

Geophysik mittels Satellitenbeobachtungen

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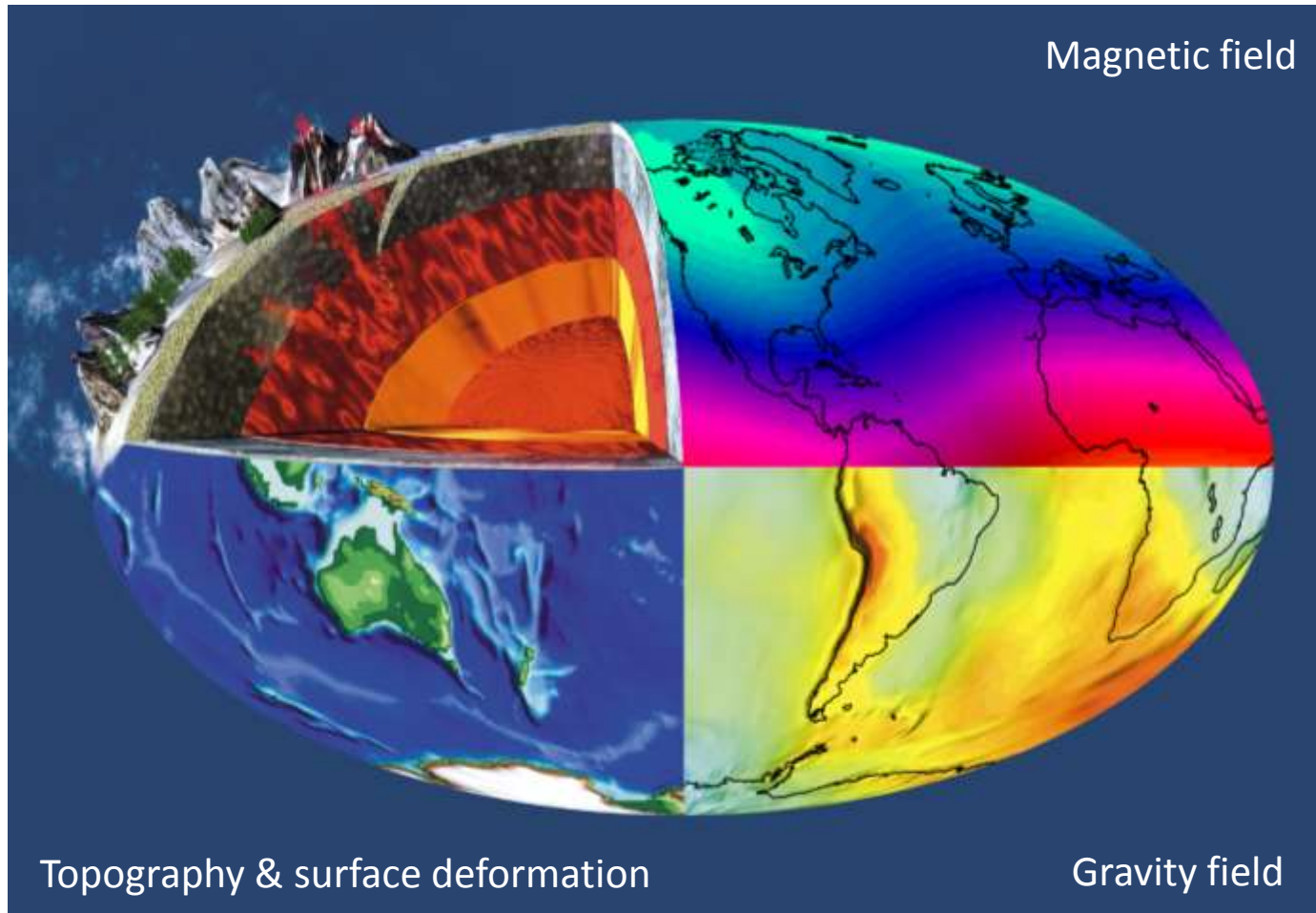
Von der Struktur zur dynamischen Betrachtung der Erde

Jörg Ebbing

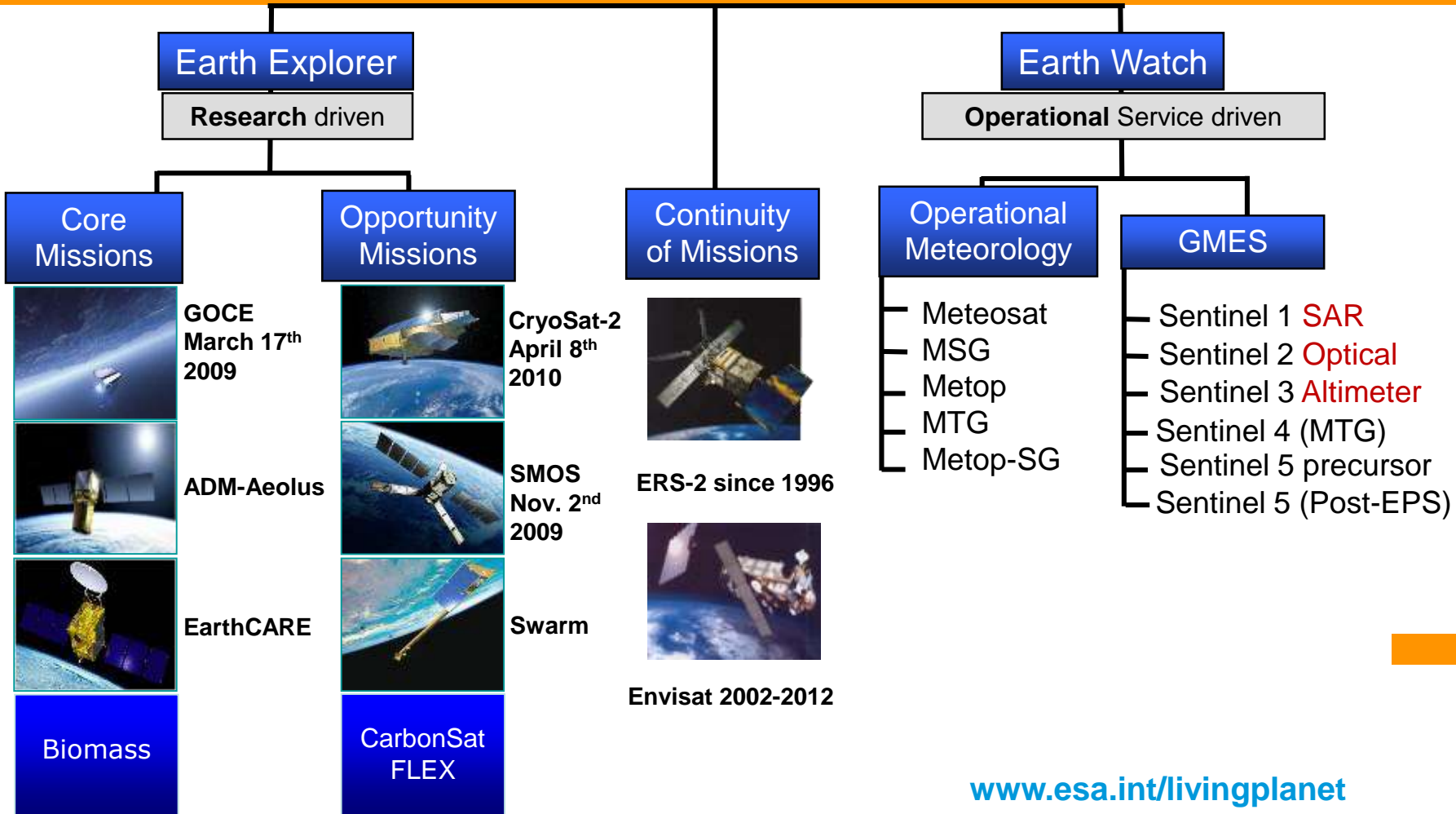
**Institut für Geowissenschaften
Christian-Albrechts-Universität zu Kiel**

102. Sitzung des FKPE
Hannover, 22. März 2015

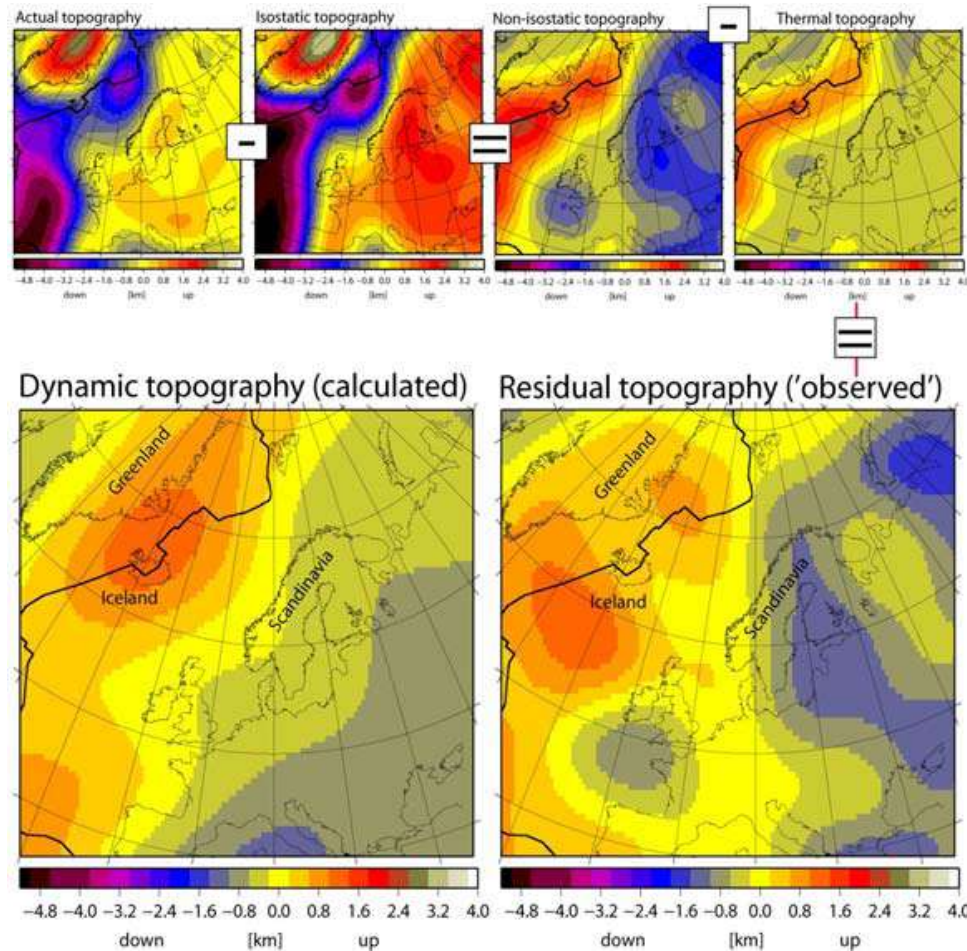
Satellite data to study the dynamic Earth



ESA's Earth Observation Missions

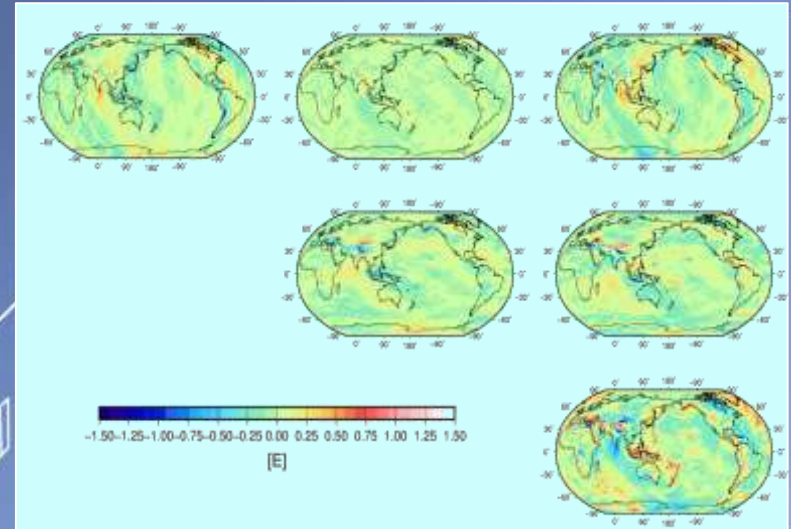
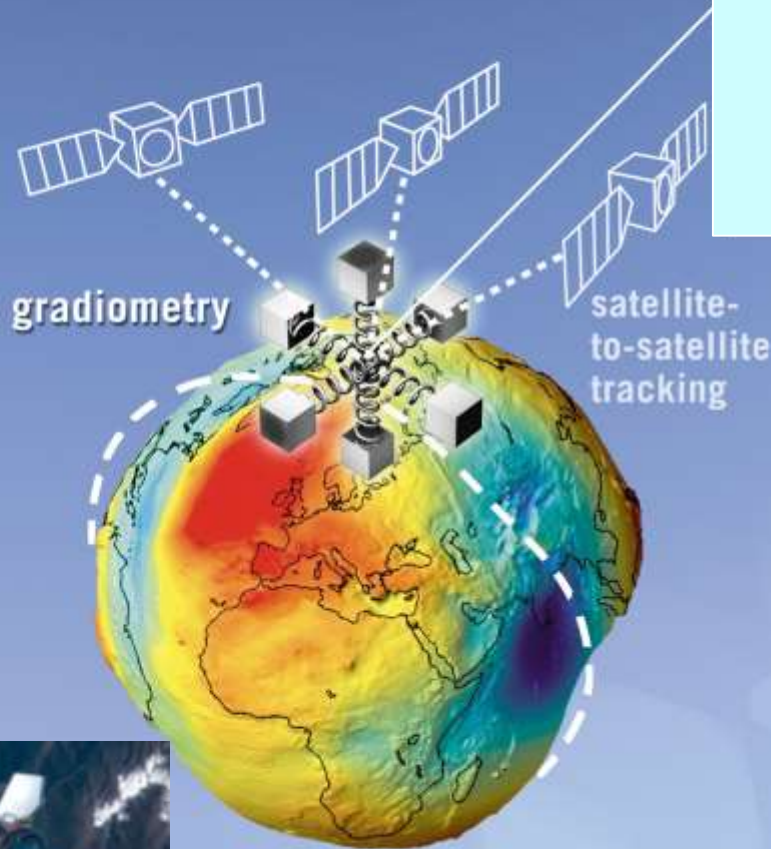


Interplay between surface, lithospheric, and mantle processes



The prediction of surface uplift and subsidence over time on a large scale is one of the most important outcomes of mantle flow models Steinberger 2007

GOCE -Gravity field and steady-state Ocean Circulation Explorer



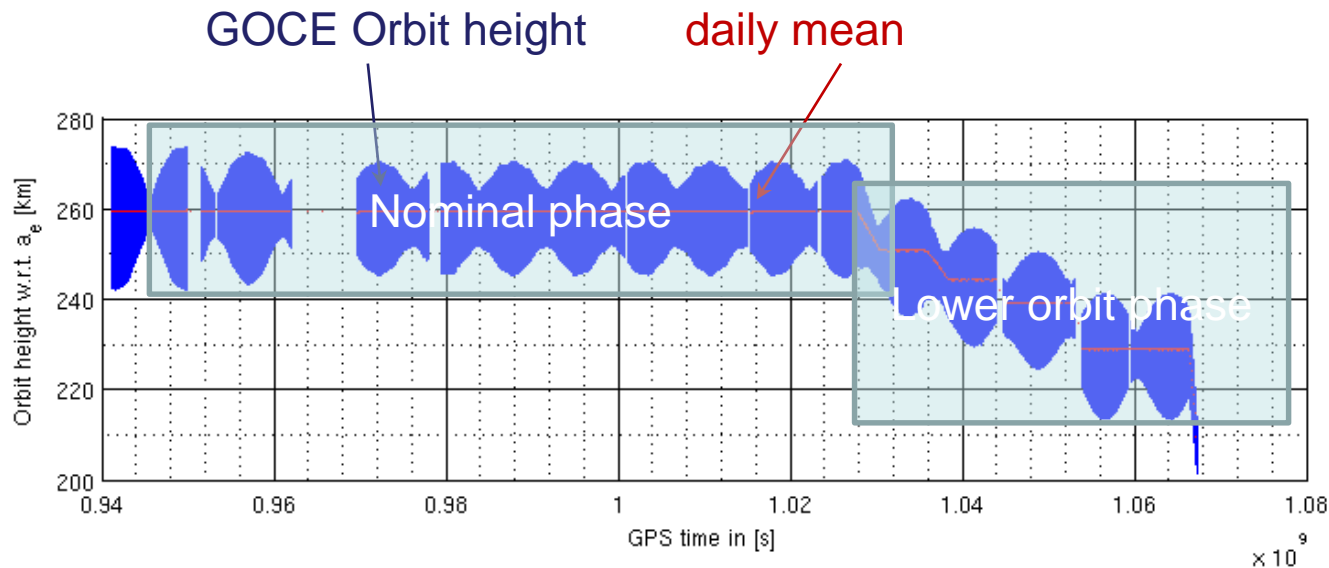
Mission period

17 March 2009 – 11 November 2013

Gradiometer; 3 pairs of 3-axis, servo-controlled, capacitive accelerometers (each pair separated by a distance of about 0.5 m).

Grids can be downloaded from
<http://goce4interior.dgfi.badw.de>

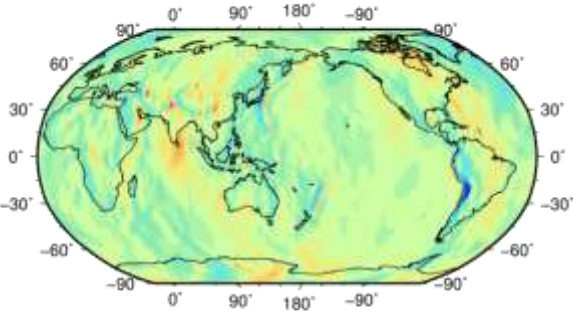
GOCE orbit heights



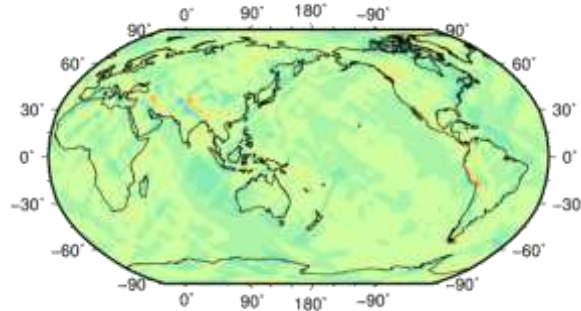
- ▶ Four times orbit lowering
- ▶ 30 km Orbit height lowering accounts for approx. 30% signal increase ($d/o > 200$)
- ▶ Nominal phase had perigee height of 255 km
- ▶ Lower orbit phase had perigee height of 225 km

Gravity gradient grids @ satellite height

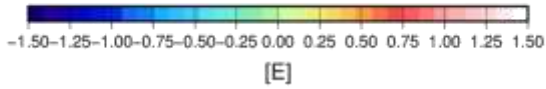
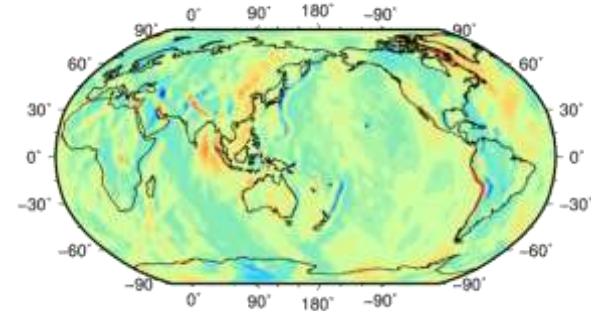
North-north



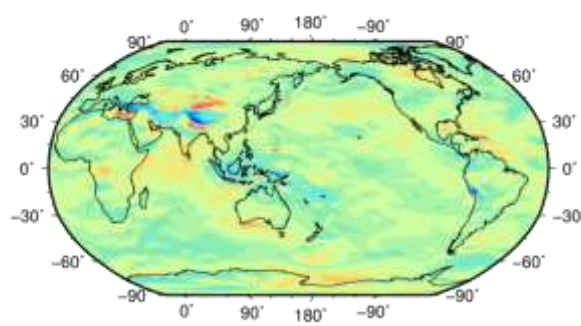
North-east



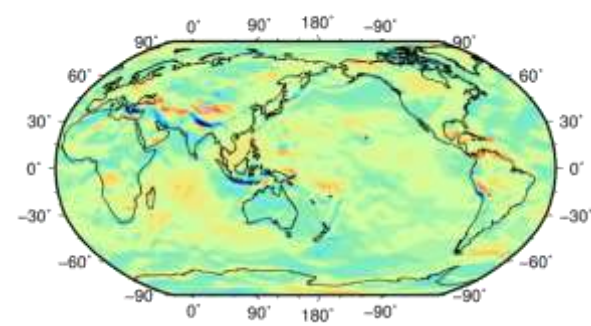
North-radial



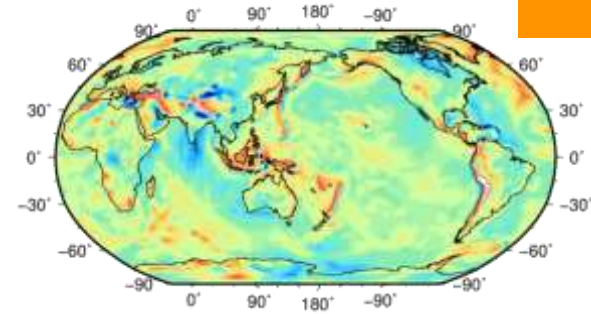
East-east



East-radial



Radial-radial



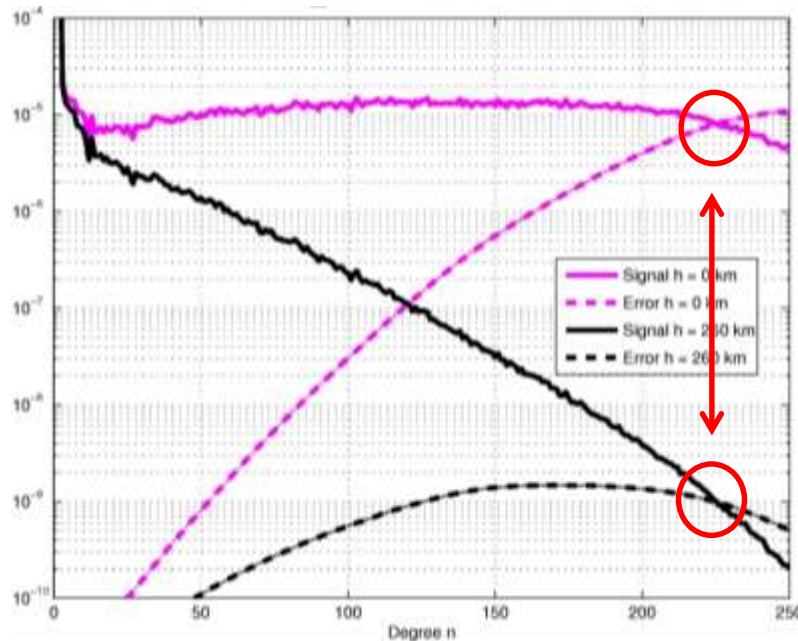
Grids can be downloaded from
<http://goce4interior.dgfi.badw.de>

GOCE data @ satellite altitude / Earth's surface

- Downward continuation also amplifies noise
- Effective resolution of data does not change
- Omission error becomes much larger (mainly high frequency topography)

V_{ZZ} degree RMS $h = 0$ & 260 km

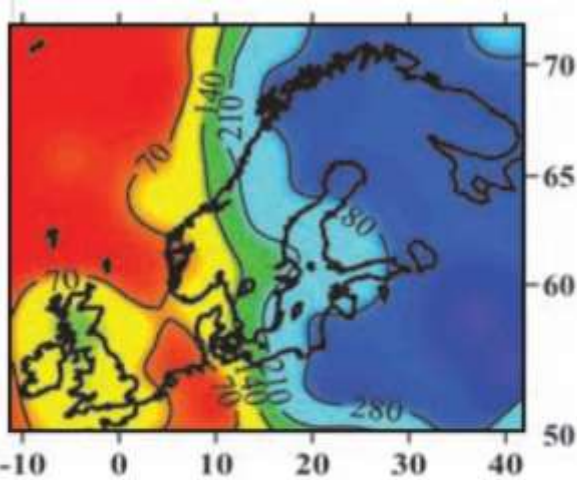
GOCC03S V_{ZZ} signal & error, $L = 225$



Saudi Arabia	Height		
	0 km	10 km	260 km
Signal RMS	5.1 E	4.1 E	0.3 E
Model error	1.3 E	0.9 E	0.4 mE

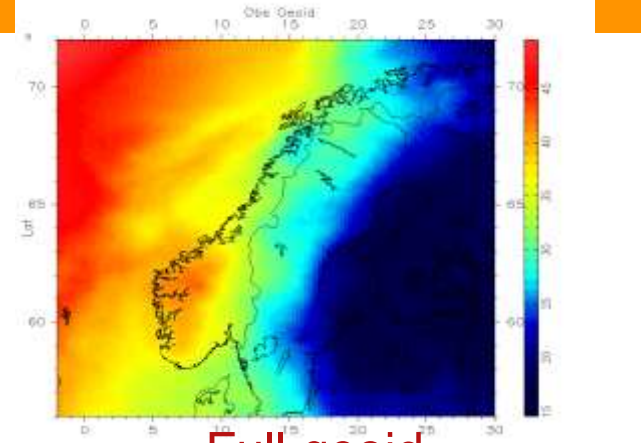
For model inversion it is probably best to use data close to their original point of acquisition.

The classical view of crust and upper mantle (for Scandinavia)

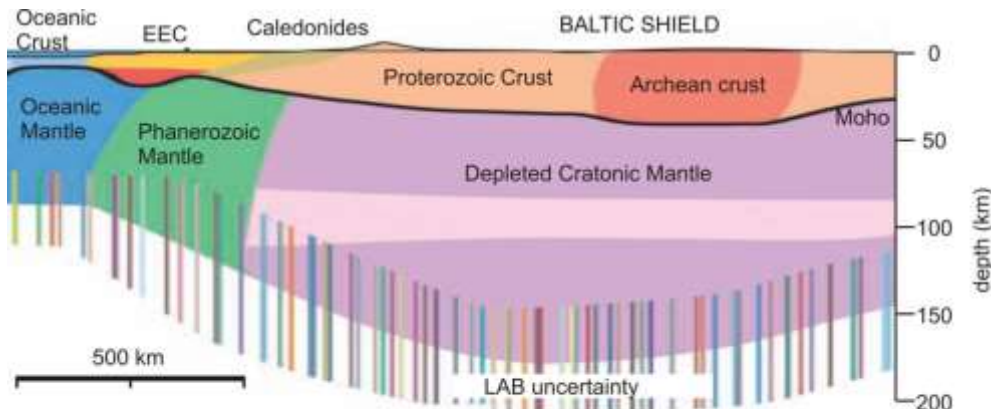


LAB depth

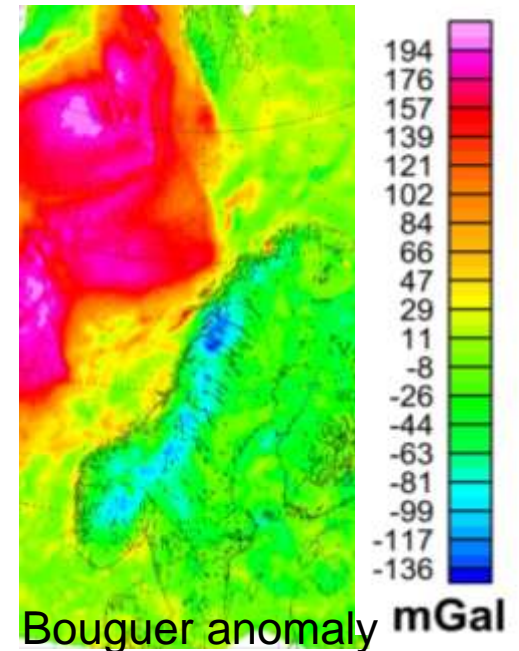
Artemieva & Thybo (2008)



Full geoid



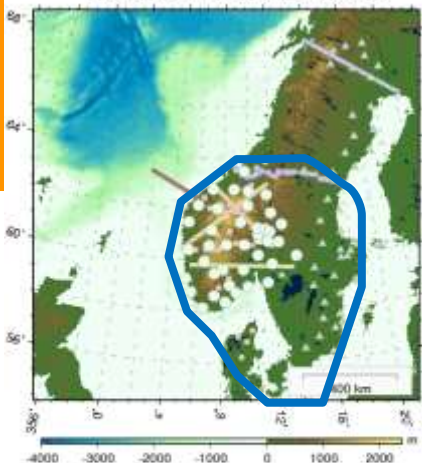
Artemieva & Thybo (2008)



Bouguer anomaly

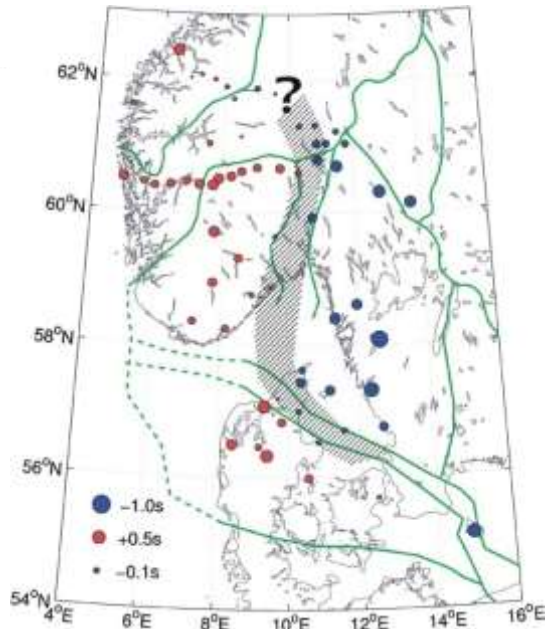
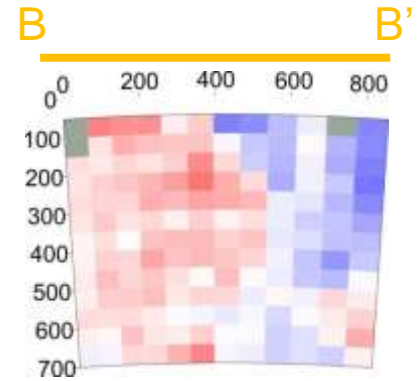
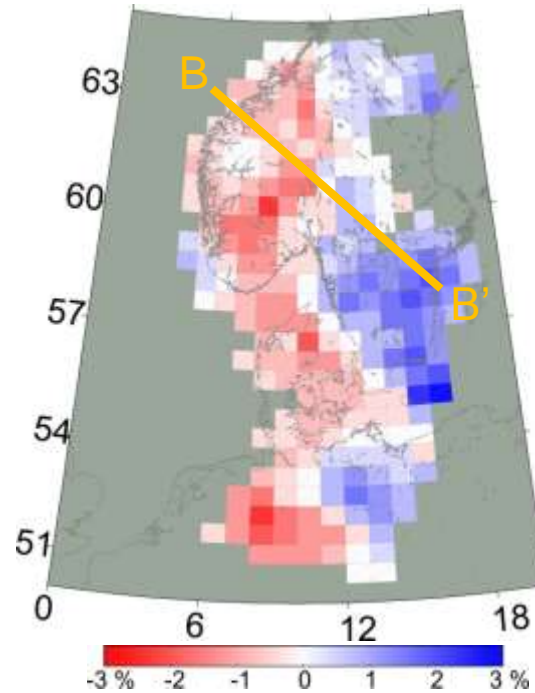
mGal

The Southern Scandinavian mountains



Relative P-wave Tomography (100-200 km)

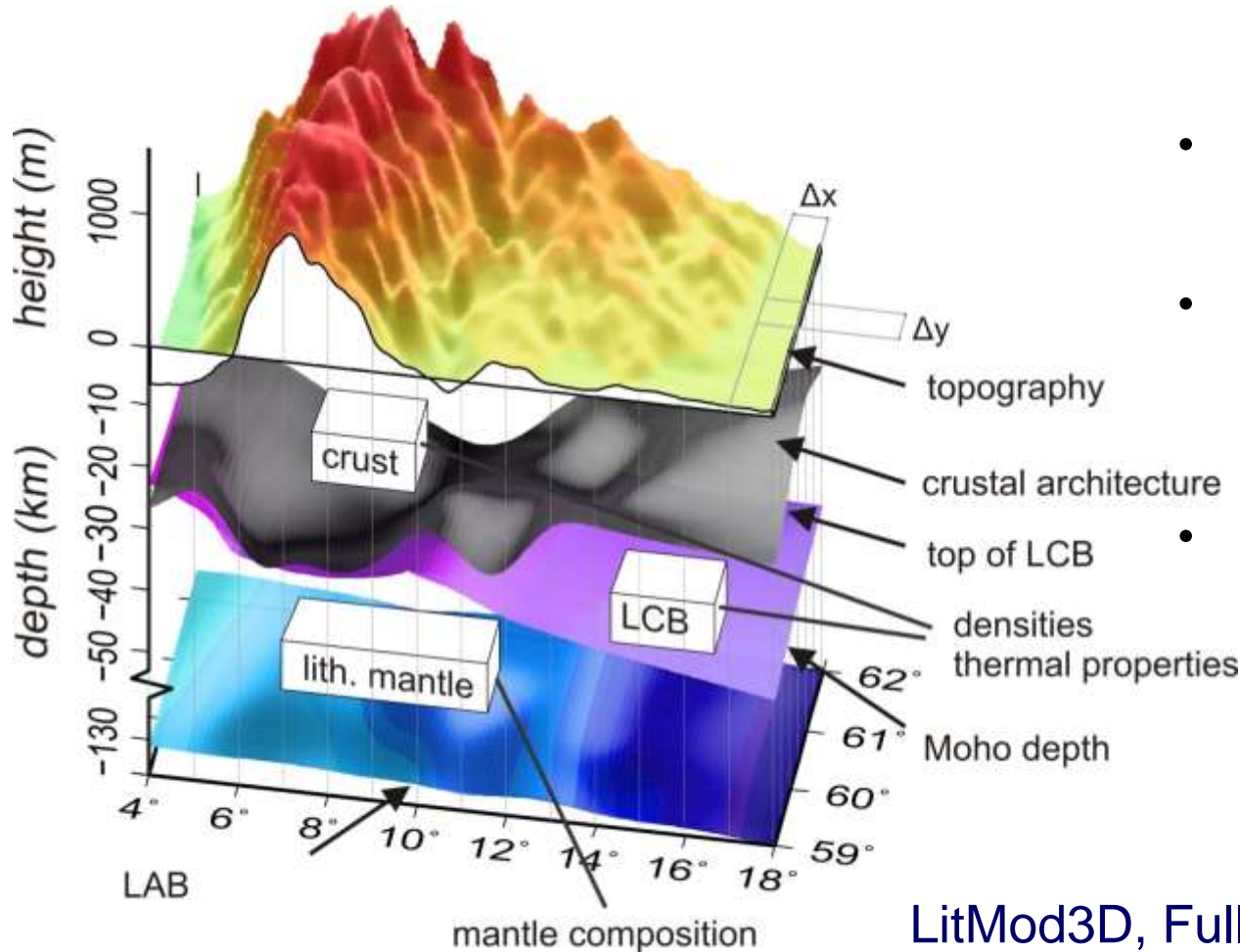
Bondo Medhus et al. (2012)



P-wave Residuals

Bondo Medhus et al. (2009)

Self-consistent 3D Subsurface Model

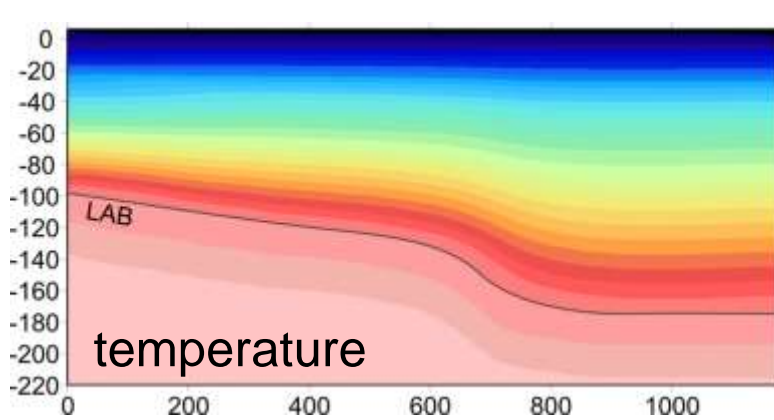


addresses:

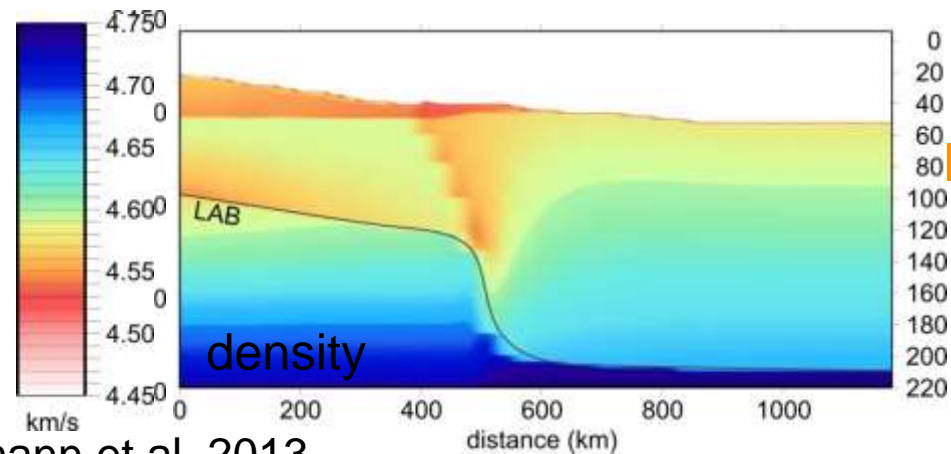
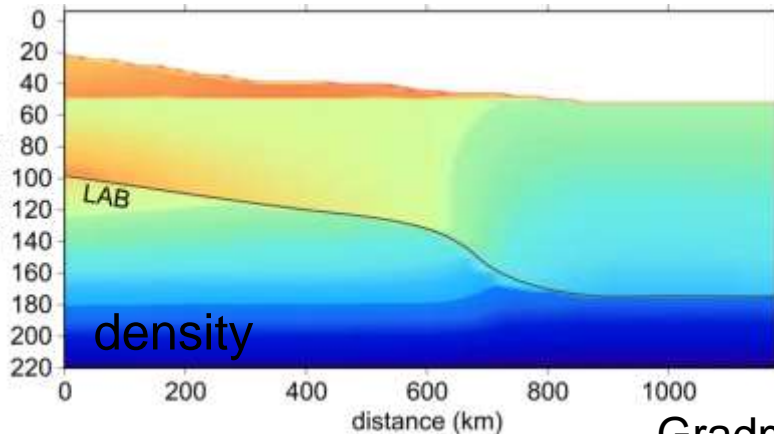
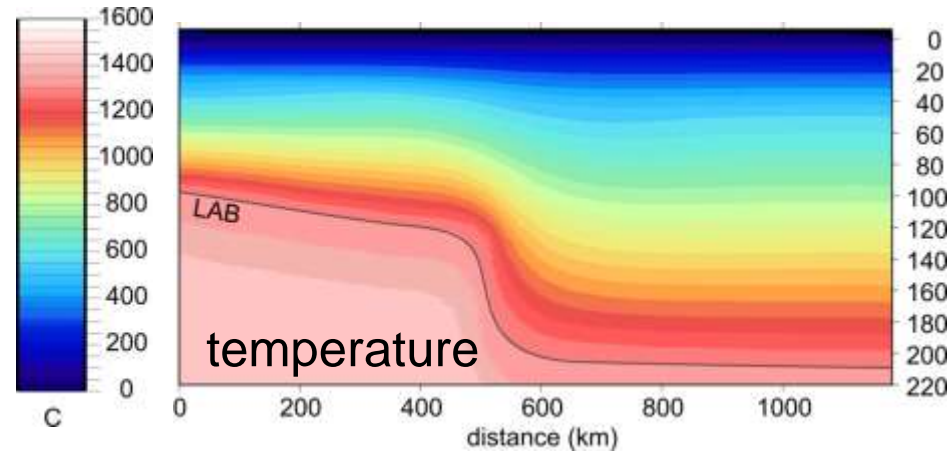
- isostatically compensated topography
- gravity anomalies
 - (Incl. gravity gradients)
- seismic velocity variations

Mantle models

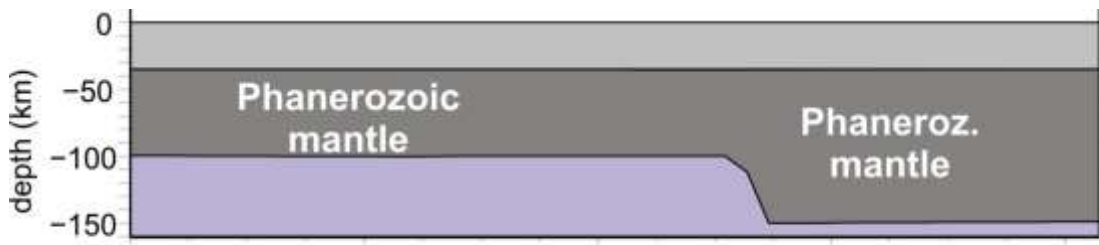
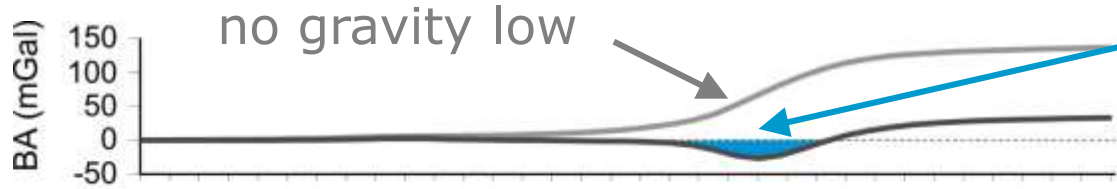
single lithospheric mantle
shallow LAB



2 lithospheric mantles
deep LAB



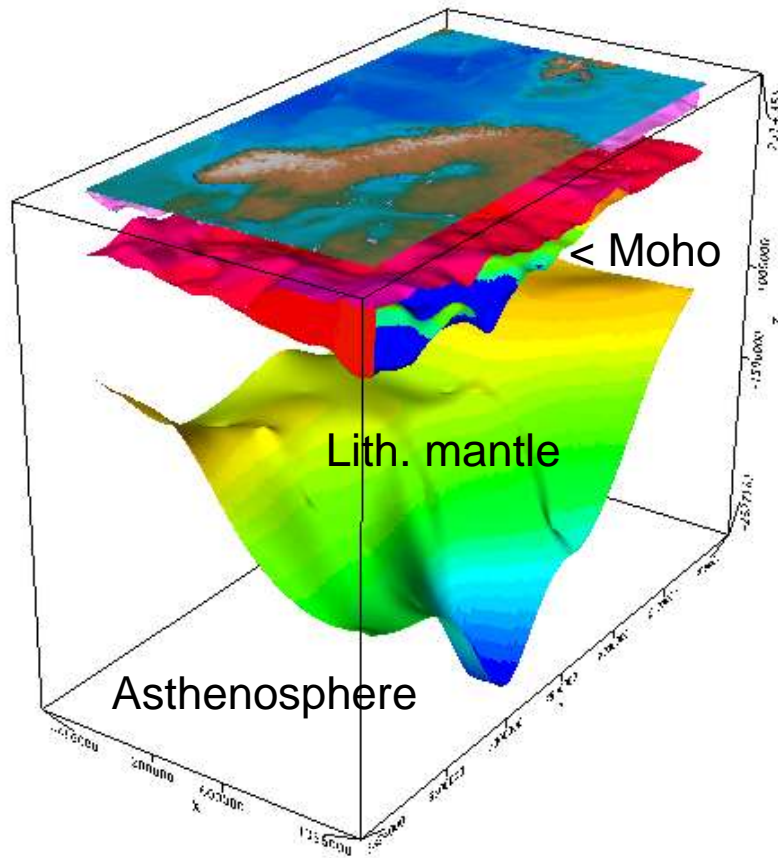
Effects on Geophysical Observables



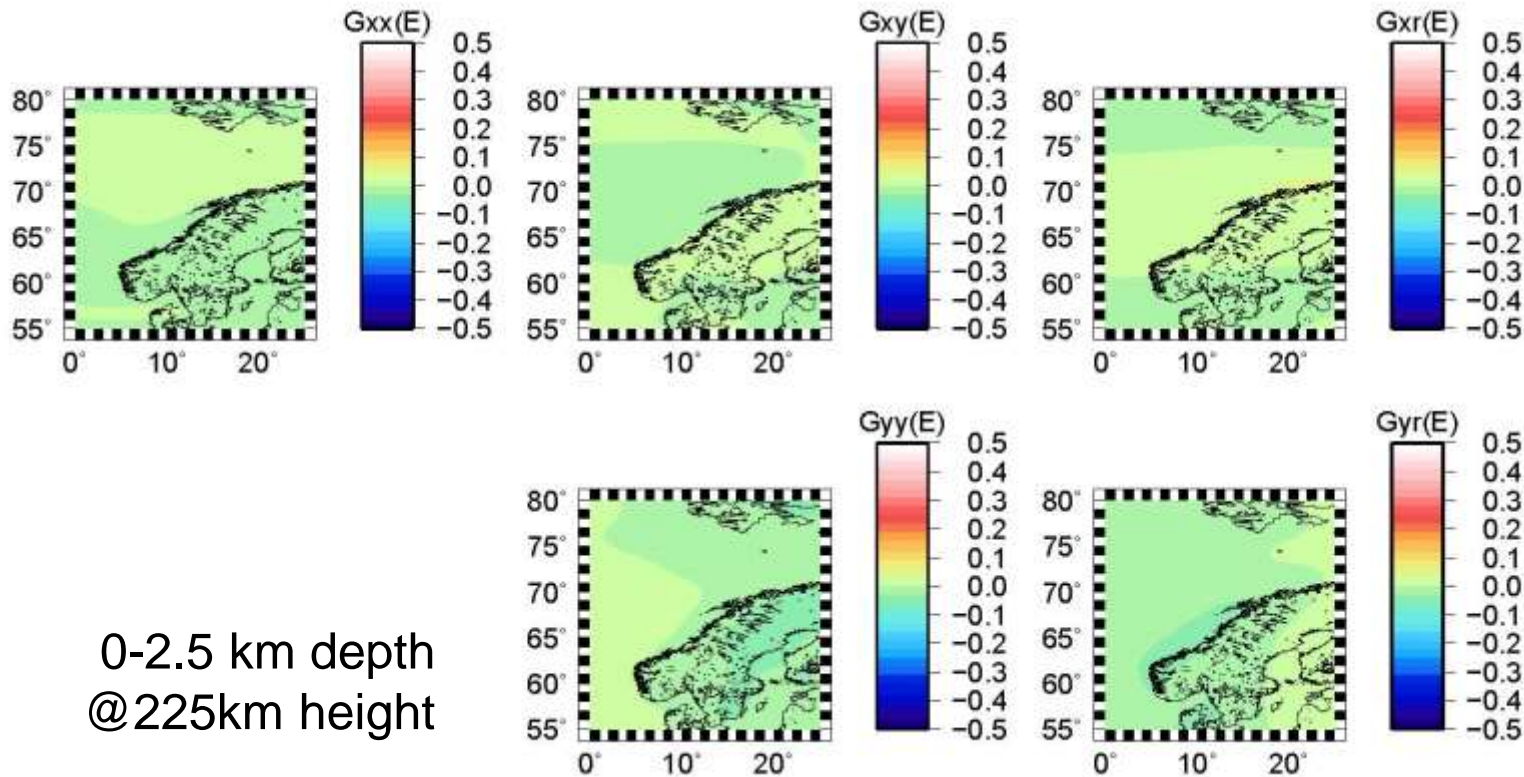
0 400 800 1200 1600
distance (km)

Gradmann et al. 2013

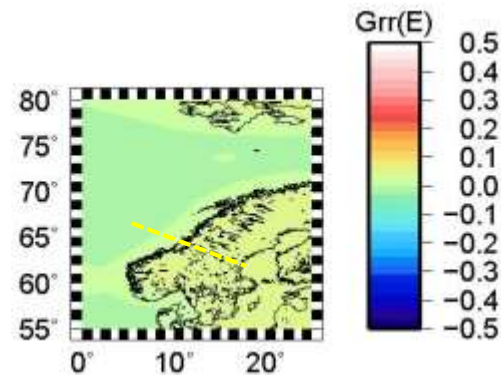
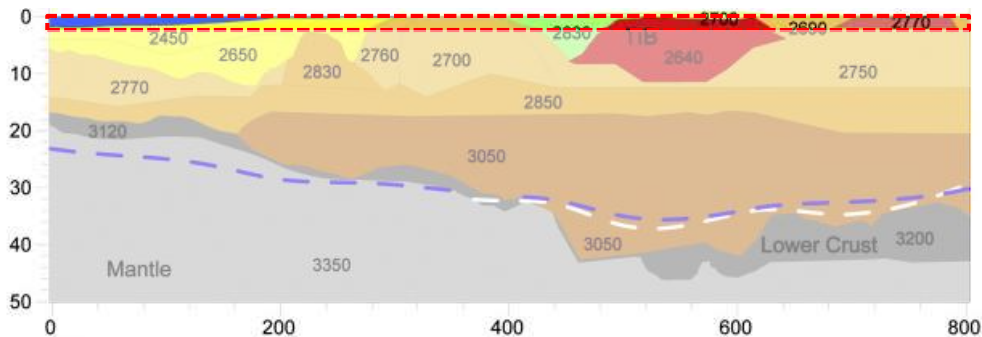
Lithospheric model set-up

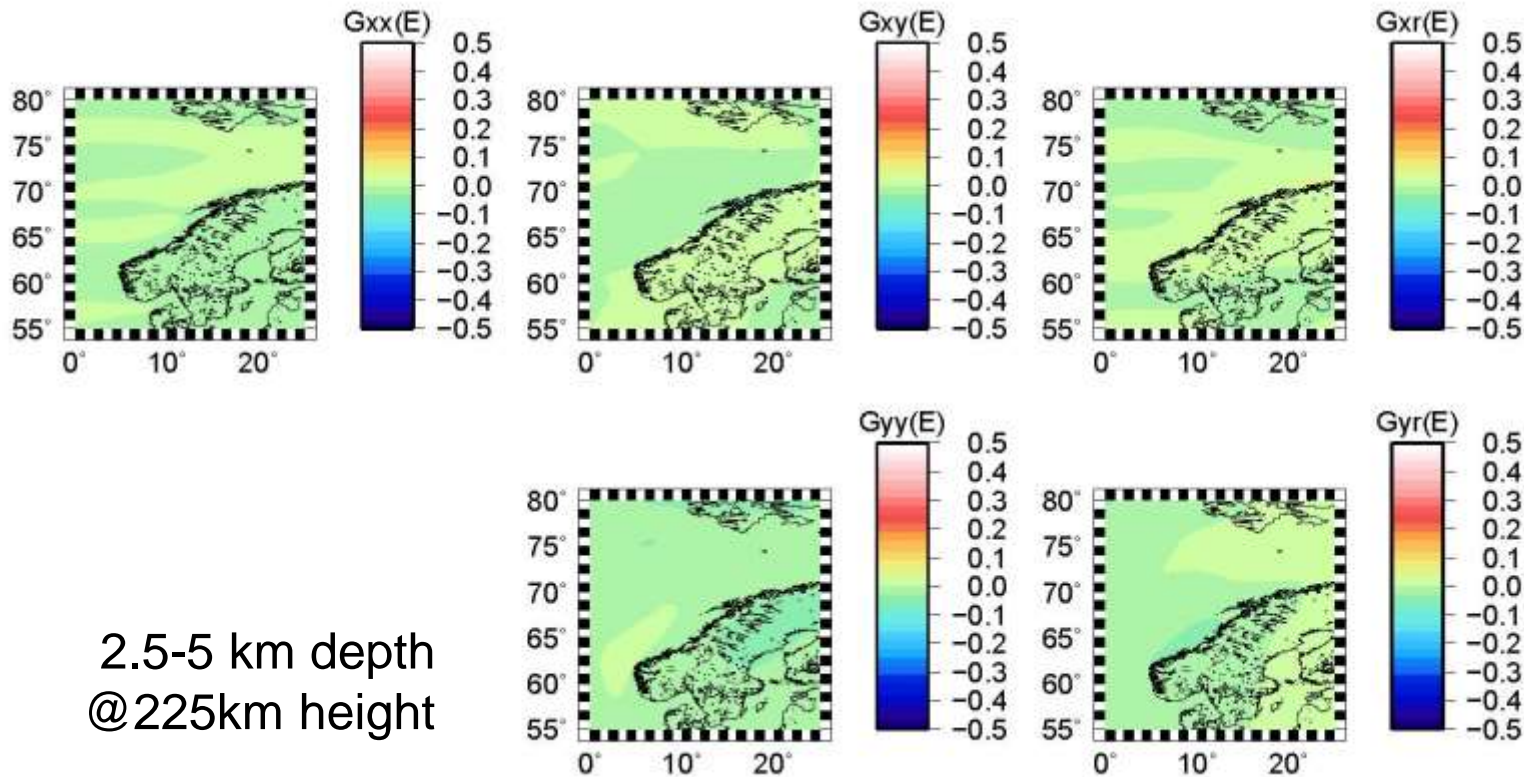


- Model Name: 3D_NEAtlantic.g3d
- Global Information
- Vertical Density Function
- Gravity
- Magnetic
- Layer 1: .\3DMod_Topography10.grd(GRD)
 - Density: 2.67
 - Susc: Constant
- Layer 2: .\Null10.grd(GRD)
 - Density: 1.03
 - Susc: Constant
- Layer 3: .\3DMod_Bathymetry10.grd(GRD)
 - Density: Vertical Density Function
 - Susc: Constant
- Layer 4: .\BaseSed_NGU_NOAA_Laske.grd
 - Density: .\D_UC1.grd
 - Susc: Constant
- Layer 5: .\JCMC.grd
 - Density: 2.8
 - Susc: Constant
- Layer 6: .\UCLC.grd
 - Density: 2.95
 - Susc: Constant
- Layer 7: .\3DMod_IsoTopLCBClipped.grd(GRD)
 - Density: 3.1
 - Susc: Constant
- Layer 8: .\3DMod_Moho_Grad.grd
 - Density: .\MantleDensityGP250km.grd
 - Susc: Constant
- Layer 9: .\LAB_Artemieva2.grd
 - Density: 3.3

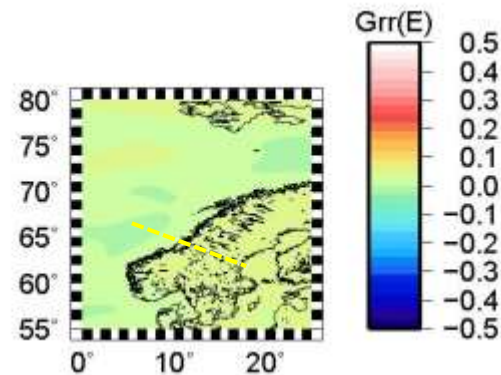
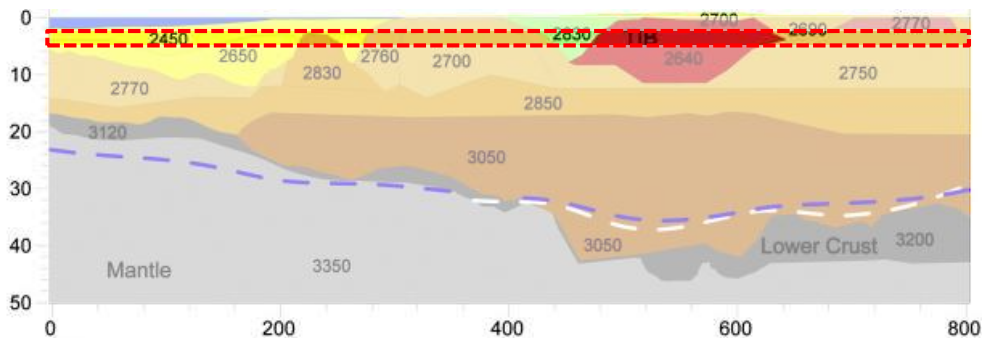


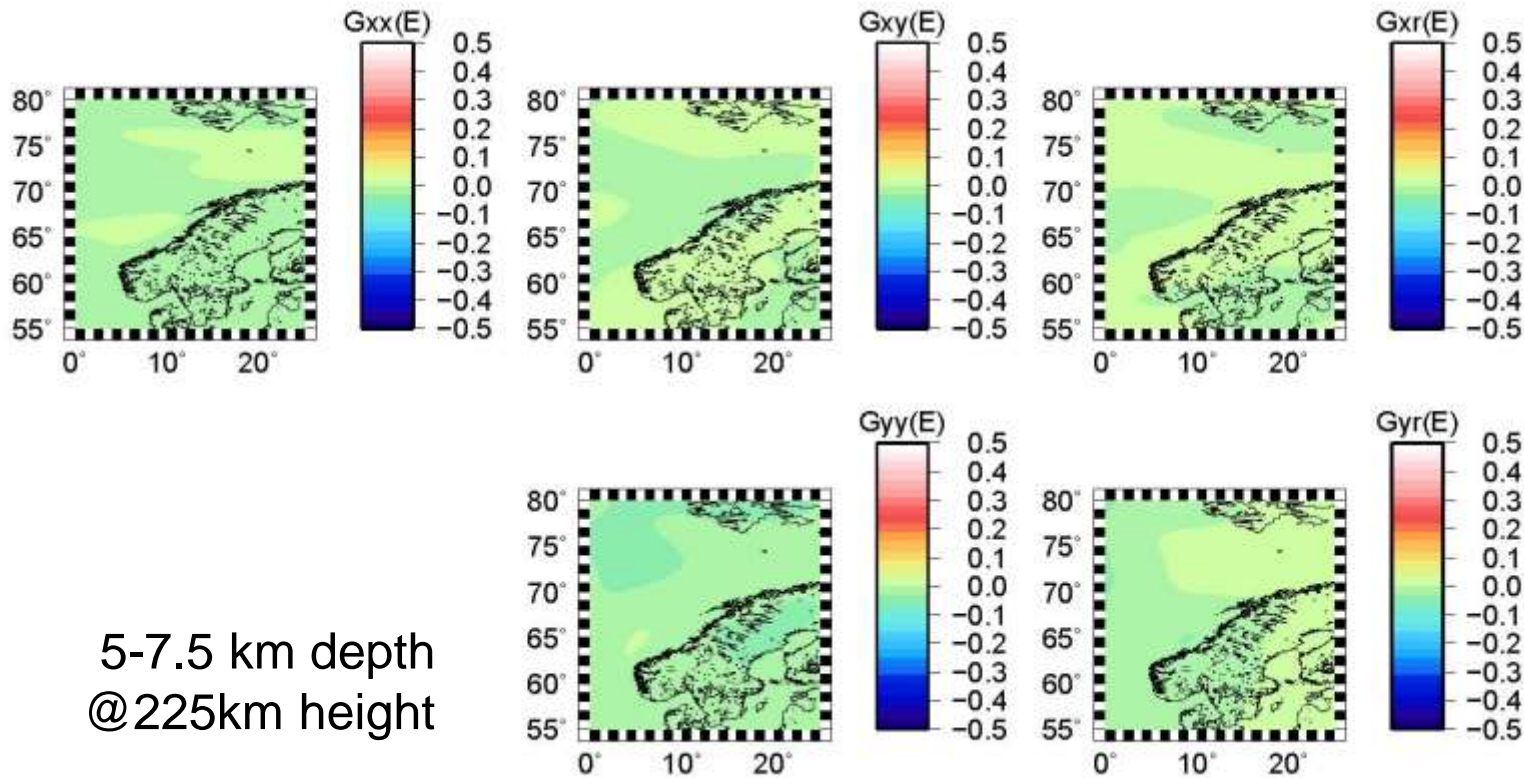
0-2.5 km depth
@225km height



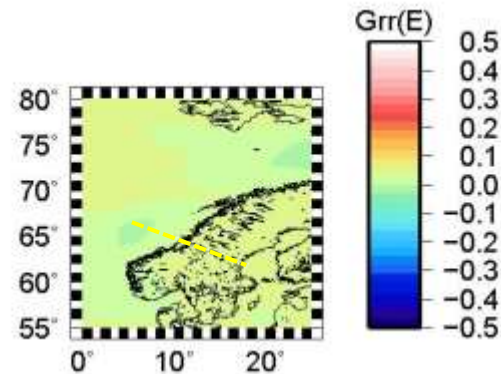
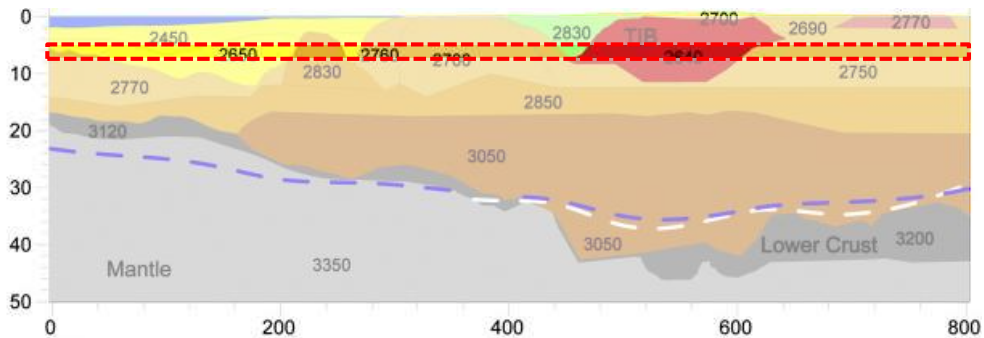


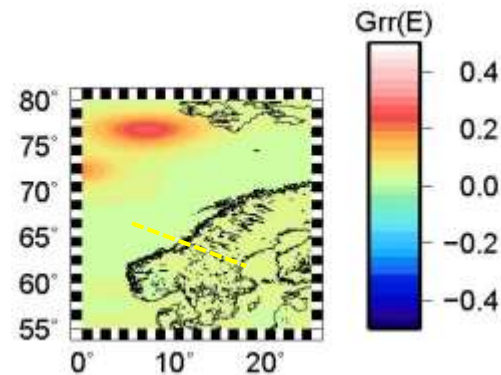
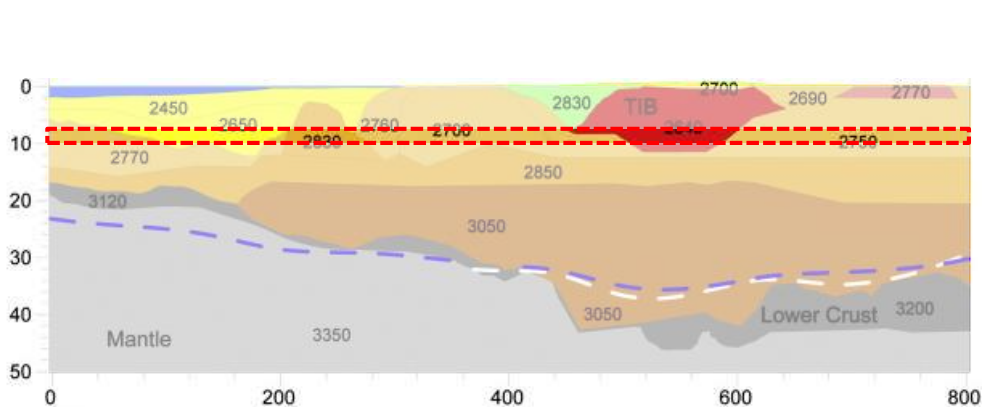
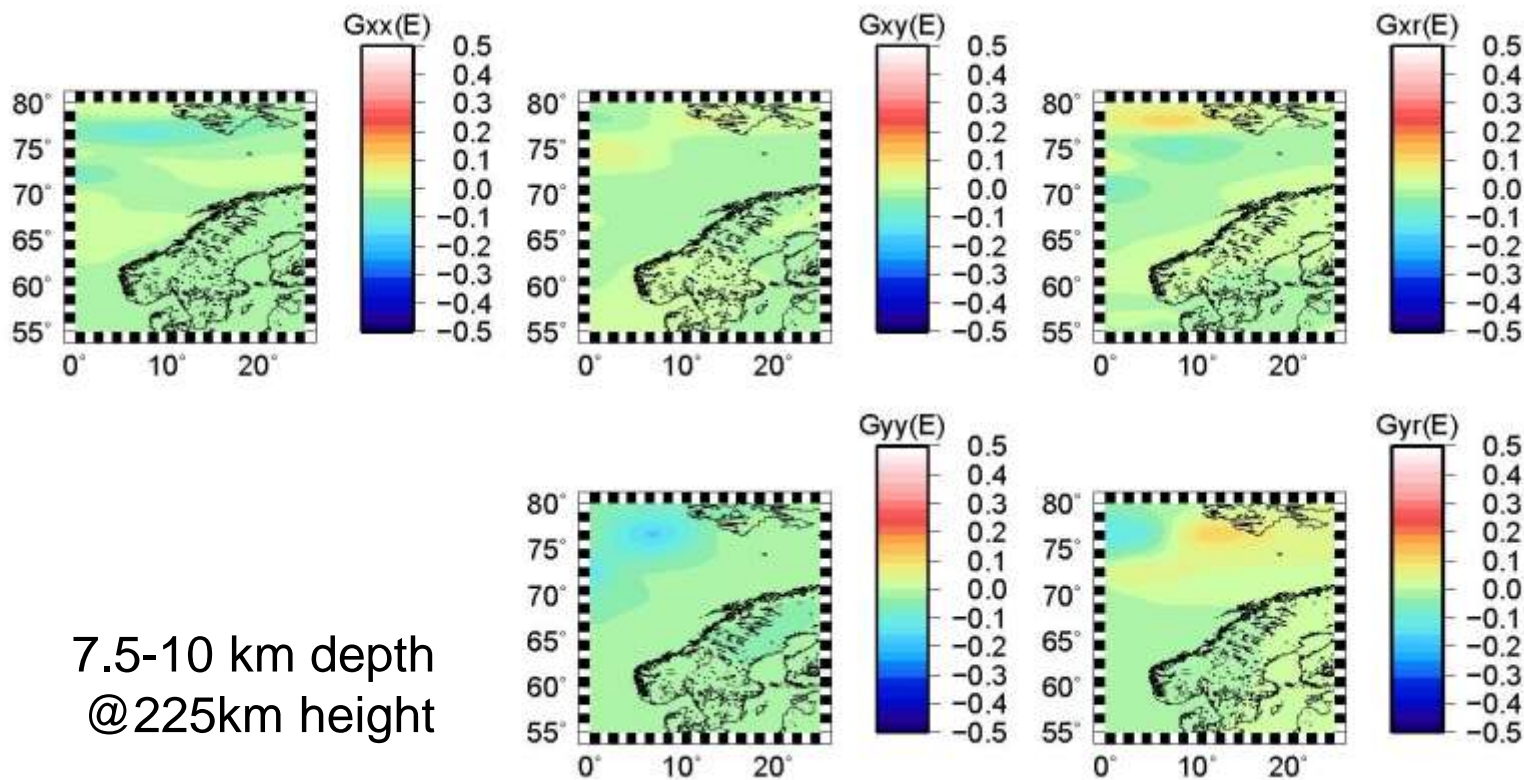
2.5-5 km depth
@225km height

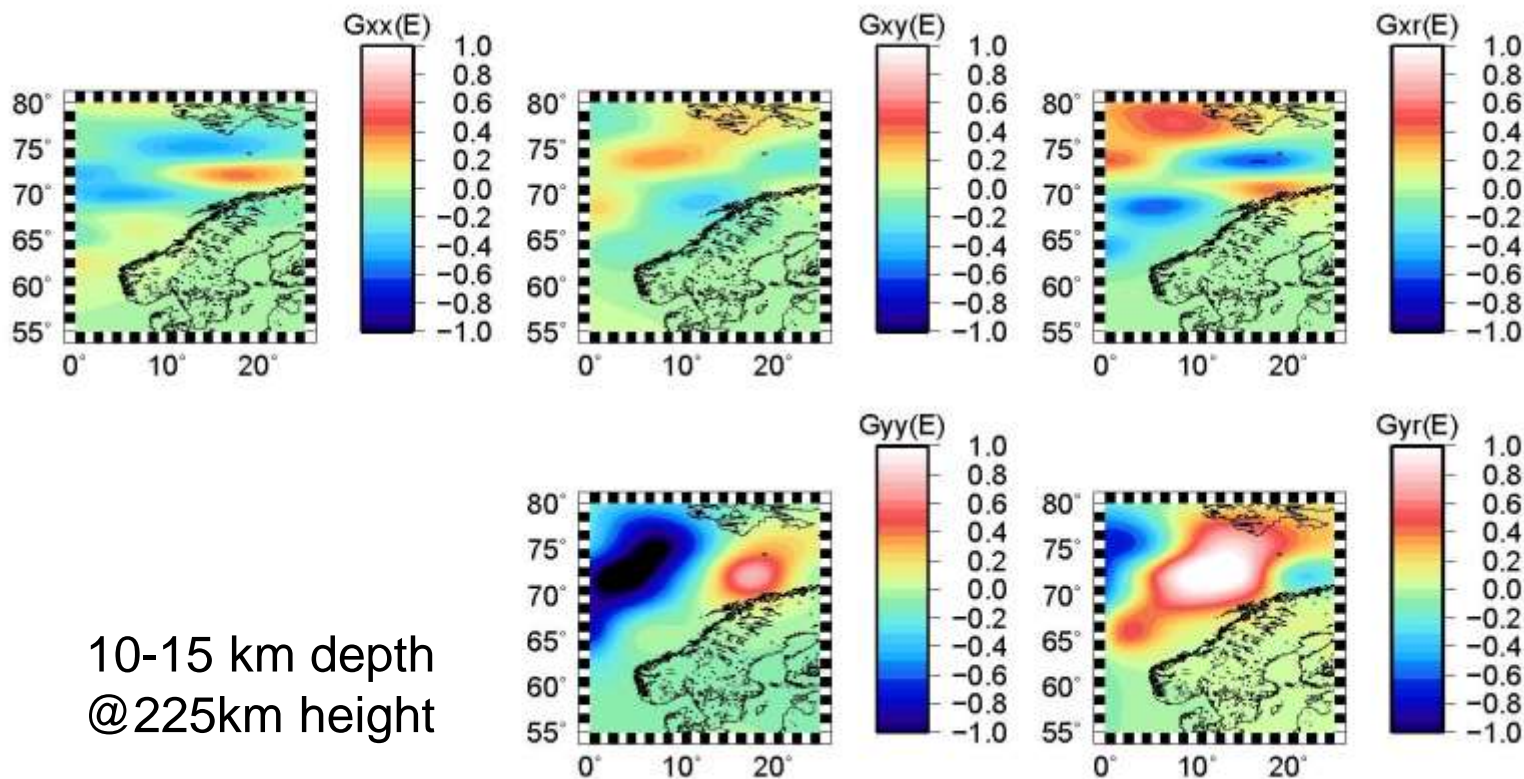




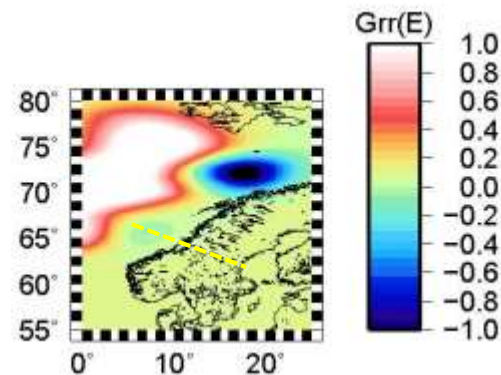
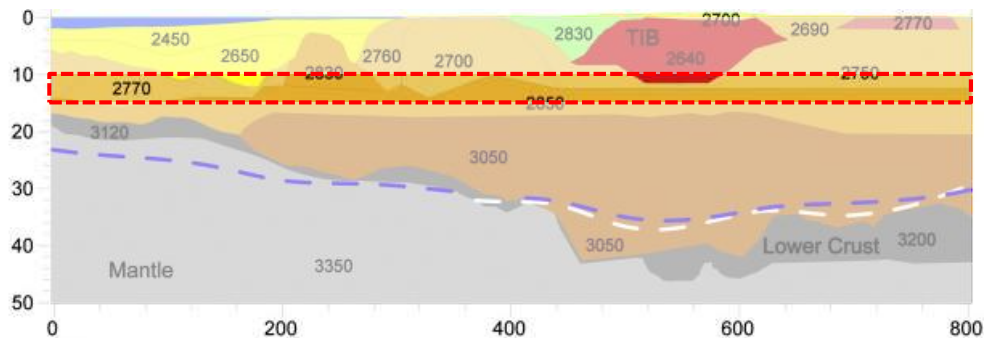
5-7.5 km depth
@225km height

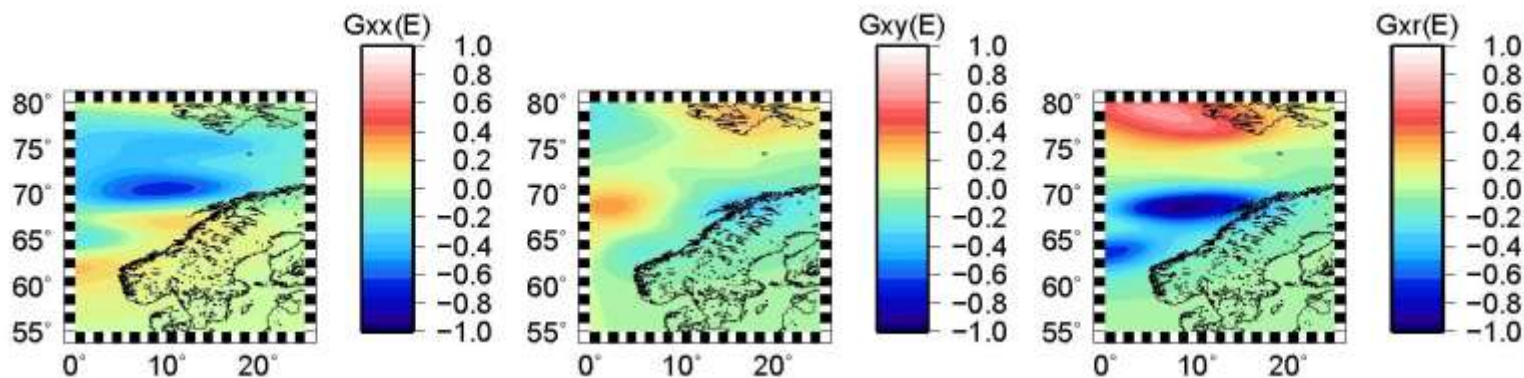




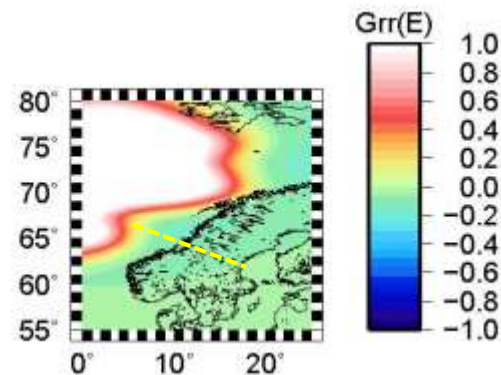
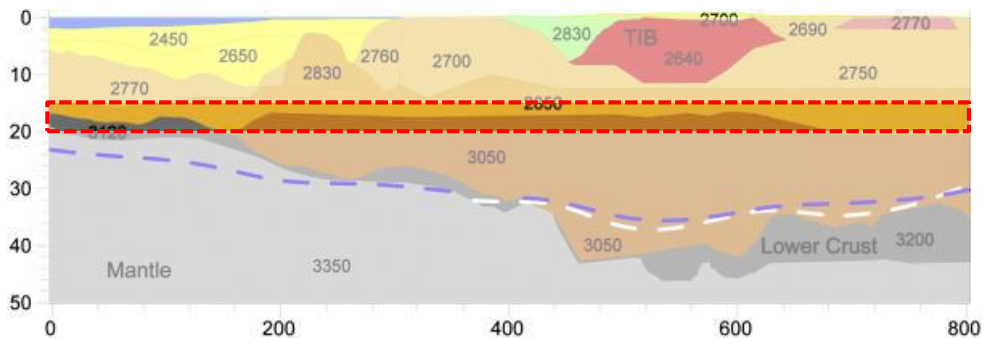
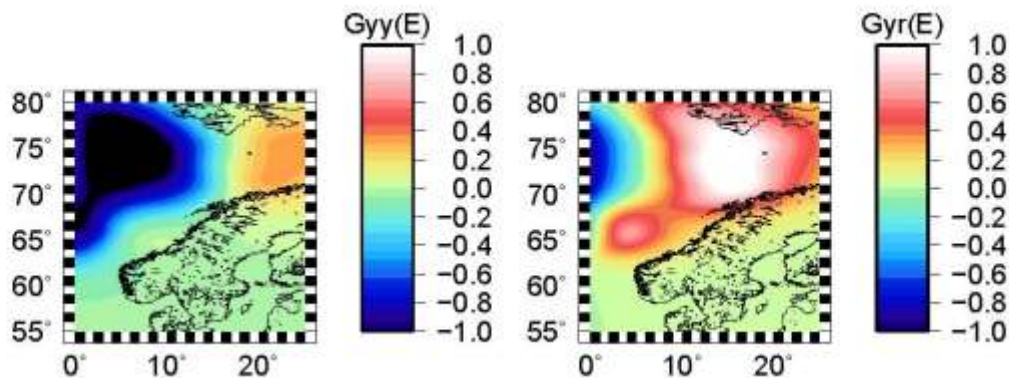


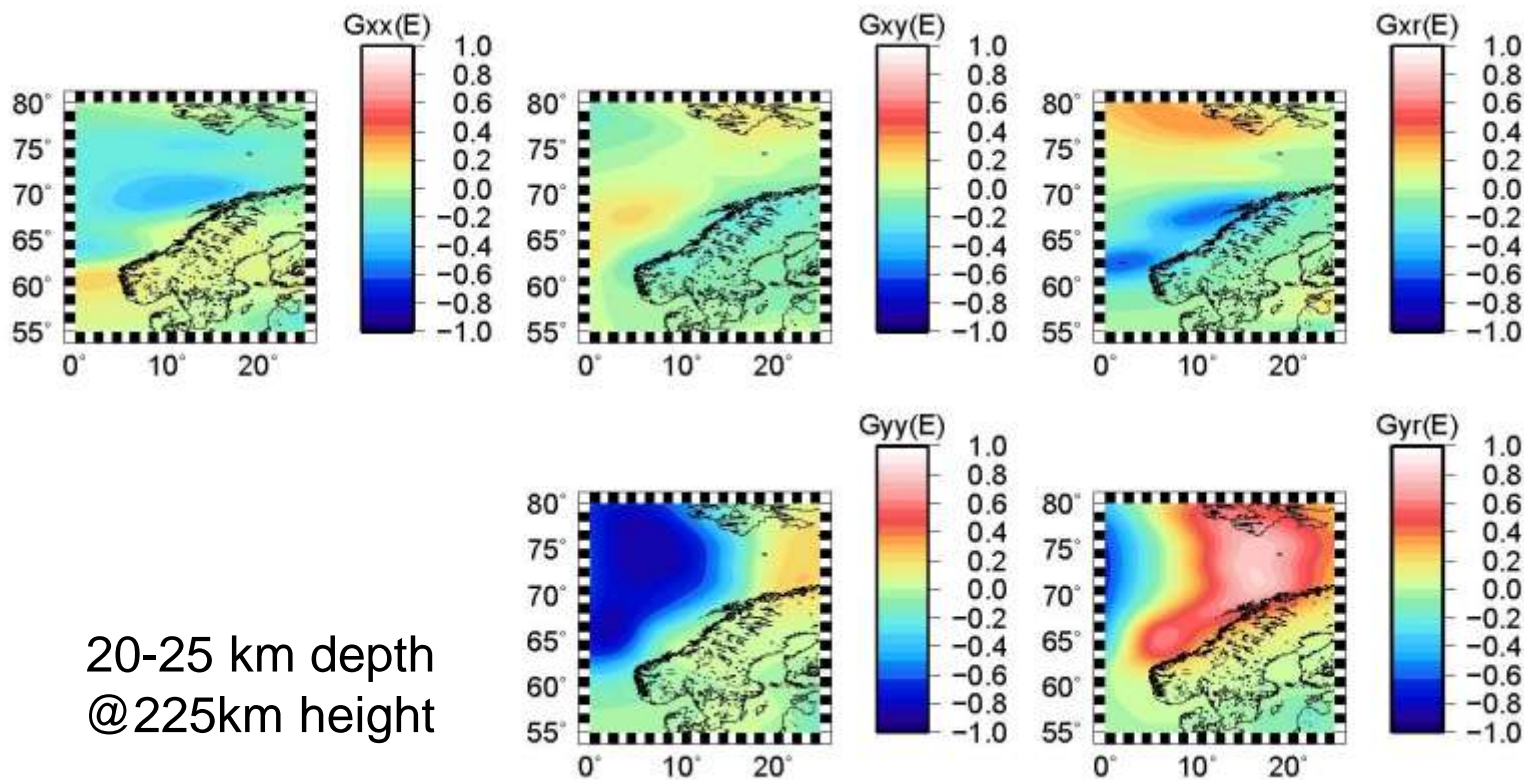
10-15 km depth
@225km height



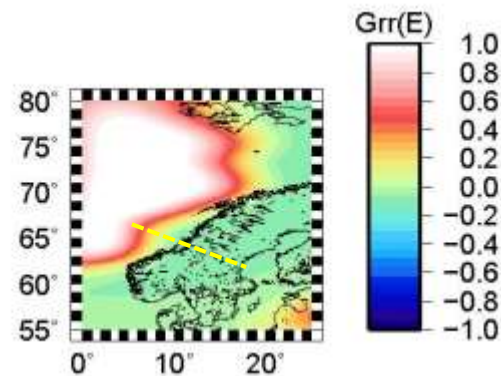
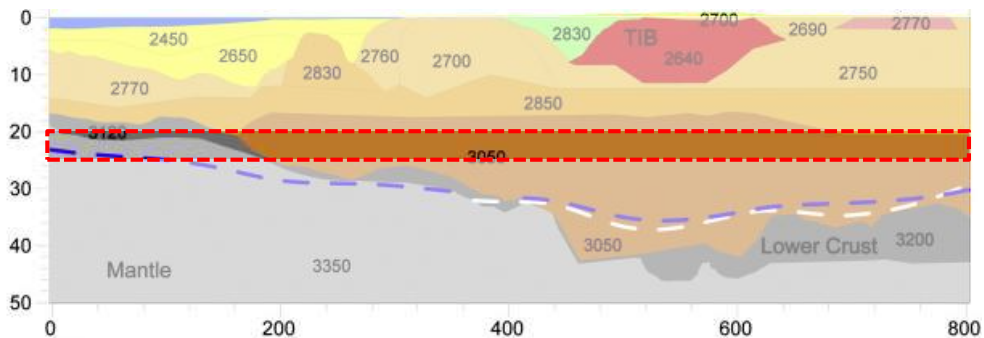


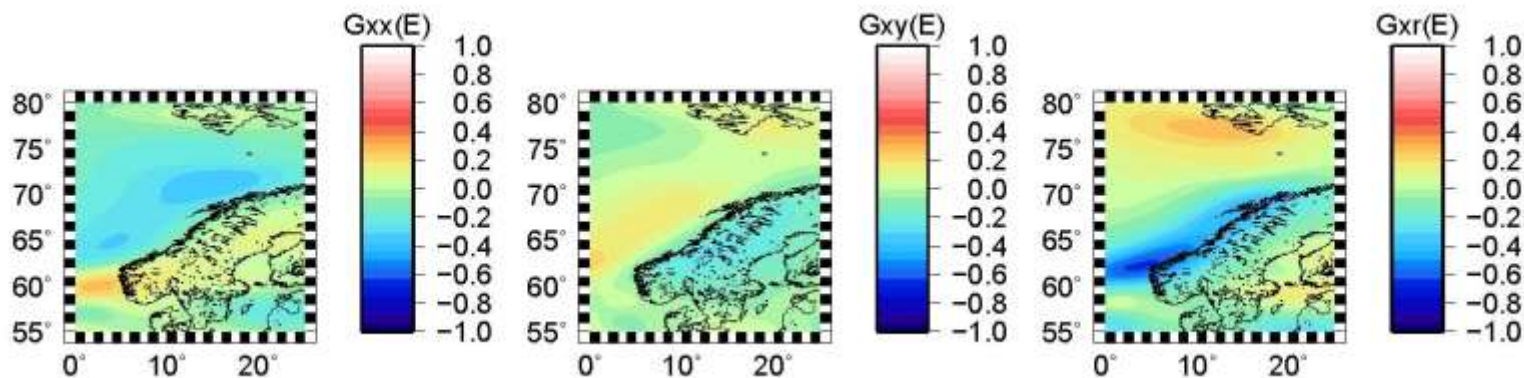
15-20 km depth
@225km height



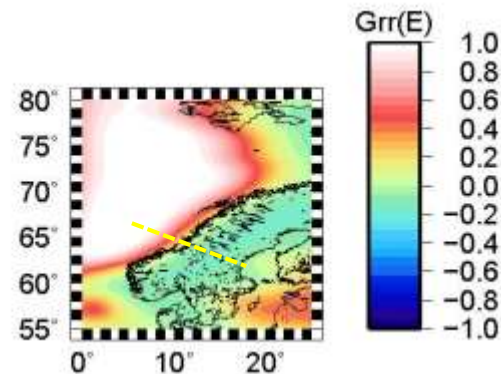
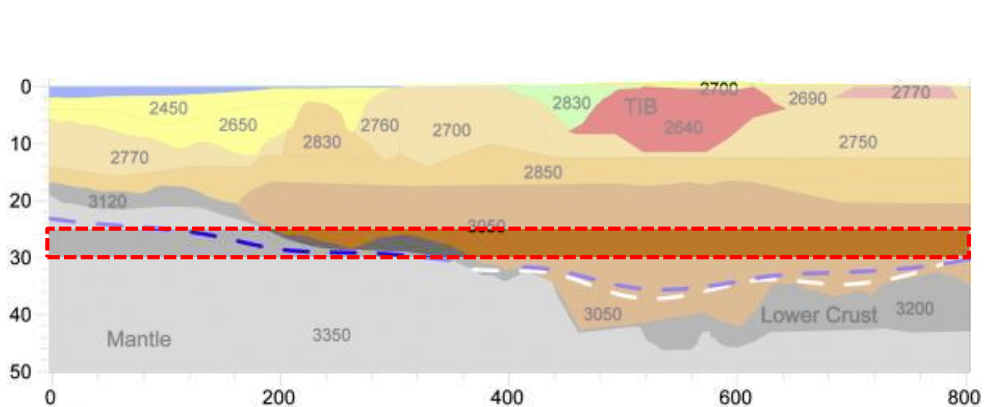
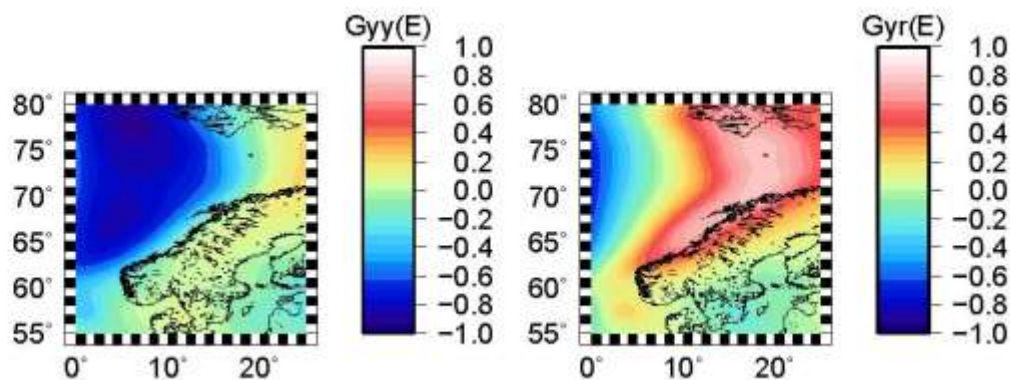


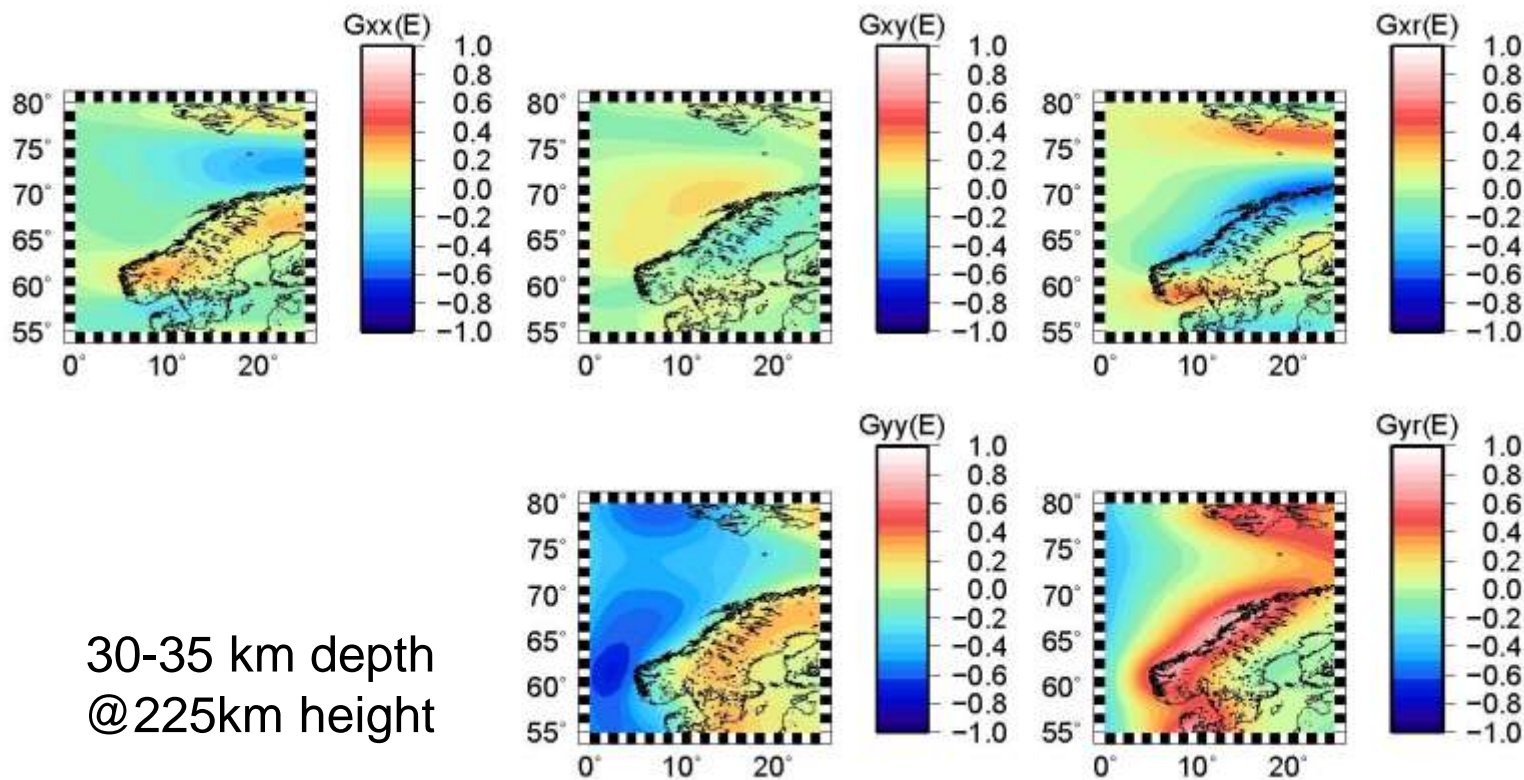
20-25 km depth
@225km height



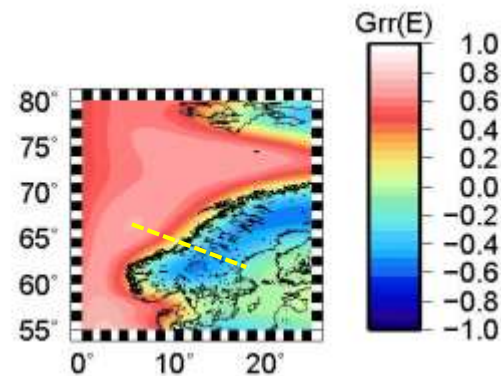
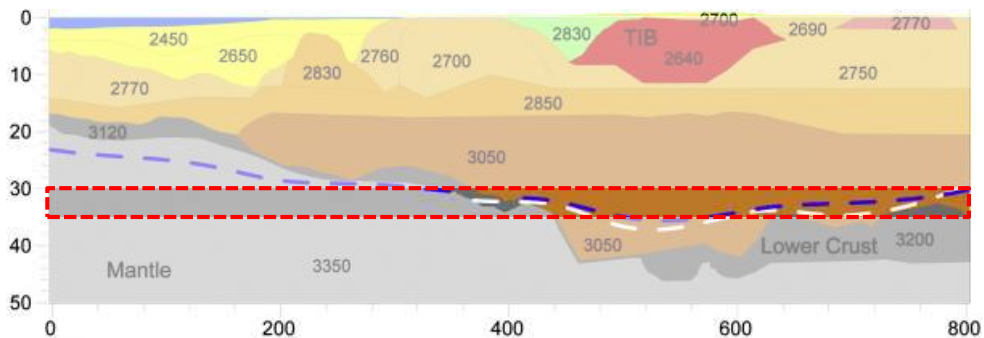


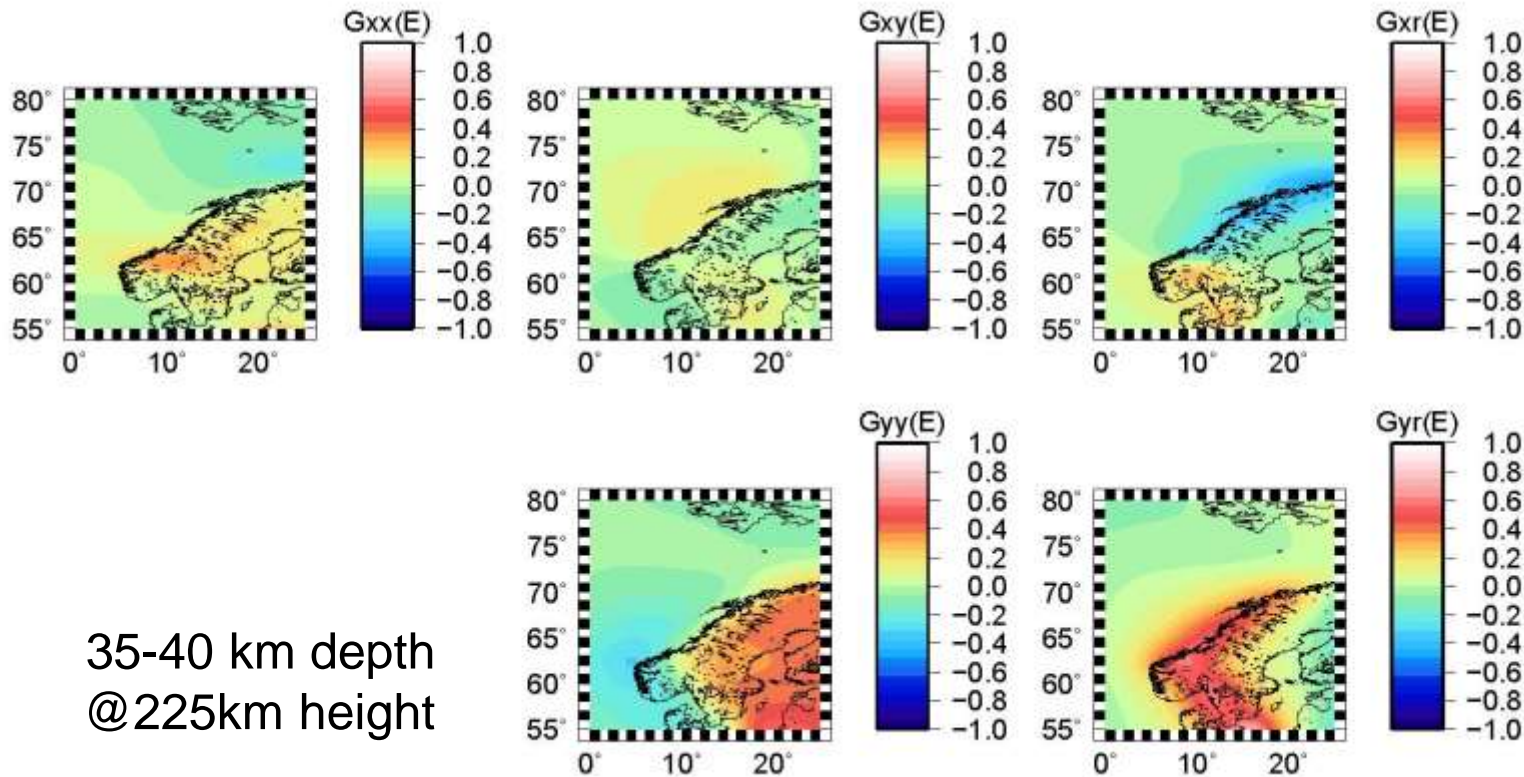
25-30 km depth
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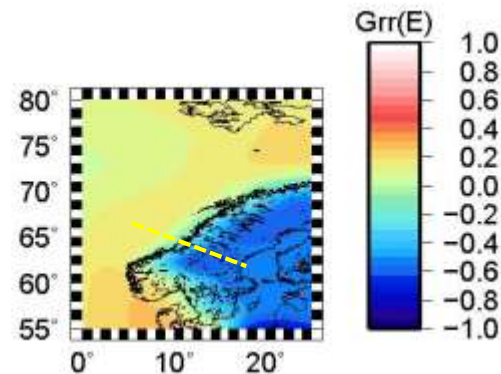
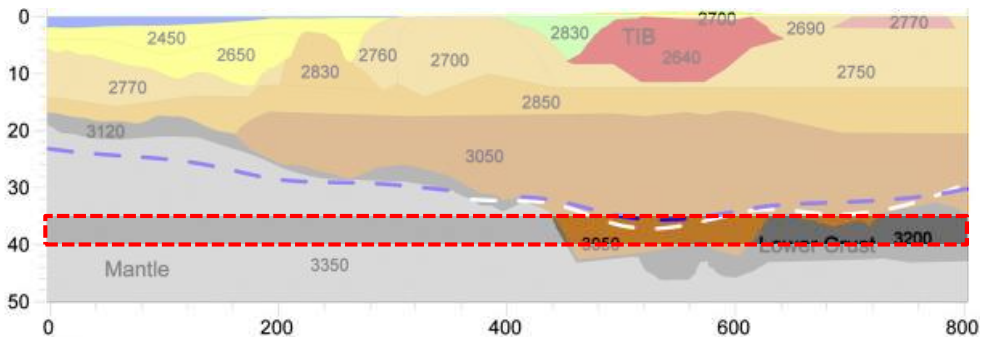


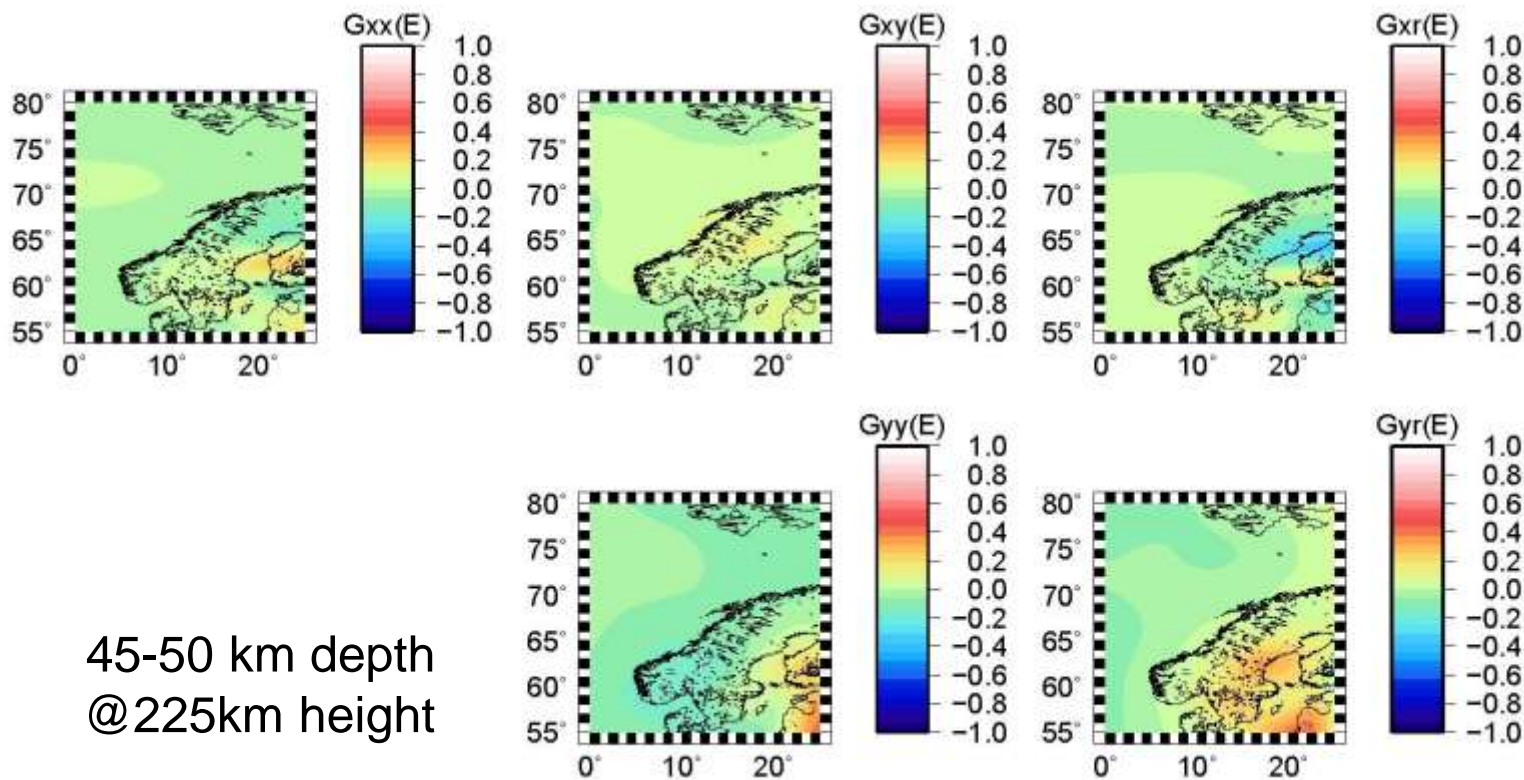
30-35 km depth
@225km height



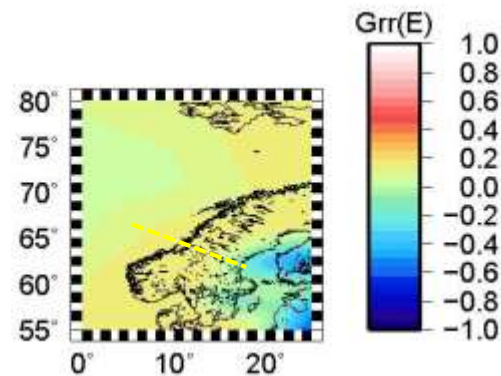
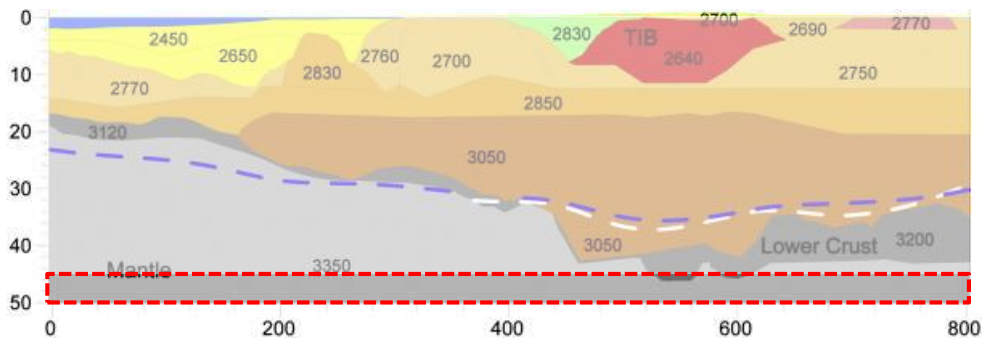


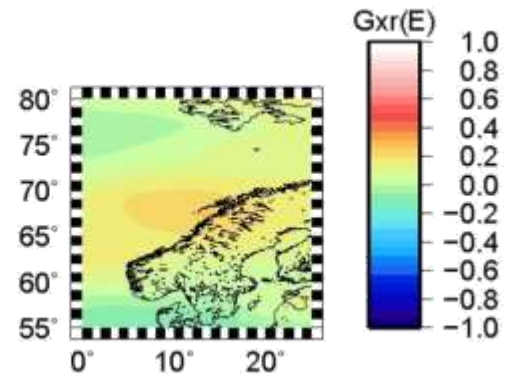
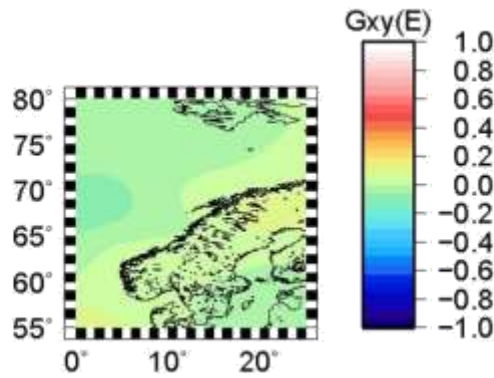
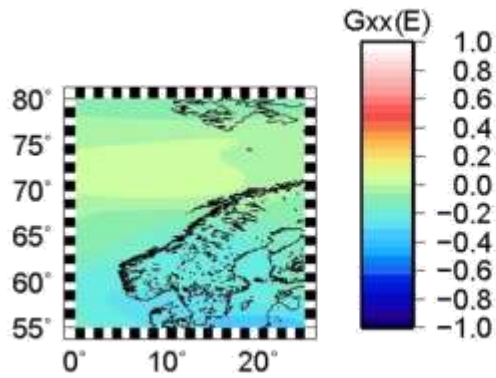
35-40 km depth
@225km height



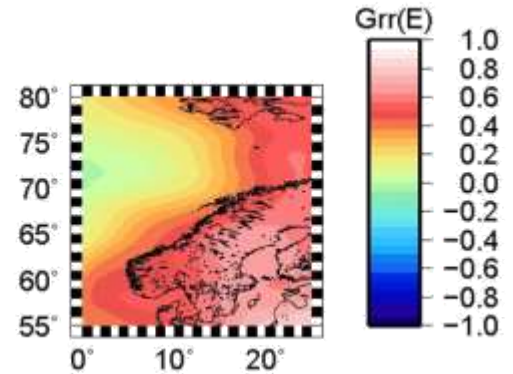
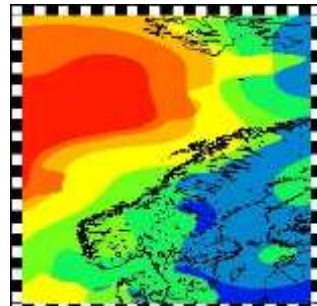
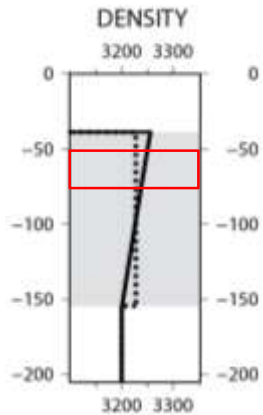
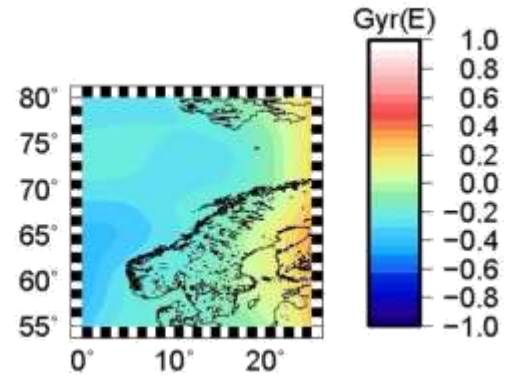
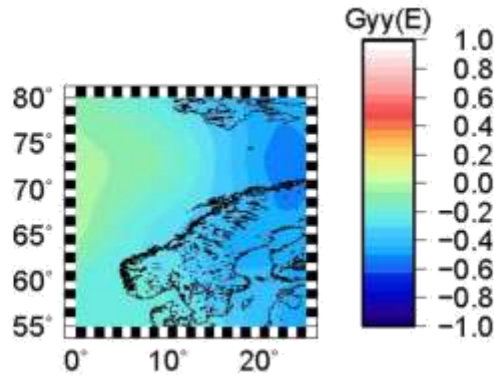


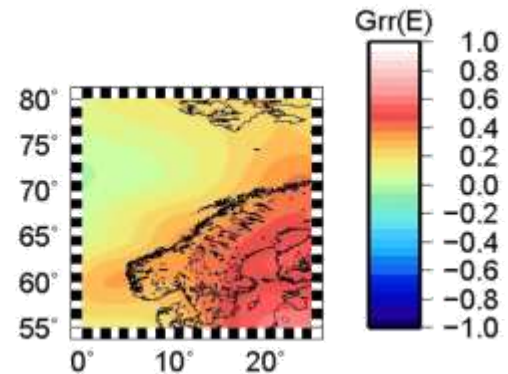
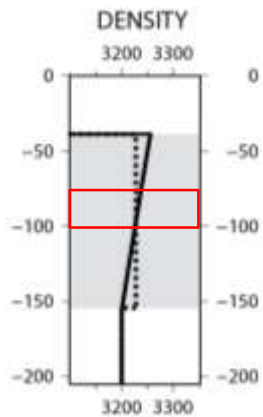
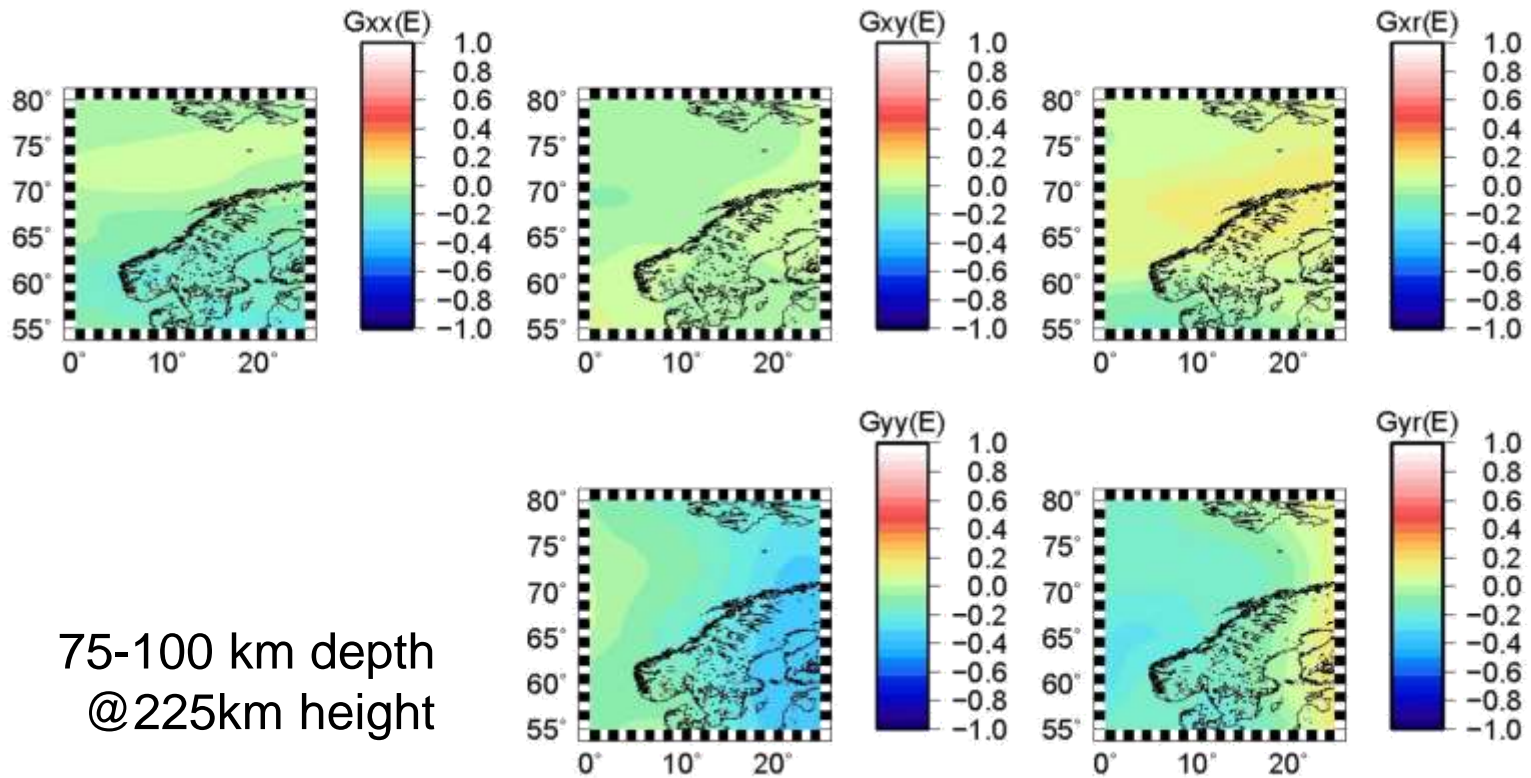
45-50 km depth
@225km height

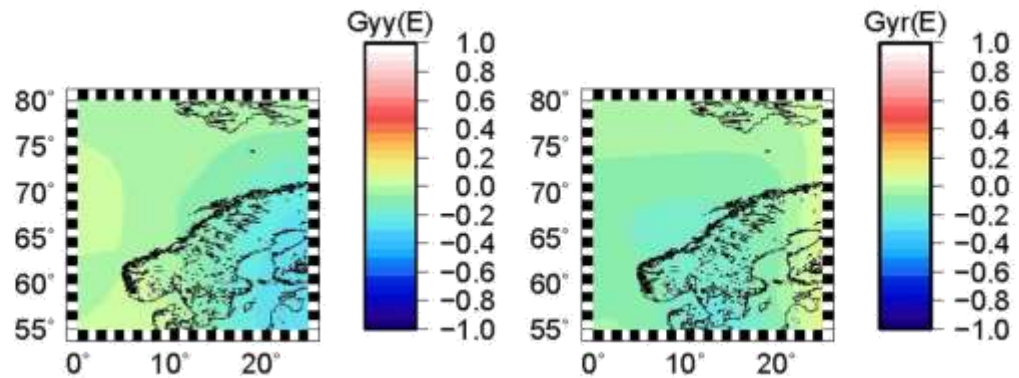
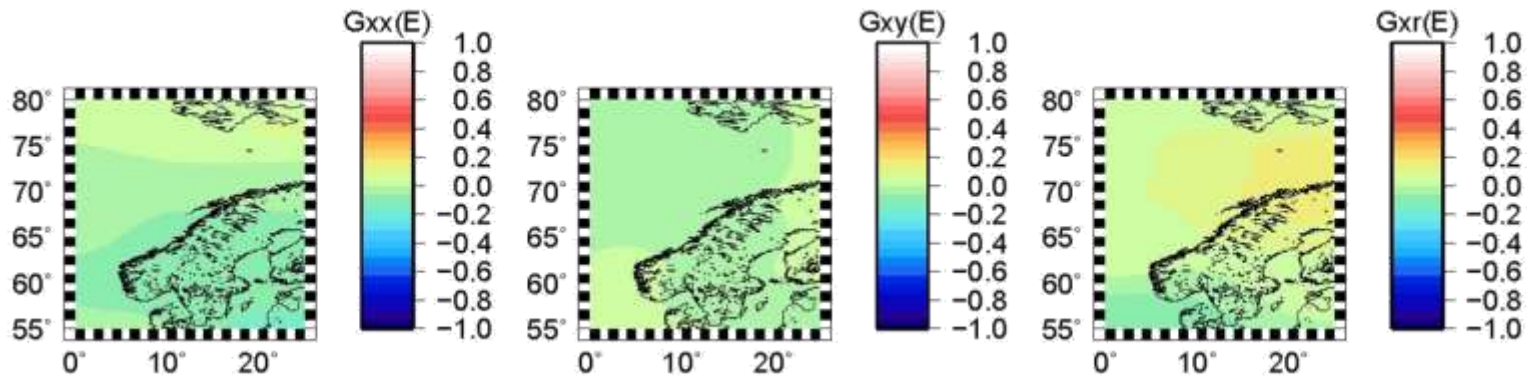




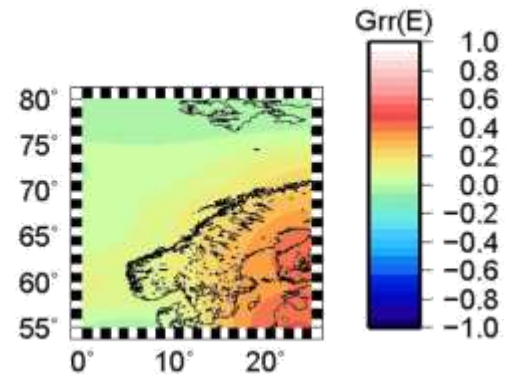
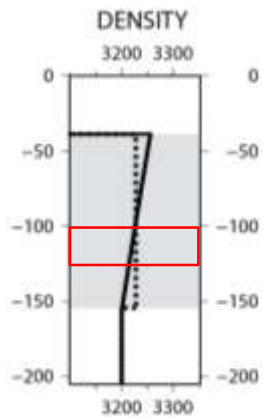
50-75 km depth
@225km height

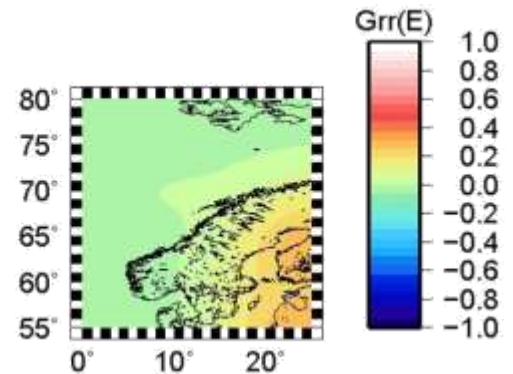
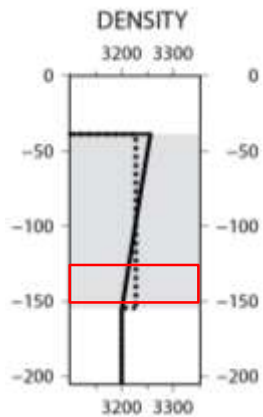
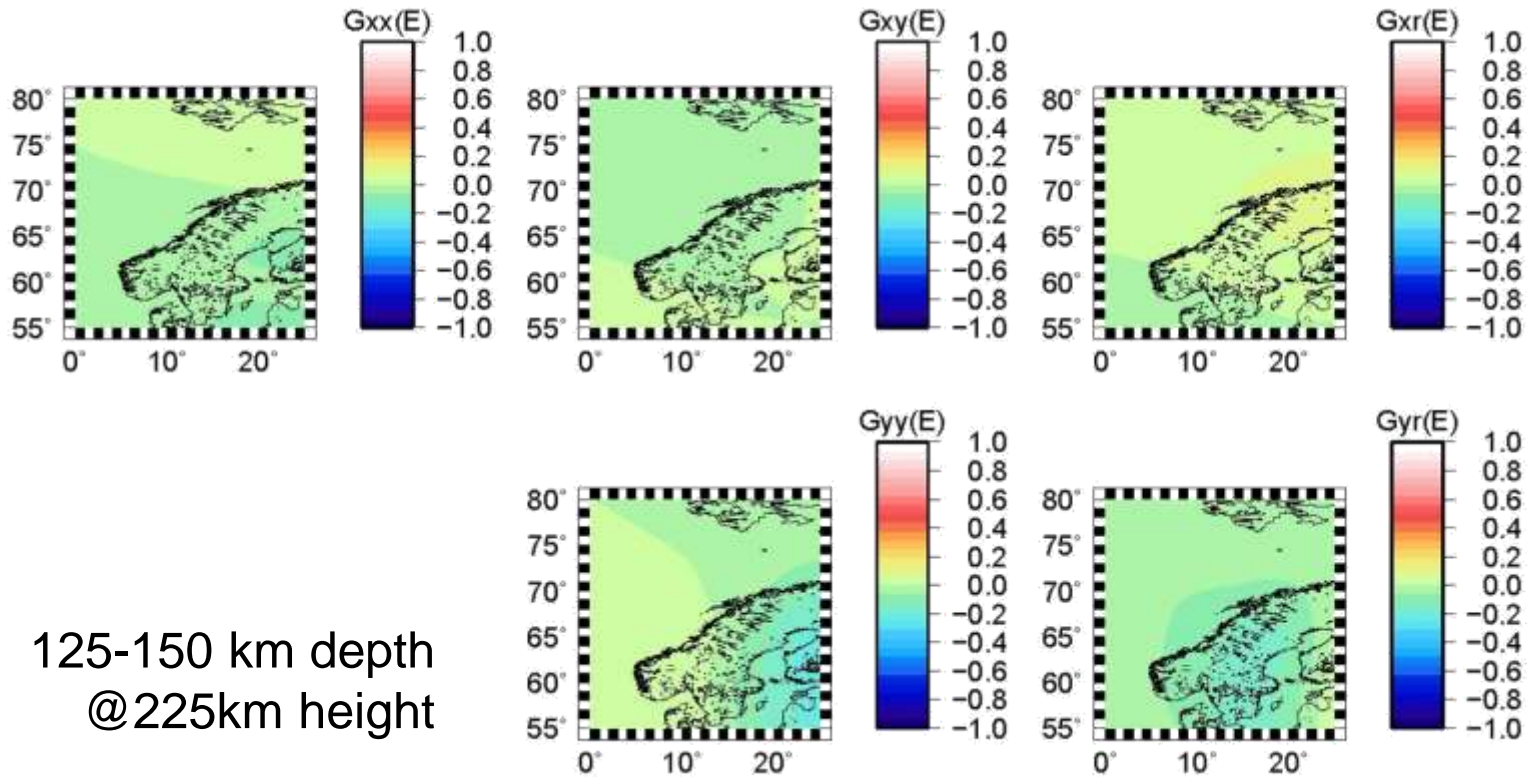


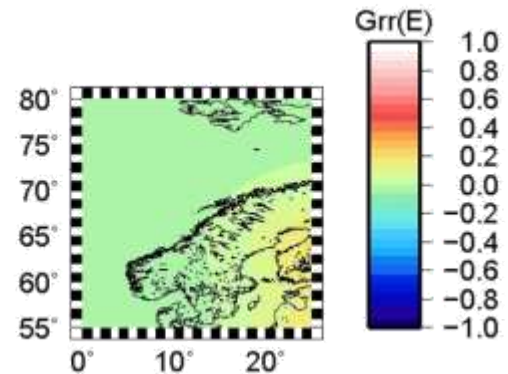
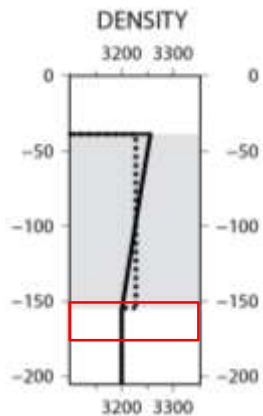
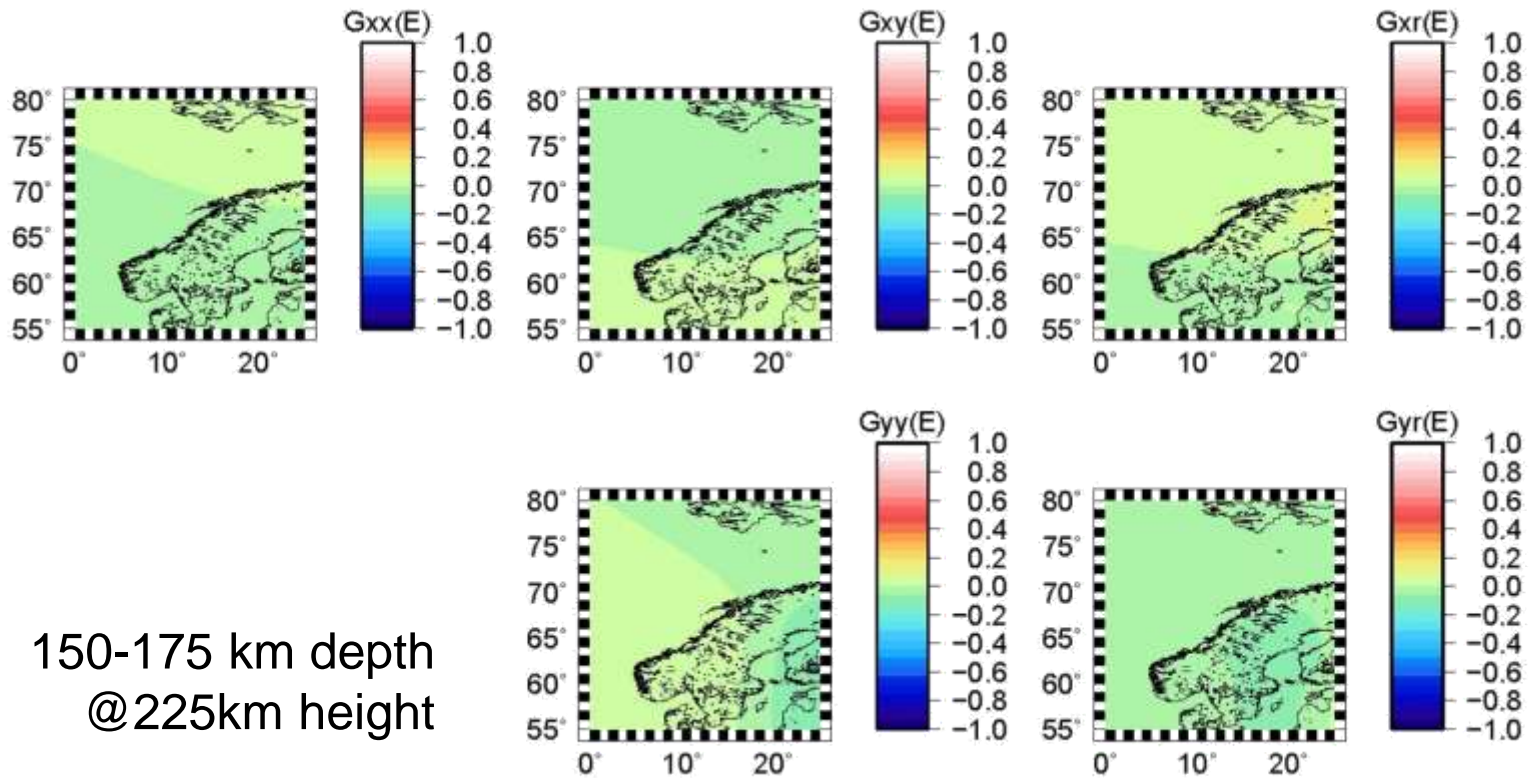


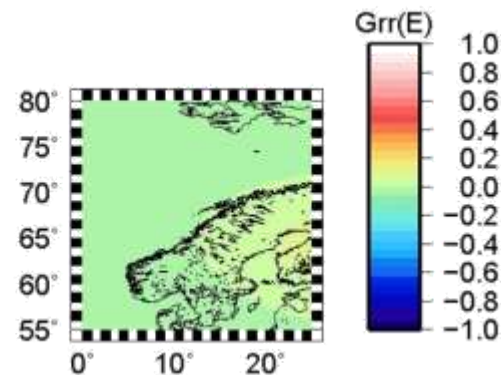
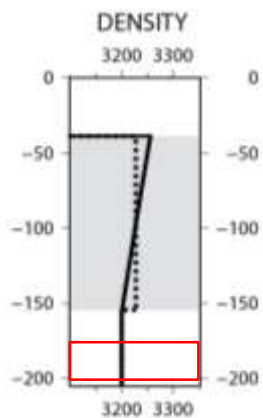
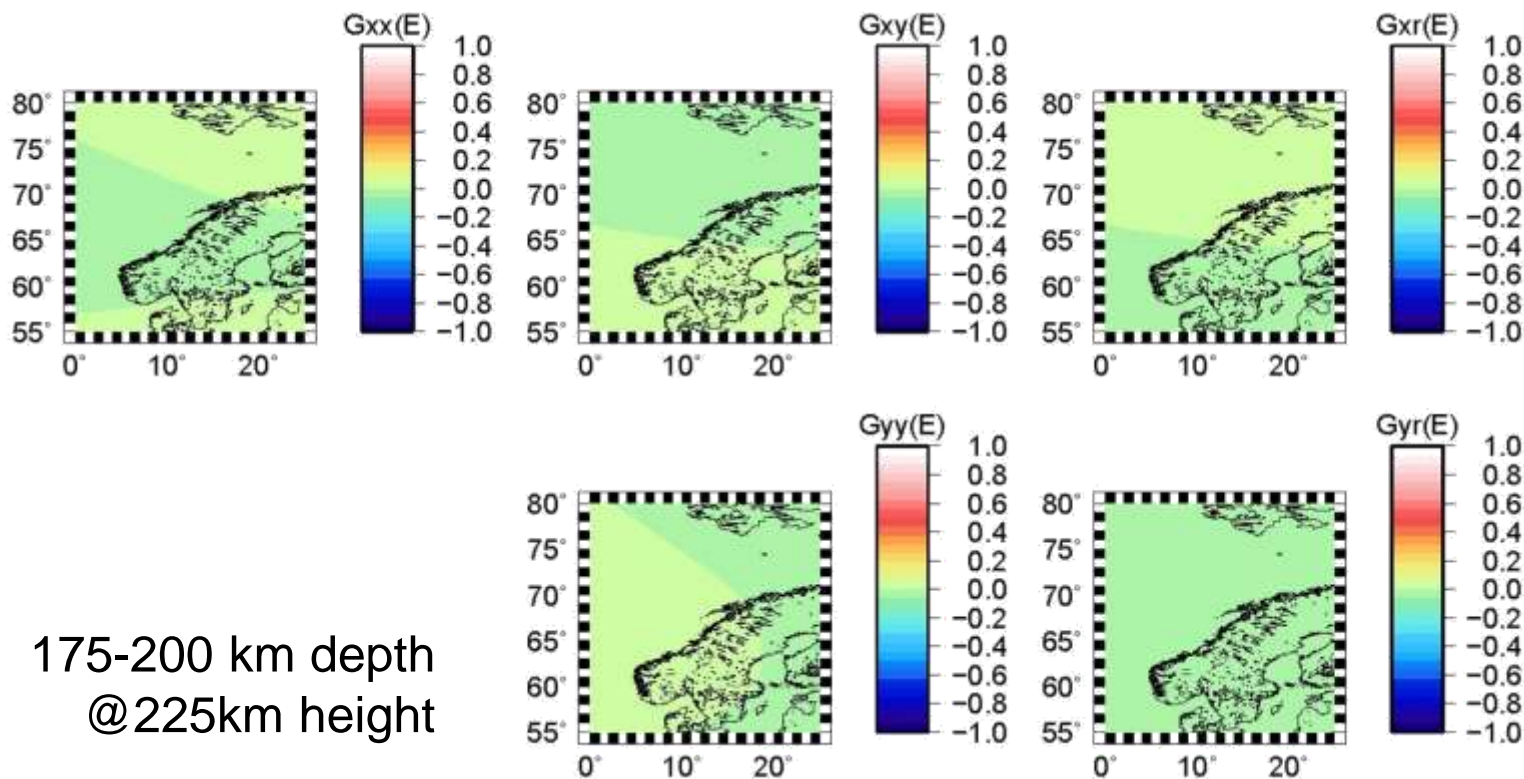


100-125 km depth
@225km height

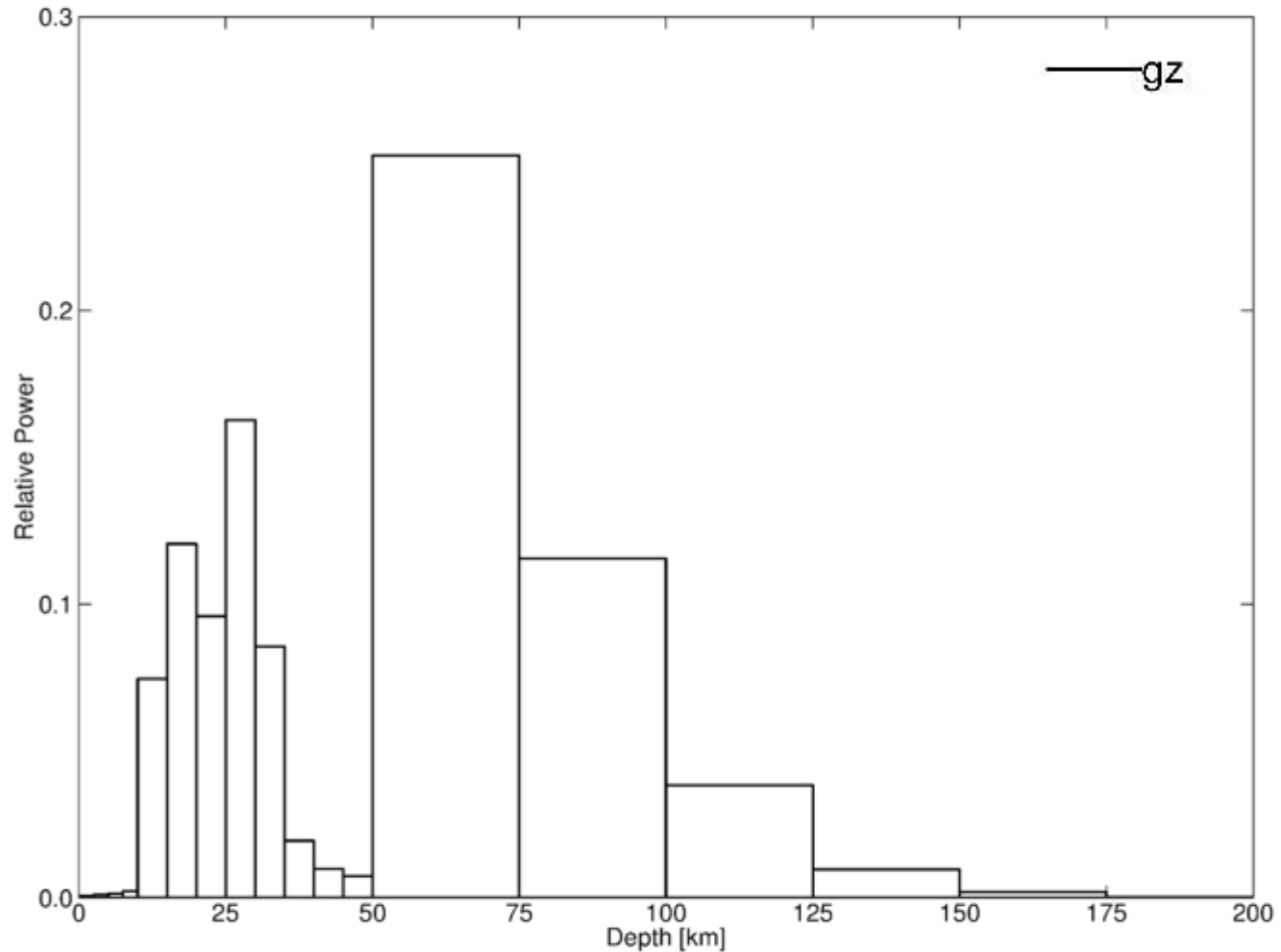




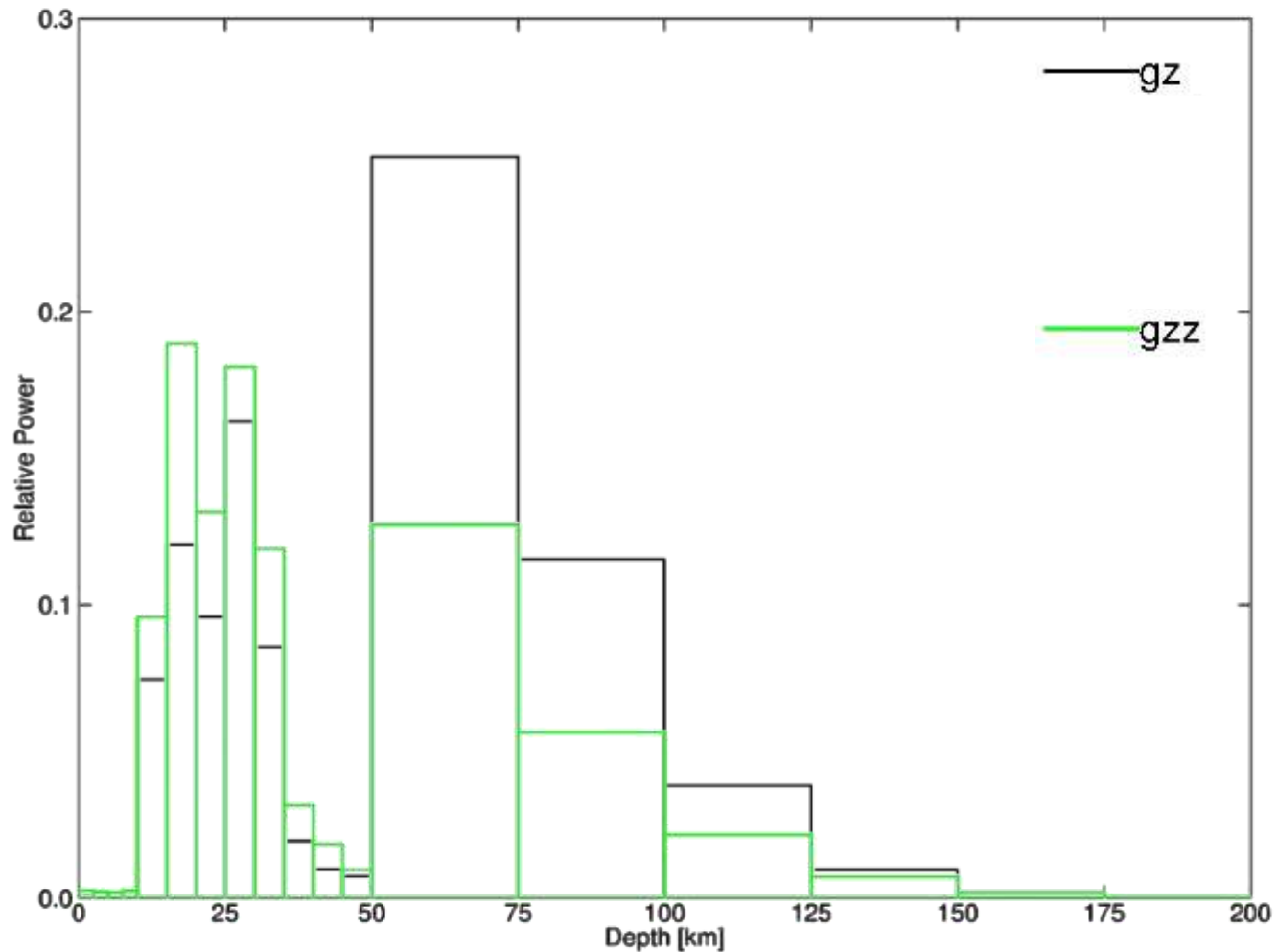




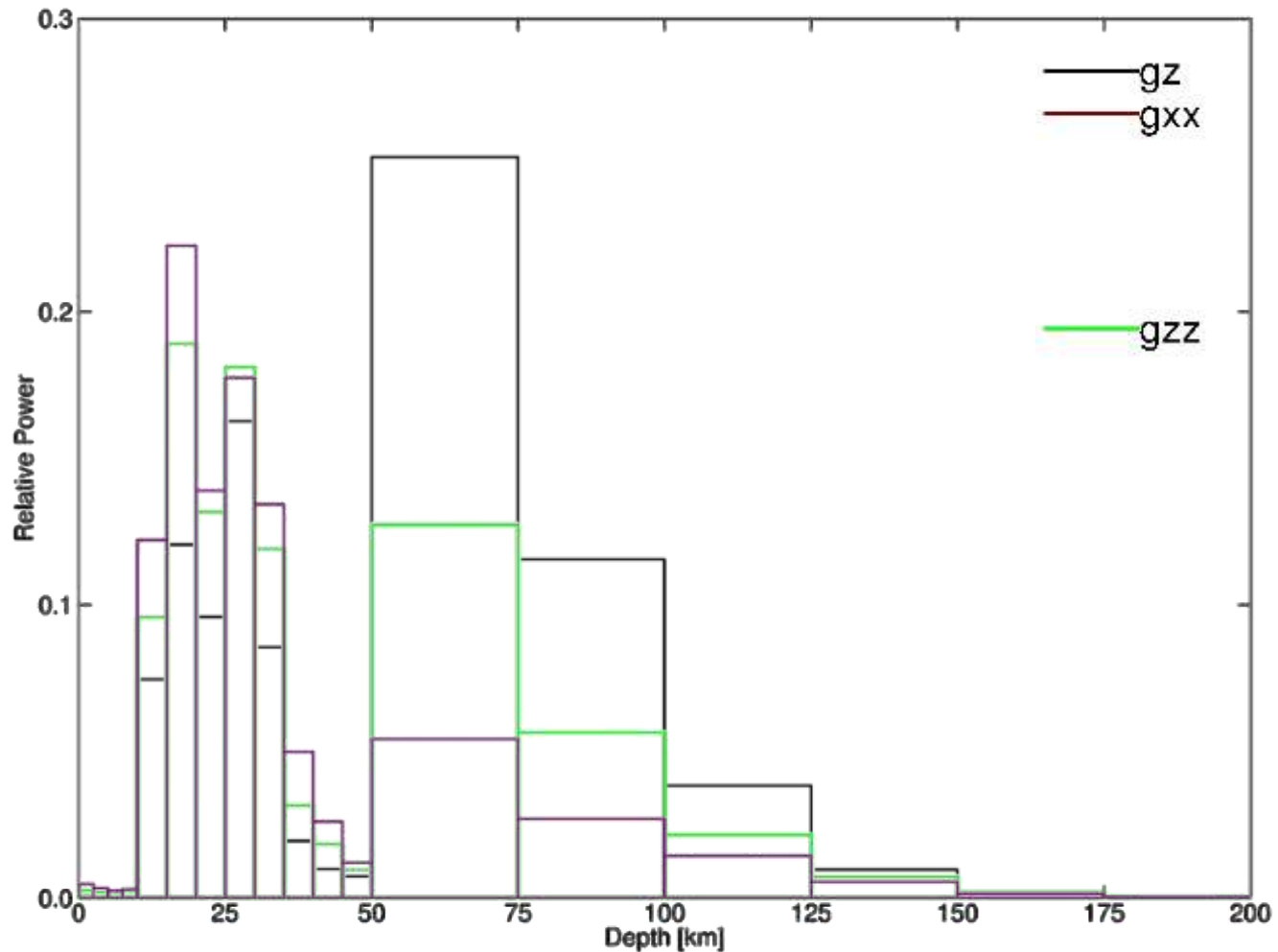
Relative signal power @225 km height



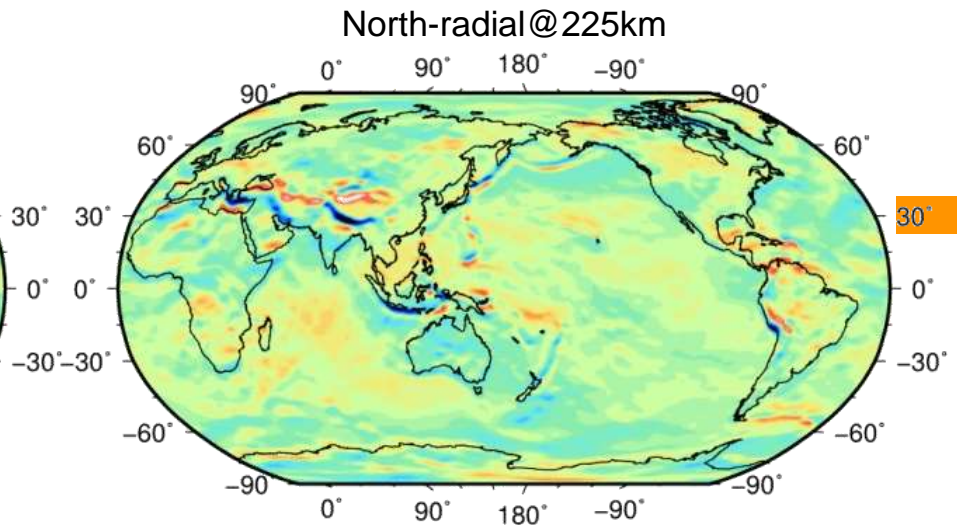
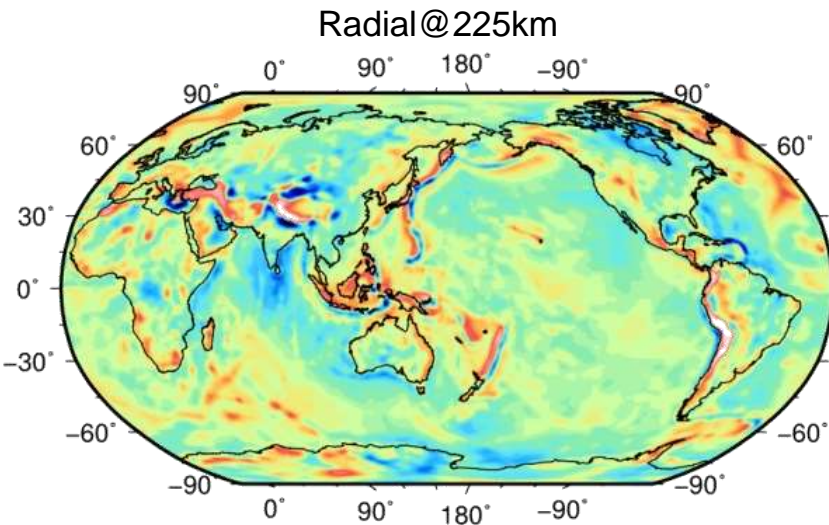
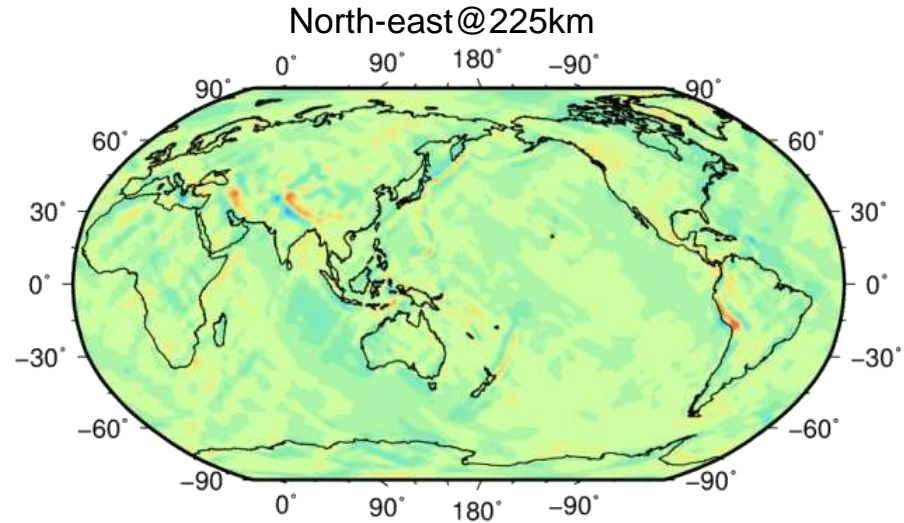
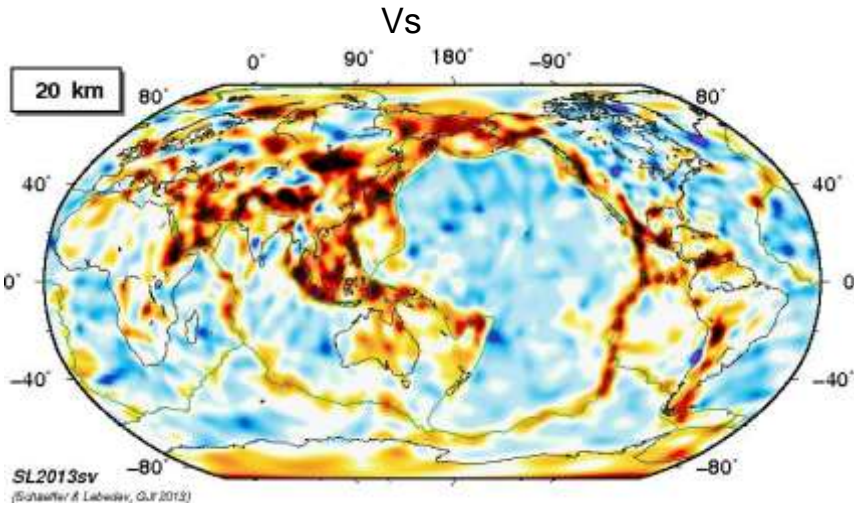
Relative signal power @225 km height



Relative signal power @225 km height

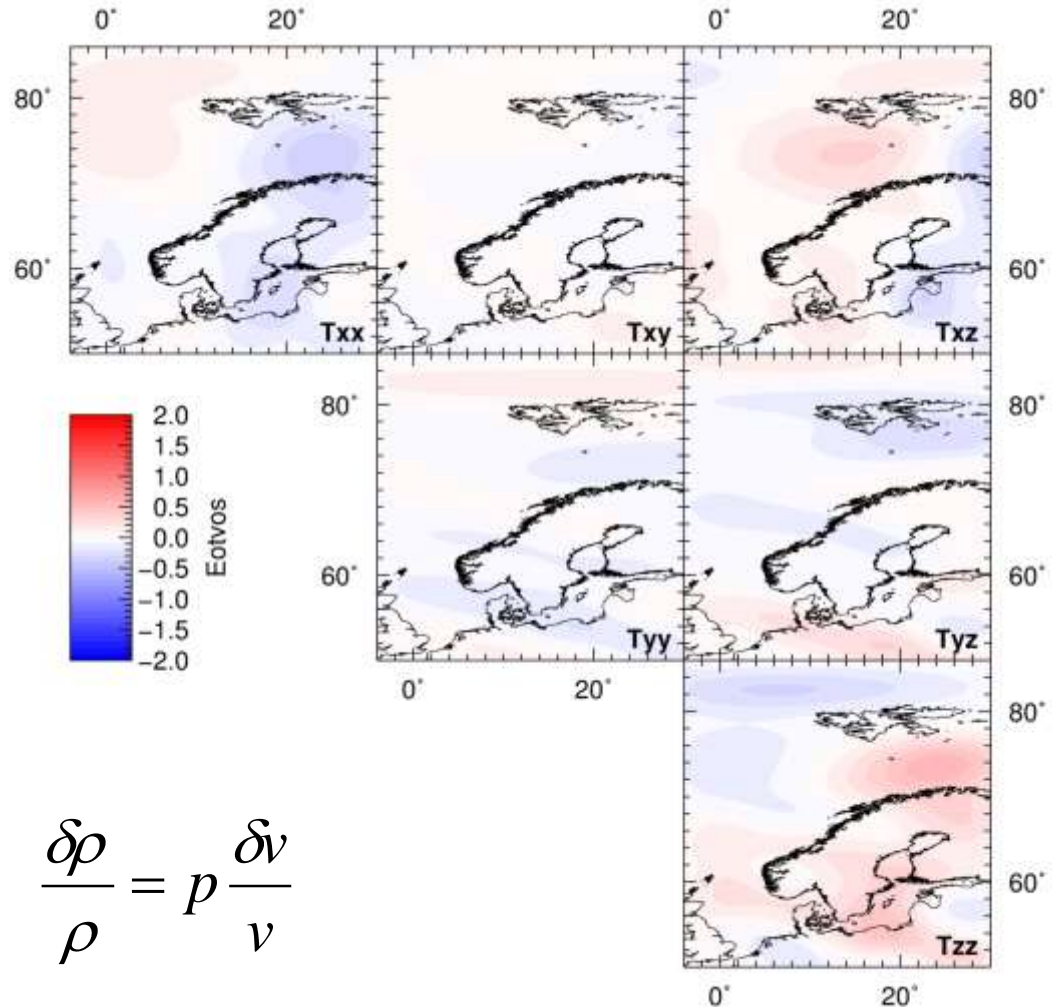


Comparison to global tomography

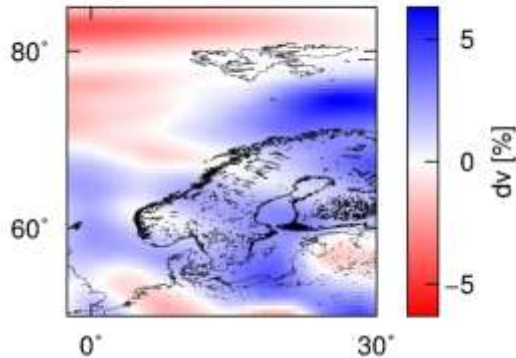


Comparison to tomography

Gradient Tensor: Depth 50 km



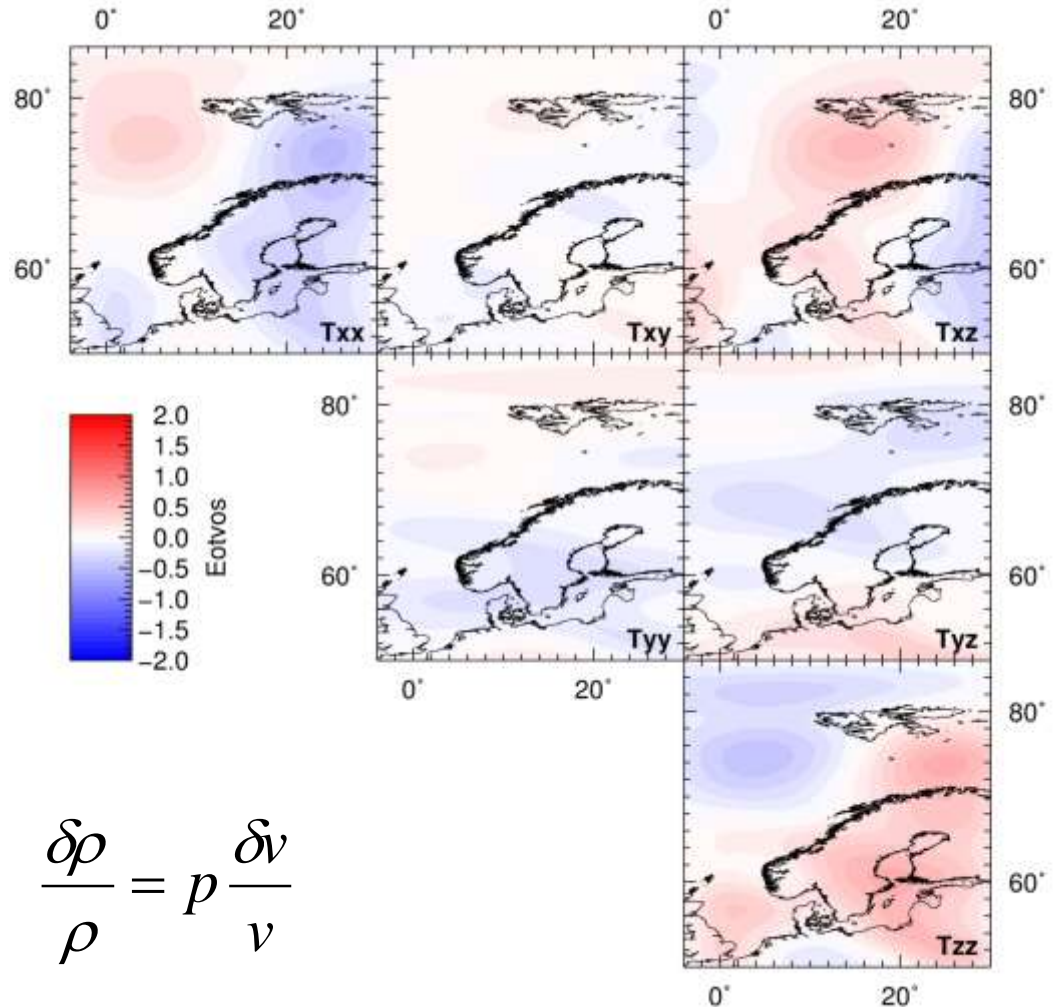
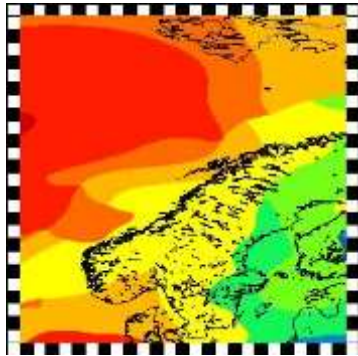
Depth 50 km



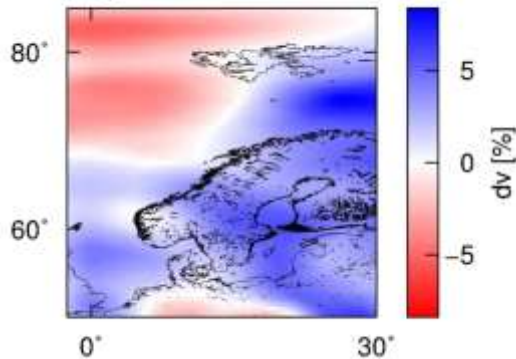
$$\frac{\delta\rho}{\rho} = p \frac{\delta v}{v}$$

Comparison to tomography

Gradient Tensor: Depth 75 km



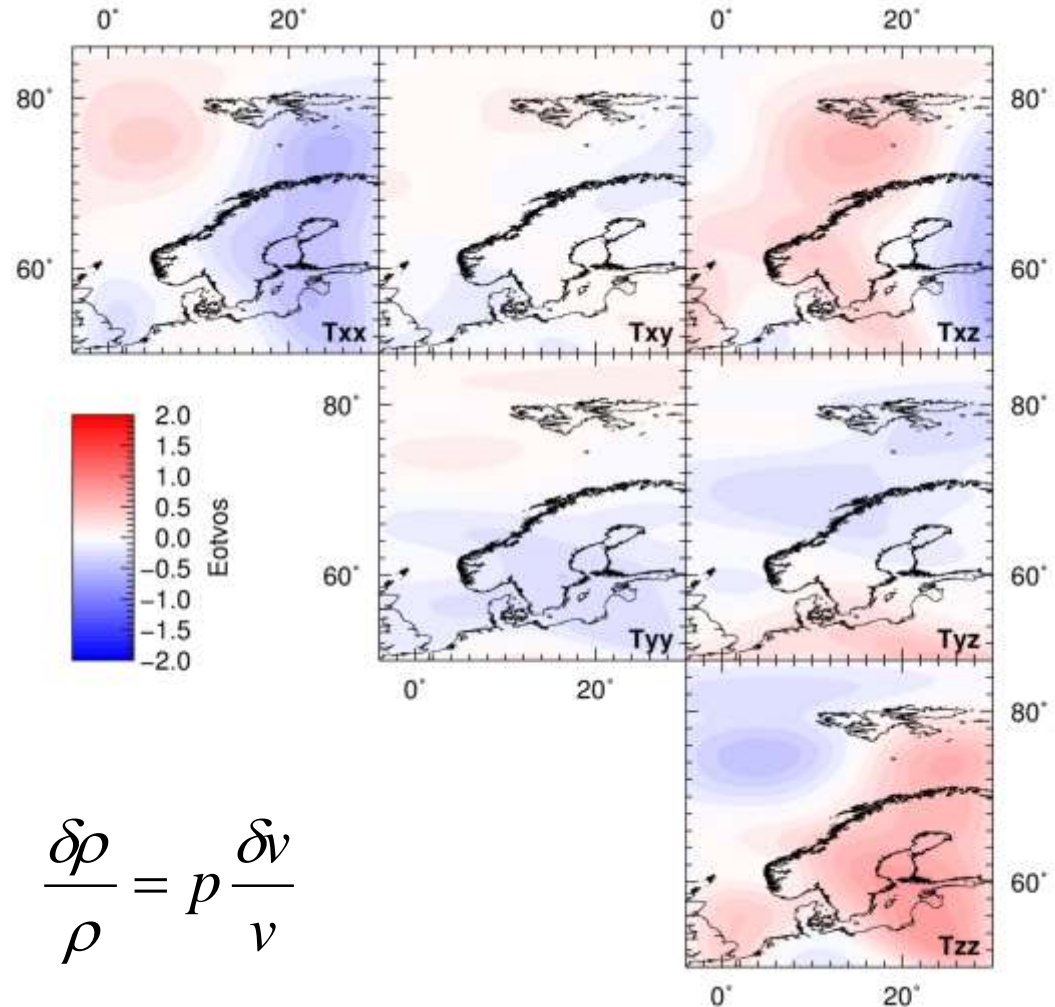
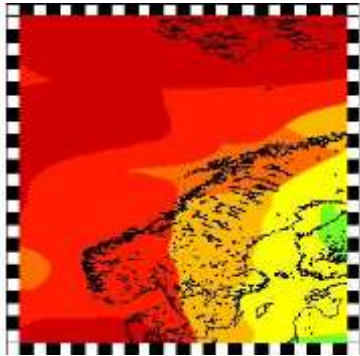
Depth 75 km



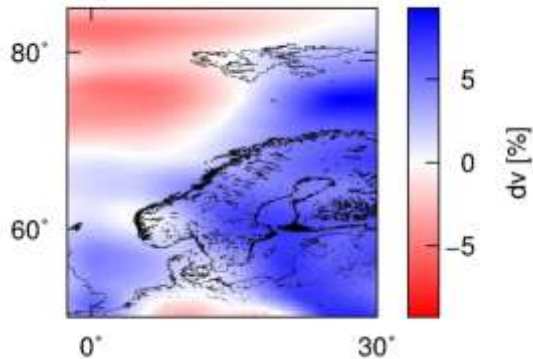
$$\frac{\delta\rho}{\rho} = p \frac{\delta v}{v}$$

Comparison to tomography

Gradient Tensor: Depth 100 km



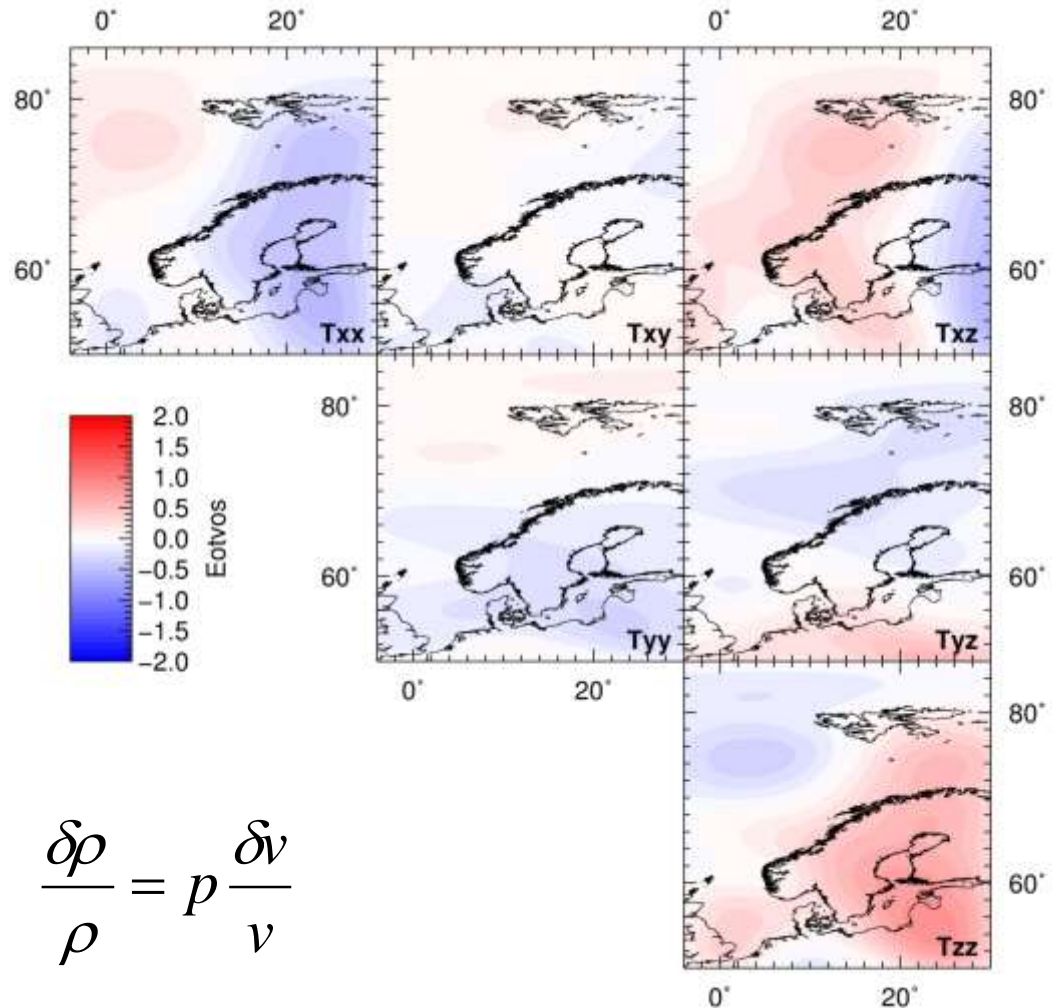
Depth 100 km



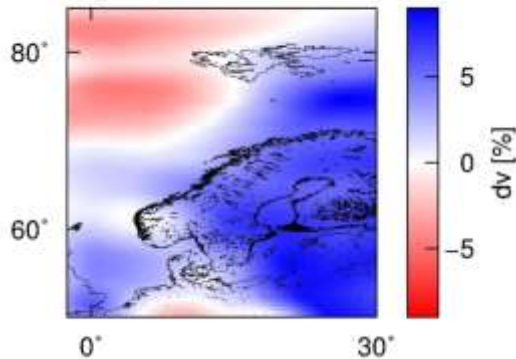
$$\frac{\delta\rho}{\rho} = p \frac{\delta v}{v}$$

Comparison to tomography

Gradient Tensor: Depth 125 km



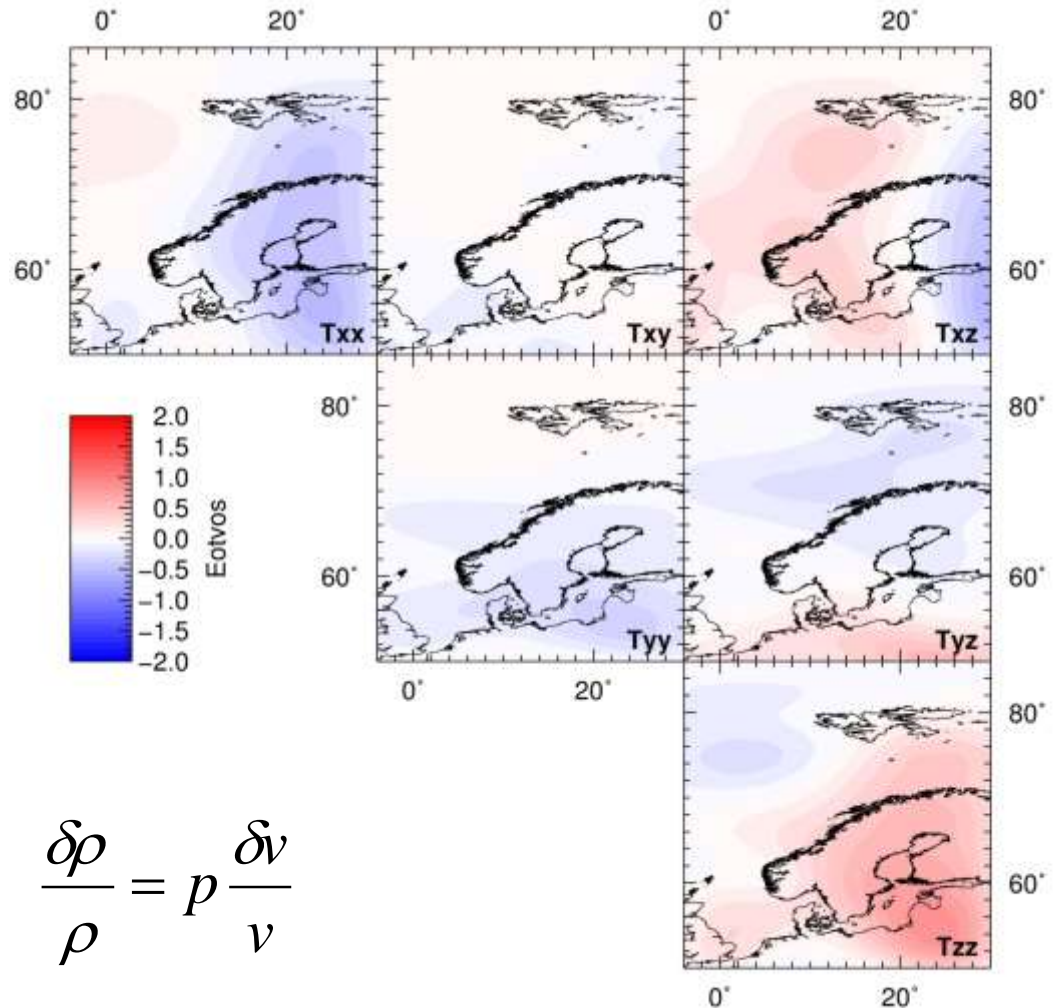
Depth 125 km



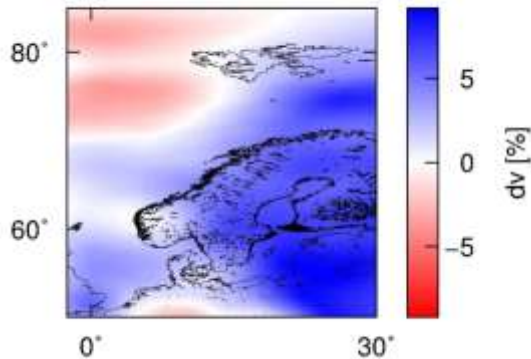
$$\frac{\delta\rho}{\rho} = p \frac{\delta v}{v}$$

Comparison to tomography

Gradient Tensor: Depth 150 km



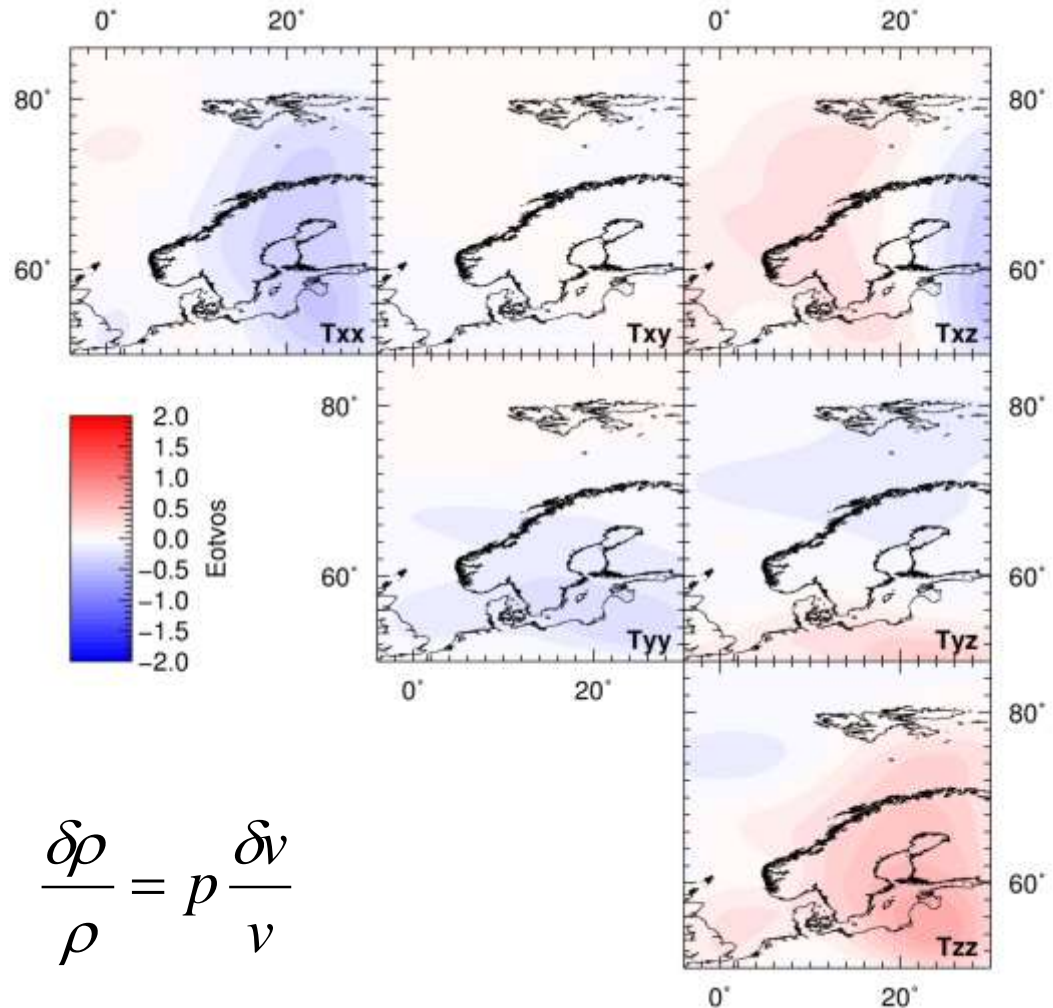
Depth 150 km



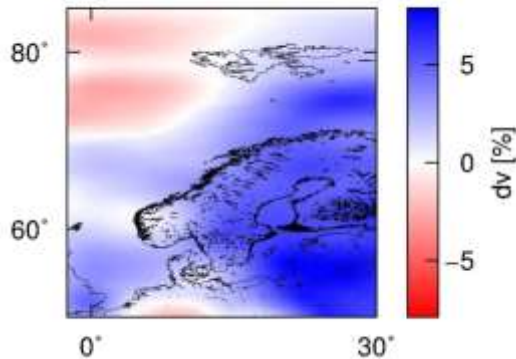
$$\frac{\delta \rho}{\rho} = p \frac{\delta v}{v}$$

Comparison to tomography

Gradient Tensor: Depth 175 km



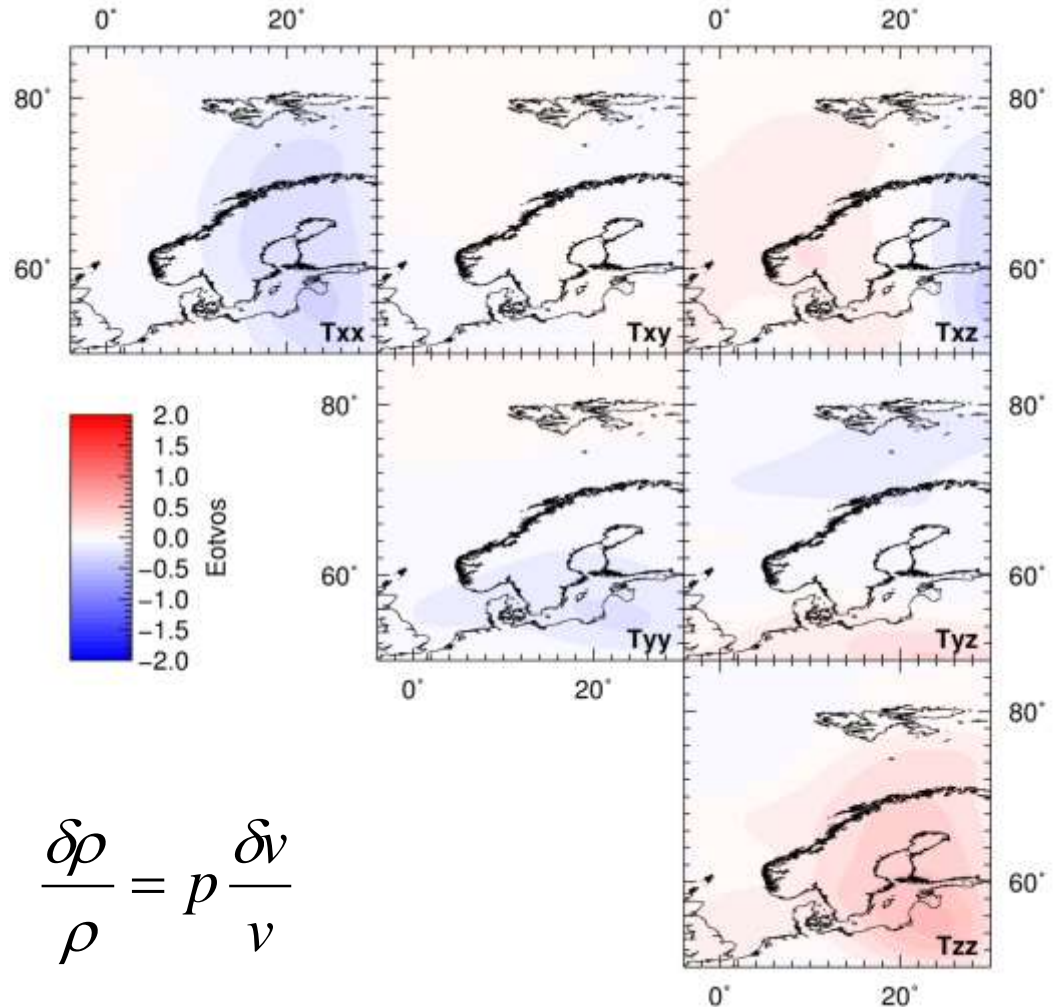
Depth 175 km



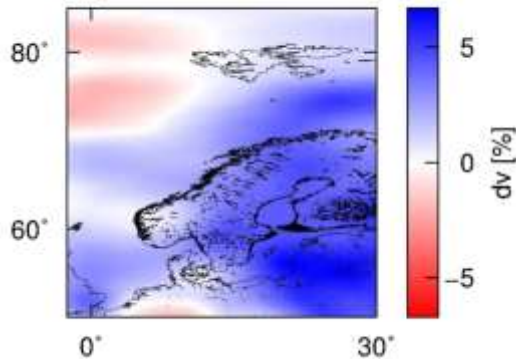
$$\frac{\delta\rho}{\rho} = p \frac{\delta v}{v}$$

Comparison to tomography

Gradient Tensor: Depth 200 km

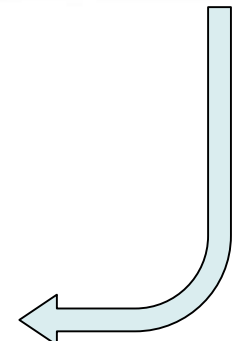
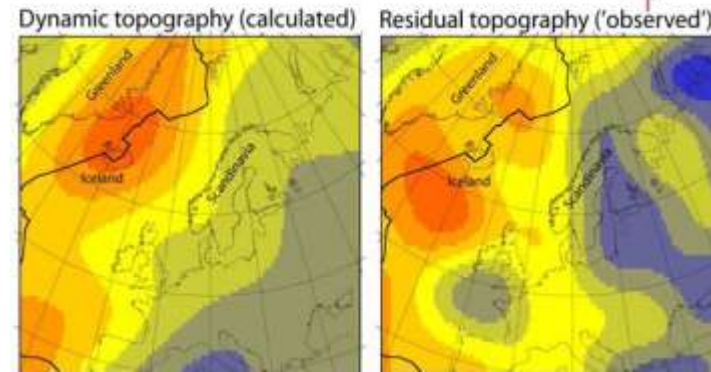
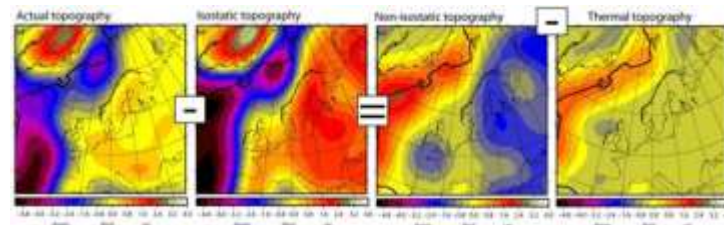
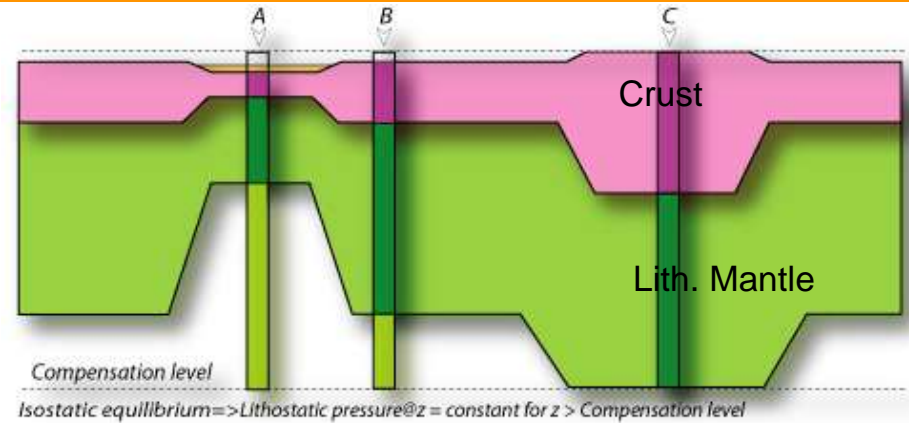
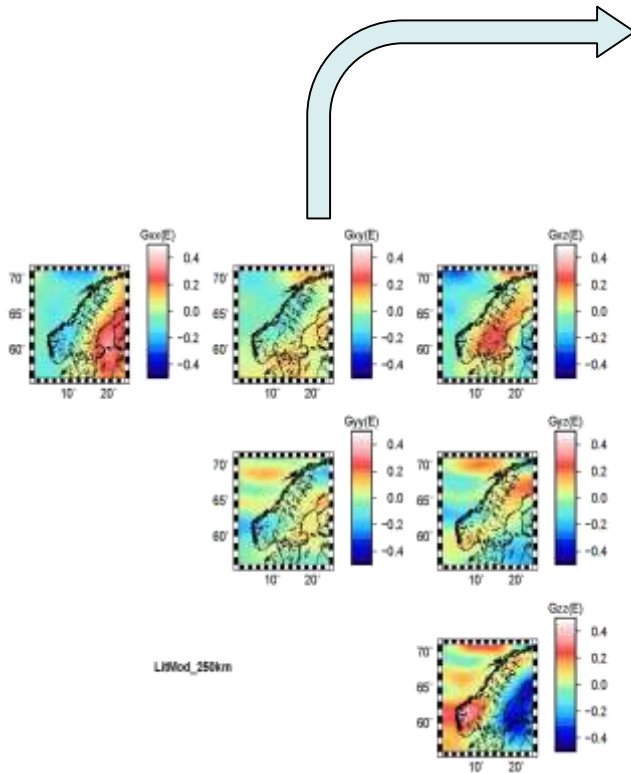


Depth 200 km



$$\frac{\delta\rho}{\rho} = p \frac{\delta v}{v}$$

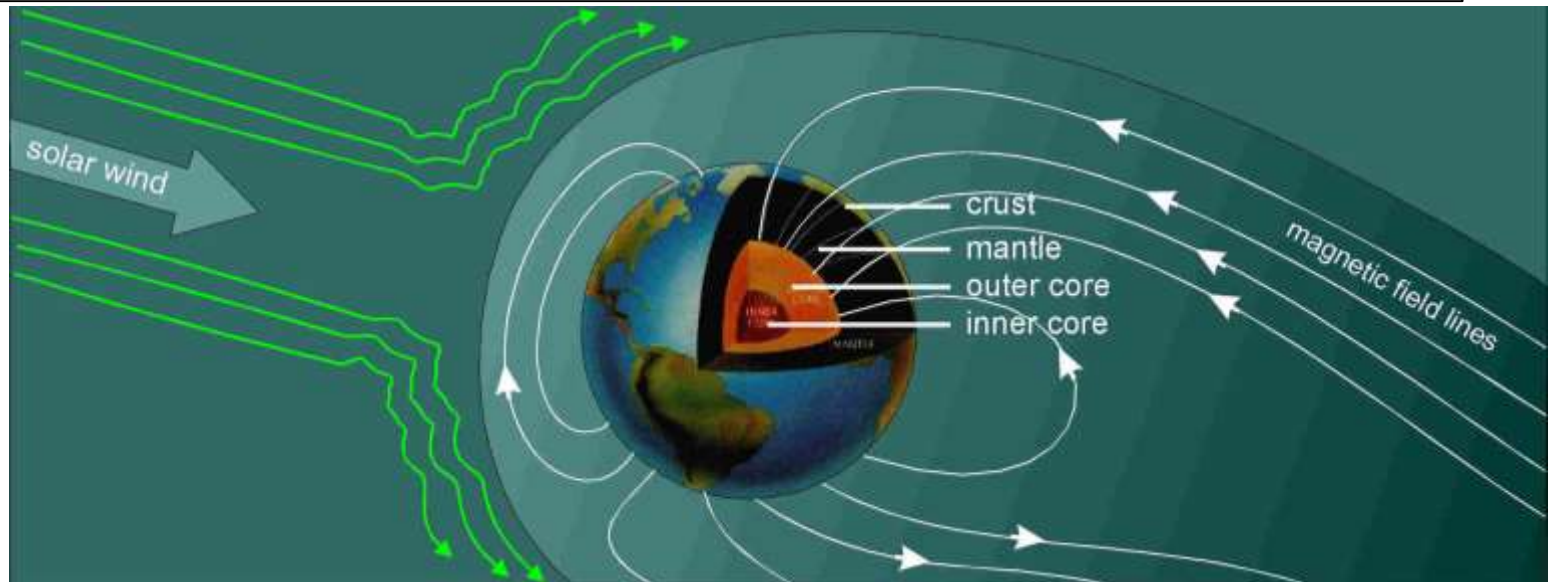
GOCE for crust and upper mantle





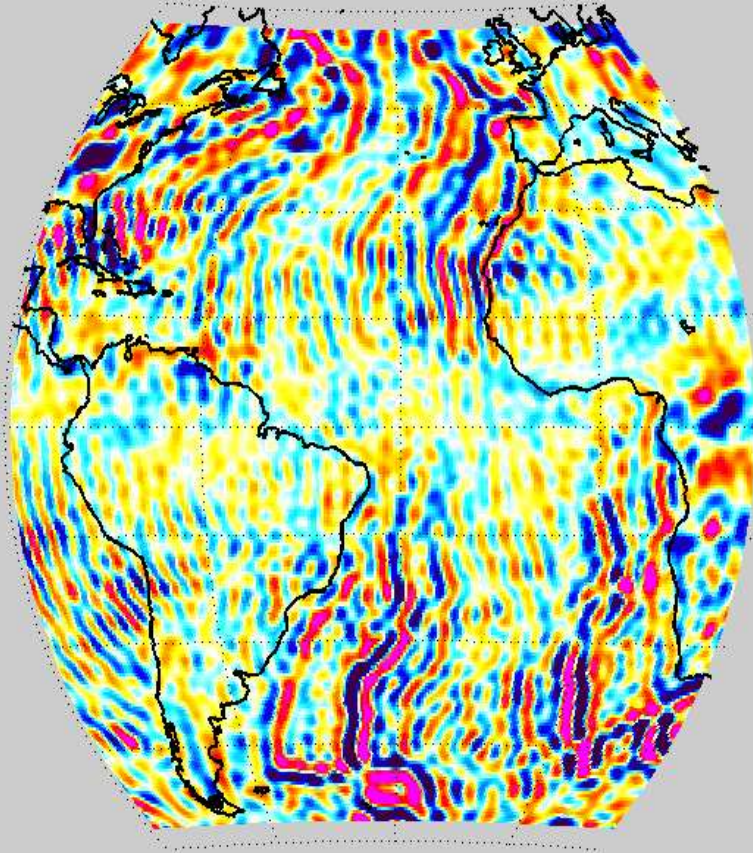
Swarm - Mission Aim

The **Swarm** mission will provide the *best ever survey of the geomagnetic field and its temporal evolution*, in order to gain new insights into the *Earth system by improving our understanding of the Earth's interior and physical climate.*



Launched November 22nd 2013, mission period: 5-10 years

Improvement of Lithospheric Field Model



Before Ørsted ...

$N = 30$, resolution: 1330 km

... with present satellites
Ørsted and CHAMP ...

$N = 60$, resolution: 670 km

... and with *Swarm*

$N = 133$, resolution: 300 km

*Magnetic field of Earth's crust
radial component at 10 km altitude*

Bewegung des magnetischen Nordpols

Expeditionen

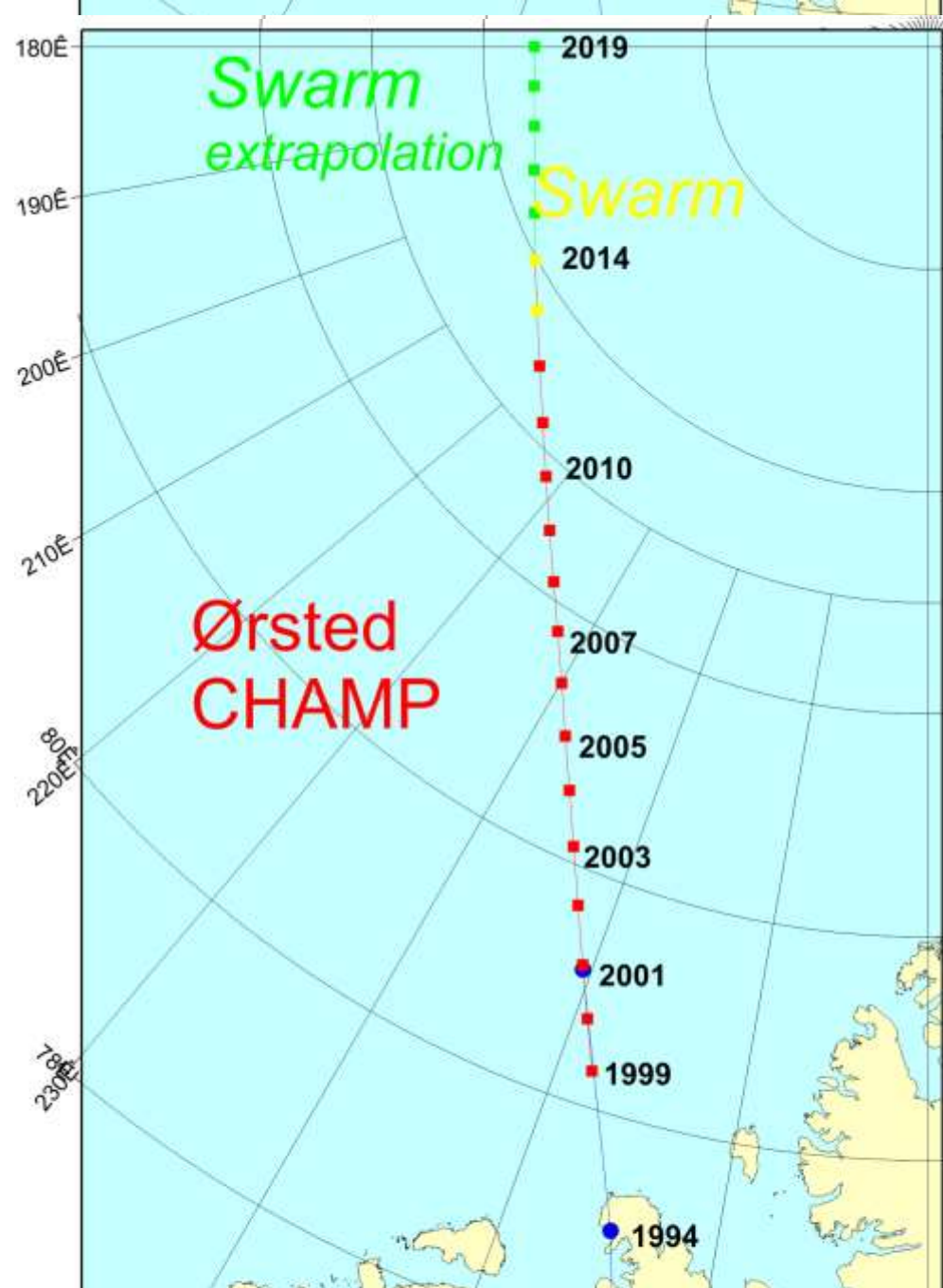
- 1831 James Clark Ross
- 1904 Roald Amundsen

Frühe Satelliten

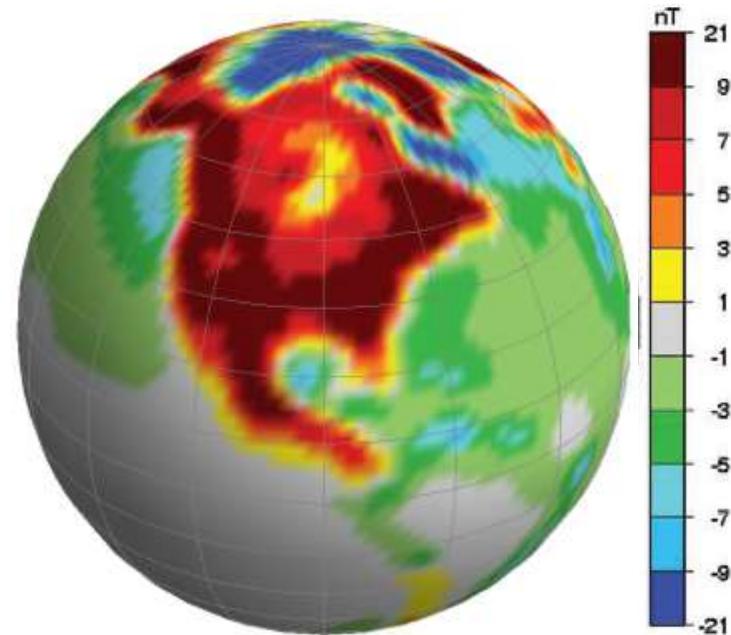
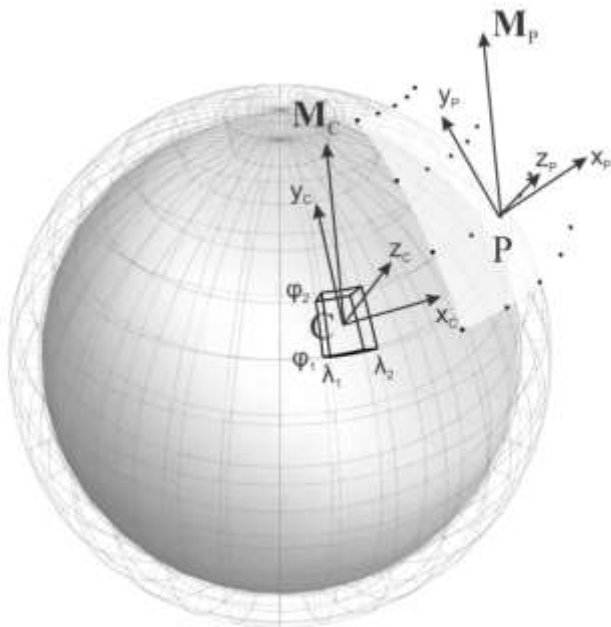
- Ørsted
- CHAMP

Die neueste Satellitenmission

- Swarm



Global model from CRUST1.0



Modelling result

- Susceptibility of the whole crust - 0.04 SI
- Ambient field – IGRF11 (Finlay et al., 2010)
- Computation grid resolution – $2^\circ \times 2^\circ$
- Computation grid altitude – 400 km

3-D Electrical Conductivity of the Mantle

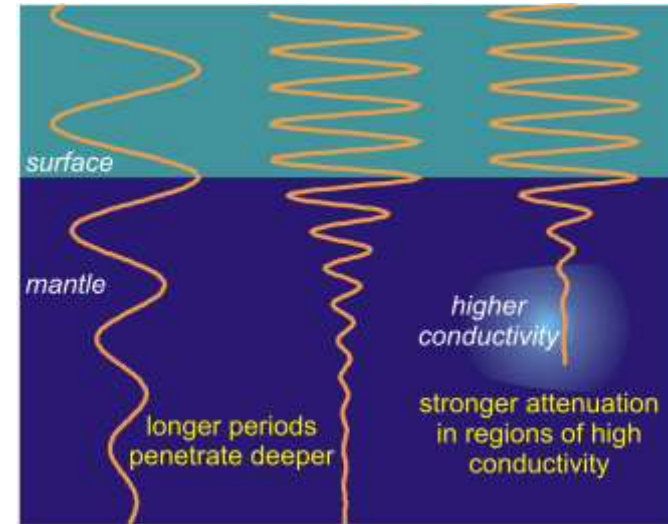


Process

- secondary magnetic fields due to electric currents in the mantle, induced by time-varying external (primary) fields

Background

- conductivity is sensitive to composition and temperature
- conductivity-depth profile given by frequency dependence of induced fields
- only 1-D models available, no information about conductivity inhomogeneities
- Unique tool for mantle study from space complementing seismology



Goal

- determine for the first time global models of mantle conductivity (3-D)

Derive global transfer functions
(hours to months period, corresponding to 100 - 1000 km depth)

Conclusions and outlook

Gradients at satellite height are well suited to complement seismic tomography to image the upper mantle

Satellite gradients should be used jointly with gravity and geoid data to model the entire lithosphere

More info and the data can be found at:
<http://goce4interior.dgfi.badw.de/>

Swarm mission will provide new image of Earth magnetic field and mantle conductivity

ESA is currently establishing a working program addressing the needs for a common 3D Earth model and geodynamic modelling!

