KNMI-HYDRA project

Phase report 13

Analysis of wind fields for wind climate assessment of the Netherlands

KNMI, May 2003
Analysis of Wind Fields for Wind Climate Assessment of the Netherlands

A Literature Survey

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June, 2002
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1 Introduction

The Institute for Inland Water Management and Waste Water Treatment (RIZA) and National Institute for Coastal and Marine Management (RIKZ) do risk analyses for the coastline and the inland waterways respectively. At the moment both institutes apply a method for storm surge calculations, in which main input data consist of statistics of wind speed and direction at several locations. An important assumption made is that during an exceptional storm event a threshold for the wind speed is exceeded at all stations at the same time, while the wind direction is uniform. These assumptions are not in agreement with the real situation during a storm event. Therefore, a method to derive statistics for wind fields has to be developed, which cannot be easily derived from point statistics. Besides the extreme statistics also the spatial and temporal development of a storm need to be analysed.

This report explores possibilities of analysing wind fields for the region of the North Sea with adjacent countries; especially we are interested in the wind climate of the Netherlands. The applicable data in the methods can be observational data of measurement sites (point measurements) or re-analysis data of weather prediction models (parameter fields). Both data sets contain information about long-term features (e.g. NAO index) as well as short-term features (e.g. depressions). To reduce the amount of data and to identify statistical relations between large and small-scale features statistical methods are available such as Empirical Orthogonal Functions (EOF) analysis. Besides EOF there are other statistical techniques in the literature described, which may be useful and need to be considered, such as Teleconnections, Empirical Orthogonal Teleconnections (EOT) and Canonical Correlation Analysis (CCA). Once statistical relations are found, these results can be implemented in a model to generate wind fields. Different approaches of wind field modelling are described in the literature, such as parametric and numerical models.

In the following chapters of the report different methods are explained together with their advantages and disadvantages. Some parts of the report are quite theoretical and may be difficult to understand. In chapter 2, the present approach of wind fields applied at RIKZ and RIZA is explained and discussed. In chapter 3, the data sets of station observations and re-analyses are described. In chapter 4, the application opportunities and the theory behind statistical techniques for analysing wind fields are examined. In chapter 5, wind field models based on dynamical and/or statistical relations are discussed. In chapter 6, conclusions and recommendation are given. The distinction between chapter 4 and 5 is rather arbitrary.
2 Current wind field methods

Information about the statistics of wind fields is of great importance for modelling water levels and waves in lakes and along the coast of the Netherlands. Both the institutes RIZA and RIKZ use a simplified wind field during a storm event as input data for water level and wave models for different regions in the Netherlands. In the derivation and the application of the wind field are some dissimilarities between the institutes, because the regions of interest differ. Main interest of RIZA is the region of inland waters: the IJssel Lake and the rivers (freshwater), while RIKZ is interested in the coastline, the tidal flats of the Wadden Sea and the estuaries of province Zeeland (saltwater).

For modelling the water level and waves, RIZA uses the statistical distribution of the mean water level, wind speed and direction over the region of interest. Together they give a rather complex interaction, because the three are not independent of each other. For wind speed, measurements that cover a period of about 30 years used for extrapolation to extreme wind speeds. In general, the data of the meteorological station at Schiphol is used for statistical analysis. RIZA transfers the wind speed with frequency of, i.e., once in 4000 year from the station Schiphol to other locations around e.g. the IJssel Lake. The resulting data at these locations are spatially interpolated to a wind field over the lake itself. Then they assume that during the storm event the wind direction is uniform over the region of interest. For a depression with a western wind, the wind direction is assumed to be veering before the maximum wind speed is achieved. For an eastern storm, the wind direction is constant during the storm event. The duration for building up a storm event, the time between the beginning of the storm and the moment the maximum in wind speed is reached, is set to 9 hours without any flexibility. The maximum wind speed is achieved at all locations at the same time. All together it is a very simplified reproduction of the real situation.

Also to RIKZ the wind field is of major importance, especially for the Wadden Sea and Zeeland. For the Wadden Sea the extreme wind field is derived from statistical data of surrounding stations. The wind field on the North Sea is determined from stations offshore and those along the coastline of the Netherlands. This data is spatially interpolated to a wind field located at sea, which causes a wave field at sea. The resulting wind and wave field are moved unchanged towards the coast and then the wave and water level along the coast are modelled. RIKZ applies the same assumptions with regard to variation of wind field in time and space, so a uniform wind field over the region. Verkaik (2000) concluded that the assumptions of a uniform wind field with no variation in time and space are valid on locale scale (about 50 km), but this assumption fails on larger scales. An extreme situation at one station does not have to occur simultaneously with the same wind speed and direction at all surrounding stations. Nowadays, both institutes develop more advanced wave field models, in which changing wind fields in time are possible input data.

Advantages of the present methods of wind field approach are that the approach is simple and therefore easy to apply and to understand. Because only a few parameters are regarded, the interaction between these parameters is rather simple. As soon as more parameters, such as the statistical distribution of the duration of a storm, have to be taken into account, the complexity of the model increases quickly. An advantage of the present models is that they result in quite reasonable wind fields and realistic water levels and waves. Disadvantages of the present methods are that the description of the wind field and the development in time is not realistic with regard to the wind field accompanying a real depression. The used wind direction and wind speed are assumed uniform over the region of interest. The wind field over the North Sea and Wadden Sea is constructed from the station data on land, which includes no information about the wind field itself over the water.

This study is focussed on the possibilities in literature about the statistical analysis and modelling techniques of wind fields that consist of gridded station data. Of special interest is the analysis of the variation of actual wind fields in space and time, because this aspect is not taken into account in the current approach. The purpose of a new method has to be an increase of the physical exactness of the wind fields. In the new model it is necessary to apply a fine grid resolution over the region of the North Sea and the Netherlands to simulate also local effects.
3 Data sets

Two kinds of meteorological data sets are available to analyse. The first type of data sets is observations of meteorological parameters at measurement stations in the region of interest. These measurements at several locations can be gridded on an irregular grid. The second data set type are results of meteorological numerical models, which produce time series of meteorological parameters on a regular grid. Both types of data and their availability are discussed below shortly.

3.1 Station observations

At about 50 places in the Netherlands wind speed, direction and other meteorological parameters are measured continuously. The length of the corrected wind data set varies per station from 2 to 50 successive years (Verkaik, 2001a). At some of the places also data of soundings is available with information about wind as function of height. Also for other countries measured data is available at the KNMI or at ECMWF, but the intensity and the lengths of these data sets are not known. To interpret wind data one has to put in mind that the methodology of registration and instrumentation has changed a lot in the last 50 years, which implies inhomogeneities in the data sets. Before 1996, wind speed was reported in knots per hour and afterwards in meters per second. Furthermore, wind measurements are directly influenced by the local environment of the measurement site, which has changed a lot in time (Verkaik, 2001a). The potential wind and macrowind computed for wind measurement stations in the Netherlands are corrected for the main influences. These measurements can form a basis for the analysis besides the actual measurements.

To minimise problems of inhomogeneities and inconsistencies, geostrophic wind derived from air-pressure readings at sea level may be taken as a proxy for the real wind (Schmidt and Von Storch, 1993). Sea level air-pressure readings are more robust to small station shifts in location and elevation, and to instrument changes. The lengths of air-pressure records are comparable or longer than wind records. Nevertheless Schmith et al. (1998) and Verkaik (2001b) say that ageostrophic effects might be important on local scales (smaller than 500 km), so geostrophic wind may not be a proxy for the real wind. So investigating geostrophic wind climate avoids inhomogeneity problems of direct wind speed observations, but is not representative for the real measured wind climate. Because air-pressure measurements give only information about the geostrophic wind and about not the additional ageostrophic effects, these measurements are not interesting to use for RIKZ and RIZA.

Advantages of using direct wind measurements are that the data are actually measured and not derived from another meteorological parameter such as air-pressure. So the data set does not consist of output data of meteorological models, which quality depends on e.g. grid size, parameterisations used, etc. Another advantage is the rather dense measurement network over the Netherlands with average distance between stations of about 30 km. Disadvantages of observational wind data are that changes in and the local environment itself influence wind measurements in time. Another disadvantage is that the measurement sites are mainly concentrated on land. There are hardly any data available over sea and especially not for a long time, while the North Sea is a region of our interest.

3.2 Model data

The European Centre for Medium-Range Weather Forecasts (ECMWF) produces since 1979 operational medium-range weather forecasts for every day. During the years a lot of procedures and parameterisations in the model have been changed, which cause perceived climate jumps associated with these changes. Therefore, ECMWF used the most recent operational model to reproduce hindcasts of meteorological and oceanographic data for a period from 1979 to 1994 (the ERA-15 dataset). At this moment a project for reproducing 40 years is started at ECMWF, which should be finished half 2003. In re-analyses, observations of the state of the atmosphere like satellite images and station measurements are taken into account. These observations are mostly not included in the
original operational analyses. The resolution of the ECMWF-model is about 100 km in horizontal direction and with 31 vertical levels. Bosveld et al. (1999) found for Cabauw that the 24-hour average of 10-meter wind speeds of ERA-15 is generally overestimated. They have not examined how ERA-15 performs on hourly basis. Similar reruns are done by NCEP-NCAR with the American forecasting model for a period of nearly 50 years.

For analysing the locale climate and especially the storm climate, the re-analysis data from ECMWF is used a lot, because the data is generated with the same procedures and model performance over the whole simulated period (e.g. Fuentes and Heimann, 2000). Studies of before 1996 or for longer time series are mostly done with the available ECMWF analyses including the inconsistencies of changing parameterisations (e.g. Kidson and Thompson, 1998; Beersma, 1994). Advantages of using re-analyses are that the used grid covers also the North Sea, which means an increase of the number of data points over sea. Also more data is available in vertical direction besides data of soundings. Disadvantages are that the data represent a spatial average value for a certain domain (100x100km), which perhaps means a decrease in the number of data points over land compared to the availability of observational data. Because of the limited grid resolution not more than six domains cover the whole North Sea. The horizontal resolution of about 100 km may be too coarse to simulate local storm events with high wind speeds. For the assessment of the local wind climate in the Netherlands, the hindcasts can be used for generating data over the North Sea and adjacent countries over a certain period. For data on a coarser scale than 100 km² these reanalysis can not be used.
4 Statistical analysis techniques

Significant spatial and temporal correlations between temporal fluctuations in meteorological parameters are of considerable interest, therefore analyse techniques are required for interpretation of observed and simulated data sets. These correlations can be studied with use of different statistical techniques. In the framework of this report we discuss the following techniques: teleconnections, Empirical Orthogonal Functions (EOF), Empirical Orthogonal Teleconnections (EOT) and Canonical Correlation Analysis (CCA). The explanation and discussion is rather theoretical at some parts.

4.1 Teleconnections

The teleconnections technique is one of the most elementary techniques to identify contemporaneous correlations between e.g. pressure or wind fields at widely separated points. As a result patterns or teleconnections arise that show the correlation between points. A review of existing literature on teleconnections reveals the existence of large-scale features. For the region of the North Atlantic, the North Atlantic Oscillation (NAO) is typically regarded as the primary regional teleconnection pattern (e.g. Wallace and Gutzler, 1981). This teleconnection pattern is found in monthly time averages over the North Atlantic (Rogers, 1997 and Lau, 1988). Use of real time hourly data as input for the teleconnection technique is rather rare. In most of the literature monthly and yearly average data are used as input for the teleconnection technique. The first step in the teleconnection analysis is computing a correlation matrix, which consists of the correlation coefficients $r_{ij}$ between the time series of the variable of interest at any selected grid point i and those at every other grid point j. Teleconnection patterns represent how each grid point is connected with its neighbours, which makes this technique suitable for examining direct physical relations. Testing of the statistical significance of the teleconnections is difficult. A popular method to check the reproducibility of the patterns is with subsets of the original data set. Wallace and Gutzler (1981) found that features with $|r_{ij}| > 0.75$ tend to be highly reproducible in an independent data set or in subsets of the original data set. The correlation coefficients in the teleconnection technique give more stable results for anomaly time series of fields (Von Storch and Navarra, 1995).

Strong points of teleconnection maps are that there is no a priori assumption needed on the shape of the patterns to be found (Von Storch and Navarra, 1995) and that the results are directly based on the measurements itself. The resulting patterns do not vary much if changes are applied to the spatial domain and length of time series used. A disadvantage of teleconnection technique is that the statistical significance of teleconnection patterns is difficult to assess, because of the lack of an a priori basis for postulating the existence of the patterns. Due to the lack of a universally agreement on criteria and procedures for calculation it is difficult to compare the results of separate studies.

4.2 Empirical Orthogonal Functions (EOF)

Principal Component Analysis (PCA) is commonly used for characterising the spatial and temporal variability of physical fields. The technique became popular for analysis of the atmospheric data following by the paper of Lorenz (1956), who called the technique Empirical Orthogonal Functions (EOF) analysis. Both names are commonly used, and refer to the same set of procedures. The terminology in the field of EOF analysis is very confusing. Wilks (1995) organises the most used terms in the field of the EOF analysis. The purpose of EOF is to reduce the data set $\mathbf{X}$ containing a large number of variables to a data set $\mathbf{Y}$ containing fewer new variables, but that represent a large fraction of the variability contained in the original data. The original matrix $\mathbf{X}$ may represent very different sets of data, such as observations at one location, grid point values of a continuous field on a regular or irregular grid, or observations of a parameter at irregular distributed stations (Von Storch and Navarra, 1995). In principle it is also possible to analyse different parameters at different heights, when using normalised data and weight functions. The temporal and spatial variation of the field $\mathbf{Y}$ is
decomposed by EOF analysis into orthogonal spatial patterns so called EOF modes, and into orthogonal temporal patterns so called principal components (PC). Each EOF mode is constant in time domain and uncorrelated over space, while each PC is constant in spatial domain and uncorrelated over time. So the results of EOF analysis are biorthogonal. EOF modes are defined as those patterns, which are most powerful in explaining variance of a field $X$, not showing physical connections or maximum correlation (Cieslikiewicz and Graff, 1996). EOF modes may represent physical modes, which operate independently and with orthogonal patterns (Von Storch and Navarra, 1995). In most real-world cases, however, physical processes are interrelated, so some carefulness to physical interpretation of EOF modes is required.

As example of EOF analysis an ideal dataset is simulated that consists of two mathematical functions that result in a moving sinus-function through the domain in horizontal direction (figure 1a). After applying EOF analysis the results consists of an averaged field (figure 1b), EOF modes (figure 1c) and principal components (figure 1d). The basic assumption comprises two mathematical functions that are equally important, which results in two equally dominant EOF modes. The principal

![Figure 1 Example of input data (a) and results of EOF analysis; b) averaged field; c) EOF mode 1 (black) and 2 (green) in spatial domain; d) principal components 1 (black) and 2 (green) in time domain](image-url)
components are time series describing the time evolution of the corresponding EOF modes. Because of the lack of noise in the dataset and the choice of simple mathematical functions no other than two EOF modes and principal components are detected. Therefore, the results of this example are not representative for real wind data. This means that out of the averaged field and the two EOF modes together with accompanying principal components the original dataset can be constructed when applying the following equation:

\[ W(t) = \bar{W}(t) + \sum_{n} PC_n \cdot EOF\text{mode}_n \]

When analysing a real data set the EOF modes and principal components are sorted in order of importance, so the first PC and EOF mode explains the greatest portion of the variance in the data set. Applying the equation above to the most important EOF modes and principal components gives a dataset similar to the origin, but with less noise in the signal. With choosing too many PCs, much noise is introduced, but with a few PC retained, there is a risk of disregarding valuable information. In meteorology and climatology, EOF analysis is performed for reduction of the original data set (e.g. Von Storch and Reichardt, 1996; Kaas et al., 1996). Description and step-by-step instructions for carrying out PCA in the meteorology and oceanography can be found in Preisendorfer (1988).

Advantages of the use of EOF analysis are that EOF analysis is optimal in representing variance. The technique is a very useful tool to compress data into a reduced dataset with a few variance-wise significant principal components and EOF modes (Von Storch and Navarra, 1995). Most of the noise is filtered out of the dataset by removing less important EOF modes and principal components from the data set. The EOF analysis does not need data available on a regular grid, therefore also observations direct on the sites can be analysed. The software and knowledge of this technique is available at the KNMI and at other institutes. Disadvantages are that EOF needs a data set continuous in time. There is not much information in the literature about the influence of transformations of the spatial and temporal domains. From EOF analyses with the simple dataset it can be concluded that changes of the spatial domains results in totally different EOF modes. The results of EOF analysis and the teleconnection technique are purely statistical, i.e. no physics are included, so the EOF modes do not have per definition a physical meaning. The most prominent EOF mode is not necessary an observed pattern in the atmosphere.

### 4.3 Empirical Orthogonal Teleconnections (EOT)

A main difference between EOF and teleconnections is that the resulting patterns from EOF analysis are orthogonal to each other, while this is not necessary for teleconnections. In an EOF analysis there is no information on the relation between grid points, while this is the basis for teleconnections. On the other hand EOF analysis provide a measure of the relative importance of a pattern yielding the percentage of variance of the fields that can be attributed to that pattern (Von Storch and Navarra, 1995). Van den Dool et al. (2000) introduces Empirical Orthogonal Teleconnections (EOT) as a technique to calculate functions, empirically and orthogonal, without these functions being traditional EOF modes or teleconnection patterns. In many respects EOTs are like one-point correlation or teleconnectivity maps, but with the added property of orthogonality in time or space. The EOT is a stepwise linear regression, where the orthogonality is only in one direction, time or space. One has to pick certain modes (or points first dependent on orthogonal direction), which means that the order of EOTs is free, and that there is a near infinite set of EOTs. The biorthogonality in EOF analysis is more constraining to the output (without any choices preceded), with as result only one set of EOF modes and principal components. The main difference with respect to EOF analysis is that the first resulting time series of the EOT technique has to be time series at one specific observational site rather than a linear combination as in EOF analysis.

Advantages of EOT technique are that in the first mode the results are linked to specific points in space or moments in time. When linked to specific moments in time the EOT modes have undeniable physical reality. The EOT technique is less constrained than the EOF technique and enables the user to pick certain modes or points first; i.e. the order of EOT is free. Disadvantages are one has to choose the orthogonal direction, time or space, without knowing the influence of this
choice. Another disadvantage is that there is no literature on applications and performances of the EOT technique itself, because the technique is introduced lately. More research with different data sets of different regions and with hourly data has to be done to gain more knowledge about possibilities for application of EOT technique.

4.4 Canonical Correlation Analysis (CCA)

Canonical Correlation Analysis (CCA) is a statistical technique that gives the best possible correlations between two different sets of variables. CCA identifies new variables that maximise the interrelationships between the two datasets, in contrast to the patterns describing the internal variability within a single data set identified in EOF analysis (Wilks, 1995). For technical reasons it is useful to “reduce” the two fields of raw data using EOF analysis before subjecting them to a CCA, because both data sets are so internally correlated that only a small number of field values are statistically independent (Thacker, 1995). Separate EOF modes are calculated for each or one of the two fields, and the resulting reduced data sets are used in CCA. This approach is followed by e.g. Kaas et al. (1996) for a statistical hind cast of the wind climatology in the North Atlantic and northwestern European region throughout the 20th century. Von Storch and Reichardt (1996) used CCA for examining correlation between air pressure and water level data for building a regression model. Thorough description and reviews of CCA are given in Preisendorfer (1988) and Wilks (1995).

One of the main advantages of CCA is that it delivers spatial patterns that lend themselves to clear physical interpolation. Zorita and von Storch (1997) showed that two pairs of canonical patterns resulting from CCA might be explained physically. A disadvantage is that the CCA is known to overestimate the correlation between the canonical patterns, so that is mandatory to check the quality of independent data. The main difference between CCA technique and other described techniques is that the first three described techniques are made to reduce the noise in a data set of wind or pressure fields and to find correlations in the data set itself. The CCA technique is not concentrated on the internal correlations in the data sets, but in between data sets.
5 Approaches to wind field modelling

A wind field model is a mathematical model used to describe the wind speed and direction at any site at any time. The accuracy and the efficient wind speed estimation become essential to assess the risk of possible storm. Wind field models can be generally classified into two categories: parametric models and downscaling models. Parametric modelling and three different procedures of downscaling modelling are discussed below. Some of the methods are based upon statistical relations found with one of the techniques considered in chapter 4.

5.1 Parametric models

Parametric models are introduced to approximate numerical solutions by functional forms with use of a few independent parameters to approximate the air pressure or wind field of a real storm. Bijl (1997) and Pan et al. (1999) developed parametric models to simulate pressure fields of storms and hurricanes, respectively. For simulating storms, a pressure field is a function of the storm characteristics and location, which can be described with the parameters: e.g. location of the centre of low pressure, central pressure difference, Coriolis parameter, propagation speed of the depression, radius to maximum winds, etc. Bijl (1997) modelled surge-generating storms in the southern part of the North Sea on the basis of air-pressure fields of the well-known storm of February 1, 1953. On the basis of 3-hourly pressure fields of this storm, parameters are derived. Time histories of nearly all parameters show more or less linear behaviour between the beginning and the end of the storm, so Bijl (1997) assumed that only parameter sets are required for the first and the last pressure field of the storm. Parameters of intermediate pressure fields are approximated by linear interpolation. Bijl (1997) is not clear in the definition of the beginning and the end of a storm. The concept of parametric storms is able to reproduce the pressure field and water level at a certain location during the 1953 storm quite reasonable. Also the results of the parametric model of Pan et al. (1999) agrees reasonably well with the real measured pressure field of hurricanes.

Bijl (1997) generated on basis of this storm event a large set of parametric storms by means of systematic variation of the storm parameters. Not all possible combinations of parameters have equal chances of occurrence, for that reason a probability distribution for each parameter is required. Bijl (1997) approximated this probability distribution with help of exceedance frequencies of wind speed thresholds. He assumed that the probability of extreme surges in this area is highly correlated with the exceedance frequencies of wind speed. A linear relationship is assumed between the latitudinal position of the storm track and the exceedance frequencies. These assumptions are not directly based on statistical analysis or known physical relations. More detailed study is necessary to determine the parameters. At KNMI, HIRLAM with a resolution of 11 and 22 km is in use, which may be useful to analyse and characterise wind fields for determining parameters for a parametric model.

Advantages of parametric modelling are that this procedure can enhance the knowledge about the statistical and physical background of storm events, and that it has better accuracy than analytical models and greater computational efficiency than the numerical models. By using storm indices it is possible to reduce the amount of data used considerably, but to choose correct independent parameters to describe different occurring wind fields is difficult. Another disadvantage is that the parameters to describe a storm are not able to describe all possible appearances of storm events, such as storms with two low-pressure centres. Another disadvantage is that Bijl (1997) and Pan et al. (1999) modelled air-pressure fields and not the real measured wind fields, which are not equal to the geostrophic wind fields derived from the pressure fields (see chapter 3.1).
5.2 Downscaling models

For reproductions of large-scale features of the global circulation, General Circulation Models (GCMs) are developed on continental scale and a time scale of years to decades. Between different GCMs dissimilarities appear even when using the same initial conditions due to the parameterisations that are used. Since GCMs work on global scale they do not have the spatial and temporal resolution that is necessary for a detailed assessment of the regional scale climate. For long-term simulations the spatial resolution of GCMs is limited to about 250 km, while inner cores of intensive storms are very intensive on small scale. Other local details like coastlines are hardly resolved by the finite-size grids. In order to be able to reproduce storms, downscaling methods are developed. Downscaling methods are generally based on a coupling of large-scale and regional scale distributions of meteorological parameters, assuming the existence of a functional relationship between both scales. Downscaling methods can be divided generally in three downscaling approaches (Fuentes and Heimann, 2000):
- statistical-empirical methods
- dynamical or nesting methods
- statistical-dynamical methods

All methods are discussed below.

5.2.1 Statistical-empirical method

The basic idea of the statistical downscaling consists in using observed relationships between the large-scale circulation and the local climate to set up statistical models that could translate anomalies of the large-scale flow into anomalies of some local climate variable (Zorita and von Storch, 1997). There are many statistical schemes found in the literature. A commonly seen approach of statistical modelling is Canonical-Correlation Forecast. As basis, the results of CCA with two sets of random vectors are used to predict future values of parameters at a specified lead-time (Thacker, 1995). Von Storch and Reichardt (1996) formed one vector time series consisting of coefficients of the first 4 EOF modes of monthly air-pressure fields and the other vector time series of several percentiles of intramonthly water levels. Their statistical-empirical model is capable of reproducing past variations of storm-related water levels in Cuxhaven. Kaas et al. (1996) used also CCA as statistical tool to base an empirical model on, but here CCA is used to identify the statistical relationships between the sea level air pressure and the sea surface temperature. In Thacker (1995) also other examples of statistical-empirical schemes that have been used for forecasting seasonal-to-interannual climate are discussed, but the method discussed above is applied mostly for simulations of the past and future climate.

Advantages of statistical-empirical models are that they make direct use of statistical relations in observational data resulting from statistical methods described in chapter 4. The results of statistical modelling are explicitly linked to past climate statistics. The applied methods are relatively simple and have low costs compared with the use of other downscaling methods. A disadvantage of statistical-empirical methods is that the statistical relations usually do not have a physical background. Another disadvantage is the requirement of calibration of the method with observed data.

5.2.2 Dynamical method

Regional dynamical modelling techniques have been applied to simulate local climate with boundary conditions from analyses of observations, or to specify local climate change from forcing by a GCM. A typically regional dynamical model has a grid spacing in the order of 50 km and covers an area with sides of several thousands of km. Examples of dynamical models used at the KNMI are HIRLAM and the finer grid model XHIRLAM (11 km resolution). Regional dynamical models operate sophisticated calculations of sub-grid processes to reproduce the observed atmospheric circulation over the period of interest. Since computational expense is large, the nesting method has been mainly applied to periods of only a few months or a few years. The initial and boundary data applied in dynamical modelling
may differ from model to model. Kidney and Thompson (1998) used ECMWF re-analysis as boundary forcing for the regional model, while others apply results from a GCM. High-resolution regional models achieve improvements on spatial scale, surface topography, land-sea marks and land use description significantly in comparison to GCMs and re-analyses. Only a few studies made a comparison between statistical and dynamical downscaling models. Murphy (1999) evaluated differences in terms of correlation between estimated and observed time series of several parameters. The dynamical and statistical methods used perform with similar skill in downscaling observed monthly mean anomalies. Kidson and Thompson (1998) found that the skill of both techniques generally follows similar patterns of both daily and monthly time scales, suggesting that the results are more dependent on the characteristics of the station than the methods used to forecast them.

Advantages of dynamical methods are that they account explicitly for physical relationships in the climate system and they provide an added value in the spatial distribution of climate parameters on seasonal to annual time scales. Disadvantages are that the computational expense is large, its skill depends heavily on the quality of the models used, as well as the model itself as the GCM or observational dataset. Another disadvantage is that the spatial resolution is limited by the resolution of the regional model used and downscaling of the resolution is limited by the model parameterisations.

5.2.3 Statistical-dynamical method

Statistical-dynamical downscaling links global and regional model simulations through statistics derived from large-scale weather types. In the literature there are different classification schemes for large-scale weather types described such as the synoptic Lamb Weather Types (e.g. Linderson, 2001), Cluster Analysis (e.g. Mengelkamp, 1999), Grosswetterlagen classification (e.g. Zorita and Von Storch, 1999) and the P27- classification (e.g. Buishand and Brandsma, 1996). Buishand and Brandsma (1996) compared the last three classification schemes with respect to the estimation of temperature and rainfall in the Netherlands. They found that the skill of the schemes are comparable, but depend much on the parameters examined. A regional dynamical model is run only once for each weather type. This method is a combination of both statistical-empirical and dynamical modelling. The statistical-dynamic method consists of three steps, which are briefly outlined below and described in more detail by Fuentes and Heimann (2000). The first step is to classify time series of an appropriate parameter into an adequate amount of large-scale weather types. The second step in statistical-dynamical modelling is performing regional numerical simulations for each weather type. The third step is a climatological evaluation of the regional model output, in which the particular simulation results are weighted and statistically evaluated. Fuentes and Heimann (2000) described a certain statistical-dynamical downscaling scheme and compared it in theory to dynamical and statistical-empirical methods. For investigating the climatological wind field over a complex terrain area with low density of measurement sites the statistical-dynamical method has proven to be a suitable tool (Mengelkamp, 1999).

In comparison with dynamical downscaling the computational effort is significantly reduced. In contrast with statistical-empirical method this method does not depend on the availability of long-term observational time series and it does not need to assume that statistical relationships derived for an observed climate are still valid in a changed climate. Disadvantages are that the spatial resolution is limited by the resolution of the regional model used like dynamical modelling. Another shortcoming is the reduction in temporal variability due to the representation of the whole variety of weather phenomena by a limited number of weather types with as consequence that climatological assessments of extreme events cannot be explicitly derived.
6 Conclusions and recommendations

The wave and water level models at RIKZ and RIZA are strongly dependent on the wind field as input variable. At both institutes a simplified approach of wind fields is applied with regard to variation of the wind speed and direction in time and space. When these variations in time and space are described in a more sophisticated way, the wave and water level models might improve qualitatively and quantitatively. In this report several methods that can deal the spatial and temporal variation of wind fields are summarized and discussed.

Literature indicates that data scarcity may limit the possibilities of wind field analyses. The observational network is variable throughout the years, especially above the North Sea. Re-analysis data from the ECMWF and NCEP contain wind at 10-meter and at other model levels, but at a less dense grid than the observational network over land. Together these data sets can form the basis for several statistical techniques to characterise and analyse spatial and temporal variation in wind fields. A case study of EOF analysis with a simplified data set shows that the resulting EOF modes do not have to have affinity with the original data set, but represent the major variance in the data set. So the statistical techniques may result into patterns that are most prominently present in a data set or into a noise-reduced data set that is easier to handle. The results of statistical analysis techniques can be applied in wind field models that give information about the development of storms and their frequency. The sensitivity of these techniques to the length of the data set and the domain is not described, so its quality for identifying patterns over short periods is debatable.

The differences between the methods of wind field modelling are large in the used physics, statistics, computational costs, etc. For assessing the wind climate, also small-scale features need to be simulated, which requires a high grid resolution. Dynamical models with a high-resolution grid require long computational time to solve all parameterisations for all grid points. Therefore dynamical or regional models may be useful for gaining more information on the physics and characteristics of certain cases that occurred in the past. However they are too time-consuming to model long time series. For this purpose a parametric models are better suited to generate a set of storms based on a number of parameters. Every storm has chances of occurrence according a probability distribution of the parameters.

From the present literature study it follows that building a parametric model opens the most satisfactory possibilities towards the demands of RIKZ and RIZA. A parametric model will be able to simulate spatial and temporal variation of wind fields more correctly then the present approach at both institutes. Such a parametric model does not require a lot of computational time and complicated parameterisations in comparison to a dynamical model. The statistical distribution of the parameters in a parametric model may be derived from observations, and fine scale dynamical models. Since wind fields are of interest it is advisable to use wind data as basis for the model, because in air-pressure data a lot of information on the real wind is lost. At locations where no wind observations are available the data set can be completed with re-analysis data. Possibly, the results of statistical analysis techniques can be applied to reduce the data set to this data, which is of importance to storms. In literature studied this far, no information is found about the quality to analyse extreme situations, like storms, statistically. Therefore the recommendations are rather arbitrary and have to be interpreted as first set up for analysing wind fields for a wind climate assessment.
References

Beersma, J.J., 1994: Storm activity over the North Sea and the Netherlands in two climate models compared with observations, scientific report, WR 94-02, KNMI, the Netherlands


Bijl, W., 1997: Impact of wind climate change on the surge in the southern North Sea, Climate Research, 8, p 45-59

Bosveld, F.C., van Ulden, A., and Beljaars, A.C.M., 1999: A comparison of ECMWF Re-Analysis data with fluxes and profiles observed in Cabauw, ECMWF, Reading, UK

Buishand, T.A., and Brandsma, T., 1996: Comparison of circulation classification schemes for predicting temperature and precipitation in the Netherlands, Memorandum KNMI, WKS-96-01, internal document KNMI


Cieslikiewicz, W., and Graff, J., 1996: Sea state parameterisation using empirical orthogonal functions, Coastal Engineering, 1, 703-716


Lau, N.C., 1988: Variability of the observed midlatitude storm tracks in relation to low-frequency changes in the circulation pattern, Journal of Atmospheric Sciences, 45, 2718-2743

Lorenz, E.N., 1956: Empirical orthogonal functions and statistical weather prediction, Scientific Report No. 1, Statistical Forecasting Project, Department of Meteorology, MIT, 49 pp

Preisendorfer, R.W., 1988: Principal component analysis in meteorology and oceanography, Developments in Atmospheric Science, 17, Elsevier, Amsterdam


Schmith, T., Kaas, E., and Li, T.-S., 1998: Northeast Atlantic storminess re-analysed: no trend during past 100 year period, Climate Dynamics, 14, 529-536

Thacker, W.C., 1995: Statistical modelling for numerical modellers, GKSS 95-E-4, GKSS-Forschungszentrum Geesthacht, Germany

Trenberth, K.E., and Owen, T.W., 1999: Workshop on indices and indicators for climate extremes, Asheville, NC, USA, 3-6 June 1997, Breakout group A: Storms, Climatic Change, 42, 9-21

Verkaik, J.W., 2000: Windmodellering in het KNMI-HYDRA project Opties en knelpunten, KNMI Klimatologische Dienst, internal report, in Dutch

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Verkaik, J.W., 2001a: *Documentatie windmetingen in Nederland*, KNMI Klimatologische Dienst, internal report, in Dutch

Verkaik, J.W., 2001b: *A method for the geographical interpolation of wind speed over heterogeneous terrain*, KNMI Klimatologische Dienst, internal report,


Von Storch, H, and Reichardt, H., 1996: *A scenario of storm surge statistics for the German Bight at the expected time of doubled atmospheric carbon dioxide concentration*, GKSS-Forschungszentrum Geesthacht, Germany, GKSS 96-E-18


