Sand Bank Formation: Comparison between 2D and 3D Models

Giovanni Besio, Paolo Blondeaux and Giovanna Vittori

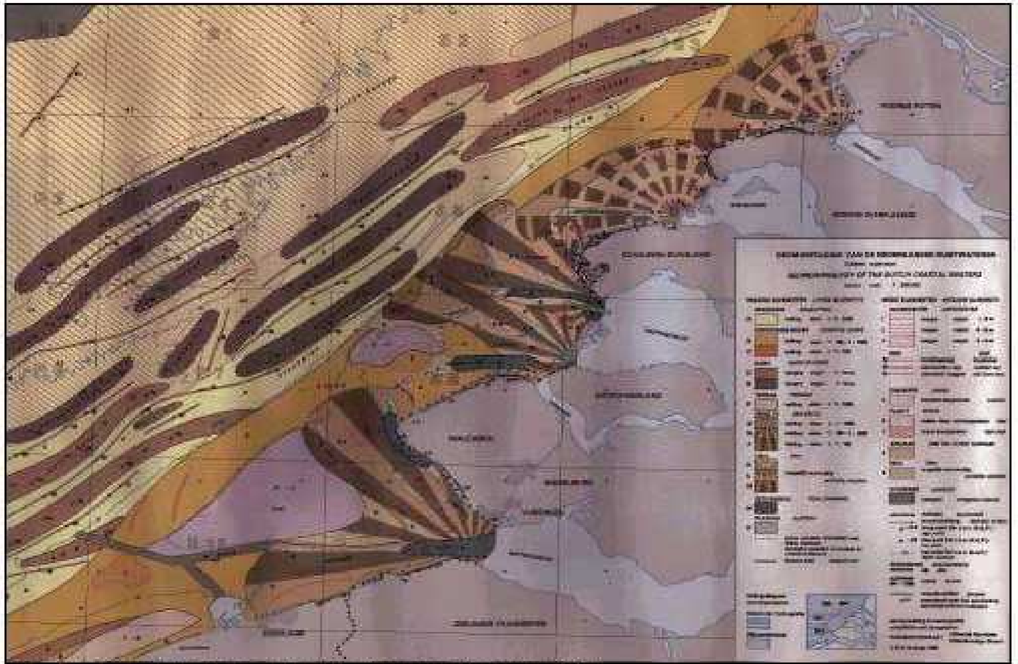

Figure 0.1: Geomorphological map Zeeland ridges (Van Alphen & Damoiseaux, 1989)

(Van Alphen & Damoiseaux, 1989)

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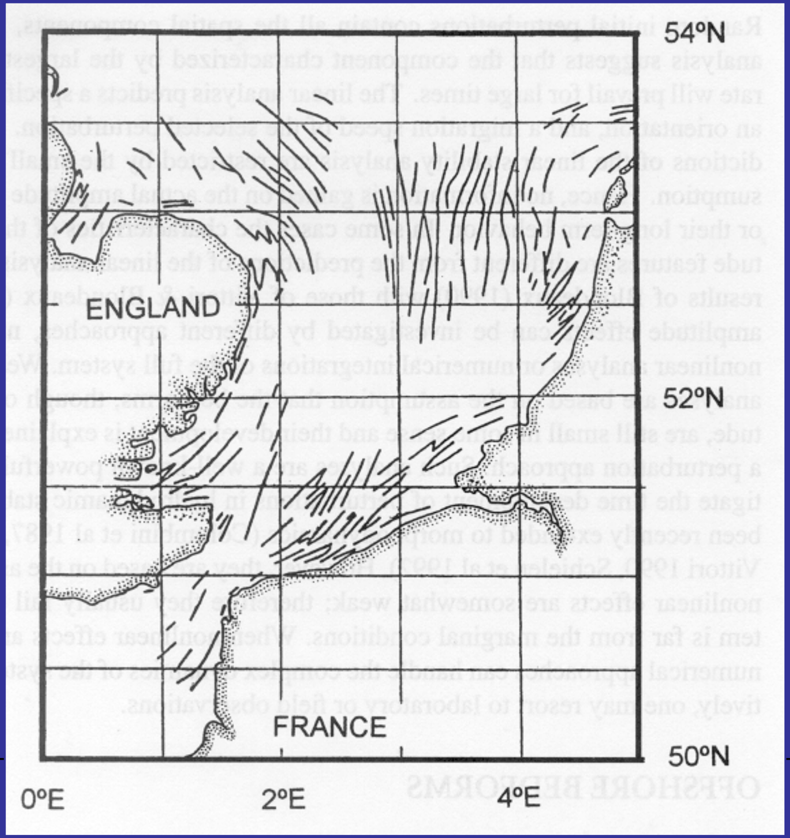
• Sand banks are formed due to an instability mechanism of the sea bottom subject to tidal flow
(Huthnance, 1982; Hulscher et al. (1993); Hulscher (1996); Besio et al. (2005))

Models available to predict sand banks appearance and their wavelength are:

- depth averaged models (Huthnance, 1982; Hulscher et al., 1993)
- 3D models with shallow water approximation (Hulscher, 1996)
- fully 3D model (Besio et al. (2005))



Only the fully 3D model has predicted so far clockwise and counter-clockwise oriented sand banks

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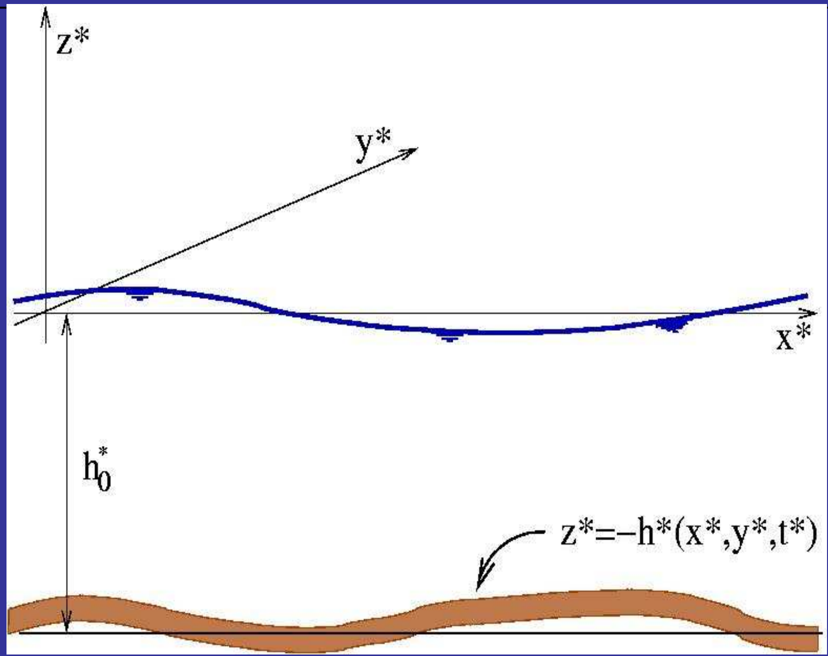
Aim of present contribution:

comparison between the predictions of sand banks orientation as obtained by means of the fully 3D and a depth-averaged models

Outline of presentation

1. Brief description of 3D model
2. Results on sand banks
3. Brief introduction of improved depth averaged model
4. Results of improved depth-averaged model
5. Conclusions

3D model



- Plane-averaged bottom subject to an elliptical tidal flow
- Stability of the basic flow with respect to 2D disturbances of the bottom (sand banks and sand waves)
- Fully 3D model
- Prediction of both sand banks (order of wavelength = a few Kilometers) and sand waves (order of wavelength ~100 m)

3D model (Besio, Blondeaux & Vittori, 2005 submitted to J. Fluid Mech)

HYDROYNAMICS

- unsteady 3D Reynolds equations with Coriolis terms + continuity
- Boussinesq closure with depth-varying eddy viscosity
- kinematic and dynamic boundary conditions at the free surface
- no-slip condition at the bottom

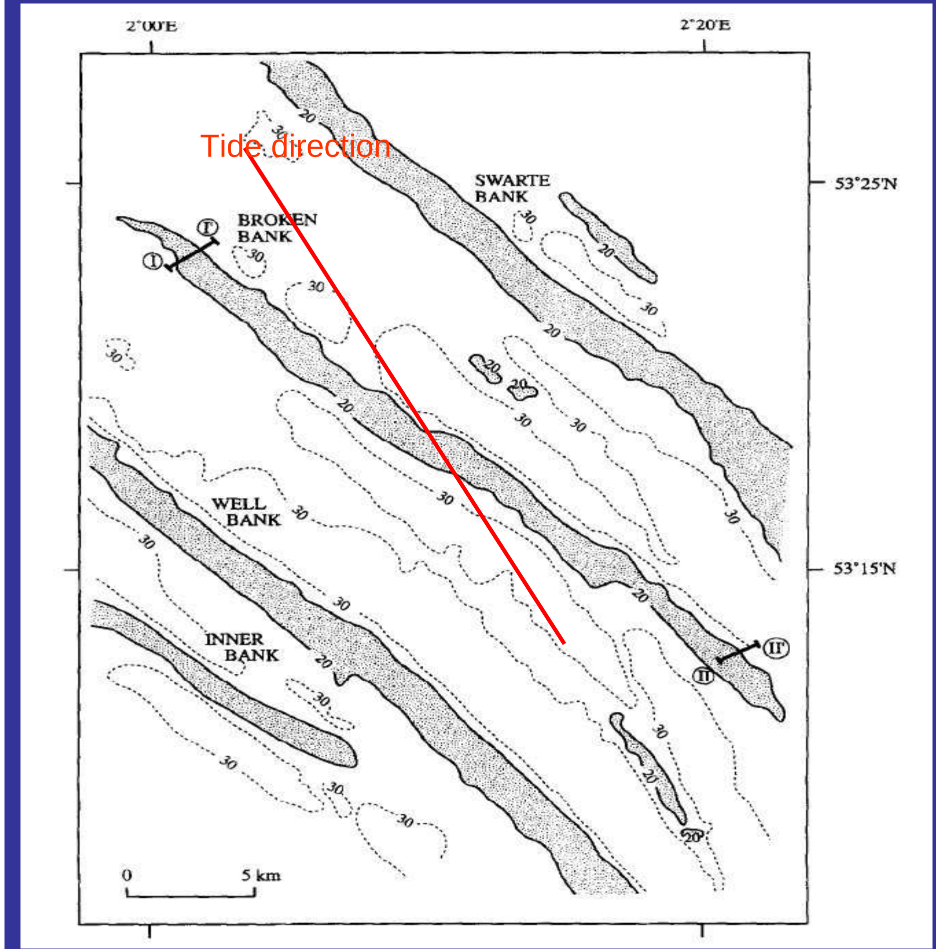
MORPHODYNAMICS

- Sediment continuity equation

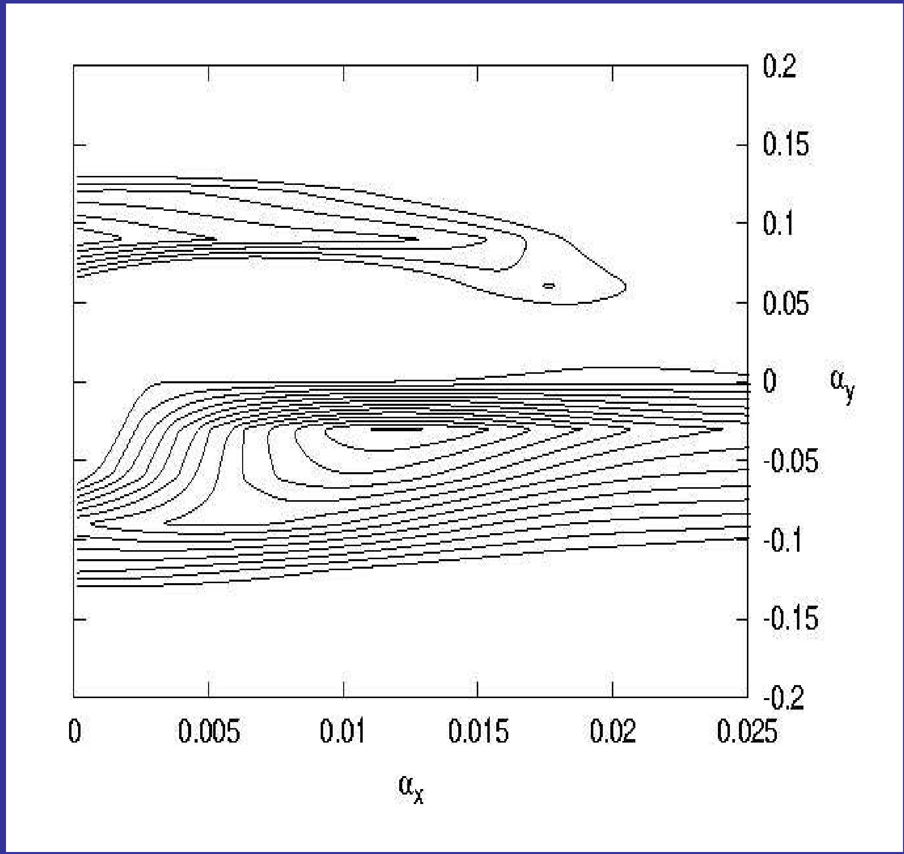
- Bedload is computed according to Van Rijn (1991) and slope effects are accounted for

- The suspended load is computed by evaluating the flux of sediment concentration c (c is obtained by integrating a convection-diffusion concentration equation)

PREDICTIONS OF SAND BANKS WITH THE 3D MODEL (Norfolk banks (UK))



Crests counter-clockwise oriented with respect to tidal flow with a typical distance of 8-10 Km e and a length of the order of Kilometers



Growth rate of bottom perturbation as a function of the horizontal wavenumbers

- wavelength=6 Km
- counter-clockwise oriented crests

(Zeeland banks (NL))

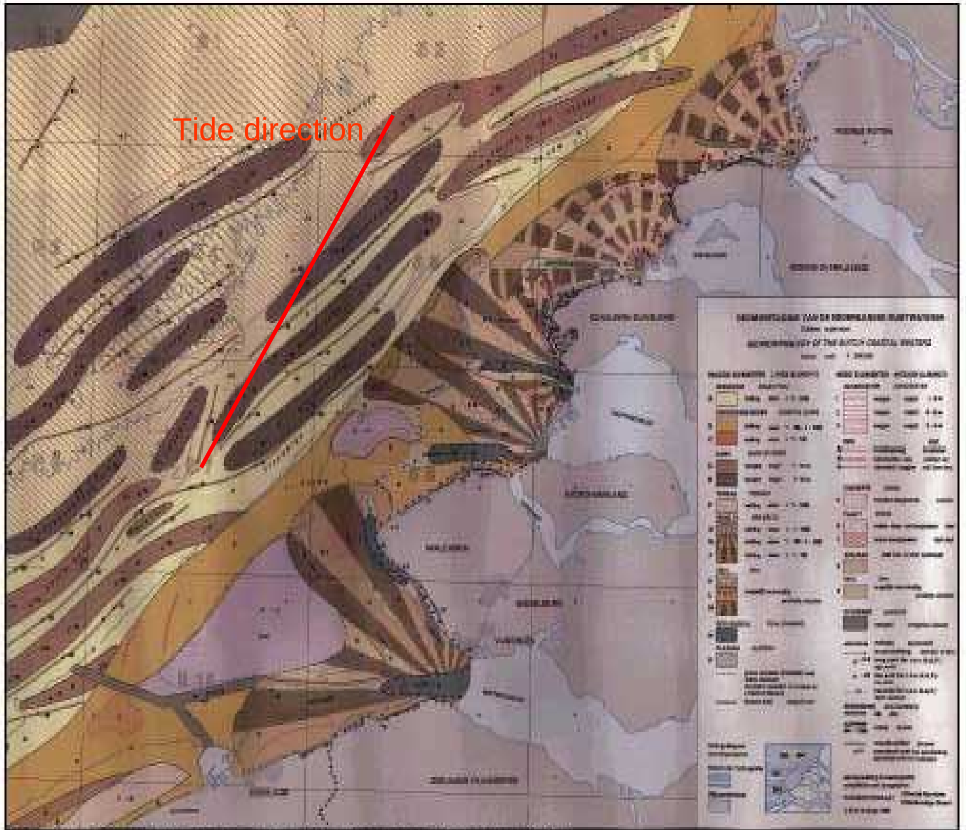


Figure 0.1: Geomorphological map Zeeland ridges (Van Alphen & Damoiseaux, 1989)

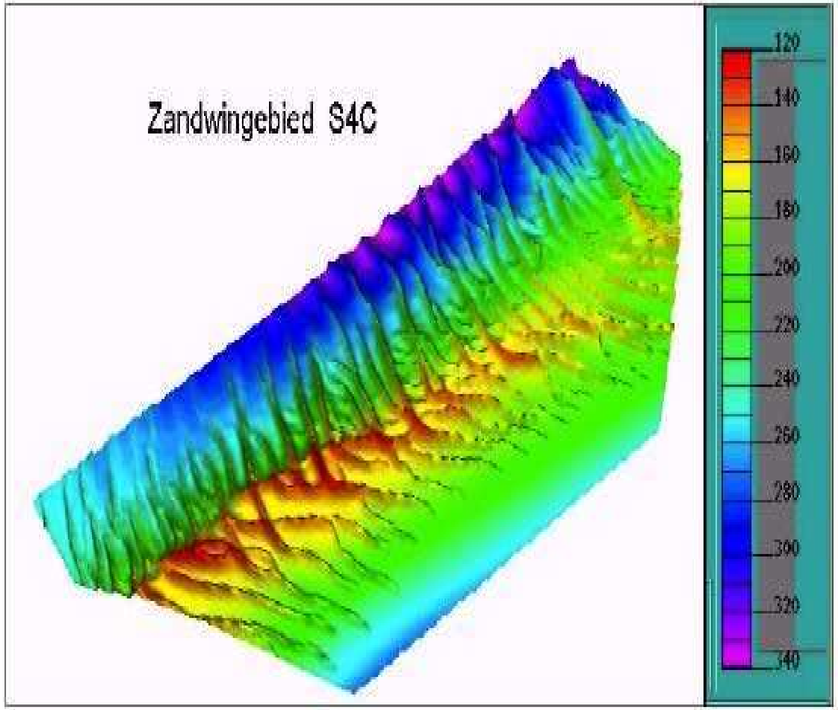


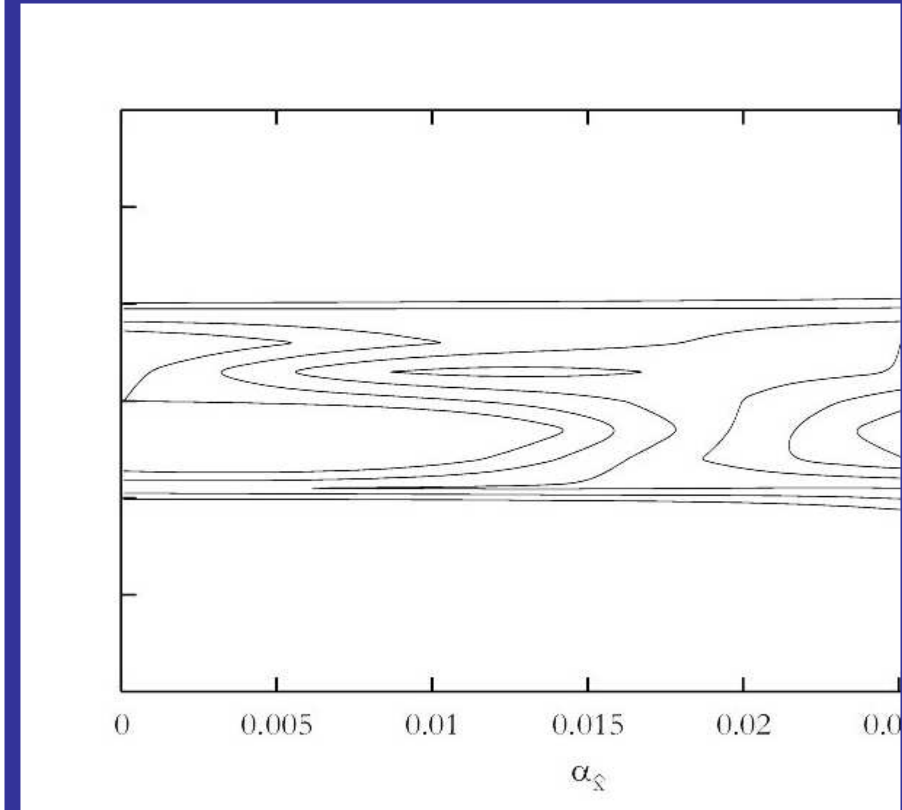
Figure 3.4: Bathymetry sand extraction area on the Middelbank, depth in dm – NAP (map from RWS, DNZ, 2003)

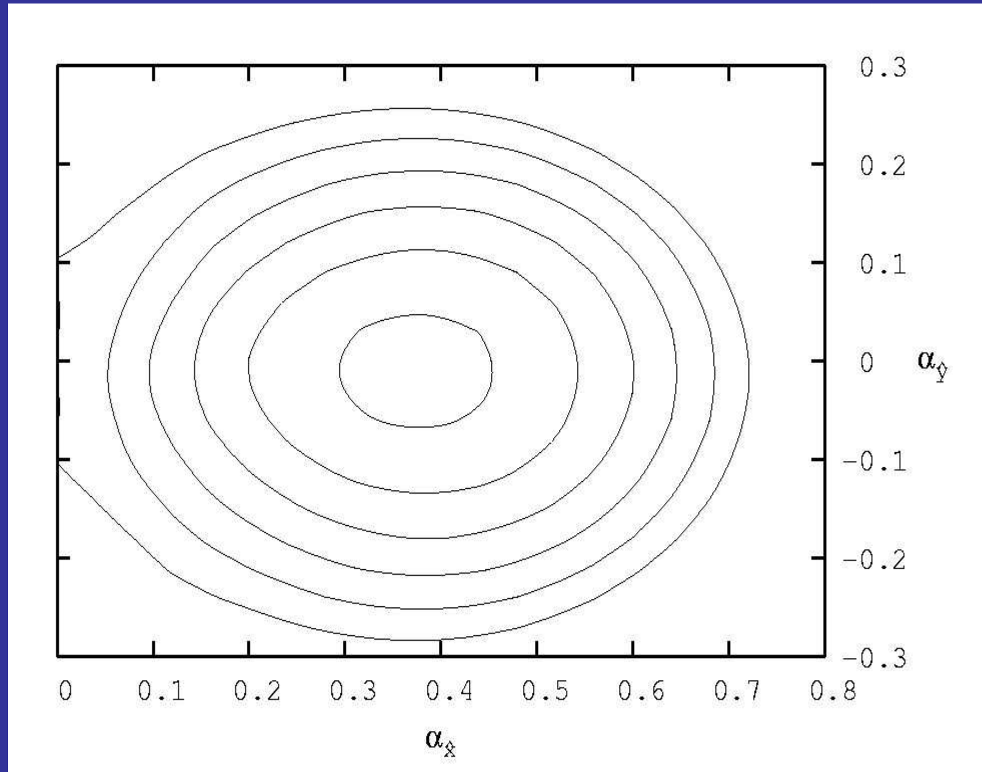
(Adapted from Hommes, 2004)

Clockwise oriented crests with respect to main tidal direction
Average crests distance 4-5 Km
Crests length ~ tens of Kilometres

Simultaneous presence of sand banks and sand waves with wavelength ranging from 100 to 800 m

PREDICTIONS OF THE 3D MODEL: growth rate as a function of wavenumbers in the direction of the tide and in the orthogonal direction.





<u>1 relative maximum</u>: sand banks clock-wise oriented with respect to the tidal current and with wavelength approximately equal to 4.5 Km

<u>2 relative maximum</u>: sand waves with wavelength approximately equal to a 300 m

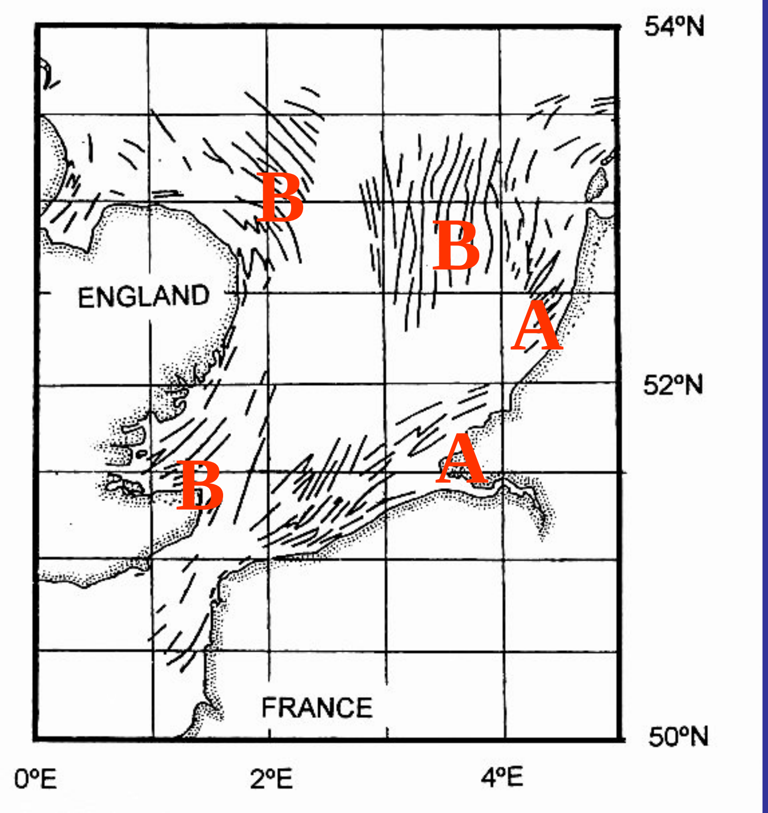
SAND BANKS AND TIDE ROTATION IN THE NORTH SEA

Shadowed regions=clockwise rotating tidal ellipse

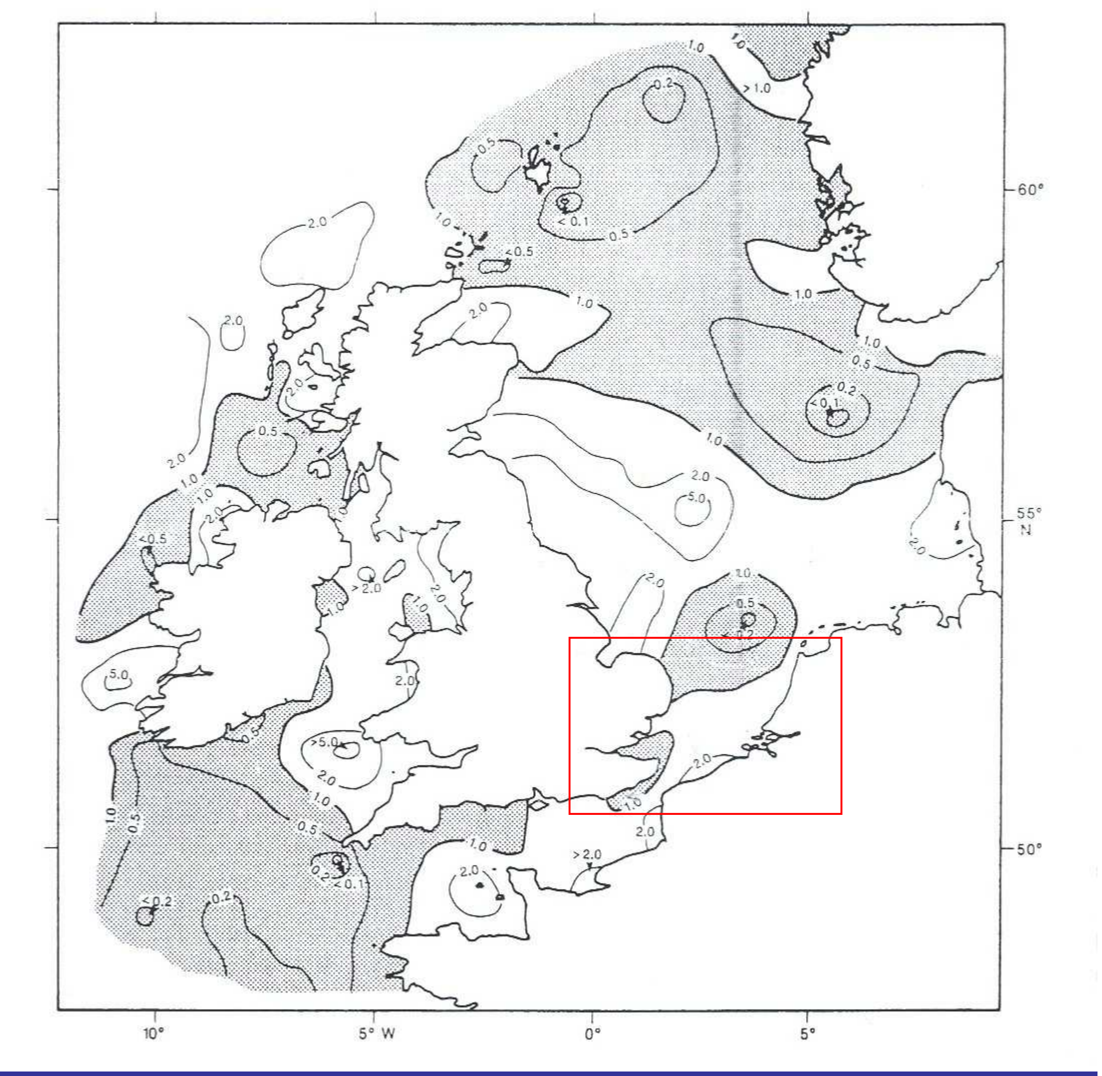
Blank regions= counter-clockwise rotating tidal ellipse

A=clockwise oriented sand banks

B=counter-clockwise oriented sand banks

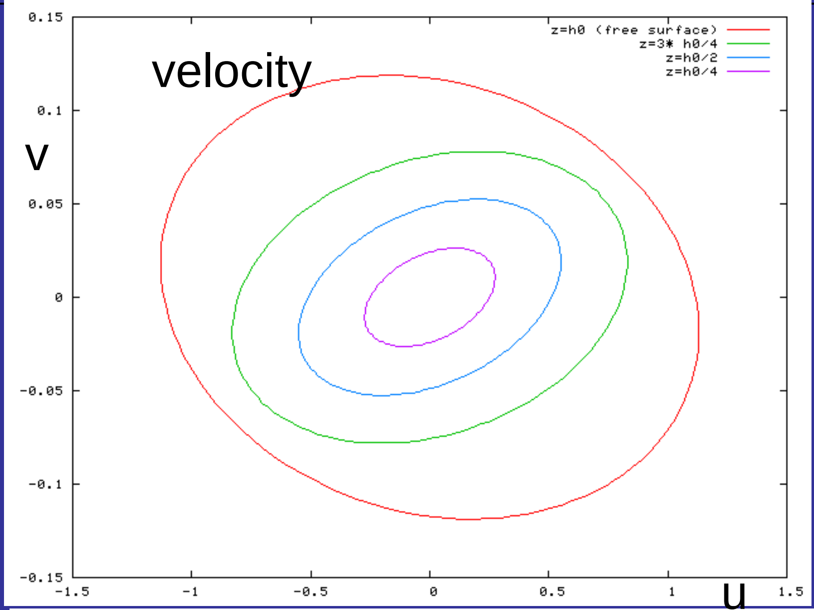


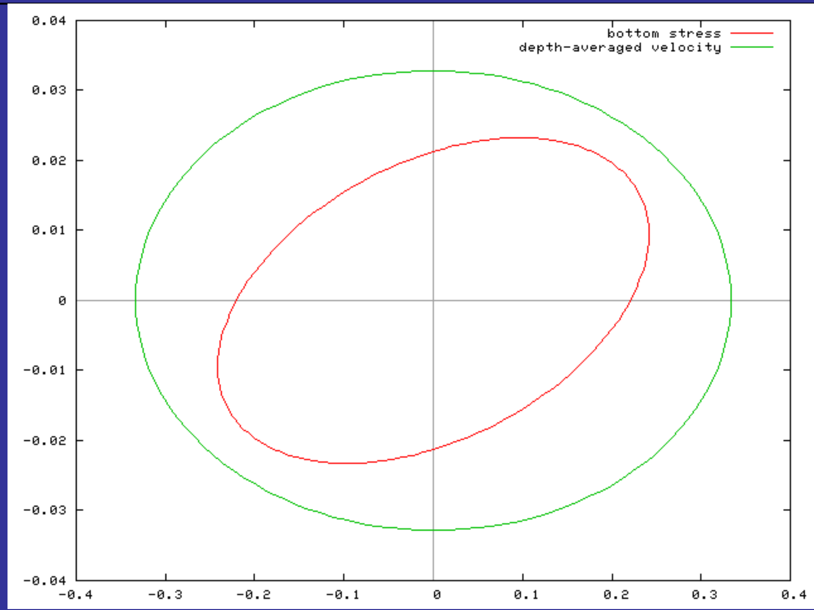
Adapted from Dyer & Huntley (1999)

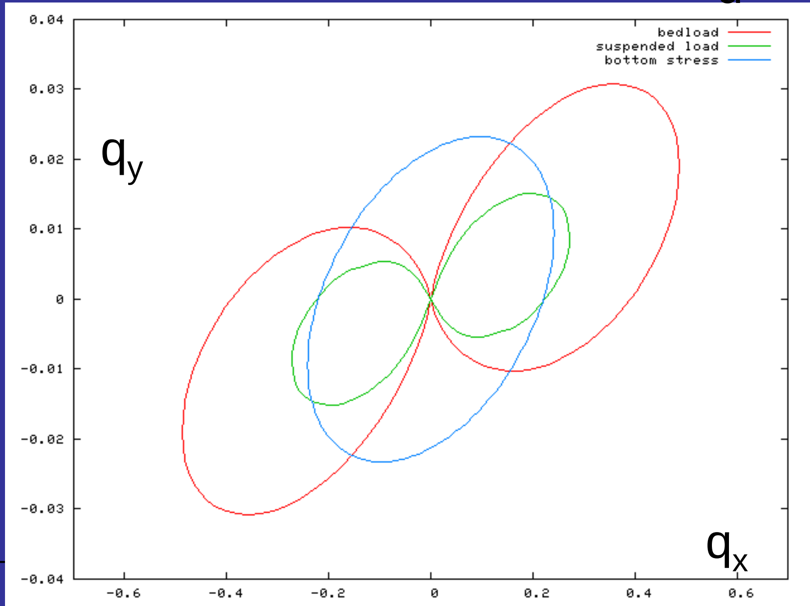


Adapted from Soulsby (1983)

3D model – results







- Coriolis effects induce a 3D distortion of the velocity profile
- The orientation of the sediment transport and depth-averaged velocity are different

e_{cc}=0.1

2D model – outline

Hydrodynamics:

- ✓ depth-averaged continuity and momentum equation
- ✓ Coriolis terms

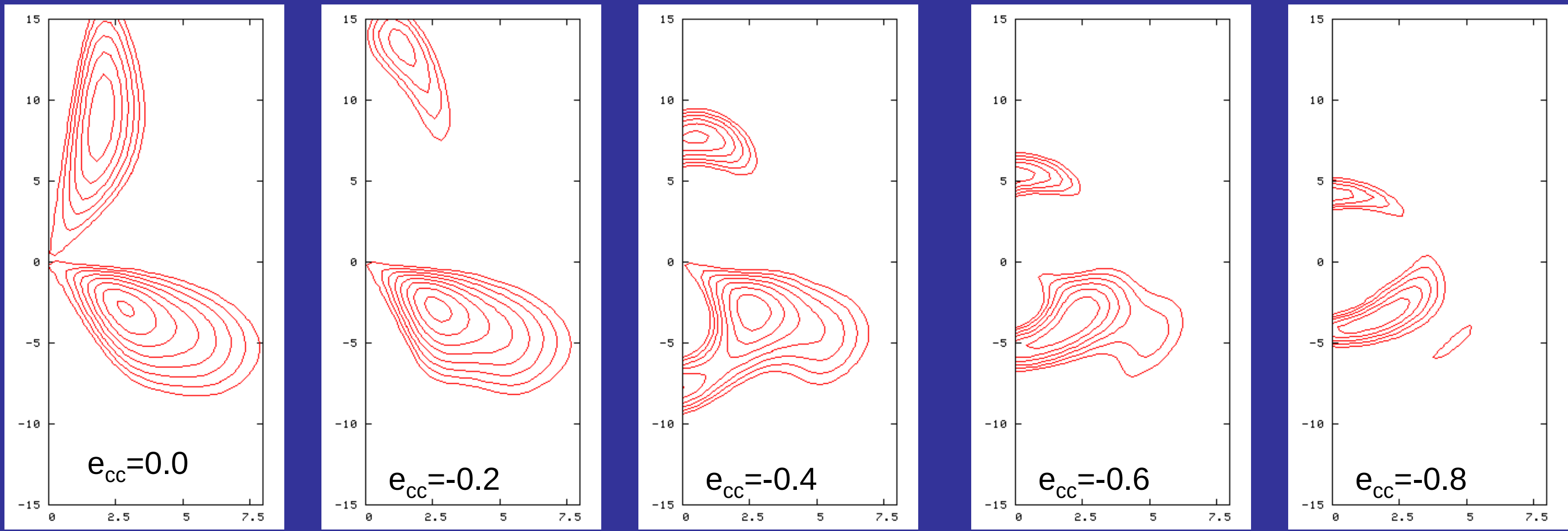
Sediment transport:

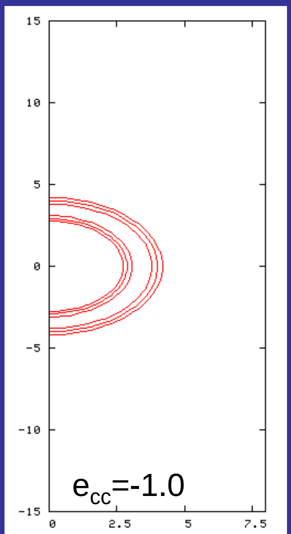
- ✓ transport rate related to depth-averaged velocity
- ✓ slope effect on sediment transport
- ✓ empirical correction to account for Coriolis effects which deviate velocity close to the bottom (de Swart & Hulscher, 1995)

$$\left(Q_x, Q_y\right) = \alpha |V|^b \left[\frac{\left(U\cos\varphi - V\sin\varphi, V\cos\varphi + U\sin\varphi\right)}{|V|} - \frac{c_\lambda}{\hat{r}} \left(\frac{\partial h}{\partial x}, \frac{\partial h}{\partial y} \right) \right]$$

Values of φ determined by means of the fully 3D model

2D model – results





Clockwise rotating velocity vector $\varphi=10^0$

- for $e_{cc}=0$ (unidirectional tide) counter-clockwise bedforms
- counter-clockwise bedforms (if $h_0=30$ m L= 8 Km)
- weak second mode (if $h_0=30$ m L= 3 Km)
- for $e_{cc}=1$ no preferred orientation

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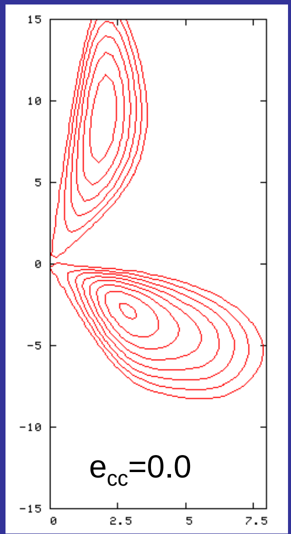
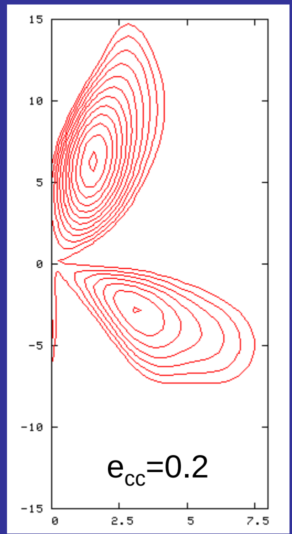
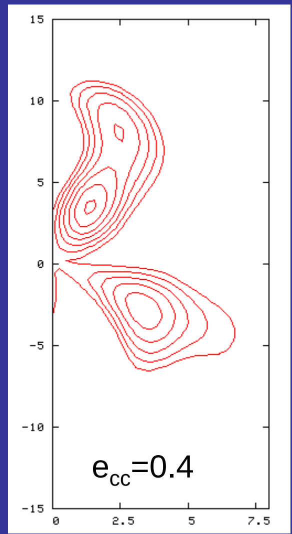
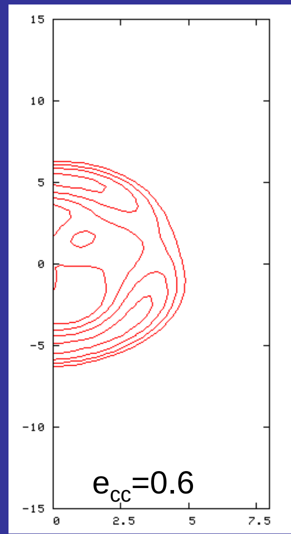
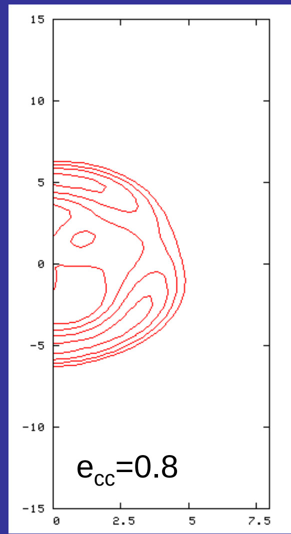
2D model – results

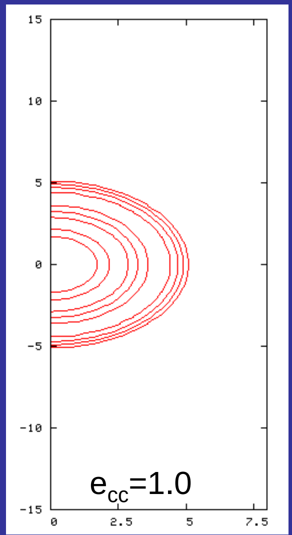












Counter-clockwise rotating velocity vector $\varphi=10^0$

- for $e_{cc}=0$ (unidirectional tide) counter-clockwise bedforms
- clockwise oriented bedforms $e_{cc}=0.2$ ($h_0^*=30$ m, L~15 Km)
- weak second mode ecc=0.2 ($h_0^*=30$ m, L~7 Km)
- for $e_{cc}=1$ no preferred orientation- more unstable than clockwise rotating velocity vector

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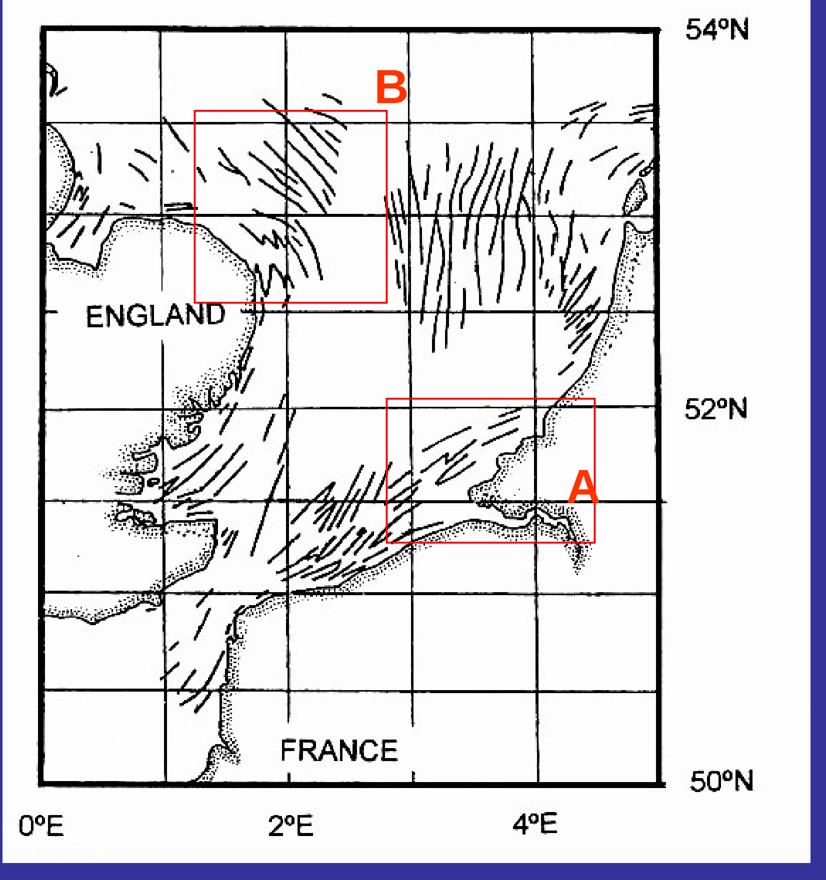
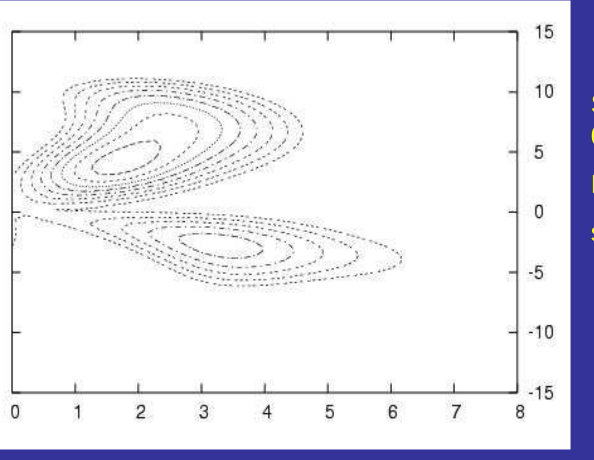
2D model – results



A



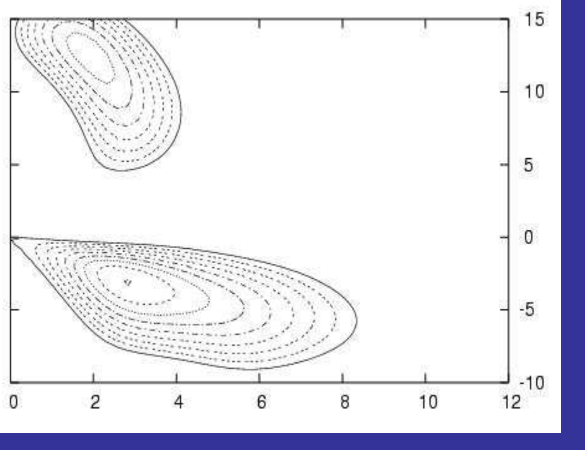
Growth rate of sand banks in the Zeeland region.

Semidiurnal tide (U_0=0.4 m/s e_{cc}= 0.4 counter clockwise rotating)

H_0= 25 m

sand banks L~4.6 Km (clock-wise)

B



Growth rate of sand banks off Norfolk coast.

Semidiurnal tide (U_0=0.7 m/s e_{cc}= 0.2 clockwise rotating)

H_0= 30 m

sand banks L~7.2 Km (counter-clock-wise)

2D model – conclusions

- the orientation of the sand-banks appears to be related to Coriolis effects which cause a deviation of the direction of sediment transport (and bottom shear stress) from that of the depth averaged velocity

- the 2D depth-integrated model can predict sand bank orientation if improved to take into account the deviation of sediment transport from depth-averaged velocity

- the model should be calibrated by using a fully 3D model

- the new 2D model provides results qualitatively similar to those obtainable with the more computationally expensive 3D model