The effect of bathymetry on barotropic geostrophic adjustment in an Arctic Ocean model.

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1. Motivation:

Drivers of Arctic Ocean circulation

a) Baroclinic Barents Sea-Fram Strait inflow/Fram Strait outflow (Shokalskiy(1940), Gordienko, Karelin, Bunitskii (1940-1958)

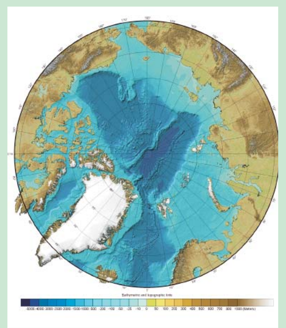
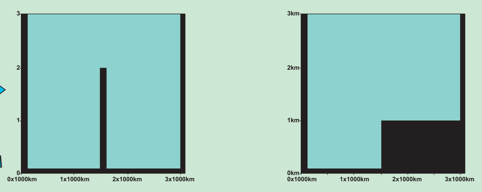
b) Wind driven inflow/outflow (Zubov and Somov, Shuleikin, Shirshov)

- Wind-driven circulation alternates between cyclonic and anticyclonic (Proshutinsky and Johnson,1997,2001)
- Geostrophic barotropic adjustment in the Arctic Ocean?
- Two important basic features:
  - "Polar plane" Coriolis force
  - Ridges and wide shelves

How does the Arctic Ocean responds to atmospheric forcing?

Strategy: from idealised configurations to realistic ocean.

Realistic Arctic bathymetry | Idealised circle basin, R= 1600km with introduced topography

F-plane | Idealised forsing

polar-plane | initial surface elevation

or finite-time Ekman pumping

2. Model:

NEMO with free surface time-split algorithm.

- Basins : a) circular or semi-circular basin 0.1° resolution depth H=3000m,.

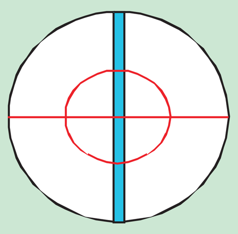
  with ridge with depth 1000 m or;
  with escarpment of depth 2000 m;

  b) Pan- Arctic model, 18 km resolution, rotated system of coordinates:

  with constant depth H =3000 m /no shelves;
  with constant depth 3000 m and shelf 500 m.

- Initial conditions :

step in sea surface height crossing Pole and perpendicular to topography anomaly.



top-hat SSH elevation centred at Pole.

or state of rest and surface forsing:
wind: Emmanuel, 2001 vortex :
wind speed 5m/s, r_{max}= 800km
duration: 100 days

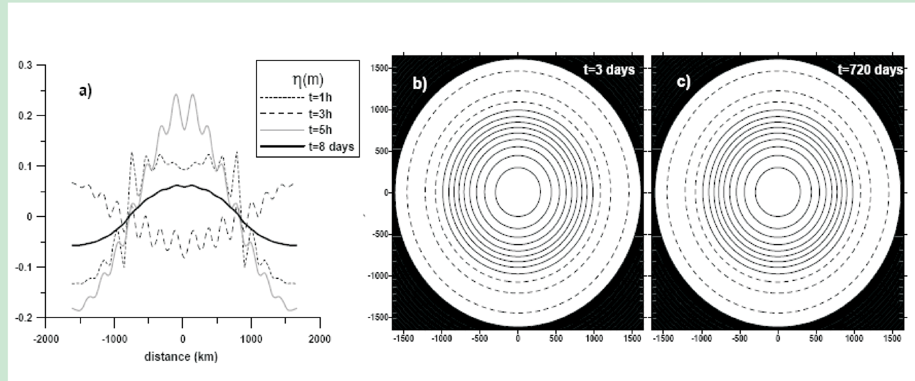
Set up of initial surface elevation equivalent to finite-time Ekman pumping or set up of atmospheric pressure

$$\nabla^2\eta - \frac{1}{gH}\left(\frac{\partial^2}{\partial t^2}+f^2\right)\eta = \eta^F + \eta_0$$

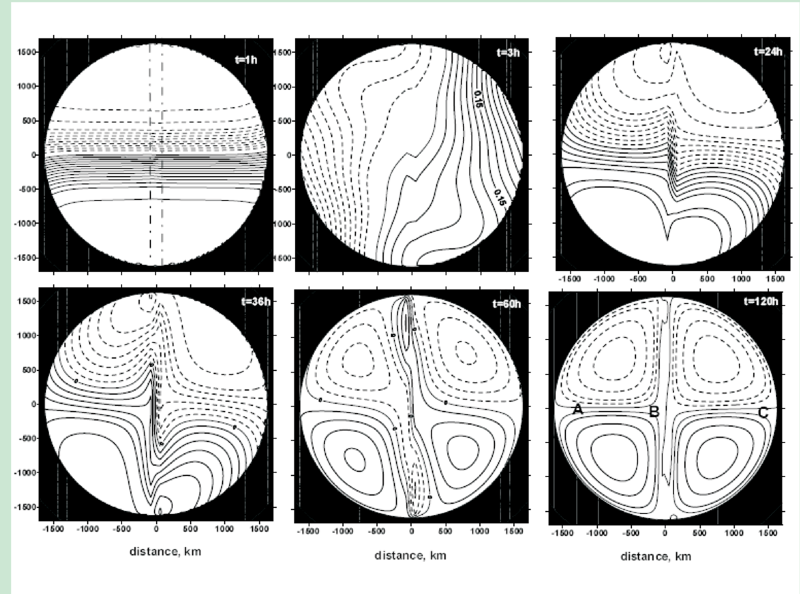
$$\eta^F = \eta^a - \int (P - E + w_e)\,dt/\rho$$

$$w_e = -rot_z(\vec{\tau})/(\rho f)$$

3. Initial stage of geostrophic adjustment
Excitation of barotropic Poincare, Kelvin waves.

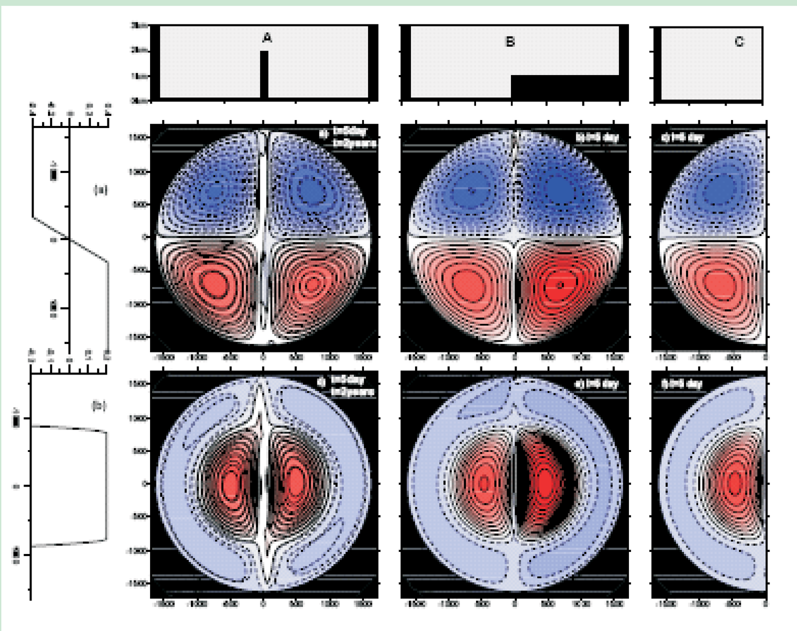


In the case of flat bottom circular basin and radially symmetric initial surface elevation fast Poincare waves dominate the adjustment processes. Adjusted solutions are concentric circles.

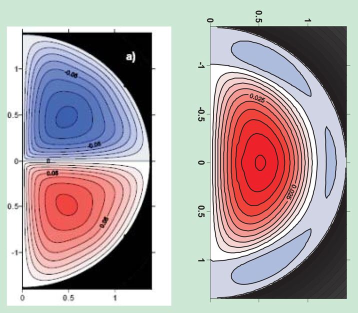


In the presence of topography anomaly (ridge or escarpment) Kelvin boundary trapped waves dominate the initial adjustment with further excitation of topographic waves and formation of the 4-gyre quasi-steady solution.

4. Quasi-steady state solutions on the f-plane :



After 3 days of modelling time solution is superposition of Kelvin waves and quasi-steady 4-gyresare formed. After damping of Kelvin waves at day 25-30, gyres stay nearly unchanged for modelling time ~ several years.



The strength of steady -state circulation is inversely proportional to depth.

Step or ridge effect is identical to the effect of the wall.

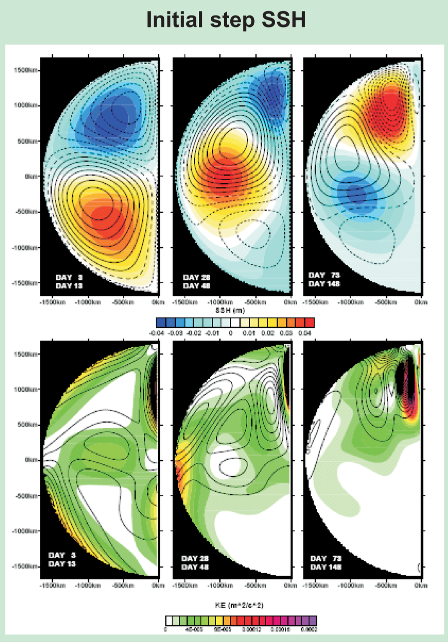
Steady state analytical solutions in a semi-circular basin are found.

Analytical solutions

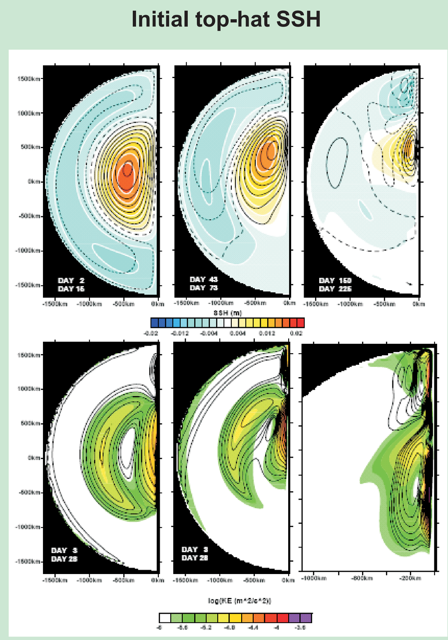
5. Geostrophic adjustment on a Polar-plane: initial stage

f=2Ω cos(θ), θ<<1 : f≈2Ω (1-θ²/2), θ=90-φ

Initial step SSH



Initial top-hat SSH



Adjustment in a circular basin with ridge/step topography is similar to that in a semi-circular basin

Initial stages of adjustment approach f-plane steady state solution

Planetary Rossby waves are responsible for further adjustment.

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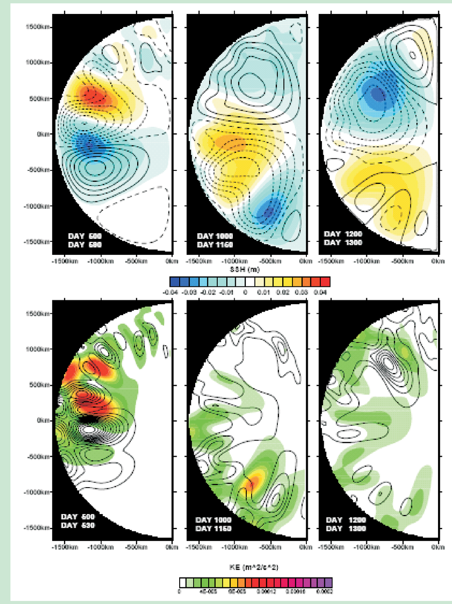
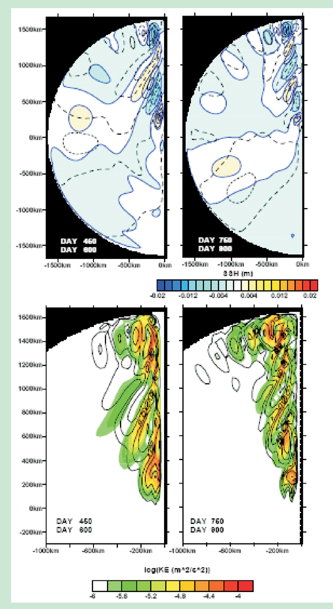
In early stage Rossby waves have a basin-scale wavelength and both phase and group velocities are westward.

After 100 (300) days for initial step (top-hat) SSH, energy maximum reaches the western boundary and concentrates near the wall

6. Geostrophic adjustment on a Polar-plane: late stage



Initial step in SSH, (radial mode k=1)
N=2: T=125 days, Twest~139 days
N=4-6: T=105 days, Teast~732days

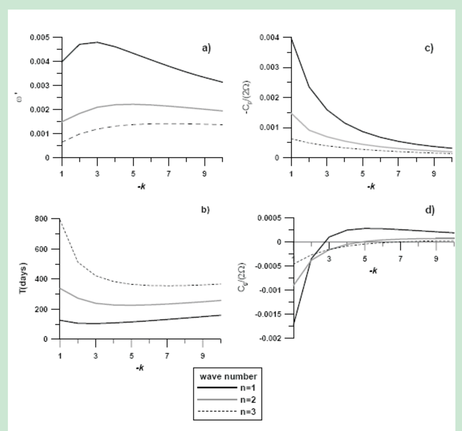


Initial top-hat in SSH, (k=2)
N=1: T=400 days, Twest1/4~155days,
Teast=30 years

Reflected waves are much shorter than incoming waves:

For initial step in SSH, the dominant eastward (westward) propagating modes are n=4-6c (2), with propagation time of 900 (100) days.

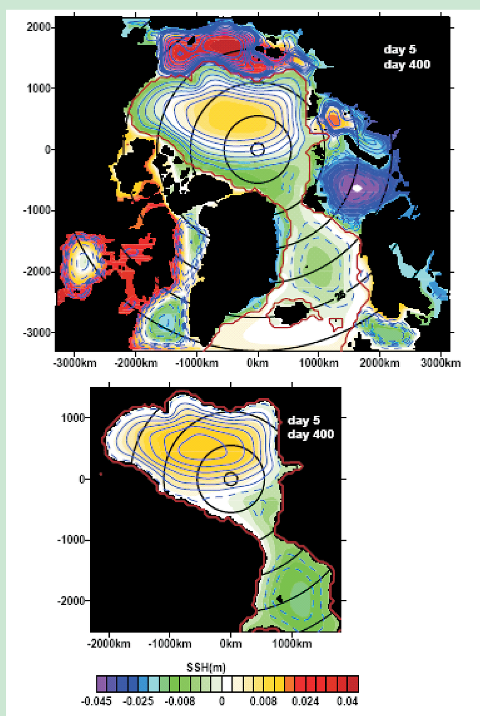
For initial top-hat SSH n=8~10 group velocity is so small that waves are captured near the western boundary as small scale barotropic eddies.



We extended LeBlond, 1964 solution and have found group velocity for free propagating waves

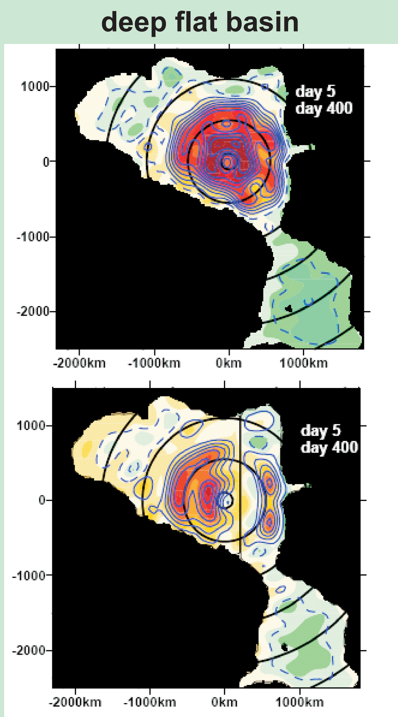
Predicted periods, phase and group velocities correspond well to simulations

7. Effect of coastline and shelves on the quasi-steady patterns of solutions on a f-plane.



initial step sea surface elevation, upper panel: deep basin with shelves,
lower panel: only deep basin

deep flat basin



initial top-hat sea surface elevation, deep basin with ridge

After 2-3 days of the adjustment the quasi-steady state solutions emerges.

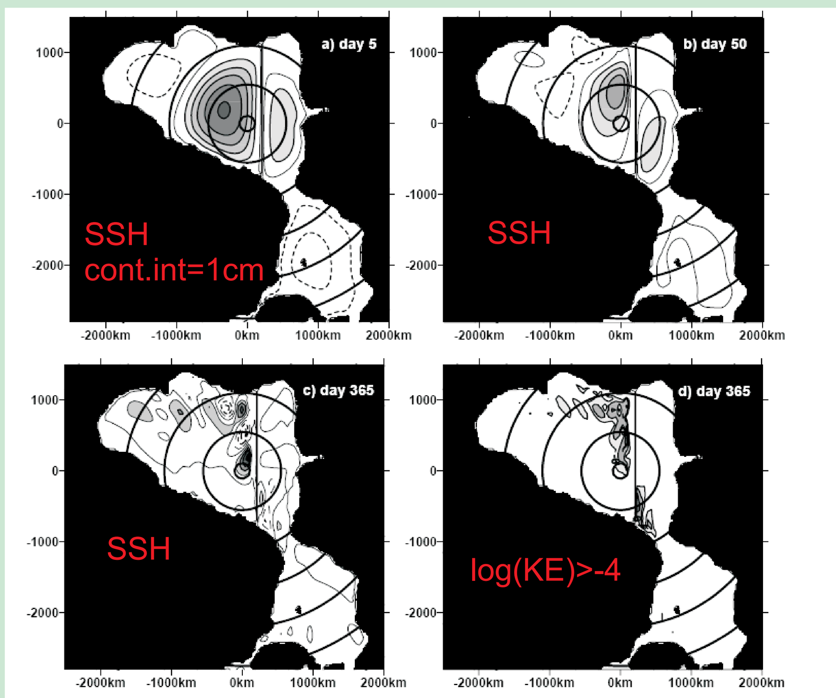
Patterns stay almost unchanged during a long period of time.

Shelf reproduces the natural step in topography and multiple gyres emerge with stronger amplitude in shallow water

In the case of initial "top-hat" SSH elevation the appearance of multiple higher mode gyres are evident as solution tend to fit with the shape of coastlines and isobaths.

The effect of ridge is similar to the wall effect.

8 .Effect of ridge on the solutions on a polar-plane.



Similarly to the idealistic case an initial stage of geostrophic adjustment corresponds to a solution on the f-plane.

Long Rossby waves are responsible for the second stage of adjustment.

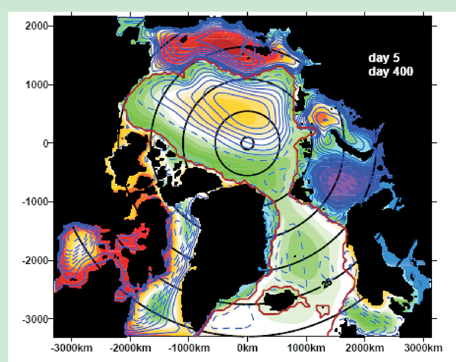
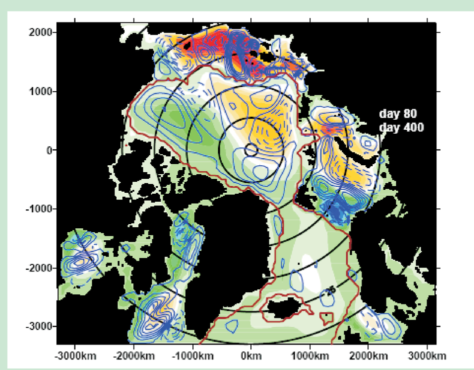
When the energy maximum reaches the western boundaries along the contours with constant potential vorticity, energy transforms to short planetary waves.

In the case of initial "top-hat" the group velocity of short waves so small that during a year just a little shifts observed in SSH elevation.

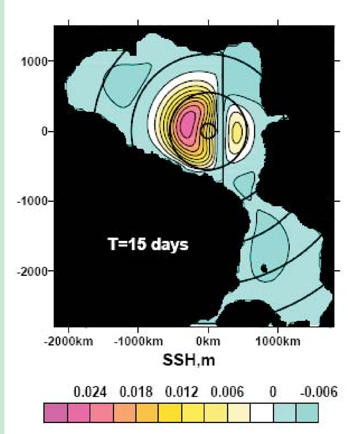
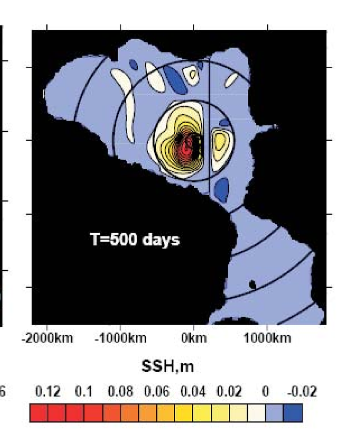
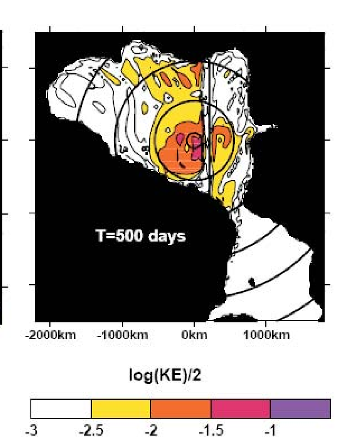
Energy is concentrated near the ridge and barotropic velocity of eddy-like features exceeds 5cm/s

The effect of ridge is similar to the wall effect.

9. Effect shelves on the adjustment on a polar-plane.

10 .Circulations generated by finite-time wind shear stress on a polar-plane .

11 .Conclusions.

The initial adjustment on the polar plane mimics the geostrophically adjusted solutions on the f-plane.

In the case of simplified geometry of the basin the geostrophical adjusted solutions on a f-plane are found by analytical methods.

This allows to estimate the part of energy transported to fast waves and to quasi-steady solutions on a f-plane.On polar plane the latter defines the part of energy transported then to planetary Rossby waves.