NOAH
North Sea Observation and Assessment of Habitats

2006 North Sea Sand Ripple Formation by Waves

GENERAL OVERVIEW

Dataset name:
Occurrence of wave-induced active sand ripples at the sea floor of the North Sea for the year 2006

Project:
North Sea – Observation and Assessment of Habitats (NOAH)

Co-Principal Investigator:
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DATASET SPECIFICATIONS

Dataset Parameter(s) and supplied Unit(s):
Height Wave Ripples [m]

Date(s) available:
2006 (Map View, yearly Statistic), 1984 – 2015 Model Tool (time resolution: hourly)

Validated:	**Version Date:**
See Notes and Limitations	*14.03.2007*

Current State:
Updates expected

Format:
netCDF, Vector (Esri FGDB), CSV

Citation:

Gaslikova, L., I. Grabemann, N. Groll (2013). „Changes in North Sea storm surge conditions for four transient future climate realizations". Nat. Hazards 66:1501–1518
https://doi.org/10.1007/s11069-012-0279-1

Feser, F., R. Weisse, and H. von Storch, 2001: Multi-decadal atmospheric modeling for Europe yields multi-purpose data. Eos Transactions, 82, 305,310

Kapitza H. and D. Eppel (2000)." Simulating morphodynamical processes on a parallel system". In: Spaulding ML and Butler HL (eds) Estuarine and Coastal Modelling, Proceedings of the sixth International Conference. New Orleans, Louisiana, USA, November 3-5, 1999

Marten, K.V., (2010). " Field Observation and Modelling of Near-shore Sediment Transport Processes". Ph.D. Thesis. School of Ocean Sciences, Bangor University, UK.

Pätsch, J., H. Burchard, C. Dieterich, U. Gräwe, M. Gröger, M. Mathis, H. Kapitza, M. Bersch, A. Moll, T. Pohlmann, J. Su, H. T. M. Ho-Hagemann, A. Schulz, A. Elizalde and C. Eden (2017). "An evaluation of the North Sea circulation in global and regional models relevant for ecosystem simulations." Ocean Modelling 116: 70-95.

Soulsby, R., 1997. Dynamics of Marine Sands: A Manual for Practical Applications. Thomas Telford Ltd, London.

Soulsby, R.L., Whitehouse, R.J.S., (2005a). "Prediction of Ripple Properties in Shelf Seas. Mark 1 Predictor"., Report TR150, HR Wallingford, Wallingford, UK. http://eprints.hrwallingford.co.uk/280/ *accessed February 2012).*

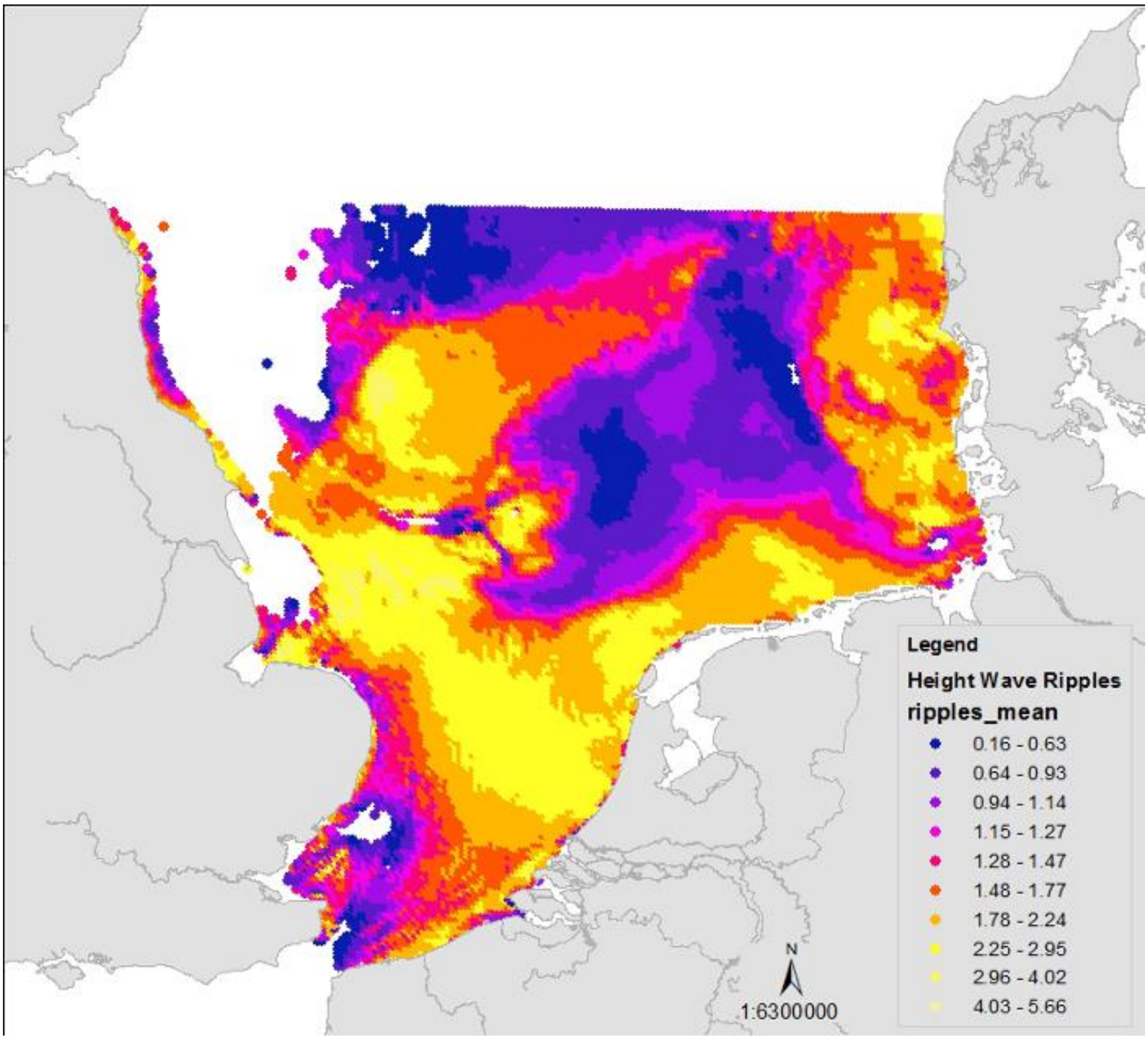
Soulsby, R.L., Whitehouse, R.J.S., (2005b). "Prediction of Ripple Properties in Shelf Seas. Mark 2 Predictor"., Report TR154, HR Wallingford, Wallingford, UK. http://eprints.hrwallingford.co.uk/281/ *accessed February 2012).*

Weisse, R., and H. Günther (2007), Wave climate and long-term changes for the Southern North Sea obtained from a high-resolution hindcast 1958–2002, Ocean Dyn., 57, 161–172, https://doi.org/10.1007/s10236-006-0094-x.

DATASET DETAILS

Abstract

The map shows the spatial distribution of average height of "active wave ripples" during 2006 in the southern North Sea.
Hydrodynamic model output was used to map the average height of wave-induced active sand ripples at the sea floor for the year 2006. Wave ripples are characterized by straight to bifurcating crestlines (aligned parallel to the crests of the water surface waves), a peaked crest and a broad trough, and their profile is rather symmetrical.
Formation and persistence of active ripples have a meaning for advective flow within the sediment and thus the ventilation of pore water with oxygen.
The general tendency of ripple height in the plot is: in deep water the ripple height is smaller than in shallow water.



Wave ripples are called "active" if (a) wave action generates sediment transport at the sea floor (i.e. if the wave bed shear stress τW is above the threshold of sediment motion), and if (b) the bed shear stress τW produced by waves is somewhat above the bed shear stress τC produced by currents. The prediction of wave ripple heights is done by the model of Soulsby and Whitehouse (2005), supplemented by Marten (2010).
Viewed from above, wave ripples form a regular pattern of almost parallel crestlines. The height of wave ripples, being in equilibrium with the wave regime, depends primarily on their length. Roughly, the wave ripple height is between 10 % and 20 % of the wave ripple length.
Wave ripples only form in sand with grain-sizes between ≈ 60 µm and ≈ 800 µm. The length of wave ripples depends both on the median grain-size and the excursion of water motion above the bed. If wave induced near-bed water motion is above a certain limit, wave ripples are washed out and the sea floor is flat.
The general tendency of ripple height in the plot is: in deep water the ripple height is smaller than in shallow water. The reason for this tendency is two-fold. First, the sediment in deep water is (in most cases) finer than in shallow water. The finer the sediment, the smaller is the ripple length and the smaller is thus the ripple height. Second, in deep water, the amplitude of the near-bed oscillatory water motion is small. This produces wave ripples with a small length and thus with a small height.
In the area off Humber the median grain-size is above 800 µm, so ripples are not formed there. In the deep water off Yorkshire and North East England, wave generated near-bed water motion was (during all 2006) too weak for ripple development.

Acquisition and Processing Description:

Acquisition:

The requirements for wave-generated ripple prediction are the availability of: (1) the bed shear stresses generated by waves and currents (including their directions) and (2) the median grain-size of bottom sediments.

The bed shear stress τ_W produced by waves is calculated from results of the WAM model while the bed shear stress τ_C produced by currents is calculated from results of the TRIM model. Both models are used for long-term computation runs at the Institute of Coastal Research, HZG Geesthacht. Both τ_C and τ_W are provided as gridded, area-covering data with a time interval of one hour.

The basis for the median grain-size distribution consists of more than 50,000 individual samples. Only samples from the sediment surface (maximum sub-bottom depth 10 cm) were taken into account. The grain-size data were collected from more than 10 institutions and databases. A full-coverage, gridded estimation of the median grain-size is obtained by Co-Kriging.

Processing Description:

The prediction of ripples in the North Sea uses the formulas and prescriptions of Soulsby and Whitehouse (2005), supplemented by Marten (2010). Their model predicts the existence, the type (current or wave ripple) and the height, length and orientation of sand ripples. The model includes processes as threshold of motion, ripple wash-out and biological degradation.

The requirements for applying the ripple predictor are the availability of: (1) the bed shear stresses generated by waves and currents (including their directions) and (2) the median grain-size.

Concerning biological degradation of ripple height during times of "no sediment movement", Soulsby and Whitehouse (2005) use a mean lifetime of 72 hours (i.e. after 72 hours the ripple height is reduced to 1/e times the initial height). The uncertainty about the mean lifetime is huge.

In the ripple predictor, the same current-generated bed shear stress τ_C was used as given in the appropriate map. The applied wave-generated bed shear stress τ_W, however, is different from the conventional τ_W. In the ripple predictor the amplitude of the wave orbital velocity just above the bed, U_W, is represented by $U_{1/10}$, the mean of the highest one-tenth velocities generated by natural (random) waves. For the calculation of $U_{1/10}$, the significant wave height H_S and the mean wave period T_{m2} were converted to $H_{1/10} = 1.27 \cdot H_S$ and $T_{1/10} = 1.28 \cdot T_{m2}$. The amplitude of the wave skin-friction shear-stress τ_W is then calculated by the standard formula

$$\tau_W = \frac{1}{2} \cdot \varrho_W \cdot f_W \cdot U_{1/10}^2$$

where f_W is the wave friction factor and ρ_W is the density of sea water.

In simplified terms, there are four seabed conditions predicted by the model:

(1) "active" wave ripples exist if the wave bed shear stress τ_W is above the threshold of sediment motion, and if

$$\theta'_W \geq max\left(0.42 \cdot \theta'^{0.47}_C, 0.04\right)$$

with ϑ'_W and ϑ'_C being the skin friction wave Shields parameter and the skin friction current Shields parameter, respectively.

(2) "active" current ripples exist if the current bed shear stress τ_C is above the threshold of sediment motion, and if

$$\theta'_W < max\left(0.42 \cdot \theta'^{0.47}_C, 0.04\right)$$

(3) "frozen" (or "relict") ripples exist if both τ_C and τ_W are below the threshold of motion. The previous ripples remain as they are, unless biological activity flattens them.

(4) For large τ_C or τ_W, ripples are washed out, leaving a flat bed

To produce an area-covering map of wave ripple heights the first step was the generation of area-covering maps of τ_C, τ_W and median grain-size. Concerning τ_C and τ_W, the models TRIM and WAM yield area covering current and wave data (being present in model grid cells) from which τ_C and τ_W are determined. For the year 2006 these maps of τ_C and τ_W are provided every one hour. Concerning the median grain-size, a map was produced by spatial interpolation of individual sample data. This interpolation was done by Co-Kriging using the R-routine "krige" (R-library "gstat"). The external variable used by Co-Kriging was log-converted %mud.

After having generated maps of τ_C, τ_W and median grain-size, the final step was the application of the ripple predictor of Soulsby and Whitehouse (2005) supplemented by Marten (2010), to produce a map of wave ripple heights.
For every full hour during 2006, a map of "wave ripple heights" was produced based on the median grain-size and the full hour values of τ_C and τ_W. The final step was to generate the map of "time-averaged wave ripple heights" for the whole year 2006. It is obvious that time periods with "no existing active wave ripples" did not enter into the averaging procedure.

Notes and Limitations:

<u>Error Estimation:</u>
The uncertainty of one individual wave ripple height η depends on the uncertainties of the input data and of the formulas used to calculate η. These uncertainties (given as standard deviations) are:

(1) The uncertainty of the median grain-size D_{50}. The uncertainty in φ-scale is about ±0.68.

(2) The uncertainty of the two wave parameters used for the calculation of the near-bed amplitude U_W of the wave orbital velocity: the wave height and the wave period. Weisse and Günther (2007) report on a comparison between observed and hindcast wave data in the North Sea. The relative errors of the significant wave height H_S and the mean wave period T_{m2} were found to be ± 30 % and 18 %, respectively.

(3) The uncertainty of the near-bed current velocity which is estimated to be ± 14 %. The current velocity is needed to decide whether there are wave ripples, current ripples or neither of the two ripple types.

(5) The uncertainty of the calculated wave (skin-) friction factor f_W. The uncertainty of the wave friction factor is estimated from the data points plotted in Fig. 15 (Soulsby 1997). The plot shows the deviations of a fitted f_W-equation from measured f_W data. The standard deviation of the difference between fitted $\log(f_W)$ and measured $\log(f_W)$ is ±0.11.

(6) The uncertainty of the formula which calculates the wave ripple height η. The uncertainty of the η-formula itself (the uncertainty if all input data are precisely known) was deduced from Fig. 10B in Soulsby et al. (2012). This scatterplot shows predicted versus observed ripple heights. Only wave-dominant ripples were taken into account. The quantity

$$\frac{\eta_{observed} - \eta_{predicted}}{\eta_{predicted}}$$

was calculated for 43 data points. The mean and the standard deviation of the quantity was 0.67 ± 0.53. The bias of 0.67 is not further considered.

The uncertainty of the predicted η is composed of the uncertainties given above. The uncertainties are joined by a Monte Carlo procedure. The random numbers for the Monte Carlo procedure were taken from a normal (Gaussian) distribution. Typically N = 10000 realizations of η were calculated during a Monte Carlo simulation run for one error estimation. The results show that the relative standard deviation of η is in the order of 60 to 80 %.

The τ_W-map shows the time-averaged bed shear stress τ_W for the year 2006. The uncertainty of this annual average is estimated by comparing the 2006 map with maps of other years. The results of the five years 2003 to 2007 were available for calculating the variability of τ_W between years. In each grid cell the standard deviation of five annual τ_W-averages is determined. To obtain a relative variability, a standard deviation is divided by the overall five-year average of τ_W. The map with the spatial distribution shows that the τ_W variability between years is between 10 % and 35 % in most parts of the southern North Sea.

Instruments / Models:
The prediction of ripples in the North Sea uses the formulas and prescriptions of Soulsby and Whitehouse (2005). Their model predicts the existence, the type (current- or wave-generated) and the height, length and orientation of sand ripples. The model includes processes as threshold of motion, ripple wash-out and biological degradation.

WAM Model
The WAM model is a state-of-the-art spectral wave model. The quality of its results depends primarily on the quality of wind forcing and on the correctness of the bathymetry. Wind forcing is simulated with the regional climate model COSMO-CLM (Gaslikova et al. 2013), the first non-hydrostatic atmosphere model of the German Weather Service (DWD). This atmosphere model is at the leading edge of research and development.
The formulas used for calculating τ_W from the near-bed wave velocities were derived by Soulsby (1997). Soulsby is one of the leading experts for hydraulics and sediment transport in the world. The formulas and procedures suggested by him are state-of-the-art.

TRIM Model
TRIM is a 3-dimensional fully baroclinic model. It calculates sea surface elevation, three velocity components, temperature and salinity. In addition it calculates the vertical eddy diffusivity by using the public domain turbulence model GOTM. TRIM is a state-of-the-art model - the quality of its results depends primarily on a correct bathymetry and correct boundary conditions (e.g. wind velocity above the water surface, water elevation at the seaward boundaries). TRIM uses the results of the REgional atmosphere MOdel REMO (Feser et al. 2001) to drive current velocities and water temperatures at the water surface.
The formulas used for calculating τ_C from the near-bed current velocity are the standard formulas found in each textbook on hydraulics.

Related Datasets:

- *Median grain-size of the surface sediment grain-size distribution*
- *Bed shear stress generated by currents*
- *Bed shear stress generated by waves*
- *Frequency of active current-generated ripples*

Data Sources

The data for the generation of sediment maps were obtained from the following institutions:

NAVAL OFFICES and RESEARCH INSTITUTES:
Forschungs- und Technologiezentrum Büsum, Germany
Bundesamt für Seeschifffahrt und Hydrographie (BSH), Hamburg, Germany
Senckenberg Institut Wilhelmshaven, Germany
Helmholtz Zentrum Geesthacht, Germany
Bioconsult Schuchardt & Scholle GbR, Bremen, Germany
Deltares, Utrecht, The Netherlands
British Geological Survey, Marine Information Project, Edinburgh, UK
Marine Scotland, Marine Laboratory, Aberdeen, UK
Universität Hamburg, Institut für Geologie und Paläontologie, Hamburg, Germany
Royal Netherlands Institute for Sea Research (NIOZ), Texel, The Netherlands
Geological Survey of the Netherlands (TNO), Utrecht, The Netherlands
School of Ocean Sciences, Bangor University, Menai Bridge, Anglesey, UK
CEFAS, Lowestoft, UK
Geological Survey of Norway (NGU), Trondheim, Norway
Geological Survey of Denmark and Greenland (GEUS), Copenhagen, Denmark
Bureau de Recherches Géologiques et Minières (brgm), Orléans, France

PROJECTS:
Management, Research and Budgeting of Aggregates in Shelf Seas related to End-users (MAREBASSE, 2002-2006), Ghent University, Belgium
North Sea Benthos Survey 1987
North Sea Benthos Project 2000
Zirkulation und Schadstoffumsatz in der Nordsee (ZISCH, 1984-1989), Universität Hamburg
Biogeochemistry and Distribution of Suspended Matter in the North Sea and Implications to Fisheries Biology (TOSCH, 1984-1988), Universität Hamburg
Geopotenzial Deutsche Nordsee (GPDN, 2009-2013), Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) Hannover, Landesamt für Bergbau, Energie und Geologie (LBEG) Hannover, Bundesamt für Seeschifffahrt und Hydrographie (BSH) Hamburg, Germany

DATABASES:
Flanders Marine Institute (VLIZ) Data Centre, Ostend, Belgium
Management Unit of the North Sea Mathematical Models (MUMM), Brussels, Belgium
International Council for the Exploration of the Sea (ICES), Copenhagen, Denmark
Publishing Network for Geoscientific & Environmental Data (PANGAEA), Alfred-Wegener-Intitut (AWI), Bremerhaven, Germany