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BEAWARE II :
Review of the physical oceanography in the area of the Bonn Agreement

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1. Introduction

The BE-AWARE I and II projects are projects coordinated by the Bonn Agreement secretariat in order to further develop and coordinate the response capacities to face oil pollution in the areas under the jurisdiction of the Bonn Agreement Contracting Parties (*i.e.*, the North Sea States and the European Union).

The BE-AWARE I project (2012-2014) assess the risk of oil pollution both now (2011) and in the future (2020) as well as the likely size of any spills. However in order to assess which methods and technologies will be most effective in reducing and responding to oil pollution further analysis is required.

BE-AWARE II (2013-2015) aims therefore at modeling the behavior (drift and fate) of the oil coming from the spills identified in BE-AWARE I. For each spill, ten different scenarios are considered taking into account the main characteristics of the hydrodynamics of the North Sea Regions. Combined with an analysis of the environmental and socio-economic sensitivity of the region allows assessing the impact of the different scenarios. Risk management conclusions are then drawn for different sub-regions.

This report is intended to provide a review of the physical oceanography of the project area. The focus will be on those physical processes that influence the transport and fate of an oil spill: *i.e.*, tidal currents, winds, storms, waves, temperature, salinity, density, ... Note that this report is neither a scientific review nor a research paper and contains no original work. It is a technical report that conveys the essential nature of the hydrography and its forcing in the area. All the information is coming from published reports and papers that have greatly contributed to the knowledge of the region.

The report is organized as follows. In the following sections, broad-scale data for the whole Bonn Agreement Area are illustrated and discussed. This includes: seabed bathymetry; tides (*i.e.* lunar and solar semidiurnal tides); meteorology; storm surges; waves; salinity and temperature for winter and summer conditions and the general circulation. When appropriate, some specificities of sub-regions like the North Atlantic approach, the Celtic and Irish seas, Northern, Central and Southern North Sea and the Channel will be further discussed. A summary is given at the end.

2. Bottom topography

The bottom topography is important in relation to its effect on water circulation and vertical mixing. Flows tend to be concentrated in areas where slopes are steepest, with the current flowing along the contours.

Roughly speaking, the Bonn Agreement Area considered within the framework of the BE-AWARE projects goes from 16°W to 14°E and from 48°N to 64°N. Several bathymetric data sets are available for this area (*e.g.*, ETOPO1[1], a one arc-minute interval grid; GEBCO_2014[2], a global 30 arc-second interval grid; the NOOS[3] bathymetry, a one arc-minute interval in latitude and a one and an half arc-minute interval in longitude grid; EMODnet[4], an overall DTM with a grid size of ⅛*⅛ arc minutes). The list is probably not exhaustive. The latter

[1] https://www.ngdc.noaa.gov/mgg/global/global.html
[2] http://www.gebco.net/data_and_products/gridded_bathymetry_data
[3] http://www.noos.cc/
[4] http://www.emodnet.eu/bathymetry

being the most recent, it is presented on Figure 1. Note however that the resolution has been degraded and is now equal to one arc-minute in latitude and one and an half arc-minute in longitude.

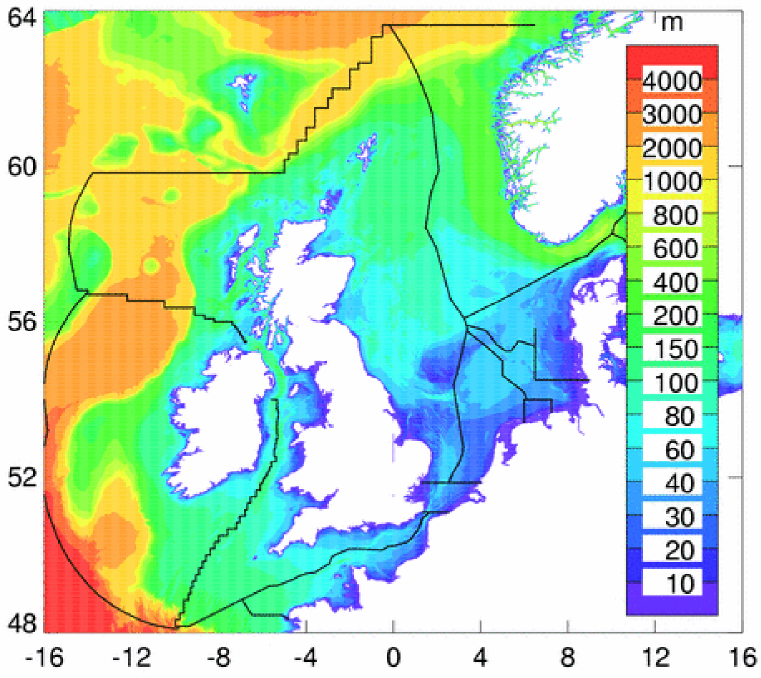


Figure 1: Bottom topography in the Bonn Agreement Area derived from the EMODnet bathymetry. The resolution is here equal to one arc-minute in latitude and to one and an half arc-minute in longitude. The solid black lines indicate the limit of the areas under the jurisdiction of the different North Sea countries.

To help the reader, some of the locations that will be often named in the text are clearly indicated on Figure 2.

Some important features of this topography are:

- the shelf break (usually defined by the 200 m isobaths) where the depth drops rapidly from 200 m to more than 2000 m;
- the Norwegian Trench which has a breadth of about 100 km and a depth of the order of 300 m increasing to 700 m in the Skagerrak;
- many sand banks rising to within 10 m of the sea surface in the Southern Bight along the English and continental coasts;
- the Dogger bank (from 1°E to 4°E and from 54°N to 55°N) rising to within 20 m of the surface.

Figure 2: atlas of the sea surroundings the British Isles[5].

Inside the North Sea (i.e. from the Strait of Dover at 51°N, 1°27'E to 61°N), the depth generally increases northward from 20 – 40 m in the Southern Bight (south of 54°N) and German Bight to 100 m near 58°N. There, the slope becomes somewhat steeper to about 150 m. There is also a west to east gradient in the depth. Depths along the east coast of England are larger than those along the continental coast.

The Channel is relatively shallow, and from a depth of about 30 m in the Strait of Dover deepens gradually to about 100 m in the west where it is connected to the Celtic Sea. The westward limit of the latter is the edge of the continental shelf.

The Irish Sea consists of a deep channel in the west and shallower bays in the east. The channel is open-ended. It is connected to the Atlantic Ocean, in the south, via the Celtic Sea and the St. George's Channel and in the North, via the North Channel and the Malin Shelf Sea. The channel is about 300 km long and 30-50 km wide. It has a minimum depth equal to 80 m and a maximum greater than 275 m. The two shallower parts (with depths less than 50 m) are the Cardigan Bay in the southeast and the area to the east of the Isle of Man.

3. Tides

M_2 and S_2 tidal water levels

Tidal motion is the dominant feature in the dynamics of the area, especially in the shallow parts like the North Sea, the Channel or the Irish Sea. Its importance for the oil pollution lies

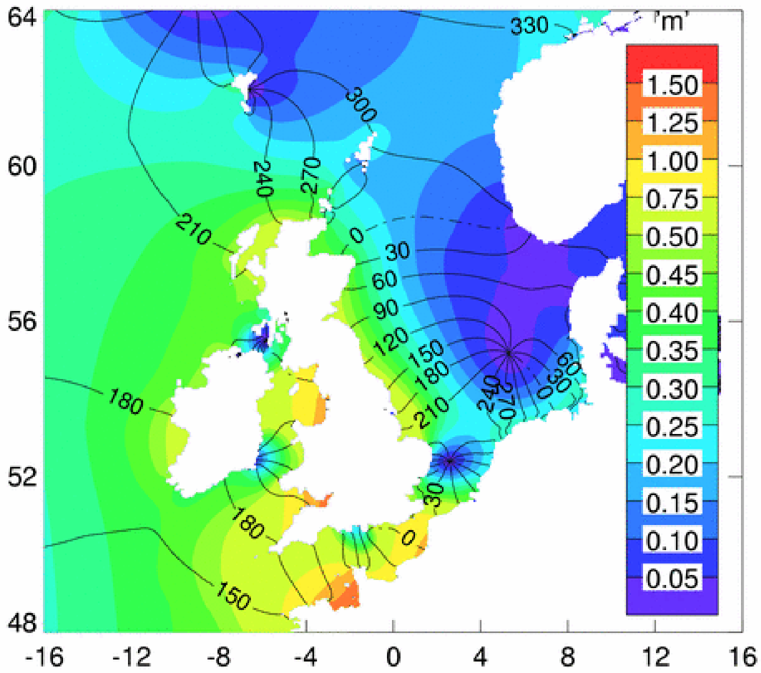
[5] https://www.google.be/search?q=Atlas+of+the+seas+around+the+British+Isles

i) in the transport as well at short time scales (due to the tidal currents) as at longer time scales (due to the so-called ‘rectified’ currents, the tidal residuals) and ii) in the turbulent exchange (horizontal and vertical) caused by tidal currents.

Tides in the North Sea result from the gravitational forces of the moon and sun acting on the Atlantic Ocean. The resulting oscillations propagate across the shelf edge, entering the North Sea both across the northern boundary and through the Channel. Semidiurnal tides M2 and S2 predominate at the latitudes concerned and are further amplified in the North Sea by a degree of resonance with the configuration of the coasts and depth of the seabed (Vincent and Le Provost, 1988). In addition, the pulsation between these two components explains the occurrence of the spring-neap cycles in the North Sea.

An atlas of the tidal components (one amongst many others) has been recently produced and validated by L. Pineau Guillou (2013). Amplitudes and phases of tidal elevations and currents are coming from the analysis of the results of the application of the MARS model developed by Ifremer (Lazure and Dumas, 2008) in an operational mode, referred to as PREVIMER[6].

The M2 tide is the largest component of the tide in the Bonn Agreement Area. The amplitudes and phases of the lunar semidiurnal tide (M_2) and the solar semidiurnal tide (S2) on the northwest European Continental Shelf (sometimes referred to as NWS in what follows) taken from the PREVIMER atlas are reproduced on Figure 3.



[6] www.previmer.org

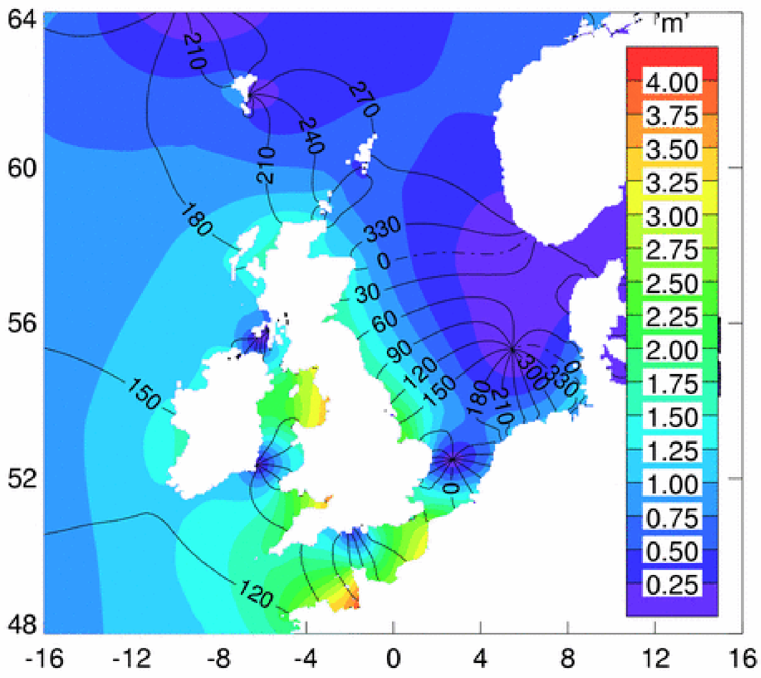


Figure 3: tidal elevation on the northwest European Continental Shelf: amplitudes and phases of the solar semidiurnal S_2 (top panel) and of the lunar semidiurnal M_2 (lower panel).

To cover this relatively wide area, the model is implemented on a grid with a horizontal resolution equal to 2 km in both directions.

M_2 and S_2, as well as the other semidiurnal components, have a very similar pattern as for the amplitude as for the phase.

In the Channel, tides propagate from southwest to northeast with the largest amplitudes along the French coast ("Baie du Month St. Michel"). There is a virtual amphidrome[7] close to the Isle of Wight.

Tides enter the North Sea by the Channel in the South and through the western part of its northern open boundary. They progress cyclonically around the North Sea, with the largest amplitudes along the coast of eastern England and in the German Bight. They leave the area in the north along the Norwegian coast. Two amphidromes are clearly visible: one in the German Bight (56°N) and one near the entry of the Southern Bight (52°N). In some constructions of the M_2 in the North Sea, a third amphidrome appears at the Southern tip of Norway. On Figure 3, this amphidrome is slightly more northward on land.

Semidiurnal tides are propagating into the Irish Sea from the Atlantic Ocean through both the North Channel and the St. George's Channel. The largest amplitudes of the semidiurnal tides are observed in the shallow eastern Irish Sea (Liverpool Bay). The diurnal tides are very weak in this area.

[7] An amphidrome is a point at sea where the tidal amplitude is almost equal to zero and from which the cotidal lines radiates. In the northern hemisphere, the tide rotates in a counterclockwise sense around it.

On the 2km grid, the largest amplitude for the M2 is equal to 3.85 m and that for the S2 is equal to 1.5 m. Greater amplitudes are more than likely observed in some bays (*e.g.*, Baie du Mont St. Michel) and in the upper parts of estuaries (*e.g.*, the upper Severn Estuary of the Bristol Channel) which are not properly represented on that grid.

Note that sufficiently far from the amphidromes, the ratio between the amplitude of the S_2 and the of the M_2 is almost constant and close to 0.35 while the S_2 phase is roughly 40° to 50° greater than that of the M_2.

Tidal currents

The spatial distribution of the major and minor axis of the M_2 current ellipse is presented on Figure 4. These current ellipses have been derived from the results of a 3D barotropic model (Davies and Kwong, 2000). The model grid has a horizontal resolution equal to 1/6° in longitude and 1/9° in latitude. On Figure 4, results are presented at every third grid node.

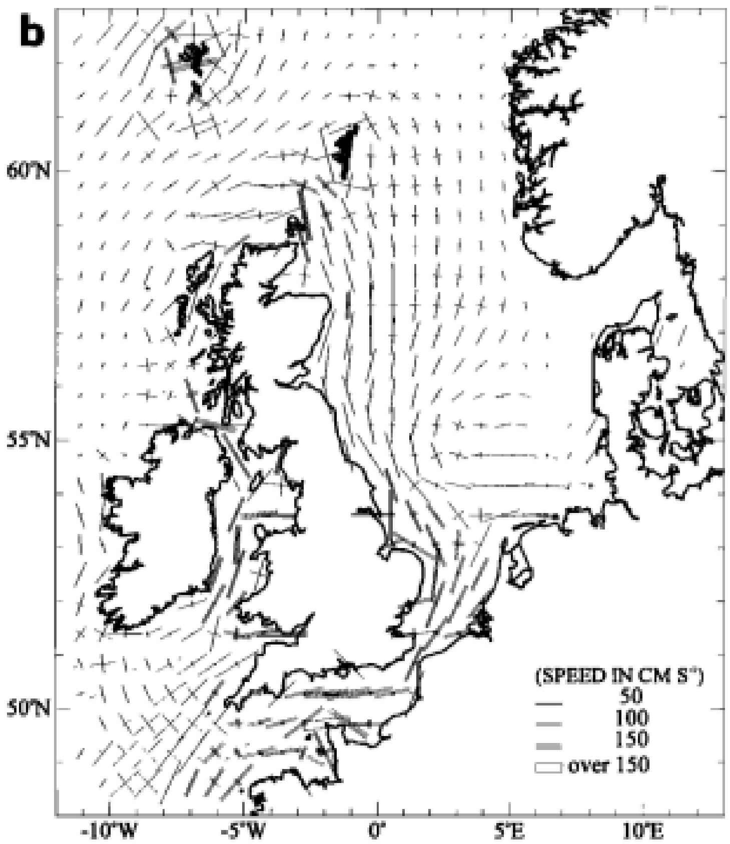


Figure 4: spatial distribution at very third grid point of the major and minor axis of the M_2 current ellipse (from Davies and Kwong, 2000).

The spatial distribution of the S_2, N_2 and K_2 tides are similar to that found for the M_2.

Tidal currents are almost rectilinear close to the coasts and in the straits. They become more elliptic or even circular far away from the coasts.

On the shelf, mean spring currents are of the order of 0.2 ms^{-1} in the north and east. They generally exceed 0.5 ms^{-1} south of 54°N. Values above 1.0 ms^{-1} are observed almost everywhere in the Channel as well as at various places in the Irish Sea.

4. Meteorology

Atmospheric pressure, winds, precipitation/evaporation and heat fluxes to and from the sea play an important role in the North Sea dynamics, water mass development and circulation.

Westerly winds are prevailing on the northwest European shelf. These westerly winds are associated with a meandering upper troposphere jet stream. Numerous cyclones are embedded within this belt of westerly winds. They develop along the zones of strongest temperature gradients and generally traverse the area from south-west to north-east. The cyclonic activity is stronger in winter than in summer (OSPAR). Westerly winds contribute to reinforce the cyclonic residual circulation induced by the tide (see §8). This latter can be reverse when sufficiently strong easterly winds are blowing. Northwesterly and southeasterly winds tend to induce states of stagnation (and then increasing residence times).

The North Atlantic Oscillation index (NAO; Jones *et al.*, 1997) is defined as the difference in atmospheric pressure at sea level between the Azores (usually high pressure) and Iceland (usually low pressure). It describes the strength and position of the westerly airflows across the Atlantic. In winter, high NAO values coincide with very mild weather over north-western Europe. When the index is unusually very small, anticyclones dominate large parts of the area and winter becomes colder.

Further, the winds also control the spectrum of sea waves in the North Sea. Storms can lead to heavy and dangerous storm surges.

For the purpose of the BE-AWAREII project, the project area has been divided into a number of meteorological units within which the wind conditions are assumed to be uniform. Wind roses for the different areas are presented and discussed in the BE AWARE II method note. One example of such a wind rose is given in §6 (see Figure 9).

5. Surges

Storm surges are the most serious hazard as far as the natural disasters in the North Sea regions are concerned.

Surges are generated by storms, both locally through the action of wind stress on the sea surface piling up water at the coast and, on the scale of the depression, through the action of atmospheric pressure – low pressure raises sea surface by about 0.01 m for each milibar deviation from the mean (about 1012 mb). Once generated, storm surges travel in the same manner as tides.

During the 20th century, the most devastator storm was that of the 1st of February 1953. In the Netherlands, up to 1835 lives were lost. The damages were so important because the storm occurred almost in conjunction with a relative strong spring tide. Coastal defenses have been strongly reinforced since that time. As a consequence, other storms events (February 1962, January 1976, December 2013) caused less damages (Note however that, in February 1962, 300 people died in Hamburg even if the city is 100 km far away from the sea; Süderman and Pohlman, 2011).

According to Hewer (1980), historical surges fell into two classes:

- 'Static' type: the low pressure comes from Iceland, crosses the Northern North Sea and finally reached Scandinavia; a long lasting but not necessary strong wind pushes the water into the German Bight.
- 'Dynamic' type: the low pressure comes from more southward (Subtropical Atlantic), passes over Great Britain and Denmark; rotating extreme wind moves the North Sea water like a centrifuge raising sea level along all coasts.

The trajectory of the storm of December 2013 was exactly that of a 'static' type according to Hewer. However, the low pressure crossed the North Sea quite rapidly (about 24 hours). Wind, atmospheric pressure and surge elevation at 0 hour on the 6th of December 2013 are presented on Figure 5. At that time, the center of the depression is already on Scandinavia. Relatively strong northerly to north-westerly winds are blowing over the North Sea. Surge elevation is at its maximum along the Belgian coast and this occurred almost 2 hours before high water. Interactions between the tide and the surge generally prevent the maximum of the latter to coincide with the extremes (low or high tide) of the former (Horsburgh and Wilson, 2013).

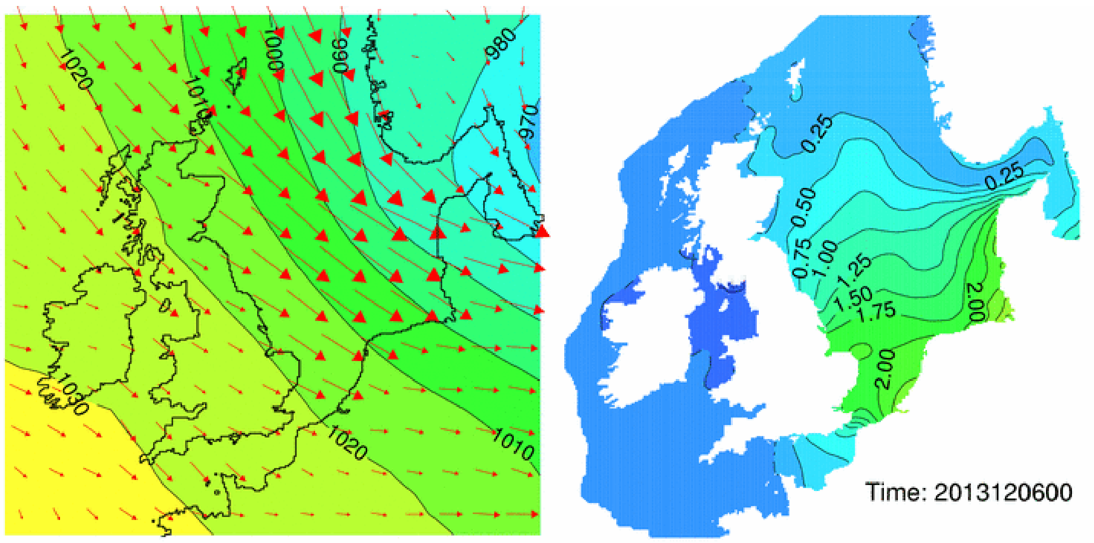


Figure 5: Wind and atmospheric pressure (hPa) on the left panel and surge elevation (m) on the right panel at 0 hour on the 6th of December 2013. This was the time at which surge elevation along the Belgian coast reached its maximum value. This occurred more or less two hours before the time of high water.

By combining estimates of 50-year return values at some stations with the results of simulations made with a numerical model for a lot of extreme storms, Flather (1987) and Flather *et al.* (1998) have inferred 50-year return values for elevations (Figure 6) and depth-averaged currents (Figure 7) .

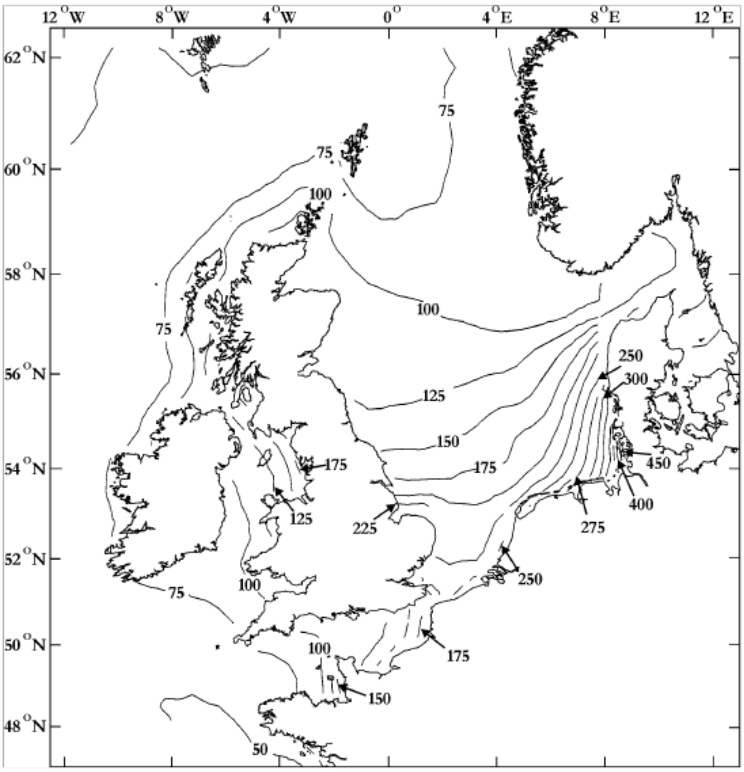


Figure 6: 50-year return period storm surge elevations in centimetres (Flather et al., 1998)

For the elevations, the pattern is quite similar to that presented on Figure 5 but with values range from about 0.7 m in the North to 4 m in the inner German Bight and to 2.5 m along the Belgian and Dutch coasts. Values around 2 m were also found in the Liverpool Bay and along the French coast in the Channel. Note that, close to the coast, the levels are somewhat underestimated due to the resolution (12 km) of the grid.

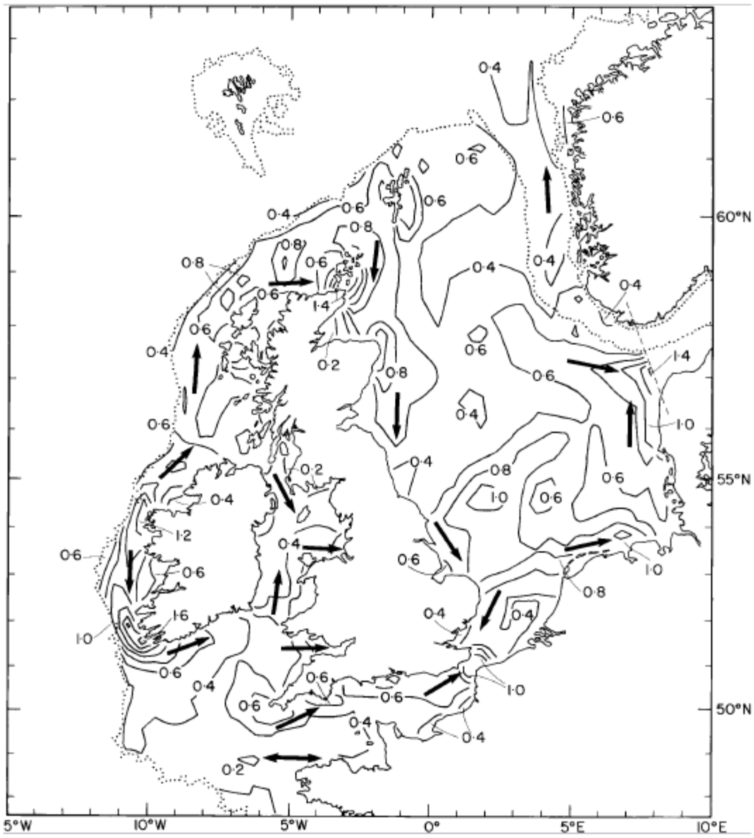


Figure 7: 50-year return period storm surge currents (ms^{-1}) (Flather, 1987)

Concerning the currents, their direction is largely determined by topography not wind. Figure 7 is only indicative since the vertical structure of wind-driven currents will in many places be more pronounced than for tidal currents and may involve flow reversal at depth.

6. Waves

Waves are important to all offshore activities, to coastal defense, to turbulence, mixing, sediment pick-up as well as transport in sea water (Stoke's drift). They clearly must be taken into account in oil spill modeling.

The wind is clearly responsible for the generation of most of the surface gravity waves (wind-waves and swell) which are nearly always present. The wind factors affecting wave development are wind speed, fetch (the linear distance over which the wind is blowing over the sea) and duration (the time for which the wind has been blowing over the fetch).

Wind speed and duration are generally quite independent of location. Fetch, on the other hand, is very dependent on location. For example, in the semi-enclosed Irish Sea it is rarely possible to obtain a fetch of any significant distance. The length of fetch is also strongly influenced by the wind direction, or more importantly, the storm track. For example, in the North Sea the fetch is quite limited compared to the open North Atlantic, apart from to the north where it extends into the Norwegian Sea. However, in a case like the North Sea the effective fetch may be limited, even from the north, by the location of the storm tracks that mostly pass from west to east throughout the area.

Average and extreme wave heights in the North Sea generally decrease southwards and inshore. Estimates of 50-year return significant wave heights (m) are presented on Figure 8.

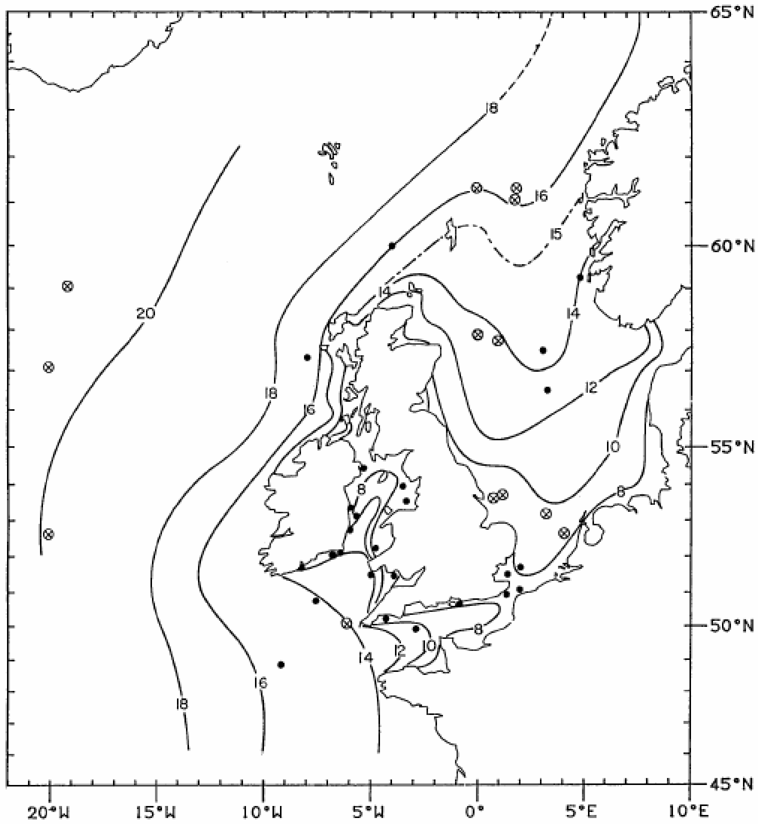


Figure 8: Estimates of 50-year return significant wave heights (m) . ● and X indicate the position of measurements. (from Carter and Challenor, 1989).

A lot of information on wind and wave frequency distributions at a series of locations around the British Isles can be found in a report prepared by Fugro GEOS for the Health and Safety Executive (Fugro GEOS, 2001)[8]. As an example, we show below the statistics drawn for a point in Southern North Sea (54.438°N; 2.513°E).

[8] http://www.hse.gov.uk/research/otopdf/2001/oto01030.pdf.

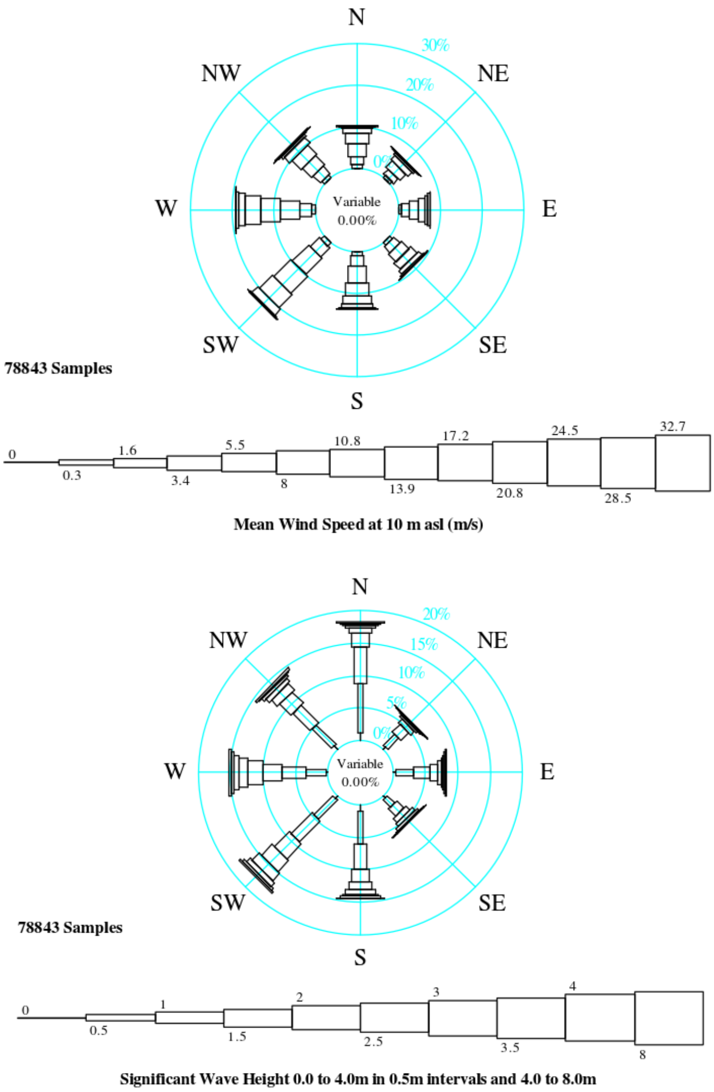


Figure 9: frequency distribution of mean wind speed at 10 m (ms^{-1}) according to the direction from which the wind is blowing (top panel) and frequency distribution of significant wave height (m) according to the direction from where the wave is coming (bottom panel). (From Fugro GEOS, 2001).

7. Temperature and salinity

The three-dimensional distribution of salinity and temperature are essential for understanding the physical conditions of the North Sea. It is well documented in a number of atlases. The latest T&S climatology developed under the ICES "umbrella" is that of Berx and Hughes (2009). Unfortunately, this latter is limited to the Northwest European continental shelf with its seaward limit following closely the 200 m isobaths. It does not cover the whole BE-AWAREII area of interest

Therefore, we decided to look at the reanalysis products made available by the Copernicus Marine Service Products and more precisely to the "Atlantic-European North West Shelf-Ocean Physics Reanalysis" of the Metoffice.

The reanalysis covers the period January 1985 until July 2012 and is based upon the Forecasting Ocean Assimilation Model 7km Atlantic Margin Model (FOAM AMM7).This is a hydrodynamic model of the North West European shelf forced at the surface by ERA-interim winds, atmospheric temperature, and precipitation fluxes. Horizontal boundary conditions were provided by the NOC global reanalysis prior to 1989 and by the GloSea reanalysis thereafter. Boundary conditions in the Baltic Sea came from the IOM-GETM model. E-Hype data were used for river inputs. Hydrodynamic calculations were performed by the Nucleus for European Modelling of the Ocean (NEMO) system, while the 3DVar NEMOVAR system was used for the assimilation of sea surface temperature data.

The quality of the NWS reanalysis simulation has been assessed by comparison with observations (Wakelin *et al.*, 2015). The results can be summarized as follows:

- Temperature:
    - Integrated over the whole domain, the bias in surface temperature is 0.4°C.
    - Mean biases in the near surface layer (above 5 m depth) have magnitude less than ≈ 0.5°C.
    - The largest errors (≈-2°C) are observed in the Bay of Biscay between 800 m and 2000 m.
- Salinity:
    - Biases, on the practical salinity scale, are generally of magnitude less than 0.5 ppt.
    - In the coastal regions of the Southern Bight however, salinity is typically ≈ 2 ppt too fresh.
    - The surface layer in the Irish Sea is ≈ 0.5 ppt too saline.

In what follows, only the monthly mean 3D fields of temperature and salinity for the period 1985 to 2009 (included) were used to compute long term (25 years) averaged fields.

The results presented are:

- mean sea surface salinity (SSS) in February and in August (Figure 10);
- mean sea surface temperature (SST) in February and in August (Figure 11);
- mean sea bottom temperature (SBT) in February and in August (Figure 12);
- top to bottom temperature difference in February and in August (Figure 13).

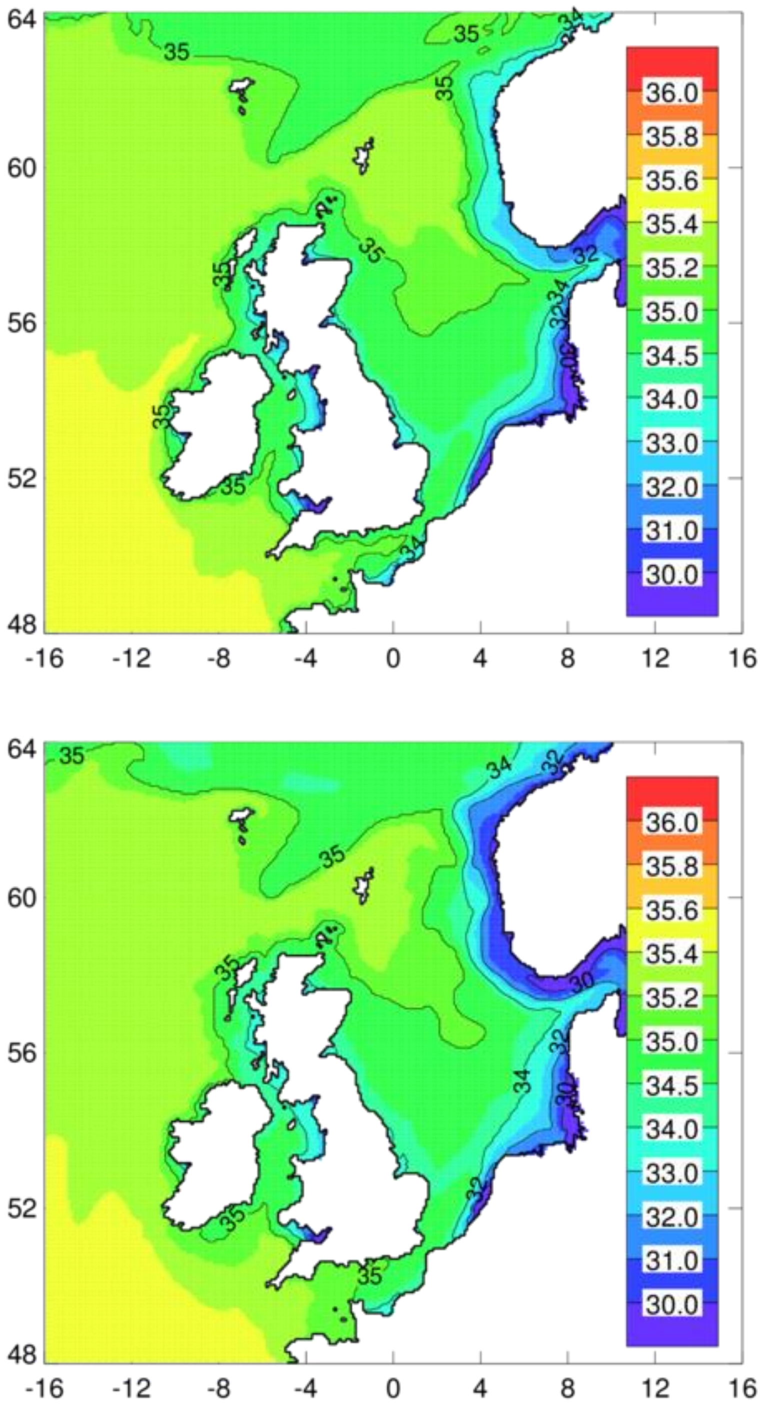


Figure 10: Mean sea surface salinity (SSS) in February (top panel) and in August (bottom panel). Mean SSS has been derived from the monthly surface fields for the period 1985-2009 obtained with the Atlantic- European North West Shelf- Ocean Physics Reanalysis from METOFFICE (adapted from Wakelin *et al.*, 2015).

The area is clearly fresher in August (Figure 10, bottom panel) compared to February (Figure 10, top panel). This is particularly clear along the Norwegian coasts. The pattern for both months is very similar and the same isohaline pattern is observed for all months as well in the surface layer as in the near-bed layer. Only the deeper parts of the Norwegian Channel and Skagerrak have their typical pattern. It seems that the advective transport over long times sufficiently dominates over possible short-time fluctuations.

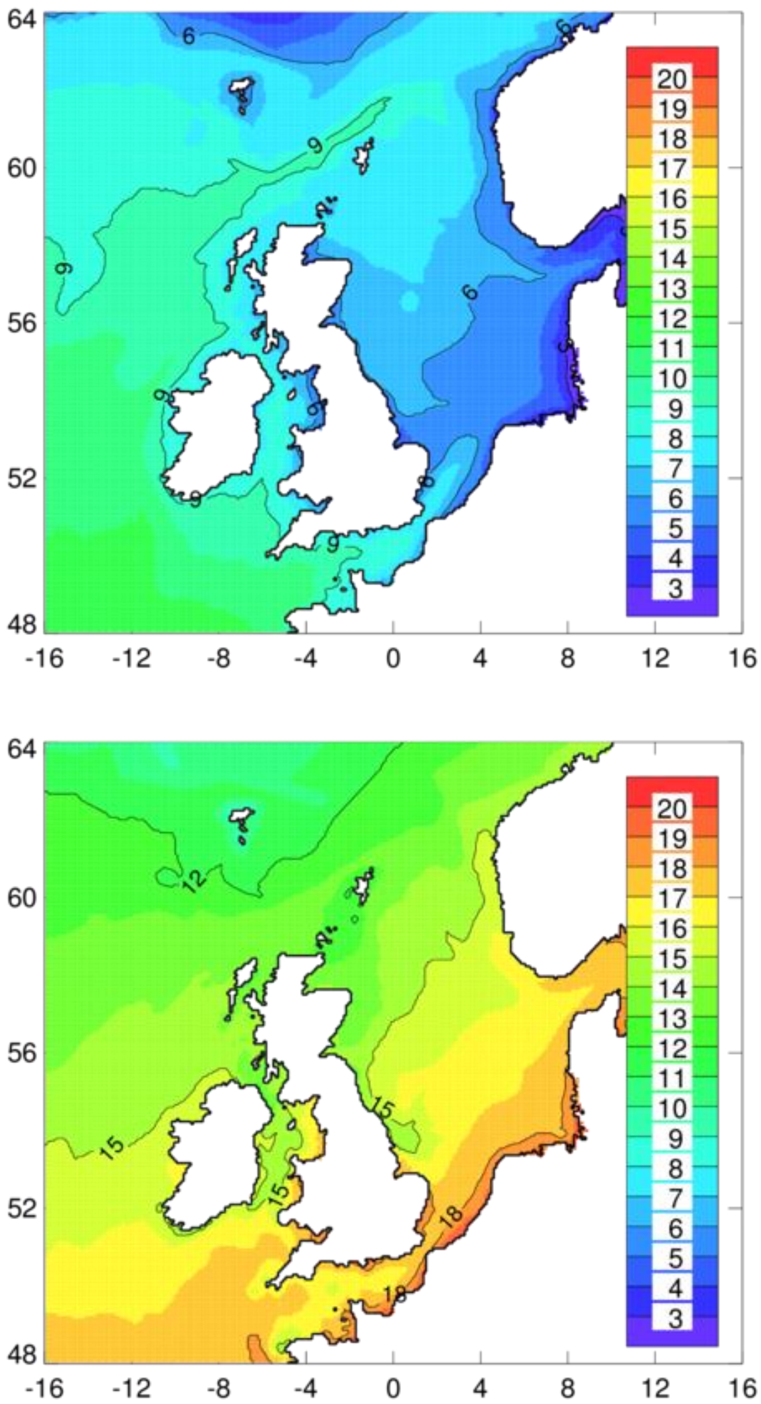


Figure 11: Mean sea surface temperature (SST) in February (top panel) and in August (bottom panel). Mean SST has been derived from the monthly surface fields for the period 1985-2009 obtained with the Atlantic-European North West Shelf- Ocean Physics Reanalysis from METOFFICE (adapted from Wakelin *et al.*, 2015).

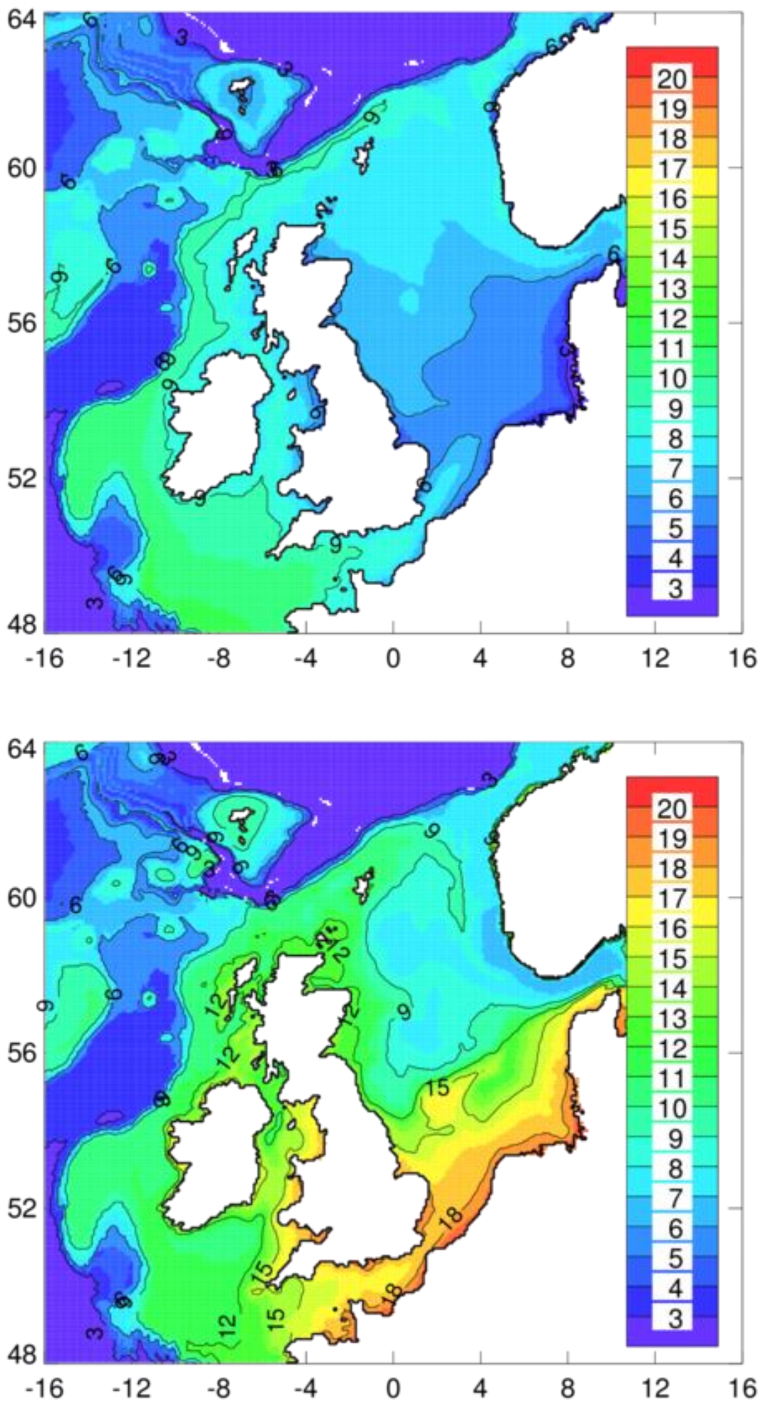


Figure 12: Mean sea bottom temperature (SBT) in February (top panel) and in August (bottom panel). Mean SST has been derived from the monthly bottom fields for the period 1985-2009 obtained with the Atlantic-European North West Shelf- Ocean Physics Reanalysis from METOFFICE (adapted from Wakelin *et al.*, 2015).

The heat exchange with the atmosphere has a strong influence on the seasonal cycle of temperature especially in the surface layers. As a consequence, in the coastal regions, the temperature gradient in winter is the inverse of the temperature gradient in summer. In winter, coastal waters become colder than offshore waters. In summer, coastal waters become warmer than offshore waters. This is clearly visible along the continental coasts.

Top to bottom temperature differences (Figure 13) help to identify the areas that are potentially thermally stratified.

In winter, most of the North West Shelf is well mixed. In winter, top to bottom temperature difference is equal to zero almost everywhere the depth is less than 200m. In small coastal areas (*e.g.*, in the area of the Rhine/Meuse plume along the Dutch coast or in the area of the Elbe plume), top to bottom temperature difference can be negative. It could be that the model turbulent closure scheme encounters some difficulties in the presence of cooling in shallow waters or that the water column remains in fact stably stratified due to the amount of fresh water coming from the river.

In summer, the area where top to bottom temperature difference is equal to zero is significantly reduced. This happens mainly in the Southern Bight of the North Sea (as in the area of the Dogger Bank) and in the Channel.

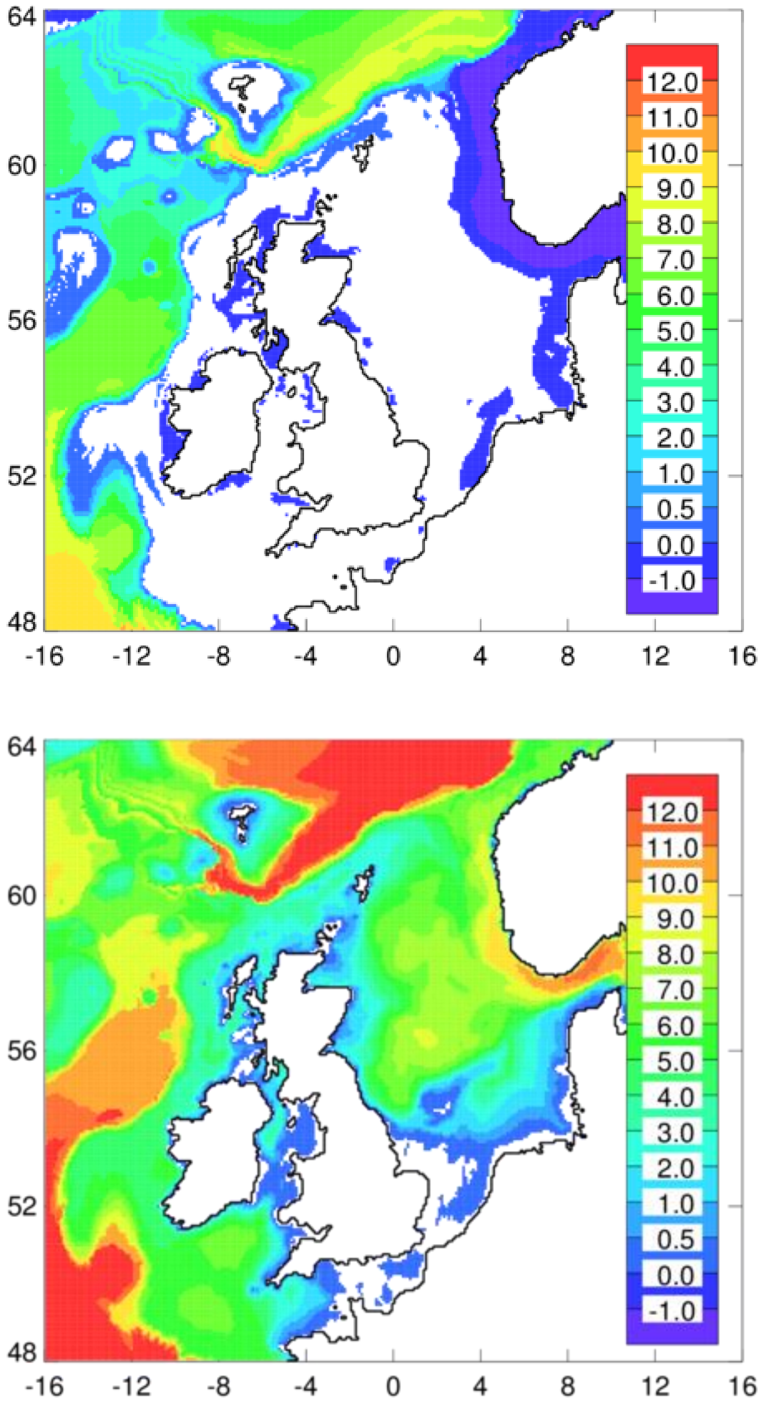


Figure 13: Mean top to bottom temperature differences in February (top panel) and in August (bottom panel). Values have been derived from the monthly bottom fields for the period 1985-2009 obtained with the Atlantic-European North West Shelf- Ocean Physics Reanalysis from METOFFICE (adapted from Wakelin *et al.*, 2015)..

8. General circulation in the Northeast Atlantic and on the Northwest European Continental Shelf.

General circulation in the Northeast Atlantic

The water current system in the Northeast Atlantic is schematically presented on Figure 14.

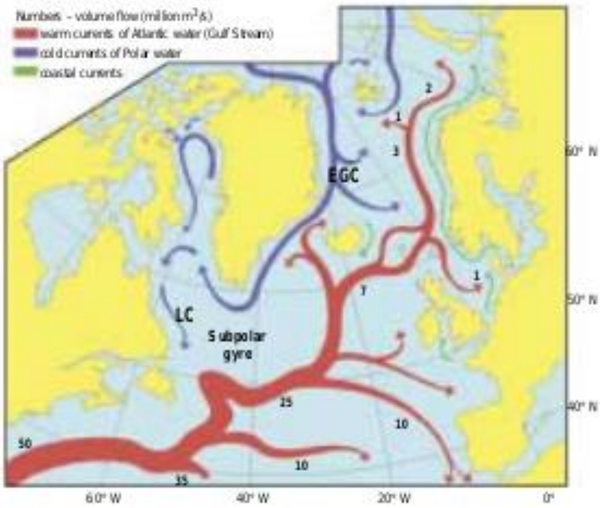


Figure 14: Mean surface currents in the Northeast Atlantic. Reproduced from OSPAR – Quality Status Report 2000[9].

In the Northeast Atlantic (see Figure 14), warm surface waters flow in a north-westerly direction towards the Norwegian Sea as the North Atlantic Current (NAC). An eastward-directed flow is referred to as the Azores Current (AzC). As extensions of the Gulf Stream, these two currents form the southern edge of the subpolar gyre and the north-eastern edge of the subtropical gyre, respectively. On the margins of Europe, a warm Northward-flowing Eastern Boundary current (EBC) is found intermittently. A western boundary current flows south from the Fram Strait as the East Greenland Current (EGC) and, its extension, the Labrador Current (LC). The northward transport of warm surface waters towards the Arctic Ocean is balanced by a southward return flow of intermediate and deep water from the Nordic Seas via the Denmark Strait and from both the Faroe–Shetland Channel and the Labrador Sea A western boundary current flows south from the Fram Strait as the East Greenland Current (EGC) and, its extension, the Labrador Current (LC). The northward transport of warm surface waters towards the Arctic Ocean is balanced by a southward return flow of intermediate and deep water from the Nordic Seas via the Denmark Strait and from both the Faroe–Shetland Channel and the Labrador Sea. The NAC and AsC, together with the dominant mid-latitude westerly winds and a mean meridional density gradient, combine to push oceanic water against the European coast. This effect, influenced by the Coriolis force, generates the northward-flowing EBC. Although the EBC does not appear to be continuous, it is evident from southern Portugal to northern Norway. It may also reverse

[9] http://qsr2010.ospar.org/media/assessments/QSR_2000.pdf.

its surface mean flow to the south in the summer upwelling period, especially off the coast of the Iberian Peninsula.

General circulation in the North Sea

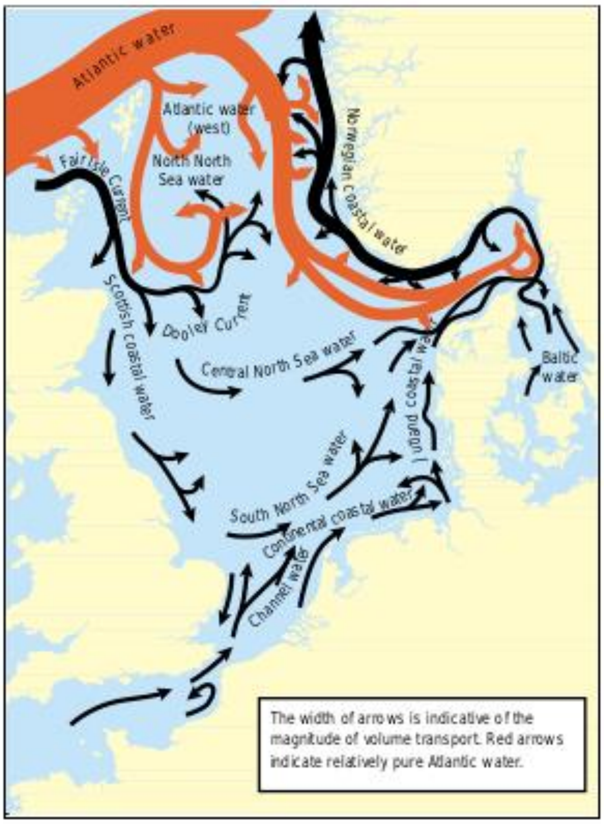


Figure 15: schematic diagram of the general circulation in the North Sea (right panel). Reproduced from OSPAR – Quality Status Report 2000.

In the North Sea (see Figure 15), the pattern that is found for the mean residual circulation using different methods agrees in its general basic character: the residual circulation is anticlockwise. Along the continental coast, the current is strong and rather restricted, up to the Skagerrak, where it meets the deeper North Atlantic inflow though the Norwegian Channel. Both currents join via a loop in the Skagerrak the Batlic Outflow and next leave the North Sea as the Norwegian Coastal Current.

The circulation along the British coast is more diffuse. Current observations and the transport of ^{137}Cs (from discharges at Sellafield) indicate a mean southerly flow. However, there are clearly secondary systems under the influence of variable wind conditions that even temporarily may obscure the southward flow.

Some elementary dynamics can explain this general circulation. Details are given in the literature. Only a summary is given hereafter:

- In a channel closed on one side, with uniform depth, no vertically integrated current is induced by a stationary irrotational wind-stress field.

- In the area, cyclonic wind fields are more frequent and accompanied by stronger winds than anti-cyclonic fields. The wind-vorticity stream function Is likely to be predominantly cyclonic.
- If the bottom of the channel is sloping along its axis, a cyclonic circulation will be generated by a wind blowing from the west.
- In a North-South channel deepening to the North, a cyclonic circulation is generated by westerly and northerly winds.
- Studies on the effect of the Norwegian Trench on a North Sea with an otherwise uniform depth provide comparable results.
- Inclusion of baroclinic effects in a 3D model shows that the density distribution enhances this pattern, especially in the Norwegian Trench.

General circulation in the Irish Sea

Figure 16: view of the Irish Sea and of its bottom topography (with contours at 20, 40, 50, 60, 80, 100, 120 and 160 m). Reproduced from Wikipedia.

In the Irish Sea (see Figure 16), the long term average flow in the deeper western channel has long been deduced to be from south to north. In the regions away from the western channel the circulation is less clear. In the Liverpool Bay, for instance, density gradients drive an offshore circulation at the surface and an inshore circulation near the bed. Overall, the density gradients tend to drive a clockwise circulation around the coasts of the bay of the bay in opposition to the winds. Accordingly, a clockwise circulation is found during periods of light winds, especially when the horizontal density gradients are strongest in winter and spring. But, at wind speed above 5-10 ms^{-1} from south-west and north-west, this pattern is reversed.

Deep ocean exchange with west-European Shelf Seas

For a detail review of the mechanisms and studies of exchange between the north-east Atlantic and the adjacent shelf seas, the reader is referred to Huthnance *et al.* (2009). A very short summary is given below.

A schematic view of the cross-slope exchange processes is given on Figure 17.

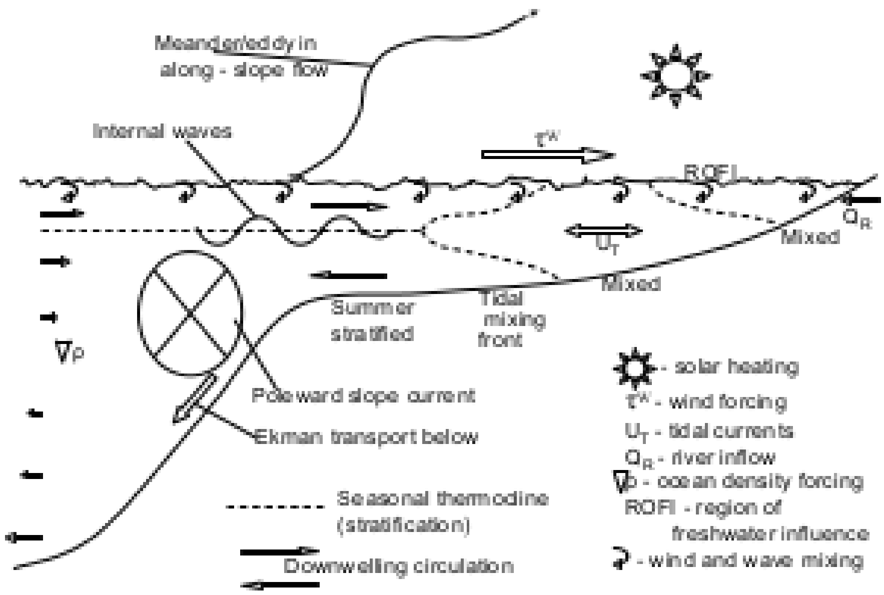


Figure 17: schematic of stratification and cross-slope exchange processes (from Huthnance *et al.* 2009).

Well-developed summer upwelling and associated filaments off Portugal and north-west Spain give exchange O(3 m^2s^{-1} per unit length of shelf). Prevailing westerly winds further north drive exchange O(1 m^2s^{-1}). Poleward flow along most of the upper slope has associated secondary circulation O(1 m^2s^{-1}), meanders and eddies. Eddies are shed from slope waters into the Bay of Biscay, and local exchanges occur at shelf spurs and depressions or canyons (e.g. dense-water cascading of order 1 m^2s^{-1}). Tidal transports are larger, but their reversal every six hours makes exchange largely ineffective except where internal tides are large and non-linear, as in the Celtic Sea where solitons carry water with exchange O(1 m^2s^{-1}). These various physical exchanges amount to an estimated 2–3 m^2s^{-1} per unit length of shelf, between ocean and shelf.

9. Summary

This technical report provides a broad overview of the hydrography in the area of interest to the BEAWARE II project, *i.e.* the North-west European Continental Shelf from 16°W to 14°E and from 48°N to 64°N. Focusing on the physical processes that influences the transport and fate of oil pollutions, the report presents the seabed bathymetry; tides (*i.e.* lunar and solar semidiurnal tides); meteorology; storm surges; waves; salinity and temperature for winter and summer conditions and the general circulation in the greater North Sea. When appropriate, some specificity of sub-regions like the North Atlantic approach, the Celtic and Irish seas, Northern, Central and Southern North Sea and the Channel have been further discussed.

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The easy access to the data of the atlas of tidal water levels and currents (Pineau-Guillou Lucia, 2013), archived at "le Centre de Données en Océanographie Côtière Opérationnelle (CDOCO), à l'Ifremer, has been greatly appreciated.

References

Berx, B., and S. L. Hughes, 2009. Climatology of Surgface and Near-bed Temperature and Salinity on the North-West European Continental Shelf for 1971-2000. CONTINENTAL SHELF RESEARCH Volume: 29 Issue: 19 Pages: 2286-2292. DOI: 10.1016/j.csr.2009.09.006.

Carter, D. J. T., and P. G. Challenor, 1989. Estimation of extreme waves. Metocean Parameters – wave parameters. Dept. of Energy report OTH 89 300, 7-66.

Davies, A. M., and S. C. M. Kwong, 2000. Tidal energy fluxes and dissipation on the European continental shelf. Journal of Geophysical Research, Vol. 105, NO. C9, 21,969-21,989.

Flather, R. A., J. A. Smith, J. D. Richards, C. Bell and D. L. Blackman, 1998. Direct estimates of extreme storm surge elevations from a 40-year numerical model simulations and from observations. The Global Atmosphere and Ocean System, 6: 165-176

Flather, R.A., 1987. Estimates of extreme conditions of tide and surge using a numerical model of the North-west European continental shelf. Estuarine, Coastal and Shelf Sciences, **24**(1) (1987) 69-73.

Hewer, R., 1980. Untershchung zur Entwicklung von Extremstrurmfluten an der deutschen Nordseeküste auf der Basis hydrodynamish-numerischer Modelle. Diplomarbeit, Univ. Hamburg.

Howarth, M. J. Hydrography of the Irish Sea. SEA6 Technical report. POL Internal Document 174. 30 pp.

Huthnance, J. M., 1991. Physical Oceanography of the North Sea. Ocean and Shoreline Management **16** (1911) 199-231.

Huthnance, J. M., J. T. Holt and S. L. Wakelin, 2009. Deep ocean exchange with west-European shelf seas. Ocean Sci., 5, 621–634, 2009.

Jones, P.D., T. Jónsson and D. Wheeler, 1997. Extension to the North Atlantic Oscillation using early instrumental pressure observations from Gibraltar and South-West Iceland. Int. J. Climatol. 17, 1433-1450.

Lazure, P. and F. Dumas F, 2008. An external-internal mode coupling for a 3D hydrodynamical model for applications at regional scale (MARS). Advances In Water Resources, 31(2), 233-250, doi://10.1016/j.advwatres.2007.06.010

Legrand, S., 2014. BEAWARE II: Data Provision Report. Reference A036390 (COWI reference).

OSPAR Commission 2000. Quality Status Report 2000. OSPAR Commission, London. 108+vii pp.

Otto, L., J. T. F. Zimmermann, G. K. Furnes, M. Mork, R. Saetre anf G. Bekkers, 1990. Review of the physical oceanography of the North Sea. Neth. J. Sea Res., 26(2-4), 161-238, doi:10.1016/0077-7579(90)90091-T.

Pineau-Guillou Lucia (2013). PREVIMER Validation des atlas de composantes harmoniques de hauteurs et courants de marée. Rapport Ifremer, 89p. http://archimer.ifremer.fr/doc/00157/26801/

Uncless, R. J., and J. A. Stephens, 2007. SEA 8 Technical Report – Hydrography. April 2007, 105 pp.

Sünderman, J., and T. Pohlman, 2011. A brief analysis of North Sea Physics. OCEANOLOGIA, 53 (3), 2011, pp. 663-689. doi: 10.5697/oc.53-3-663.

Vincent, P. and C. Le Provost, 1988. Semidiurnal tides in the northeast Atlantic from a finite element numerical model. Journal of Geophysical Research 93: doi: 10.1029/JC093iC01p00543. isn: 0148-0227

Wakelin, S., J. While, R. K. Enda O'Dea, J. Holt, R. Furner, J. Siddorn, M. Martin, R. McEwan and E. Blockley, 2015. Quality Information Document: North West European Shelf Reanalysis - NORTHWESTSHELF_REANALYSIS_PHYS_004_009 and NORTHWESTSHELF_REANALYSIS_BIO_004_011. EU Copernicus Marine Service.

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