coastDat – Model Data for Science and Industry

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Summary

The coastDat data set is a compilation of regional meteo-marine hindcasts and scenarios of possible future developments derived from numerical models. The core of the data set comprises high-resolution wind, wind wave and tide-surge hindcasts mostly for the North Sea. Other areas progressively become available. Depending on parameter, the hindcast period covers the last five to six decades of years including the most recent ones. The data set was successfully applied for a variety of scientific as well as more practically oriented applications comprising, for example, naval architecture or offshore wind farms. Here the data set and the history leading to its development are briefly described, validation is reviewed, and an overview about recent uses of the data is provided. Eventually access to the data is briefly sketched.

Keywords

coastDat, hindcast, met-ocean data, meteo-marine data, North Sea

Zusammenfassung

Der coastDat Datensatz ist eine Zusammenstellung meteo-mariner Rekonstruktionen und von Szenarienrechnungen für die Zukunft, die mit Hilfe numerischer Modelle erstellt wurden. Die Kernstücke des Datensatzes umfassen hoch aufgelöste Wind-, Seegangs- und Wasserstandsrekonstruktionen (Hindcasts), die bisher hauptsächlich für die Nordsee entwickelt wurden. Rekonstruktionen und Szenarien für andere Gebiete werden jedoch zunehmend verfügbar und in den Datensatz integriert. Je nach Parameter umfassen die rekonstruierten Zeiträume die letzten etwa 50-60 Jahre. Daten aus coastDat wurden erfolgreich sowohl zur Untersuchung wissenschaftlicher Fragestellungen als auch zur Betrachtung von mehr praxisorientierten Anwendungen z. B. im Schiffbau oder der Offshore Windindustrie eingesetzt. In diesem Beitrag werden der Datensatz und die notwendigen Entwicklungen kurz vorgestellt sowie ein Überblick über Validierungsergebnisse gegeben. Anschließend werden eine kurze Übersicht über derzeit existierende Anwendungen gegeben und die Zugangsmöglichkeiten zu den Daten beschrieben.

Schlagwörter

coastDat, Hindcast, meteo-marine Daten, Nordsee

Contents

1 Introduction

Assessing statistics such as the mean, the variability or the extremes of marine environmental conditions and their long-term changes are essential for both, marine science and a variety of commercial offshore activities. Marine scientists are interested, for example, in the understanding of the processes, their variability and changes. Authorities or industry may need comparable information for planning, designing or maintaining for example, coastal defences or offshore structures. Often data to derive such statistics are unavailable for various reasons. In many cases observational records are too short to cover the full spectrum of time scales. In some cases, sampling in space and time is insufficient or data for the parameters of interest are unavailable. Frequently, longer records are not homogeneous; that is, technical changes, for example in measurement techniques, exist and may introduce artificial variability or spurious trends in the data (e.g. WEISSE and VON STORCH 2009).

The coastDat approach was developed to address such problems. It uses quasi-realistic numerical models of the marine atmosphere, tide-surges or wind waves to optimally exploit existing observations and to reconstruct the marine climate providing detailed hourly descriptions of changing marine environmental conditions from 1948/1958 up to know. Scenarios of potential future developments in a changing climate are also available, complementing the reconstruction of past conditions in a consistent way. For the North Sea, the coastDat approach was developed over more than 10 years and was successfully applied, for example, for providing assessments of the effectiveness of political measures to reduce chronic oil pollutions (e.g. CHRASTANSKY et al. 2009; CHRASTANSKY and CALLIES 2009) or changes in wind (e.g. WEISSE et al. 2005) and storm surge climate (e.g. WEISSE and PLUESS 2006). Industrial applications comprise, for example, uses in ship design, oil risk modelling and assessment, or the construction and operation of offshore wind farms (WEISSE et al. 2009). As of mid-2014 the coastDat data set is used by more than 80 users with about 46 % of them located in industry, 15 % in authorities and 39 % in other research institutes. In the following we briefly introduce this data set. In section 2 some background informations are provided, in particular on how the approach developed over time and the major achievements and milestones eventually leading to the development of coastDat. In section 3 a brief comparison is made between the first version of coastDat (the origins of which are dating back to the late 1990s) and a newer version that is gradually and progressively replacing the first one. Validation aspects are touched in section 4 and in section 5 a brief overview of scientific and more practically oriented applications is given. In section 6 we describe how coastDat data may be located and accessed and in section 7 a short summary and discussion are provided.

2 History

Using numerical models to hindcast or to reconstruct specific events such as an extreme storm or storm surge has a long tradition. The objective of such studies was twofold. In some cases hindcasts were performed to reproduce extreme events that caused severe damages. Examples comprise, for instance, the simulation of the so-called Halloween storm in 1991 (CARDONE et al. 1996) or the simulation of the severe wave conditions causing the abandonment of five yachts in the 1998 Sydney to Hobart yacht race (GREENSLADE 2001). In other cases hindcasts were used to validate the models under extreme conditions (e.g. HOPE et al. 2013; DIETRICH et al. 2009).

In the course of time as models matured and computers became more efficient, hindcasts covering longer periods or a large number of selected extreme events became more popular. The purpose of such studies usually was to generate data bases from which climatologies of environmental conditions in data sparse regions could be derived. In particular for wind waves, the efforts were often driven by demands from naval and offshore (mostly oil) industry and as a consequence many of the studies were classified and unavailable for further research (WEISSE and GÜNTHER 2011). An example of such a study is the seasonal wave climatology for the North Sea based on a wave hindcast of 16 years forced by winds calculated from a quasi-geostrophic model using digitized analyzed surface pressure maps (N.N. 1987).

In the early 1990s there was considerable concern about an intensification of the extra-tropical storm climate and the offshore industry was confronted with reports on waves higher than had ever been observed (WASA 1998). In this atmosphere, the European project WASA (Waves and Storms in the North Atlantic) was inspired and implemented to prove or disprove hypotheses about a worsening storm and wave climate in the North Atlantic (WASA 1998). One approach taken by the project was to *continuously* hindcast waves and surges over more than four decades of year. To our knowledge, this provided the first *multi-decadal* hindcast aiming at assessing *long-term changes*. The project also the first time emphasized the need for homogeneity in multi-decadal hindcasts; that is, in-homogeneities caused, for example, by changes in the observational network or measurement techniques may introduce artificial trends making the hindcasts unsuitable for assessing long-term changes (WASA 1998). For a detailed discussion see e.g. WEISSE and VON STORCH (2009).

A major conclusion from the WASA project was the need for a more homogeneous wind forcing of the storm surge and wave hindcasts that was unavailable at the time the project was running. The situation improved considerably when global atmospheric reanalyses became available at the mid-1990's aiming at providing gridded atmospheric data sets and reducing effects from in-homogeneities. A particular useful product which is still continuously updated was provided by the National Center for Environmental Prediction (NCEP) (KALNAY et al. 1996; KISTLER et al. 2001). In this reanalysis 6-hourly data are available from 1948 onwards until now at about 210 km x 210 km spatial resolution (KALNAY et al. 1996).

While the latter was very useful for studies at the global or continental scale, the spatial and temporal resolution remained too coarse for many regional or smaller scale studies and a number of attempts were therefore undertaken to further downscale global reanalyses. To fully exploit the information contained in the global product, VON STORCH et al. (2000) proposed a special technique called spectral nudging for dynamically downscaling of global reanalysis. The idea behind the approach is the following: The skill of the global reanalyses is scale dependent with higher confidence in the larger scales supported by data assimilation. Consequently, at larger scales the downscaling solution should be more strongly confined to the global solution while at smaller scales (where added value can be expected) the regional model should be less constrained. The approach is sometimes also referred to as regional data assimilation without observations (VON STORCH et al. 2000). It is nowadays widely used (for an overview see e.g. WEISSE and VON STORCH 2009) and it was demonstrated to provide substantial added value when compared to the standard approach (e.g. WEISSE and FESER 2003; FESER et al. 2011).

The availability of global reanalyses, the development of the spectral nudging technique to improve downscaling, and the need for consistent and high-resolution met-ocean hindcasts paved the way for the set-up of the HIPOCAS (Hindcast of Dynamic Processes of the Oceans and the Coastal Areas of Europe) project in the late 1990's. Based on the aforementioned developments this project, for the first time, aimed at providing a detailed, high-resolution, and consistent met-ocean hindcast for European shelf seas and coastal areas. Typically, hindcasts were performed from 1958-1998 at grids varying from 50 km x 50 km for the atmosphere to about 5 km x 5 km for waves and up to a few hundred metres for storm surges (SOARES et al. 2002). Data were stored every hour, allowing for both, a detailed validation and assessment of long-term changes (e.g. WEISSE and GÜNTHER 2007; CIEŚLIKIEWICZ and PAPLIŃSKA-SWERPEL 2008; MUSIĆ and NICKOVIĆ 2008). As the project terminated, the data set produced became rapidly outdated. Because of existing demands and requests, both from the scientific community and offshore industry, the effort was, for the North Sea, routinely continued and extended at the Helmholtz-Zentrum Geesthacht (HZG) using the model system and techniques implemented during the HIPOCAS project. As the effort became increasingly comprehensive further including scenarios of potential future developments in the course of the expected anthropogenic climate change or hindcasts for the Baltic Sea area, the effort was renamed and continued as coastDat.

The effort was finally terminated around 2007, when model developments and computational efficiency allowed the set-up of a new coastDat-2 system for which the entire period from 1948 until now (presently 2013) is simulated and continuously updated. The original coastDat data set is now referred to as coastDat-1 and still available but no longer updated. In the following the similarities and differences between the two data sets are briefly described.

3 coastDat-1 and coastDat-2

In the following we limit ourselves to the core simulations and data available from both coastDat products; that is, wind, waves and tide-surge hindcasts for the North Sea. Note that additional products are available such as climate change scenarios (e.g. WOTH et al. 2006) and temperature and salinity hindcasts (MEYER et al. 2014) for the North Sea or tide-surge reconstructions for the Baltic Sea (WEIDEMANN 2014). As this list is continuously increasing, an up-to-date-list is maintained the coastDat Website (see section 6 for details).

Both data sets used the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP-NCAR) global reanalysis (KALNAY et al. 1996) in combination with spectral nudging (VON STORCH et al. 2000) to first drive a regional atmosphere model (Tab. 1) for an area covering most of Europe and the adjacent seas. For coastDat-1, the regional atmosphere model REMO (JACOB and PODZUN 1997; FESER et al. 2001) at a spatial resolution of approximately 50 km x 50 km was used to hindcast the period 1948-2007. For coastDat-2, this model was replaced by the COSMO model in CLimate Mode (COSMO-CLM) version 4.8_clm_11 (ROCKEL et al. 2008; BALDAUF et al. 2011; STEPPELER et al. 2003). Compared to REMO, the COSMO model is a non-hydrostatic operational weather prediction model that is developed and applied by a number of national weather services affiliated in the COnsortium for SMall-scale MOdeling (COSMO). The climate mode of this model is developed and applied by the Climate Limited-area Modelling Community (http://www.clm-community.eu). For coastDat-2, the model was run at a spatial resolution of about 24 km x 24 km to hindcast the period 1948-2013. For both, coastDat-1 and coastDat-2 full atmosphere model output was stored every hour. While the production of coastDat-1 terminated in 2007, coastDat-2 is continuously extended and updated.

From the atmospheric simulations in coastDat-1 and coastDat-2, near-surface marine wind fields and atmospheric sea level pressure were used to drive high-resolution wave and tide-surge models (Tab. 1). For the waves, changes in the modelling system from coastDat-1 to coastDat-2 are minor. In both cases the most recent release of the wave model WAM at the time when production started was used. In both cases, the model was run in a nested mode with a coarse grid (approximately 50 km x 50 km) covering most of the Northeast Atlantic and a fine grid (about 5.5 km x 5.5 km) covering the North Sea south of 56N in coastDat-1 and the entire North Sea in coastDat-2. Apart from some technical modifications such as grid restructuring or introducing parallelized code, depth induced wave breaking was introduced in coastDat-2, limiting the wave heights in extreme shallow waters that were sometimes reported too high in coastDat-1. For both, coastDat-1 and coastDat-2 full wave model output was stored every hour. While the production of coastDat-1 terminated in 2007, coastDat-2 is continuously extended and updated.

For tide-surges in coastDat-1 a 2D version of TELEMAC (HERVOUET and HAREN 1996) was used. The model was run on an unstructured grid with typical spatial resolutions of about 5 km in the open North Sea increasing up to about 100 m near the coasts. In coastDat-2, the model was replaced by a 2D version of TRIM-NP (KAPITZA 2008), a nested non-hydrostatic shelf sea model with spatial resolutions increasing from 12.8 km x 12.8 km in the North Atlantic to 1.6 km x 1.6 km in the German Bight. In both cases, the models were forced with amplitudes and phases from a global tidal data set (LYARD et al. 2006). While in coastDat-1 external surges were accounted for by assimilating tide-surge data from Aberdeen, they were explicitly accounted for in coastDat-2 by using boundaries from a coarse grid simulation covering the Northeast Atlantic. For both, coastDat-1 and coastDat-2 full tide-surge model output was stored every hour. While the production of coastDat-1 terminated in 2002, coastDat-2 is continuously extended and updated.

Table 1: Comparison of set-ups and hindcast periods for coastDat-1 and coastDat-2.

Hindcast period	Model (Model Reference; Set-up reference)	Model area	Grid distance	Forcing data
		coastDat-1		
1948-2007	REMO (JACOB and PODZUN 1997; FESER et al. 2001)	Western Europe; Adjacent seas	50 x 50 km	NCEP/NCAR reanalysis
1948-2007	WAM (WAMDI 1988; WEISSE and GÜNTHER 2007)	Northeast Atlantic; North Sea south of 56N	50 x 50 km 5.5 x 5.5 km	Near-surface winds from REMO
1958-2002	TELEMAC2D (HERVOUET and HAREN 1996; WEISSE and PLUESS 2006)	North Sea	Unstructured grid from approx. 5 km to 100 m	Near-surface wind and pressure from REMO
		coastDat-2		
1948-2013	COSMO-CLM (ROCKEL et al. 2008; GEYER 2014)	Europe; Adjacent seas	24 x 24 km	NCEP/NCAR reanalysis
1948-2013	WAM (WAMDI 1988)	Northeast Atlantic; North Sea	50 x 50 km 5.5 x 5.5 km	Near-surface winds from COSMO-CLM
1948-2013	TRIM-NP (KAPITZA 2008)	Northeast Atlantic; North Sea	12.8 x 12.8 km 6.4 x 6.4 km 3.2 x 3.2 km 1.6 x 1.6 km	Near-surface wind and pressure from COSMO-CLM

4 Validation

Validation of wind, tide-surge and waves from coastDat-1 are comprehensively described in the peer-reviewed literature. WEISSE et al. (2005) compared wind speed percentiles and storm counts derived from North Sea station data with data obtained from coastDat-1 and generally found a good agreement for both, average conditions and variability. Similar results for tide-surges and wind waves are inferred and described in WEISSE and PLUESS (2006) and WEISSE and GÜNTHER (2007). In particular WEISSE and PLUESS (2006) showed that high water levels and surges are reasonably reproduced while a tendency to overestimate the lowest water levels was reported. WEISSE and GÜNTHER (2007) in general demonstrated a good agreement between observed and modelled wave parameters but found the highest waves to be somewhat overestimated in very shallow areas where bathymetry effects could not adequately be resolved by the model, a finding also confirmed in GASLIKOVA and WEISSE (2006). Both WEISSE and PLUESS (2006) and

WEISSE and GÜNTHER (2007) found the interannual and decadal variability to be reasonably reproduced within coastDat-1. Using both, in-situ wind speed measurements from a series of buoys and wind speeds derived from different satellite products WINTERFELDT et al. (2011, 2010) and WINTERFELDT and WEISSE (2009) assessed the added value of coastDat-1 compared to the driving global NCEP/NCAR reanalysis and found that wind speeds from coastDat-1 are improved, in particular in coastal areas and along coastlines with complex orography.

Since data from coastDat-2 are relatively new, less comprehensive results for validation are available so far. Validation of the atmospheric hindcast is described in GEYER (2014) focusing mostly on the validation of near-surface temperatures and precipitation. For near-surface wind speeds GEYER (2014) compared results from coastDat-2 with observations from two buoys confirming the good offshore quality of coastDat-2 wind fields and the findings of WINTERFELDT et al. (2011) regarding the added value of coastDat.

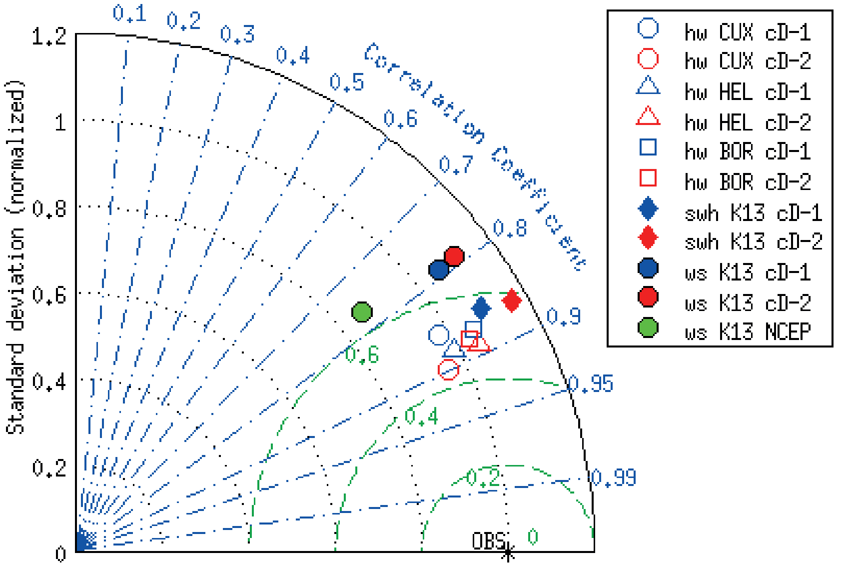

Figure 1: Taylor diagram for wind speed (filled circles) and significant wave height (filled diamonds) at platform K13 as well as for high water levels at Cuxhaven (open circles), Helgoland (open triangles) and Borkum (open squares) for 2000-2002 comparing results from coastDat-1 (blue) and coastDat-2 (red) with observations. For wind speed, also a comparison with the driving global NCEP reanalysis is shown (green). The black star denotes the location of a data set that would perfectly match observations.

Fig. 1 shows some additional validation of wind speed, significant wave heights and tide-surges from coastDat-2. The so-called Taylor diagram shows a comparison of validational statistics between modelled and measured data in terms of correlation (blue lines), centered root mean square error (green lines) and standard deviation (black lines). The latter two are normalized by the standard deviation of the corresponding observational datasets. In general, correlations between hindcast and modelled data vary between about 0.8 for wind speeds and 0.9 for high water levels for both, coastDat-1 and coastDat-2.

Centered root mean square errors range from about 0.4 for tide-surges to 0.6 for wave heights and they are somewhat larger for wind speeds. For high water levels, the standard deviation of the modelled data is close to the observed values, while for wave height and wind speed it appears to be somewhat larger with a tendency towards higher values in coastDat-2. Generally, however, both versions of coastDat are hardly distinguishable in the diagram indicating comparable qualities. The added value of the coastDat approach is further illustrated by a comparison with wind speeds derived directly from the driving global NCEP reanalysis which show too small variability compared to observations.

5 Applications

Being available for more than 15 years, coastDat was used in a large variety of scientific and more practically oriented applications. While quite different in detail, all applications require long, consistent and mostly homogeneous time series.

A substantial fraction of studies is related to long-term changes in marine environmental conditions. For example, WEISSE et al. (2005) studied the variability and long-term trends in storm activity over the Northeast Atlantic and Northern Europe. Similarly, changes in the frequency of polar lows (ZAHN et al. 2008) or tropical cyclones (BARCIKOWSKA et al. 2012) were studied. Changes and variability in storm surge and wind wave climate were addressed, for example, in WEISSE and PLUESS (2006), GASLIKOVA and WEISSE (2006), or WEISSE and GÜNTHER (2007) while MEYER et al. (2011) studied thermodynamic variability and change. Future changes in storm surge and wind wave climate were considered, for example, in WOTH et al. (2006) and GRABEMANN and WEISSE (2008).

The coastDat data set was also used extensively to investigate methodical aspects of the approach. For example, the review provided by FESER et al. (2011) summarizes the findings from a number of studies analysing the added value of the dynamical downscaling. Moreover, KRUEGER and VON STORCH (2011, 2012) used the data base to systematically investigate the informational content of proxy based indicators for storm activity and FESER and VON STORCH (2008) systematically assessed the performance of the spectral nudging approach for the case of typhoons in Southeast Asia.

There are also some studies dealing with different aspects of risk assessment. For example, CHRASTANSKY and CALLIES (2009) coupled a Lagrangeian transport and an oil chemistry module with coastDat. By assuming a constant frequency of oil releases, a large number of simulations (hypothetical oil spills) at different locations was initialized with constant time lags (28 h) between them. Subdividing the German North Sea coast into a couple of receptor regions, results provided a proper description of both the mean risk exposure of different coastal areas and corresponding variability. CHRASTANSKY et al. (2009) were successful in using these data for a more in-depth interpretation of monitoring data. CHRASTANSKY and CALLIES (2009) summarized the results in terms of probabilistic relationships that describe spatial dependences and sensitivities between parameters addressed in the study. Coupling storm surges from coastDat with a loss model, GASLIKOVA et al. (2011) investigated future storm surge impacts on insurable losses for the North Sea region. Superimposing different mean sea level changes GASLIKOVA et al. (2011) found a nonlinear response at the country level, as the future storm surge changes were found to be higher for Germany and Denmark emphasizing the necessity to assess the socio-economic impacts of coastal flooding by combining expected sea level rise with storm surge projections.

Data from coastDat were also used for addressing questions related to the use of renewable marine energy. For example, WIESE (2008) used data from coastDat to simulate the impacts of offshore wind production on the national grid for a scenario in which all planned offshore wind farms in the German exclusive economic zone in the North Sea are fully operational. MARX (2010) analyzed long-term variability of the wave energy potential in the North Sea and the report by BÖMER et al. (2012) contains a description of the theoretical potential from various sources based on coastDat.

Data from coastDat have been used extensively for example for designing, planning and installation of offshore wind farms. Return periods of extreme wind speed, surge and wave heights are used by a variety of users involved in the design and construction of offshore wind parks. Moreover, planning of installation and maintenance requires the estimation of probabilities of fair weather windows; that is, for example the probability of an extended period with wave heights below a given threshold to enable installation and/or maintenance. Data from coastDat were frequently used in such cases as observational data are too often too short to derive reliable statistics. Other examples comprise the use in naval architecture or coastal protection and adaptation. For a more detailed description we refer to the summary provided in WEISSE et al. (2009).

6 Accessing coastDat

The unique entry point for accessing coastDat data is the central coastDat webpage http://www.coastdat.de from which all data sets in coastDat-1 and coastDat-2 are locatable. For some of the more frequently used and requested data online access was realized that can be reached from the central coastDat webpage. Physically these data are stored at the World Data Center for Climate (WDCC) in Hamburg and the online access is generally realized via their CERA data interface. Each of the data sets was assigned with a unique doi simplifying referencing and identification of data sets. Fig. 2 shows an example of the usage of the online data access by external users. It illustrates that the access is increasingly used and that, in terms of volume and counts, coastDat-1 and coastDat-2 in total are among the top products downloaded from the WDCC.

Additionally, an interface allowing for a visualisation of the gridded model data is available at http://vis.coastdat.de. Initially, parameters such as wind speed, significant wave height, currents and water levels were introduced at hourly resolution so that visualization or animation of extreme events such as storms or storm surges is possible. Simple statistics such as monthly maximum wind speed or seasonal cycles are also available.

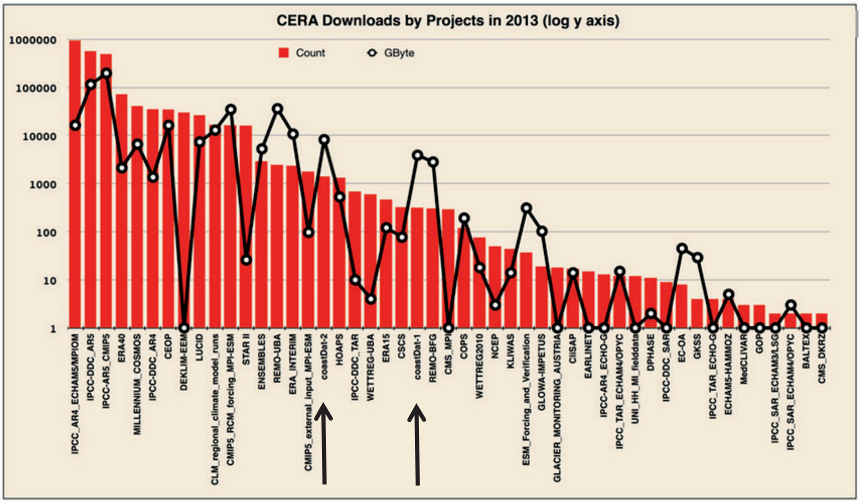

Figure 2: Downloads in 2013 from major products and data bases available from the CERA data base at the World Data Center for Climate.

7 Summary

The coastDat data base, its development and validation together with a brief summary of recent uses were briefly described. Data from coastDat were successfully used for both, research and more practically oriented questions sharing similar data needs. Both require long, consistent and homogeneous data sets to derive statistics such as the mean, the variability or the extremes of marine environmental conditions and their long-term changes. Frequently such data are unavailable and the approach described here provides one possibility to address such issues.

The need and the success of both, the approach and data base derived are illustrated by the large number and variety of users applying coastDat for their own research or practical questions. As of mid-2014, there are presently about 80 external registered users with about 45 % of them coming from the industrial sector while about 40 % are from academic and 15 % from authorities. Added values derived are manifold, ranging from assessments of long-term changes to improvements in ship designs, risk assessments, or planning of logistics for offshore wind farms.

Climate information plays a crucial role for many purposes and the dissemination of climate information to the public or a specific user is often referred to as climate services (http://www.wmo.int/pages/themes/climate/climate_services.php – last accessed: 23.05.2014). Implicitly such services are associated with atmospheric parameters such as temperature or precipitation from scenarios of future developments in the course of anthropogenic climate change. Related parameters such as storm surges or wind waves as well as recent climate and climate variability traditionally receive less attention. Based on our experiences and on feedbacks from users it is concluded that hindcasts of past decades of years and derived products such as waves or surges are just as important. While scenarios are mostly important for sectors planning for long time horizons (e.g. coastal protection, policy regulations), hindcasts are more often requested from sectors planning for shorter periods or operating in data sparse regions (e.g. offshore wind, naval architecture). So far the latter is frequently unaccounted for from climate service perspectives and we proposed that their value may be substantially enhanced taking shorter time scales and natural climate variability into account.

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