Memo

DONG energy

Subject	GOW01 and GOW02, Cables
To	[redacted]
Copy	[redacted]
From	[redacted]
Regarding	Thermal conductivity etc. of seabed

DONG Energy A/S
Nesa Allé 1
2820 Gentofte
Denmark

[redacted]

www.dongenergy.com
Company no. 36 21 37 28

13 March 2013

Our ref. XCABK/XCABK
Doc. no. 1493660
(ver. no. 1493660A)
Case no. 200-12-2748
[redacted]

1. Introduction

After a summary of the upper soil layers this memo presents the results from laboratory tests determining the thermal conductivity of the top soils; results are attached. In addition indications of the seabed temperatures are illustrated by examples found on the internet; chosen pages are attached.

The only tests of the thermal conductivity at the two wind farms are performed during the recent investigations for the two substations OSS11 and OSS21. The samples are taken at depths of 0.00-2.40m.

Previous DONG-documents from other wind farms are not found, but should be searched. Maybe the LAC-tean[redacted]) can guide further.

2. Geology

The seabed sand cover is to a depth of 1.2-5 m in a Very loose to Loose state; in general the loose sand layer is thickets in the deepest (northern) part of the wind farms. The sand is often silty and in nearly half of the borings/CPTs a small cohesive layer of peat and/or, clay is found at the base of the loose sand.

Below this loose cover is far more dense sand deposited by melt water/diluvial streams from the glaciers of the Ice Age and compacted by later ice caps etc. For further details see Doc. no 1380869, Memo of 07.11.2012 with cross sections forwarded to MIKNI, ANDRE and MARTU.

3. Thermal conductivity

GOW01, Substation OSS11:
The loose sand is 1.20m thick with a peat layer from 0.60-0.80m. The thermal conductivity is determined at two samples of Sand above respectively below the peat layer to 2.5-2.7W/(m x K). The thermal conductivity of the Peat is determined to 0.55-0.58W/(m x K).

GOW02, Substation OSS21:
The loose sand is 1.90m thick with a peat layer from 1.50-1.70m. The thermal conductivity is determined at two samples **above** the peat to 2.3-2.4W/(m x K) and one sample below the peat to 2.7-2.8W/(m x K). There is no test at the peat here; it might be a little higher than at OSS11 because of a denser state.

4. Temperature and currents

From Wikipedia is quoted: (The first mentioned temperatures are believed to be water temperatures, taking the context into consideration)

Temperature and salinity

The average temperature in summer is 17 °C (63 °F) and 6 °C (43 °F) in the winter.[4] The average temperatures have been trending higher since 1988, which has been attributed to climate change.[15][16] Air temperatures in January range on average between 0 to 4 °C (32 to 39 °F) and in July between 13 to 18 °C (55 to 64 °F). The winter months see frequent gales and storms.[1]

The salinity averages between 34 to 35 grams of salt per litre of water.[4] The salinity has the highest variability where there is fresh water inflow, such as at the Rhine and Elbe estuaries, the Baltic Sea exit and along the coast of Norway.[17

Water circulation and tides

The North Sea is an arm of the Atlantic Ocean receiving the majority of ocean current from the northwest opening, and a lesser portion of warm current from the smaller opening at the English Channel. These tidal currents leave along the Norwegian coast.[19] Surface and deep water currents may move in different directions. Low salinity surface coastal waters move offshore, and deeper, denser high salinity waters move in shore.[20]

The North Sea located on the continental shelf has different waves than those in deep ocean water. The wave speeds are diminished and the wave amplitudes are increased. In the North Sea there are two amphidromic systems and a third incomplete amphidromic system.[21][22] In the North Sea the average tide difference in wave amplitude is between 0 to 8 metres (0 to 26 ft).[4]

The Kelvin tide of the Atlantic ocean is a semidiurnal wave that travels northward. Some of the energy from this wave travels through the English Channel into the North Sea. The wave still travels northward in the Atlantic Ocean, and once past the northern tip of Great Britain, the Kelvin wave turns east and south and once again enters into the North Sea.[23]

More specific informations are found in the attached pages from:

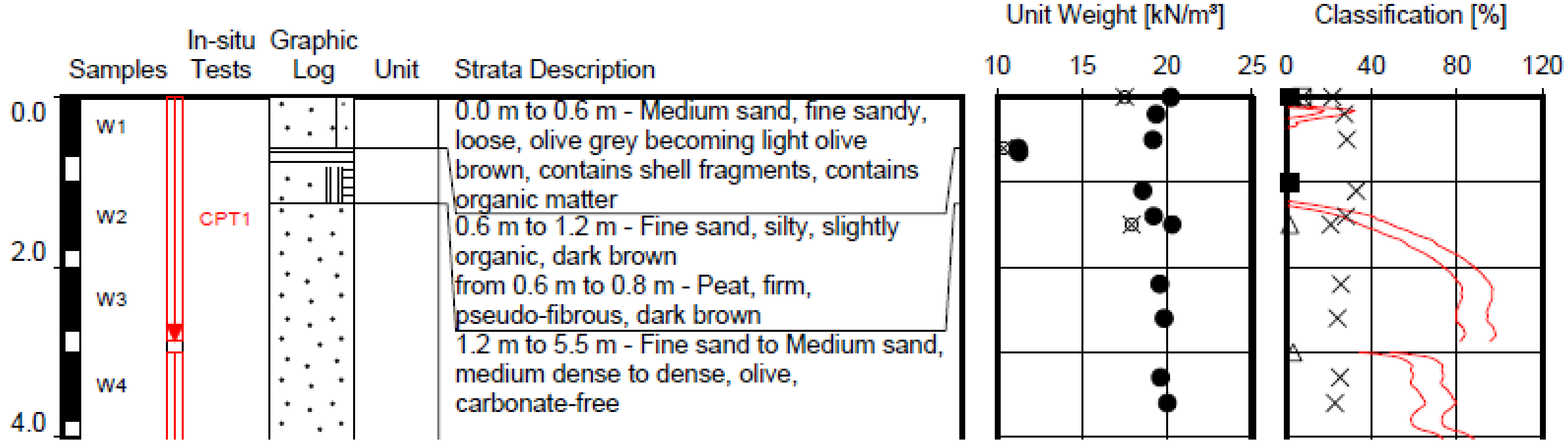
NORSEPP: Update report on North Sea conditions- 2nd quarter 2007
(seabed and German Bight mentioned)

MEFEPO: North Sea Atlas, August 2007

[redacted]

GOW01, OSS11_Sub_BH

GEOTECHNICAL LOG (Top 4 m), Plate A1 in Fugro report N5686_2 (3)

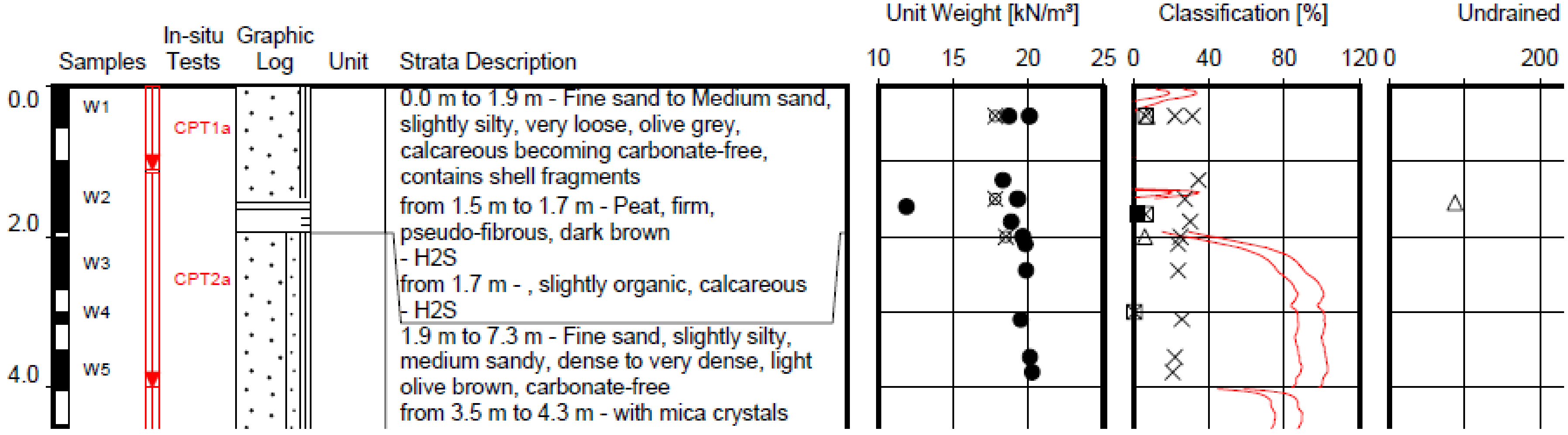


Compendium of general information, ... results of geotechnical standard laboratory tests, Plate C2-33,Fugro report N5686_2 (3)i

	Geotechnical standard tests											
	Water content	Density of soil				Particle density	Total carbonat content	Loss on ignition	Thermal conductivity			
		Wet/Dry density		Min./Max density					Test 1		Test 2	
Sample depth		Wet density	Dry density	Min. dry	Max. dry				Wet density	Therm. cond.	Wet density	Therm. cond.
-	DIN 18121	DIN 18125-1	DIN 18125-1	DIN 18126	DIN 18126	DIN 18124	DIN 18129	DIN 18128	DIN 18125-1		DIN 18125-1	
[m]	[%]	[g/cm³]	[g/cm³]	[g/cm³]	[g/cm³]	[g/cm³]	[%]	[%]	[g/cm³]	[W/(m*K)]	[g/cm³]	[W/(m*K)]
0,00 - 0,45	21.50	1.780	1.465	1.419	1.722	2.668	7.430	1.40	1.780	2.619	1.788	2.696
0,60 - 0,70	393.42	1.065	0.216	-	-	-	-	-	1.065	0.582	1.072	0.550
1,00 - 1,15	-	-	-	-	-	-	-	1.62	-	-	-	-
1,50 - 1,80	20.99	1.829	1.512	-	-	-	-	-	1.829	2.494	1.839	2.628

GOW02, OSS21_Sub_BH

GEOTECHNICAL LOG (Top 4 m), Plate A1 in Fugro report N5686_2 (3)



Compendium of general information, ... results of geotechnical standard laboratory tests, Plate C2-33,Fugro report N5686_2 (3)i

	Geotechnical standard tests											
Sample depth	Water content	Density of soil				Particle density	Total carbonat content	Loss on ignition	Thermal conductivity			
		Wet/Dry density		Min./Max density					Test 1		Test 2	
		Wet density	Dry density	Min. dry	Max. dry				Wet density	Therm. cond.	Wet density	Therm. cond.
-	DIN 18121	DIN 18125-1	DIN 18125-1	DIN 18126	DIN 18126	DIN 18124	DIN 18129	DIN 18128	DIN 18125-1		DIN 18125-1	
[m]	[%]	[g/cm³]	[g/cm³]	[g/cm³]	[g/cm³]	[g/cm³]	[%]	[%]	[g/cm³]	[W/(m*K)]	[g/cm³]	[W/(m*K)]
0,40 - 0,50	22.11	1.818	1.489	1.430	1.742	2.662	6.260	1.77	1.818	2.399	1.810	2.320
1,50 - 1,70	27.10	1.818	1.431	-	-	-	-	-	1.818	2.396	1.820	2.398
1,70 - 1,95	-	-	-	-	-	-	6.560	2.00	-	-	-	-
2,00 - 2,35	24.65	1.886	1.513	-	-	-	-	-	1.886	2.738	1.891	2.751

NOTE: Sample "1.50-1.70m" is only representative for the SAND at 1.50m, cf. Labotatory Classification Test Results, Plate C2-1 in the report

PEAT at 1.50-1.70m has a water content 253 % and wet density 1.20g/cm^2

ICES/EuroGOOS North Sea Pilot Project – NORSEPP ICES/EuroGOOS Planning Group for NORSEPP (PGNSP)

Update report on North Sea conditions – 2nd quarter 2007

Editor:
Hein Rune Skjoldal
Institute of Marine Research
Bergen, Norway

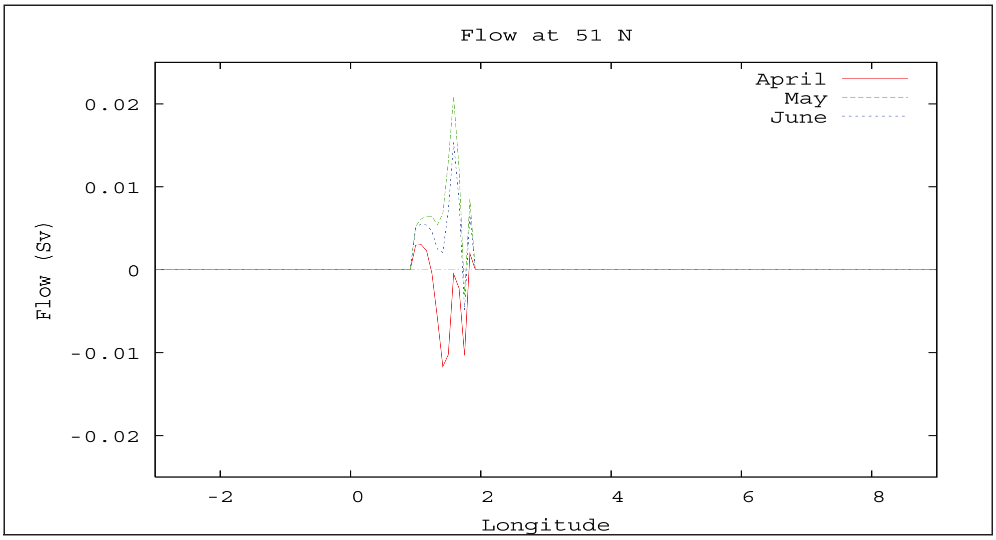


Figure 7. Modelled monthly averaged transports across 4 E-W sections in the North Sea at 57, 55, 53, and 51°N latitude, computed with the Optos_nos model (MUMM, Belgium).

Distribution and properties of water masses

Sea surface temperature

Monthly mean sea surface temperatures over the North Sea for January through October 2007 are shown in Figure 8, while monthly mean temperature anomalies (deviation from long-term climatology) for the same time period are shown in Figure 9.

The sea surface temperature increased somewhat from the winter minima in February and March to around 8–10 °C in April. The temperature increased further during the 2nd quarter to mean values of 11–12 °C in the northern and 15–16 °C in the southeastern parts of the North Sea (Figure 8). The North Sea had been unusually warm during the preceding autumn and winter, with positive temperature anomalies of 1–4 °C over the central and southern areas. This situation persisted during the 2nd quarter although the anomalies decreased somewhat to about +1–2 °C in June (Figure 9).

Modelled monthly mean sea bed temperature

The UK Met Office runs the POLCOMS shelf seas modeling system developed by Proudman Oceanographic Laboratory (POL; www.pol.ac.uk) for a variety of configurations for the NW European shelf and adjacent waters. Surface forcing is taken from the available Met Office numerical weather prediction (NWP) models, either the 40km global NWP model, or for the NW European shelf the 12 km mesoscale (to be replaced by 12 km North Atlantic European) NWP model.

The results presented below are taken from the 7 km Medium Resolution Continental Shelf POLCOMS model, which is nested within the ~12 km Atlantic Margin POLCOMs model. In turn the Atlantic Margin Model (AMM) is nested into the Atlantic FOAM model at the open ocean boundaries. A summary of the model configurations was given in the NORSEPP 2Q

The monthly mean modelled seabed temperature for January to October 2007 is presented in Figure 10. The modelled seabed temperature increased little during the 2nd quarter for the northern and central North Sea where seasonal stratification typically develops. The shallow waters of the southern and eastern North Sea in contrast warmed to around 15–16 °C in June.

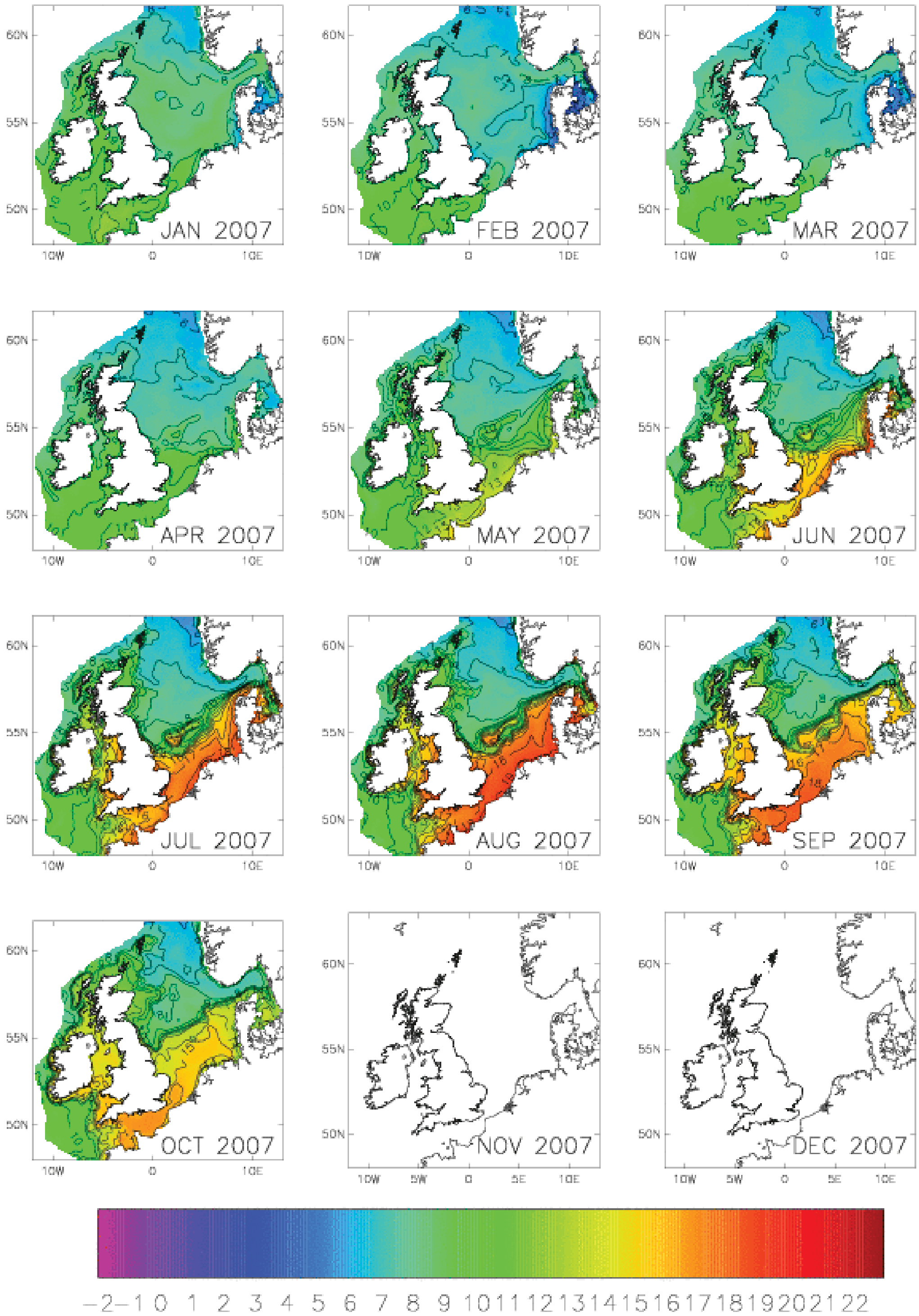


Figure 10. Monthly mean modelled near-bed temperature from the Met Office run of the MRCS POLCOMS model, from January to October 2007.

Modelled distributions of temperature and salinity in the central and southern North Sea

Maps of modelled monthly averaged surface and bottom temperatures and salinities computed by the Optos_NOS model operated by MUMM (Belgium) are presented in Figures 11 and 12.

Higher temperatures in the surface than at the bottom are indicative of stratification. This took place in the offshore areas west of Denmark in April and over most of the central North Sea in May (Figure 11). The Southern Bight and the eastern part of the Channel are typically tidally mixed with little difference in temperature or salinitiy between the surface and bottom.

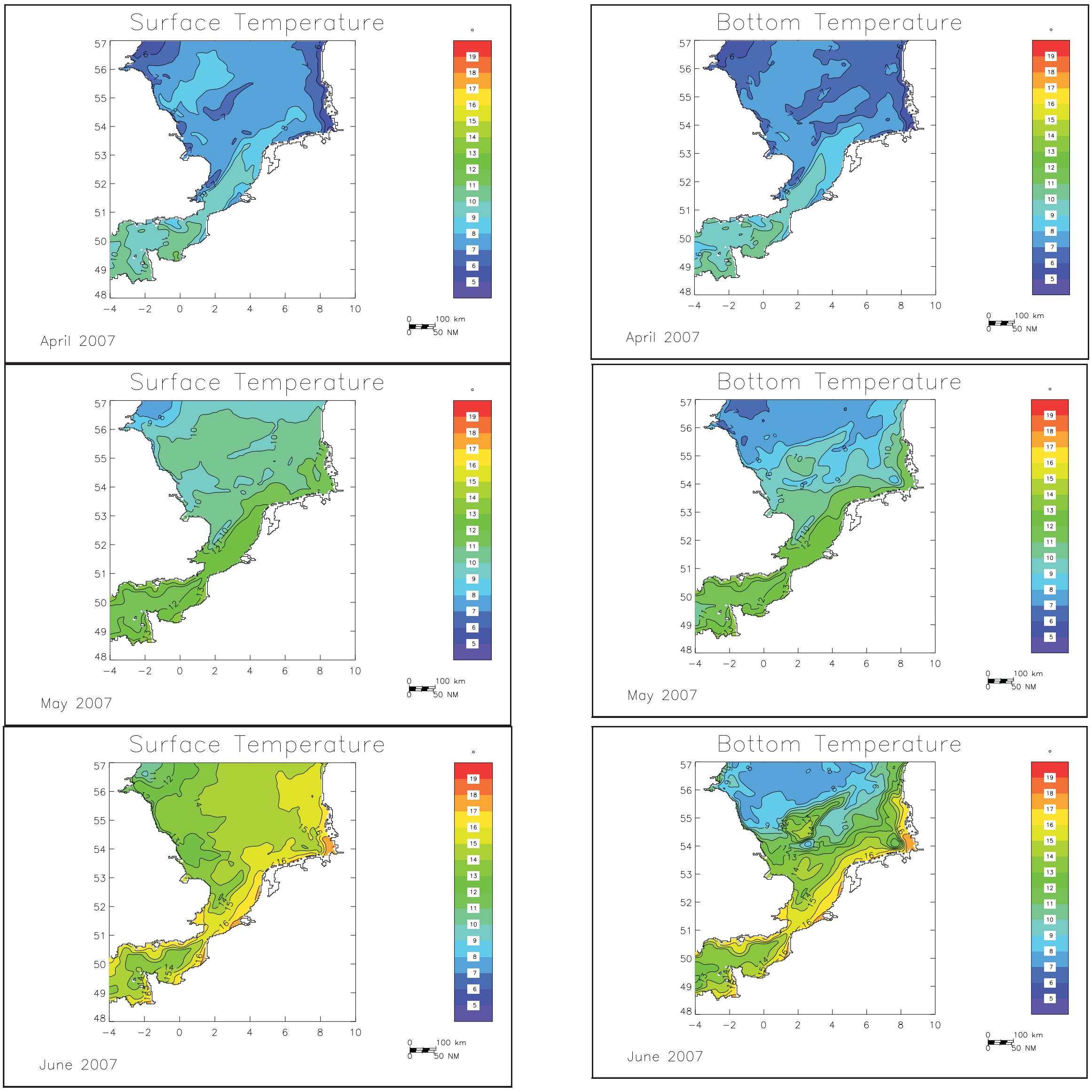


Figure 11. Monthly average of the surface and bottom temperature computed with the Optos_nos model in April, May and June 2007. From MUMM, Belgium.

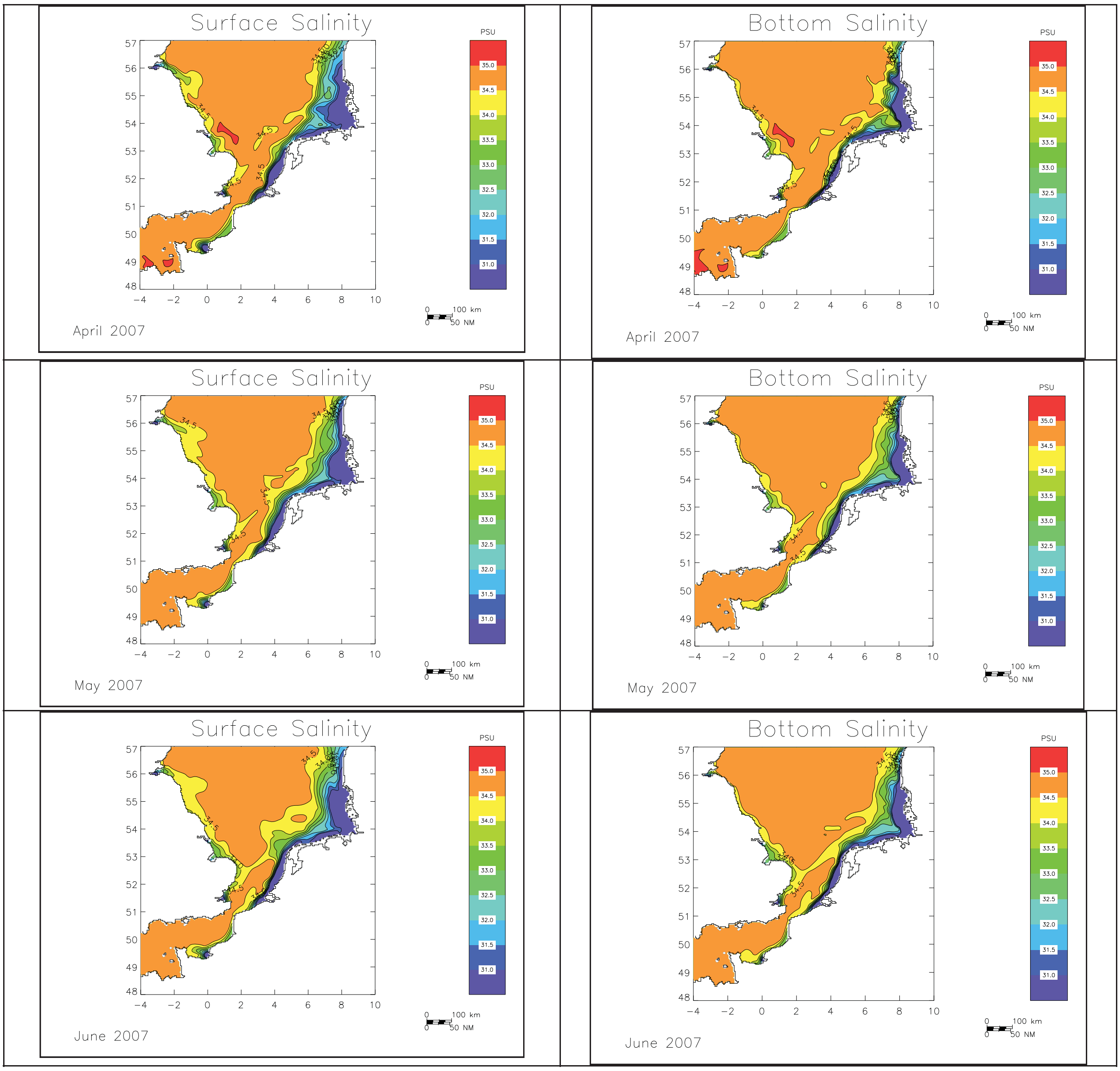


Figure 12. Monthly average of the bottom and surface salinity computed with the Optos_nos model in April, May and June 2007. From MUMM, Belgium.

Seasonal temperature development in the German Bight

Temperature recordings from the Ems station in the German Bight are shown in Figure 13. The temperature increased from about 8 ^{o}C in the beginning of April to 15–16 ^{o}C by the end of June. Periods of stratification, evidenced by higher temperature in the surface layer than deeper down, occurred around mid April, in late April and early May, and again in June. Stratification was particularly strong in the first part of June when the sea surface temperature reached 17–18 ^{o}C.

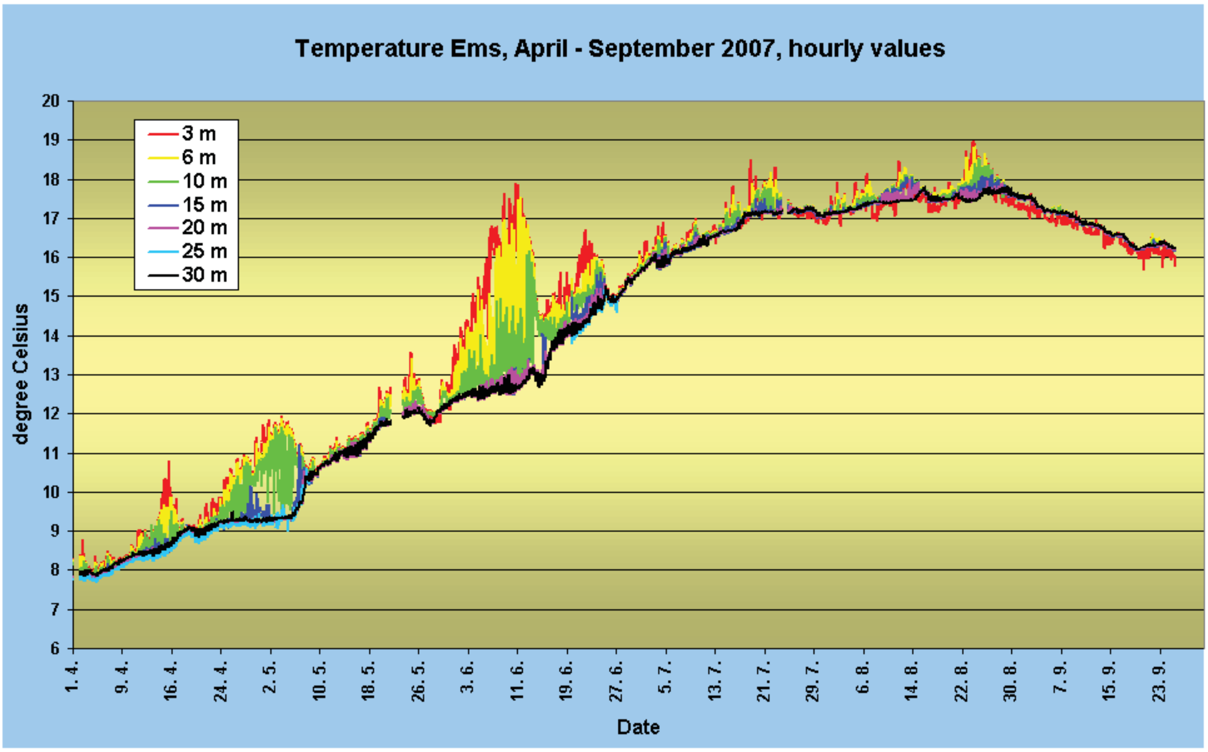


Figure 13. Temperature at different depths of the water column at the Ems monitoring station in the German Bight from 1 April to the end of September 2007. From BSH.

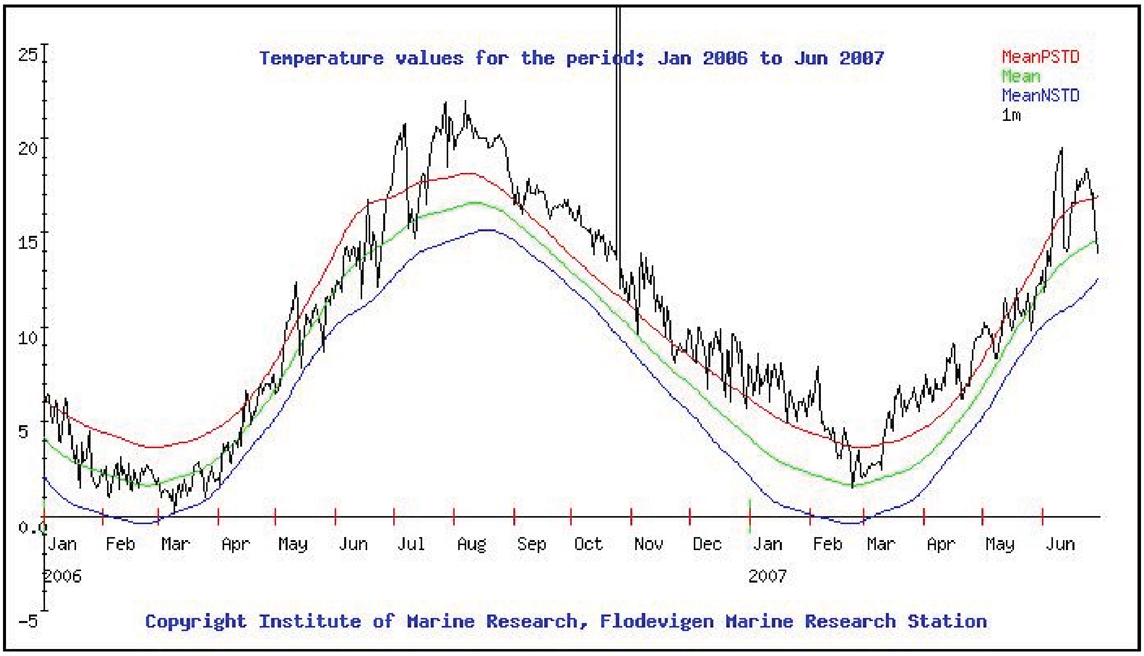


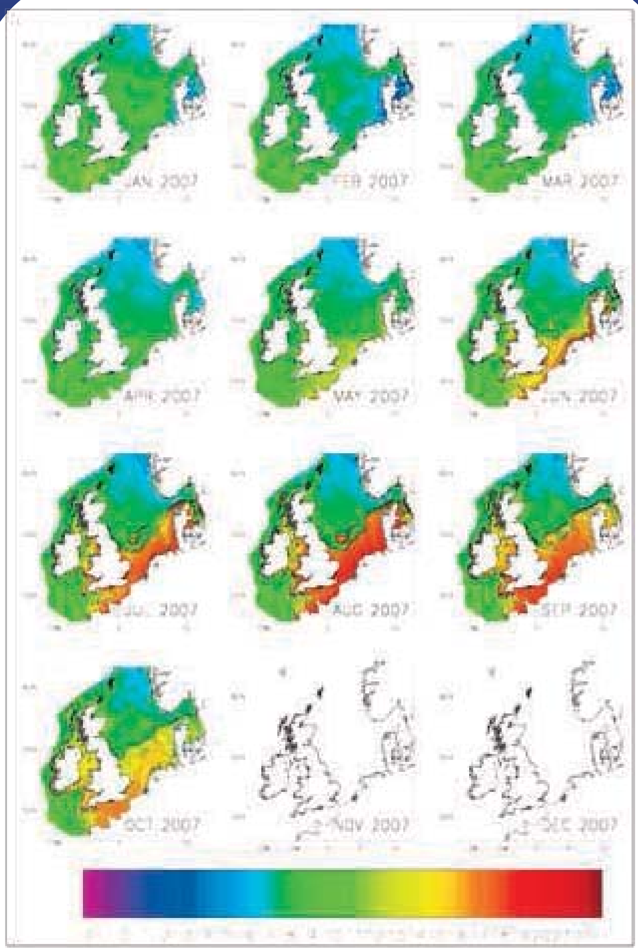
Figure 14. Daily sea surface temperature recordings at Arendal on the Norwegian Skagerrak coast from January 2006 to June 2007. Also shown is the long-term average temperature +/− 1 SD (standard deviation). Data from Institute of Marine Research (IMR).

Bottom Temperature

The temperature of bottom waters (those near or on the sea bed) tends to be more stable than that on the surface. It is largely affected by the water bodies entering the North Sea from the Atlantic Ocean. Cold water flows into via northern North Sea and remains below the surface mixed layer . In the southern North Sea warmer water enters the southern basin via the English Channel. The shallow nature of the southern basin and the English Channel and the strong tidal flows mean that this region is well mixed and bottom water temperatures follow those of the surface waters.

The temperature of the sea bottom shows strong seasonal patterns. Long term variability is closely correlated with circulation in the atmosphere and in particular the pattern of wind, which in turn is driven by variation in the distribution of atmospheric pressure.
In the North Sea, the winter bottom temperature has increased by 1·6 °C over 25 years, with a 1 °C increase in 1988-1989 alone. On average temperatures have increased by between a quarter and half a degree centigrade per decade.

Climate Change
Climate change is affecting the distribution of fish as they move towards their preferred temperature range.
If the sea temperature increases, fish at the northern limit of their temperature range will have new, more northerly areas to move into as formerly cold water becomes more habitable. In contrast, fish at the southern limit of their range will be forced to move northwards to escape the rising temperatures. Analyses indicate that this is already happening (see opposite).

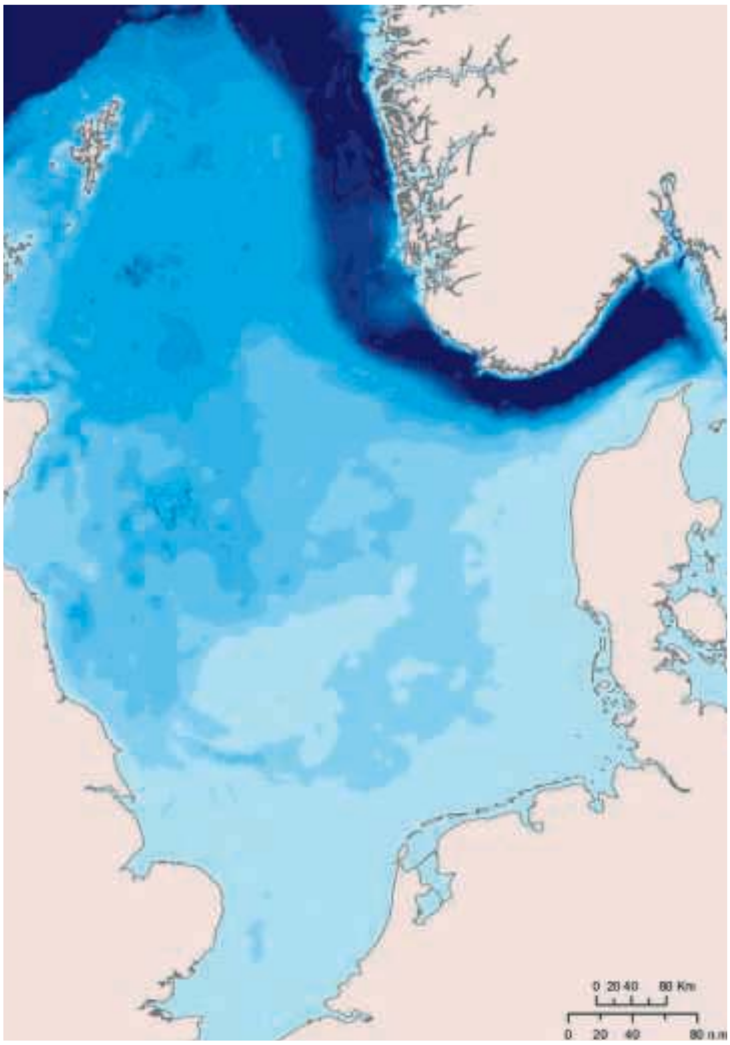


Monthly near-bed temperatures in 2007. (Source: Skjoldal, 2007)

MEFEPO

Making the European Fisheries Ecosystem Plan Operational

North Sea Atlas



August 2009

Surface Temperature

We consider the effects of both surface and bottom temperatures separately because they affect very different environments and systems.

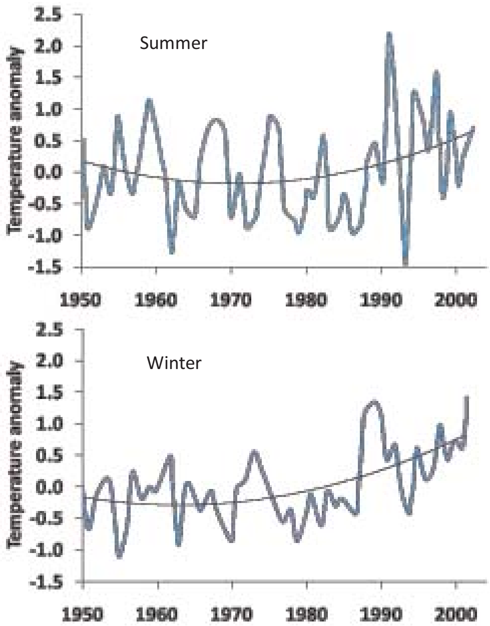
Sea surface temperatures (SST) follow a strong annual cycle (see maps opposite). SST is affected by heating by the sun and heating/cooling through contact with the air, which is accentuated during high wind conditions. It is also influenced by mixing of surface water with deepwater caused by wind or tidal currents in shallow areas; by the inflow of freshwaters, in particular cold water following the spring melting of ice and snow; and by the temperature of water entering from the Atlantic and Channel, the temperature and volume of which vary interannually in response factors such as large scale atmospheric patterns such as the North Atlantic oscillation.

The temperature of surface waters varies more than the temperature of deeper waters as they are exposed to a greater number of parameters. This means that there is more 'disturbance' in these areas and the organisms need to be tolerant of a wide range of temperatures.

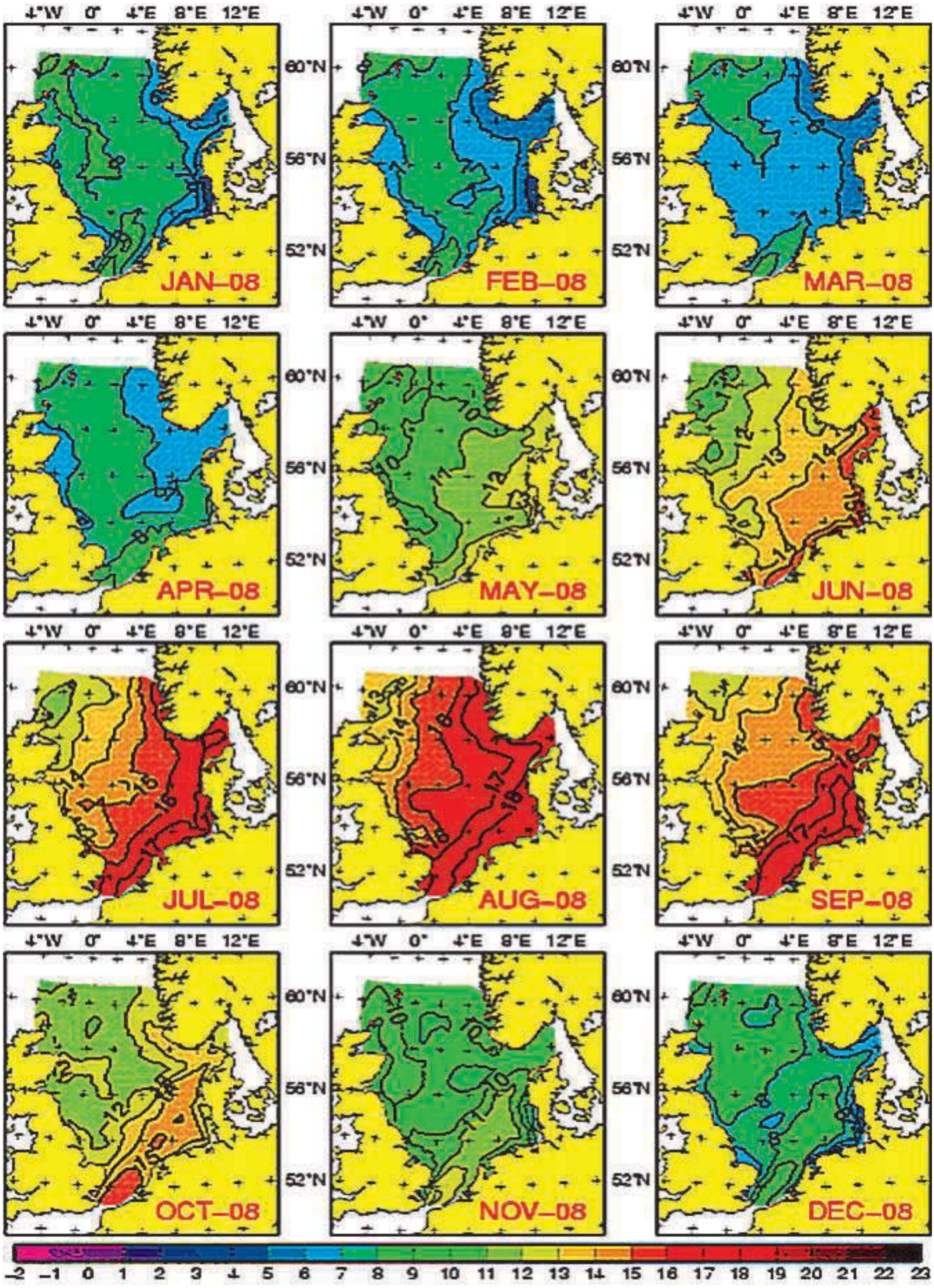
Changing temperature has implications for the organisms which live in marine habitats. Most marine organisms are cold blooded and so changes in temperature directly affect biological processes such as their growth, metabolic rate and hence food requirements. Temperature also provides a cue for many organisms triggering events such as migration or breeding. As different species respond differently to changes in temperature, there is the possibility that warming of the seas may lead to biological events becoming decoupled. For example, prey populations may increase earlier in the year, while other animals continue to breed as they do now, so their larvae fail to synchronise with the period of maximum food availability.

The temperature of the surface water also affects organisms which require light (such as the plant component of the plankton) and their predators (such as fish larvae and crustaceans in the plankton).

Over the entire North Sea, both summer and winter sea surface temperatures have been increasing since the 1970s with increased interannual variability in summer temperatures also occurring. SST in the North Sea has been above its long-term mean (1950-2008) in recent years, with the exception of winter 1996. While the years since 1989 have been above the long-term mean, no clear rising trend is visible; instead an increase (around 0.5 to 1.0 °C) occurred at the end of the 1980s after which temperatures stayed high.



Summer (top) and winter (bottom) temperature anomalies, 1950-2002 in the northern North Sea. Anomalies produced by subtracting the mean for the whole period.



Temperature in °C

The annual cycle of surface temperatures of marine waters in the North Sea (scale in degrees Celsius). (Source: BSH, 2008)

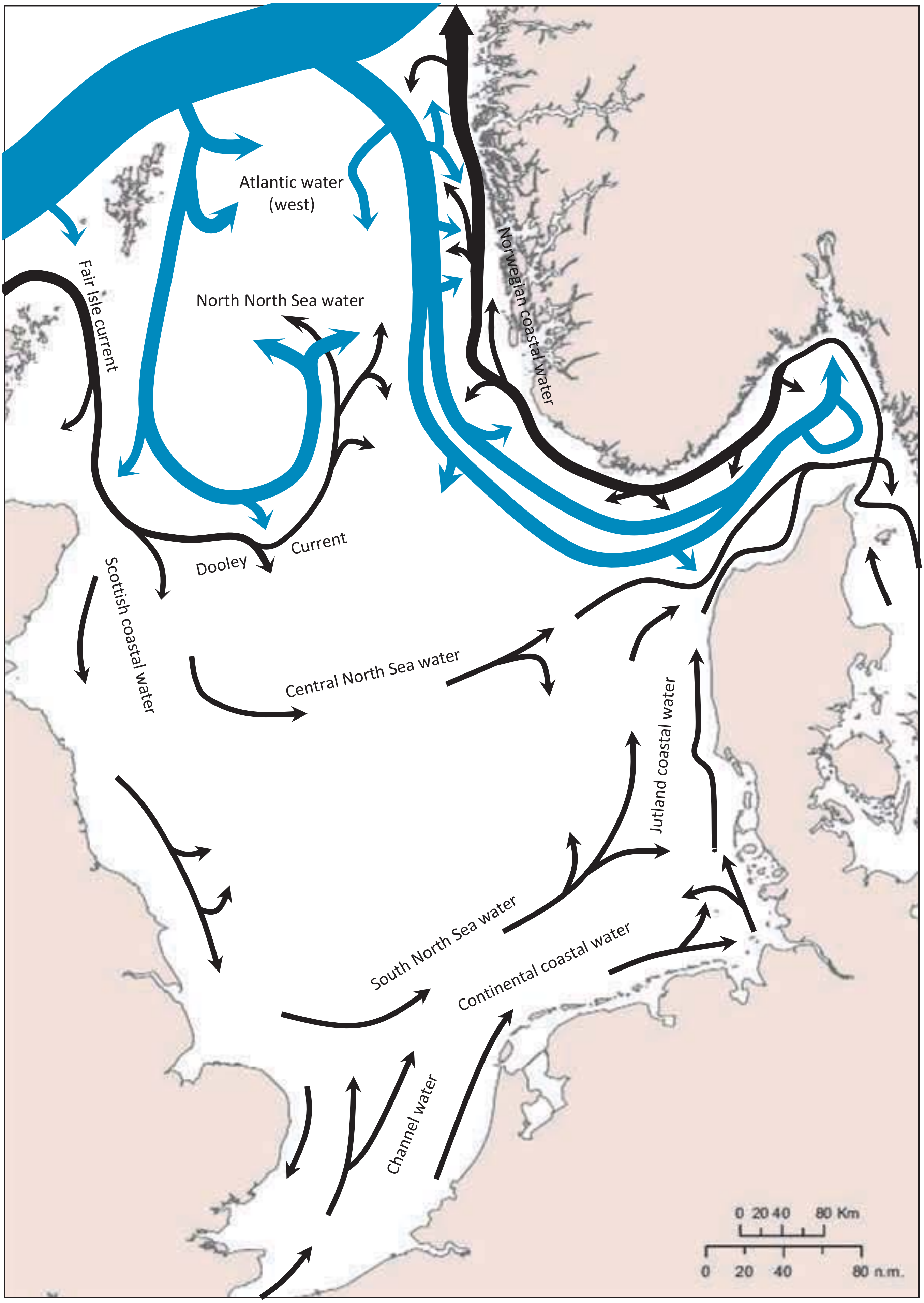
Currents and Circulation

Water enters the North Sea through two main routes:

- from the northern North Sea
  - this is the main inflow of water into the North Sea
  - water enters via the Fair Isle Channel and either the northern North Sea Plateau or along the Norwegian Trench
  - inflow through this route is strongly correlated to climatic conditions (the North Atlantic Oscillation)
- from the English Channel
  - this a smaller, warmer and more saline flow than the northern inflow
  - water flow into the North Sea has increased significantly through this route since 1958.

Water leaves the North Sea via the Norwegian coastal current. This current is a combination of wind-driven coastal water from the southern North Sea, saline water from the western North Sea and low salinity water from the Baltic Sea outflow.

The source and volume of water entering the North Sea is highly variable between seasons and years, and is strongly correlated to climatic conditions (mainly the North Atlantic Oscillation).



Schematic diagram of circulation in the North Sea. Arrow width represent the magnitude of volume transport. Blue arrows indicate the flow of Atlantic water and black arrows water of other types (Source: Turrell, 1992; OSPAR, 2000)