Morphological Changes of Tidal Flats at the German North Sea Coast Induced by Tidal Asymmetry

N. E. Asp

† Research and Technology Center
Westcoast - Büsum
Kiel University
D-25761 Büsum, Germany
asp@fz-west.uni-kiel.de

ABSTRACT


Results of an investigation aimed at the morphodynamics of tidal channels and flats are summarized in this paper. The investigation area is the Dithmarschen District on the German North Sea coast, characterized by a mean tidal range of 3.2 m, being widely tide-dominated. The main objective of this study was to evaluate short to middle-term morphological changes and, on the basis of measurements on hydrodynamics and geology, explain the observed patterns of modifications. Periodic bathymetric measurements were carried out at pre-selected channel cross-sections and reveal important morphological changes, which can be summarized in two main trends, including a gradual lateral migration of the channels and a seasonal cycle of erosion (autumn to winter) - deposition (spring to summer). Current measurements over entire tidal cycles were also carried out in several surveys, in different periods at the pre-selected cross-sections. These measurements show important lateral asymmetric pattern for ebb and flood currents that, combined with seasonal variations in the hydrodynamic regime, explains the observed morphological changes. Particularities of the morphological changes at each evaluated cross-section are related with especial geological and morphological characteristics of each area, which were also evaluated due to cores, seismic and side scan sonar.

ADDITIONAL INDEX WORDS: Morphodynamics, tidal channel migration, seasonal variation.

INTRODUCTION

The present study was carried out in the Dithmarschen area of the North Sea coast of Germany, between the rivers Elbe and Eider, comprising the so-called Dithmarschen Bight (figure 1). The aim of this study was identify and investigate the morphological changes and the associated hydrodynamics on the area in temporal scales of months to years.

The investigated tidal flat region is integrated in the Wadden Sea and is characterized by a mesotidal regime, according to the classification of HAYES (1975), with a mean tidal range of 3.2 m, resulting in wide and open tidal flats. EHLERS (1988) stressed that according to its characteristics and landforms the area could be classified as a low macrotidal environment. Despite the absence of genuine barrier islands, shallow sandbanks in the outer part prevent the inner tidal flats from wave energy of the open sea.

The core study area comprises the Piep channel system and its belonging tidal flats, with the south and north limits about the latitudes 54°01’N and 54°12’N, and the west and east boundaries almost about the 08°30’E and 09°00’E longitudes (figure 1). In fact, the east and west limits are represented by the coastline and by the intertidal outer sand shoals (e.g. D-Steert and Tertius).

The Piep channel has the shape of a lying “Y”, in which the northern and southern inlets (Norderpiep and Süderpiep, respectively) form the connection to the open North Sea. From the point of intersection of the two sub channels, the actual Piep stretches in a more or less straight W-E line towards the city of Büsum. The mean water depth in the central part of the channels stretches in a more or less straight W-E line towards the city of Büsum. The mean water depth in the central part of the channels is about 10 m, with maximum values of about 23 m. East of Büsum, the Piep splits up into three second order channels and finally into several tidal creeks, which scatter in the tidal flat area of the Meldorf Bight (figs. 1 and 2).

Hydrology and Climatic Conditions

The hydrology of the area is dominated by a semidiurnal tidal regime. Refereed to the German water level datum (NN), the mean high water at Büsum is about +1.6 m and the mean low water is about 1.6 m. The difference between neap and spring tidal range is approximately 0.9 m.

According to SPIEGEL (1997) considering the Piep channel and its drainage area, 73% of the tidal basin is covered by intertidal flats. There the tidal prism is in the order of 414 x 10^6 m^3.

The daily motion of this water mass generates high current velocities in the channels. The alternating tidal currents in the Piep channel system can reach maximum values of about 2 m/s with mean maximum velocities of about 1.2 to 1.5 m/s. On the intertidal flats the maximum tidal induced currents are mainly about of 0.3 m/s and seldom exceed 0.5 m/s. Although here the superposition of tidal and wind driven currents can lead to magnitudes of more than 1 m/s under storm conditions. More information about tides and currents is given in SIEFERT et al. (1980) and WIELAND et al. (1984).

The wave climate in the investigation area differs very much depending on the exposition and the water depth. In the inlets close to the open sea significant wave heights of up to 4 m can occur. Measurements near the North Frisian Islands realized between 1986 and 1993 show that the characteristic open sea waves come from the directions northwest, west and southwest, with a significant wave height of 2.5 m and a period around 7.3 seconds. In the inner parts wave heights use to surpass 0.5 m only during storms (WILKENS et al., 2001).

Associated with the normal wave climate and tides, frequent storms influence the coastal zone on the German Bight. Their action can be separated in the storm surge effect and the storm waves. Storm surges in the area can result in an upset of the water level of more than +5 m (EHLERS, 1988).

The climate in the area is of a sub-oceanic type of the tempered latitudes. The monthly mean air temperature can reach values about 16 °C (August) and about 1 °C (February). This oscillation in the air temperature is followed by the variation in the water temperature, which might oscillate between 0 °C and 20 °C, considering monthly means (usually between 1 and 18 °C).

The precipitation is usually about of 800 mm/y and the main rain period is between August and December. The salinity oscillates normally between 20% in the winter and 28% during...
the summer, but an eventual strong evaporation in the tidal flat areas during the summer or strong rainfalls during the winter may cause salinity values as big as 33‰ and 15‰, respectively, being also influenced by the brackish waters from the rivers Elbe and especially Elbe (Becker, 1998).

Westerly winds (SW-W) are dominating in frequency and magnitude in the investigation area, being especially strong during November and December.

METHODS

For a detailed investigation of the morphological changes on the Piep system several channel cross-sections were chosen (see figure 1), which were measured periodically with a vessel-mounted echo sounder and a D-GPS system for positioning. The bathymetric measurements covered usually a 500 m wide section of the channels, comprising several transversal and longitudinal profiles, with regular intervals of about 100 m. The evaluated cross-sections present a length in the range of 800 m (Kronenloch) and 3,500 m (Süderpiep). The obtained data was corrected according to the sound speed in the water (influenced by local temperature and salinity) and water levels, obtained continuously at the tidal gauge of Büsum. Each data set was further interpolated in a digital elevation model (DEM).

In three selected cross-sections (A, B and C, figure 1) several current measuring campaigns over entire tidal cycles were also carried out during the last 3 years in the scope of the PROMORPH project (Mayerle et al., 2003). The measurements were carried out using a 1200 kHz vessel-mounted ADCP (Acoustic Doppler Current Profiler) configured with 12 seconds averaging ensemble and 0.5 m depth cell length. The measurements comprise continuous profiling at each cross-section over an entire tidal cycle. In the case of the cross-section A Norderpiep a measurement of an entire tidal cycle comprised usually about 70 profiles. The figures 2A and 2B show a schematic representation of a typical ADCP measurement.

For the interpretation of the current velocity measurements cross-sectionally averaged velocities for each profile were calculated. Furthermore an ensemble in the north side and another one in the south side of the channels were chosen for investigation of eventual lateral asymmetries (figure 2B). Surface, bottom and depth-integrated velocities were calculated for each ensemble.

RESULTS

Based on bathymetric measurements covering the whole area carried out over the last 30 years (BSH German Federal Agency for Navigation and Hydrography) the general patterns of morphological changes in the area were analyzed. The figure 3 shows the comparison of the bathymetries of 1977 and 1996. at first, the channels are very dynamic compared to the tidal flats, as expected. The outer part of the study area is characterized by mobile sandbanks that are also quite dynamic and usually migrate landwards in rates of about 30 m/year (Goñi, 1975; Kesper, 1992).

Furthermore, several channels seem to migrate laterally. This process can be identified in several sections of the main channels, due to the alternated erosion (figure 3A) and deposition (figure 3B) pattern.

Besides, in such places a consolidated muddy layer (so-called Dithmarscher Klei) outcrops in the channelbed. It hinders channel incision and might lead to erosion in a side of the channel, as a reaction to the deposition in the opposite side, in the "attempt" to preserve the cross-sectional area of the channel. This mud layer use to be several meters thick (up to 10 m) and its top can be found usually in depths about 15 to 20 meters, which correspond also to the range of maximum depths usually reached in the channels. Measurements show that this layer is widespread and can be found almost in the whole study area (Asf, 2003). The migration of the outer sandbanks resulting in narrowing process of the channels, associated with the hindrance of channel incision due to the Dithmarscher Klei, results in the lateral migration of the channels.

However, lateral migration of tidal channels occurs in the study area also independently of migration of sandbanks and hindrance of channel incision. This process can be called meandering, or estuarine meander development (Ahnert, 1960).

The meandering, resulting in the lateral migration of tidal creeks is a well-known process and have been studied for a long time (Vansatraen, 1951, Reineck, 1958; Ahnert, 1960 and Goñi, 1995). However, the exact origin of the lateral migration of tidal creeks is not well understood. Most reliable explanations consider tidal asymmetry as the main source of this process, as proposed by Ahnert (1960):

Ebb- and flood-tide flow paths occur in opposite sides, generating ebb and flood bends. Both currents are subject to

![Figure 2. Schematic representation of an ADCP measurement (A) and of the selection of points to analyze lateral asymmetry of currents (B).](image)
centrifugal forces in their bends; this and the fact that the directions of their forward motions are opposed to each other lead to a horizontal displacement, a spatial shift of phase: the line of highest velocity of each current tends to stay close to the downcurrent edge of the channel.

Furthermore, where the lateral displacement becomes sufficiently great, ebb and flood currents may maintain channels of their own, separated by an elongated sand bar in the middle of the channel cross-section (ROBINSON, 1960 and AHNERT, 1960).

In the study area genuine estuarine meanders as described by AHNERT (1960) are not present. However, the same process of meandering takes place. This becomes evident due to the curvature of channels and the erosional depositional processes visualized in the figure 3, which shows the comparison of the bathymetries of 1977 and 1996 overlaid by the isobaths from 1996.

Concerning the periodic measurements of the last three years, the data analyses show in general the same patterns and trends of changes for the six evaluated areas. The frequency of measurements and the coverage of different areas enable to recognize usually erosion from summer to winter season, and deposition from winter to summer season. However, local particularities have an important influence and can mask this seasonal pattern.

This seasonal pattern is well-known for several coastal environments, especially for beaches. This is usually associated to seasonal weather patterns resulting in more frequent storms and storm waves (erosion) in the winter and more frequent calm weather and swell (deposition) in the summer (INMAN and PILLOUX, 1960). However, for tidal dominated areas, especially inner tidal flats protected of direct wave attack (e.g. Dithmarschen tidal flat area) the seasonal cycle seems to be associated with other factors like exceptional tidal ranges during winter (storm surges) and higher kinematic viscosity of the water as a result of lower temperatures in the winter (EHLERS, 1988; FLEMMING and BARTHOLOMA, 1997).

To explain and exemplify the referred morphological changes, results comprising the cross-sections A Norderpiep and Kronenloch (see figs. 1 and 3 for location) are presented here.

**Norderpiep**

The bathymetric measurements show seasonal depth variations up to 4 meters locally in the cross-section A. The obtained bathymetric profiles are shown in the figure 4. In the middle of the cross-section (deeper part) the cycle of erosion from the summer to winter and deposition from winter to summer could be identified clearly. In the scope of short-term time scale measurements from a single winter were collected and results in terms of seasonal variations have to be cautiously interpreted. In the shallower parts, i.e. the flanks of the channel, this cycle is masked by the lateral migration of the channel, usually from south to north in the Norderpiep. This lateral migration is more evident in the comparison of several years (figure 4B). There, the migration of the sandbank at the south margin (northern part of Tertius) seems to force erosion in the north margin, in the “attempt” of the channel to maintain its cross-sectional area, since the Dithmarscher Klei outcropping in the deeper parts of the cross-section hinders channel incision (figure 4).

In the case of the evaluated cross-section at the Norderpiep, a deposition in the southern and erosion in the northern margin could be already detected after a period of about 6 months (December 2000 to July 2001, figure 4A). The measurement realized on March 2003 shows as well a clear erosion at the north side of the Norderpiep, compared to the previous measurements.

Besides, the comparison between March and August 2003 shows an important deposition in the south side, while in the north side the erosion between March and August 2003 is not substantial. This indicates a seasonality in the morphological changes as well, where deposition is pronounced in the spring and summer, while erosion use to be reduced. Compared to the other measurements, the situation in August 2003 shows the highest deposition. This would be the result of the very hot summer of 2003, when the air and water temperatures reach record values, which would have reduced more intensely the kinematic viscosity of the water and favor deposition due to a general reduction of the settling velocity of sediment particles.

A sediment sheet of about 2 meters thick was deposited between December 2000 and July 2001 in the channelbed. Even with such variations, a relative stability in the cross-section can be identified: in the summer deposited sediments seem to be eroded again in the following winter and erosion during the winter used to be compensated in the next summer. Despite this seasonal cycle, the general form of the cross-section seems to be preserved, but the channel migrates laterally, where during the autumn/winter the erosion seems to be more intense on one side and during the spring/summer the deposition seems to be more intense on the opposite side.

**Kronenloch**

This channel cross-section is located in a distal part of the main channel, in the inner part of the study area (figs. 1 and 3). There the depths rise to reach about 8 m (NN). It was found out that the seasonal cycle of erosion and deposition also takes place in this area, i.e. the inner part of the domain. The lateral migration of the channel was detected as well and it seems to be even more intense than in outer areas, like the Norderpiep.

Comparing annual measurements of the last 30 years, a continuous lateral migration of the channel can be identified.
This seems to happen in rates of about 15 m/year (figure 5). Several measurements obtained in the last three years show also this lateral migration.

Following the observed trends in the cross-section A norderpiep, the seasonal cycle could be also identified in the cross-section Kronenloch. It can be seen that during spring and summer the sedimentation at the west side of the channel is very pronounced, while erosion in the east side is reduced. During the autumn and winter the opposite pattern can be observed (figure 5A).

The comparison of measurements from the summer 2002 (June, July and August) with the winter of 2001 (December) shows important deposition in the west side of the channel, while the erosion in the east side was not relevant. However, comparing the profiles of the summer 2002 with the following winter (December 2002), the deposition was insignificant, while the erosion in the east side was intensive. The same pattern could be observed for the following winter and summer.

DISCUSSIONS

The lateral migration of the channels and the seasonal cycle of erosion during autumn and winter, and deposition during spring and summer seem to be interconnected.

The seasonal cycle presents a lateral asymmetric pattern, in which erosion prevails in the winter, but is more intense in one side, while the same pattern, in the other way around, can be identified in the summer. This seems to result in the lateral migration of the channel.

Due to the current measurements was possible to identify a lateral asymmetric pattern of ebb and flood currents in the cross-sections A Norderpiep, B Süderpiep and C Piep. The figure 6 shows the results of a current measurement over an entire tidal cycle at the cross-section A Norderpiep. It can be seen that the maximum depth-integrated current velocity at the south ensemble (AS), as well as the maximum current velocity at the surface in the south ensemble (ASS) are distinctly higher during the flood. Considering the results of the north ensemble, the opposite pattern can be observed, where the maximum depth-integrated velocity (AN) and at the maximum surface velocity (ANS) are substantially higher during the flood.

This pattern was observed at the three evaluated cross-sections in almost all measurements, including neap and spring cycles, however the difference is reduced during neap tidal cycles. In this context, it can be assumed that this lateral asymmetry would be found along the whole main channel, including the cross-section Kronenloch.

At the Norderpiep, the lateral migration of the channels seems to be also associated with the landward migration of the sandbanks. However, at the cross-section Kronenloch, at the inner part of the study area, there is no migration of such sandbanks, and the lateral migration of the channel is even more intense. It allowed the conclusion that the lateral asymmetric pattern of the tidal currents is the main driving force of the lateral migration.

For the study area flood currents are supposed to be more associated with deposition and ebb currents with erosion. Besides the presence of direct river inflow in the area, mechanisms of scour lag and settling lag also support this assumption. Studies of DIECKMANN et al. (1987) already argued that ebb channels are associated with erosion (negative sediment transport) and flood channels are associated with positive sediment transport into the tidal flat areas of the Wadden Sea.

To explain the seasonal cycle, i.e. predominance of erosion during autumn and winter, as well as deposition during spring and summer, two general mechanisms can be formulated:

The first one involves the physical characteristics of the water, which varies distinctly between summer and winter in the study area. Important variations in the water density are caused by changes in the salinity and especially in the water temperature. Due to strong rainfalls or ice formation during the winter, as well as strong evaporation during the summer, the salinity can oscillate in a range of more than 10%. Besides, the difference of the mean water temperature in the tidal channels of the Pie system between summer and winter can exceed 20 °C, being usually about 15 °C, considering monthly averages. In the study area the lowest water temperatures are reached in February, which has a monthly average of about 2 °C. The highest water temperatures are reached usually in August, when the monthly average uses to be 17°C (BECKER, 1998).

With the much lower water temperatures, the water density is much higher during the winter and the settling velocities of the sediment particles are consequently much lower during the winter. FLEMMING and BARTHOLOMY. (1997) pointed out that a reduction of 15 °C in the water temperature (20 to 5 °C) results in a reduction of around 25% in the settling velocity of particles, due to a higher kinematic viscosity of the water.

An important conclusion based on the analysis of morphological changes in the scope of seasonal cycles is the finding that erosion seems to happen mainly in the transition between summer and winter and not in the winter itself. A maximum of erosion seems to be reached usually in December, in the beginning of the winter. However, it must be considered that in the period of January and February it was not possible to carry out measurements, due to ice formation and frequent storms. It means that a maximum of erosion could be reached during January or February and would not be detected.

The reverse process seems to happen from winter to summer. Important accretion can be usually determined between winter and summer, however here a maximum of accretion is often detected in July, around the middle summer. The mechanism associated with the erosion between summer and winter would be mainly related to the increase of kinematic viscosity of the water and subsequent decrease of settling velocities. With the regular decrease of kinematic viscosity of the water, finer sediments will be deposited gradually from winter to summer and in the summer itself. These sediments would be gradually eroded again with the gradual increase of kinematic viscosity of the water from summer to winter.

The second mechanism to explain the identified seasonal cycle implies that the wave action and the variations in the wave regime during winter and summer would force erosion in the winter, due to an increased wave action and more frequent storms (higher energy level). During the summer calm weather would result in more sedimentation.

This mechanism would act in the outer part of the tidal flats in the same way as it usually works on beach coasts, especially in the shallow parts. Besides, the seasonal variations are more distinct in the deeper parts of the evaluated cross-sections, in depths about 15 meters, usually bellow the wave basis. Although the area of Kronenloch is located in a quite protected inner part of the area (with respect to the wave action), the seasonal cycle could be clearly identified there. It is reliable to propose that if the seasonal cycle of erosion-deposition occurs in inner (Kronenloch) and outer parts (Norderpiep) of the study area, the main propellant of the cycle should be the same at inner and outer parts.
Frequent storms in the winter might also result in increased current velocities in the channels during the winter, due to the storm surge effect, which might produce exceptional tides (tidal ranges), with corresponding elevated current velocities. This mechanism would act over channels in the whole area, but the evaluation of effects of a storm during 30th October 2002 indicated actually deposition in the channels after the storm. In this context, storms would result in deposition at the channelbeds, instead erosion, and can not explain the observed seasonal cycle. However, the lateral asymmetric pattern of tidal currents would occur along the entire main channel, and in association with the seasonal variation in the physic properties of the water would explain the lateral migration and the observed seasonal cycle.

CONCLUSIONS

Due to the periodic measurements of morphology and hydrodynamic during the last 3 years it was possible evaluate the short-term morphological changes in the Piep tidal channel system. These results were complemented by the analyses of bathymetric measurements from the last 30 years, carried out by the German Federal Agency for Navigation and Hydrography. The results delivered very interesting results about the morphodynamics of the study area. It was possible to identify the main morphological changes and morphodynamic trends that are taken place and, due to the study of the hydrodynamics, the mechanisms forcing the observed changes.

Two main trends of morphological changes were identified. These comprise a lateral migration of channels and a seasonal cycle of predominant erosion in the autumn to winter and predominant deposition in the spring to summer.

It could be determined that a substantial lateral distortion (asymmetry) in the tidal flow takes place in the evaluated cross-sections. This was concluded to be the main forcing of lateral migration of the channels. This lateral asymmetry is attributed to the Coriolis effect, in connection with the constriction of tidal flow in the channels. The flood currents are more associated with positive sediment transport and the ebb currents with negative sediment transport (erosion). Since flood and ebb currents are stronger in opposite sides, a lateral migration of the channel takes place.

The seasonal erosion sedimentation cycle observed in the channels would be mainly associated with the seasonal variation in the kinematic viscosity of the water mass involved in the tidal flow, resulting from important differences in the average water temperature during summer and winter. An increased energy level resulting from a more intense wind and wave action during the winter seems to have a secondary role, especially regarding to the channels. Measurements of channel cross-sections before and after a storm have shown that increased wave action result in fact in substantial deposition in the channels, which seem to be driven enough to prevent erosion due to wave action. Sediment would be eroded from shallow parts and transported/deposited in the channels, as indicated in the present study.

Furthermore, it can be concluded that the two main identified processes of morphological changes are closely related. In general the lateral migration of the main channels is the result of combination of tidal asymmetry with the seasonal cycle in terms of substantial differences in the kinematic viscosity of the water between summer and winter. Erosion prevails in the winter, especially in the flood-side, while deposition prevails in the summer, especially in the ebb-side of the channels, resulting in the general lateral migration of the channels.

ACKNOWLEDGMENTS

I would like to sincerely thank all colleagues from the Coastal Research Laboratory (CORELAB) and from the Research and Technology Center Westcoast (FTZ) of the Kiel University for their collaboration and support in the measurements in the scope of the PROMORPH project. In this context I would like to thank especially Prof. Dr. Roberto Mayerle and Dr. Klaus Ricklefs. I really appreciate the collaboration of the German authorities for dispose several data sets for the development of this work, especially bathymetric data (Federal Maritime and Hydrographic Agency - Hamburg, Germany) and water level measurements (Gewässerkunde Bismark (ALR. Husum)). The German Academic Exchanges Service (DAAD) is acknowledged for supporting my Ph.D. studies, in which the present work is inserted.

LITERATURE CITED


ASP, N.E., 2003. Long to short-term morphological evolution of the tidal flats in the Dithmarschen Bight, German North Sea. Kiel, Germany: University of Kiel for their collaboration and support in the measurements in the scope of the PROMORPH project. In this context I would like to thank especially Prof. Dr. Roberto Mayerle and Dr. Klaus Ricklefs. I really appreciate the collaboration of the German authorities for dispose several data sets for the development of this work, especially bathymetric data (Federal Maritime and Hydrographic Agency - Hamburg, Germany) and water level measurements (Gewässerkunde Bismark (ALR. Husum)). The German Academic Exchanges Service (DAAD) is acknowledged for supporting my Ph.D. studies, in which the present work is inserted.

LITERATURE CITED


ASP, N.E., 2003. Long to short-term morphological evolution of the tidal flats in the Dithmarschen Bight, German North Sea. Kiel, Germany: University of Kiel for their collaboration and support in the measurements in the scope of the PROMORPH project. In this context I would like to thank especially Prof. Dr. Roberto Mayerle and Dr. Klaus Ricklefs. I really appreciate the collaboration of the German authorities for dispose several data sets for the development of this work, especially bathymetric data (Federal Maritime and Hydrographic Agency - Hamburg, Germany) and water level measurements (Gewässerkunde Bismark (ALR. Husum)). The German Academic Exchanges Service (DAAD) is acknowledged for supporting my Ph.D. studies, in which the present work is inserted.

LITERATURE CITED


ASP, N.E., 2003. Long to short-term morphological evolution of the tidal flats in the Dithmarschen Bight, German North Sea. Kiel, Germany: University of Kiel for their collaboration and support in the measurements in the scope of the PROMORPH project. In this context I would like to thank especially Prof. Dr. Roberto Mayerle and Dr. Klaus Ricklefs. I really appreciate the collaboration of the German authorities for dispose several data sets for the development of this work, especially bathymetric data (Federal Maritime and Hydrographic Agency - Hamburg, Germany) and water level measurements (Gewässerkunde Bismark (ALR. Husum)). The German Academic Exchanges Service (DAAD) is acknowledged for supporting my Ph.D. studies, in which the present work is inserted.

LITERATURE CITED


ASP, N.E., 2003. Long to short-term morphological evolution of the tidal flats in the Dithmarschen Bight, German North Sea. Kiel, Germany: University of Kiel for their collaboration and support in the measurements in the scope of the PROMORPH project. In this context I would like to thank especially Prof. Dr. Roberto Mayerle and Dr. Klaus Ricklefs. I really appreciate the collaboration of the German authorities for dispose several data sets for the development of this work, especially bathymetric data (Federal Maritime and Hydrographic Agency - Hamburg, Germany) and water level measurements (Gewässerkunde Bismark (ALR. Husum)). The German Academic Exchanges Service (DAAD) is acknowledged for supporting my Ph.D. studies, in which the present work is inserted.

LITERATURE CITED


ASP, N.E., 2003. Long to short-term morphological evolution of the tidal flats in the Dithmarschen Bight, German North Sea. Kiel, Germany: University of Kiel for their collaboration and support in the measurements in the scope of the PROMORPH project. In this context I would like to thank especially Prof. Dr. Roberto Mayerle and Dr. Klaus Ricklefs. I really appreciate the collaboration of the German authorities for dispose several data sets for the development of this work, especially bathymetric data (Federal Maritime and Hydrographic Agency - Hamburg, Germany) and water level measurements (Gewässerkunde Bismark (ALR. Husum)). The German Academic Exchanges Service (DAAD) is acknowledged for supporting my Ph.D. studies, in which the present work is inserted.

LITERATURE CITED


ASP, N.E., 2003. Long to short-term morphological evolution of the tidal flats in the Dithmarschen Bight, German North Sea. Kiel, Germany: University of Kiel for their collaboration and support in the measurements in the scope of the PROMORPH project. In this context I would like to thank especially Prof. Dr. Roberto Mayerle and Dr. Klaus Ricklefs. I really appreciate the collaboration of the German authorities for dispose several data sets for the development of this work, especially bathymetric data (Federal Maritime and Hydrographic Agency - Hamburg, Germany) and water level measurements (Gewässerkunde Bismark (ALR. Husum)). The German Academic Exchanges Service (DAAD) is acknowledged for supporting my Ph.D. studies, in which the present work is inserted.

LITERATURE CITED


ASP, N.E., 2003. Long to short-term morphological evolution of the tidal flats in the Dithmarschen Bight, German North Sea. Kiel, Germany: University of Kiel for their collaboration and support in the measurements in the scope of the PROMORPH project. In this context I would like to thank especially Prof. Dr. Roberto Mayerle and Dr. Klaus Ricklefs. I really appreciate the collaboration of the German authorities for dispose several data sets for the development of this work, especially bathymetric data (Federal Maritime and Hydrographic Agency - Hamburg, Germany) and water level measurements (Gewässerkunde Bismark (ALR. Husum)). The German Academic Exchanges Service (DAAD) is acknowledged for supporting my Ph.D. studies, in which the present work is inserted.

LITERATURE CITED


ASP, N.E., 2003. Long to short-term morphological evolution of the tidal flats in the Dithmarschen Bight, German North Sea. Kiel, Germany: University of Kiel for their collaboration and support in the measurements in the scope of the PROMORPH project. In this context I would like to thank especially Prof. Dr. Roberto Mayerle and Dr. Klaus Ricklefs. I really appreciate the collaboration of the German authorities for dispose several data sets for the development of this work, especially bathymetric data (Federal Maritime and Hydrographic Agency - Hamburg, Germany) and water level measurements (Gewässerkunde Bismark (ALR. Husum)). The German Academic Exchanges Service (DAAD) is acknowledged for supporting my Ph.D. studies, in which the present work is inserted.

LITERATURE CITED


