THE COASTDAT DATA SET AND ITS POTENTIAL FOR COASTAL AND OFFSHORE APPLICATIONS

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Abstract:

The coastDat data set is a compilation of coastal analyses and scenarios for the future from various sources. It contains no direct measurements but results from numerical models that have been driven either by observed data in order to achieve the best possible representation of observed past conditions or by climate change scenarios for the near future. Contrary to direct measurements which are often rare and incomplete, coastDat offers a unique combination of consistent atmospheric, oceanic, sea state and other parameters at high spatial and temporal detail, even for places and variables for which no measurements have been made. In addition, coastal scenarios for the near-future are available which complement the numerical analyses of past conditions. The backbones of coastDat are regional wind, wave and storm surge hindcast and scenarios mainly for the North Sea and the Baltic Sea. We will discuss the methodology to derive these data, their quality and limitations in comparison with observations. Long-term changes in the wind, wave and storm surge climate will be discussed and potential future changes will be assessed. We will conclude with a number of coastal and offshore applications of coastDat demonstrating some of the potentials of the data set in hazard assessment. Examples will comprise applications of coastDat in ship design, oil risk modelling and assessment, and the construction and operation of offshore wind farms.

I. INTRODUCTION

Coastal and offshore applications require appropriate planning and design. For most of them, statistics of extreme wind, waves and storm surges are of central importance. To obtain such statistics long and homogeneous time series are needed.

Usually such time series are hardly available. In many cases observations are either missing, cover too short periods, or are lacking homogeneity, that is long term changes in the time series are not entirely related to geophysical changes but are partly due to changes in instrumentation, measurement technique or other factors.

There are in principal two approaches to address these issues: One is the use of proxy data that are considered to be more homogeneous and are available for longer periods. An example is the use of pressure data to derive indices for changes in storm activity (e.g. [1]). The other approach is to use numerical models driven by re-analysis[1] data over sufficiently long periods and at high spatial and temporal resolution (e.g. [3]).

Both approaches have advantages and disadvantages. While proxy data can generally be used to reconstruct indices for rather long time periods (up to centuries), their spatial resolution remains limited and proxy data must be available at sufficient detail and quality. Hindcasts, on the other hand, are limited to periods for which global re-analyses are available (nowadays about 60 years) and by the quality of the involved models.

In the following we describe a set of coastal hindcasts based on global re-analysis data. The hindcasts are complemented with consistent climate change scenarios for the future. Data obtained from this exercises are integrated into a joint data base referred to as *coastDat* (see www.coastdat.de). In section 2 model set-up and experimental design are briefly described. Additionally some validation is

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[1] A re-processing of existing weather data with frozen state-of-the-art numerical models and data assimilation schemes in order to increase homogeneity (see e.g. [2]).

provided. In section 3 some representative examples are provided in which coastDat has been applied for the analysis of recent and potential future changes. In section 4 some coastal and offshore applications are presented that should demonstrate the potential of coastDat for marine hazard assessments. A brief summary is given in section 5.

II. MODEL SET-UP AND EXPERIMENTAL DESIGN

We used the NCEP/NCAR global re-analysis to first drive a regional atmosphere model for an area covering most of Europe and adjacent seas. Initially the model was integrated for the years 1958-2002 at a spatial resolution of about 50x50 km with some simple data assimilation applied [4]. The period has been extended later and currently covers the 60 years 1948-2007. Full model output is available for every hour within this 60 year period.

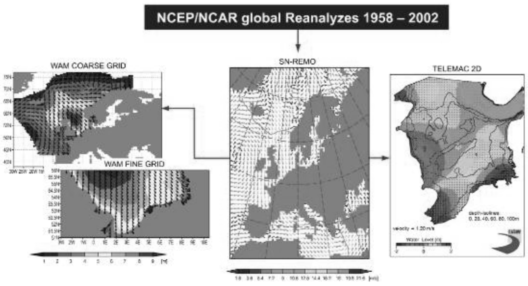


Figure 1. Layout of the consistent met-ocean hindcast 1948-2007 for the Southern North Sea. From the regional atmosphere hindcast (middle) hourly wind fields were used to force a tide-surge (right) and a wave model hindcast (left). The figure shows an example of consistent met-ocean conditions obtained from the hindcast for 12 UTC on 21 February 1993. Middle: near-surface (10 m height) marine wind fields in ms^{-1} and corresponding wind direction obtained from the regional atmospheric reconstruction. Left: corresponding significant wave height fields in m and mean wave direction from the coarse and the fine grid wave model hindcast. Right: Tide-surge levels in m from the corresponding tide-surge hindcast. After [3].

From this atmospheric simulation, near-surface marine wind fields have been used subsequently to drive high-resolution wave and tide-surge models. While the wave model was run in a nested mode with a coarse grid (about 50x50 km) covering most of the Northeast Atlantic and a fine grid (about 5x5 km) covering the North Sea south of 56N, the tide-surge model was run on an unstructured grid with typical grid spacing of about 5 km in the open North Sea and largely enhanced values (up to 80 m) near the coast and in the estuaries. As for the atmospheric part, full model outputs have been stored every hour. This way a high-resolution meteo-marine data set for the North Sea covering the last 6 decades of years has been created. Figure 1 shows an example of conditions obtained for 21 February 1993.

An impression of the extent to which this approach is able to provide a reasonable reconstruction of the observed wind and wave climate is given in Figure 2. Shown are observed and hindcast wind speed and direction as well as significant wave height, period and wave direction for a three months period at station K13 (53.22 N, 3.22 E). In principal a good agreement can be inferred. For instance, the storm event on 21 February which caused observed significant wave heights of more than 6 m is reasonably reproduced for all parameters. On the other hand, there are also events with larger discrepancies such as the one around 1 March for which wave heights are considerably underestimated, in this case caused by too low wind speeds in the atmospheric hindcast. A comparison of modelled and hindcast storm indices for Lund in Sweden is shown in Figure 3. Generally it can be inferred, that the observed year to year variability is captured reasonably by the hindcast although some bias may occur. More validation can be found for the atmospheric part in [6], for the tide-surge simulation in [7], and for the wave model hindcast in [3].

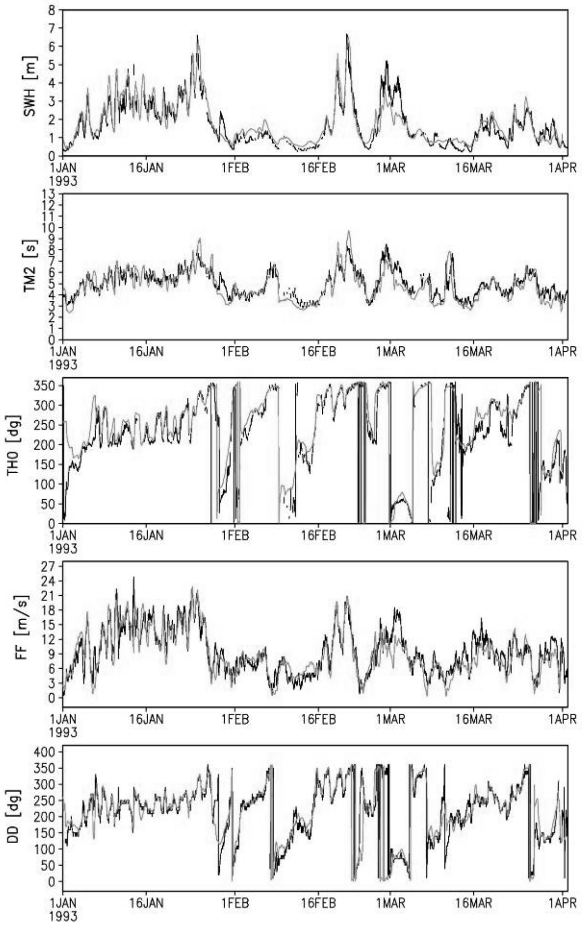


Figure 2. Time series of significant wave height in m, Tm2 wave period in s, mean wave direction in degrees coming from, wind speed in ms^{-1} and wind direction in degrees coming from (from top to bottom) at K13 for a three months period 01 January 1993-31 March 1993. Observations - black, model results – green. After [3].

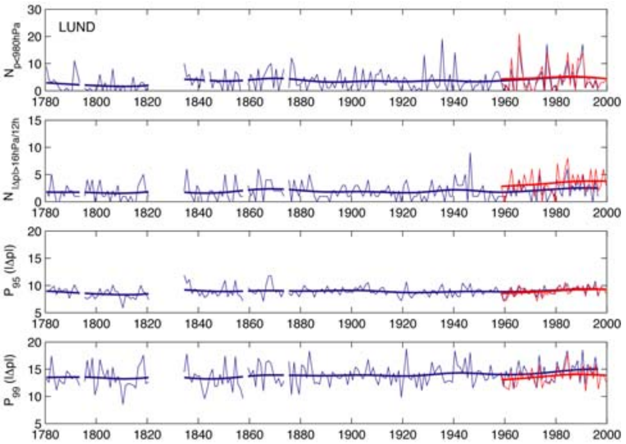


Figure 3. Comparison between different storm indices for Lund, Sweden. From top to bottom: Number of deep pressure readings; Number of strong pressure tendencies; 95- and 99-percentiles of strong pressure tendencies. Blue: Obtained from observations. Red: Obtained from coastDat. After [5].

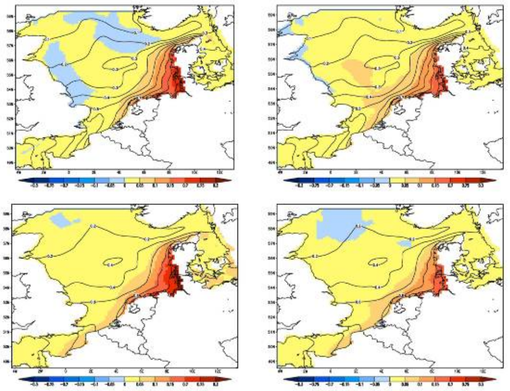


Figure 4. Differences of annual maximum storm surges between potential future (2071-2100) and present day (1960-1990) conditions obtained from tide-surge simulations using forcing from different climate models and emission scenarios. Left column: Response for the A2-emission scenario. Right column: Response for the B2-emission scenario. Upper row: Response for near-surface wind speeds from the RCAO regional climate model driven by global ECHAM4/OPYC3 model. Lower row: Response for near-surface wind speeds from the RCAO regional climate model driven by global HadAM3H model. After [10, 11].

Scenarios for future climate conditions have been obtained in a similar way. Here the global re-analysis has been replaced by an ensemble of different global climate change simulations. These have subsequently been used to drive a number of different regional atmosphere models (see [8] for a summary). From some of these regional atmospheric simulations near-surface wind and pressure fields have subsequently been used to produce high-resolution wave [9] and storm surge scenarios [10, 11].

III. RECENT AND POTENTIAL FUTURE CHANGES

The coastDat data set was used by [6] to analyze long term changes in storm activity over the North Sea and the Northeastern North Atlantic. They found an increase in storm activity from about 1960. Storm activity peaked around 1990/1995, afterwards a decrease was inferred. These results are consistent with those obtained from proxy data for the area. For instance, [1] and an update in [12] report a similar behavior based on the analysis of upper geostrophic wind speed percentiles derived from station pressure data. Covering a longer period than the coastDat hindcasts in particular theses studies showed that the 1960-1990 increase in storm activity was not unusual but that activity levels reached in the mid-1990's were comparable to that at the beginning of the 20th century. Long term changes in extreme storm surge and ocean wave heights based on the coastDat data set were analyzed by [7] and [3]. In particular they found that the changes correspond to that of storm activity with increases in storm surges and wave heights between about 1960 and 1990 and decreases afterwards.

Changes of the North Sea storm surge climate in an ensemble of climate change simulations that form part of the coastDat data set were analyzed by [10, 11]. Figure 4 shows the changes in extreme storm surge levels expected towards the end of the century. Although regional details differ among the different models and scenarios, all point towards a moderate increase in severe storm surge levels along most of the Netherlands, German and Danish coast lines. When compared to the natural variability estimated from the coastDat hindcast [7] climate change related increases in storm surge heights are found to be smaller for most of the Netherlands and Danish coast, while they are larger along most of the German coast line.

Using near-surface marine wind speeds from the same set of scenario simulations [9] performed a similar ensemble of wave model simulation. Although the same wind forcing was used, changes appeared to be more diverse. In particular, changes in severe wave conditions were strongest when wind fields from the RCAO/ECHAM4 model line were applied. When wind fields from the RCAO/HadAM3H combination were used, future changes were smaller and maximum increases were found for the Southern North Sea, while largest changes under RCAO/ECHAM forcing appeared to occur in the Northeastern part of the North Sea.

IV. MARINE APPLICATIONS

The coastDat data set has been used for a variety of coastal and offshore applications. This comprises applications in ship design, oil risk modeling and assessment, and the construction and operation of offshore wind farms. In the following a few examples will be provided.

A. *Ship Design*

The coastDat data set was used to simulate operation profiles of RoRo vessels operating on fixed routes in the North Sea [13]. Here ship traffic was simulated over decades of years with environmental conditions (wind, water depth, sea state) provided by the coastDat data set. Operation profiles (such as velocity or power) were varied under the constraint, that the operations are time critical, that is, the individual trips need to be finished within a given time window, as long as permitted by safety requirements (weather conditions). Results for a

200 m RoRo vessel operating on a 332 nm round trip between Zeebrügge, Belgium and Immingham, UK are provided in [13]. For the 3,650 trips simulated within a 10 year period they found fuel consumption to be increased by about 9% when compared to calm weather conditions and attributed the effect to the additional power required to face with the environmental conditions caused by wind, waves and water levels. They also showed that operation profiles may be optimized compared to conventional approaches such that operation costs are reduced and delay becomes minimal. They concluded that data bases such as coastDat may provide valuable tools to optimize ship design with respect to the expected environmental conditions on the route.

B. Construction of Offshore Wind Farms

There is considerable interest in the use of coastDat data for planning the construction and operation of offshore wind farms. Here available observations are usually limited and the application of hindcast data represents a common approach to address the problem. In particular, there are several statistics that may be derived from hindcast data and that may help in design process:

1. *Estimates of extreme conditions at the site.* As coastDat data are available for 60 years at high spatial and temporal resolution they are used to estimate the magnitude of rare events that may have considerable impacts on the site, such as the 50 year return value for near-surface wind speed or significant wave height. [3] have shown that there is a reasonable agreement of such values when estimated from observations and from coastDat data.

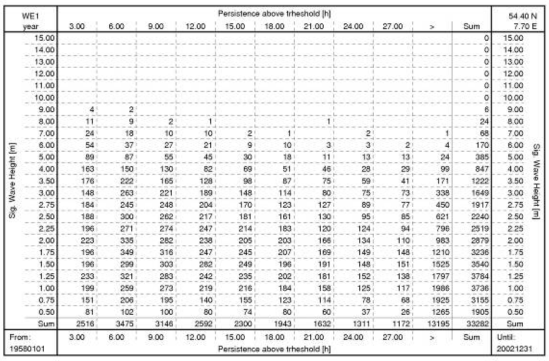
2. *Estimates of frequency distributions.* Frequently coastDat data are used to estimate joint probability distributions needed in the design process. This comprises, for instance, scatter diagrams of any combinations of the following parameters: wind speed, wind direction, significant wave height, wave periods and wave direction.

3. *Estimates of weather windows and other durations.* Because of its high temporal resolution coastDat allows also for the estimation of weather windows and similar measures. For instance, it may be of interest how long severe sea state conditions may last on the site. Figure 5 shows such an estimate derived from coastDat data. For the site considered it is found, for example, that severe sea states with significant wave heights exceeding 8 m in most cases last less than 6 hours. However, within the period 1958-2002 there has also been one event which lasted between 18 and 21 hours. Similarly, weather windows may be derived. For instance, the time window within which sea states on average remain below a given threshold (e.g. 2 m) may be estimated. The latter may be required to plan maintenance of the wind farm, or to estimate whether it would be feasible, at a given probability, to arrange the site within a given timeframe, e.g. a season.

C. Oil Risk Modeling

A toolbox (PELETS-2d[1]) for Lagrangian drift modeling based on fields from coastDat has been developed. An oil chemistry model may also be included and wind drift may or may not be taken into account. The latter represents an essential forcing factor when oil spills or drifting materials are considered.

On the basis of coastDat PELETS-2d has been applied to a number of problems including the assessment of fresh water signals at Helgoland, the comparison of station data with ship based measurements, or the assessment of oil related risks. An example is shown in Figure 6. Here the drift



Sig. Wave Height [m]

WE1	Persistence above trheshold [h]										54.40 N
year	3.00	6.00	9.00	12.00	15.00	18.00	21.00	24.00	27.00	>	Sum	7.70 E
15.00											0	15.00
14.00											0	14.00
13.00											0	13.00
12.00											0	12.00
11.00											0	11.00
10.00											0	10.00
9.00	4	2									6	9.00
8.00	11	9	2	1			1				24	8.00
7.00	24	18	10	10	2	1		2		1	68	7.00
6.00	54	37	27	21	9	10	3	3	2	4	170	6.00
5.00	89	87	55	45	30	18	11	13	13	24	385	5.00
4.00	163	150	130	82	69	51	46	28	29	99	847	4.00
3.50	176	222	165	128	98	87	75	59	41	171	1222	3.50
3.00	148	263	221	189	148	114	80	75	73	338	1649	3.00
2.75	184	245	248	204	170	123	127	89	77	450	1917	2.75
2.50	188	300	262	217	181	161	130	95	85	621	2240	2.50
2.25	196	271	274	247	214	183	120	124	94	796	2519	2.25
2.00	223	335	282	238	205	203	166	134	110	983	2879	2.00
1.75	196	349	316	247	245	207	169	149	148	1210	3236	1.75
1.50	196	299	303	282	249	196	191	148	151	1525	3540	1.50
1.25	233	321	283	242	235	202	181	152	138	1797	3784	1.25
1.00	199	259	273	219	216	184	158	125	117	1986	3736	1.00
0.75	151	206	195	140	155	123	114	78	68	1925	3155	0.75
0.50	81	102	100	80	74	80	60	37	26	1265	1905	0.50
Sum	2516	3475	3146	2592	2300	1943	1632	1311	1172	13195	33282	Sum
From:	3.00	6.00	9.00	12.00	15.00	18.00	21.00	24.00	27.00	>	Sum	Until:
19580101	Persistence above trheshold [h]											20021231

Sig. Wave Height [m]

Figure 5. Statistics (1958-2002) of significant wave height persistence above given thresholds for a grid point in the Southern North Sea. Thresholds are indicated on the first and last column; durations are given on the first and last row. Numbers in the table indicate how often a given threshold was exceeded in 1958-2002 with a particular duration.

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[1] Program for the Evaluation of Lagrangian Ensemble Transport Simulations.

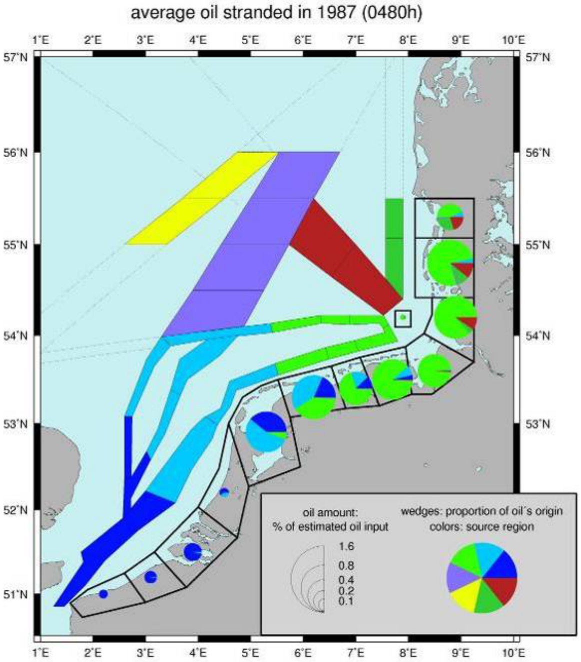

Figure 6. Example of oil from illegal oil dumping along major shipping routes stranded at different coastal areas as a result of simulations for 1987 (integration time of 20 days).

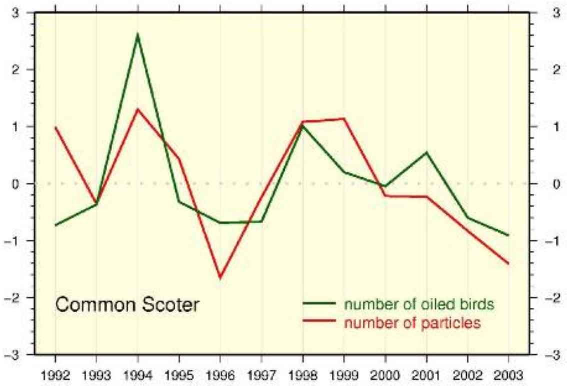

Figure 7. Number of observed beached oil-contaminated Common Scoters at the German coast and simulated number of stranded particles in standardized form when constant chronic oil pollution is simulated using PELETS-2d and coastDat. After [14].

of a large number of oil spills caused by illegal oil dumping along major shipping routes in the North Sea was simulated. The Figure shows estimates of the relative amount of stranded oil for different coastal regions and the relative contribution from the different shipping routes and is indicative for the risk.

Another example is provided by using coastDat in combination with PELETS-2d to interpret chronic oil pollution. Chronic oil pollution predominantly results from illegal oil dumping and represents a major threat for the marine environment. Often, the number of oil-contaminated beached birds is used as indicator for trends in the level of chronic oil pollution. It turns out that the latter may be misleading [14]. Figure 7 shows that variations within the number of beached birds (e.g. Common Scoter) may equally likely be explained by changes in atmospheric wind conditions and that atmospheric variability needs to be accounted for in the interpretation of the data.

D. Other Applications

There are a number of other applications not addressed in detail here. These include applications related to coastal flood risk assessment, water quality studies, or the definition of safety criteria for navigation. For more details we refer to www.coastdat.de.

V. SUMMARY

The coastDat data set consists of a set of coastal analyses and scenarios for potential future developments. It constitutes a consistent meteo-marine data set at high spatial and temporal resolution available for the last 60 years. It was shown (e.g. [3, 6, 7]) that the statistics of extreme events can be estimated from coastDat at a reasonable degree of approximation. The coastDat data set has been applied to a large number of different coastal and offshore applications ranging from ship design, to oil risk modelling and the construction and operation of offshore wind farms. It was shown that long term variations in extreme weather conditions can be reliably derived (e.g. [3, 6, 7]) making the data set a particularly useful tool in the interpretation of long term changes and variability.

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