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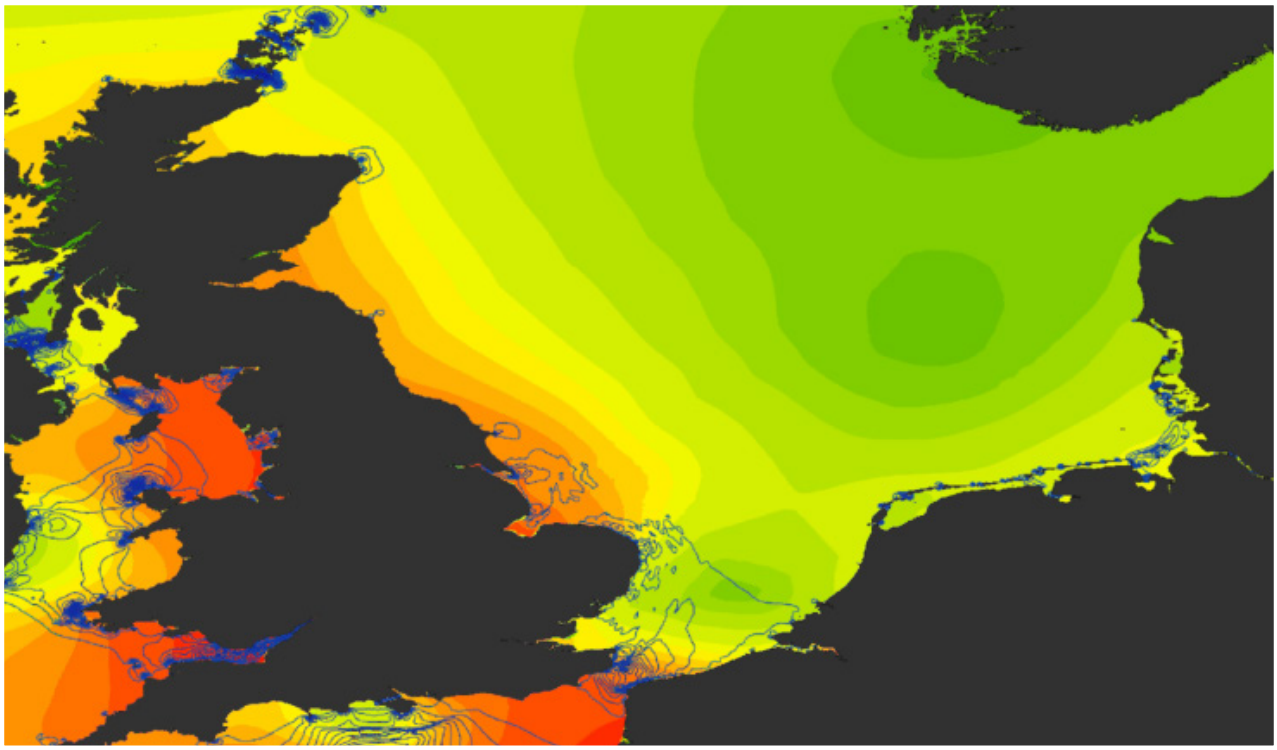
Working with water

Growth and Innovation in the Ocean Economy: North Sea Checkpoint

Data Adequacy Report - Climate and Coastal Protection Challenge



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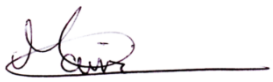		

Executive Summary

This document summarises the findings of the Climate and Coast Protection challenge, conducted as part of the North Sea Checkpoint Project (NSCP)

This report constitutes deliverable 09 to DG Mare, under the North Sea Checkpoint Project (Growth and Innovation in the Ocean Economy – Gaps and Priorities in Sea Basin and Observation Data MARE/2012/11: North Sea) contract reference SI2.658142. The work was undertaken by HR Wallingford with input from the project members, IMARES and McAllister-Elliot & Partners (MEP) in particular.

It should be stressed that, although this document reports on the data challenge for assessing marine climate and coast protection, this does not give measureable results nor definite conclusions on climate change nor advice on coast protection. Figures presented are for illustration of purpose of data accessibility only.

Points for EMODnet

Physics portal –The zip file of tidal gauge information appeared to download but couldn't be opened, hence it was not used.

General – It was not possible to fully meet the challenge aims. Whilst metadata provide some information, it is rarely sufficient to appraise 'fitness for purpose' and data is available from multiple sources, which took time to appraise in terms of being definitive and most up-to-date. .The time series of measurements is in most cases historically insufficient and geographically patchy, e.g. tidal gauges are limited to coasts and islands with only occasional mid-basin information where structures had been placed, such as rigs. Since the historic record deemed appropriate for the challenge was a singular dataset, no validation of the results was achieved. More recent data, such as the satellite observations are far more comprehensive, but their time series is not yet sufficiently long for deriving climate change considerations.

On the scale of the North Sea basin, no sediment data was discovered that could address the challenge. Usable data for non-experts is rare, as the datasets available require expert processing.

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1. Introduction

This report constitutes the ninth deliverable to DG Mare under the North Sea Checkpoint Project (Growth and Innovation in the Ocean Economy – Gaps and Priorities in sea basin and observation data MARE/2012/11: North Sea) contract reference SI2.658142. The work was undertaken by HR Wallingford with input from the project members, IMARES and McAllister-Elliot & Partners (MEP) in particular. This document is the Data Adequacy Report (DAR) presenting the findings for the Climate and Coastal Protection Challenge. A number of other challenges are presented in separate reports.

The Climate and Coastal Protection Challenge addresses the stages of work required for desk-based assessments intended to calculate variables such as annual sea level rise, annual change in temperature and annual sediment mass balance over the North Sea Basin. The assessment was made using data when and where it was appropriately accessible. On several occasions, the data assessment exercise has resulted in a figure or a map being produced by way of a thorough trial of the entire process. It must be stressed, however, that it is the process of gathering, appraising and using the data to meet a certain challenge which is being evaluated here to inform the overall objectives of the North Sea Checkpoint project and not the result itself. Nonetheless, the creation of a number of results for key variables has allowed the assessment of data quality through each stage of a challenge (data gathering, initial appraisal of the data, analysis and quality assurance of results), therefore providing different insights into the accessibility and usefulness of a datasets at each stage.

Finally, all data gathered has been itemised in the Data Adequacy Assessment Database (DAAD), providing a searchable record of each of the datasets reviewed and the results of its evaluation when considered for one or more challenges. Separately, the DAAD is being transformed to be made available via the project website.

2. Aim

The primary aim of the Climate and Coastal Protection Challenge is to assess the possibility of producing very specific spatial data layers and time history plots for selected climate and coastal variables for the study area of the North Sea Basin. The challenge is to be carried out on the basis of existing data in order to assess whether the availability, consistency and resolution of the data are sufficient. Information gathered during this challenge provides a detailed assessment of the data gaps and priorities of observations and data on climate and coastal parameters required for coastal protection in the North Sea Basin.

This challenge was split into two sets of assessments: (1) to produce spatial data layers for the past 10, 50 and 100 years and; (2) to produce time history plots averaged over the whole Basin of selected climate and coastal process variables for different depths and geographic locations.

1. The spatial data layers produced are:
    a. Average annual sea-level rise[1] at the coast (absolute and relative to the land);
    b. Average annual change in temperature at surface, midwater (also referred to and interpreted as mid-depth) and sea-bottom (also referred to and interpreted as near-bed);

[1] Terminology from the project definition has been used for these variables, but it is noted that this, and other similar variables listed here, are also commonly referred to as ‘annual average’.

   c. Sediment mass balance at the coast.
2. The time history plots (at least 50 years of data) are produced as:
   a. Average annual sea temperature over sea-basin at surface, midwater column (mid-depth) and bottom (near-bed);
   b. Average annual changes in internal energy of sea;
   c. Average annual sea-level rise relative to the land for each NUTS3 region along North Sea coast;
   d. Annual sediment balance along North Sea coast for each NUTS3 region along North Sea coast.

Also, the challenge is to be undertaken from the perspective of a data user or a consultancy company requiring easy access and interpretation of sea level, sea temperature and sediment data. The challenge is not to be undertaken from the perspective of a scientist looking to predict future marine climate or to reconstruct past climate. In particular, it should be highlighted that climate scientists often refer to longer periods of time or epochs than those defined in the Climate and Coastal Protection Challenge.

3. Context

Sea temperature and internal energy of the sea

Sea Surface Temperature is most often collected via remote sensing and is not measured directly but is inferred from the radiance of various wavelength bands which are then used to calculate an inferred temperature. The relationship between the measured wavelength and the inferred temperature is dependent on the exact method used to calculate the temperature and the instrumentation on the carrier (e.g. satellite), which collected the wavelength data. Midwater and sea bottom temperatures are usually not collected using satellite data and where direct measurements have not been collected these temperatures are inferred using the sea surface temperature data.

Internal energy is a thermodynamic property which is a function of kinetic and potential energy. In the case of the sea, the variables required to estimate the internal energy are the water temperature and salinity.

Sea level rise and sediment mass balance

Sea level rise is influenced by changes in atmospheric pressure and temperature, melting of sea ice and the polar ice caps and water temperature. Past measurements of sea level rise have been carried out at select locations since the 18th Century and have indicated an average sea level rise of 1.5mm/year in the North Sea since 1850 (Permanent Service for Mean Sea Level, 2012). Both relative sea level rise (i.e. the change relative to land) and absolute sea level rise (i.e. the change in sea level if land were not a factor) are plotted for the spatial data layers in this study. Given the ranges of period defined in the aim of the study (see Section 2) the assessment of historical sea level rise are considered as annual averages for the 10-, 50- and 100-year periods when possible.

Sediment mass balance for the purpose of this project has been interpreted as the type of sediment present and its repartition along the North Sea coast. This will include inorganic suspended sediment, small particles, sand, silts and gravels. There is no comprehensive dataset available to draw conclusions on sediment budget (or the quantity of sediment in movement) in the North Sea Basin overall. An extensive literature review would be necessary to gather all site specific information available in various forms from the published literature.

4. Method

Firstly, a very broad literature review was carried out to determine the available datasets, their cost and licensing agreements, their documentation and quality check procedures and their appropriateness to compute each of the following parameters:

- Sea level;
- Sea surface temperature;
- Mid and bottom sea water temperature;
- Sediment type.

All data gathered were itemised in the DAAD.

Once available datasets were identified, their appropriateness for the challenge was evaluated, as far as the documentation allowed, in term of their accuracy and consistency, and was further filtered with different criteria as follows:

- Spatial Coverage;
- Temporal coverage;
- Data access or delivery;
- Data use.

That dataset evaluation allows the best data to be selected to meet the challenge objectives outlined in Section 2**Error! Reference source not found.**. More details about the criteria are given in Section 6.2. All conclusions drawn from the above were added to the DAAD.

5. Data

A wide range of data types and sources were identified, downloaded when possible and reviewed for the challenge. The primary sources of the larger sets of data seem to be split into two online resources categories:

- EU funded websites (EMODnet portals, MyOcean); and
- National government funded resources (BODC, NOC resources, NASA).

Table 5.1, below, lists those datasets deemed suitable to answer the objectives of the Climate and Coastal Protection Challenge. It gives the full dataset names and information on the type of data. Table 5.2, below, lists the suitable datasets and the corresponding objectives the dataset can meet. Datasets are assigned codes such as ‘DT.Clim.NS016’ where ‘Clim’ refers to the ‘Climate and Coastal Protection Challenge’, NS ‘North Sea’ and 016 a sequential number. Please refer to the DAAD for more information.

Table 5.1: Data suitable in meeting the Climate and Coastal Protection Challenge

Data	Inspire theme	Sources Suitable
Sea Level Tide gauges	3.15 Oceanographic geographical features	DT.Clim.NS016-The Permanent Service for Mean Sea Level Rise
Sea Level Satellite Altimetry	3.15 Oceanographic geographical features	DT.Clim.NS017-MyOcean - Global Ocean Along-Track Sea Level Anomalies Reprocessed (1993-Ongoing)
Models SSH, Sea Water Potential Temperature and Salinity	3.15 Oceanographic geographical features	DT.Clim.NS024-MyOcean - Global Ocean Physics Reanalysis GLORYS2V3 (1993-2013) DT.Clim.NS026-MyOcean - Global Ocean Physics Reanalysis ECMWF ORAP5.0 (1979-2013)
Reconstructed Sea Level	3.15 Oceanographic geographical features	DT.Clim.NS042-PODAAC - Reconstructed Sea Level Version 1
Reconstructed SST	3.15 Oceanographic geographical features	DT.Clim.NS043-PODAAC - Smith and Reynolds NCDC Level 4 Historical Reconstructed SST Monthly Version 3b NetCDF

Table 5.2: Data suitable in meeting the Climate and Coastal protection Challenge with corresponding objectives

Objectives		Spatial layer for the past 10 years	Spatial layer for the past 50 years	Spatial layer for the past 100 years	Time plot for the Sea Basin	Time plot for each NUTS3 Regions
Annual Change in Sea Level Rise		DT.Clim.NS017 DT.Clim.NS024 DT.Clim.NS026	DT.Clim.NS042	-	X	DT.Clim.NS042
Annual Change in Temperature	Surface	DT.Clim.NS024 DT.Clim.NS026 DT.Clim.NS043	DT.Clim.NS043	DT.Clim.NS043	DT.Clim.NS043	DT.Clim.NS043
	Midwater	DT.Clim.NS024 DT.Clim.NS026	-	-	-	-
	Bottom	DT.Clim.NS024 DT.Clim.NS026	-	-	-	-
Annual Change in Sediment mass Balance		-	-	-	X	-
Annual Change in Internal Energy of the sea		X	X	X	-	X

X: Not an Objective

Only two datasets were found to provide records combining both a long period of time and a fairly resolved geographical coverage of the North Sea Basin: DT.Clim.NS042 and DT.Clim.NS043. Those datasets are readily available, with documentation, related scientific articles available and data hosted on a well maintained data server (at PODAAC). Both datasets are distributed free of charge as NetCDF files.

The dataset DT.Clim.NS042 is a reconstructed sea level from 1950 to 2009, with a 0.5 degree spatial coverage and a yearly mean temporal resolution. Tide gauge data from the PSMSL (DT.Clim.NS016) and satellite altimetry data are both combined to reconstruct the sea level using cyclostationary empirical orthogonal functions ([1] *Hamlingdon et al.*, 2011). The dataset DT.Clim.NS043 used the same type of method. Sea Surface Temperature from 1854 to nowadays is reconstructed from *in situ* SST data combined with statistical methods ([2] Smith *et al.*, 2008).

The other two datasets identified in Table 5.1, DT.Clim.NS024 and DT.Clim.NS026, were downloaded from the MyOcean website after registering to the website. Both datasets are modelling results from different versions of the global model based on the NEMO software, reanalysed and corrected on the basis observations from different sources. Output variables from those models are daily mean of the Sea Surface Height (SSH), the sea water potential temperature and the salinity. Spatial coverage is 0.25 degree, the vertical grid consists in 75 levels from the surface to the bottom (near 6,000 m deep). DT.Clim.NS024 gives data from 1993 to 2013 and DT.Clim.NS026, from 1979 to 2013.

6. Results

6.1. Challenge output

6.1.1. Introduction

The Climate and Coastal Protection Challenge has presented difficulties, not least because data availability for the past 50 and 100 years – and in some cases for most recent years - is limited.

Tide gauges are the principal sources of data for long historical sea level measurements. However, the spatial coverage is restricted to single points situated on coastlines, islands and offshore platforms. Satellite altimetry has been providing continuous, near global sea level measurements but only for the past 25 years.

It is noted that recent research initiatives established methods to reconstruct historical sea level maps by combining historical measurements from tide gauges and satellite altimetry data. The output of one of these recent research initiatives was made available through the NASA website. It gives a reconstructed sea level from 1950 to 2009. Information and sea level rise computed from this dataset is presented in Section 6.1.2.

It is worth noting that in climate science, a typical time-step (“epoch”) is considered to be thirty years, thus highlighting the short timescales being considered here. A thirty year period is used, as it is long enough to filter out any inter-annual variation or anomalies, but also short enough to be able to show longer climatic trends ([3] WMO).

6.1.2. Trends calculated from reconstructed Sea Level (PODAAC)

[1] *Hamlingdon et al.*, 2011, used cyclostationary empirical orthogonal functions, derived from satellite altimetry, and combined with historical sea level measurements from tide gauges to create the Reconstructed Absolute Sea Level dataset spanning from 1950 through to 2009. Combining the altimetric

and tide gauge records alleviates the difficulties caused by the short record length and poor spatial distribution of the satellite altimetry and tide gauges, respectively.

This dataset (DT.Clim.NS042) is freely downloadable from the NASA website and easy to use (standard NetCDF format). The dataset covers the globe with a spatial resolution of 0.5 degree and a 7 days temporal resolution from June 1950 to June 2009. Of course, this does not allow the analysis of tidal constituents but it does provide a global trend over several decades.

In order to test computation of the average annual sea-level rise for the challenge using this source, applications were developed to acquire, read, interpret and further transform the dataset (from a NetCDF form). The annual Mean Sea Level (MSL) (the average sea level in one year) was computed for each point, to which a linear regression analysis was applied. The resulting trend is the annual sea level rise.

The result of the process is illustrated in the Figure 6.1 for a given point. The data from DT.Clim.NS042 is in blue, the annual absolute MSL is in black, and the trend calculated by linear regression is in red.

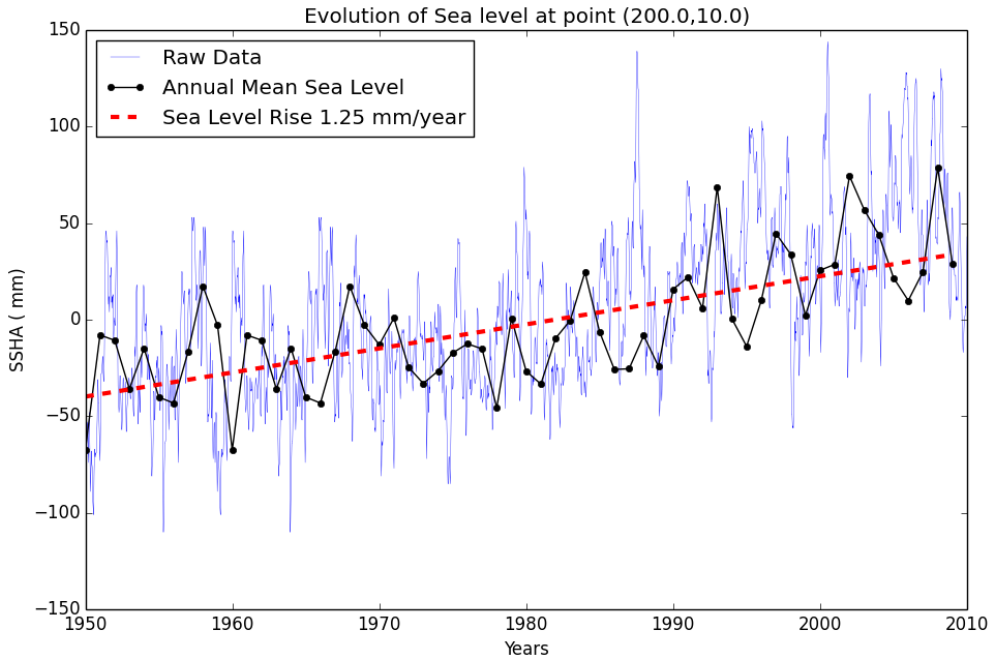


Figure 6.1: Example of Method used to calculate the annual absolute Sea Level Rise from the dataset DT.Clim.NS042

Once the analysis had been carried out at all locations, the data was interpolated to produce an isocontour map covering the North Sea (Figure 6.2).

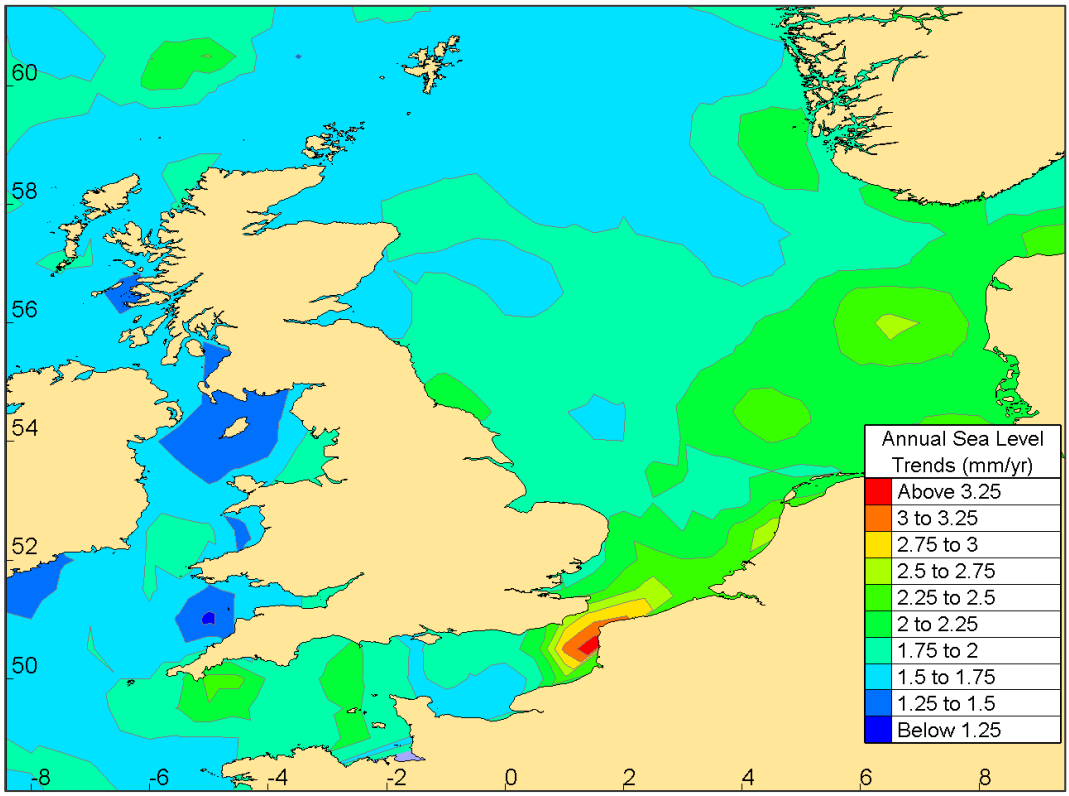


Figure 6.2: Absolute Annual Sea Level Rise from 1950 to 2009, computed from the dataset DT.Clim.NS042

It is noted that the results given by the Figure 6.2 are extracted from DT.Clim.NS042, and as such, may include undocumented assumptions which could explain possible differences with other datasets. Again, the purpose of the challenge is to assess the availability and accessibility of the data over a complete scientific assessment of the results obtained. Following that objective, the dataset DT.Clim.NS042 is concluded to be suitable to assess the annual absolute MSL Rise for the past 50 years, although validating results such as those obtained here requires further assessment.

The reader is asked to refer to the documentation and article delivered with that dataset. The article gives a large amount of details about methods and data sources used to compute the reconstructed sea levels, but it may be too complex to be valuable for non-expert users. As result, it is advised to use this dataset with caution.

6.1.3. Outcome

It is important to note that the past 6 years are missing from the data source which compromises the computation of the requested MSL Rise for the last 10-year period (as a deliverable to the Climate and Coastal Protection Challenge). Therefore the map of the annual sea level rise from 1950 to 2009 produced is probably suitable to assess the average annual sea level rise for the past 50 years, but is not suitable for the deliverable covering the past 10 years.

Finally, the same method can be used to compute the average annual change in the Sea Surface Temperature, from the dataset DT.Clim.NS043 and for the past 10, 50 and 100 years or even for the past 150 years as the dataset provides data from 1854.

6.2. Data adequacy

Data adequacy for the Climate and Coastal Protection Challenge is reported under the six value assessments used for screening the data.

6.2.1. Contribution – Does the data contain the right parameters?

At first sight there is a large amount of data sources and data types available that can contribute to solving the Climate and Coastal Protection Challenge. The difficulties arise when investigating deeper into these datasets to actually produce one of the variables. It is difficult to appraise the precise contribution that data sources can make unless the data is processed and used from the perspective of a data user or a consultancy company. For example, the metadata may be too imprecise to rule data in or out and there may be no lineage information to verify the provenance of the data and hence the value of its contribution. As a result, the range of data considered, downloaded and reviewed was much broader than the data deemed appropriate for use.

The most frequently found parameters are sea level and sea surface temperature. Temperature profiles and salinity are slightly less common datasets. The rarest parameter is information on sediment balance, which is non-existent at the scale of the North Sea Basin.

6.2.2. Location – Does the data cover the correct time / space location?

As previously mentioned in the specific case of tide gauges, measurements and observations give the longest data history but their spatial coverage is restricted to single points usually situated at the coast. Satellite altimetry data has near global spatial coverage but only from the 1990s.

Therefore, datasets including SSH and SST for the past 10 years with a spatial coverage from 2km to 50km are relatively accessible from satellite data. However, to construct long history records and near global spatial coverage, scientists had to calculate and extrapolate SSH and SST from measurements and satellite data with mathematical methods.

Reconstructed sea water potential temperature does not exist, nor does reconstructed sea water salinity. Only Global models with reanalysis give this data for the past 10 to 30 years.

6.2.3. Commercial – Are the commercial terms acceptable?

All gathered data for the Climate and Coastal Protection Challenge is freely available. No commercial product was identified as appropriate for the long term data, which could imply that there is no market for historical data outside research.

6.2.4. Attributes – Does the data have the correct attributes?

During the review of possible data sources, it was found that there were considerable overlaps between websites, particularly for National Government and EU funded data. In many cases, the same data source was available through different websites but presented differently, raising questions on which was the most up-to-date and definitive version. There were similarly themed datasets also available through different government funded resources, although the data needed to be compared and metadata reviewed thoroughly before being able to decide whether the datasets were the same or not.

Where the same data was available from more than one source, and the metadata seemed similar but different, the data had to be downloaded from both sources for comparison purposes to ensure that the most up-to-date version was used. Data from multiple sources was grouped by type and assessed to identify the sources best suited to meet the challenge. For example, tide gauge data was downloaded from BODC (DT.Clim.NS011) and from PSMSL (DT.Clim.NS016) and compared to one another. In the end, while the two tide gauge datasets were exactly the same in the UK, the data from the PSMSL was used because the website assembles tide gauge data from all around the world and hence more comprehensively covers the North Sea Basin.

Regarding the accuracy of the data, it was difficult to identify if the data was sufficiently accurate for the purpose of the Challenge before downloading and processing. It is particularly complex to find the right dataset in MyOcean or PODAAC products, for instance. While many products seem to be appropriate to the Challenge requirements (the spatial and the temporal coverages, the assumptions made for each parameter), measuring instruments, numerical models or data sources are very different between different sources.

For instance, one of the MyOcean products, DT.CLim.NS030 from NERCPOL, was considered and seemed suitable for the challenge (and would be for a data user or consultancy company) until the annual sea level trends were calculated (Figure 6.3). From those results we notice that the sea level seemed to decrease all around the Northwest shelf, which is not correct compared to tide gauge data or published sea level research. After reading the product documentation in detail and other articles about sea level rise research, it was found that the MyOcean product, DT.CLim.NS030 from NERCPOL does not consider the melting of the ice caps, which is essential for sea level trend research.

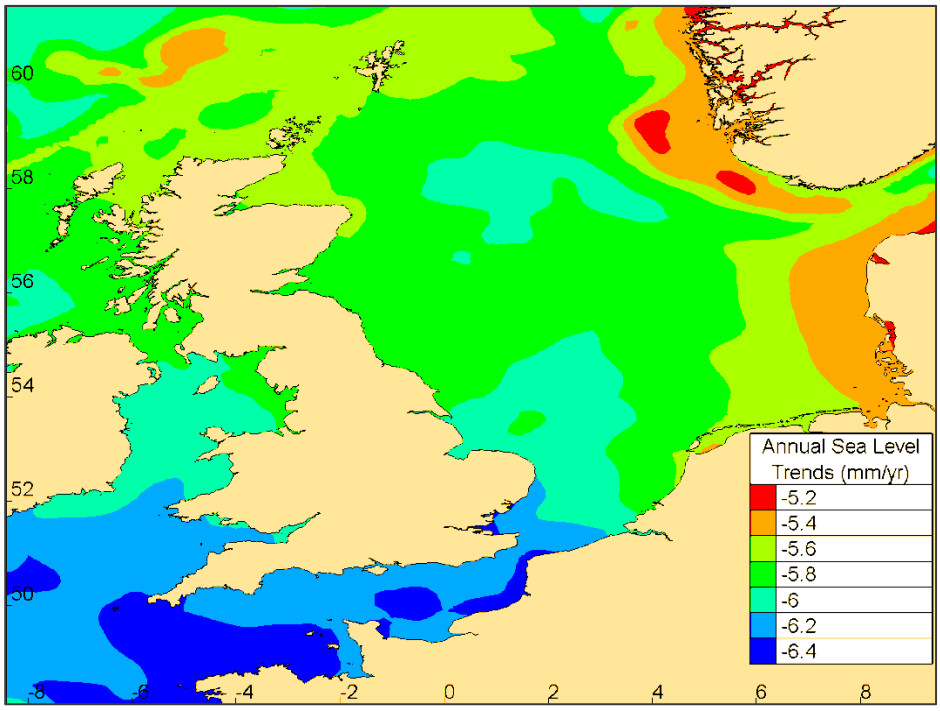


Figure 6.3: Absolute annual sea level trends calculated from DT.CLim.NS030

In conclusion, whilst data sources are typically appropriately attributed and accompanied by additional metadata, this is often not sufficient to easily determine the fitness for purpose. For example, the coverage or accuracy of modelling data sources is difficult to assess since the accuracy assessment may require unpacking the raw dataset itself. For observations, which are only available at single locations, the datasets are more manageable and the accuracy or the appropriateness of the dataset is easier to establish.

6.2.5. Delivery - Can the data be provided to match the timeframe of the challenge?

The majority of the datasets reviewed for the challenge were easily accessible, downloaded from the internet, sometimes following registration to a website. This was the case for all of the freely available resources assessed. The requirement for registration was not considered to be a barrier to data access, although in some instances, where the registration process was not automated, the response from the data provider could be slower.

Datasets could be up to several gigabytes in size causing long download times and high processing demand. This is particularly true for datasets computed from models, such as potential temperature output. Indeed, the size of a dataset increases with increasing two-dimensional spatial resolution, increasing temporal resolution and when a vertical dimension is also incorporated.

Moreover, there were instances when downloading a large amount of data would fail. For example, on the NOOS website (DT.Clim.NS045), when downloading the temperature, salinity and water level data within one request, the download would fail randomly, or appear to be successful, but for the zip file to be corrupted and impossible to read.

6.2.6. Usability – Is the data format and supporting information suitable?

Most of datasets identified for the Climate and Coast Protection Challenge are either time series delivered in ASCII format or numerical model results delivered as NetCDF files. Those two formats are standard and easy to visualise. However, the variables required by the challenge need processing of the datasets before being computed. For instance, monthly or yearly mean sea level or average temperature are available. Specific processing tailored to individual datasets is needed to obtain the annual change in temperature or the annual sea level trends, for instance. Consequently, those datasets would not be readily suitable for non-expert users.

Usable data for non-expert users is rare and mainly for informative purposes only. For example, NOAA (DT.Clim.NS046) provides maps and downloadable tables of sea level trends. Other data for non-expert users includes maps of annual change in sea surface temperature and mean sea level, produced from published researches like [1] *Hamlingdon et al.*, 2011 and, [2] Smith *et al.*, 2008.

6.3. Key Data gaps

As underlined so far in this report, the Climate and Coastal Protection Challenge has identified many useful and appropriate datasets, but also significant limitations in that available.. Significant gaps exist in the requested datasets. The main gaps are a lack of long time history and an absence of sediment data.

6.3.1. Mean sea level rise

As highlighted in Section 6.1.1, tide gauge data is the principal source of data for long history sea level measurements. However, the spatial coverage is restricted to single points situated on islands, offshore platforms and coastlines. Still, very long time history is rare, particularly for 50 or 100 years.

Figure 6.4 shows the progressive history of the presence of tide gauges in time. There are intermittent records of sea level at Amsterdam from 1700 and three more sites in Northern Europe starting after 1770. Figure 6.5 gives more details about tide gauge data in Northern Europe from the PSMSL (DT.Clim.NS016). It is noted that tide gauges are unequally spread. For example, many more tide gauges are located on the coast of France, Belgium and the Netherlands than on the English coast. Tide gauges are even more irregularly spread when looking at long historical records (50 and 100 years).

When calculating annual sea level trends at different locations (method in section 6.1.2), no pattern appears and trends seem different from one location to another (Appendix A).

Considering all those variances (scattered spatial coverage, lack of long historical records and the difference between trends), it is impossible to obtain accurate sea level trends whether at the coast, or for each NUTS3 zone.

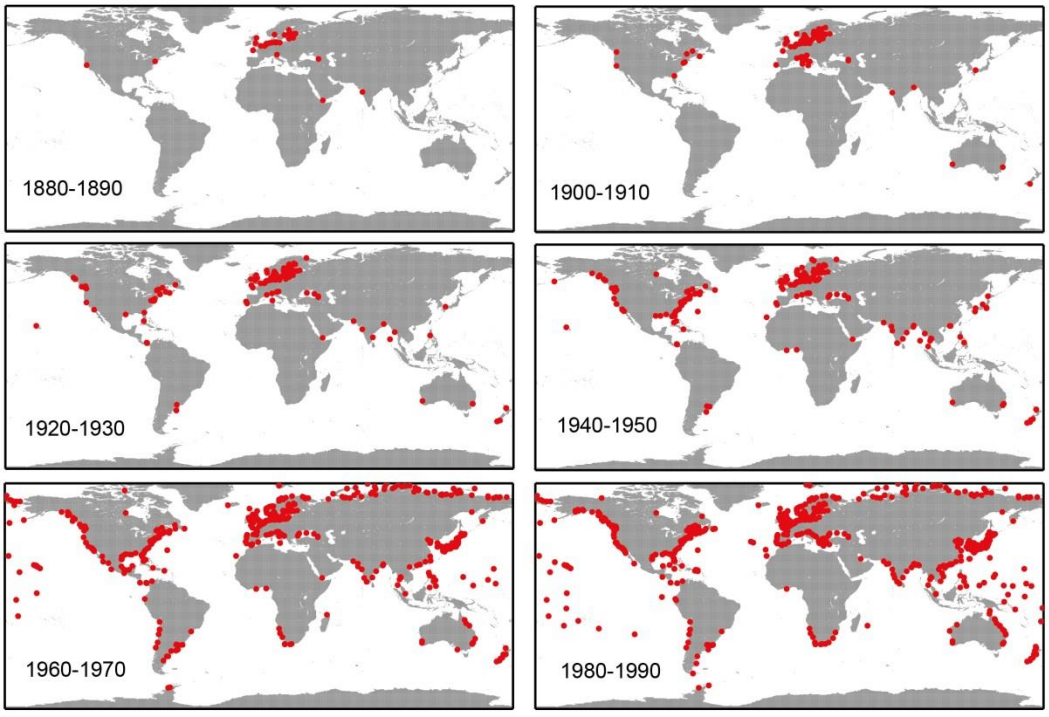


Figure 6.4: Location of tide gauges (red dots) with at least one year of observations within the decade indicated

Source: IPPC, Climate change 2013: The Physical Science Basis

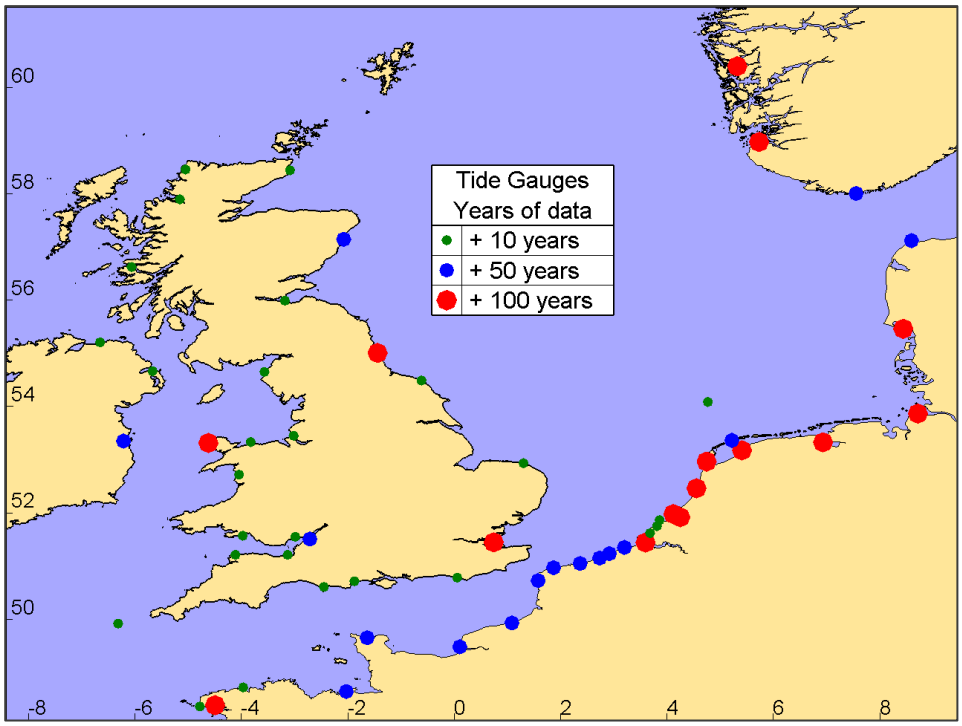


Figure 6.5: PSMSL Tide gauge data – Number of years of observations

Since the 1990s, satellite altimetry has provided accurate measurements of the SSH with near global coverage. These relatively short records, however, provide no information about the state of the ocean prior to this time. Furthermore, the earlier satellite altimetry data has a coarse resolution (20km to 50km).

A reconstruction of the mean sea level was carried out from both tide gauges (longer time records) and satellite altimetry data (larger geographical coverage). This was done in the dataset (DT.Clim.NS042) used for the Climate and Coastal Protection Challenge (see Section 6.1.2). However, it only provides a relatively short window in time, from 1950 to 2009, which is not long enough to compute the requested MSL Rise for the last 100-year period (as a deliverable to the Climate and Coastal Protection Challenge).

6.3.2. Average annual change in Temperature

Sea Surface Temperature

Sections 5 and 6.1.3 explain how the dataset DT.ClimNS043 (a reconstructed sea surface temperature from 1854 to today) has been found to be suitable to compute the average annual change in sea surface temperature, for the past 10, 50 and 100years.

However, for the observed data the dataset is reconstructed from, the gaps are similar as those identified for sea level datasets. Long history records (ships, moorings, buoys) are at singular locations and satellite data has a short and recent historical record.

Mid-depth and near-bed temperature

The only sources of data for mid-water and sea-bottom temperature seem to be from global numerical models with reanalysis (DT.Clim NS024 and DT.Clim NS026). These datasets have been corrected with available observations. However, those model results provide only data for the past 10 to 35 years. No

suitable dataset was found to assess the average annual change in temperature at mid- depth and at near-bed for the past 50 and 100 years.

6.3.3. Sea internal energy

The sea's internal energy is calculated from the temperature and salinity profiles. Therefore the same conclusions apply as for the average annual change in temperature at midwater and at sea bottom. There is insufficient data available to assess the average annual change in the sea's internal energy for the past 50 and 100 years.

6.3.4. Sediment mass balance

The geology data available from the EMODnet portal, OneGeologyal or the European Atlas of the Seas provided only a rough indication of sediments near the coast. No datasets were found to compute the sediment mass balance and no historical sediment data was found.

7. Discussion and Conclusions

7.1. Discussion

The Climate and Coastal Protection Challenge has been partially met, identifying many useful and appropriate datasets but also encountering significant limitations, especially because data availability for the past 50 and 100 years – and in some cases for most recent years – is limited.

Tide gauges are the principal sources of data for long history sea level measurements. However, the spatial coverage is restricted to single points situated on islands, offshore platforms and coastlines. On the other hand, satellite altimetry has been providing continuous, near global sea level measurements albeit only for the past 25 years.

The quality assessment of data was a step-by-step process, based on assessing accessibility of data, relevance, usability and usefulness. Processing the data to compute variables and mapping also highlighted issues with data quality and suitability, all of which varied widely between datasets.

The following key points regarding data adequacy for the North Sea have been identified through the completion of the Climate and Coastal Protection Challenge.

- Data **Usability:**

  Data identified is delivered in two main formats: ASCII and NetCDF. Those formats are standard and, as such, typically easy to use. However it is only relatively easy to use for engineers or scientists and not straightforward to use or even read for non-expert users.

- Data **Delivery:**

  Most data available was simple to download. Download times could be a bit long for global datasets, but it was not a major issue as data was accessible through FTP websites.

- Data **Location:**

  Data location was an issue with long history data. The spatial coverage for long record observations (50 and 100 years) is really poor. Since the 1990s satellite altimetry provides near global measurements of sea level and sea surface temperature. Therefore it is not possible to have long history observations and

a regular spatial coverage at the same time. Reconstructed maps using both observations and satellite data can fill some gaps but many remain.

- Data **Attributes:**

  A large proportion of the data identified is observations or measurements, which are sufficiently attributed and accurate for climate change assessment. Another large proportion are numerical model results. For those, it is more difficult to ascertain suitability from the attributes and supporting information. Some North Sea models with reanalysis are not considering important climate drivers such as the effect of the ice cap melting.

- Data **Contribution:**

  In many cases, similar datasets, referred to from common sources, were available through different websites, raising questions on which was the most up-to-date and definitive version. There were similarly themed datasets also available through different government funded resources. Thorough comparison of the data and its metadata were necessary to decide whether these were, indeed, the same. Such comparison consumed a large amount of time.

- Data **Access:**

  All data identified and used for the climate challenge is freely available, with a fair amount accessible after registering through a website.

7.2. Conclusions

The key conclusions for the Climate and Coastal Protection Challenge are as follows:

- The Climate and Coastal Protection Challenge was partially met with the data available. While one spatial layer was produced (the annual absolute sea level rise for the past 50 years, for illustration purposes), the following spatial layers and time history plots **can be produced** from suitable datasets identified in the Table 5.1:
  - Spatial layer of the annual mean sea level rise for the past 10 and 50 years;
  - Spatial layers of the annual change in sea surface temperature for the past 10, 50 and 100 years;
  - Spatial layers of the annual change in temperature at mid-depth and near-bed for the past 10 years;
  - Time plot of the annual mean sea level rise for each NUTS3 region;
  - Time plot of the annual change in sea surface temperature over the North Sea Basin.
- The main gaps identified were the lack of long historical observations and the poor spatial coverage of measurements. Only satellite data allows a near global spatial coverage. Sediment mass balance data also seems to be non-existent. Consequently, the following spatial layers and time plots **cannot be produced**:
  - Spatial layer of the annual mean sea level rise for the past 100 years;
  - Spatial layers of the annual change in temperature at mid-depth and near-bed for the past 50 and 100 years;
  - Spatial layers of the annual sea temperature at midwater and sea bottom over the North Sea Basin;
  - Spatial layer of the sediment mass balance at the coast;
  - Time plot of the annual change in temperature at midwater and sea bottom;
  - Time plot of the sediment mass balance for each NUTS3 region;
  - Time plot of the average annual change in internal energy of sea.

- Some of the outputs necessary for the Climate and Coastal Protection Challenge had to be computed from available datasets. Time spent on writing scripts to process specific and unique datasets, to compute variables and display them is non negligible and needs be considered for any research or project. As a result, a large amount of data identified by this challenge is not usable for non-expert users.
- There is a plethora of EU-level websites offering data that would be appropriate to the project. These data sources are, however, often derived from a combination of the same sources. The interpretation and the investigation into this combination of sources remains difficult and requires investigative analysis to determine the true value of each of the datasets. There is a need to adopt persistent signposting services (like that being proposed by North Sea Check Point) to broker the right data to the right application.

8. References

1. Hamlington, B. D., Leben, R. R., Strassburg, M. W. and Kim, K.-Y. (2014), Cyclostationary empirical orthogonal function sea-level reconstruction. Geoscience Data Journal. doi: 10.1002/gdj3.6.
2. Smith, T.M., R.W. Reynolds, T.C. Peterson, and J. Lawrimore, 2008: Improvements NOAAs Historical Merged Land–Ocean Temp Analysis (1880–2006). Journal of Climate, 21, 2283–2296.
3. World Meteorological Organisation (WMO), Climate Data and Data Related Products, Web link: http://www.wmo.int/pages/themes/climate/climate_data_and_products.php.

Appendices

A. Annual Relative Mean Sea Level trends from PSMSL tide gauge data

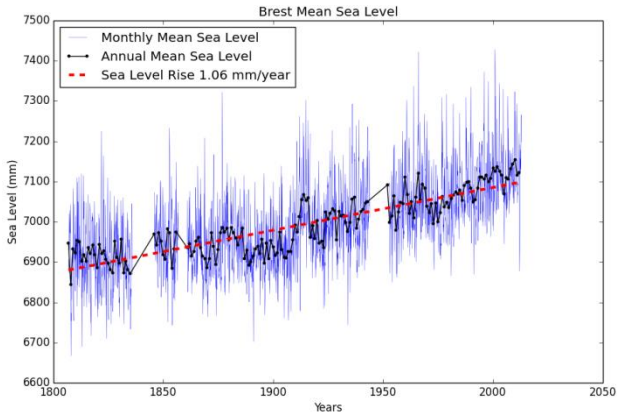


Figure A.1: Brest MSL

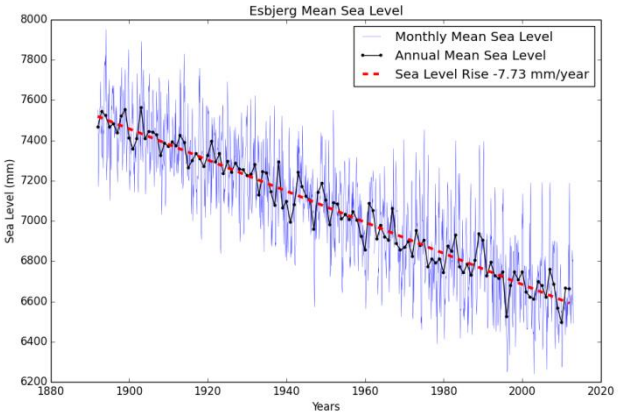


Figure A.2: Esbjerg MSL

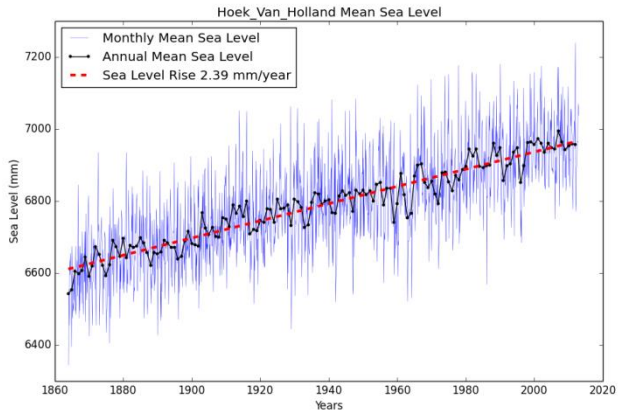


Figure A.3: Hoek Van Holland MSL

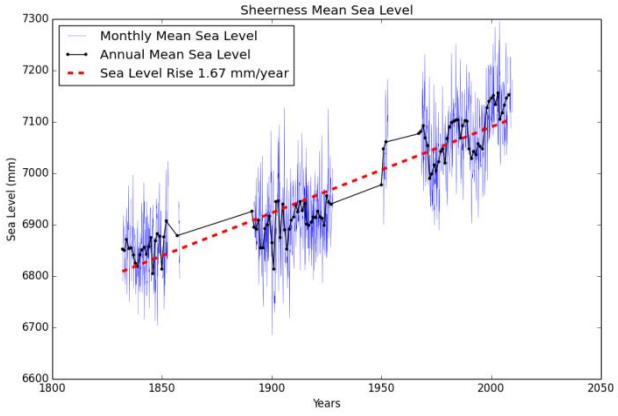


Figure A.4: Sheerness MSL

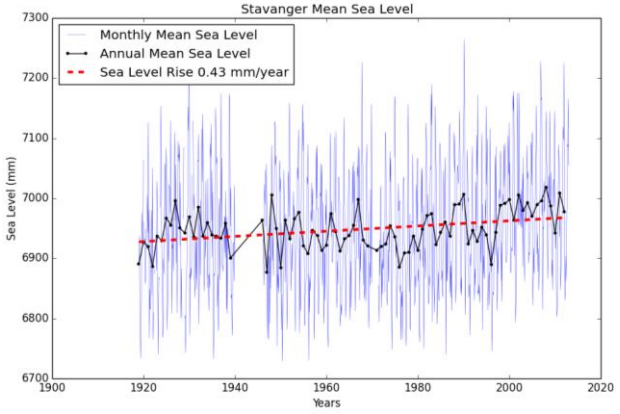


Figure A.5: Stavanger MSL

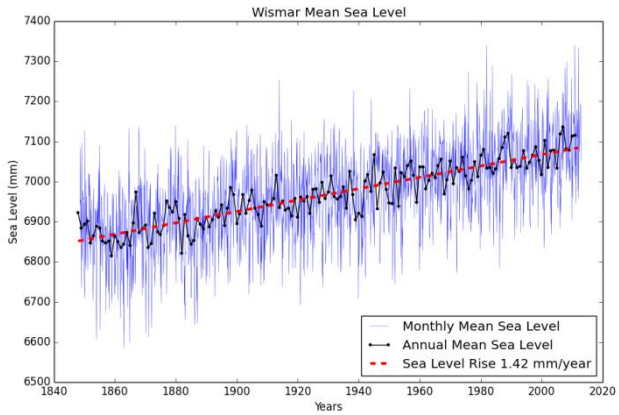


Figure A.6: Wismar MSL

B. Data Assessment

Valuation of the data to solving a challenge (a sheet per challenge)

NSC-004-Clim

Data Set	Consideration	ValueCriteria	VCFlag	ValueCriteriaReason
DT.Clim.NS001-EMODNET Physics portal for water temperature	NotConsidered	Contribution	True	point data, good for calibration/validation
NSC-004-Clim		Location	True	
		Commercial	True	free
		Attributes	True	many
		Delivery	False	can download many datasets at the same time, but download files sometimes wouldn't open
		Usability	True	a lot of post processing needed
DT.Clim.NS002-EMODNET Physics portal for sea level	NotConsidered	Contribution	True	point data, good for calibration/validation
NSC-004-Clim		Location	True	
		Commercial	True	free
		Attributes	True	many
		Delivery	False	can download many datasets at the same time, but download files sometimes wouldn't open
		Usability	True	a lot of post processing needed
DT.Clim.NS003-EMODNET Physics portal for currents	NotConsidered	Contribution	True	point data, good for calibration/validation
NSC-004-Clim		Location	True	
		Commercial	True	free
		Attributes	True	many
		Delivery	False	can download many datasets at the same time, but download files sometimes wouldn't open
		Usability	True	a lot of post processing needed
DT.Clim.NS004-European Atlas of the Seas - Coastal geology	NotConsidered	Contribution	True	
NSC-004-Clim		Location	False	info about geological nature of the coasts (include sediment types)
		Commercial	True	
		Attributes	True	many
		Delivery	False	clickable maps (no download)
		Usability	True	for model setup
DT.Clim.NS005-European Atlas of the Seas -tidal amplitude	NotConsidered	Contribution	True	points
NSC-004-Clim		Location	False	just points around coasts (100km away)
		Commercial	True	
		Attributes	True	many
		Delivery	False	clickable maps (no download)
		Usability	True	for model validation
DT.Clim.NS006-European Atlas of the Seas - Sea level change per year (mm)	NotConsidered	Contribution	True	points
NSC-004-Clim		Location	False	just points around coasts (100km away)
		Commercial	True	
		Attributes	True	many
		Delivery	False	clickable maps (no download)
		Usability	True	for model validation
DT.Clim.NS007-European Atlas of the Seas - Seabed sediments	NotConsidered	Contribution	True	
NSC-004-Clim		Location	False	very few samples
		Commercial	True	
		Attributes	True	many
		Delivery	False	clickable maps (no download)
		Usability	True	for model validation
DT.Clim.NS008-EUSeaMap	Considered	Contribution	True	SeaMap website is active but data download is directed to the EMODnet portal.
NSC-004-Clim		Location	True	Covers North Sea and parts of the North Atlantic. Excludes Baltic, Southern Atlantic and Mediterranean
		Commercial	True	Freely available
		Attributes	True	Extensive attribution of habitat classifications including EUNIS

Data Set	Consideration	ValueCriteria	VCFlag	ValueCriteriaReason
		Delivery	True	Downloaded via the EMODnet portal
		Usability	True	Useful in characterising both seabed habitats and comparison with seabed sediment information (in the absence of other sediment data)
DT.Clim.NS009-One Geology	Considered	Contribution	True	Offshore sediment mapping viewable via the mapviewer through the EMODnet geology tab
NSC-004-Clim		Location	True	Europe
		Commercial	True	Freely downloadable
		Attributes	True	Attribute information had to be extracted from reports
		Delivery	True	Data downloadable as kml for terrestrial and marine geology and sediment data
		Usability	True	kml data could be converted for use in GIS but only as an image, therefore losing all attribute information. Data was used as no other freely available data could be found.
DT.Clim.NS010-Vannstand	NotConsidered	Contribution	True	Tide gauges
NSC-004-Clim		Location	False	Norway
		Commercial	True	
		Attributes	True	
		Delivery	True	
		Usability	True	different format available
DT.Clim.NS011-British Oceanographic Data Centre	NotConsidered	Contribution	True	mean sea level and CTD
NSC-004-Clim		Location	False	UK
		Commercial	True	need to be registered as a BODC web user
		Attributes	True	
		Delivery	True	zip files to download
		Usability	True	ASCII
DT.Clim.NS012-University of Hawai Sea Level Center	NotConsidered	Contribution	True	daily, hourly, sea level
NSC-004-Clim		Location	False	only few stations
		Commercial	True	
		Attributes	True	
		Delivery	True	
		Usability	True	csv or NetCDF
DT.Clim.NS013-COSNYA	NotConsidered	Contribution	True	
NSC-004-Clim		Location	False	mainly around Germany, with few data in the North Sea
		Commercial	True	
		Attributes	True	
		Delivery	True	download zip files for many sets
		Usability	True	NetCDF and xml files to be post processed
DT.Clim.NS014-REFMAR	NotConsidered	Contribution	True	Tide gauge data
NSC-004-Clim		Location	False	only in France
		Commercial	True	need to register (not automatic)
		Attributes	True	
		Delivery	True	request
		Usability	True	ASCII
DT.Clim.NS015-Previmer	NotConsidered	Contribution	True	
NSC-004-Clim		Location	False	France
		Commercial	True	Need to fill up form and send by email
		Attributes	True	
		Delivery	True	??
		Usability	True	
DT.Clim.NS016-The Permanent Service for Mean Sea Level Rise	Suitable	Contribution	True	
NSC-004-Clim		Location	True	worldwide but only point data, not suitable for spatial layer
		Commercial	True	
		Attributes	True	
		Delivery	True	
		Usability	True	

Data Set	Consideration	ValueCriteria	VCFlag	ValueCriteriaReason
DT.Clim.NS017-MyOcean - GLOBAL OCEAN ALONG-TRACK SEA LEVEL ANOMALIES REPROCESSED (1993-ONGOING)	Suitable	Contribution	True	SSH
NSC-004-Clim		Location	True	20km , 1993- present
		Commercial	True	need to register
		Attributes	True	
		Delivery	True	ftp
		Usability	True	NetCDF
DT.Clim.NS018-MyOcean - GLOBAL OCEAN GRIDDED SEA LEVEL ANOMALIES REFERENCE CHANGE CORRECTION	Considered	Contribution	True	SSH
NSC-004-Clim		Location	True	0.25 degrees , 1993- present
		Commercial	True	need to register
		Attributes	True	
		Delivery	True	ftp
		Usability	True	NetCDF
DT.Clim.NS019-MyOcean - GLOBAL OCEAN GRIDDED SEA LEVEL ANOMALIES NOISE NRT	NotConsidered	Contribution	True	SSH
NSC-004-Clim		Location	True	2 degrees , 1993- present
		Commercial	True	need to register
		Attributes	False	resolution considered too poor, given that better was available
		Delivery	True	ftp
		Usability	True	NetCDF
DT.Clim.NS020-MyOcean - GLOBAL OCEAN GRIDDED SEA LEVEL ANOMALIES NOISE REPROCESSED	Considered	Contribution	True	SSH
NSC-004-Clim		Location	True	20km , 1993- present
		Commercial	True	need to register
		Attributes	True	
		Delivery	True	ftp
		Usability	True	NetCDF
DT.Clim.NS021-MyOcean - Global Ocean Mean Dynamic Topography	Considered	Contribution	True	SSH
NSC-004-Clim		Location	True	0.25 degrees , 1993- present
		Commercial	True	need to register
		Attributes	True	
		Delivery	True	ftp
		Usability	True	NetCDF
DT.Clim.NS022-MyOcean - Global Ocean Mean Sea Surface	Considered	Contribution	True	SSH
NSC-004-Clim		Location	True	0.03 degrees , 1993- present
		Commercial	True	need to register
		Attributes	True	
		Delivery	True	ftp
		Usability	True	NetCDF
DT.Clim.NS023-MyOcean - Global Ocean- CORA- In-situ Observations Yearly Delivery in Delayed Mode (1950-2013)	Considered	Contribution	True	Sea water Temperature Salinity
NSC-004-Clim		Location	True	spatial resolution: none , 1950 - present, -6000m to 0
		Commercial	True	need to register
		Attributes	True	
		Delivery	True	ftp
		Usability	True	NetCDF

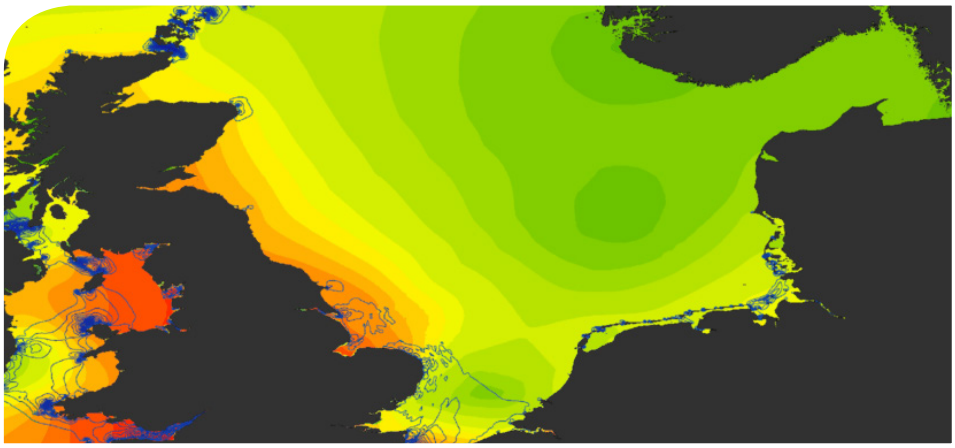
Data Set	Consideration	ValueCriteria	VCFlag	ValueCriteriaReason
DT.Clim.NS024-MyOcean - Global Ocean Physics Reanalysis GLORYS2V3 (1993-2013)	Considered	Contribution	True	SSH and Sea water potential temperature, Salinity
NSC-004-Clim		Location	True	0.25 degrees , 1993 - 2013, -5500m to 0
		Commercial	True	need to register
		Attributes	True	
		Delivery	True	ftp
		Usability	True	NetCDF
DT.Clim.NS025-MyOcean - Global Ocean Physics Reanalysis CGLORS (1982-2012)	Considered	Contribution	True	SSH and Sea water potential temperature, salinity
NSC-004-Clim		Location	True	0.25 degrees , 1982- 2012, -5500m to 0
		Commercial	True	need to register
		Attributes	True	
		Delivery	True	ftp
		Usability	True	NetCDF
DT.Clim.NS027-MyOcean - Global Ocean OSTIA Sea Surface Temperature and Sea Ice Reprocessed (1985-2007)	NotConsidered	Contribution	True	SST
NSC-004-Clim		Location	False	0.25 degrees , 1985- 2007 (missing the past 8 years)
		Commercial	True	need to register
		Attributes	True	
		Delivery	True	ftp
		Usability	True	NetCDF
DT.Clim.NS028-MyOcean - Global Ocean- Delayed Mode gridded CORA- In-situ Observations objective analysis in Delayed Mode (1990-2013)	Considered	Contribution	True	Sea water temperature, salinity
NSC-004-Clim		Location	True	0.5 degrees , 1990- 2013, -2000m to 0
		Commercial	True	need to register
		Attributes	True	
		Delivery	True	ftp
		Usability	True	NetCDF
DT.Clim.NS029-MyOcean - Atlantic - European North West Shelf - Ocean Physics Analysis and Forecast	NotConsidered	Contribution	True	SSH, Sea water temperature, Velocity, salinity
NSC-004-Clim		Location	False	7km, 2011 - present (not enough years)
		Commercial	True	need to register
		Attributes	True	
		Delivery	True	ftp
		Usability	True	NetCDF
DT.Clim.NS030-MyOcean - Atlantic - European North West Shelf-Ocean Physics NON ASSIMILATIVE Hindcast from NERCPOL (1960-2004)	Considered	Contribution	True	SSH, Sea water temperature, Velocity, salinity
NSC-004-Clim		Location	True	12km, 1960 - 2004 (suitable for the past 50 years)
		Commercial	True	need to register
		Attributes	True	
		Delivery	True	ftp
		Usability	True	NetCDF
DT.Clim.NS031-MyOcean - Atlantic- European North West Shelf-Ocean Physics NON ASSIMILATIVE Hindcast from IMR (1985-2008)	NotConsidered	Contribution	True	SSH, Sea water temperature, Velocity, salinity
NSC-004-Clim		Location	False	12km, 1985-2008 (missing the past 7 years)
		Commercial	True	need to register
		Attributes	True	
		Delivery	True	ftp
		Usability	True	NetCDF

	Data Set	Consideration	ValueCriteria	VCFlag	ValueCriteriaReason
	DT.Clim.NS032-MyOcean - Atlantic- European North West Shelf-Ocean In-Situ Near Real Time observations	NotConsidered	Contribution	True	Temperature, Salinity
	NSC-004-Clim		Location	False	spatial resolution: none (point data, buoys, ships) , time coverage depends on the files/location/instruments
			Commercial	True	need to register
			Attributes	True	
			Delivery	True	ftp
			Usability	False	NetCDF (important amount of files)
	DT.Clim.NS033-MyOcean - EUROPEAN OCEAN ALONG-TRACK SEA LEVEL ANOMALIES NRT	NotConsidered	Contribution	True	SST
	NSC-004-Clim		Location	False	1985-2008 (missing the past 7 years)
			Commercial	True	need to register
			Attributes	True	
			Delivery	True	ftp
			Usability	True	NetCDF
	DT.Clim.NS034-MyOcean - European North West Shelf- Ocean Physics REANALYSIS from METOFFICE (1985-2012)	Considered	Contribution	True	Sea water temperature, Velocity, salinity
	NSC-004-Clim		Location	True	7km, 1985 -2012, -5000m to 0m
			Commercial	True	need to register
			Attributes	True	
			Delivery	True	ftp
			Usability	True	NetCDF
Ignored	DT.Clim.NS035-MyOcean - Atlantic- European North West Shelf-Ocean Physics NON ASSIMILATIVE Hindcast from IMR (1985-2008)	Null	Contribution	True	
	NSC-004-Clim		Location	True	
Entered Twice			Commercial	True	
			Attributes	True	
			Delivery	True	
			Usability	True	
	DT.Clim.NS036-MyOcean - Atlantic- European North West Shelf-Ocean Physics Reanalysis from IMR (1993-2012)	Considered	Contribution	True	SSH, Sea water temperature, Velocity, salinity
	NSC-004-Clim		Location	True	8km, 1993-2012 , -3000m to 0
			Commercial	True	need to register
			Attributes	True	
			Delivery	True	ftp
			Usability	True	NetCDF
	DT.Clim.NS037-MyOcean - European Ocean- Sea Surface Temperature Multi Sensor L4 three-hourly Observations	NotConsidered	Contribution	True	SST
	NSC-004-Clim		Location	False	2km , from 2014
			Commercial	True	need to register
			Attributes	True	
			Delivery	True	ftp
			Usability	True	NetCDF
	DT.Clim.NS038-MyOcean - European Ocean- Sea Surface Temperature Multi-Sensor L3 Observations	NotConsidered	Contribution	True	SST
	NSC-004-Clim		Location	False	2km , from 2012
			Commercial	True	need to register
			Attributes	True	
			Delivery	True	ftp

Data Set	Consideration	ValueCriteria	VCFlag	ValueCriteriaReason
		Usability	True	NetCDF
DT.Clim.NS039-MyOcean - European Ocean- Sea Surface Temperature Mono-Sensor L3 Observations	NotConsidered	Contribution	True	SST
NSC-004-Clim		Location	False	2km , from 2014
		Commercial	True	need to register
		Attributes	True	
		Delivery	True	ftp
		Usability	True	NetCDF
DT.Clim.NS040-MyOcean - Atlantic European North West Shelf Ocean - ODYSSEA Sea Surface Temperature Analysis	NotConsidered	Contribution	True	SST
NSC-004-Clim		Location	False	2km , from 2010
		Commercial	True	need to register
		Attributes	True	
		Delivery	True	ftp
		Usability	True	NetCDF
DT.Clim.NS041-MyOcean - Atlantic-European North West Shelf- In-situ Observations Yearly Delivery in Delayed Mode (1990-2011)	NotConsidered	Contribution	True	Temperature, Salinity
NSC-004-Clim		Location	False	spatial resolution: none (mooringsm drifters, ships), 1990-2013
		Commercial	True	need to register
		Attributes	True	
		Delivery	True	ftp
		Usability	True	NetCDF
DT.Clim.NS042-PODAAC - Reconstructed Sea Level Version 1	Used	Contribution	True	SSH
NSC-004-Clim		Location	True	0.5 degrees , 1950 - 2009
		Commercial	True	
		Attributes	True	
		Delivery	True	ftp
		Usability	True	NetCDF
DT.Clim.NS043-PODAAC - Smith and Reynolds NCDC Level 4 Historical Reconstructed SST Monthly Version 3b netCDF	Suitable	Contribution	True	SST
NSC-004-Clim		Location	True	2 degrees , 1854 - present, only surface
		Commercial	True	
		Attributes	True	
		Delivery	True	ftp
		Usability	True	NetCDF
DT.Clim.NS026-MyOcean - Global Ocean Physics Reanalysis ECMWF ORAP5.0 (1979-2013)	Considered	Contribution	True	SSH, Sea water temperature, salinity
		Location	True	0.25 degrees, 1979-2013 , -5500m to 0
		Commercial	True	need to register
		Attributes	True	
		Delivery	True	ftp
		Usability	True	NetCDF
DT.Clim.NS044-MyOcean - Atlantic Iberian Biscay- In-situ Observations Yearly Delivery in Delayed Mode (1990-2013	Considered	Contribution	True	Sea water temperature, salinity
		Location	True	spatial resolution: none , 1990-2013 , -6000m to 0
		Commercial	True	need to register
		Attributes	True	
		Delivery	True	ftp
		Usability	True	NetCDF
DT.Clim.NS045-NOOS	NotConsidered	Contribution	True	Temperature, Salinity, water level
		Location	True	North west shelf

Data Set	Consideration	ValueCriteria	VCFlag	ValueCriteriaReason
		Commercial	True	free
		Attributes	True	
		Delivery	False	download zip files(not always working for many datasets)
		Usability	False	zip file corrupted
DT.Clim.NS046-NOAA - Sea Level Trends	NotConsidered	Contribution	True	Sea Level Trends (calculated from the PSMSL)
		Location	True	Global (point Data)
		Commercial	True	Free
		Attributes	True	
		Delivery	False	clickable maps, downloadable table
		Usability	False	tables don't have coordinates just city names

HR Wallingford
Working with water



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