Bachelor Earth Sciences
Final exam of GEO3-4306 Coastal Morphodynamics

Date: January 27, 2016
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Please note the following:

- Answer each question on a separate piece of paper.
- Before you start, carefully read the whole question.
- Put your name and student number on each piece of paper.
- You may use the book by Masselink, Hughes & Knight, the readers by Hoekstra, and a calculator. The use of hand-outs (ppts), your own notes, papers used during the course, and answers to papers and exercises is NOT allowed.
- In several sub-questions a *brief* answer is requested. This means that a few short sentences are already sufficient.

Question 1: Coastal zone management of sandy beaches

Terschelling is a barrier island along the northern part of the Dutch coast (Figure 1.1). On its northern side it faces the North Sea, while on its southern side it is bordered by the Wadden Sea, an extensive area characterized by tidal flats and channels. Figure 1.2 provides information on the North Sea wave climate just north of Terschelling, schematized as wave roses for various significant-wave-height classes. During storms, the significant wave height offshore of Terschelling can reach values of 5 to 6 m, with corresponding periods of 10 to 15 s. The tide at Terschelling is semi-diurnal, with an approximately 2.5-m range during spring tide.

The nearshore zone of Terschelling is characterized by 3 subtidal sandbars; see the black line in Figure 1.1 denoted 23-04-1993. The grain size in the nearshore zone is approximately 300 μm. The foredune is approximately 20 m high and fully covered by marram grass.

Large parts of the Terschelling coast experienced severe erosion over the last decades. Therefore, a shoreface nourishment was implemented in late-summer 1993 (see Figure 1.1, dotted line denoted 06-10-1993) between beach-poles 14 and 18. The expectation was that natural processes would bring the nourished sand landward onto the beach to create a wide beach that is less prone to erosion. Also, the wide beach was expected to create new opportunities for tourism and nature.

As can be seen in Figure 1.1, the nourishment filled up the trough between the outer and middle subtidal sandbar. The total volume of the nourishment was 2.5 million m^3. To the east and to the west of this nourishment, the trough remained unaltered.

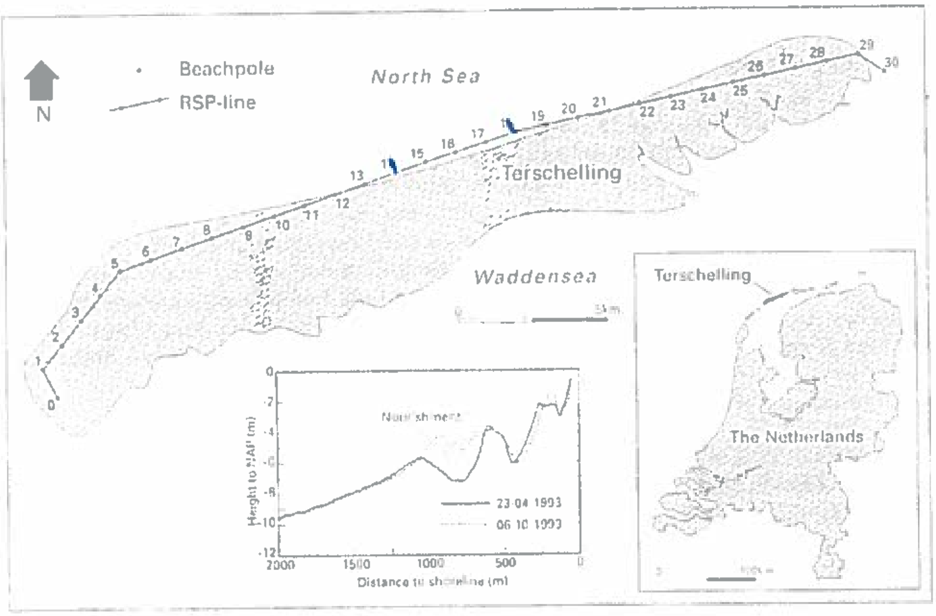
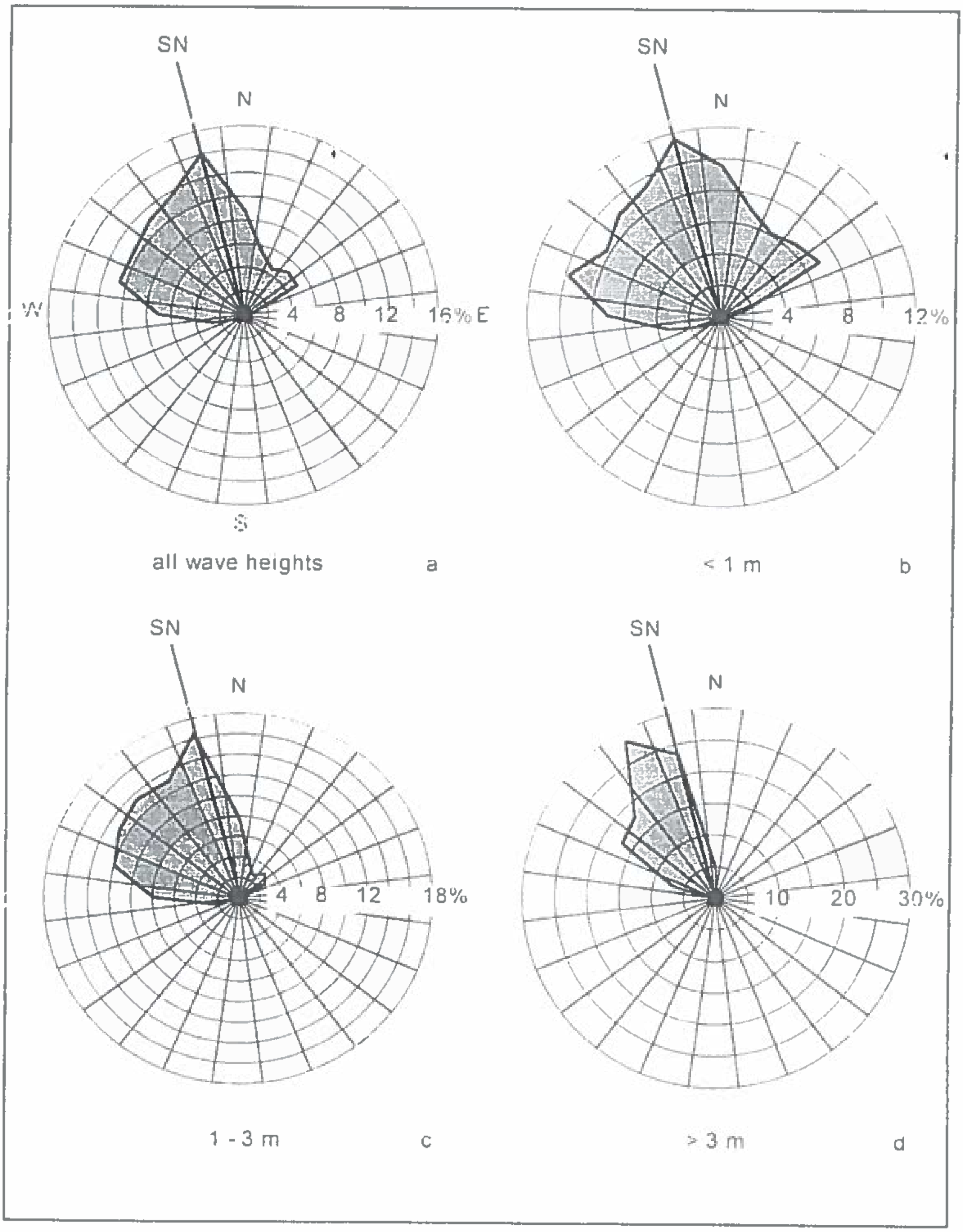


Figure 1.1 Location of Terschelling



all wave heights a

< 1 m b

1 - 3 m c

> 3 m d

Figure 1.2 Directional frequency of occurrence ('wave roses') of the offshore significant wave height H_s at Terschelling: (a) for all H_s, (b) for H_s < 1 m, (c) for 1 < H_s < 3 m, and (d) H_s > 3 m. SN stands for the shore-normal direction. N, E, S and W are North, East, South, and West, respectively.

a) *Briefly* explain why the nourishment at Terschelling is a good example of the Building-with-Nature approach in coastal zone management.

b) The nourishment was implemented in such a way that energetic shoaling waves will particularly contribute to the onshore transport of the nourished sand. Explain why energetic shoaling waves transport sand onshore.

c) Use Figure 1.2 to determine whether the net alongshore sand transport along Terschelling is to the east or to the west. *Briefly* explain your answer.

d) After 3 years, a total of 0.8 million m^3 of sand had been lost from the nourishment area and presumably been transported onshore. The area shoreward of the nourishment, however, had gained a total of 2.4 million m^3 of sand. This implies that $2.4 - 0.8 = 1.6$ million m^3 of the deposited sand did not come directly from the nourishment. What is the most likely source of the additional 1.6 million m^3 of sand? Explain your answer.

e) *Briefly* explain how the expected wider beach may lead to new opportunities for nature.

Question 2: Sand transport and morphological evolution during a storm

In September and October 1992 measurements of waves, currents, sand concentrations and morphological change of subtidal sandbars were performed at Burley Beach (Canada). Figure 2.1 shows the cross-shore bed profile at the start of the measurements, on 24 September. The location of the instruments across the sandbar, labeled B-I, B-II, B-III, H and B-IV, is also shown.

On October 16 and 17 the wind speed increased to over 15 m/s, which resulted in waves that were sufficiently high to start breaking at location B-IV. The morphology was observed to be uniform in the alongshore direction.

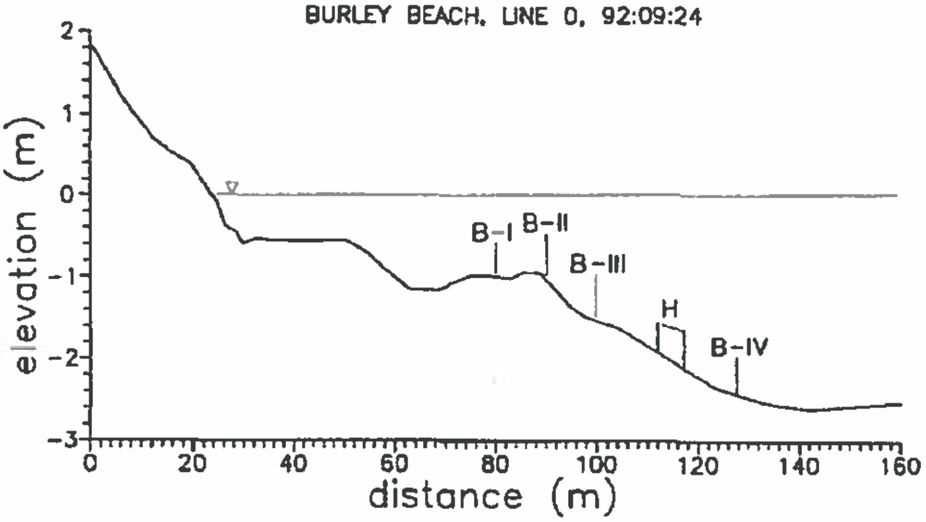


Figure 2.1 Cross-shore profile with instrument locations. The sandbar has its crest at distance ~90 m.

Figure 2.2 shows several sand transport rates as measured at location H during the peak of the storm on October 16. The upper transport rate is the net transport rate. The other three rates are (in downward direction) the sand transport rates by the cross-shore mean current, by incident sea waves and by infragravity waves. The net transport rate is the sum of these three transport rates.

a) Explain what is meant by the sand transport rates by the cross-shore mean current, by the incident sea waves and by infragravity waves. For each of these 3 rates, pay attention to which processes are responsible for sand stirring and which for the actual transport. Do not explain the direction or the relative importance of these rates.

b) The measurements at location H (Figure 2.2) show that the sand transport rate by the cross-shore mean current dominates the net transport rate. Provide a motivated answer which cross-shore mean current is most likely to dominate the sand transport at location H. Also provide an estimate of the magnitude of this cross-shore mean current.

c) Figure 2.2 also shows the cross-shore profile before (92:10:15) and after (92:10:20) the storm. Use the *morphodynamic system approach* to explain why the sandbar migrated offshore during the storm.

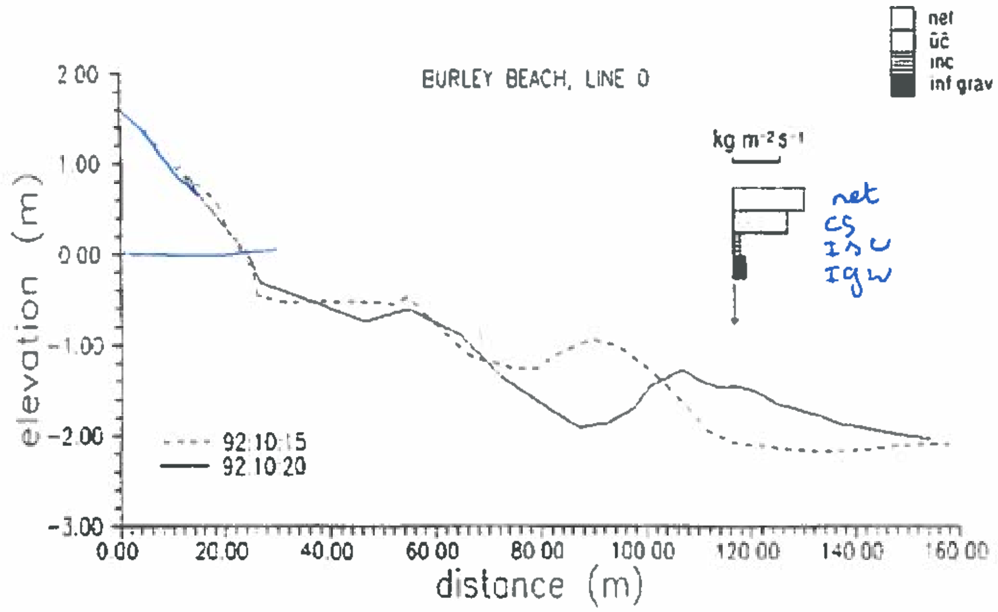


Figure 2.2 Cross-shore profile before (92:10:15 = October 15, 1992) and after (92:10:20 = October 20, 1992) the storm. The histogram at location H (distance ~ 115 m) shows sand transport rates during the peak of the storm (October 16, 1992). From top to bottom: net, mean-current, incident wave and infragravity transport rate. The net rate is the sum of the other three terms.

Question 3: Tidal conditions in a shelf sea environment and the morphodynamics of a river delta

The Gulf of Tonkin (Figure 3.1) is located in South East Asia, near the coast of North Vietnam and South China; the Red River flows into the Gulf of Tonkin and has created a large river delta with its apex NW of Hanoi, see Figure 3.2. The Red River Delta has developed several river branches; each subdelta will have its own morphological characteristics based on the local fluvial and marine conditions. Tidal conditions in the Gulf of Tonkin are also depicted in Figure 3.1.

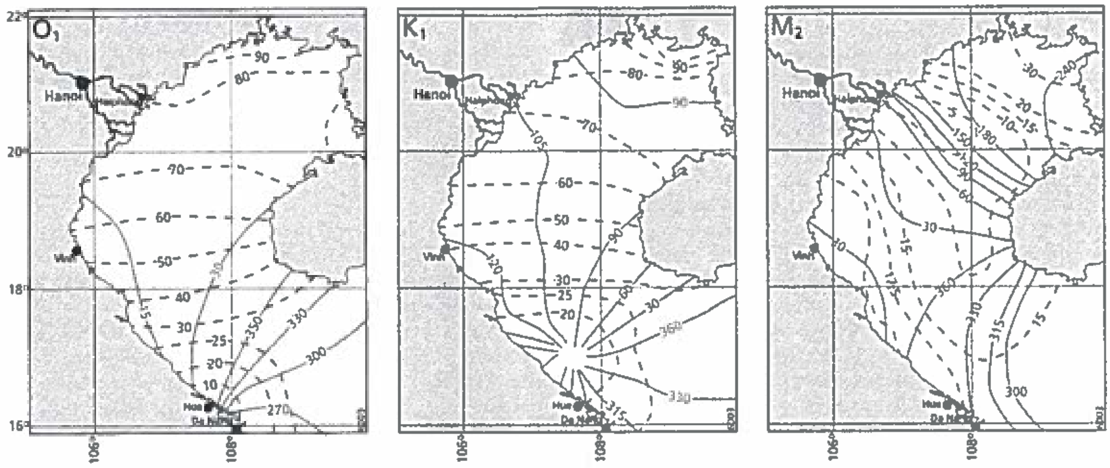


Figure 3.1 Tidal conditions for different tidal constituents O_1, K_1 and M_2 in the Gulf of Tonkin, near the coast of the Red River Delta (north Vietnam). Indicated are co-tidal and co-range lines.

a) Explain the pattern of co-tidal and co-range lines for the three tidal constituents in the Gulf of Tonkin. In your answer, explain the difference in behaviour for the diurnal and semi-diurnal tides.

b) Are the tidal conditions near the City of Hue (in the south) diurnal, semidiurnal or mixed? Briefly motivate your answer.

Due to the variability of fluvial and marine conditions, the morphological characteristics of the Red delta will vary in time and space. Figure 3.2 gives an overview of the delta and an example of one of the subdeltas, the Ba Lat delta (southwest). The subdelta near Haiphong (north) is clearly different from the Ba Lat delta.

c) Describe the main morphological characteristics of both subdeltas.

d) Outline the relative role of river outflow, waves and tides in shaping the morphological characteristics of both subdeltas.

e) *Briefly* motivate where you expect the presence and development of buoyant river plumes.

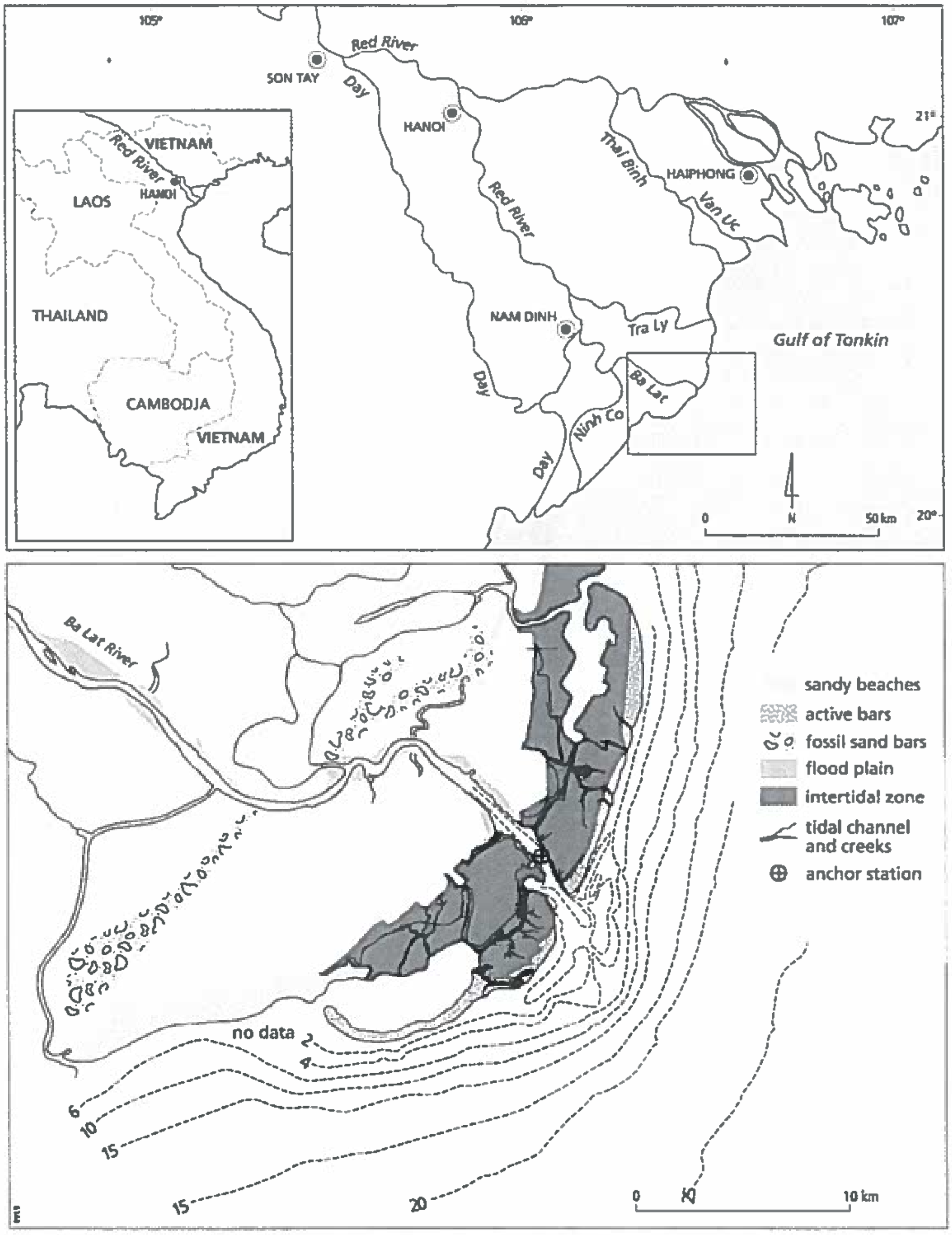


Figure 3.2 The Red river delta with subdeltas: near Haiphong in the north and the Ba Lat in the southwest.

Question 4: Flow processes in the Marsdiep Tidal inlet

In the Marsdiep tidal inlet regular velocity and salinity measurements are carried out by a series of sensors installed on the ferryboat that connects the city of Den Helder (code DH) with the island of Texel (code TX). During a large part of the tidal cycle information is collected about the streamwise velocities (in the direction of the longitudinal axis of the inlet), the secondary circulation (across the inlet, almost north - south or v.v.) and the density distribution. The location of the inlet and the position of the ferry transect is indicated in Figure 4.1.

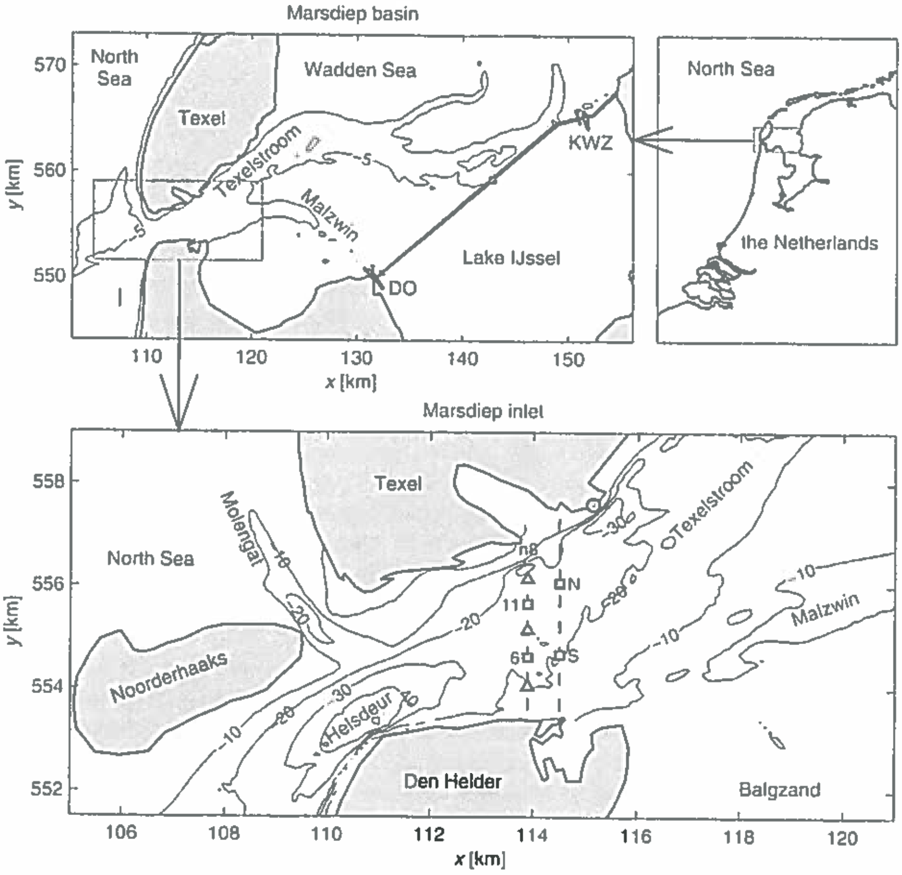


Figure 4.1 The Marsdiep basin (top left panel) and inlet (bottom panel) in the Netherlands. DO and KWZ refer to discharge sluices of freshwater (referring to Den Oever and Kornwerderzand). The vertical dashed line in the bottom figure marks the ferry transect **f.** Bathymetry is contoured in (m) relative to mean sea level.

Major forces that are relevant for secondary flow within the inlet are due to the effect of curvature (geometry of the bend: centrifugal force), the Coriolis force, and the baroclinic pressure gradient due to the density distribution. The relative magnitude of these forces will vary over the tidal cycle (e.g., ebb or flood) and will also depend on the cross-sectional location within the inlet. The secondary flow pattern in the inlet can be described in a conceptual model, see Figure 4.2. In this model the three mechanisms are indicated by a code C1, D and E.

a) Clearly explain which mechanism corresponds to C1, D and E, respectively.

b) Based on the three mechanisms, explain the secondary flow field within the inlet (Figure 4.2) for maximum flood (well-mixed), maximum ebb (well-mixed), late flood (stratified), early ebb (stratified) and late ebb (stratified).

c) In the conceptual model the effect of waves is ignored. Outline how important the waves are for the hydrodynamics in the tidal inlet. In your answer, address how the presence of waves – from either the North Sea or Wadden Sea – is likely to impact the conceptual model for conditions during late flood or late ebb.

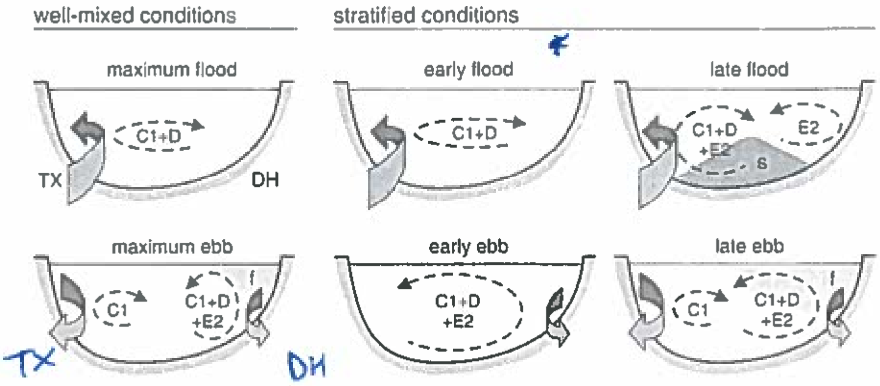


Figure 4.2 Conceptual model of the secondary circulation during several phases of the tidal cycle and for well-mixed as well as stratified conditions in the cross-section of the inlet. The view is in the flood direction with Texel (TX) to the left and Den Helder (DH) on the right hand side. The dashed arrows indicate the secondary circulation; the shaded arrows indicate the curvature of the flow. The influx of saline water during flood is represented by s in the diagram. The f represents fresh water influx during ebb.