GFZ's Shipborne Gravity Measurements and Data Processing Efforts along Ferry Lines in the Baltic Sea

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GFZ Helmholtz Centre Potsdam

FAMOS

Co-financed by the European Union
Connecting Europe Facility

HELMHOLTZ

Mobile Gravimetry in GFZ

- Shipborne and airborne gravimetry for more than 20 years
- Chekan-AM gravimeter purchased in 2011 (CSRI Elektropribor)
- Gravimeter is based on double quartz elastic torsion system and viscous liquid
- Platform stabilized in 2D by gyros
- Since purchase, 1 airborne (GEOHALO) in 2012 and 10 shipborne campaigns (including two on ferries) performed
- Most of the campaigns were organized within the EU co-funded project FAMOS

Shipborne (Ferry) Gravimetry

- On commercial ferries (StenaLine, Finnlines)
- Piggy-back method (not dedicated campaigns)
- Measurements are not performed in ideal conditions (e.g. much higher speed, installation position)
- Different characteristics in terms of ships‘s movements leaking into measurements

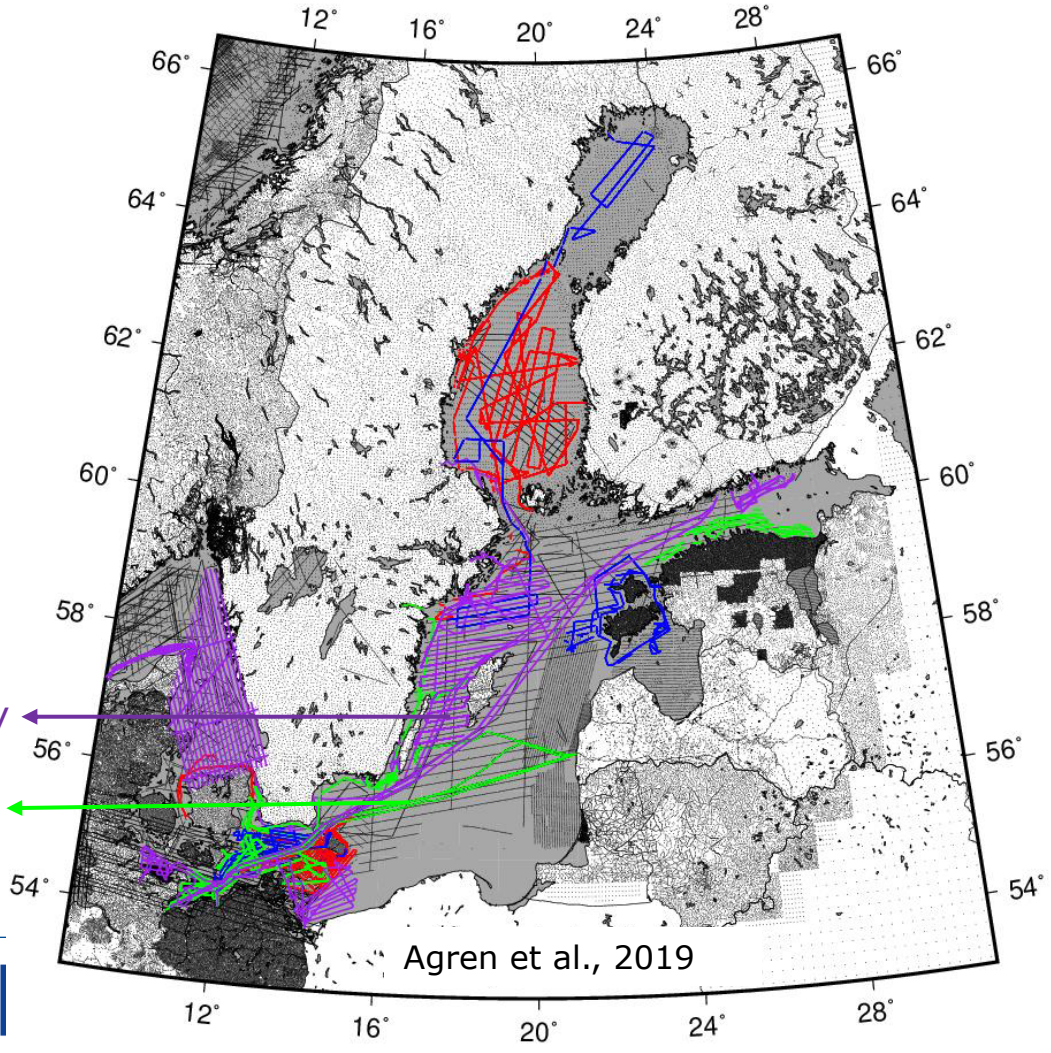
Can we still deliver high quality measurements?

(potential use of other ferry lines in Baltic Sea or North Sea)

FAMOS (Finalising Survey for the Baltic Motorways of the Sea)

The main purpose is to contribute to future satellite navigation and hydrographic surveying with GNSS based methods by improving the marine geodetic infrastructure.

Our shipborne gravity measurements support the development of a geoid model of uncertainty better than 5 cm to be used as the common unified chart datum in the Baltic Sea (Baltic Sea Chart Datum 2000 - BSCD2000).



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FAMOS
FINALISING SURVEYS FOR THE BALTIC MOTORWAYS OF THE SEA

2017 Urd

1st Ferry Campaign

October 6th – 13th 2017

- "Piggy back" campaign along a ferry link between Travemünde and Liepaja
- Total track length ca. 4300 km
- Individual tracks of ca. 700 km
- Average speed of the ferry 14.7 kn

In Cooperation with
- Stena Line
- Federal Agency for Cartography and Geodesy (BKG, Germany)
- Technical University Riga
- Maritime Administration of Latvia

2018 Finnlady

2nd Ferry Campaign

October 29th – November 6th 2018

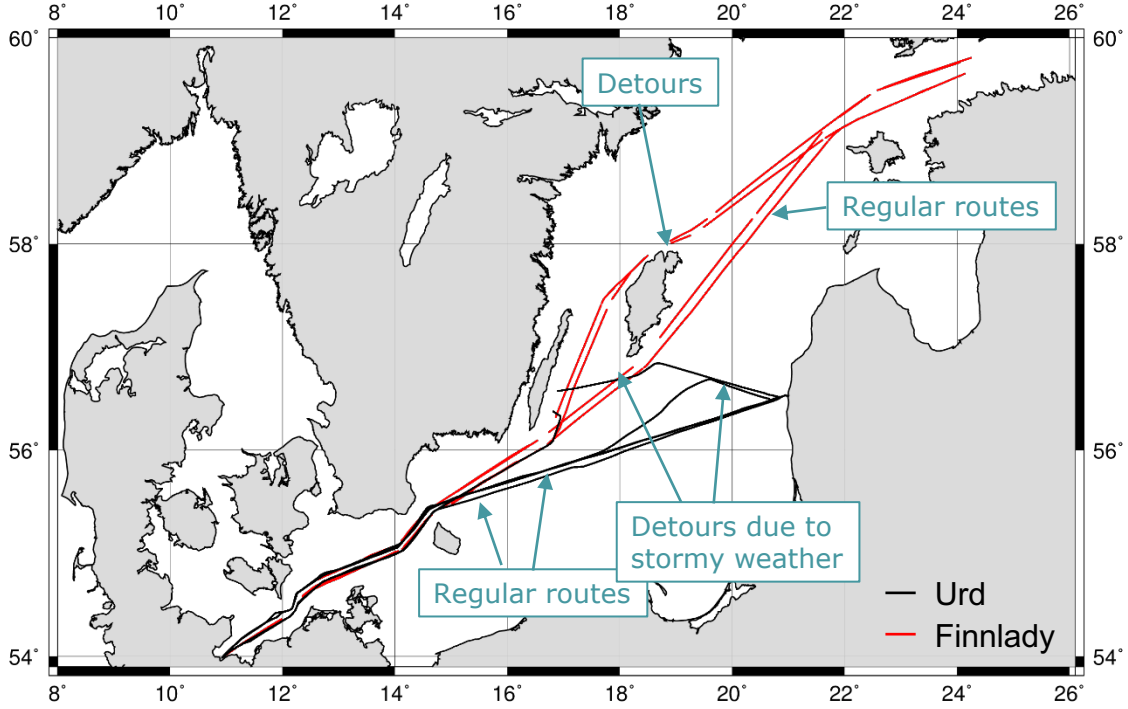
- "Piggy back" campaign along a ferry link between Travemünde and Helsinki
- Total track length ca. 5400 km
- Individual tracks of ca. 1200 km
- Average speed of the ferry 21.8 kn
- Stabilisation system is present

In Cooperation with
- Finnlines Plc, Helsinki
- Finnish Geospatial Research Institute (FGI), Masala

Ferry campaigns trajectories

URD2017
3 x Travemünde →Liepaja
(the first ride for warm-up)
3 x Liepaja →Travemünde

FINNLADY2018
3 x Travemünde → Helsinki
(the first ride for warm-up, second one also – longer warming period)
3 x Helsinki→ Travemünde



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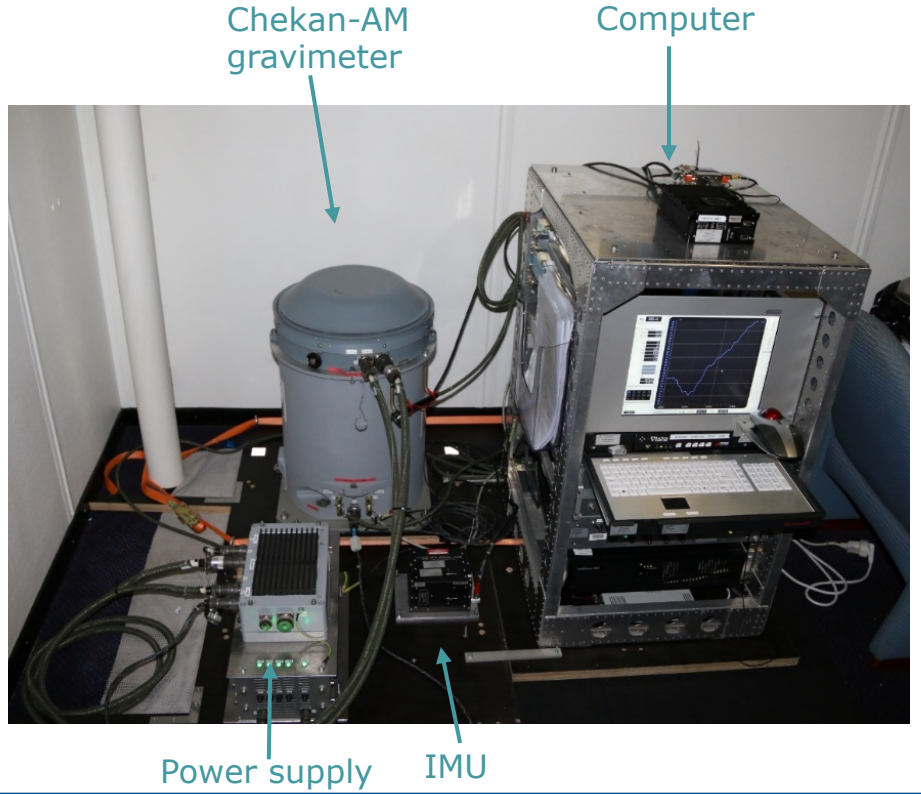
Mobile Air-Marine Gravimeter Chekan-AM

Double quartz spring-type relative gravimeter

Drift and bias are estimated by linking measurements to absolute reference measurements in harbours.

Accuracy of the gravity records and stability of the drift rate are verified by cross-over points analyses

Drift up to 3 mGal/day max
Accuracy < 1 mGal

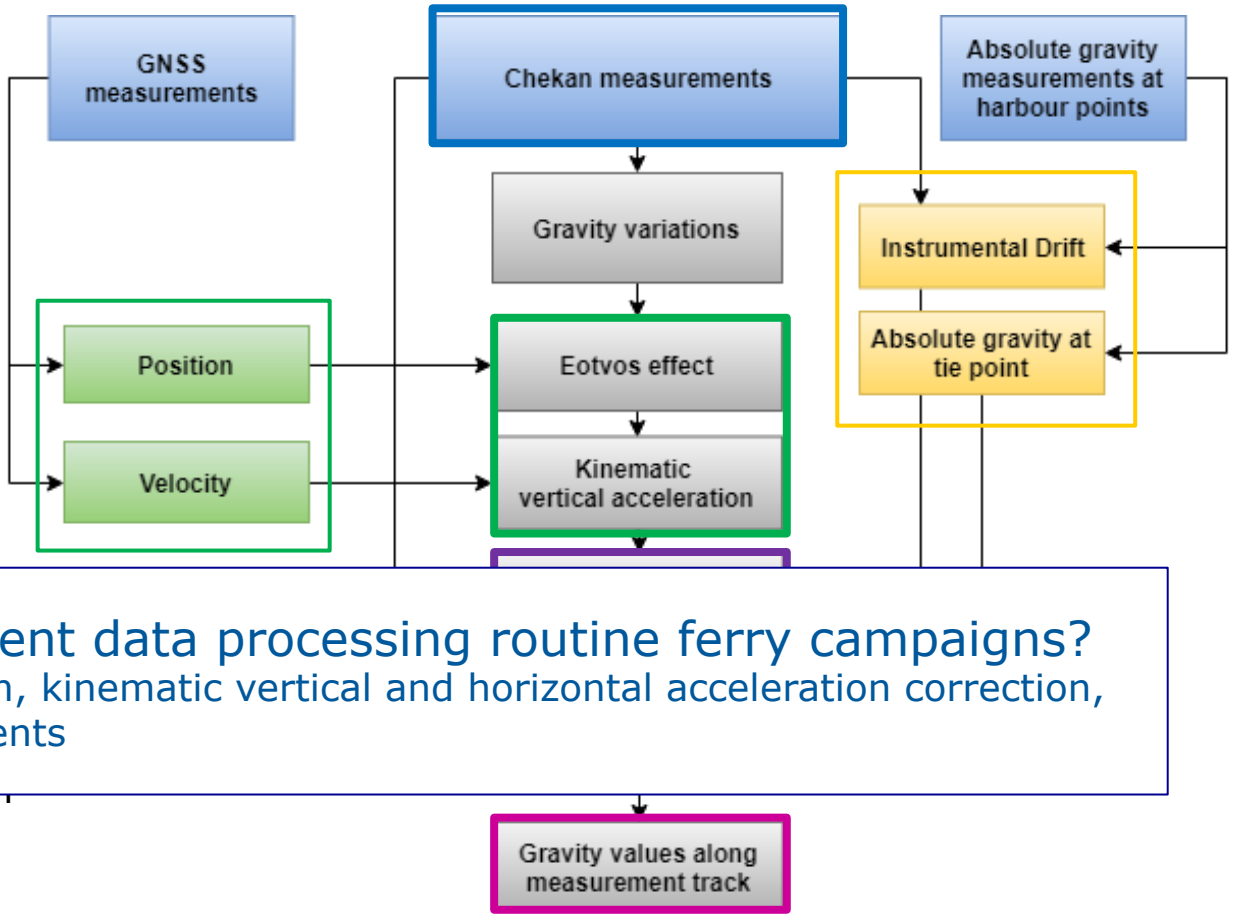


Chekan gravimeter installation on Stena Line URD.

Data Processing

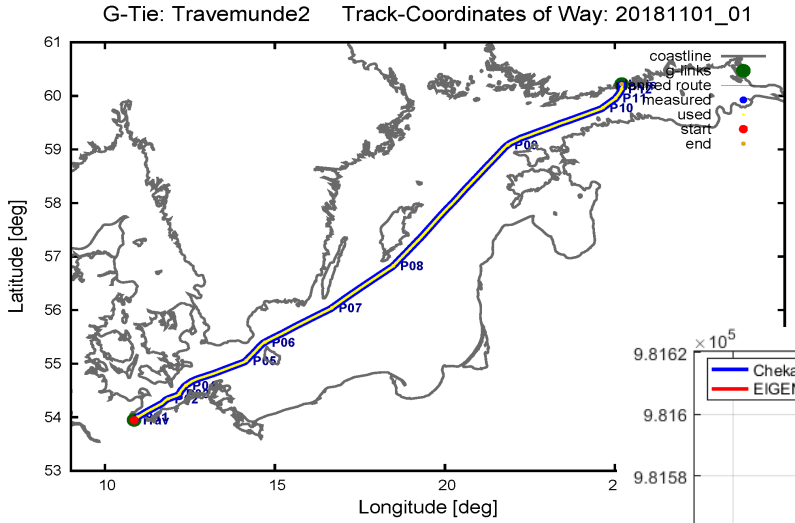
Remarks for ferry campaigns:

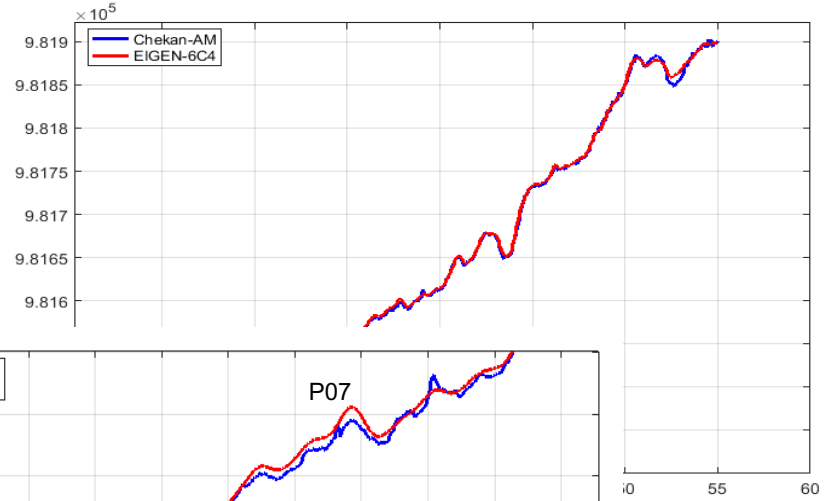
- Gradient measurements for harbour reference points
- Drift calculation becomes more challenging
- Eliminate effect of vehicle's dynamics

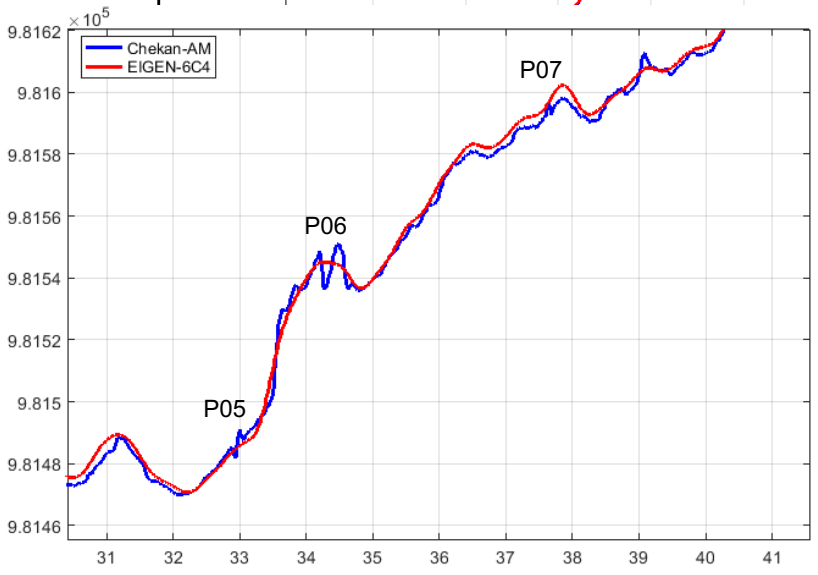


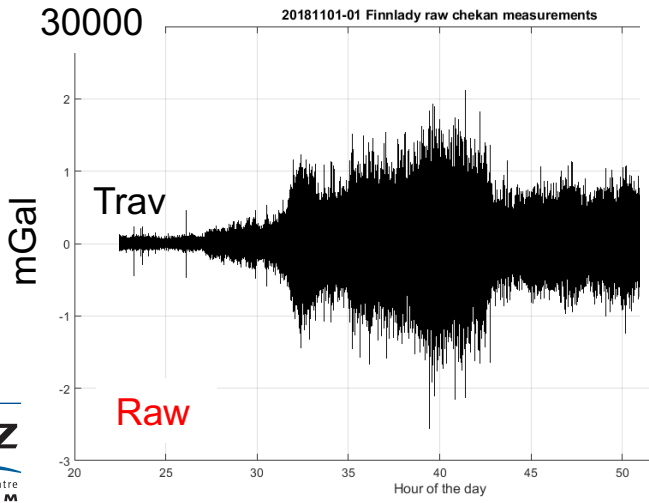
- Do we need a different data processing routine ferry campaigns?
  - Different filter length, kinematic vertical and horizontal acceleration correction, gradient measurements

$$g = g_{Chekan} - a_{GNSS} + \delta g_{eotv} - \delta g_{HAC} - \delta g_{drift} + \delta g_{link}$$

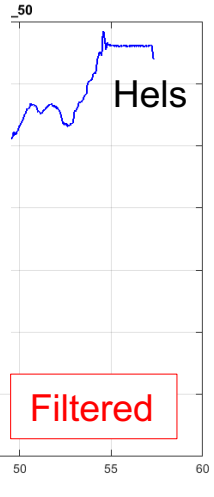

G-Tie: Travemunde2 Track-Coordinates of Way: 20181101_01
coastline
g-links
planned route
measured
used
start
end
P10
P11
P08
P07
P06
P05
Trav
Latitude [deg]
Longitude [deg]

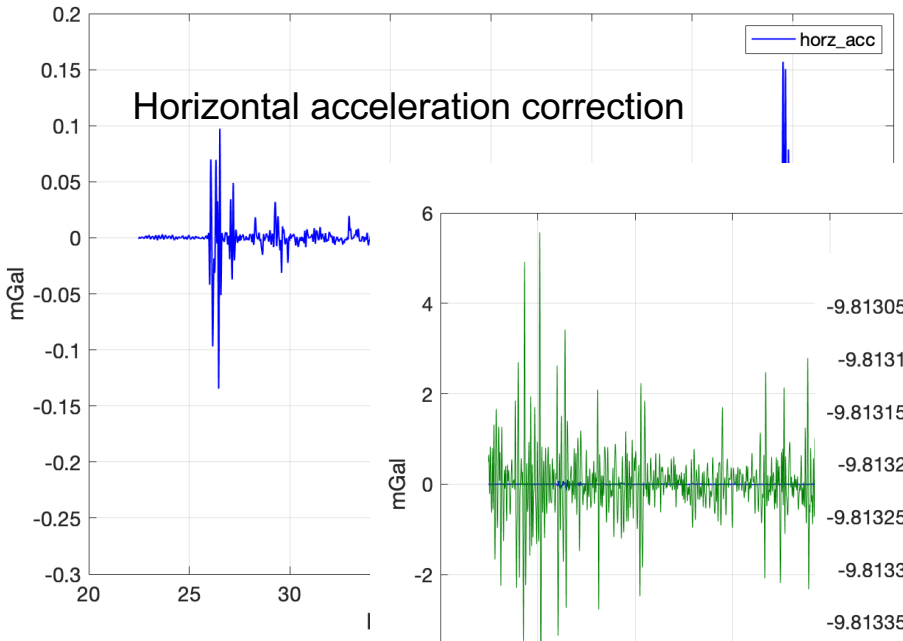

Chekan-AM
EIGEN-6C4

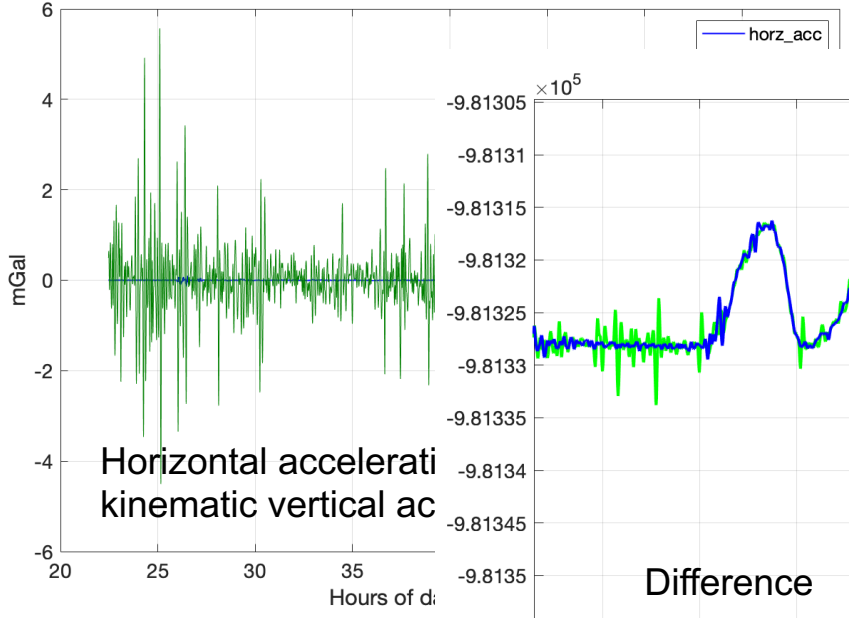

Chekan-AM
EIGEN-6C4
P05
P06
P07

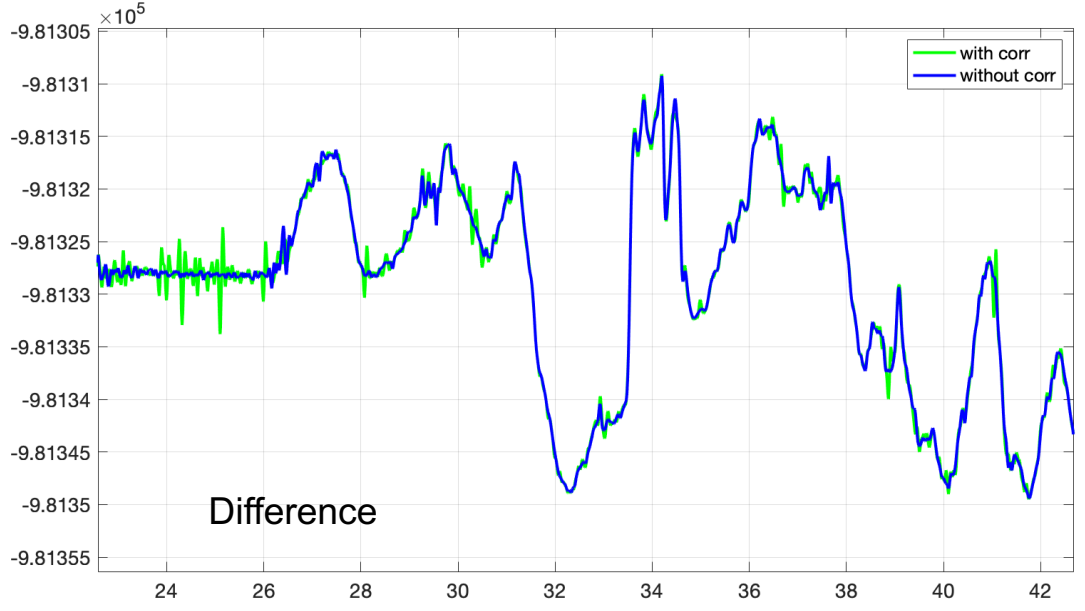

30000
20181101-01 Finnlady raw chekan measurements
mGal
Trav
Raw
Hour of the day

Filtering


Hels
Filtered
Hour of the day


horz_acc
Horizontal acceleration correction
mGal

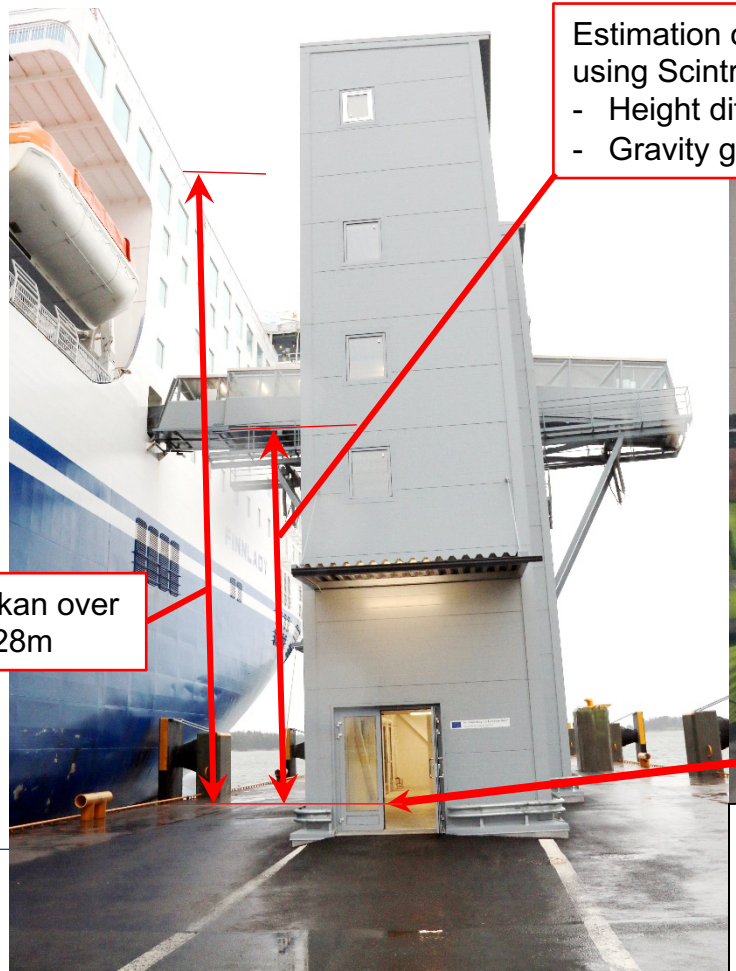

horz_acc
mGal
Horizontal accelerati
kinematic vertical ac
Hours of d

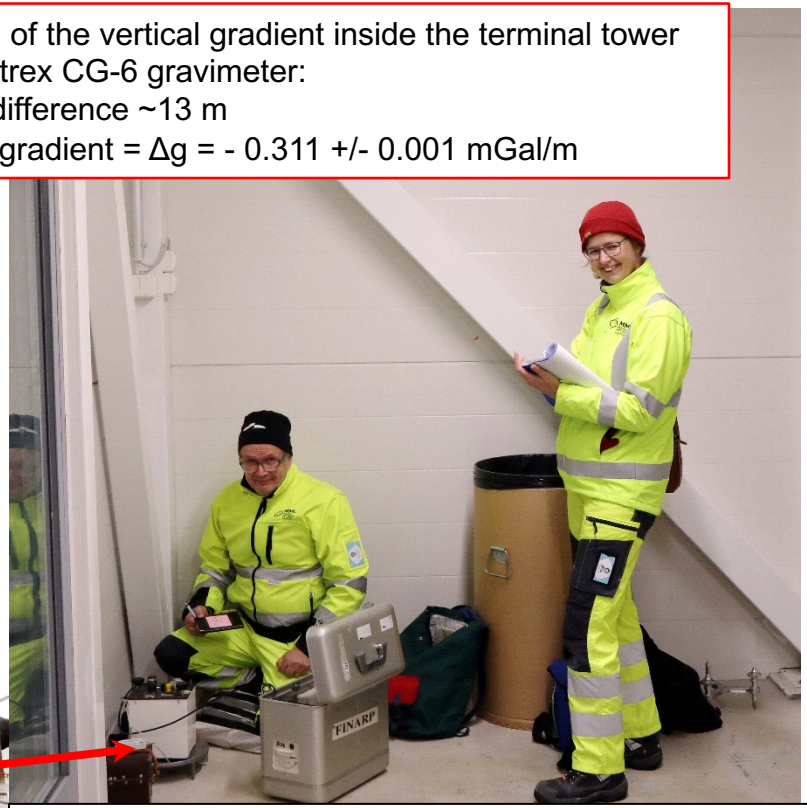

×10^5
with corr
without corr
Difference

Reference measurements in Helsinki/Vuosaari

Estimation of the vertical gradient inside the terminal tower using Scintrex CG-6 gravimeter:
- Height difference ~13 m
- Gravity gradient = Δg = - 0.311 +/- 0.001 mGal/m

Height Chekan over the peer > 28m





Gravity reference value on the peer (inside the terminal tower):
- Esimated by Finnish Geospatial Research Institute (FGI)
- Relatively to an absolute point in Masala (near Helsinki)
  g = 981907.1722 +- 0.0085 mGal

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Drift calculation

URD 2017

Liepaja:

Reference: 981629,035 +/- 0,030 mGal

Gradient: -0,334 +/- 0,005 mGal/m

Travemünde:

Reference: 981414,356 +/- 0,010

Gradient (Pier 3, Urd, BKG 2017): -0,327 mGal/m

FINNLADY 2018

Helsinki:

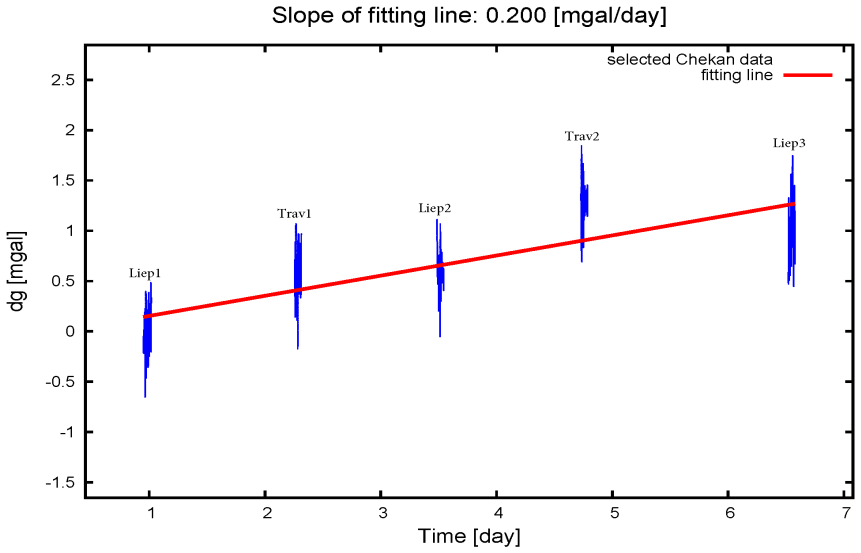
Reference: 981907,150 mGal

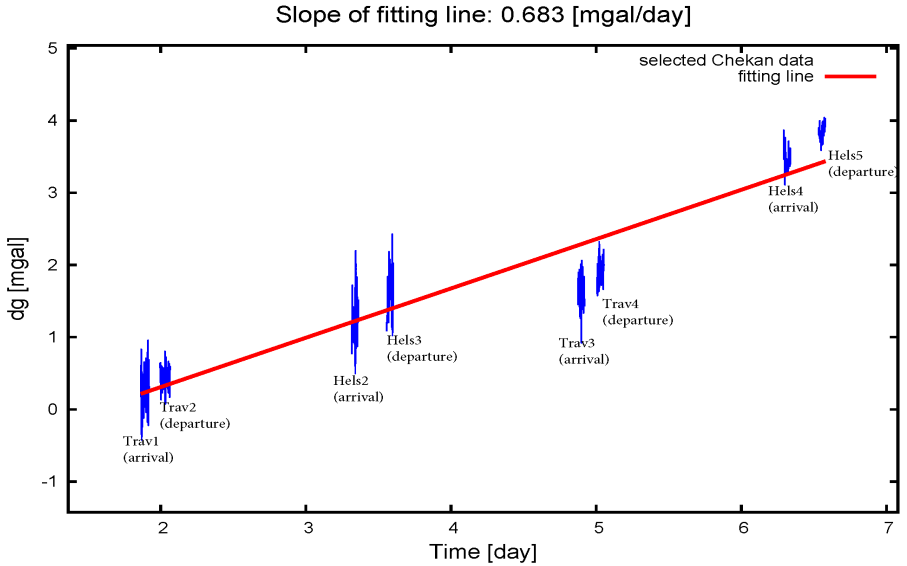
Gradient: -0,311 +/- 0,01 mGal/m

Travemünde:

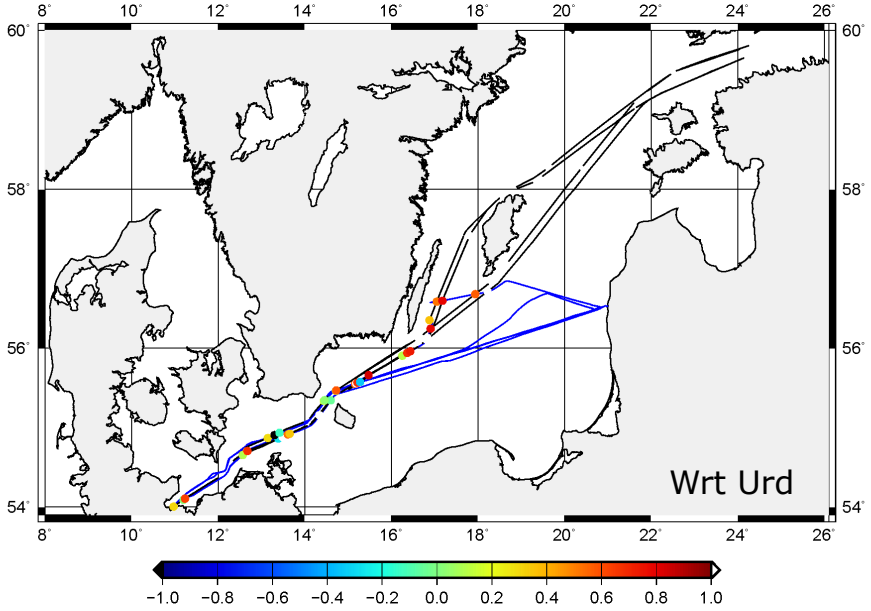
Reference: 981412,245 mGal

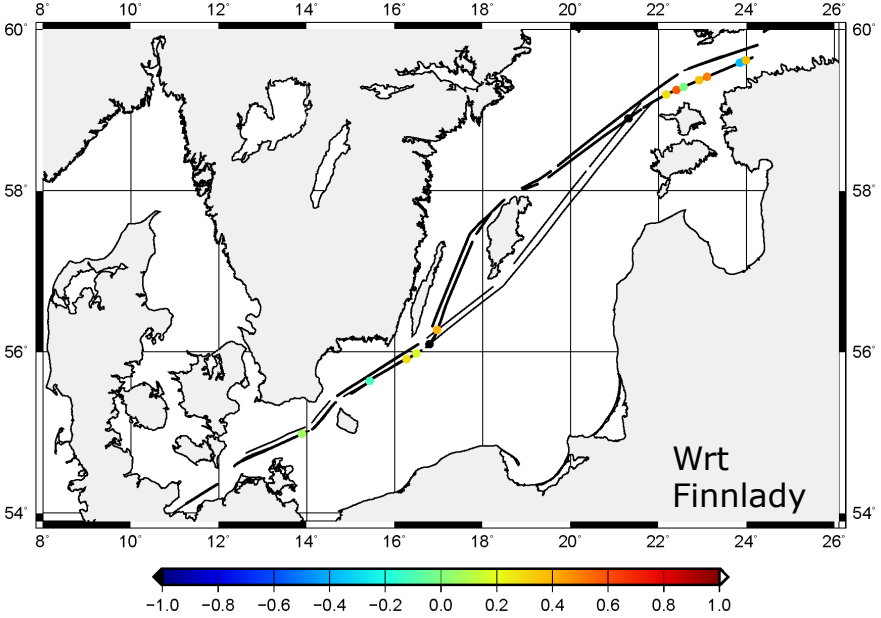
Gradient (Pier 6, Finnlady, GFZ 2018): -0,307 mGal/m





Cross-over analyses





in mGal

Finnlady	Max	Min	Mean	Std	Rms
Wrt Urd (38 xo)	2.278	-1.362	0.457	0.732	0.855
Wrt Finnlady (15 xo)	1.119	-1.946	-0.023	0.908	0.878

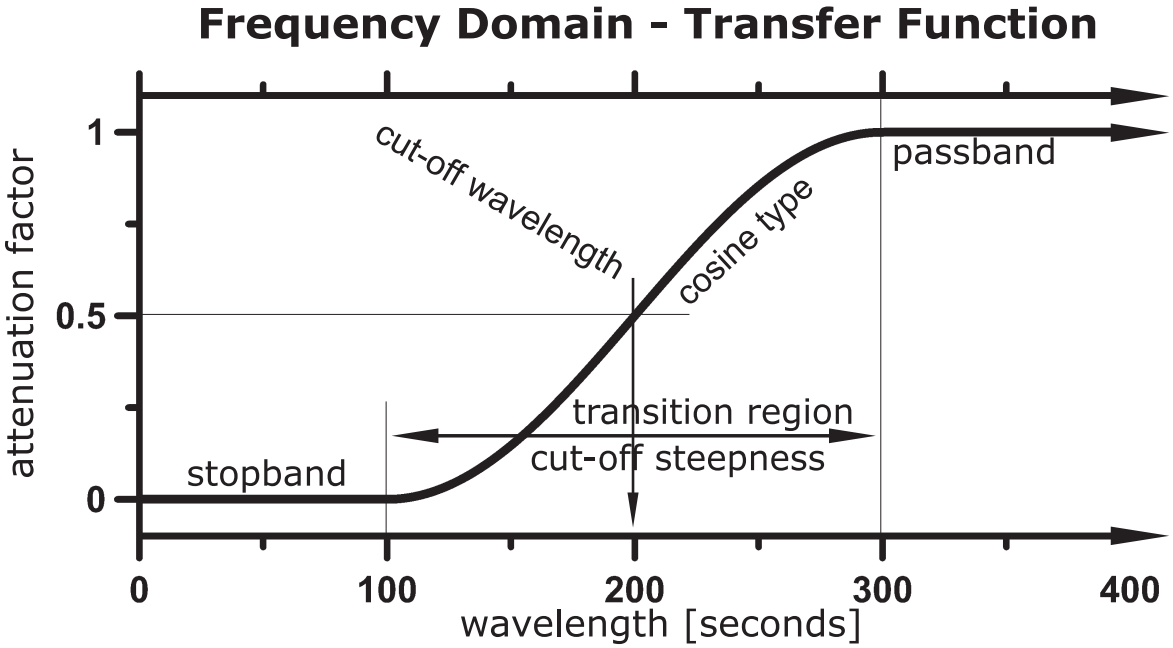
Conclusion

- Our aim is to improve the knowledge of gravity field (~1 mGal accuracy at a few km resolution)
- Absolute gravity is estimated by linking to tie points, in this context estimation of the vertical gradients at the tie points is advisable
- Data processing needs to be tuned (e.g., low-pass filtering)
- Vertical accelerations derived from GNSS measurements are not suitable in the open seas or routine data processing directly for reduction of disturbing signals
- Good quality measurements (as good as in dedicated campaigns) from our two ferry campaigns

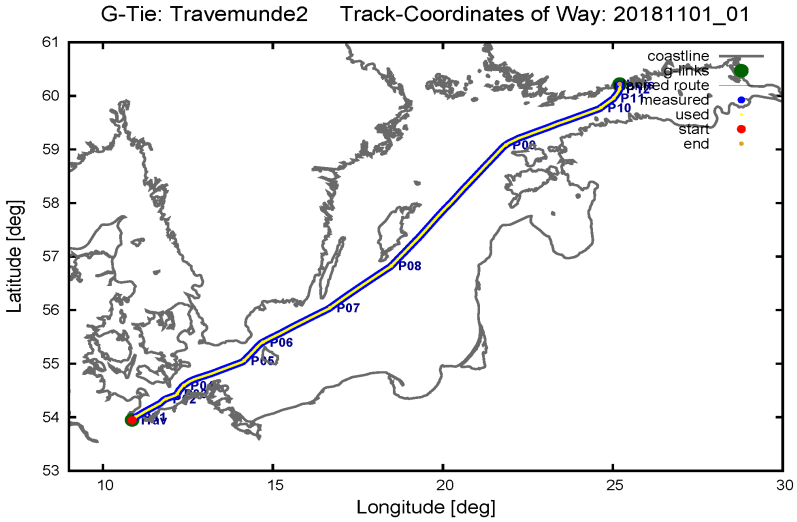
Thank you for your attention!

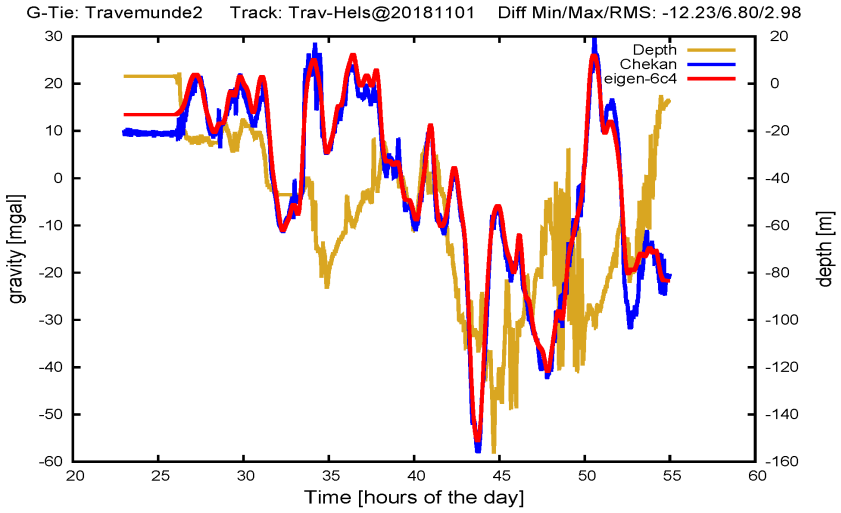
Fast Fourier Transform Low-pass filter

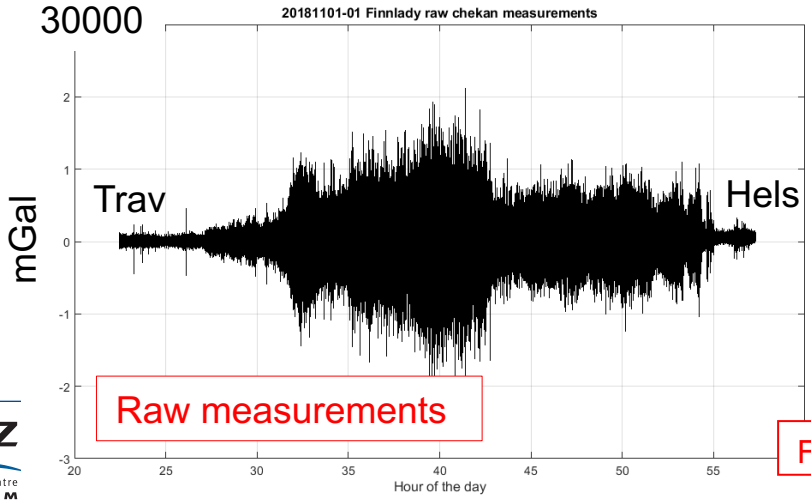
1) Cut-off wavelength (generally 400s) – resolution of the final products
2) Transition region



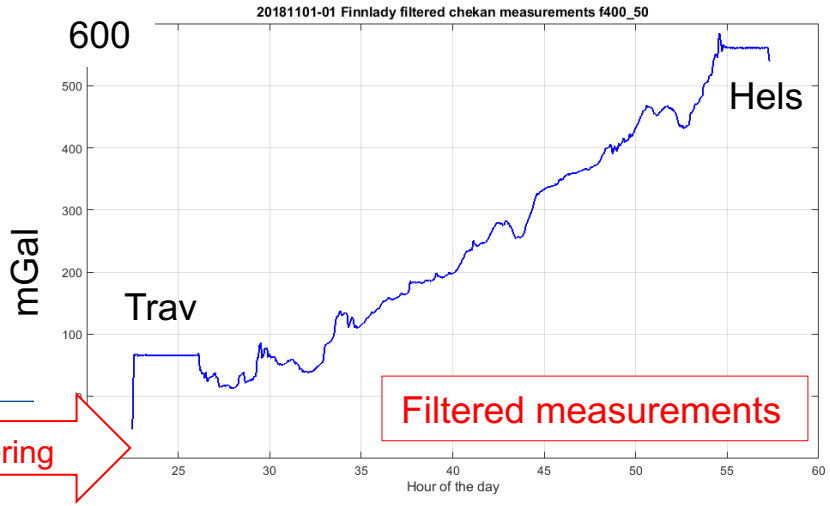
Fast Fourier Low Pass Filter that is applied to the raw Chekan measurements and GNSS trajectory. Generally 400s cut-off wavelength meets our needs (This example shows 200s).


G-Tie: Travemunde2 Track-Coordinates of Way: 20181101_01
coastline
G-links
planned route
measured
used
start
end
P12
P11
P10
P09
P08
P07
P06
P05
P04
P03
P02
P01
Trav
Latitude [deg]
Longitude [deg]

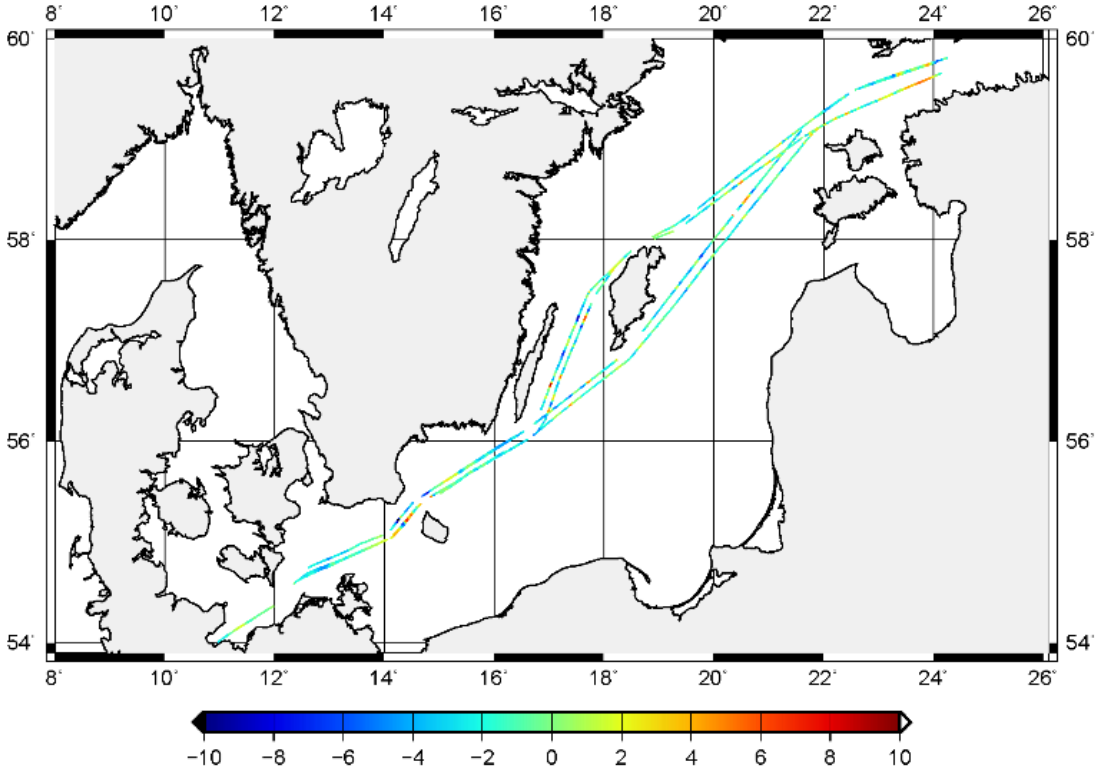

G-Tie: Travemunde2 Track: Trav-Hels@20181101 Diff Min/Max/RMS: -12.23/6.80/2.98
Depth
Chekan
eigen-6c4
gravity [mgal]
depth [m]
Time [hours of the day]


30000
20181101-01 Finnlady raw chekan measurements
Trav
Hels
mGal
Hour of the day
Raw measurements

Filtering


600
20181101-01 Finnlady filtered chekan measurements f400_50
Hels
Trav
mGal
Hour of the day
Filtered measurements

Differences wrt EIGEN-6C4



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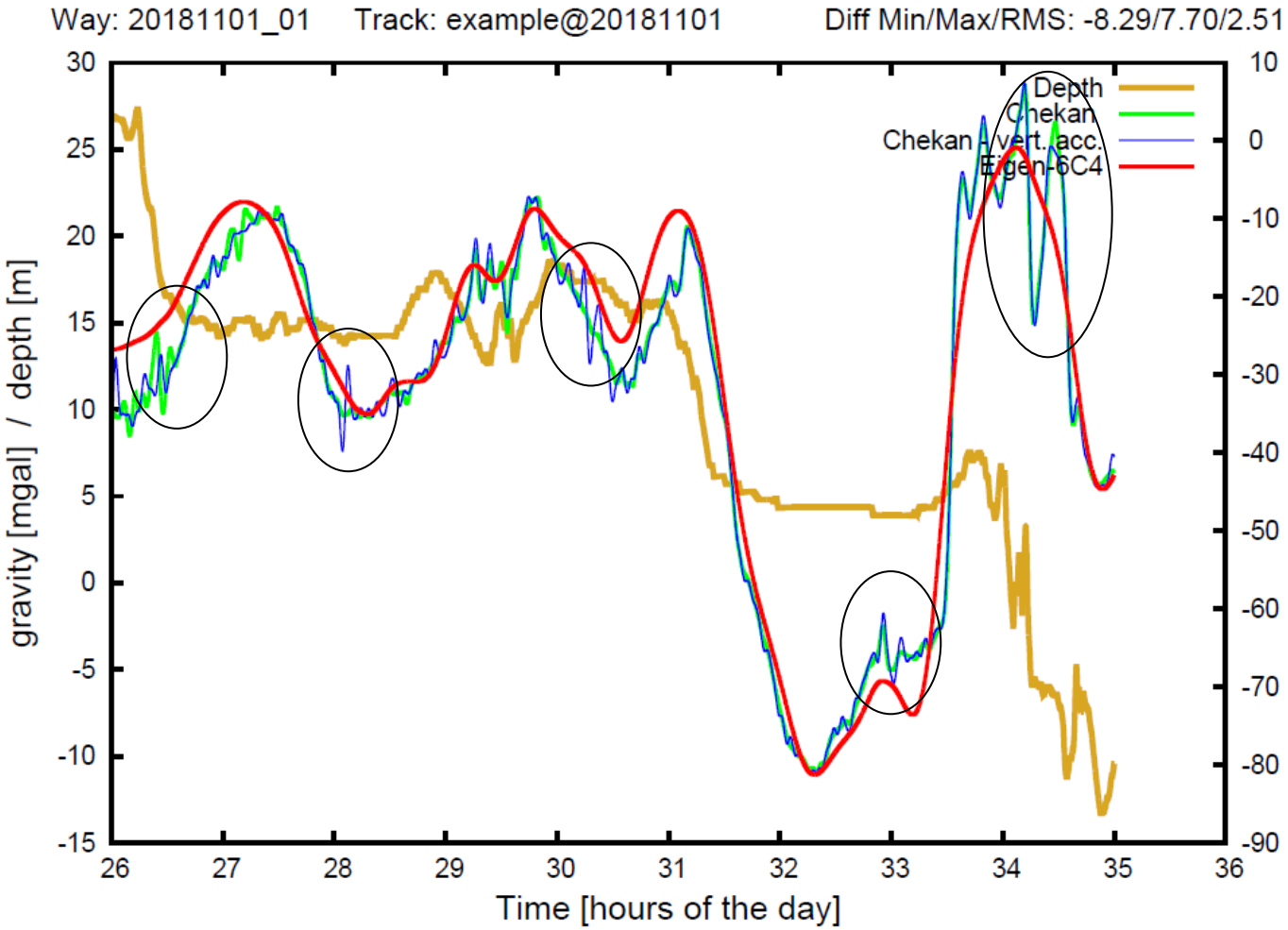
Way: 20181101_01
Track: example@20181101
Diff Min/Max/RMS: -8.29/7.70/2.51
Depth
Chekan
Chekan / vert. acc.
Eigen-6C4
gravity [mgal] / depth [m]
Time [hours of the day]
30
25
20
15
10
5
0
-5
-10
-15
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
26
27
28
29
30
31
32
33
34
35
36