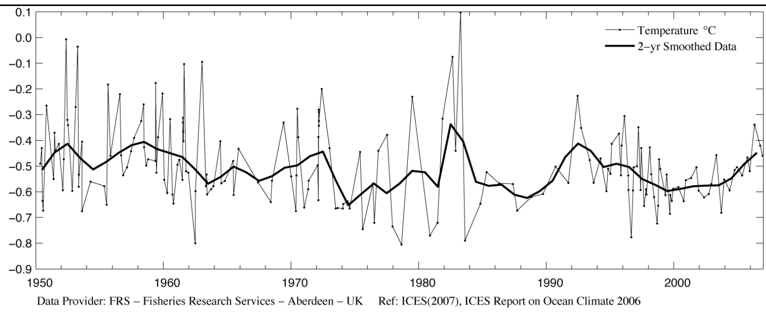

Figure 11: Faroe Shetland Channel. Temperature at 800m in the Faroe Shetland Channel.

Confidence Assessments

'What is already happening' - High

Confidence in the global increase in SST is high (e.g. IPCC 2007), and UK waters are relatively well sampled.

Time series of measurements of water temperature with depth in UK waters have moderate confidence due to relatively sparse observations and a fairly poor sampling of the seasonal cycle. However the observations themselves are typically of good quality and show a consistent overall picture which is well understood, giving a medium confidence overall.

Temperature profile information in the North Atlantic is now much better sampled than in the past due to the deployment of many **Argo profiling floats**. However questions of biases in recent batches of floats (Willis *et al.* 2007) and in homogeneity between Argo and **eXpendable BathyThermographs (XBT's)** data (Gouretski & Koltermann, 2007) mean the overall confidence probably remains moderate, pending further research.

Knowledge Gaps

More stations and improved sampling of the seasonal cycle would be desirable for subsurface ocean temperatures. The available sampling is not sufficient for a full understanding of variability and hence reduces confidence in the representativeness of measurements made.

The deep ocean (below ca. 2 km depth) is poorly sampled.

For the surface to mid-depth ocean questions of the homogeneity of data from Argo floats and between Argo and other sampling technologies (e.g. XBT's) remain.

SST is reasonably well measured, but requires continuity of satellite missions and availability of adequate *in situ* data for validation and bias adjustment. Recent rapid changes in the *in situ* observing system means that the homogeneity of the current observing system, and its consistency with earlier observations, needs urgent assessment.

Commercial Impacts

Not stated

References

Dickson, R., I. Yashayaev, J. Meincke, W. R. Turrell, S. Dye, and J. Holfort, (2002), Rapid freshening of the deep North Atlantic Ocean over the past four decades, Nature, 416, 832-837.

Fisheries Research Services. (2007). The Scottish Ocean Climate Status Report 2004 and 2005. Hughes, S.L. (ed.) Aberdeen: Fisheries Research Services.

Gouretski V., and K. P. Koltermann (2007), How much is the ocean really warming?, *Geophys. Res. Lett.*, *34*, L01610, doi:10.1029/2006GL027834.

Graham, R. J., and 15 others (2006). The 2005/06 winter in Europe and the United Kingdom: Part 1 – How the Met Office forecast was produced and communicated. Weather, 61, 327-336.

Hátún, H., A. B. Sando, H. Drange, B. Hansen and H. Valdimarsson, (2005), Influence of the Atlantic subpolar gyre on the thermohaline circulation, Science, 309, 1841-1844.

Holliday, N. P. (2003), Air-sea interaction and circulation changes in the northeast Atlantic, Journal of Geophysical Research, 108, 3259, doi:3210.1029/2002JC001344.

ICES, 2007, ICES Report on Ocean Climate 2006, Ed: Hughes S.L. and N. P. Holliday. ICES Cooperative Research Report (in press).

Intergovernmental Panel on Climate Change (2007) Climate Change 2007 - The Physical Science Basis Contribution of Working Group I to the Fourth Assessment Report of the IPCC (available from http://ipcc-wg1.ucar.edu/)

Ivchenko, V. O., N. C. Wells and D. L. Aleynik (2006). Anomaly of heat content in the northern Atlantic in the last 7 years: Is the ocean warming or cooling? Geophys. Res. Lett., 33, L22606, doi:10.1029/2006GL027691.

Johnson, G. C., J. M. Lyman and J. K. Willis (2007). State of the Climate in 2006: Ocean Heat Content. For Bulletin of the American Meteorological Society (http://www.pmel.noaa.gov/people/gjohnson/BAMS_2006_OHCA.pdf)

Knight J. R., R. J. Allan, C. K. Folland, M. Vellinga and M. E. Mann, (2005), A signature of persistent natural thermohaline circulation cycles in observed climate. Geophys. Res. Lett. 32: L20708, doi:10.1029/2005GL024233.

Lyman, J. M., J. K. Willis, and G. C. Johnson (2006). Recent cooling of the upper ocean. Geophys. Res. Lett., 33, L18604, doi:10.1029/2006GL027033.

Rayner, N.A., D. E. Parker, E. B. Horton, C. K. Folland, L. V. Alexander, D. P. Rowell, E. C. Kent and A. Kaplan, (2003), Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late Nineteenth Century. Journal of Geophysical Research, 108, (D14), 4407. (doi:10.1029/2002JD002670).

Willis, J. K., J. M. Lyman, G. C. Johnson and J. Gilson, (2007), Correction to "Recent Cooling of the Upper Ocean". Submitted to Geophysical Research Letters (see

http://www.pmel.noaa.gov/people/lyman/Pdf/heat_2006.pdf)
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