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ROSSBY RADIUS OF DEFORMATION IN THE HORNSUND FJORD

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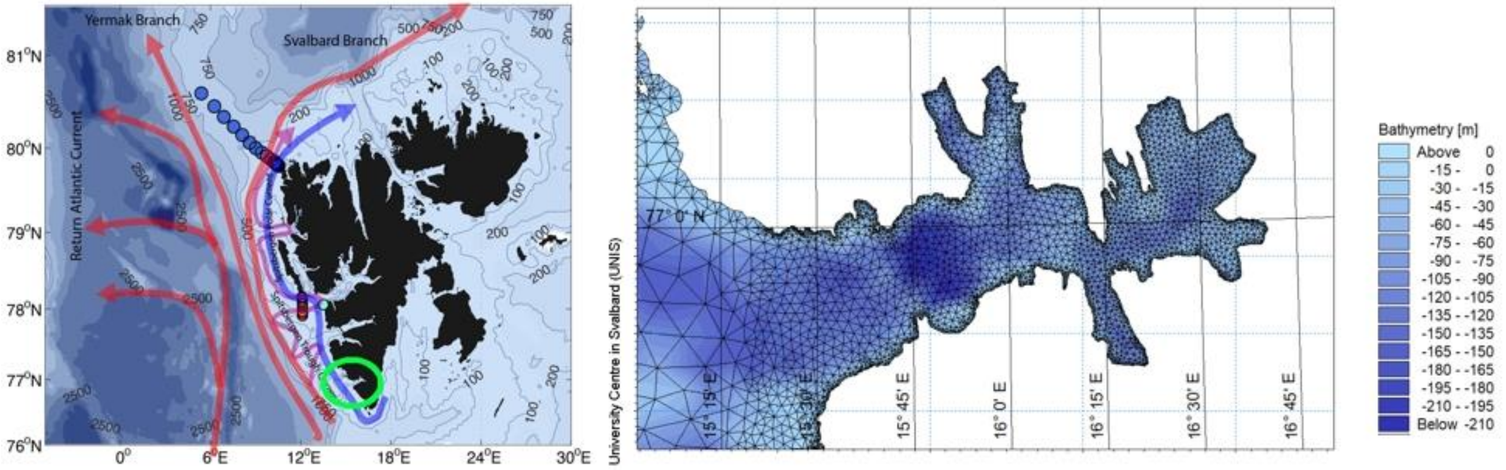
Study area

Atlantic Ocean Currents & Hornsund Fjord



Location of the study area (green polygon), the mesh grid and bathymetry

Hornsund fjord

- surface area: 275 km2
- Volume: 23 km3
- 30 km long
- entrance is ca. 10 km wide and
- faces west towards the Greenland Sea
- The shoreline is complex,
- with a lot of bays with glaciers entering
  the fjord.

West Spitsbergen Current - warm and salty waters from the North Atlantic

Sørkapp Current - fresher and colder water masses from the Barents Sea.

Motivation

General circulation

- The influence of the rotational effects on the general circulation in the Hornsund fjord
- The residual current which enters the fjord on the southern side and then recirculates along its northern part
- In winter (January) the volume exchange between the fjord and the shelf is much smaller than in summer (July), a cyclonic motion is observed in the central part of the fjord.
- In summer (July) the shelf waters penetrate much further into the main pool of the fjord and reach the entrance to the inner pool called Brepollen, the cyclonic flow is disturbed by intensive fresh water circulation from terrestrial and glacial sources.
- Circulation at Brepollen, the easternmost part of the fjord, is also characterised by seasonal variability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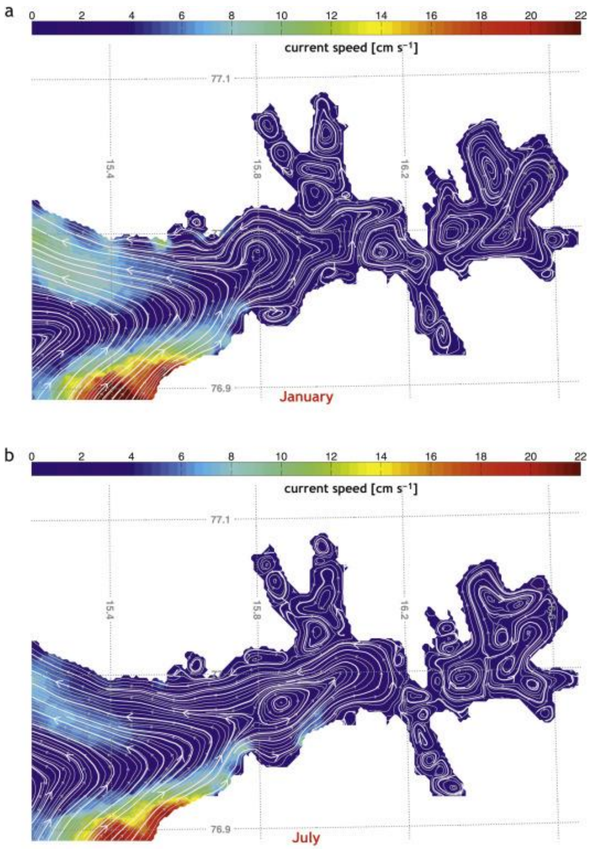
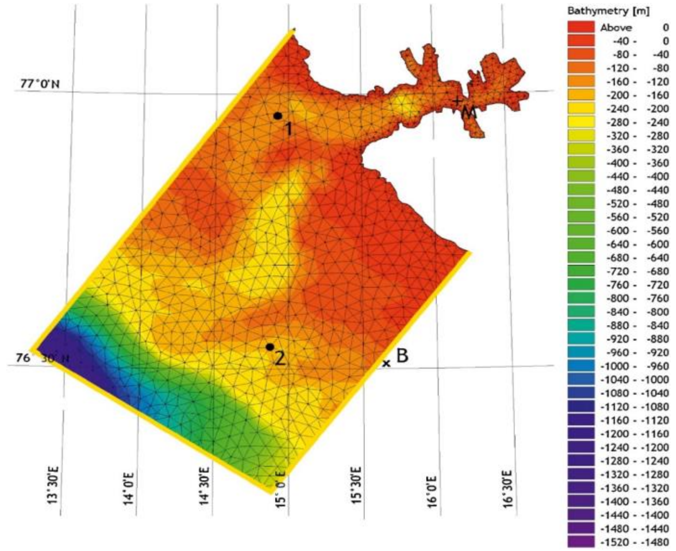
Original Research Article
Modelling of the Svalbard fjord Hornsund

Jaromir Jakacki [a], Anna Przyborska [a], Szymon Kosecki [a], Arild Sundfjord [b], Jon Albretsen [c]



Streamlines (white lines) and current speed (colour-coded) over domain and time averaged in Hornsund for January (a) and July 2008 (b)

Numerical model for the fjord Hornsund



1)Model engine – MIKE by DHI (commercial product)
Sigma coordinate model (35 vertical levels) with variable horizontal resolution (mesh grid).

Open boundary conditions

- Data (temperature, salinity, barotropic velocity) from Norway Arctic Model (ROMS) – 800 meters horizontal resolution
- Tidal sea level data from Global Tidal Model (0.25 degrees resolution)
- At the lateral boundary implemented Flather boundary (combined sea level with barotropic velocity)

$$\overline{u} = \overline{u}^{\text{ext}} - \sqrt{\frac{g}{D}}(\zeta - \zeta^{\text{ext}})$$

.

Table 1 Parameters used in the model

Parameter	Value	Model option or comments (if needed)
General information		
Horizontal resolution	Size of cell (max, min) = (300,3000)	Mesh grid presented in Figure 2
Vertical coordinates	35 vertical levels, min~0.2m, max=~40m	Sigma coordinates
Simulation periods	01.2005-06.2010	
Maximum time step	30 seconds	
Bathymetry source	NavSim (based on Electronic Navigational Charts - ENC)	
Flood and dry	Included	
Horizontal turbulence model	Smagorinsky	
Vertical turbulence model	k - ε	
Bed friction	Constant in domain, but depends on cell thickness	
Flood and dry	Included	
Density	Salinity and temperature dependent	
Coriolis forcing	Included	
Atmospheric forcing	Included	Based on ERAi: – Mean sea level pressure – Wind speed and direction – 2 m potential temperature – Cloudiness – Precipitation – Wind speed
Ice thickness and concentration	Included	Based on S800 model
Critical CFL value	0.8	Courant–Friedrichs–Lewy number
Initial conditions		Initialization from cold start
Surface level	0 m	
Velocities	0 m/s	

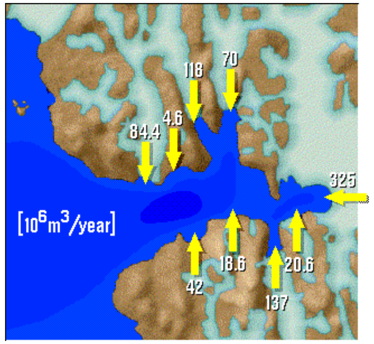
Numerical model for the fjord Hornsund

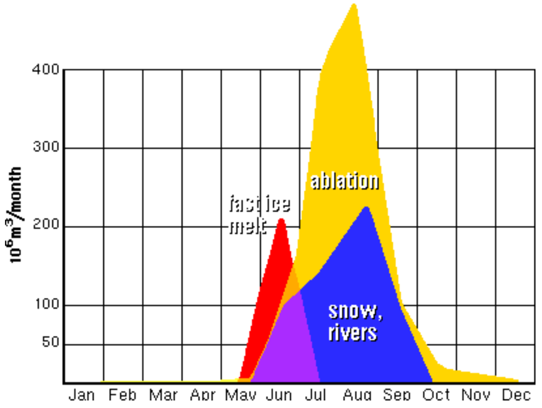
2D field was interpolated for the upper boundary layer

- Mean sea level pressure,
- Wind speed and direction,
- 2 m potential temperature,
- Cloudiness,
- Precipitation,
- Sea ice concentration,
- Sea ice thickness.

Atmospheric fields were prepared on the basis of the ERA Interim reanalysis data set (from the European Centre for Medium-Range Weather Forecasts) and ice coverage was taken from the S800 model.

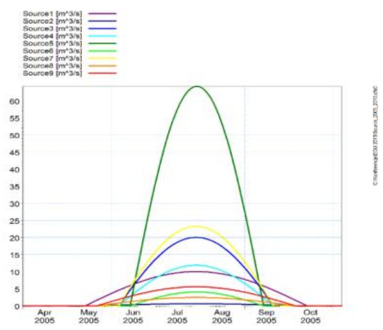
FRESH WATER SOURCES:

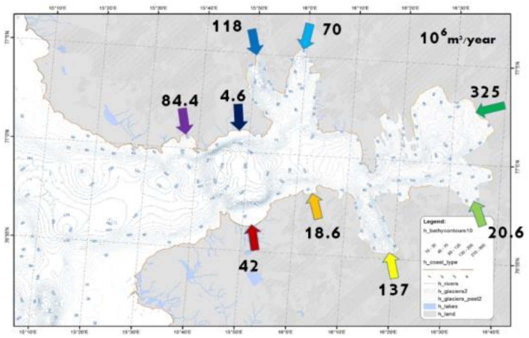




Pulina & Jania 1994

Weslawski et al. 1995





Material and methods

Outside of the tropics, for latitude $|\phi| >= 5^o$ Rossby radius can be defined as Gill (1982)

$$R_n = \frac{c_n}{|f|} \quad (3)$$

for $n = 0, 1, 2, \ldots,$, where c wave phase speed , and f is the Coriolis parameter by:, $\Omega = 2\pi/86164s^{-1}$;, ϕ-latitude The $n = 0$ mode is called the barotropic Rossby radius of deformation and is compared to basin scales, where $c_0 = \sqrt{gH}$ for a water depth H and the acceleration due to gravity g. The next modes are baroclinic ones. The first baroclinic mode, $n = 1$, is the most important one as regards mesoscale motions and is the subject of this article.

n=0

Barotropic Rossby Radius of deformation R0

$$R_0 = \frac{\sqrt{gH}}{|f|}$$

n=1

Baroclinic Rossby Radius of deformation R1

$$R_1 = \frac{c_1}{|f|}$$

a) Sturm-Liouville eigenvalue problem **(numerical method)**

$$\frac{d^2\Phi}{dz^2} + \frac{N^2(z)}{c_1^2}\Phi = 0$$

$$\Phi(0) = \Phi(H) = 0$$

b) Wentzel-Kramers-Brillouin method **(WKB)**

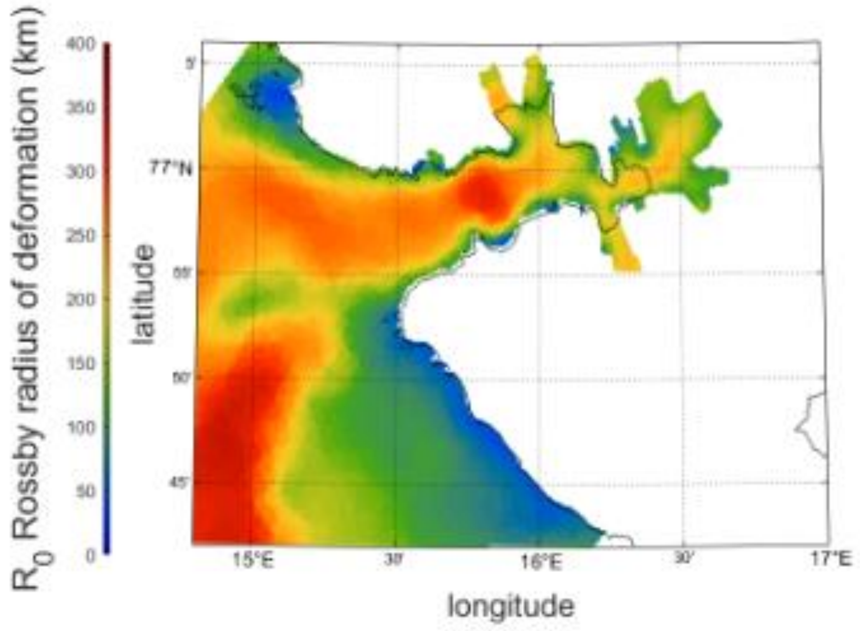
$$c_1 = \frac{1}{\pi}\int_{-H}^{0} N(z)dz$$

where N is the Brunt-Väisälä frequency (BVF)

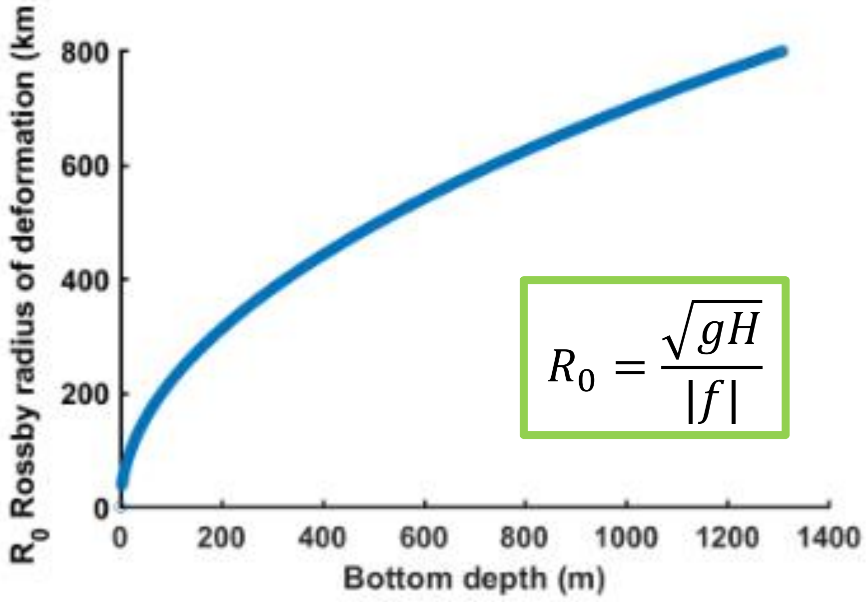
$N^2=-g/\rho \, d\rho/dz$

Results:

The barotropic Rossby radius in the Hornsund fjord R0



a)



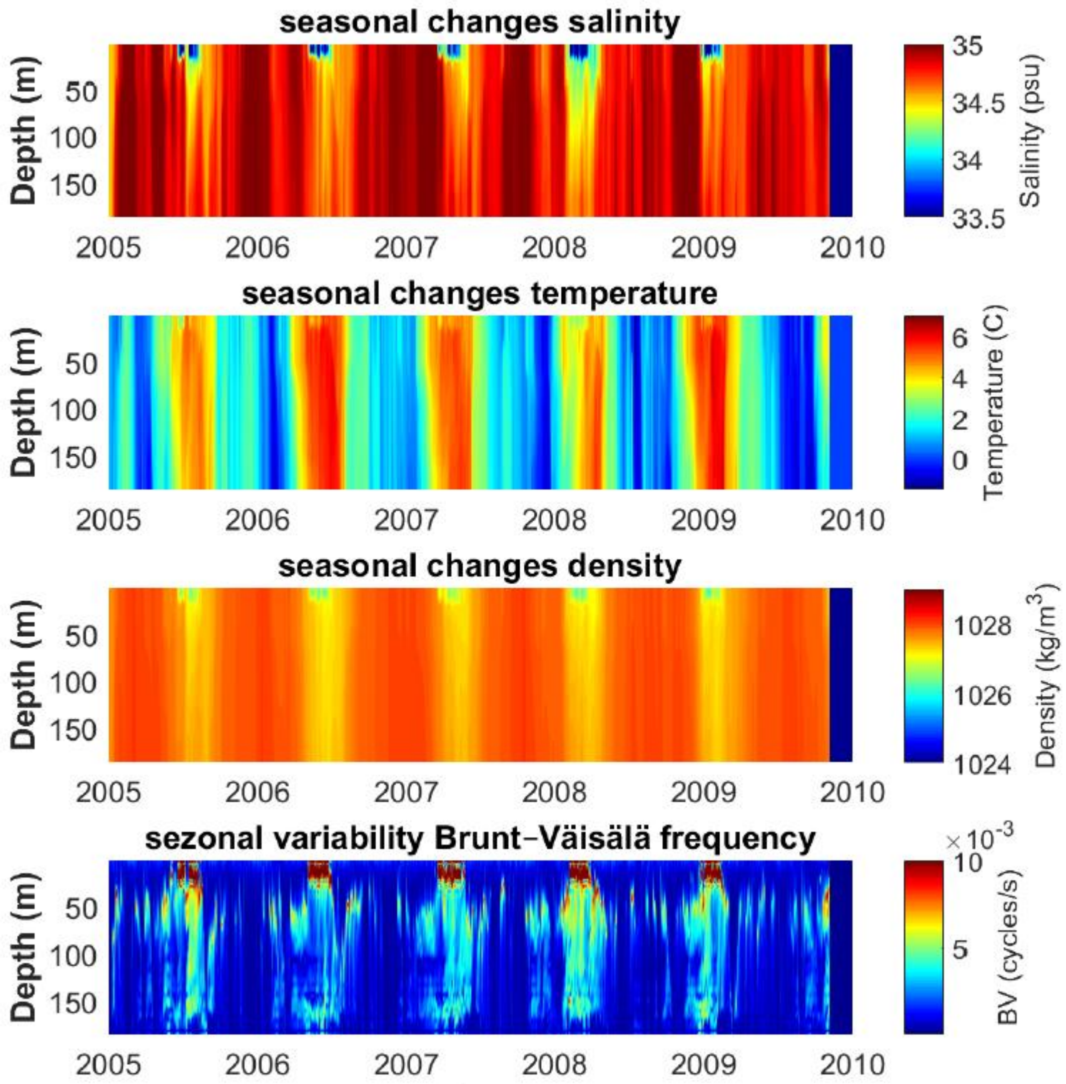
b)

Results:

- Seasonal variability of water temperature, salinity and density

The complex variety of factors :
the influence of WSC and SC on the Hornsund waters, wide opening, the numerous glaciers in the fjord, all together make the hydrological conditions in the fjord highly variable.
These factors can affect the hydrodynamic condition of water in short scale - days or weeks, as well as in a long scale - annual or multiannual.

The structure of a water column in the Hornsund fjord strongly depends on the time of year.
The data analysis confirmed the seasonal variability of the vertical structure of water in the fjord - sezonal variability salinity, temperature and density which leads to cyclic changes in the vertical structure of the Brunt-Vaisail.



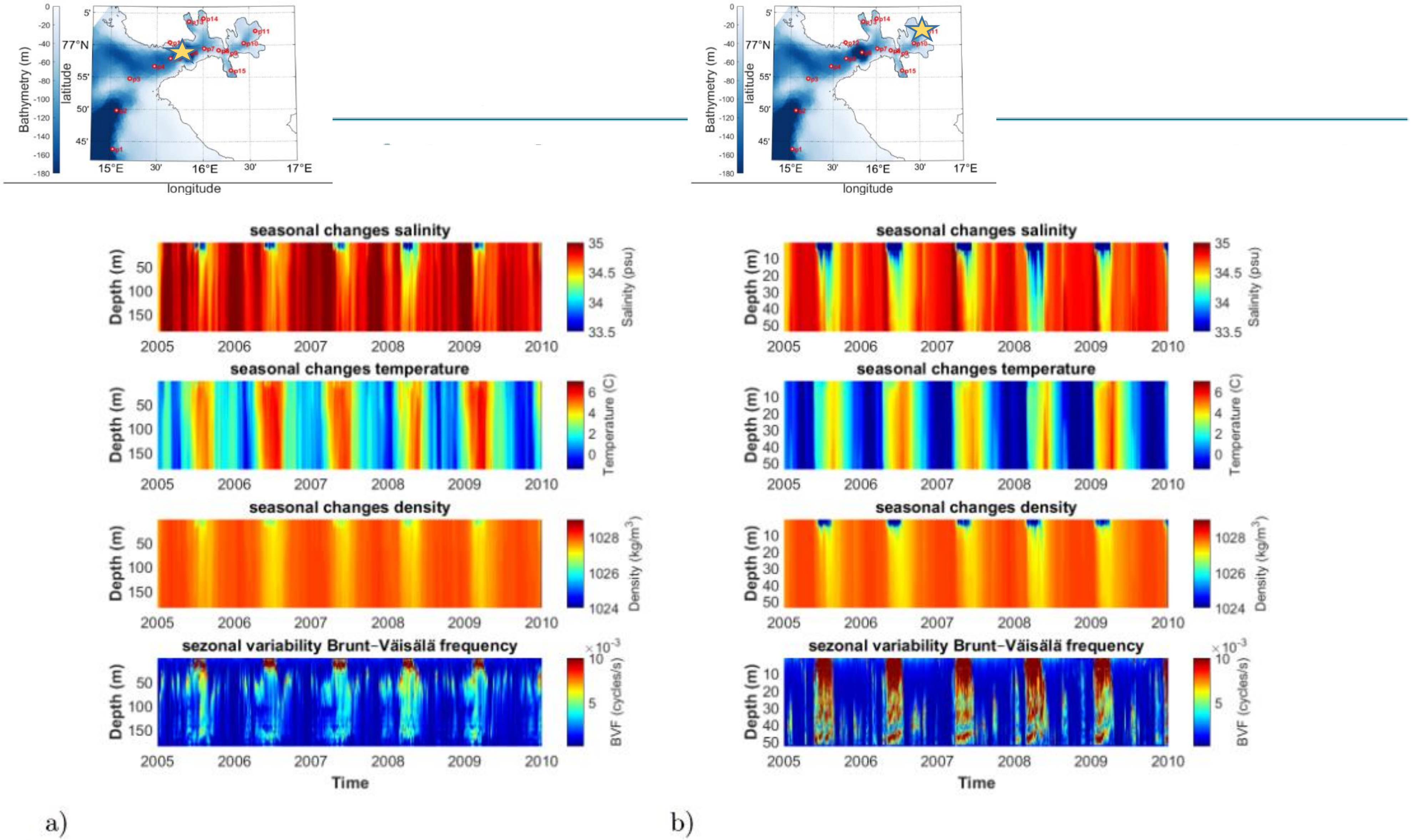


Figure 3: Seasonal variability of temperature, salinity, density, and BVF for the period January 2005 – June 2010, (a) - point p_6, main fjord and b) station p_{11} in Brepollen)

- ## Geographical variability of The baroclinic Rossby radius

14.08.2008

14.10.2008

The largest values of R1 were observed in late summer when temperature stratification is strongest, whereas the smallest values were in winter.

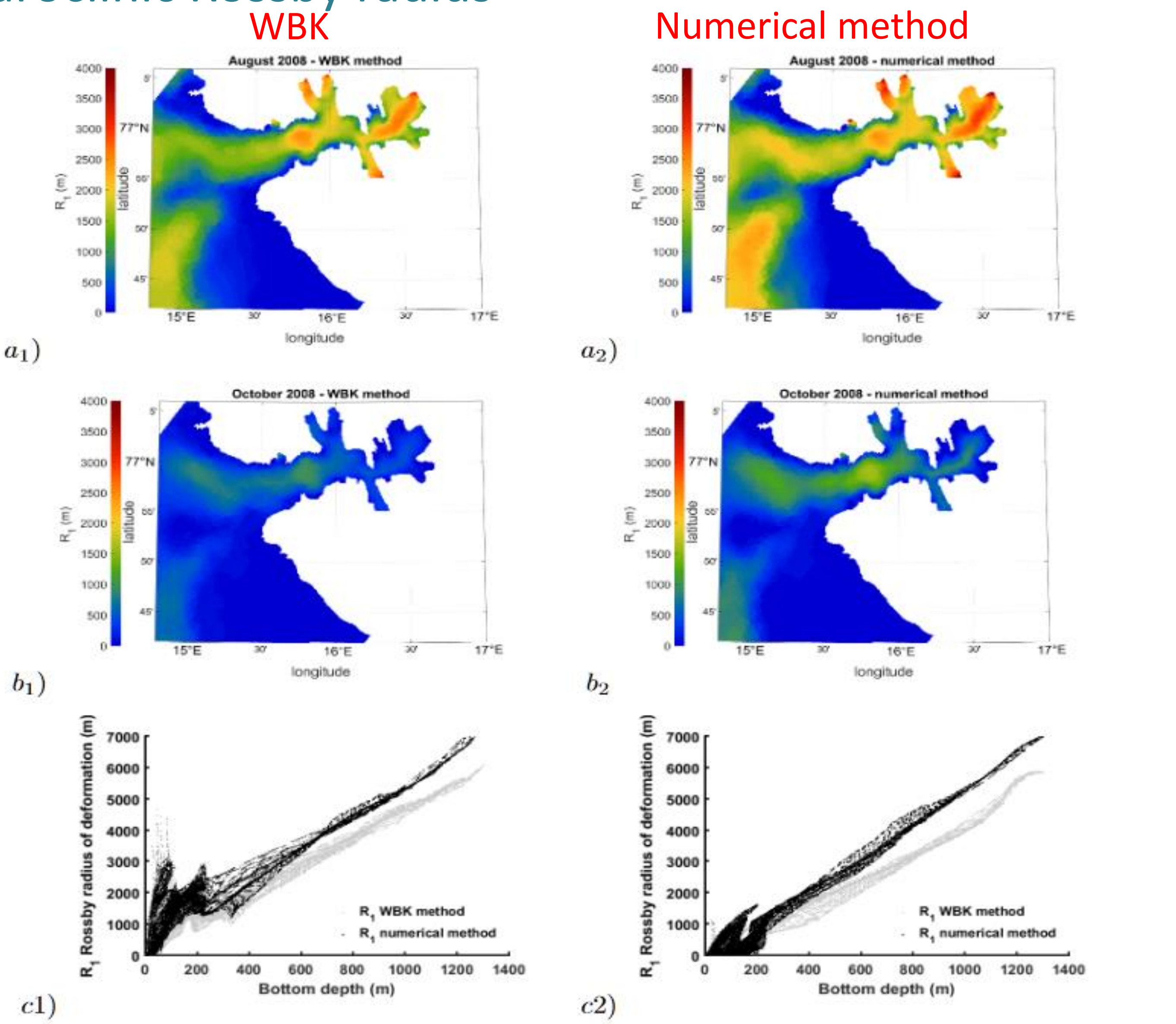


Figure 7: Distribution of baroclinic Rossby's radius of deformation R_1 calculated on the basis of data from the numerical model HIRM, a_1) 14 August 2008 (WBK method), a_2) 14 August 2008 (numerical method) b_1) 14 October 2008 (WBK method), b_2) 14 October 2008 (numerical method) and relationship of R_1 WBK calculated by WBK method to depth (black points) versus R_1 numerical calculated by numerical method and depth (grey points): c_1) 14 August 2007 and c_2) 14 October 2007

• Geographical variability of The baroclinic Rossby radius

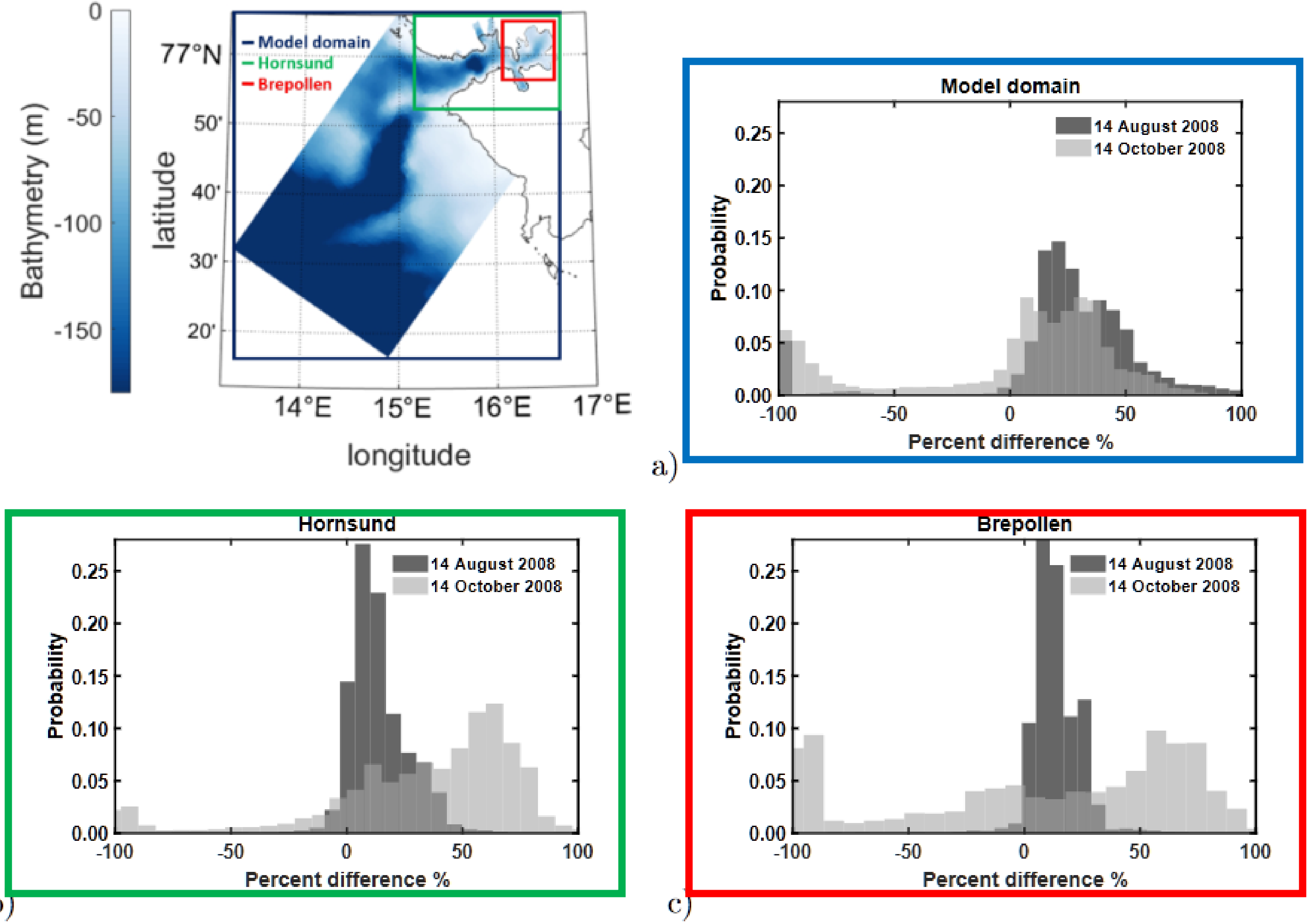


Figure 8: Histogram of the differences expressed as a percentage and probability of the percentage errors of the numerical method and the WBK method for August and October, a) model domain, b) Hornsund fjord, c) Brepollen

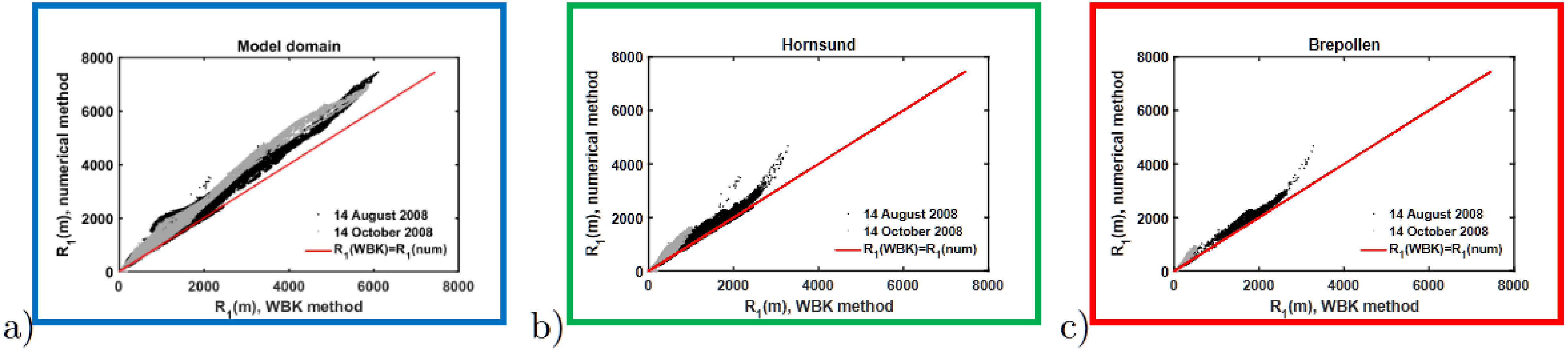


Figure 9: Scatterplot of R_1(WBK) calculated by WBK method versus R_1(num) calculated by numerical method for 14 August 2008 (black points) and 14 October 2008 (grey points), the red line represents the line of perfect agreement a) model domain, b) Hornsund fjord, c) Brepollen

Results:

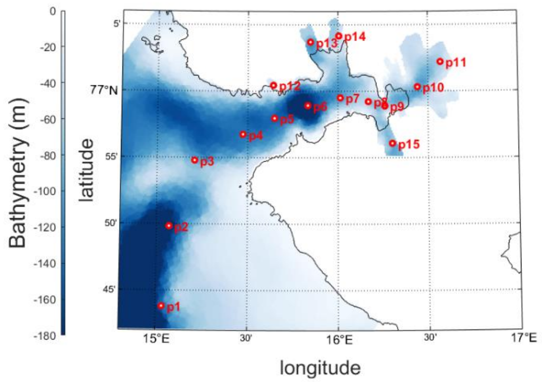


Figure 3: The bottom topography of the basins and the location of points selected for seasonal analysis

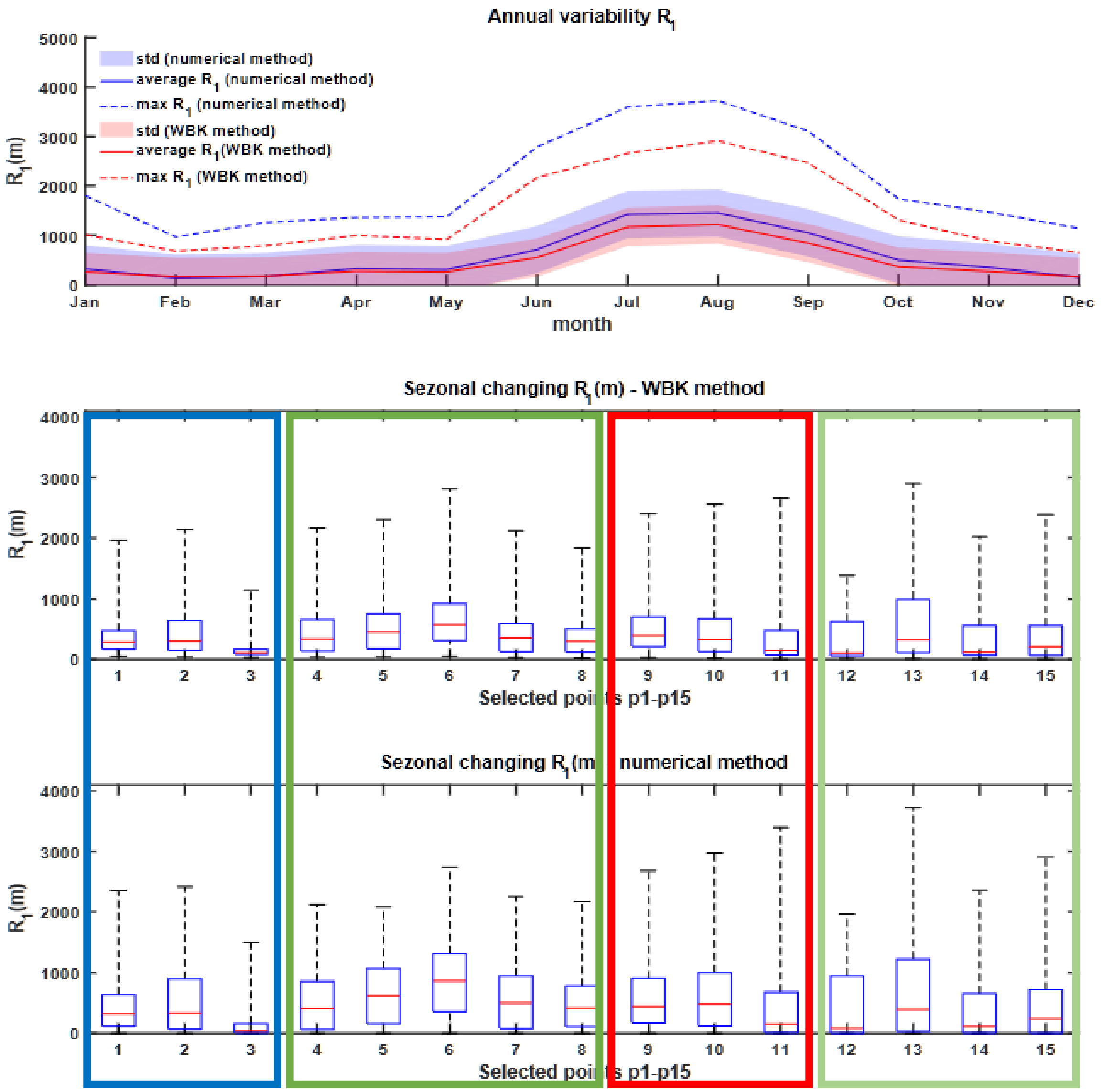
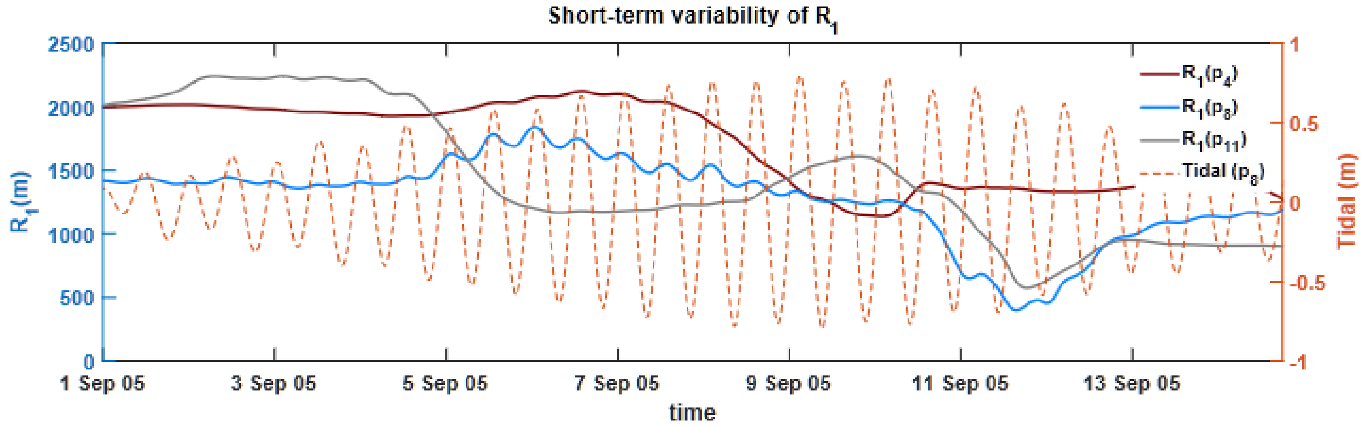
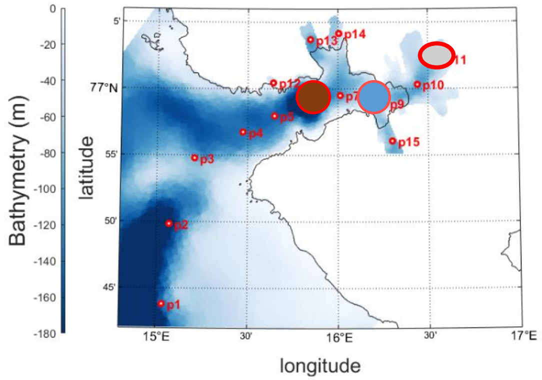


Figure 10: Variability of baroclinic Rossby's radius deformation R_1 for 15 selected points: a) annual variability of average R_1 values, standard deviation and maximum R_1 for both methods: blue – numerical method, red – WBK method, b_1) boxplot R_1 for 15 points (WBK method) b_2) boxplot R_1 for 15 points (numerical method). The red mark in boxplot for each point indicates the median, and the bottom and top edges of the box indicate the 25th and 75th percentiles, respectively, and the whiskers extend to the most extreme data points.

Short-term variations



Short-term variability of R_1 overtime, 1 September 2005 – 14 September 2005, for the three points p_4, the tidal at point p_8 at time



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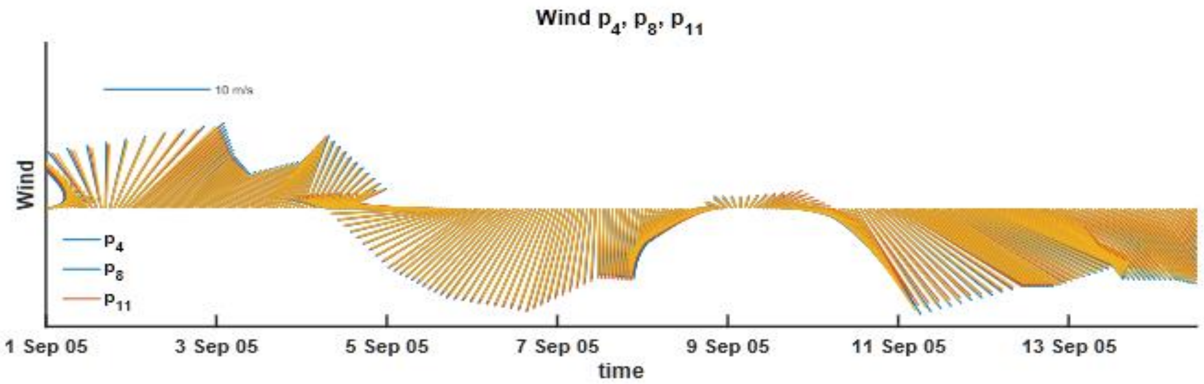


Figure 12: Wind, 1-14 September 2005

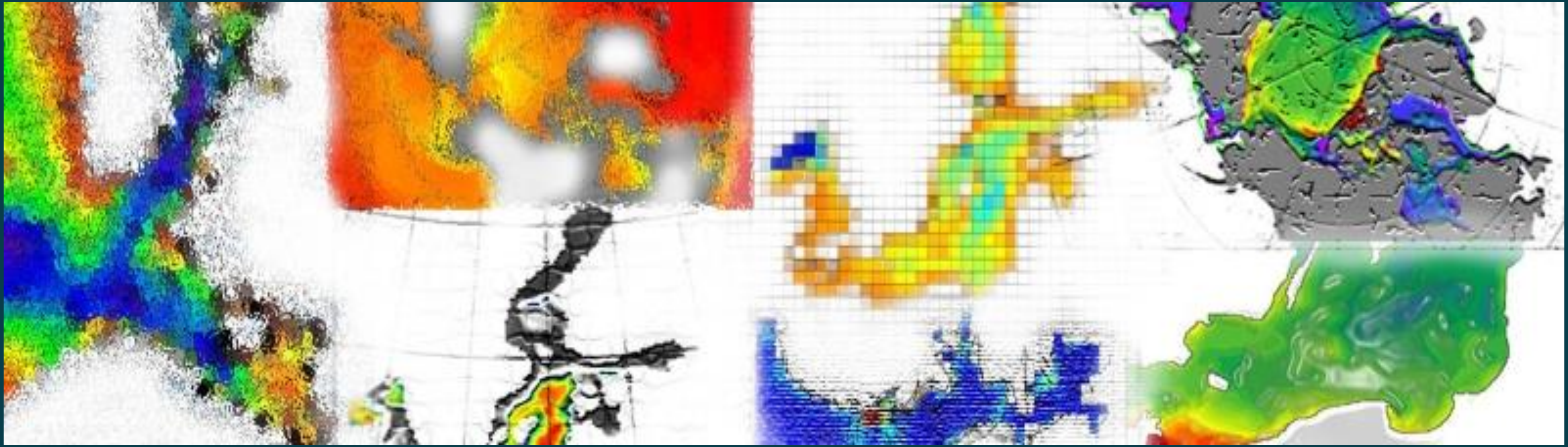
Final remarks

- Changes in the vertical structure of the Brunt-Vaisail frequency lead to the **seasonal variability** of baroclinic Rossby radius of deformation
- R1 has a **large spatial and temporal variability**, can be different even at points close to each other.
- The **largest** values R1 are **in late summer**, **the smallest in winter**.
- R1 **depending** on the adopted **calculation metho**d. **WKB** method gives **smalle**r values **than numerical method,** WKB gives proper results if the variability of BVF in the vertical direction is weak.

CONCLUSION

- WKB gives proper results if the variability of BVF in the vertical direction is weak.
  In the Hornsund fjord, the halocline and the seasonal thermocline and highly influence BVF.
  Therefore, the numerical solution is more appropriate.
- Taking into account melting of glaciers at the model boundaries and updating freshwater sources from land should improve the results obtained from the numerical model
- It is supposed that the interannual variation of the baroclinic Rossby deformation radius may be significant, possibly even greater than the seasonal variation due to the advection of salt water from the shelf
- Running longer simulations can help observe changes in the deformation radius on a multi-year scale and how these changes affect the circulation of the fjord

Thank you for your attention ☺



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