Centre for Environment Fisheries & Aquaculture Science

Cefas

Suspended Sediment Climatologies around the UK

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6 December 2016

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Contents

Reference and accompanying dataset

This report is accompanied by a publicly available dataset of monthly averaged non-algal Suspended Particulate Matter concentrations on the UK shelf waters from satellite observations. This is available at http://data.cefas.co.uk/#/View/18133

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CEFAS 2016. Monthly averages of non-algal SPM (doi:10.14466/CefasDataHub.31).

"This is described in CEFAS Report (2016). This dataset was based on the Ifremer OC5 algorithm (Gohin et al 2011)."

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Introduction

This report has been prepared as part of the United Kingdom Department for Business, Energy and Industrial Strategy's (BEIS) sponsored Offshore Energy Strategic Environmental Assessment referred to as OESEA3. The SEA provides support to policy makers, developers and licensing authorities for the purpose of licensing and leasing of hydrocarbon, gas and renewable energy developments. Since the last SEA, the UK has made progress in the decarbonisation of its energy supply through the offshore renewables sector. For instance, currently the Offshore wind sector has an installed capacity of over 5GW with further ~17.5GW of new offshore windfarms either in construction, awaiting financial approval or in the planning process. Furthermore, Ocean Energy technologies (wave, tidal stream, tidal elevation, salinity gradient and ocean thermal) are in various stages of deployment. The first tidal stream array (Meygen) is currently being installed in the Pentland Firth. An ambitious European Roadmap for these technologies has been published in November 2016 (https://webgate.ec.europa.eu/maritimeforum/en/frontpage/1036).

In order to produce electricity reliably, offshore renewable energy devices tend to be large (> 1000 tonnes) and with a significant footprint on the seabed. For offshore windfarms, structures vary from monopiles (up to 8m diameter) to large Gravity Based Structures (GBS) weighing several thousand tonnes when laid on the seabed. Therefore, disturbance of seabed sediments from constructional activities (seabed levelling, cable laying, rock dumping and laying of protective mattresses) or from the consequences of construction (scour pits, scour wakes) can be potentially significant. Similarly, operational impacts from offshore windfarms have been observed as suspended sediment plumes from a number of sites (London Array, Thanet and Humber Offshore Windfarms). Decommissioning activities are likely to be similar to construction activities and hence potential impacts from sediment disturbance to be equivalent.

Whilst the third round of Offshore Windfarms are increasing in scale with hundreds of turbines (Figure 1) in each field, blade and turbine developments have resulted in more powerful devices which has resulted in a reduction in the number of structures being deployed offshore for a given overall power generation. Additionally, as the number of structures decreases and the size of the blades increases, the distance between structures has increased from as little as 350 m in Round 1 (http://www.lorc.dk/offshore-wind-farms-map/north-hoyle) to a predicted 1500-1800 m in Round 3 (Merz, 2016).

In order to understand the scale and significance of these sediment disturbance processes, the background spatial and temporal variations in suspended sediment concentrations are required. This report extends both spatially and temporally, the report and spatial database developed under the Marine Aggregate Levy Sustainability Fund (MALSF - http://www.marinealsf.org.uk/) project P114 developing maps of surface suspended sediment concentration.

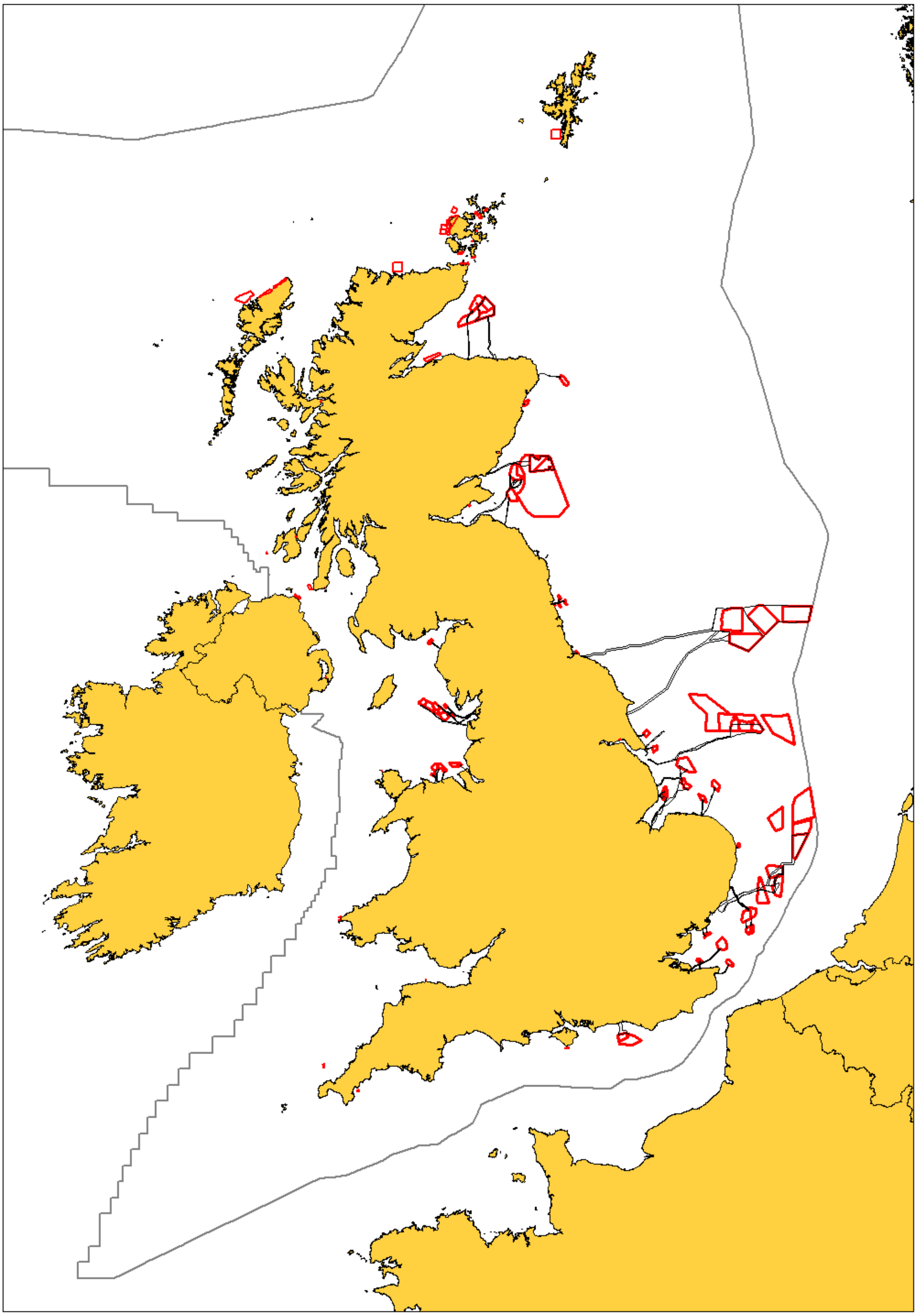


Figure 1: UK continental shelf and renewable energy activities (wind, wave, tidal current but not tidal elevation – i.e. Swansea Bay Tidal Lagoon not included). Source TCE GIS (version dated 16th Nov 2016)

Climatologies of non-algal SPM

Data sources

Ocean colour satellite images allow mapping of the surface suspended sediments load for large areas at resolutions of 9 km to 300 m. The launch of NASA's SeaWiFS instrument in 1997 was followed by Moderate-resolution Imaging Spectroradiometer (MODIS) on the Aqua and Terra satellites, ESA's Medium Resolution Imaging Spectrometer (MERIS) and NASA's Visible Infrared Imager Radiometer Suite (VIIRS), to provide a continuous dataset covering over 18 years.

The narrow bandwidth or ocean colour sensors allow for the isolation of the green response of chlorophyll pigment in phytoplankton, which absorbs red and blue, the red pigments in some harmful algal blooms or the brownish colour of suspended sediments.

The radiometric signal in oceanic deep waters (Case-1) is dominated by the absorption of the water molecules, which is constant, and the green signature of chlorophyll where phytoplankton is present. Following O'Reilly et al. (1998) multiple algorithms have been proposed to extract chlorophyll and applied at a global scale.

In coastal waters (Case-2) the runoff from rivers and coastal erosion and the resuspension of bottom sediments due to the action of waves and tidal current in the shallow areas of the continental shelf can make it difficult to measure chlorophyll. Gohin et al. (2005) proposed the OC5 algorithm that jointly estimates the load of chlorophyll and non-algal suspended particulate matter. This algorithm has been validated against in-situ coastal observations for the English Channel and Bay of Biscay (Gohin, 2011) and modified to merge multiple sensors (Saulquin et al., 2011): SeaWiFS from 1998-2002; MODIS + MERIS, January 2003-March 2012 and MODIS + VIIRS from April 2012 to the present.

The water depth related to the reading depends on the diffuse attenuation coefficient Kd; on the coastal regions Kd is in the range 0.1-2.0 m^{-1} (Gohin et al., 2005) which with a penetration depth given by 1/kd results in 0.5 to 20 m. Using SeaWiFS data this algorithm has been validated for a suspended load range of 0.1-20 gm^{-3} (r^2=0.59, Gohin et al., 2005).

The daily products generated from multiple sensors and interpolated to 1.1 km were extracted from Ifremer's ftp site: ftp://ftp.ifremer.fr/ifremer/cersat/products/gridded/ocean-color/atlantic/EUR-L4-SPIM-ATL-v01/. The data extends from 13°W to 12°E and 36°N to 60°N. This covers the continental shelf in UK waters with the exception of the Faroe-Shetland Channel, north of 60°N. The example image in Figure 2 is from day one of the largest storms of the winter of 2013/14 (illustrated in Figure 3).

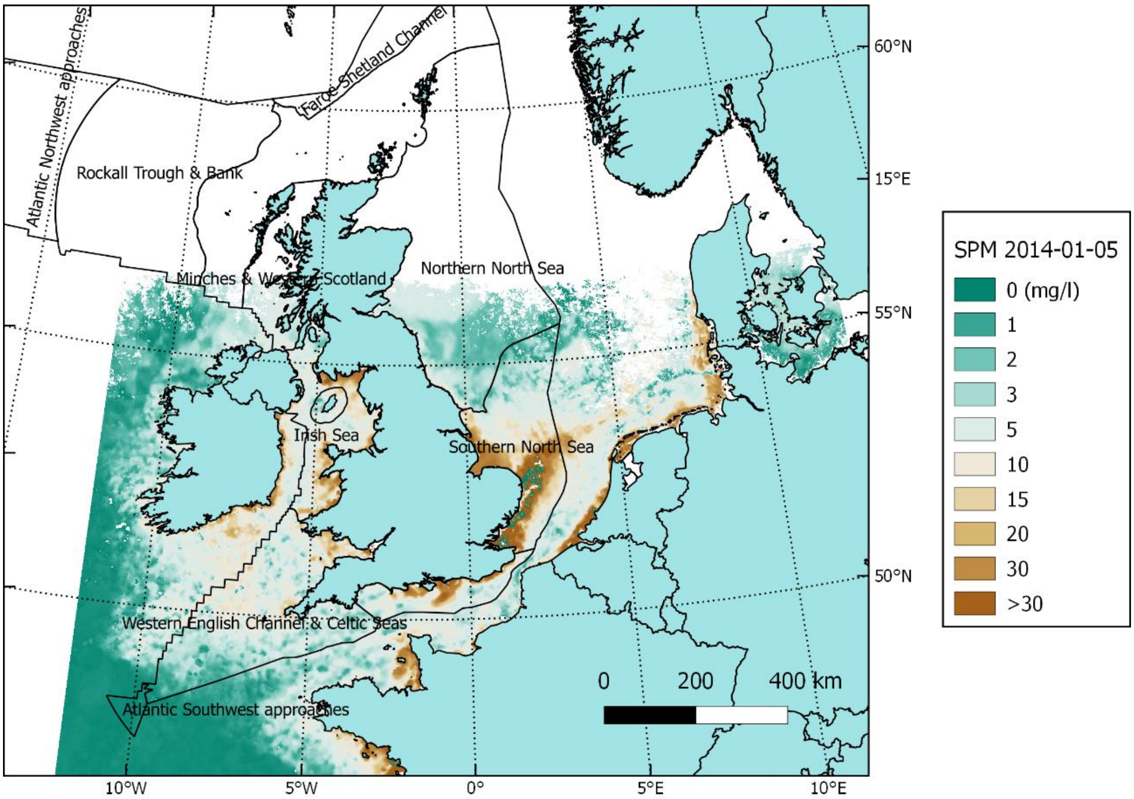
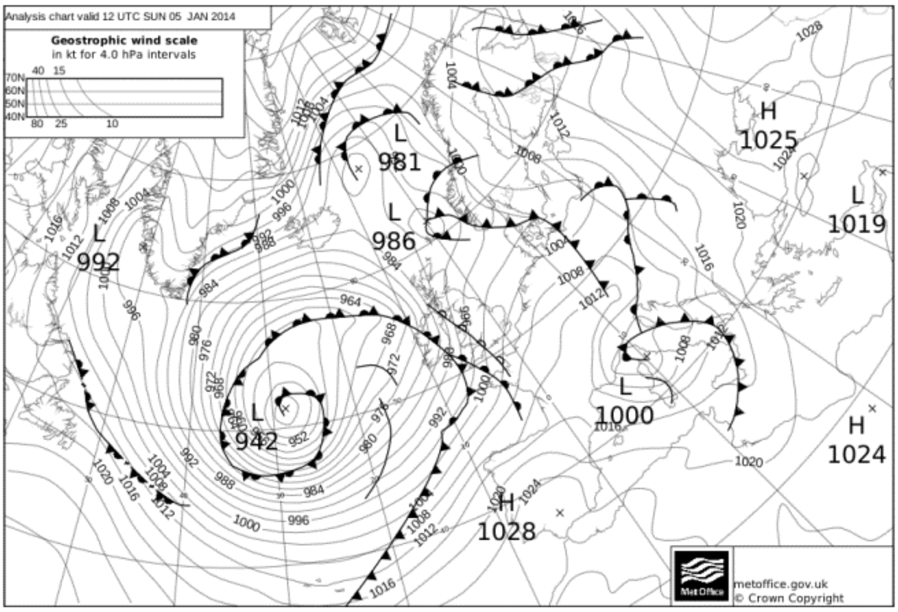


Figure 2: Daily image on non-algal SPM for the 5th of January 2014, when a storm drove large waves towards southern and western coasts of the British Isles.



Analysis chart 1200 GMT 5 January 2014

Figure 3: Pressure chart from the height of the storm of 5th of January 2014 (credits:UK Met Office).

Data Analysis

The daily images of non-algal SPM from 1/1/1998 to 31/12/2015 were averaged into 12 monthly means for the 18 years (216 fields). These were used to calculate a climatological average (Figure 4) as well as climatological monthly averages (see Appendix A). The yearly anomaly was calculated as the difference between the yearly average and the climatological mean (see Appendix B).

The temporal variation of the SPM was analysed by averaging the values of non-algal SPM within the Charting Progress 2 regions (http://chartingprogress.defra.gov.uk). There was no data for the Atlantic NW approaches and very little data for the Faroe-Shetland Channel.

The existence of a monotonic temporal trend in annual mean SPM within each region was tested using the non-parametric test Mann-Kendall (Mann, 1945). Seasonal trends used the periods January-March, April-June, July-September and October-December for Winter, Spring, Summer and Autumn, respectively.

Spatial Patterns

Figure 4 shows the spatial distribution of average non-algal SPM for the majority of the UK continental shelf. The largest feature is the Anglian plume extending from the Thames Estuary across the Southern North Sea (Southern Bight) northeast towards the Danish coast (Jutland Bank). The mouths of the large European rivers, Elbe, Rhine and Meuse, show mean SPM values greater than 10 mg/l. On the UK coast the Thames estuary, Humber, the Wash, Severn and Liverpool Bay also show mean values of SPM above 10 mg/l.

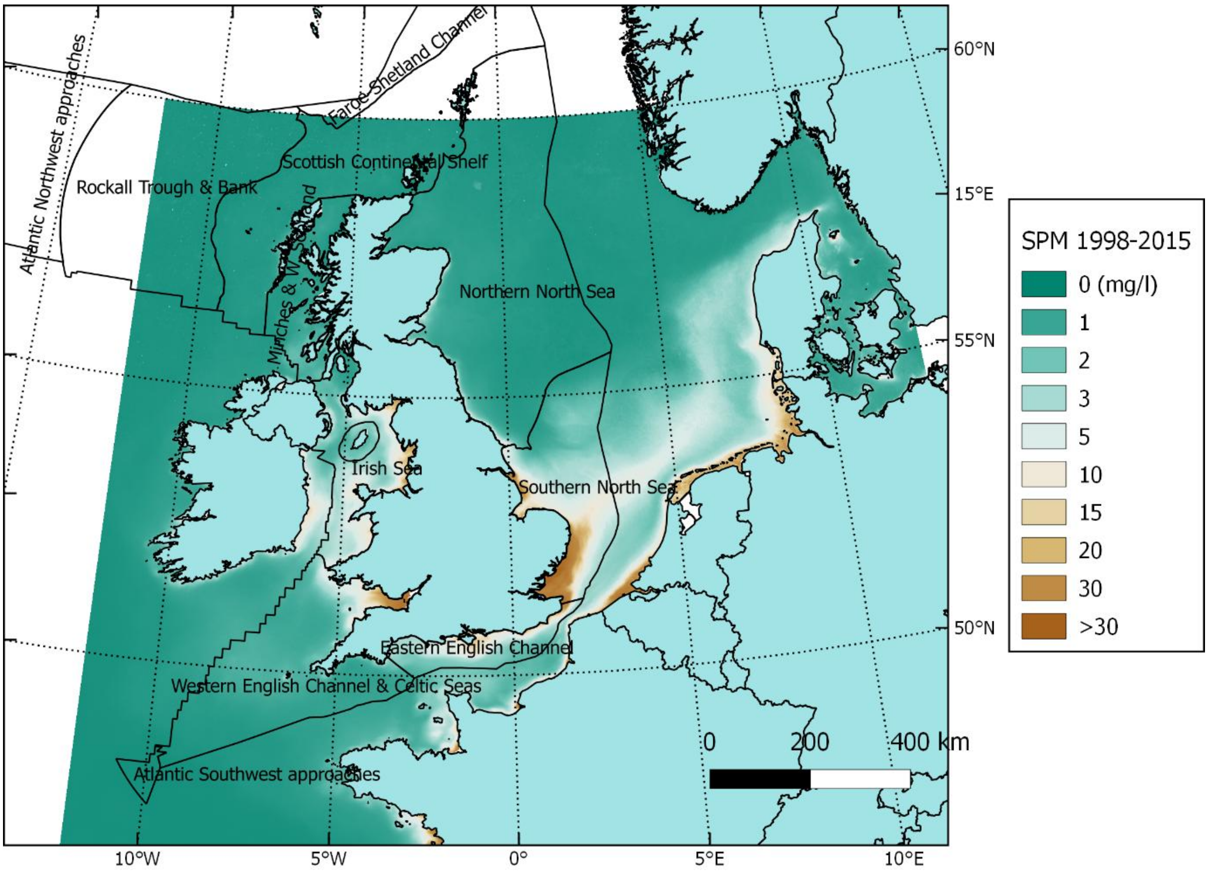


Figure 4: Average Suspended Particulate Matter (SPM) for the period 1998-2015 and Charting Progress 2 regions.

Satellite ocean colour observations suffer from the following sampling biases:

- Latitudinal bias due to winter sun angle; this limits useful data from December and January to 57°N and because during winter the sea condition is normally worse this leads to a local underestimate in mean annual SPM values.
- Cloud cover; observations are biased towards clear skies which are generally associated with better sea conditions and lower SPM values; in some coastal areas, such as the Danish part of the North Sea, less data is available in winter due to higher cloud cover.

Figure 5 shows the average percentage of available observations in January while Figure 6 shows the same quantity for the whole year. In January the cells at 55°N have valid data between 60 and 90% of the time. Over the whole year the areas at 60°N have observations at least 70% of the time.

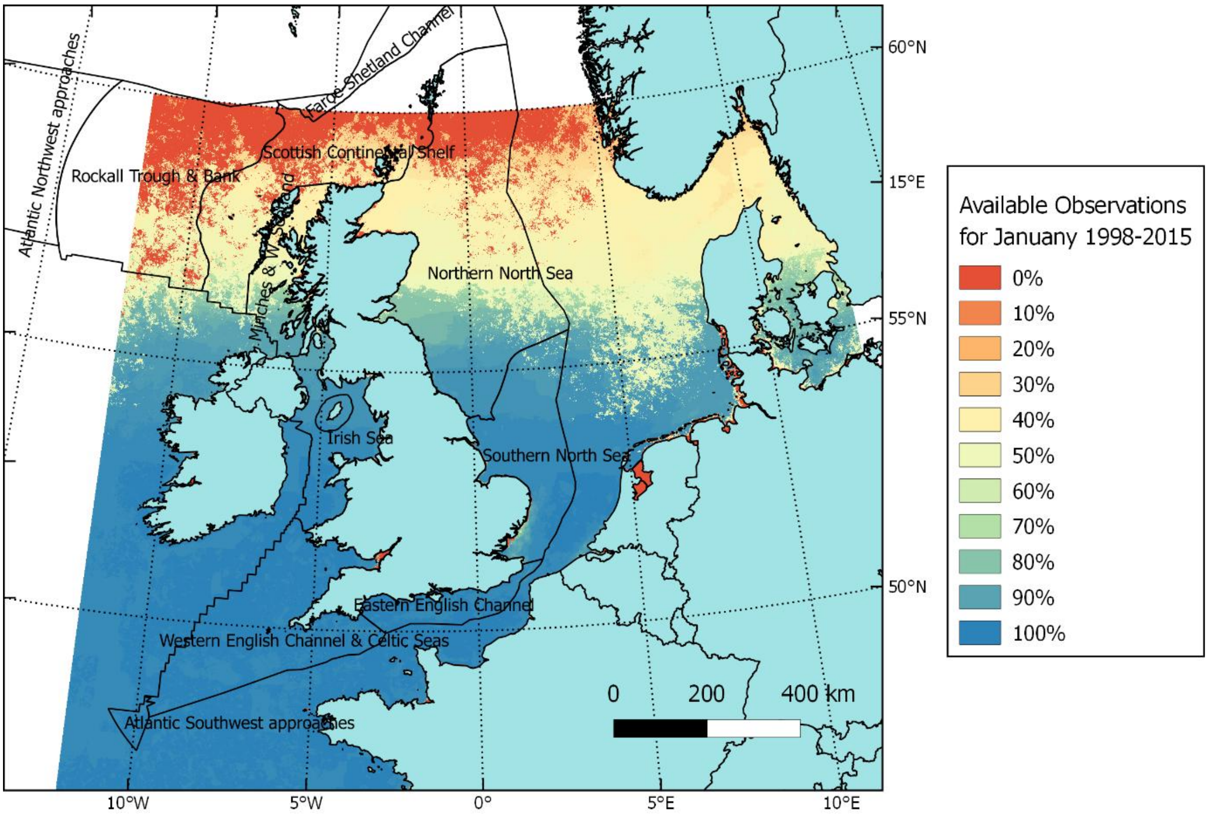


Figure 5: Availability of observations due to sun angle and cloud cover for January during the period 1998-2015.

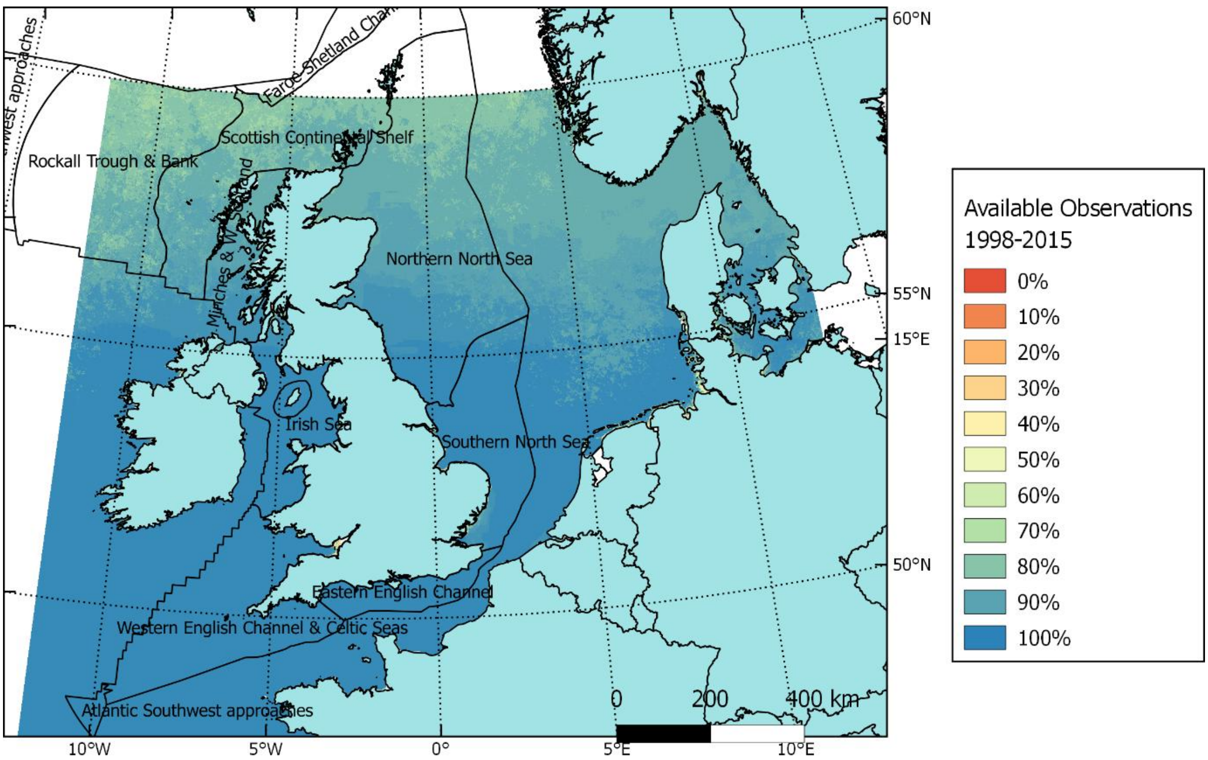


Figure 6: Availability of observations due to sun angle and cloud cover for the period 1998-2015.

Temporal Trends

The mean monthly fields were used to calculate regional trends for the period of 18 years (see Figure 7). The monthly time series shows a strong seasonal signal as well as large interannual variability. The seasonal signal was eliminated by calculating a time series of annual averages and the Mann-Kendal test was applied to detect monotonic trends. The null hypothesis is that no trend is present. When the test value is greater than 0 (less than 0) and the probability of the test value is $p<0.05$, the significance threshold, we can reject the null hypothesis and consider there to be a significant increasing (decreasing) trend. In all significant tests in Table 2 the significant tests correspond to increasing trends.

The following on-shelf regions showed significant increasing trends of annual SPM during this period: Scottish Continental Shelf, Northern North Sea and Minches and Western Scotland. The off shelf regions of Rockall Bank and Trough and SW Approaches also saw significant trends.

By applying the Mann-Kendal test to the seasonal time series it is possible to identify if trends are happening at specific times of the year (see Table 2 and Figure 8). The Scottish Continental Shelf had a significant trend in Autumn (Oct-Dec), Northern North Sea in Summer and Autumn and Western Scotland in Spring, Summer and Autumn. It is worth noting that no one shelf region had significant trends in Winter (Jan-Mar). It is also worth noticing that the regions Western and Eastern Channel, Irish Sea and Southern North Sea all had trends in Spring and/or Summer but these were not strong enough to create a trend in the annual mean, possibly because the Spring and Summer values are much lower than in Winter.

The annual trends in the off shelf regions of Rockall and SW Approaches were caused by increases year-round but not including Spring.

One outcome that stands out from these results is that only positive trends were detected, but the pattern between on and off shelf and seasonality is less clear. For shelf regions there is an increase in Oct-Dec turbidity that could be related to early storms but none in Winter when SPM values peak. The pattern of windiness in the North Eastern European shelf seas, defined by annual mean geostrophic wind in the region, has been an increase since the 1950s which peaked in the 1990s and has stabilised since (Bakker and van den Hurk 2012). The interannual variability dominates and decadal variations are not well understood (Bakker et al. 2013).

Direct anthropogenic factors such as trawling, dredging, shipping or wind farms would be more likely to cause a measurable effect in Summer when background levels are low, and according to the results that is a possibility for the North Sea and Eastern Channel but it has yet to be demonstrated if such localised activities could affect large regions.

Increased river discharge of sediments should be more noticeable in Winter, when precipitation is stronger and around the largest rivers mostly around the English Coast. But this is not supported systematically by the test results where only the Northern North Sea seas a significant increase in Autumn.

Table 2: Results of the Mann-Kendall test for trends in SPM for each region. Significant trends, with p<0.05, are highlighted in bold.

Region	Spring	Summer	Autumn	Winter	Annual
On shelf					
Scottish Continental Shelf	0.363	0.405	**0.001**	0.069	**0.012**
Northern North Sea	0.325	**0.023**	**0.008**	0.112	**0.010**
Southern North Sea	**0.012**	**0.041**	0.150	0.130	0.058
Eastern English Channel	**0.005**	0.058	0.405	0.649	0.198
Western English Channel & Celtic Seas	0.762	**0.041**	0.449	0.363	0.198
Irish Sea	**0.028**	0.069	0.545	0.820	0.226
Minches and Western Scotland	**0.010**	**0.019**	**0.012**	0.096	**0.002**
Off shelf					
Rockall Trough and Bank	1.000	0.325	**0.000**	**0.049**	**0.010**
Faroe-Shetland Channel	0.880	0.256	0.081	**0.006**	0.649
Atlantic SW Approaches	0.130	**0.002**	**0.028**	**0.023**	**0.023**

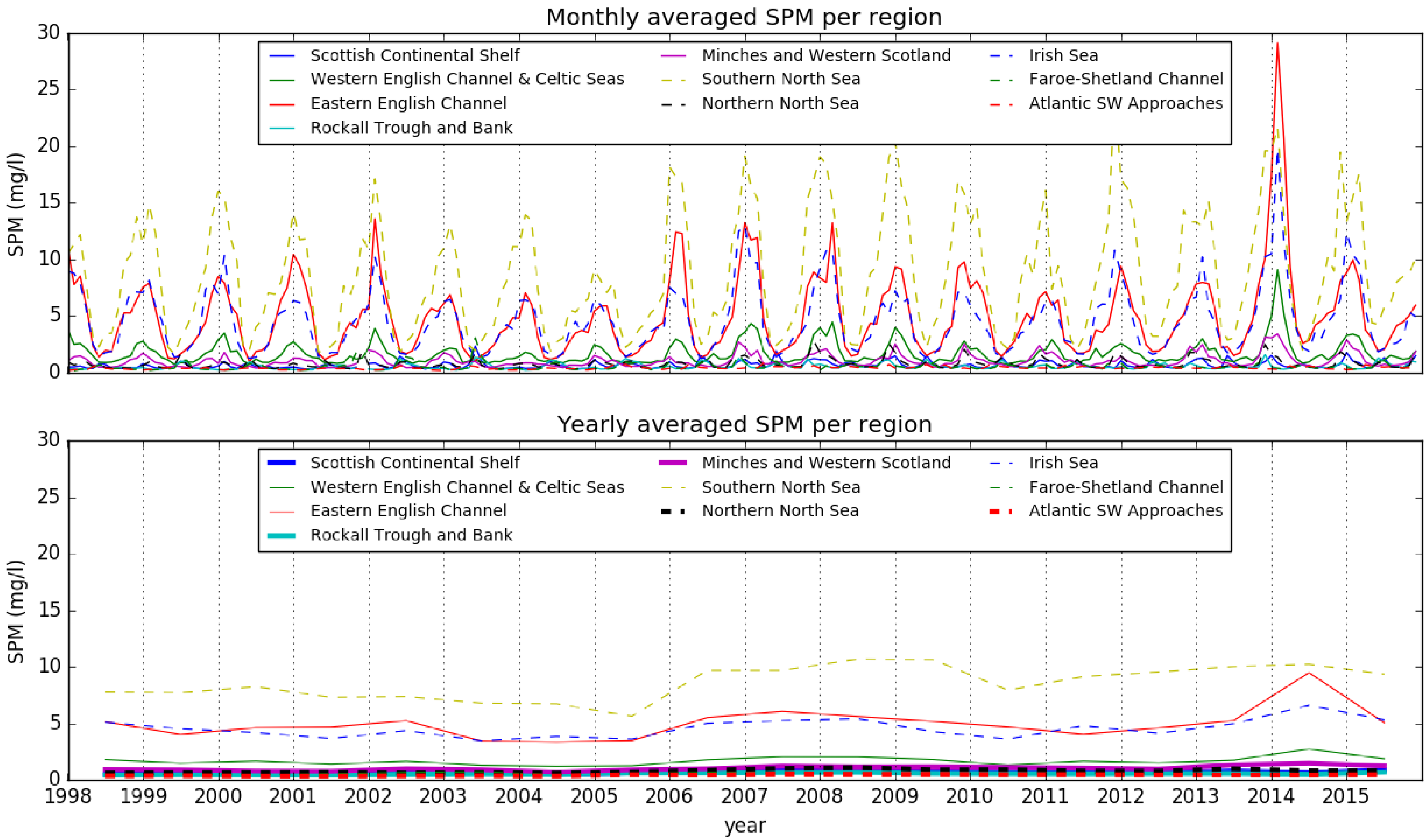


Figure 7: Monthly and annual SPM for each region in the period 1998-2015. Top: monthly averages; Bottom: yearly averages. The thick lines in the bottom panel represent the statistically significant trends according to the Mann-Kendall test (see Table 2).

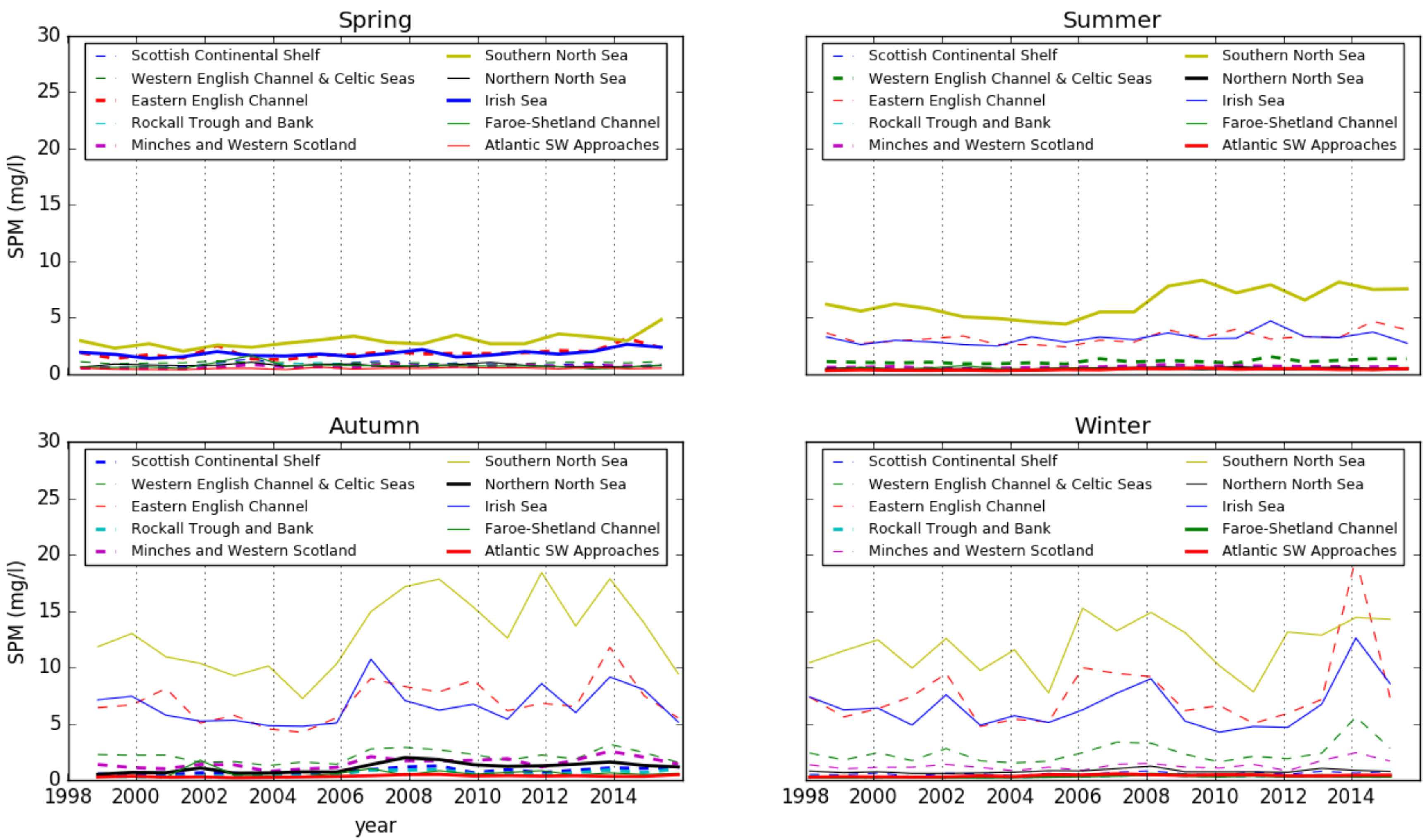


Figure 8: Seasonal mean SPM for each region in the period 1998-2015. The thick lines represent the statistically significant trends according to the Mann-Kendall test (see Table 2).

Test cases

Individual monopiles are able to generate a sediment plume aligned with tidal currents (Baeye and Fettweis, 2015). This plume constitutes mostly of fine sediments that can stay in suspension for 1-2 km in the wake of the turbine. In this section we do a preliminary test of the hypothesis that a large operational wind farm can cause a rise in SPM load that is detectable at a regional scale. Two test cases were considered:

- Walney 1 and 2 with 102 3.6 MW turbines and a capacity of 367 MW. Construction started in 2010 and completed at the end of 2011.
- Greater Gabbard with 140 3.6 MW turbines and a capacity of 504 MW. Construction started in 2009 and completed in 2012.

For each site a location was chosen outside the licensed area in the direction of local residual flows (see Figure 9):

- 52.00°N 1.94°E for Walney
- 54.13°N 3.67°W for Greater Gabbard

The monthly non-algal SPM dataset was used to extract a time series for these locations for the periods before and after construction. The two periods were tested for the hypothesis that both samples come from the same distribution using the non-parametric test Mann-Whitney.

The results of the test in Table 3 show that the null hypothesis was rejected with the two-sided p value being larger than the critical value. If we assume that after the construction of the windfarm the SPM would have to increase, then we would apply a one-sided test. In this case, the hypothesis is still rejected but it is worth pointing out that for the Greater Gabbard wind farm the p value (0.07) is close to the critical value.

It should be taken into account that it has not been proven beforehand that this satellite product could be used to detect such localised plumes. The kriging method used to merge and interpolate multiple satellite observations to 1.2 km resolution will blur point sources of sediments such as individual turbines or dredging. Another limitation is the aliasing of the tidal signal that results from the satellite image capture being at the approximately at the same time every day. A better test would require using high resolution SPM estimates, such as those from Landsat 8 (30 m) and take into consideration the state of the tide for each observation. This was outside the scope of the present study and we will focus on investigating this in future work at Cefas.

Table 3: Results of the Mann-Whitney test for the Walney and Greater Gabbard wind farms.

Test	Two sided p	One-sided p	Mann-Whitney u
Walney 1998-2009 vs. 2012-2015	0.727	0.364	3316
Gabbard 1998-2008 vs. 2013-2015	0.142	0.071	1965

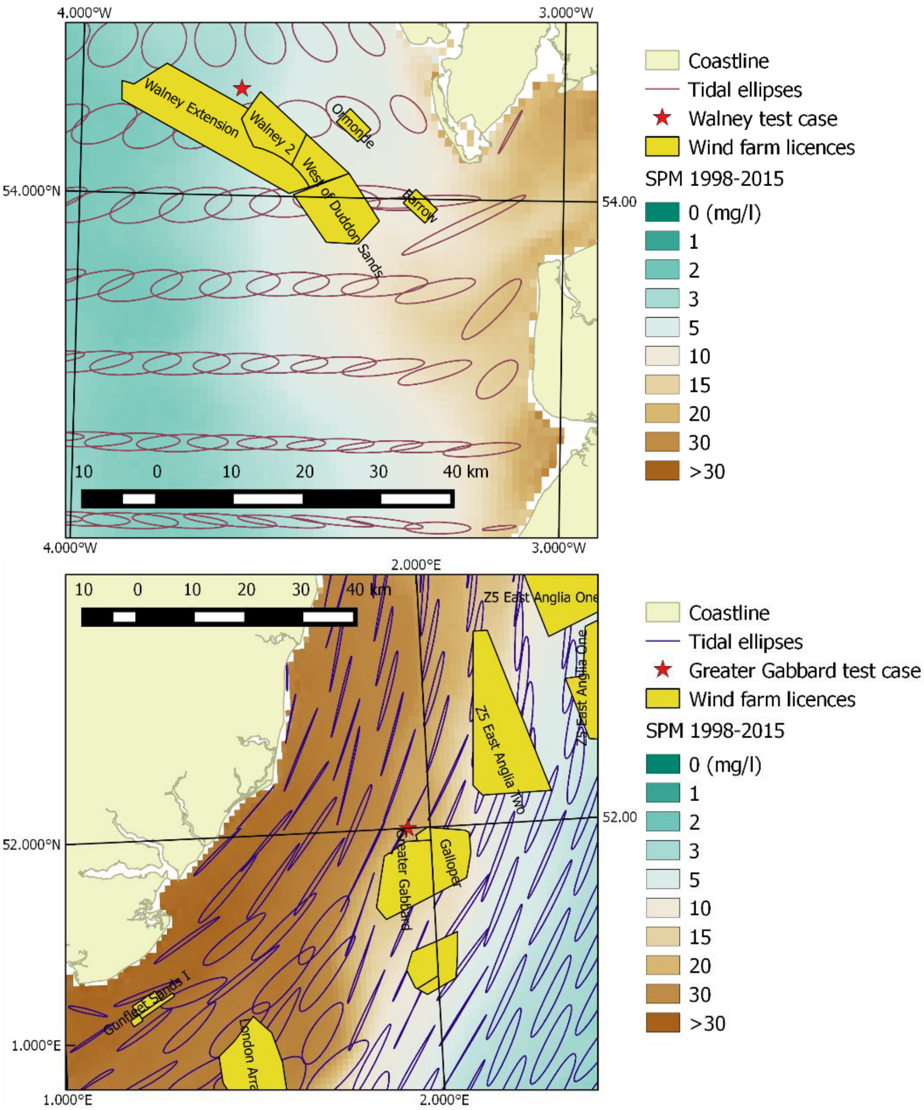


Figure 9: Location of the windfarms used in the test cases: Walney 1 and 2 (top) and Greater Gabbard (bottom). The tidal ellipses indicate the direction of the tide. The red stars mark where the non-algal SPM values were extracted from.

The effects of external influences on water clarity in UK waters

Aeolian Input

The distinction between large dust and small dust is crude, but important for establishing the division between loess (travelled over short distances) and aerosolic (travelled over long distances) dust (Stuut et al., 2008). In Europe, large dust tends to be produced 'in continent' and deposited by aeolian action (Husar et al., 2000). Small dust, on the other hand, gets blown to the continental region from mainly North Africa, the old Lake Chad basin and the Great Sand Sea (Goudie and Middleton, 2001), then carried to the west and out over the Atlantic (Figure 10).

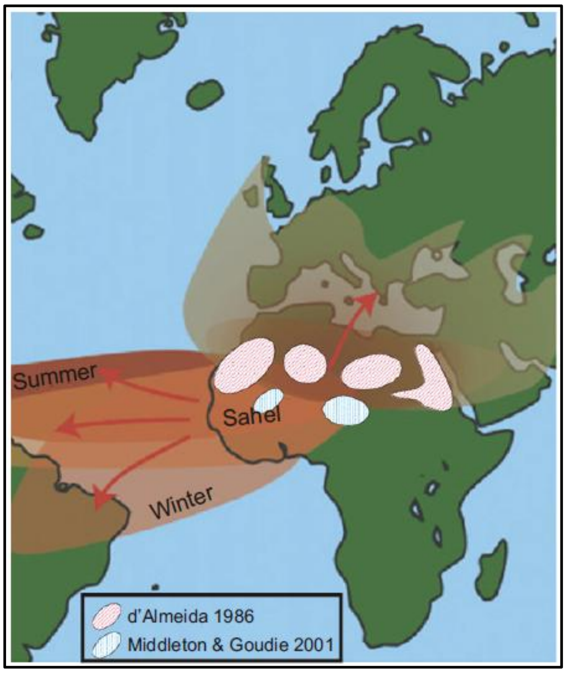


Figure 10: Present-day active dust sources in the Saharan Desert (modified by Stuut et al., 2008, incorporating Kellogg and Griffin, 2006, d'Almeida, 1986; Middleton and Goudie, 2001; Engelstaedter and Washington, 2007).

Because of the proximity of the North Atlantic Ocean to the Sahara Desert, it is these waters that receive the bulk (43%) of the total dust input to the global ocean (Jickells et al., 2005) (Figure 11). However, this process of aeolian deposition is not constant and half of the annual deposition occurs in just 10 weeks (Swap et al., 1996) through "episodic dust pulses" (Sarthou et al., 2007) of 3–8 days that tend to occur in winter, or summer to autumn (Pérez-Marrero et al., 2002; Torres-Padrón et al., 2002, Neuer et al., 2004; Sarthou et al., 2007). According at Gao et al. (2001), the North Atlantic receives highest concentrations of wind-blown iron over the summer.

Figure 11: Aerosolic small dust from the Sahara Desert blowing out over the Atlantic Ocean and the Canary Islands (true colour image source: NASA – MODIS Terra).

Although events of significant fertilization of phytoplankton production have been observed off Great Britain (Spokes et al., 2000), UK waters tend to experience less dust input as they are farther removed from the main Saharan dust cloud (Duce and Tindale, 1991) (Figure 10 and Figure 12). Importantly, even when aerosolic dust travels unusually far north, strong southward advection of surface water masses generates a net export of suspended dust from the area. For these reasons, aeolian deposition is highly unlikely to be a contributor to suspended materials and overall turbidity of UK waters.

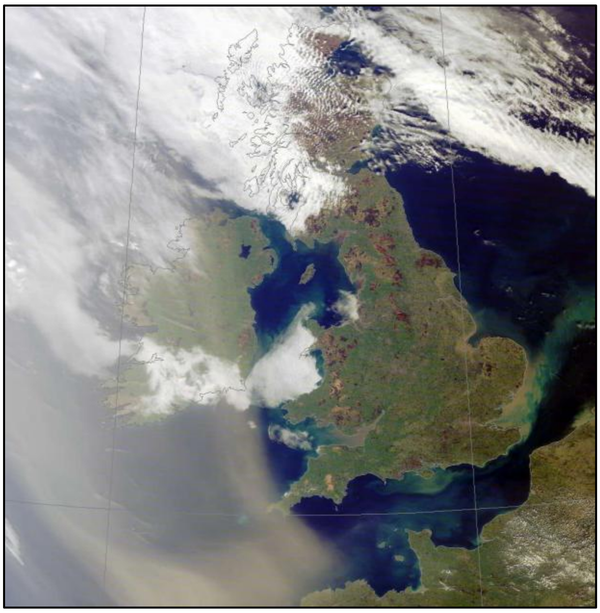


Figure 12: Aerosolic small dust from the Sahara Desert blown unusually far north to the south west of the UK in April 2011 (true colour image source: Dundee Satellite Receiving Station, NASA MODIS Terra/ Aqua)

Volcanic input

The Macauley Land Use Research Institute conducted a study in the aftermath of the Eyjafjallajökull eruption to assess the impact on pastures and livestock, soils and surface waters. Chemical samples of surface water and precipitation, from before and after the eruption were compared (e.g. pH, sulphate, fluoride, dissolved organic carbon, major cations and trace metals). It was concluded that there were little measurable effects in surface waters before and after the eruption.

Another study, this conducted by the Norwegian Institute for Water Research looked at the short and long term impacts of the Eyjafjallajökull eruption in Norwegian freshwater resources. Additionally, they also considered the potential impacts of an eruption of the Katla volcano (NIVA Communication 2010 in Dawson et al., 2010). This other Icelandic volcano is expected to produce 10 to 100 times more material that the recent eruption at Eyjafjallajökull. As can be seen on the summary reproduced here (Table 4) the main effect is expected to be potential acidification episodes caused by increasing SO_4 deposition.

In the short-term (up to four weeks post eruption), the impacts of particle concentrations should not be sufficiently severe for there to be a measurable change to water clarity or water quality, or for there to be a negative impact on fish or other aquatic organisms. In the longer term, if prolonged eruptions occur, there may be increased contributions to deposits to what currently occurs naturally and by long-distance anthropogenic pollution. However, it is still unlikely that particle concentrations would be sufficiently high in UK surface waters to enable observation of negative effects on fish or other aquatic organisms. The impact on water clarity is uncertain, but still unlikely to be significant.

Table 1: Summary of measured (Eyjafjallajökull) and anticipated (Katla) effects of volcanic eruptions to the UK aquatic environment (from NIVA Communication, 2010 in Dawson et al., 2010)

Component	Short-lasting eruption of the volcano under Eyafjellajøkull	Long-lasting eruption of the volcano under Eyafjellajøkull	Eruption of Katla
Sulphur	Little or no effect, but a possibility of episodic acidification under special conditions	Effect on aquachemisty in areas vulnerable to acidification and that are already acidic	Fish death in areas that are vulnerable to acidification and areas that are already acidic
Particles	Little or no effect	Little or no effect	Little or no effect (?)
Fluoride	No effect	No effect	No effect
Trace Metals	No effect	No effect	No effect

Note: In the event of an eruption, Icelandic volcano Katla is expected to produce from 10-100 times more ash than Eyjafjallajökull.

Conclusions

A remote sensing climatology of suspended particulate matter observations covering 18 years is presented. Maps of monthly climatologies and yearly anomalies are included in the appendix.

Analysis of time series averaged for the Charting Progress 2 regions polygons identified increasing tends in the annual averages SPM in 5 out of the 10 regions. Further analysis of seasonal trends showed a mixed picture, with a trend in Winter for off shelf regions and only outside Winter for shelf regions. The longer term background for this 18 year time series is an increasing trend in turbidity since the beginning of the 20th century (Dupond and Asknes, 2013; Capuzzo et al., 2015). Several factors have been proposed for this longer term change, including increased windiness in the second half of the 20th Century (Bakker and van den Hurk, 2012), changes to land use and river management, draining of wetlands, and marine activities such as trawling. The present 18 year dataset is able to define a baseline with much more information than point based measurements (e.g. Secchi depths or SPM concentrations) but the present methodology of analysing time series within CP2 regions it is not possible to do an attribution of cause for the changes detected.

Two large windfarms, Walney and Greater Gabbard, were used as test cases to investigate the hypothesis that after the construction the non-algal SPM outside the licensed site has increased. At this spatial scale and using monthly averages it was not possible to see a significant effect. It is discussed that only using higher resolution ocean colour products and treating the data for the effect of tides could this be tested conclusively.

Two remote sources of sediment are considered using bibliographic references: aeolian deposition of Saharan dust and volcanic eruptions. The possible eruption of the Katla volcano in Iceland, 10 to 100 times larger than that of the Eyjafjallajökull eruption in 2010 is considered. Both sources are considered unlikely to have an effect in the turbidity of UK waters.

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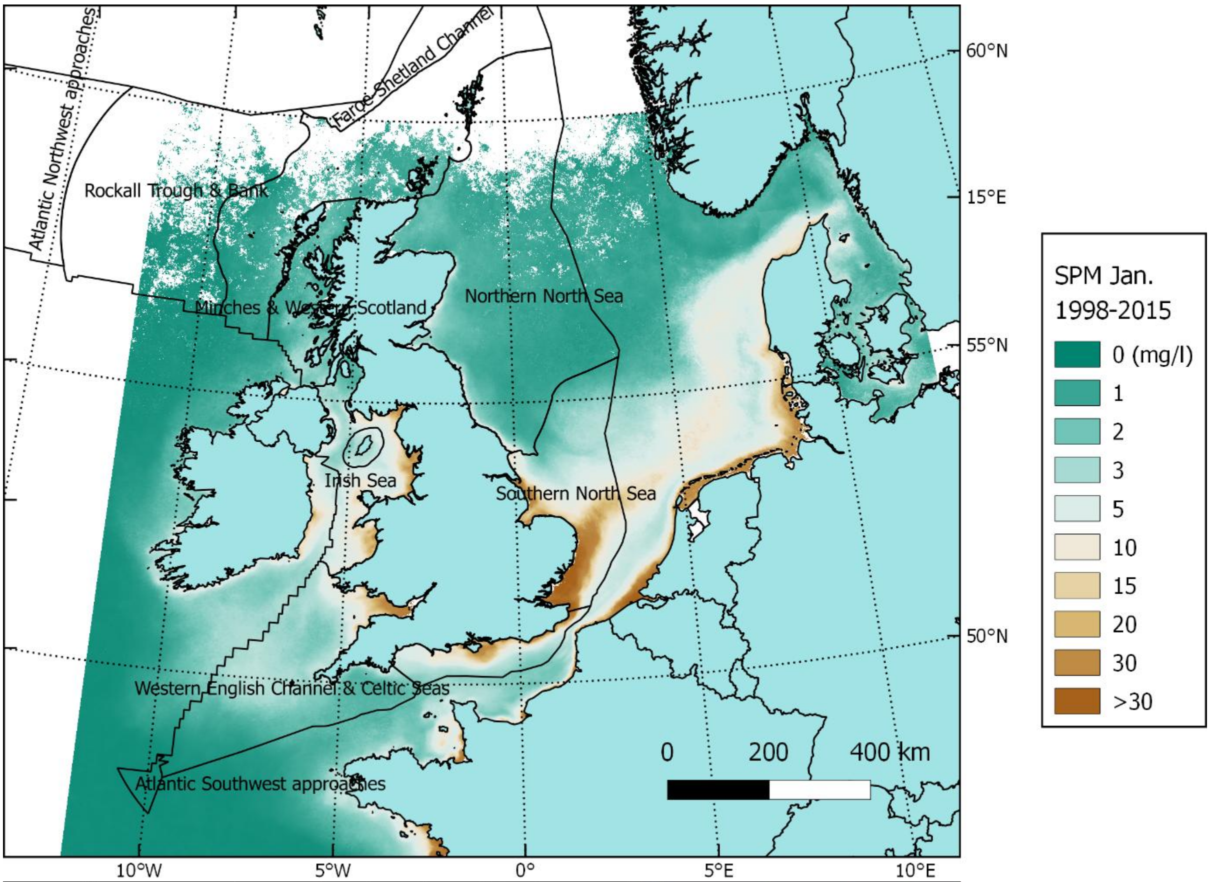
Appendix A: SPM Monthly Climatologies 1998-2105



Atlantic Northwest approaches
Faroe-Shetland Channel
Rockall Trough & Bank
Minches & Western Scotland
Northern North Sea
Irish Sea
Southern North Sea
Western English Channel & Celtic Seas
Atlantic Southwest approaches
60°N
15°E
55°N
50°N
10°W
5°W
0°
5°E
10°E
0
200
400 km
SPM Jan.
1998-2015
0 (mg/l)
1
2
3
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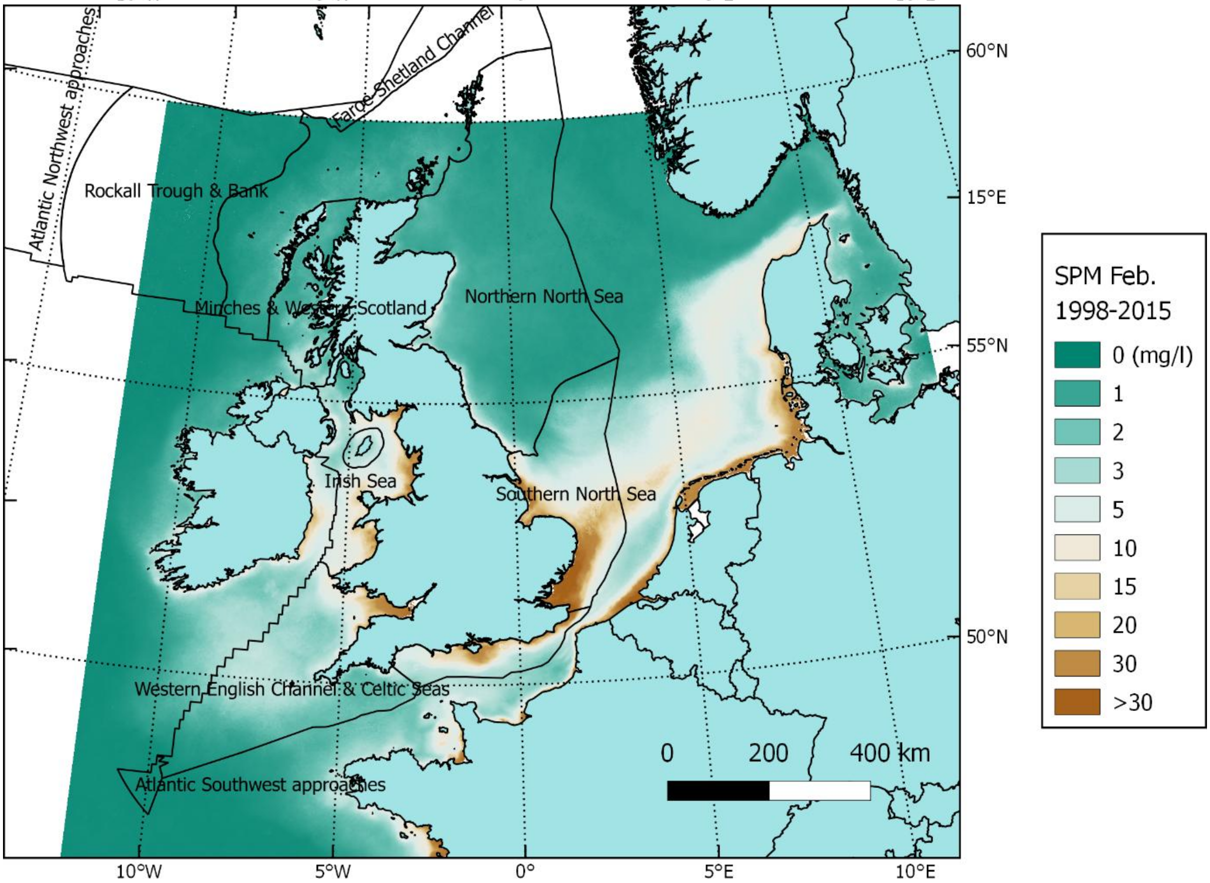
15
20
30
>30



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Faroe-Shetland Channel
Rockall Trough & Bank
Minches & Western Scotland
Northern North Sea
Irish Sea
Southern North Sea
Western English Channel & Celtic Seas
Atlantic Southwest approaches
60°N
15°E
55°N
50°N
10°W
5°W
0°
5°E
10°E
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400 km
SPM Feb.
1998-2015
0 (mg/l)
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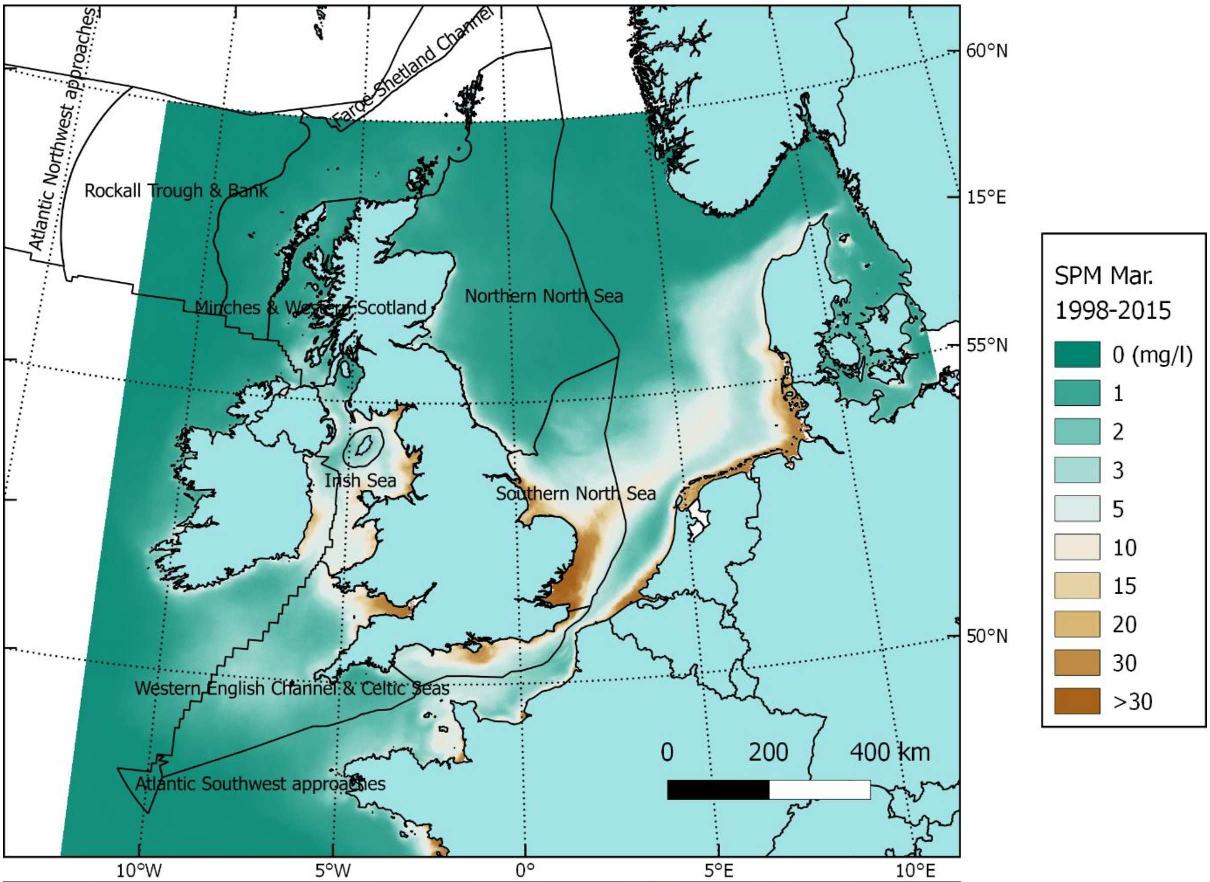
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Faroe-Shetland Channel
Rockall Trough & Bank
Minches & Western Scotland
Northern North Sea
Irish Sea
Southern North Sea
Western English Channel & Celtic Seas
Atlantic Southwest approaches
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400 km
60°N
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50°N
15°E
10°W
5°W
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SPM Mar.
1998-2015
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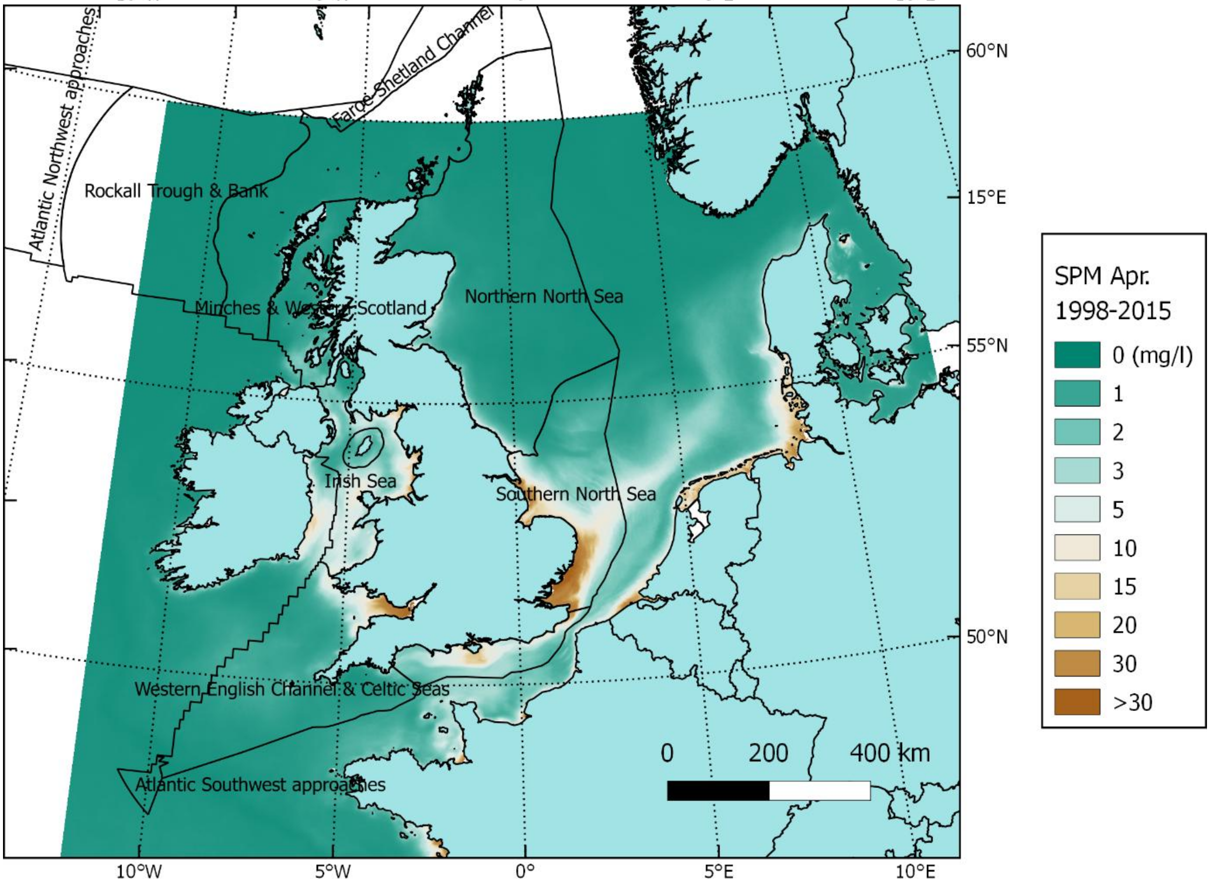
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Minches & Western Scotland
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Atlantic Southwest approaches
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10°W
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SPM Apr.
1998-2015
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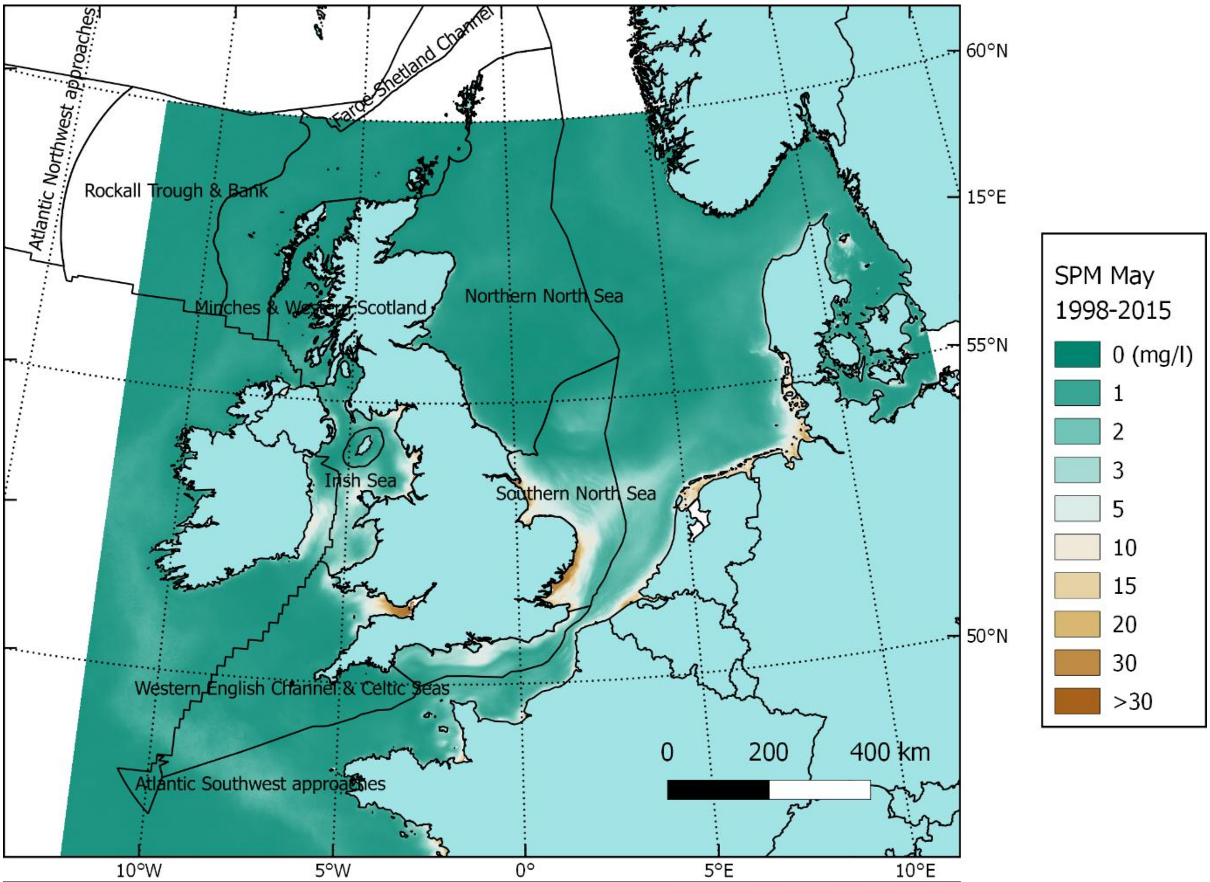
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Northern North Sea
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Southern North Sea
Western English Channel & Celtic Seas
Atlantic Southwest approaches
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400 km
60°N
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55°N
50°N
10°W
5°W
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5°E
10°E
SPM May
1998-2015
0 (mg/l)
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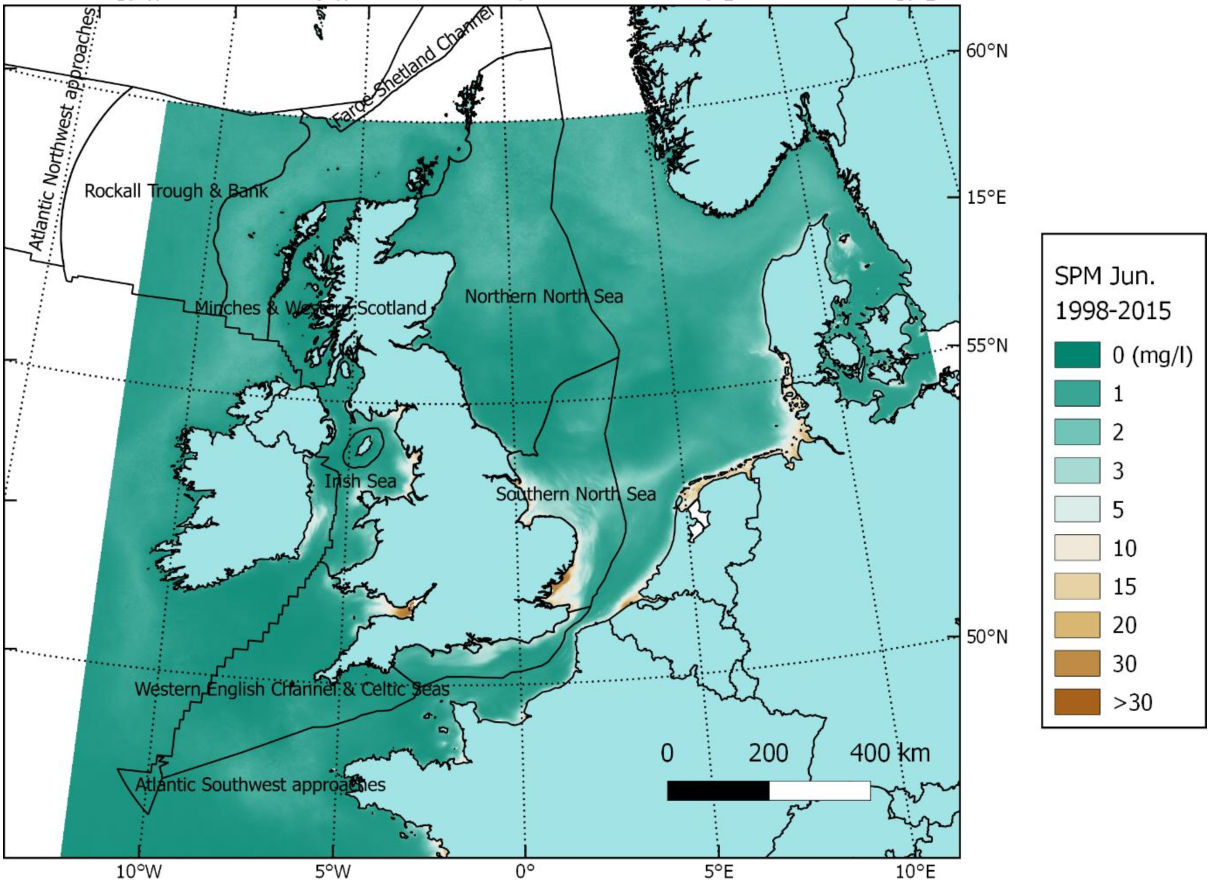
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Northern North Sea
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Western English Channel & Celtic Seas
Atlantic Southwest approaches
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400 km
60°N
15°E
55°N
50°N
10°W
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5°E
10°E
SPM Jun.
1998-2015
0 (mg/l)
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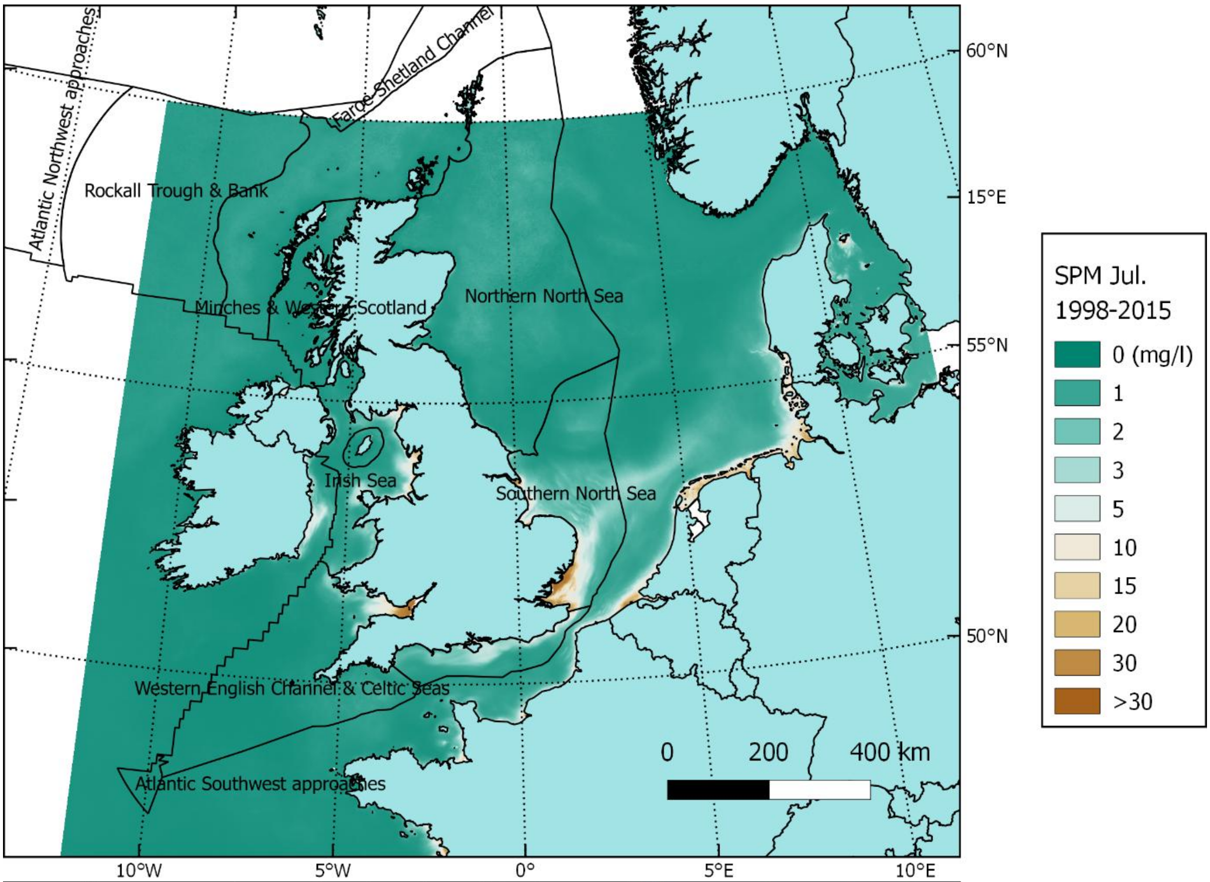
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Irish Sea
Southern North Sea
Western English Channel & Celtic Seas
Atlantic Southwest approaches
60°N
15°E
55°N
50°N
10°W
5°W
0°
5°E
10°E
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200
400 km
SPM Jul.
1998-2015
0 (mg/l)
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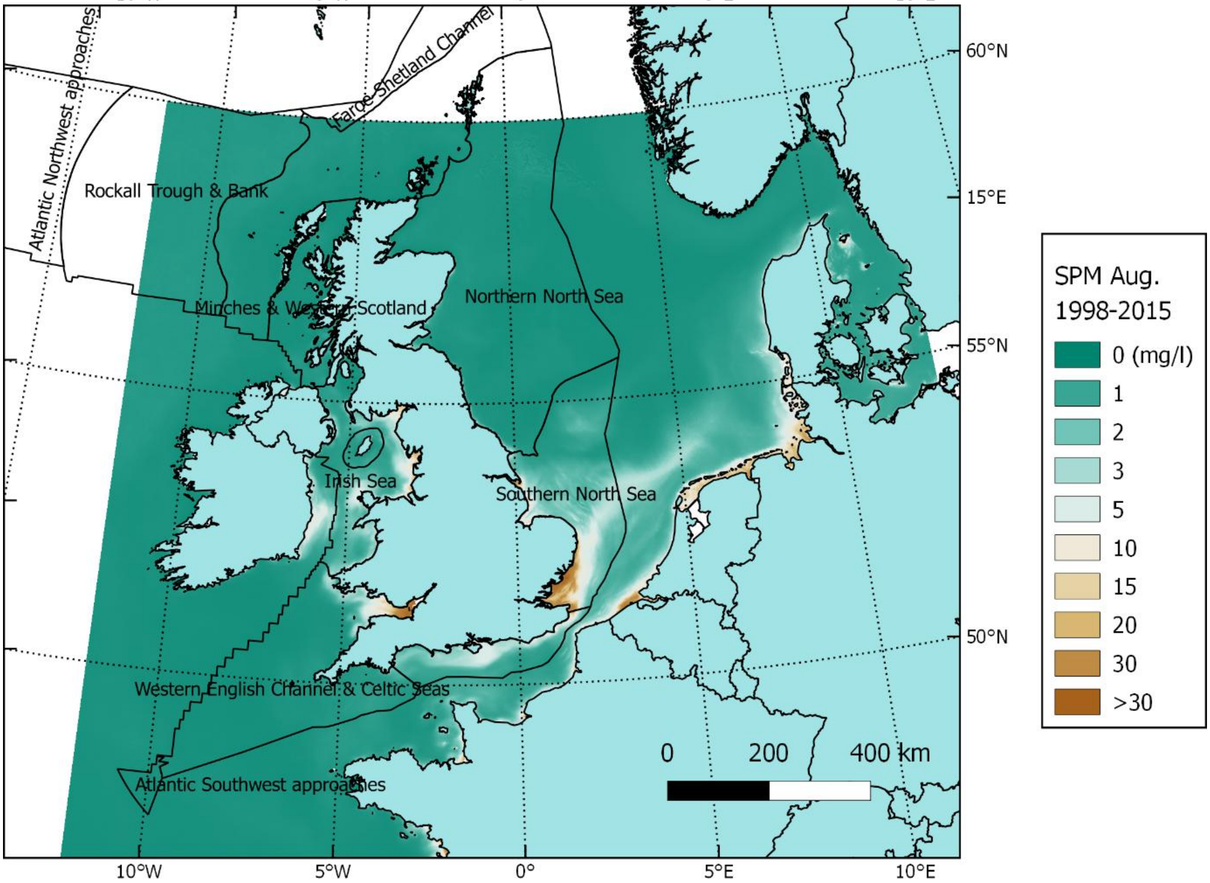
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Minches & Western Scotland
Northern North Sea
Irish Sea
Southern North Sea
Western English Channel & Celtic Seas
Atlantic Southwest approaches
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15°E
55°N
50°N
10°W
5°W
0°
5°E
10°E
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200
400 km
SPM Aug.
1998-2015
0 (mg/l)
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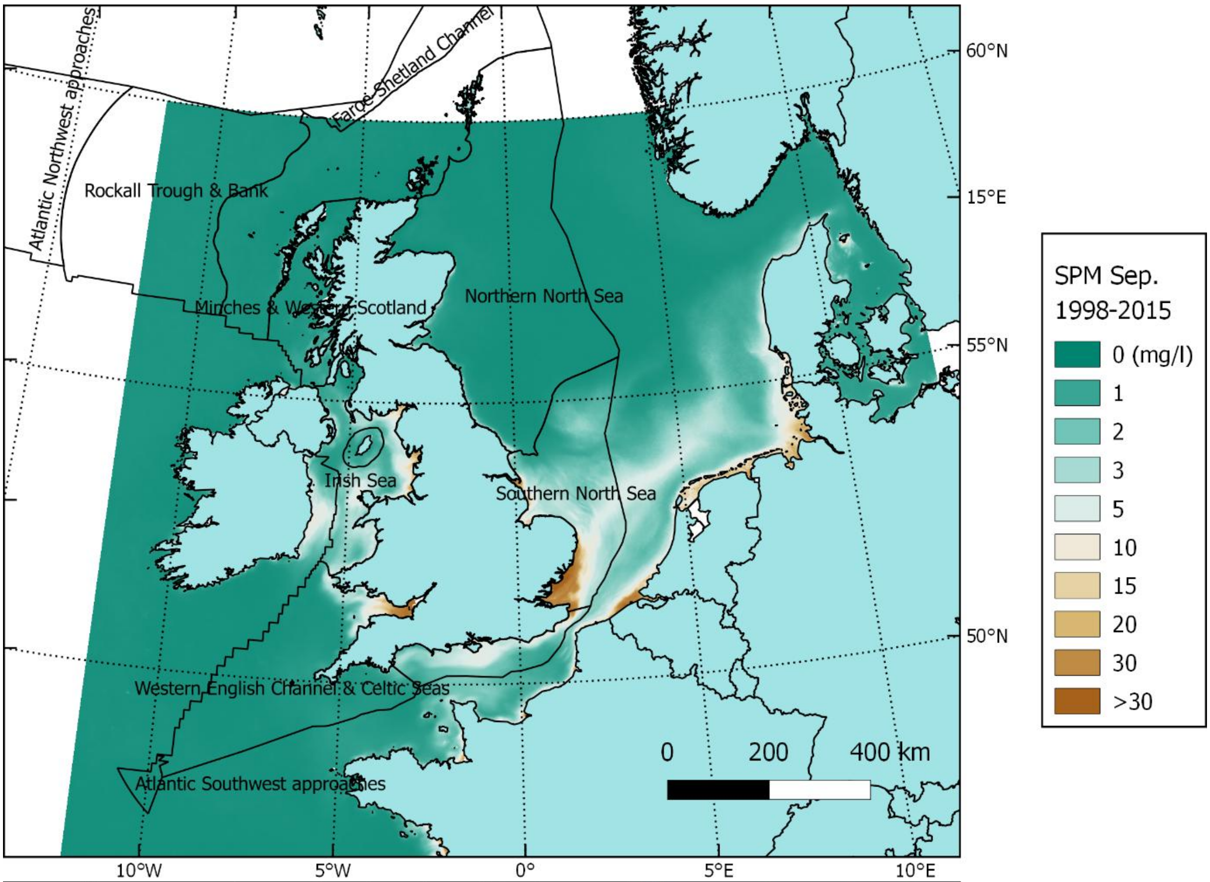
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Minches & Western Scotland
Northern North Sea
Irish Sea
Southern North Sea
Western English Channel & Celtic Seas
Atlantic Southwest approaches
0 200 400 km
60°N
15°E
55°N
50°N
10°W
5°W
0°
5°E
10°E
SPM Sep.
1998-2015
0 (mg/l)
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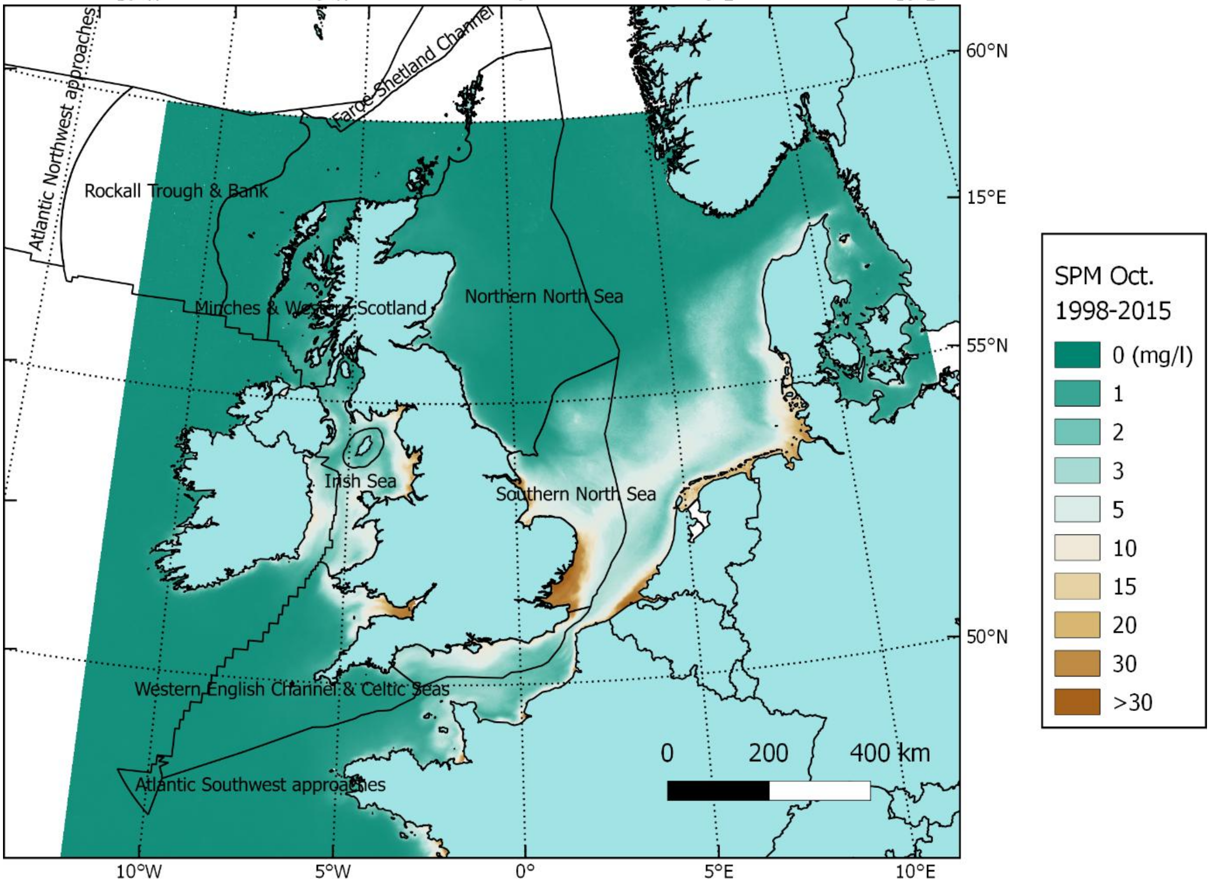
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Rockall Trough & Bank
Minches & Western Scotland
Northern North Sea
Irish Sea
Southern North Sea
Western English Channel & Celtic Seas
Atlantic Southwest approaches
0 200 400 km
60°N
15°E
55°N
50°N
10°W
5°W
0°
5°E
10°E
SPM Oct.
1998-2015
0 (mg/l)
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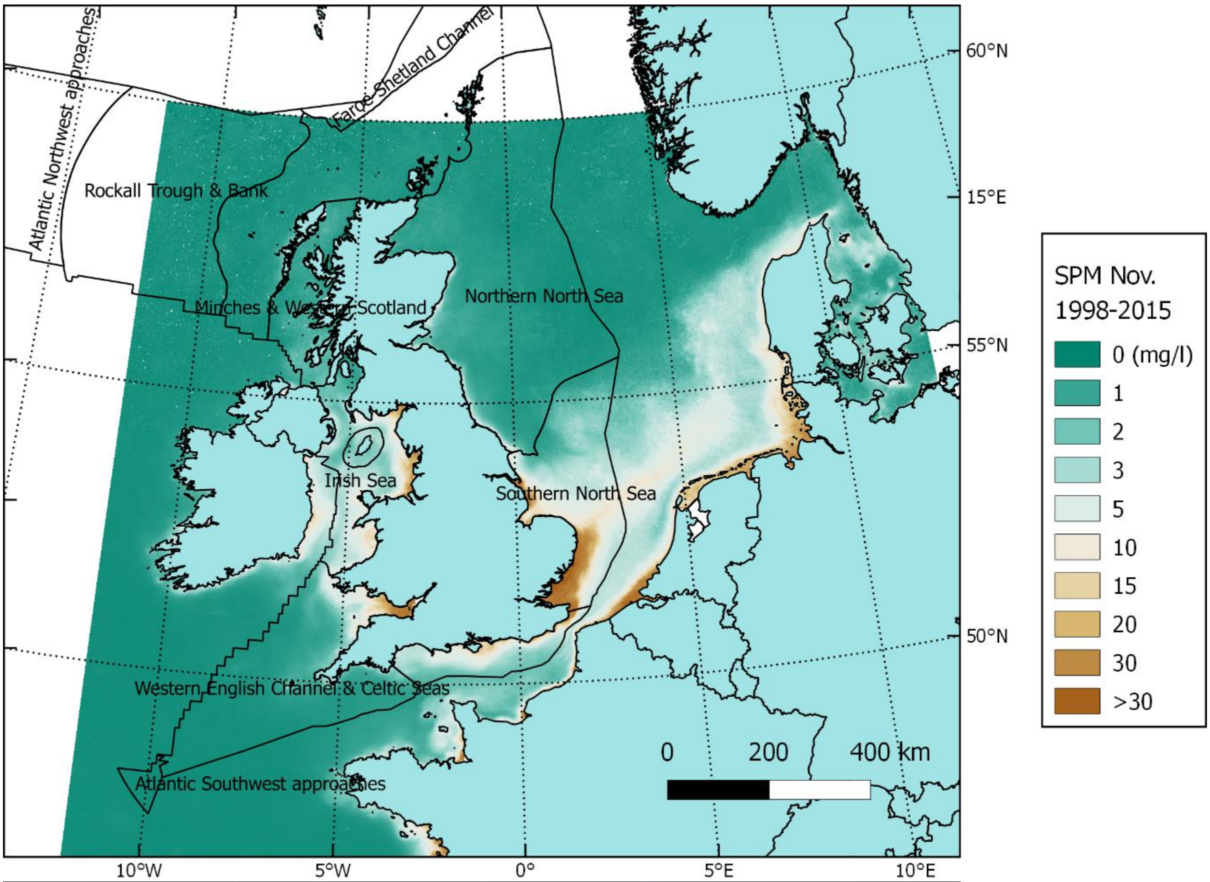
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Minches & Western Scotland
Northern North Sea
Irish Sea
Southern North Sea
Western English Channel & Celtic Seas
Atlantic Southwest approaches
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400 km
SPM Nov.
1998-2015
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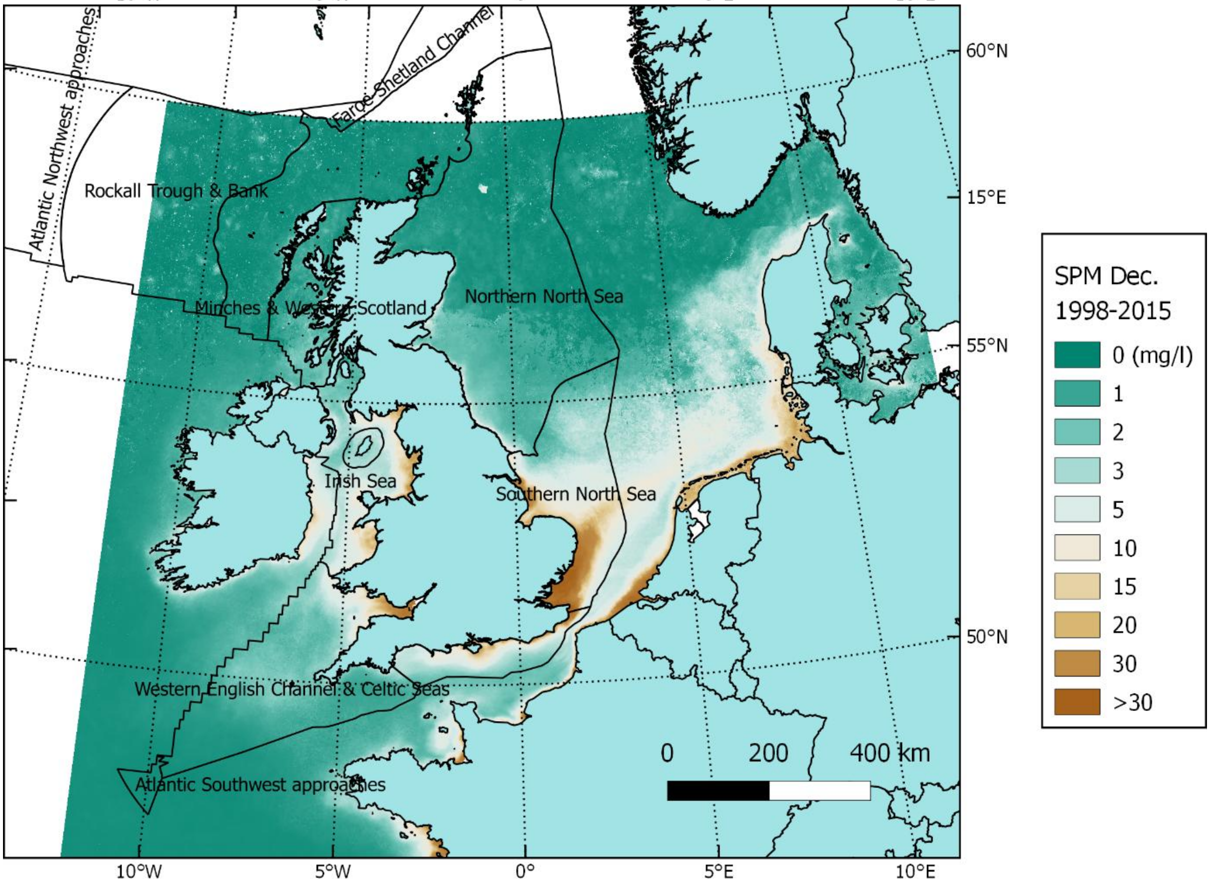
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Minches & Western Scotland
Northern North Sea
Irish Sea
Southern North Sea
Western English Channel & Celtic Seas
Atlantic Southwest approaches
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5°E
10°E
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400 km
SPM Dec.
1998-2015
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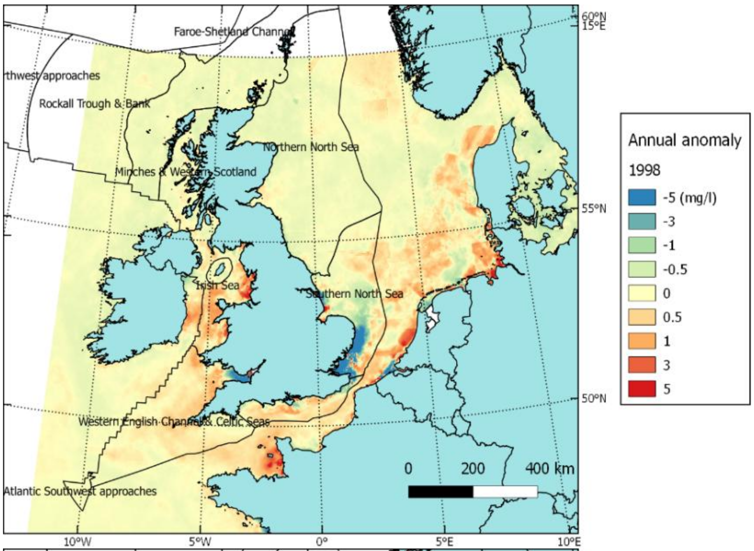
>30

Appendix B: SPM Yearly Anomalies 1998-2015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Rockall Trough & Bank
Northern North Sea
Minches & Western Scotland
Irish Sea
Southern North Sea
Western English Channel & Celtic Seas
Atlantic Southwest approaches
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55°N
50°N
10°W
5°W
0°
5°E
10°E
Annual anomaly
1998
-5 (mg/l)
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-1
-0.5
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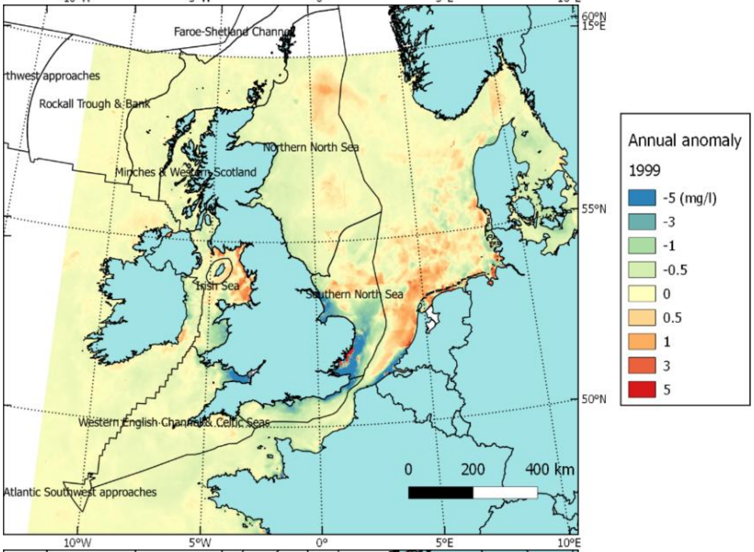
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Northern North Sea
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Irish Sea
Southern North Sea
Western English Channel & Celtic Seas
Atlantic Southwest approaches
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10°W
5°W
0°
5°E
10°E
Annual anomaly
1999
-5 (mg/l)
-3
-1
-0.5
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0.5
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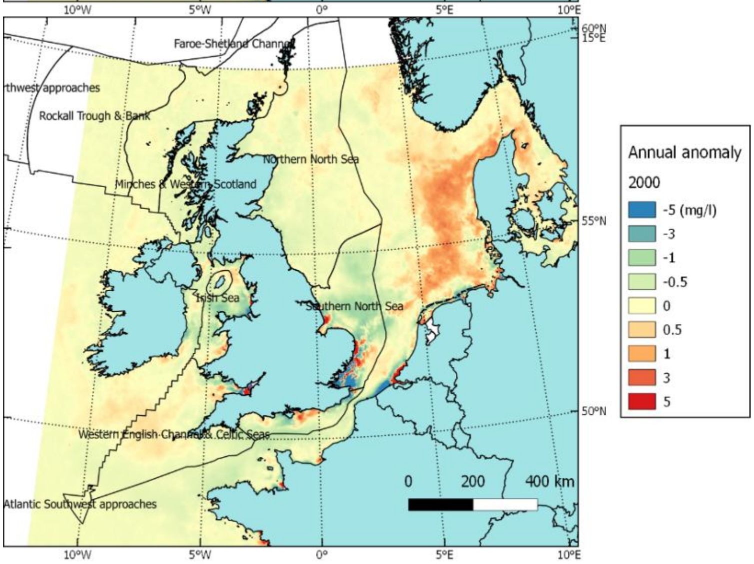
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Rockall Trough & Bank
Northern North Sea
Minches & Western Scotland
Irish Sea
Southern North Sea
Western English Channel & Celtic Seas
Atlantic Southwest approaches
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60°N
15°E
55°N
50°N
10°W
5°W
0°
5°E
10°E
Annual anomaly
2000
-5 (mg/l)
-3
-1
-0.5
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0.5
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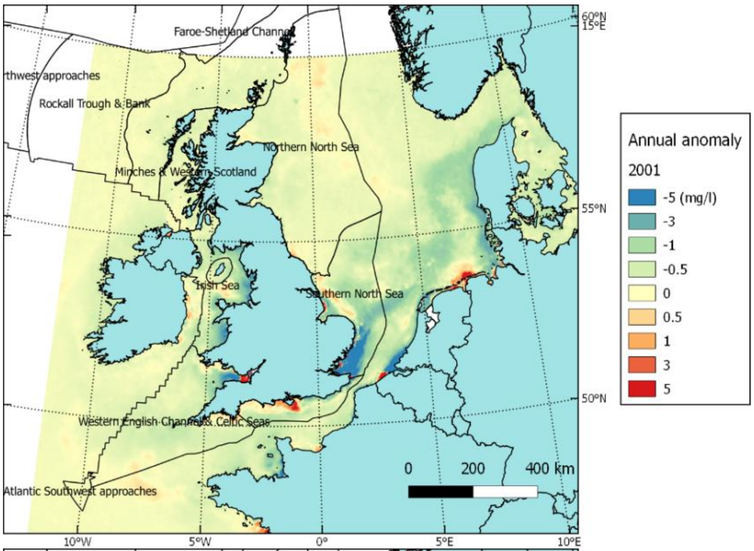
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Northern North Sea
Minches & Western Scotland
Irish Sea
Southern North Sea
Western English Channel & Celtic Seas
Atlantic Southwest approaches
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Annual anomaly
2001
-5 (mg/l)
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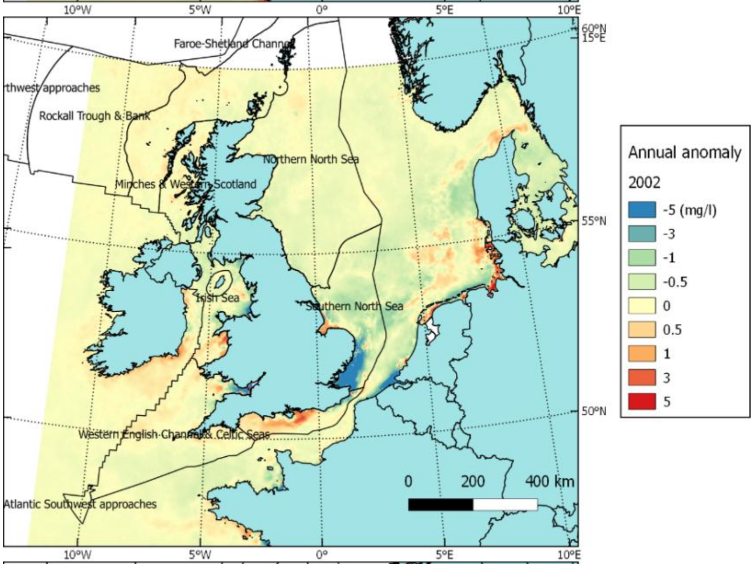
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Irish Sea
Southern North Sea
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Atlantic Southwest approaches
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10°W
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5°E
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Annual anomaly
2002
-5 (mg/l)
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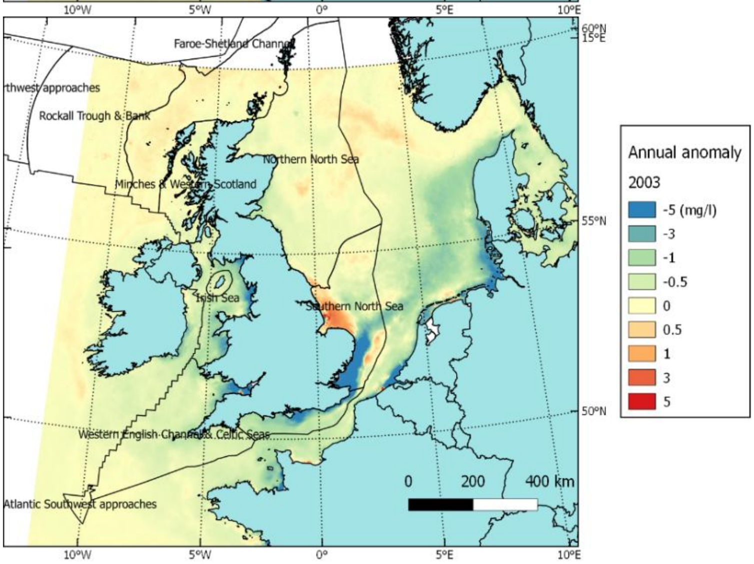
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Atlantic Southwest approaches
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Annual anomaly
2003
-5 (mg/l)
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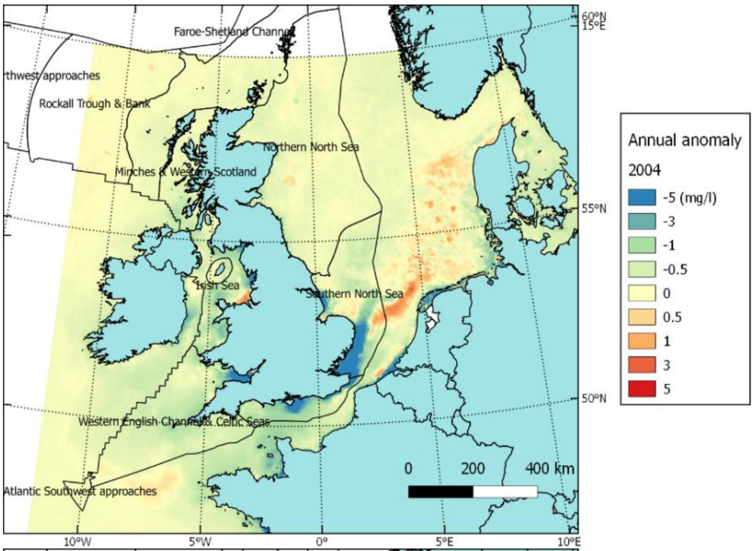
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Western English Channel & Celtic Seas
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Annual anomaly
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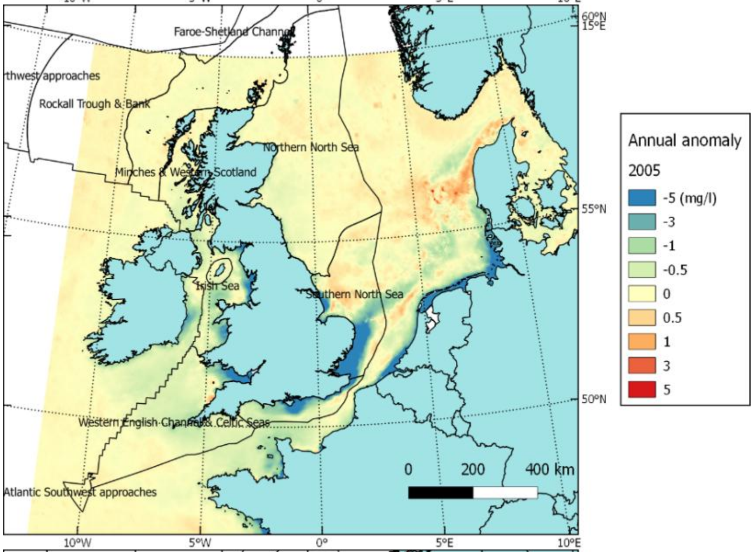
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Annual anomaly
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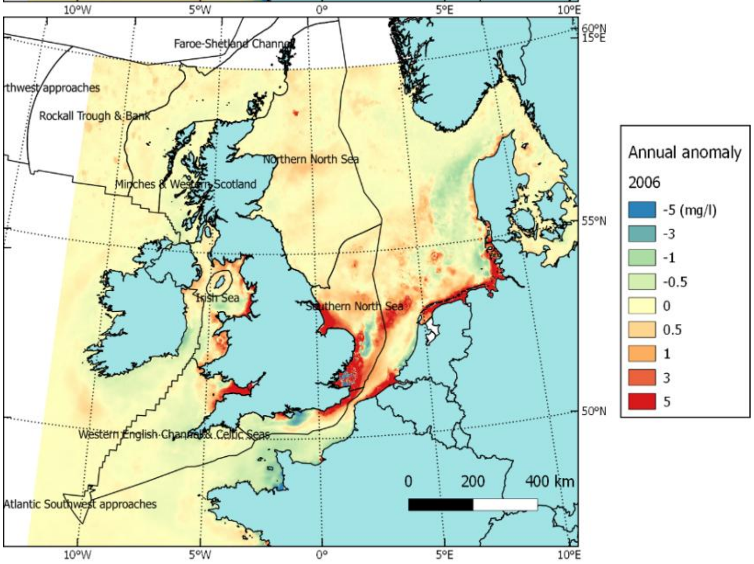
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Annual anomaly
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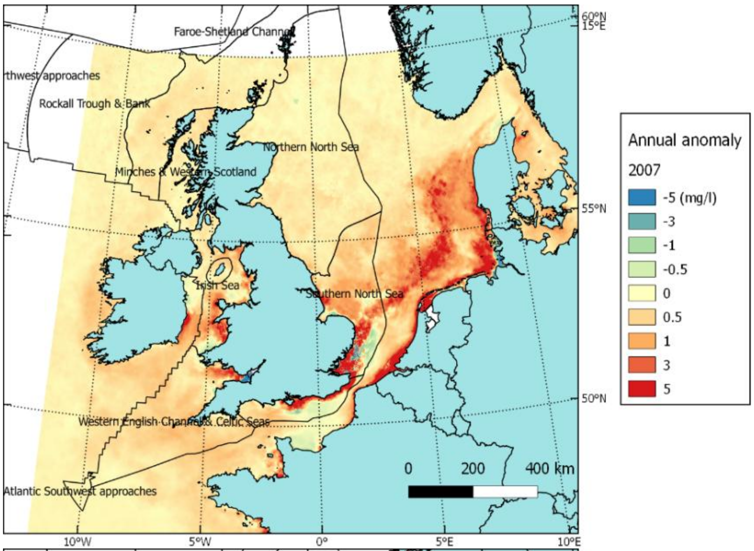
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Annual anomaly
2007
-5 (mg/l)
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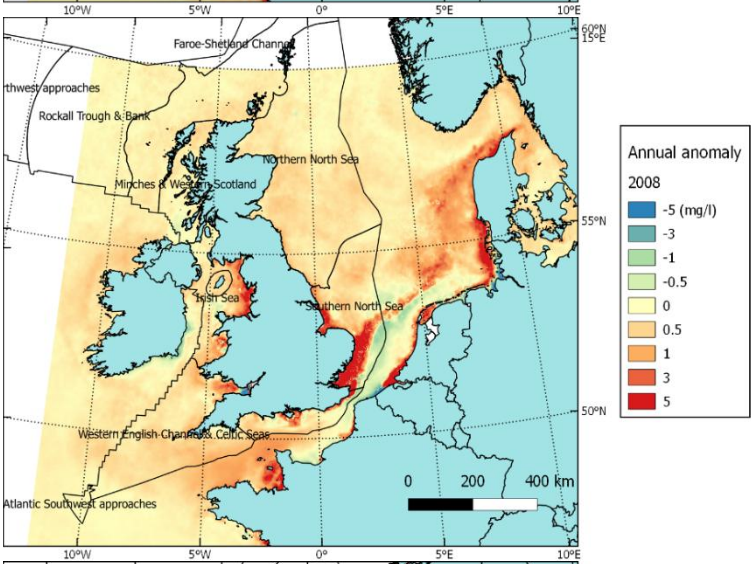
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Annual anomaly
2008
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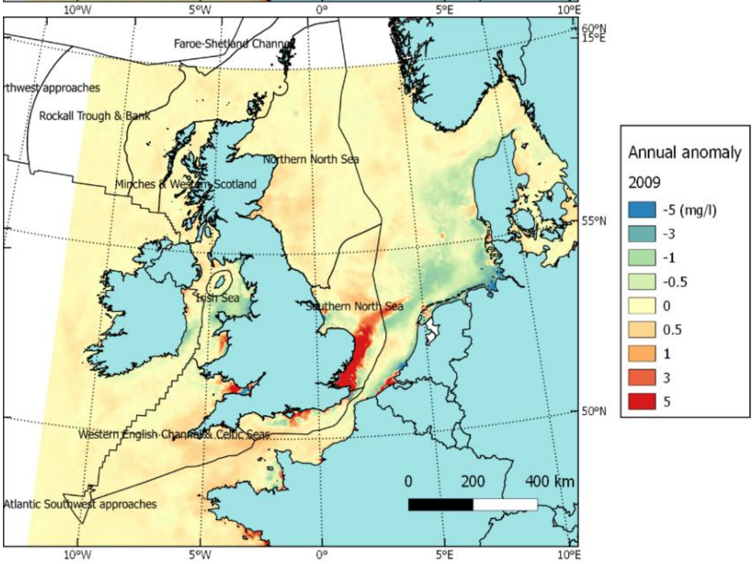
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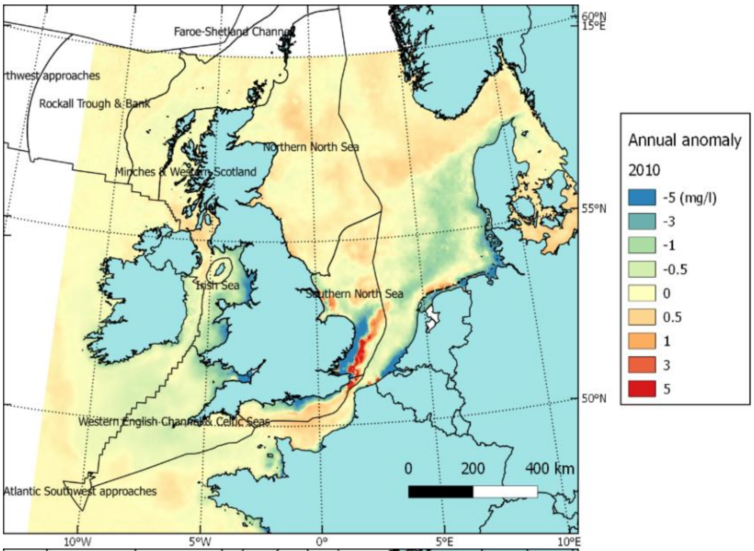
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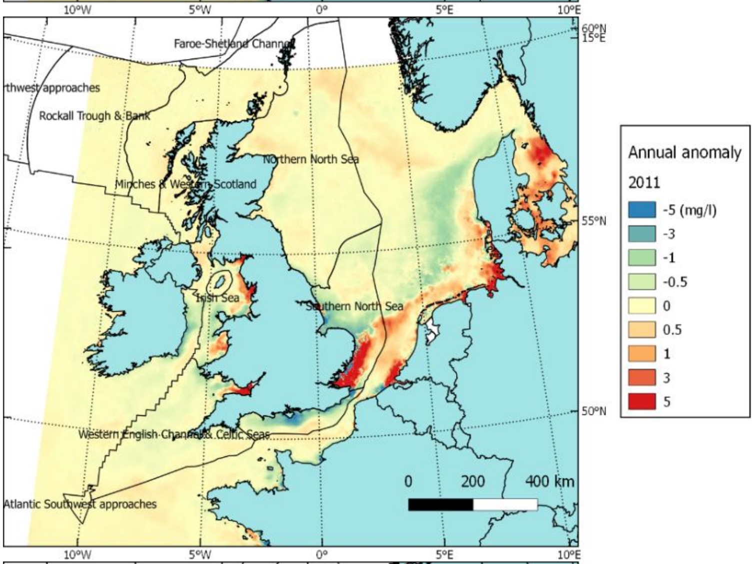
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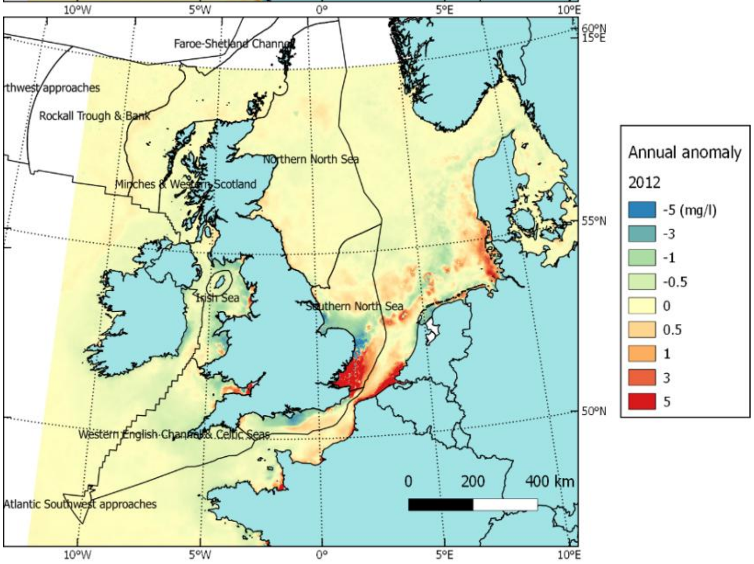
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Annual anomaly
2012
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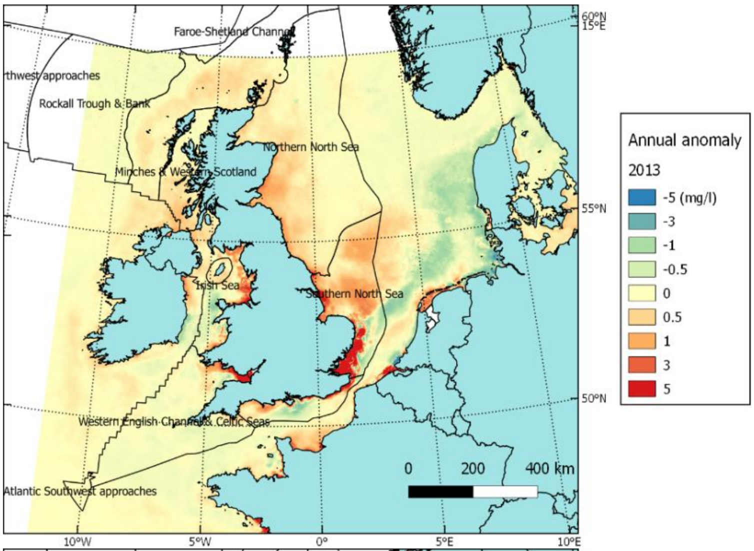
Rockall Trough & Bank
Northern North Sea
Minches & Western Scotland
Irish Sea
Southern North Sea
Western English Channel & Celtic Seas
Atlantic Southwest approaches
0 200 400 km
60°N
55°N
50°N
10°W
5°W
0°
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10°E
Annual anomaly
2013
-5 (mg/l)
-3
-1
-0.5
0
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1
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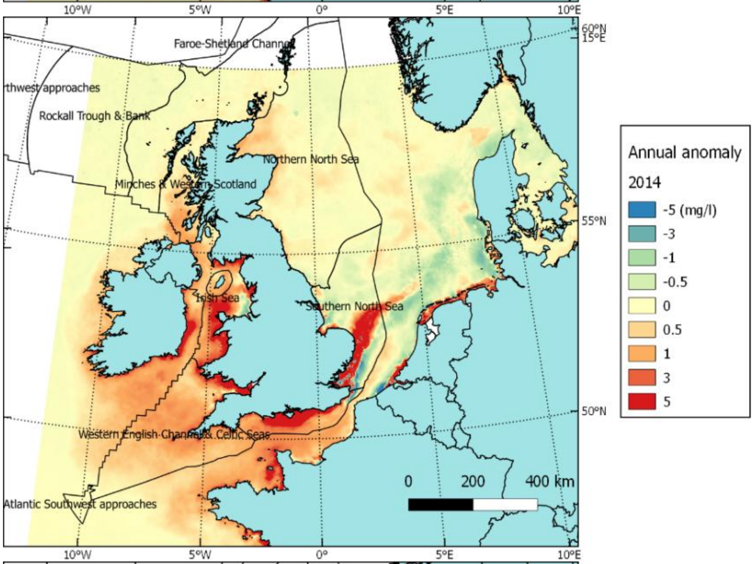
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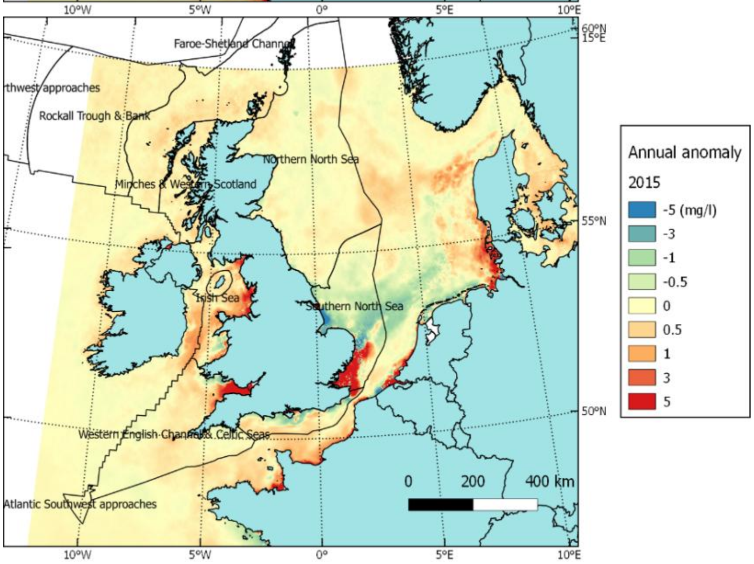
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Centre for Environment Fisheries & Aquaculture Science

Cefas

About us

The Centre for Environment, Fisheries and Aquaculture Science is the UK's leading and most diverse centre for applied marine and freshwater science.

We advise UK government and private sector customers on the environmental impact of their policies, programmes and activities through our scientific evidence and impartial expert advice.

Our environmental monitoring and assessment programmes are fundamental to the sustainable development of marine and freshwater industries.

Through the application of our science and technology, we play a major role in growing the marine and freshwater economy, creating jobs, and safeguarding public health and the health of our seas and aquatic resources

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Customer focus

We offer a range of multidisciplinary bespoke scientific programmes covering a range of sectors, both public and private. Our broad capability covers shelf sea dynamics, climate effects on the aquatic environment, ecosystems and food security. We are growing our business in overseas markets, with a particular emphasis on Kuwait and the Middle East.

Our customer base and partnerships are broad, spanning Government, public and private sectors, academia, non-governmental organisations (NGOs), at home and internationally.

We work with:

- a wide range of UK Government departments and agencies, including Department for the Environment Food and Rural Affairs (Defra) and Department for Energy and Climate and Change (DECC), Natural Resources Wales, Scotland, Northern Ireland and governments overseas.
- industries across a range of sectors including offshore renewable energy, oil and gas emergency response, marine surveying, fishing and aquaculture.
- other scientists from research councils, universities and EU research programmes.
- NGOs interested in marine and freshwater.
- local communities and voluntary groups, active in protecting the coastal, marine and freshwater environments.

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