The impact of baroclinity on tidal ranges in the North Sea

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Introduction

- Importance

  Tidal ranges have a significant influence on coastal ecology, beach morphology, maritime activities, coastal protection etc.

- Former studies
  - Effect of stratification was focused on tidal current profiles
  - Studies of tidal range mostly concentrated on sea level rising senarios
  - Lacking of studies on changes of tidal ranges induced by baroclinity

Scientific Questions

- How does the baroclinity influence coastal tidal ranges?

- What are the potential processes responsible for these changes?

Methods

- Model configurations
  - Nested regional circulation model HAMSOM (*Backhaus, 1985*)
  - Horizontal resolutions: outer model ca. 20 km; inner model ca. 3 km
  - Outer model delivers open boundary data for inner model
  - Contrast experiments (1948-2014)
    - Barotropic: tides, wind stress, rivers, boundary SSH (DHA)

      (here, river discharge only increases local SSH, no influence on density)
   - Baroclinic: tides, wind stress + heat flux, rivers, boundary SSH(DH+DHA) & T/S

Source:
Topo: SRTM30_Plus
Tides: TPXO8-atlas v1 (13)
Met.: NCEP1
River: WaterGAP
DHA: from Siegen University
(DHA: dynamic height anomoly)
DH: calculated by T/S
(DH: dynamic height)
T/S: WOA13

HAMSOM topography (m)
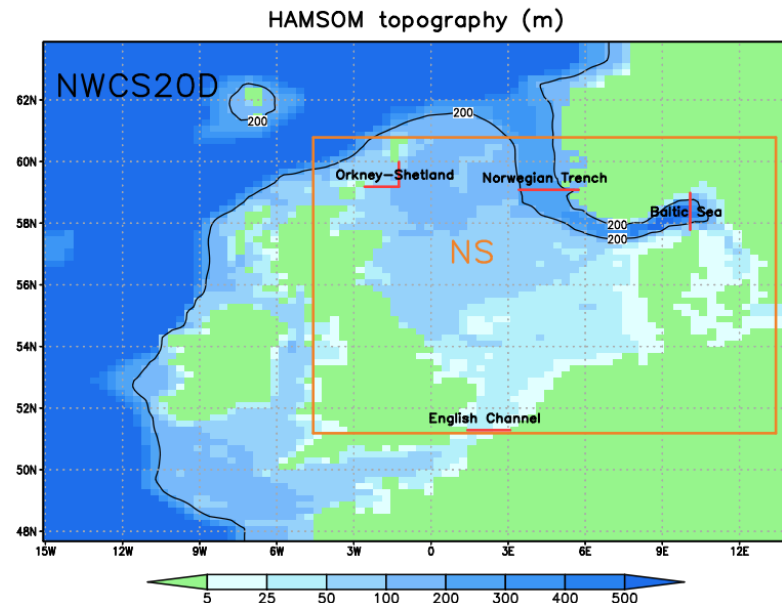
Validation

- Section transport (1998-2009)

HAMSOM topography (m)

Reference values refer to Pätsch et al. (2017)
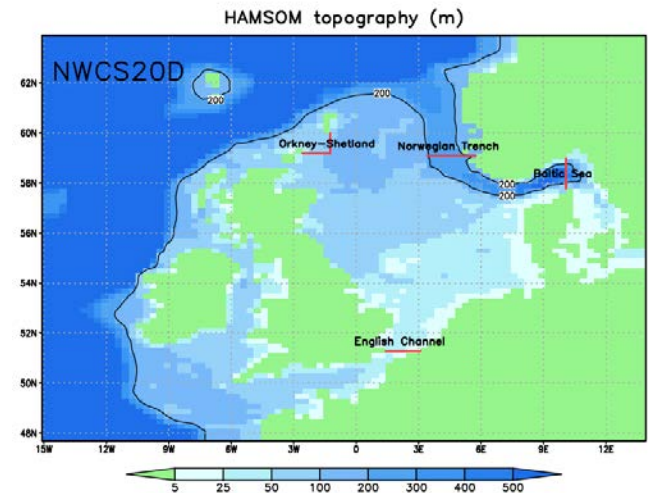
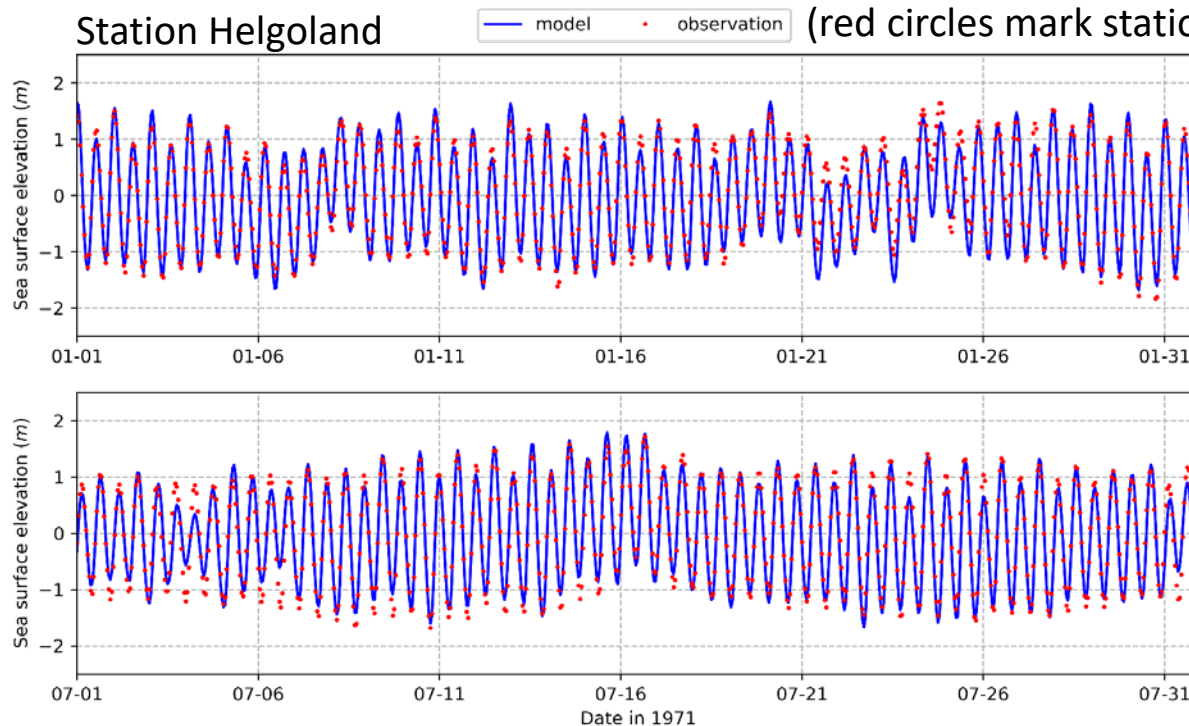| Section	Model (Sv)	Reference (Sv)
English Channel	0.102	0.10-0.17
Baltic Sea	0.016	0.015
Norwegian Trench	-1.34	-0.9
Orkney-Shetland	0.31	0.30

Positive: inflow to the North Sea;
Negative: outflow from the North Sea.

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Validation

- Tide gauges
  - Simulated SSH shows good agreement with observations at more than 20 stations around the North Sea.
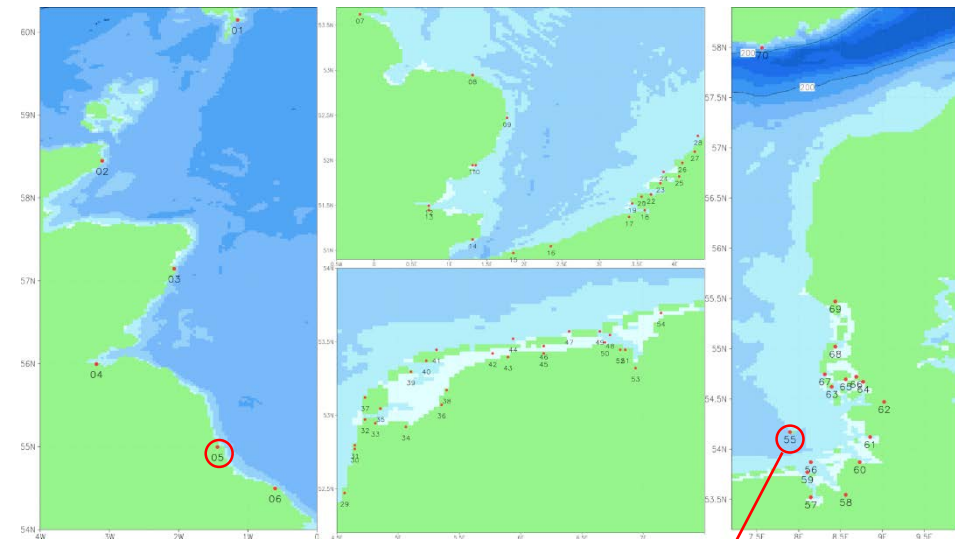

Location of tide-gauge stations
(red circles mark stations for latter exhibition)

Station Helgoland

Tide gauges are provided by Research Institute for Water and Environment (fwu), University of Siegen, (Jänicke et al., in preparation)

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Validation

- Improvement of SSH accuracy in the baroclinic simulation
  - Correlation & slope in barotropic and baroclinic conditions

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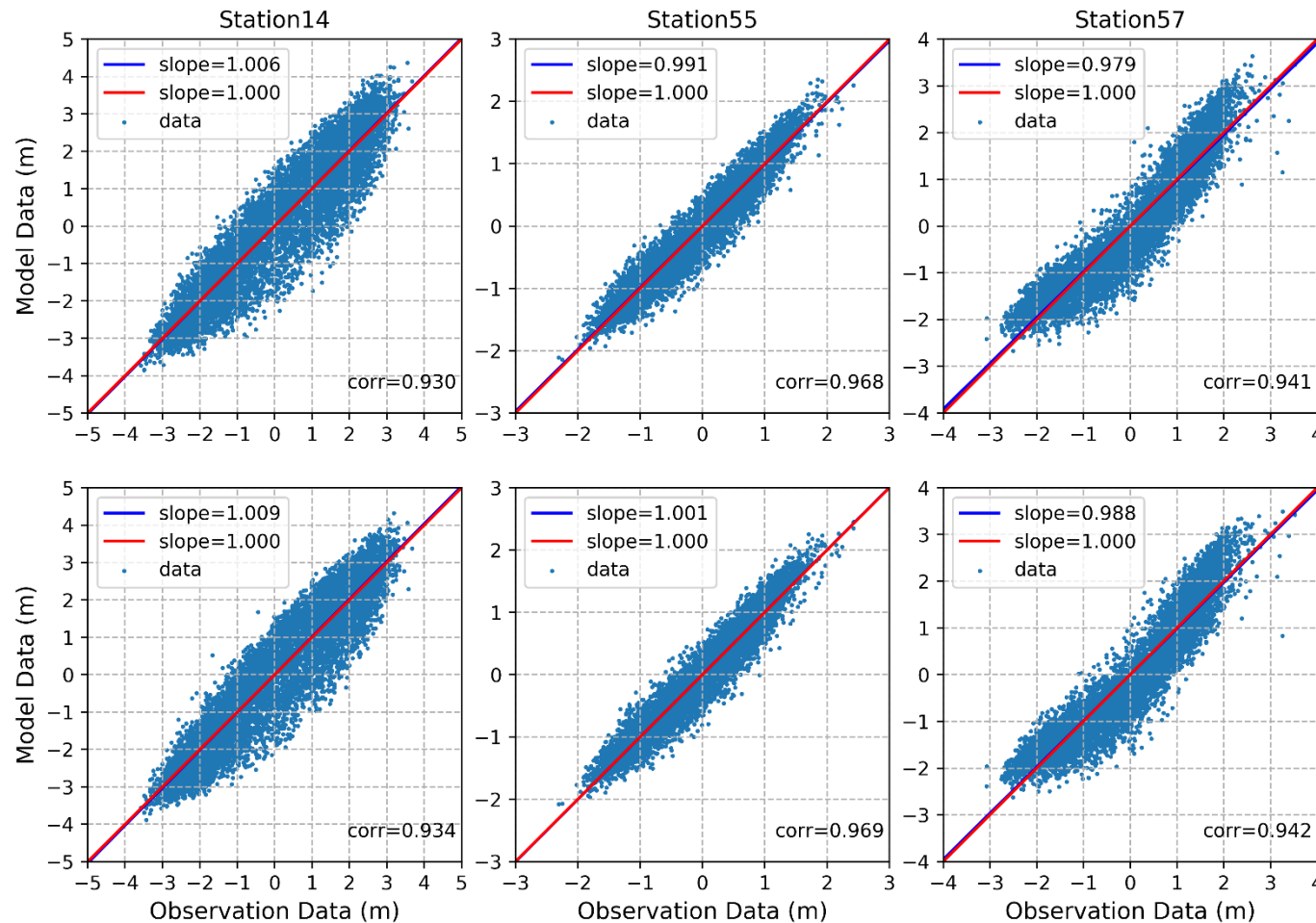
Results & Discussion

- Tidal range difference (TRD: baroclinc - barotropic)

a. Station Helgoland Binnenhafen

b. Station North Shileds

Station locations see Slide 5. Both are located in well-mixed areas

Positive TRDs: baroclinic > barotropic

Summer TRDs are more significant.

summer: Jun. - Aug.
winter: Dec. - Feb.

Negative TRDs: baroclinic < barotropic

Results & Discussion

- ## Statistical Analysis

At 22 stations where simulated SSH agrees well with observed SSH.

Questions:
- How many stations show larger TRDs in summer than in winter?
- For how many years?

18 stations (81.8%) more than 50% of the period
13 stations (59.1%) more than 80% of the period
10 stations (45.5%) more than 90% of the period

Station	number of years	percentage of the whole period
Aberdeen	52	80%
Leith	32	49%
North Shileds	53	82%
Dover	16	25%
Calais	27	42%
Dunkerque	39	60%
Texel Noordzee	26	40%
Terschelling Noordzee	33	51%
Wierumergronden	42	65%
Huibertgat	41	63%
Borkum Südstrand	62	95%
Norderney RiffgatundHafen	64	98%
Helgoland Binnenhafen	65	100%
LT Alte Weser-RoterSand	65	100%
Wilhelmshaven AlterVorhafen	65	100%
Mellumplate	65	100%
Büsum	63	97%
Wittdün	64	98%
Schlüttsiel	63	97%
Hörnum	63	97%
List	53	82%
Esbjerg	50	77%

Results & Discussion

- MSL difference (baroclinc - barotropic)

a. Station Helgoland Binnenhafen

b. Station North Shileds

Steric effect influenced by:
- temperature
- freshwater

MSLD: O(0.01-0.1 m)

1-2%
(Müller et al., 2011)

TRD: max. O(0.001 m)

Results & Discussion

- Horizontal distribution of TRD

TRDs in winter are similar to TRDs in summer, and the latter are more significant.

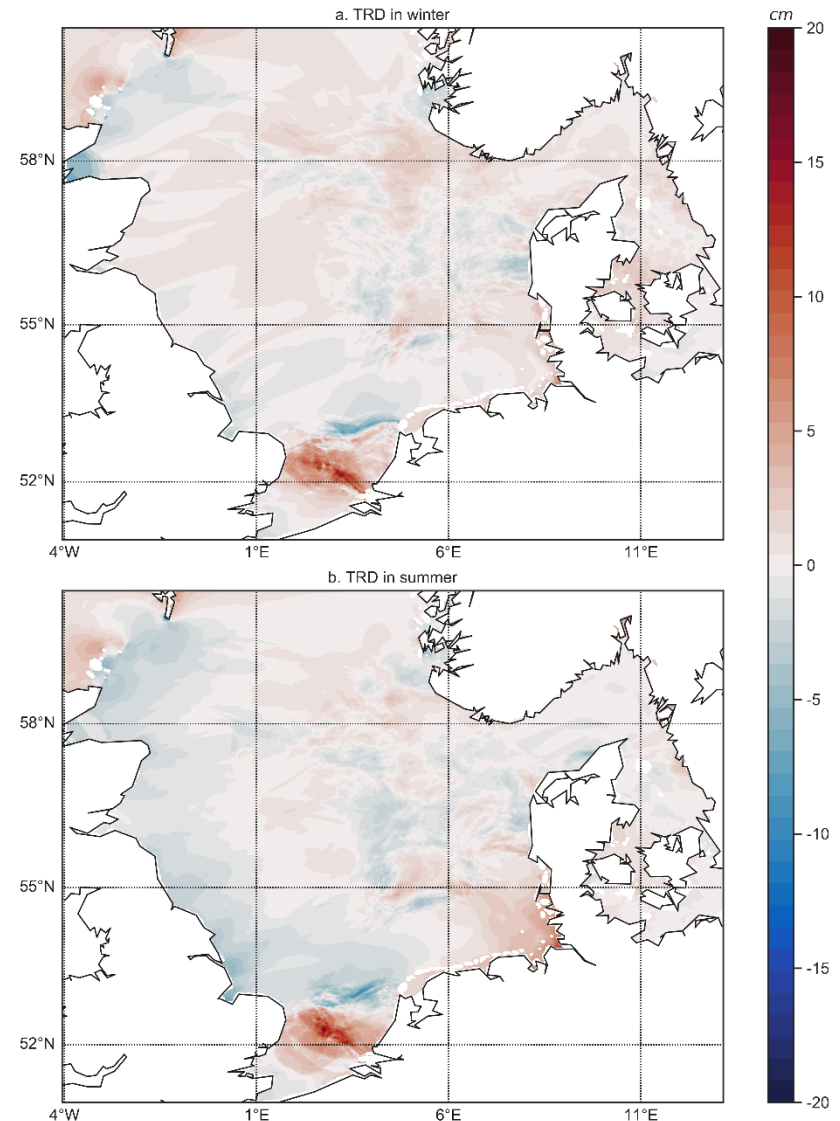> British Coast: mostly negative
> German Bight: positive

+

> Dipole structures:
> - in Southern Bight
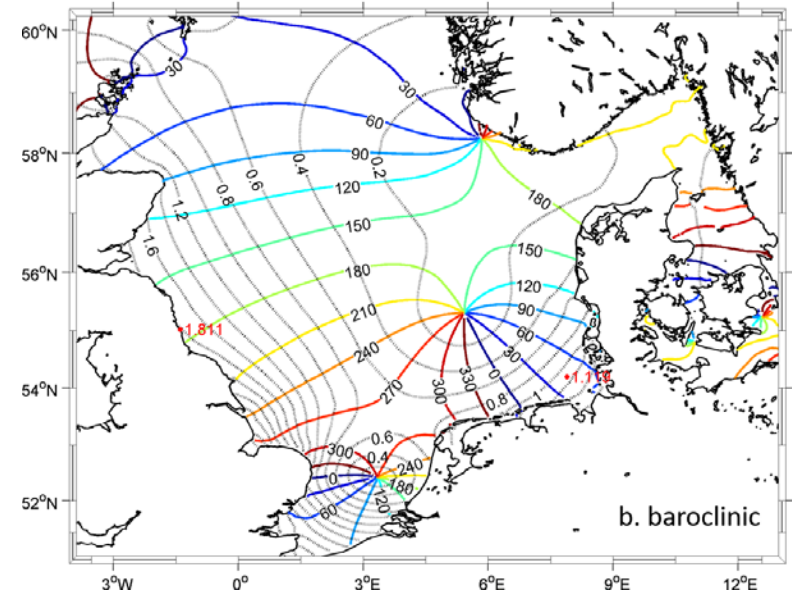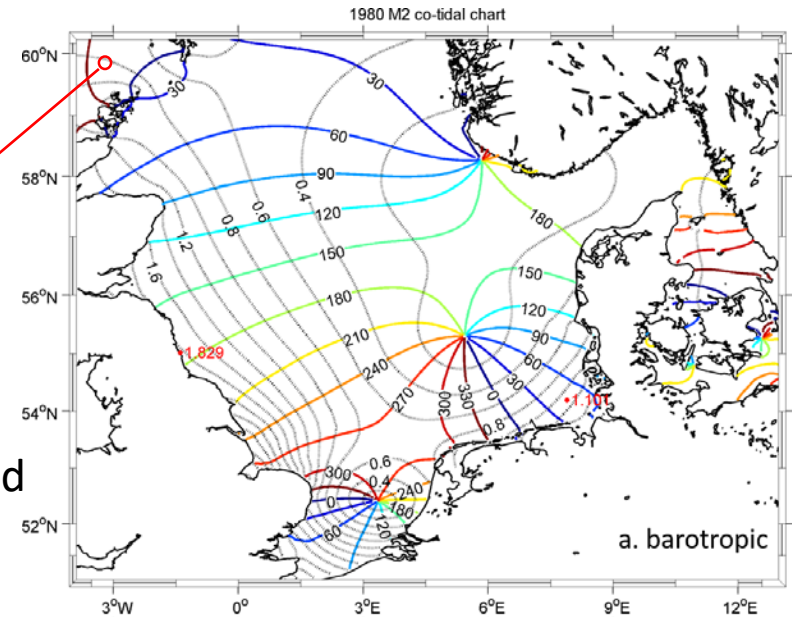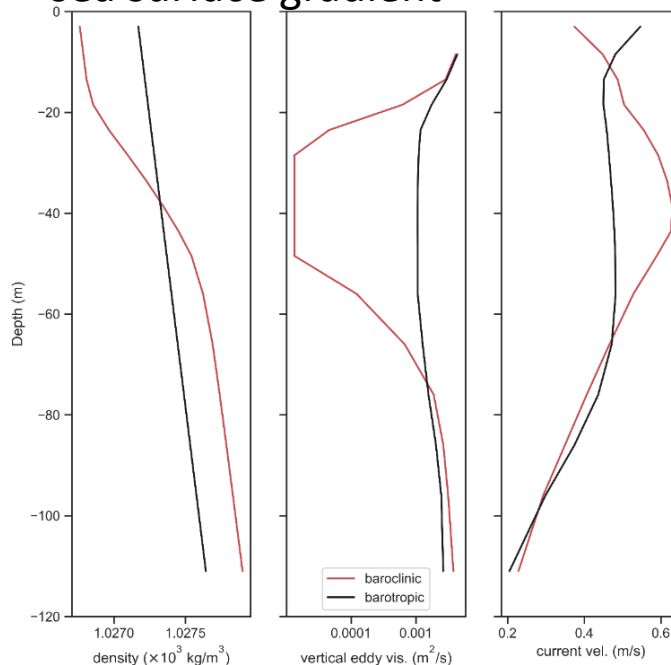> - At around 56°N, 4.5°E

↓

> Indication of the shift of amphidromic points

Results & Discussion

- ## M2 co-tidal charts
  - M2 amphidromic system slightly shifts westward in the baroclinic mode

- ## Decoupling (NW entrance)
  - Vertically averaged tidal current is altered by stratification
  - New balance between Coriolis force and sea surface gradient

1980 M2 co-tidal chart

a. barotropic

b. baroclinic

Summary & Conclusions

1. Baroclinity improves the accuracy of model results regarding the tidal movement.

2. Summer TRDs are more significant than winter TRDs, and show spatial difference with positive values in German Bight and negative values along British coast.

3. TRD could be generated not only locally but also by far-field effects, with the latter one being more significant for coastal well-mixed areas.

Local effect: MSL increase by steric effect could weaken the damping effect of bottom friction, but it is a minor importance.

Far-field effect: the altered vertically averaged tidal current in stratified regions may change the characteristics of Kelvin waves, which in turn modify the amphidromic system in the North Sea, causing changes in coastal tidal ranges.