A method to correlate granulometrical sediment parameters and hydrographical data

Von Björn Heise, Bernd Bobertz u. Jan Harff

Abstract

This article presents a method for the semi-quantitative investigation of the impact of near bottom currents on the sediments at the sea floor. The critical shear stress velocities of the surface layer sediments, characterised by grain size parameters "median" and "sorting" and the free flow velocities next to the sea bottom are combined in one diagram ("Erosion-Rose"). Currents capable of transporting sediment ("events") were detected by quantitative methods presented in this paper and form the base of this study. The method is applied using data obtained by a 3D numerical circulation model and grain size data from bottom sediments. The simulation covers the period from October 1996 to September 1997.

Keywords

Erosionsrose, Sedimenttransport, Strömungsereignis, Korngrößenverteilung, hydrodynamische Situation, Hauptkomponentenanalyse, Schubspannungsgeschwindigkeit, Strömungsbeständigkeit, Tangentenwinkel, Varianzellipse

Erosion-Rose, sediment transport, current event, grain size distribution, hydrographical situation, principal component analysis, shear stress, velocity, current constancy, tangent angle, variance ellipse

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1. Introduction

The influence of near bottom currents on sediments at the sea floor is an intensively studied field of science (e.g. MILLER et al., 1997; NIELSEN, 1992; SOULSBY u. WHITEHOUSE, 1997; SOULSBY, 1997b; ZANKE, 1982 u. 2002). Sedimentologists, biologists and oceanographers as well as engineers are interested in the change of the sea floor sediment properties due to the hydrodynamic conditions, the drift of dumped sediment material from excavation and dredging or possible transport of contaminated matter escaped as a consequence of ship acci-

dents such as the "Baltic Carrier Accident" in 2001. Especially the western Baltic Sea with its narrow Kadet Channel is a highly frequented traffic area. In view of these facts, an interdisciplinary project DYNAS ("Dynamics of Natural and Anthropogenic Sedimentation", <u>http://www.io-warnemuende.de/projects/dynas</u>), funded by the Federal Ministry of Education and Research of Germany, was started in 2001. Here, scientists of different disciplines (sedimentology, oceanography, macrozoobenthos and microbiology, geostatistics, numerical modelling) from the Baltic Sea Research Institute Warnemünde (Germany) and the University of Rostock (Germany) work closely together with national state agencies and federal government authorities.

The task of this study was to create a tool for the correlation of the surface sediment's properties with the near bottom currents. The quality and quantity of the influence of the current on the surface sediment were to be defined and displayed in a graph. The method presented in this paper can be applied as a supporting tool for the decision where and when to dump dredged material.

2. Data

The primary data needed for this study are the current directions and current velocities next to the sea bottom and grain size parameters describing the mean grain size and the "sorting" (approximation of the standard deviation of the grain size distribution).

Generally, there is no way to measure the **hydrographical situation** all over the area of survey and period of investigation. For this reason, results from a numerical model were taken instead. The results originate from the oceanographic Baltic Sea model which is run by the Section of Physical Oceanography and Measuring Technique of the Baltic Sea Research Institute Warnemünde (IOW - Germany). During the application, this hydrographical 3D numerical model was based on MOM-2 (PACANOWSKI, 1996). Today MOM-3 is used (KUHRTS et al., 2002). The modelled data were taken from the period 1996-10-01 – 1997-09-30. The horizontal model resolution was 1 nm (nautical mile) in the area of investigation. Every 6th hour the current vectors in the model box closest to the sea floor were stored for further processing (RIETZ et al. 2000). Waves were not taken into account because they have no capability for directed transport. Anyway, they lower the threshold for mobilisation of clastic material. Further methodological developments will include this fact.

The **sediment data** were taken from HARFF et al. (1997). They contain sieve analyses as well as settling analyses obtained when applying different measurement standards.

HYPOTHESIS

The assumption is that the surface sediment is primarily mobilised and/or transported for the period of **Current Events** (*CE*, *see* definitions for currents). The *CE* are defined by their capability to mobilise and/or transport surface sediments. Therefore, conditions have to be defined where currents near the sea floor are influencing the sediment qualitatively.

2.1 Definitions for sediment properties

Grain Size Distribution

The cumulative frequency distribution of the sediments at the sea floor is approximated applying a method after TAUBER (1995). The function proposed approaches the Gaussian

normal distribution. The values of parameters "median" and "sorting" are adjusted to the given grain size data of a sample using a least sum of squares algorithm. The parameters are roughly comparable with the grain size parameters proposed by FOLK and WARD (1957).

$$f(x) = \frac{1}{1 + e^{-1.7} \frac{x - median}{sorting}}; "sorting" > 0$$
(1)

х	particle size (phi-scale)
"median"	"median" of the grain size distribution
"sorting"	"sorting" resp. standard deviation of the grain size distribution
-1.7	parameter of adjustment to approach the Gaussian normal distribution.

The function values range between 0 and 1.

Critical Shear Stress Velocities

The critical shear stress velocities were derived using the mean grain diameter of the surface sediments.

The equation from ZANKE (1982) reads:

$$u_* = \sqrt{c_1(\rho'gd)} \tag{2}$$

u* critical shear stress

 $c_1 = 0.04$

g = 981-cm/s² (gravitation constant)

d = mean of the particle size distribution in cm

 $\rho' = (\rho_s - \rho_f) / \rho_f$ (relative density of sediment particles in relation to the density of a fluid)

 $\rho_s = 2.65$ -g/cm³ (density of sediment particles)

 $\rho_{\rm f} = 1 - {\rm g/cm^3}$ (density of water)

The relation between critical shear stress velocities and free flow velocities expressed after SOULSBY-(1983,-1997a):

"quadratic friction law":

$$\tau = pC_D u^2 \tag{3}$$

"friction (or shear) velocity":

 $u_* = \sqrt{\frac{\tau}{p}} \tag{4}$

equations 3 and 4 added:

$$u_* = \sqrt{C_D u} \tag{5}$$

After SOULSBY-(1997a) it is possible to use for C_D ("drag coefficient") an averaged value of 0,0025.

$$u_* = \sqrt{0,0025u} \tag{6}$$

$$u_* = \frac{1}{20} u \tag{7}$$

- τ = critical shear stress (N/m²)
- u_* = critical shear stress velocity
- u =free flow velocity
- p = density of water (1027 kg/m³ after SOULSBY [1997a])
- C_D = drag coefficient

To calculate the critical free flow velocities (u) for selected grain sizes the value for u_* from equation 2 was inserted in equation 7.

In order to calculate critical shear stress velocities and free flow velocities in this work, the way presented above is sufficient. If there are further considerations e.g. of shielding or bed armouring it is necessary to change the equations 2 to 7 to make it suitable for such current task. However, these changes will not have any influence on the applicability of the method presented here.

2.2 Definitions for currents

In general, a **Current Event** (CE) is characterised by a low to relatively constant current direction within a specific time frame. The current velocity is not considered for the definition of a CE because a current with a specific velocity may have different effects on the sediment depending on it's grain size. In order to assure a verifiable sediment transport and particle movement distance a time frame of 72 hours was chosen based on the investigation of the temporal autocorrelation of the dataset used.

Basic mathematical principles to define Current Events (CE)

In order to define a CE the *current constancy* and the *angle between the tangents at the variance ellipse and the origin of the coordinate system* (*TA*) are used.

Current constancy

The **current constancy** characterises the positions of the vector endpoints in reference to the origin of a coordinate system (Fig. 1).

$$current constancy = \frac{norm of the average vectors}{mean of the norms of the single vectors}$$
(8)

norm of the average vectors =
$$\begin{vmatrix} \sum_{i=1}^{n} \vec{x}_i \end{vmatrix}$$

mean of the norms of the single vectors $= \frac{1}{n} \sum_{i=1}^{n} \left| \overrightarrow{x_i} \right|$

 $\vec{x_i}$ = current vectors (v_i, u_i) u_i and v_i = u- and v- component of the current vector n = number of values

The current constancy has high values when the cloud of vector endpoints is distributed over one or two adjacent quadrants of the coordinate system (see Fig. 1, clouds number 3, 4, and 5). It is low when the cloud of vector endpoints scatters over three or four quadrants

or within opposite quadrants (see Fig. 1, cloud numbers 1 and 2). The values of the current constancy range from 0 till 1.

Through the calculation of the current constancy a first classification of the contemplated period can be made (e.g. Fig. 1 cloud 3 = high current constancy and low variation of current directions is postulated in the definition of a *CE*). The test of the current constancy assures that the centre of the coordinate system does not fall into the current variance ellipse. This is important for further calculations.



Fig.1: Examples for clouds (one cloud = one time frame with all included modelled values) of current vector endpoints displayed through the vector components u_i and v_i over a defined period. All current situations with low current constancy (CC) are not Current Events (CE) in the sense of this study

Tangent Angles (TA)

The angle between the tangents of the variance ellipse and the origin of the Coordinate System (*TA*) is used to characterise the average variation of the flow direction of a current event. A relative proportion of the vector endpoints of $(e-1)/e \approx -0.63(e-=-Euler's Number)$ falls inside the variance ellipse characterising the majority of the data sets.

The calculation of the variance ellipses is based on the Principal Component Analysis (e.g. EMERY and THOMSON, 1998). The variances and covariances are measures of the variability of the 2D vector components (u and v). Through these parameters, the major axis and minor axis of a variance ellipse can be derived.

Calculation of the major axis (a) and minor axis (b) of the two principal variances after EMERY and THOMSON (1998):

$$a = \sqrt{\frac{S_{uu} + S_{vv} + \sqrt{S_{uu} - S_{vv}}^2 + 4S_{uv}^2}{2}}$$
(9)

$$b = \sqrt{\frac{S_{uu} + S_{vv} + \sqrt{S_{uu} - S_{vv}}^2 + 4S_{uv}^2}{2}}$$
(10)

Calculation of the eigenvalue of the principal components:

$$S_{uv} = \frac{1}{n} \sum_{i=1}^{n} u_i v_i$$
 (11)

$$S_{uu} = \frac{1}{n} \sum_{i=1}^{n} u_i^2$$
(12)

$$S_{vv} = \frac{1}{n} \sum_{i=1}^{n} v_i^2$$
(13)

S	= empirical covariance between the vector components
S and S	- empirical vertice of the single vector components
S_{uu} and S_{vv}	= empirical variance of the single vector components
u _i	$=(u_i-\overline{u})$ difference of u-component of the i-th vector and the u-component of
	the average vector
V _i	$=(v_i-\overline{v})$ difference of v-component of the i-th vector and the v-component of
	the average vector
a	= major axis
b	= minor axis
\overline{u} and \overline{v}	= mean of the u- and v-component

With increasing fluctuation of the vector endpoints, the major and minor axis are getting longer. To set these facts in relation to the current direction, the tangents (Fig. 2) at the variance ellipses crossing the origin of the coordinate system were calculated. Between these tangents at least 63-% of the current vector endpoints are enclosed. In order to express the variation of the current directions over a period of time the TA (Fig. 2) was used.

Calculation of the "principal angles" in a bivariate data set after PREISENDORFER (1988):

$$\vartheta = \frac{1}{2} \arctan\left[\frac{2S_{uv}}{S_{uu} - S_{vv}}\right]$$
(14)

 $\begin{array}{ll} S_{uv} & = \text{empirical covariance between the vector components} \\ S_{uu} \text{ and } S_{vv} & = \text{empirical variance of the single vector components} \\ \vartheta & = \text{angle of the major axis of the variance ellipse to the u-axis of the coordinate} \\ \text{system (see Fig. 2)} \end{array}$

Thereby, a statement can be made about the directional characteristic of the currents over a pre-determined period.



Fig. 2: Angle between the tangents of the current ellipse and the point of origin (between the tangents are at least approximately 63 % of the vector endpoints)

 ϑ (theta) = angle between major axis of the variance ellipse and the u-axis TA = angle between the tangents of the ellipse tangents = tangents of the ellipse crossing the origin vector endpoints = endpoints of the current vectors

3. Method

3.1 General scheme

In Fig. 3 the general working scheme is presented. There are two data sources (grain size and current velocity) described by different parameters. They have to be transformed to compare them in one graph (Erosion-Rose).

In order to automate this process, the software Surfer[®] for Windows TM (SURFER, 1999) was used and macros were written in programming language Visual Basic for ApplicationsTM.

3.2 Definition of a current event (CE)

For this investigation, a **Current Event** (CE) is defined through a high current constancy and a small TA. A threshold value for each parameter was obtained by empirical statistical analysis of the given data. Therefore, the current vectors at a location (Fig. 5, point





Fig. 3: General working scheme

24-32, longitude 12.3 decimal degree East, latitude 54.52 decimal degree North) in the area of survey were taken during the time span 1996-10-1 06:00 to 1996-10-22 18:00. This period was chosen because of its low variation in the vector-norm vs. time diagram of point 24-32. The location was selected because of the relatively constant current direction during this period.

In order to calculate the threshold values for the current constancy and the *TA* the following method was used. A 72 hours time frame was set at the beginning of the investigation period. Within this, the values of current constancy and *TA* were calculated. Afterwards the time frame was shifted one time step forward and current constancy and *TA* within the new period were calculated. This process was repeated until the end of the entire investigation period (ref. Fig. 4). From all values of current constancy the third quartile was calculated and selected as a threshold value. The first quartile was taken as a threshold for the *TA*.

Consequently, for the contemplated area of survey a Current Event over a distinct period (at least 72 hours) is defined by a current constancy \geq -0.96 and a *TA* \leq 23°.

3.3 Scheme to distinguish a current event

The scheme shown in Fig. 4 describes the way determining CE.

Stage 1 (Fig. 4):

The first step is to set a constant time frame (e.g. 72 h, Fig. 4) at the beginning of the period of investigation. Within this time frame current constancy and *TA* are calculated from the current data. The values obtained are compared with the selected thresholds. If the requirements of a *CE* are fulfilled (current constancy \geq -0.96, *TA* \leq 23°), the values and time step are stored for further processing.

Thereafter, the constant time frame is moved one time step forward and the calculations are repeated until the end of the investigation period.



Fig. 4: Method of detecting current events

Stage 2 (Fig. 4):

The improved version of the moving time window presented in stage 1 is the extension of the time frame as long as the requirements for a *CE* are satisfied. This reduces the number of single CEs which are assumed to be parts of one longer CE.

Combining Graph (EROSION-ROSE)

In this paper, the diagram combining the sediment properties and the current events is called **Erosion-Rose** (HEISE, 2002). Its components are described in Fig. 5. The figure shows *CEs* and their relation to the surface sediment at the location marked in Fig. 7 (Northwest of Darßer Ort in the Southwestern Baltic Sea) exemplarily. The average direction and average



Fig. 5: Erosion-Rose: This graphic displays CE (direction, average velocity, annual occurrence) in relation to the surface sediment (mean grain size, "sorting", free flow velocities derived from critical shear stress velocities for selected grain sizes). As an example a location Northwest off Darßer Ort in the Southwestern Baltic Sea was chosen (see Fig. 7)

free flow velocities of the *CE* with a length of 72 hours, their annual occurrence, the critical shear stress velocity for the sediment at the sea floor and the granulometrical parameters "median" and "sorting" are integrated in one diagram.

Every **coloured dot** represents one *CE*. It's average flow direction and average flow velocity is given through the position in the direction circle.

The **black circles** (numbers 1–4) characterise free flow velocities estimated from the critical shear stress velocities necessary for transport of particles with a diameter equal or less than the grain size associated with the circle. This assumes a linear dependency between grain size and critical shear stress velocity (ZANKE, 1982). For the conversion of the critical shear stress velocity an equation after SOULSBY (1983, 1997a) was applied.

The percent values below the circle numbers are the estimated (cf. equation 1) weight percents of the particles of the surface sediment with smaller diameters (larger numbers at the phi scale KRUMBEIN, 1934) than the grain size values associated with the circles.

The **red circle** (labelled with U) reflects the minimal free flow velocity which is needed to mobilise particles with grain sizes smaller or equal than the "median".

The grey annulet describes the range of "median"- \pm -"sorting". Approximately 2/3 of the mass of all sediment particles are within this range. Through the size of the annulet the "sorting" can be appraised.

How to interpret the Erosion-Rose (Fig. 5)?

- 1. A dominance of *CE* into the North-Northeast to Northeast direction is visible through accumulation of CE.
- 2. CE into Southwest occur sporadically.
- 3. The average velocities of the Northeast directed *CE* are higher than Southwest directed events visible through the distance from the circle centre.
- 4. The main occurrence of *CE* at this point of survey falls into autumn and spring (colour of dots).
- 5. A part of the *CE* in Northeast direction influence almost the entire spectrum of particle sizes of the surface sediment. They are outside the grey annulet, meaning that more than 80 % of the sediment mass is influenced.
- 6. The Southwest directed CE are not capable to mobilise or transport all particle sizes of the surface sediment. Most of them are placed near the circle centre below the inner border of the grey annulet, meaning that less than 16 % of the sediment mass may be influenced.
- 7. The mobilised sediment was mainly transported into the Northeast direction, in agreement with the conclusion of the facts presented before.
- 8. The surface sediment consists of particles with approximately 1 % silt fraction, 79 % fine sand fraction and 20 % medium sand fraction.
- 10. The surface sediment is well sorted.
- 11. The value for the "median" lies in the fraction of fine sand.

4. Applications

The area of survey (Fig. 6) is situated in the Southwestern Baltic Sea between the Northeastern part of the Mecklenburgian Bight and the western part of the Arkona Basin. Both basin structures are separated by the shallow Darss Sill located in the centre of the area. It is separated by the Kadet Channel system.

In Fig. 7 the high variability of the modelled near bottom currents expressed by the variance ellipses and average current vectors can be seen. Often the variance ellipses and average current vectors reflect the morphology of the seafloor (e.g. Kadet Channel). In Fig. 8 the "median" of the bottom sediments in the area of survey and the location of the point of closer examination are displayed. Near the coast and in the Darss Sill area sediments with a small value for the "median" (phi-scale) can be found. On the contrary, the marginal areas of the Mecklenburgian Bight and the Arkona Basin show high values for the "median".



Fig. 6: Western Baltic Sea with area of survey; (bathymetry data by SEIFERT and KAYSER, 1995); K = Kadet Channel (modified from LEMKE, 1998)



Fig. 7: Current-ellipses, average current vector for the model-year 1996-10-1 – 1997-09-30 (modified after HEISE, 2002)



Fig. 8: "median" of the surface sediments in the area of survey with contemplated points (see further on)

Example

Fig. 9 presents an example of the *CE* occurring within the period of investigation in the Kadet Channel (point 24–32). The extended *CE* (see Fig. 4) with their duration and direction of the first six months of the period of survey are presented here.



Fig. 9: Extended CE occurring in the first six months of the investigation period at the point 24–32 (Kadet Channel)

In the following section, three locations are examined in detail. The locations were chosen because of their different morphologic properties.

Point 16-21:

This point is situated in the transition area between the Mecklenburgian Bight and the Darss Sill (Fig. 8). The sediment is well sorted fine sand (93 %) with a portion of 7 % medium sand (Fig. 11), and a "median" of 2.8 (phi-scale). The examination of the current vector endpoints and the current rose (Fig. 10) over the modelled period (1996-10-01 to 1997-09-30) reveals a slightly bi-directional current situation.

The Erosion-Rose shows only a few CE (Fig. 11). The mean velocities of these CE are too low to influence the surface sediment.



Fig. 10: Endpoints of the current vectors and the current rose at the point 16–21, transition area from the Mecklenburgian Bight to the Kadet Channel (see Fig. 8) during the modelled year 1996-10-01 – 1997-09-30



Fig. 11: Erosion-Rose: Point 16-21: transition area Mecklenburgian Bight - Darss Sill; *CE:* current constancy > = 0.96, angle between the tangents of the variance ellipse $< = 23^{\circ}$; modelled year: 1996-10-01 - 1997-09-30;

sediment: "median" = 2.8, "sorting" = 0.33;

numbered circles: velocities of free flow currents calculated from critical shear stress velocities for special grain sizes (phi-scale)

- 2 cm/s,9 phi, clay/silt-boundary 1.
- 2. 13 cm/s,4 phi, silt/sand-boundary
- 3. 23 cm/s, 2.3 phi, fine/medium sand-boundary
- 40 cm/s, 0.7 phi, medium/coarse sand-boundary 4.

U. 19.3 cm/s, 2.8 phi, "median" of the grain size distribution of the surface sediment;

grey annulet: velocity of free flow currents calculated from shear stress velocities for the distribution of grain sizes "median" ± "sorting";

percentage values at the black circles: portion (%) of the grain size distribution with particle sizes larger 1. to 4 (phi-scale);

coloured dots: Current Events occurring during the term of survey, day from - until -

- 1 until 36 147 until 182
- 37 until 73 183 until 219
- \bigcirc
- 110 until 146

- 293 until 328
 - 329 until 365
- 74 until 109 220 until 255
- 256 until 292

Point 24-32:

The point is located in the centre of the Kadet Channel (Fig. 8). The surface sediment is poorly sorted with a "median" of 2.3 (phi-scale). The illustration of the endpoints of the current vectors and the current rose reflects a bi-directional current situation, mainly caused by the bathymetry (Fig. 12). The Erosion-Rose shows a high number of occurring CE (Fig. 13). The main CE direction is North-Northeast. The mean current velocities of the CE into this direction are partly high enough to influence nearly the whole spectrum of the particle sizes. A minor CE direction occurs in south direction. The velocities into this direction are relatively low and rarely influence the surface sediment. The main direction for sediment transport for the period of survey was North-Northeast. The transport of sediment appears mainly during autumn (Fig. 13).



Fig. 12: Endpoints of the current vectors and the current rose at the point 24–32 (see Fig. 8) over the modelled year 1996-10-01 – 1997-09-30



Fig. 13: Erosion-Rose: Point 24–32: Kadet Channel;

CE: current constancy > = 0.96, angle between the tangents of the variance ellipse $< = 23^{\circ}$;

modelled year: 1996-10-01 - 1997-09-30;

sediment: "median"= 2.4, "sorting"= 1.9;

numbered circles: velocities of free flow currents calculated from critical shear stress velocities for special grain sizes (phi-scale)

- 2 cm/s,9[°]phi, clay/silt-boundary 1.
- 2. 13 cm/s,4 phi, silt/sand-boundary
- 3. 23 cm/s, 2.3 phi, fine/medium sand-boundary
- 40 cm/s, 0.7 phi, medium/coarse sand-boundary 4.
- U. 22.6 cm/s, 2.3 phi, "median" of the grain size distribution of the surface sediment;

grey annulet: velocity of free flow currents calculated from shear stress velocities for the distribution of grain sizes "median" ± "sorting";

percentage values at the black circles: portion (%) of the grain size distribution with particle sizes larger 1. to 4 (phi-scale);

coloured dots: Current Events occurring during the term of survey, day from - until -

- 1 until 36
- 37 until 73 183 until 219 \bigcirc
- \bigcirc
- 110 until 146

- 147 until 182 293 until 328
 - 329 until 365
- 74 until 109 220 until 255
- 256 until 292

Point 47-47:

The point is located at the transition area into the Arkona Basin (Fig. 8). The surface sediment here is well sorted and consists of 61% fine sand fraction with 39% medium sand fraction (Fig. 15). The endpoints of the current vectors and the current rose indicate a unidirectional current situation (Fig. 14). This situation is reflected by the Erosion-Rose (Fig. 15). The major *CE* direction is East-Northeast throughout the period of investigation. These *CE* differ in their directions only in a small angle. Their velocities are mostly high enough to mobilise the whole spectrum of particle sizes of the surface sediment. As a result, the sediment should be transported into the Arkona Basin. There are just a few *CE* into Southwest direction. Their velocities are not high enough to influence the surface sediment.



Fig. 14: Endpoints of the current vectors and the current rose at the point 47–47 (see Fig. 8) over the modelled year 1996-10-01 – 1997-09-30



Fig. 15: Erosion-Rose: point 47-47: transition area Darss Sill-Arkona Basin; *CE:* current constancy > = 0.96, angle between the tangents of the variance ellipse $< = 23^{\circ}$; modelled year: 1996-10-01 - 1997-09-30;

sediment: "median" = 2.4, "sorting" = 0.48; numbered circles: velocities of free flow currents calculated from critical shear stress velocities for special grain sizes (phi-scale)

- 2 cm/s, clay/silt-boundary 1. 9 phi,
- 2. 13 cm/s, 4 phi, silt/sand-boundary
- 3. 23 cm/s, 2.3 phi, fine/medium sand-boundary
- 40 cm/s, 0.7 phi, medium/coarse sand-boundary 4.

"median" of the grain size distribution of the surface sediment; U. 21.9 cm/s, 2.4 phi,

grey annulet: velocity of free flow currents calculated from shear stress velocities for the distribution of grain sizes "median" ± "sorting";

percentage values at the black circles: portion (%) of the grain size distribution with particle sizes larger 1. to 4 (phi-scale);

coloured dots: Current Events occurring during the term of survey, day from - until -

- 1 until 36
- 37 until 73 \bigcirc 183 until 219
- 74 until 109 \bigcirc
- 110 until 146

- 147 until 182 293 until 328
 - 329 until 365
- 220 until 255
- 256 until 292

5. Summary

In order to correlate the surface sediment properties with the currents near the sea floor, two tasks were solved. First, the descriptions of the sediment properties were done. Secondly, the question "how the potential influence of current situations onto the sediments at the sea bottom can be estimated at selected points" is answered.

The primary data required for the investigation were the current directions and current velocities near the sea bottom measured or modelled in short lags (e.g. 6 h) over a period of time (e.g. half or one year) as well as the grain size parameters "median" and "sorting" of the surface sediments. For the characterisation of the hydrographical situation numerically modelled data were taken. They originate from a Baltic Sea Model operated by the Section of Physical Oceanography of the Baltic Sea Research Institut Warnemünde. The granulometry of the surface sediments is characterised by parameters "median" and "sorting" of a function describing the cumulative grain size distribution (TAUBER, 1995).

The assumption behind this work is that the sediment is mainly influenced (mobilised, transported) during **Current Events** (CE). The main aspect for the characterisation of such CE is their ability for sediment erosion/transport in one direction. In order to obtain this, the following question needs to be answered: Which conditions have to exist at the sea floor that the surface sediments are qualitatively influenced and changed in their granulometrical properties?

The current conditions at a specific location have to be almost stable over a defined minimal period in order to initiate a transport of clastical material over verifiable distances. The variation of the current direction has to be low in order to assure a directed transport. Two characteristics were chosen to assure the requirements: the currents constancy and the angle between the tangents, crossing the origin of the u-v-coordinate system, at the variance ellipse of the vector endpoints (TA). A statistical analysis at a specific location gives threshold values for the current constancy (\geq 0.96) and the *TA* (\leq 23°). The velocity of the current at the point of investigation is not considered for the definition of a *CE*.

The *CE* and the critical shear stress velocity of the sediment at the sea floor are compared in the diagram explained in Fig. 5. It was named Erosion-Rose.

The average *CE* directions and average *CE* velocities, the annual occurrence of the *CE*, the sediment properties critical shear stress velocities as well as grain size parameters "median" and "sorting" are displayed in one comprehensive and easy-to-interpret graph. This graph relates the current situation to the sediment at the sea floor. Information about the situation at/near the sea floor like the dominance of *CE* directions and annual occurrence, their velocities related to grain size dirstribution of the surface sediment and, as a deduction, possible erosion and transport directions of sediment material can be obtained. The surface sediment is displayed by the portion of selected particle size fractions and the "sorting".

With this information at selected locations continuative conclusions can be made, e.g. about the main transport directions of sediment material.

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