GOCE+ GeoExplore for geophysical research

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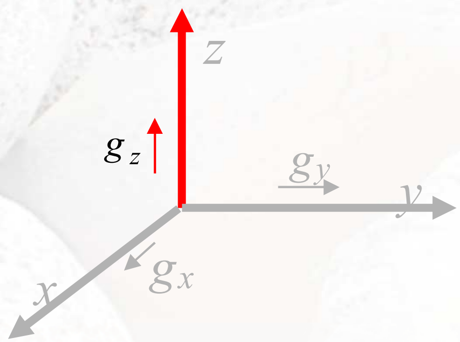
3: TNO, Utrecht
4: ESA/ESTEC, Noordwijk

GOCE Solid Earth workshop
Enschede
October, 17th 2012

Some definitions

$$g_z = -\frac{\partial \Phi}{\partial z}$$

Gravity - we normally use only g_z



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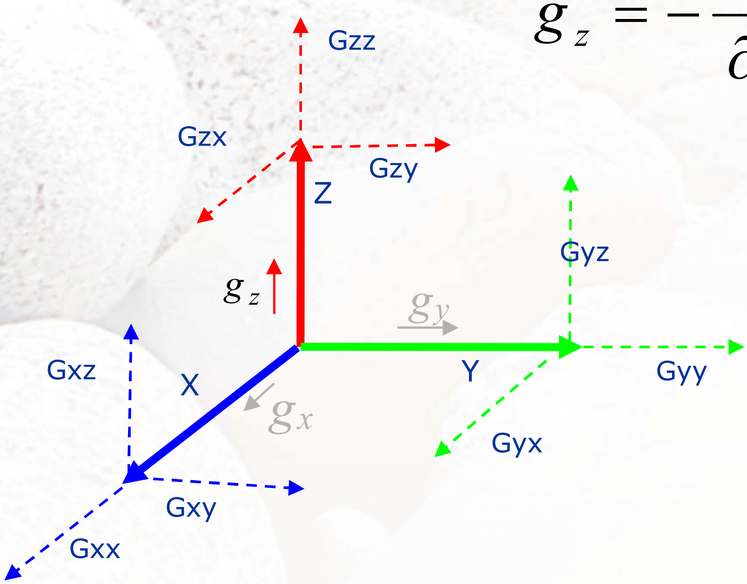

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Gravity - we normally use only g_z

Gravity Gradiometry uses the second derivatives of the scalar potential

Gravity Gradient Tensor:

9 components (5 independent) represent the spatial *rates of change* of the gravity field

Unit: 1 Eötvös [E] = 0.1 mGal/km

$$G = \begin{bmatrix} \frac{\partial g_x}{\partial x} & \frac{\partial g_x}{\partial y} & \frac{\partial g_x}{\partial z} \\ \frac{\partial g_y}{\partial x} & \frac{\partial g_y}{\partial y} & \frac{\partial g_y}{\partial z} \\ \frac{\partial g_z}{\partial x} & \frac{\partial g_z}{\partial y} & \frac{\partial g_z}{\partial z} \end{bmatrix} = \begin{bmatrix} G_{xx} & G_{xy} & G_{xz} \\ G_{yx} & G_{yy} & G_{yz} \\ G_{zx} & G_{zy} & G_{zz} \end{bmatrix}$$

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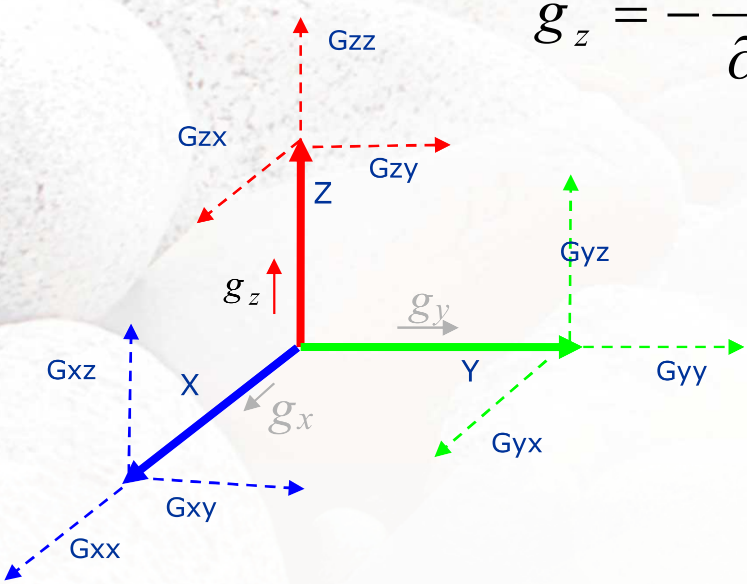

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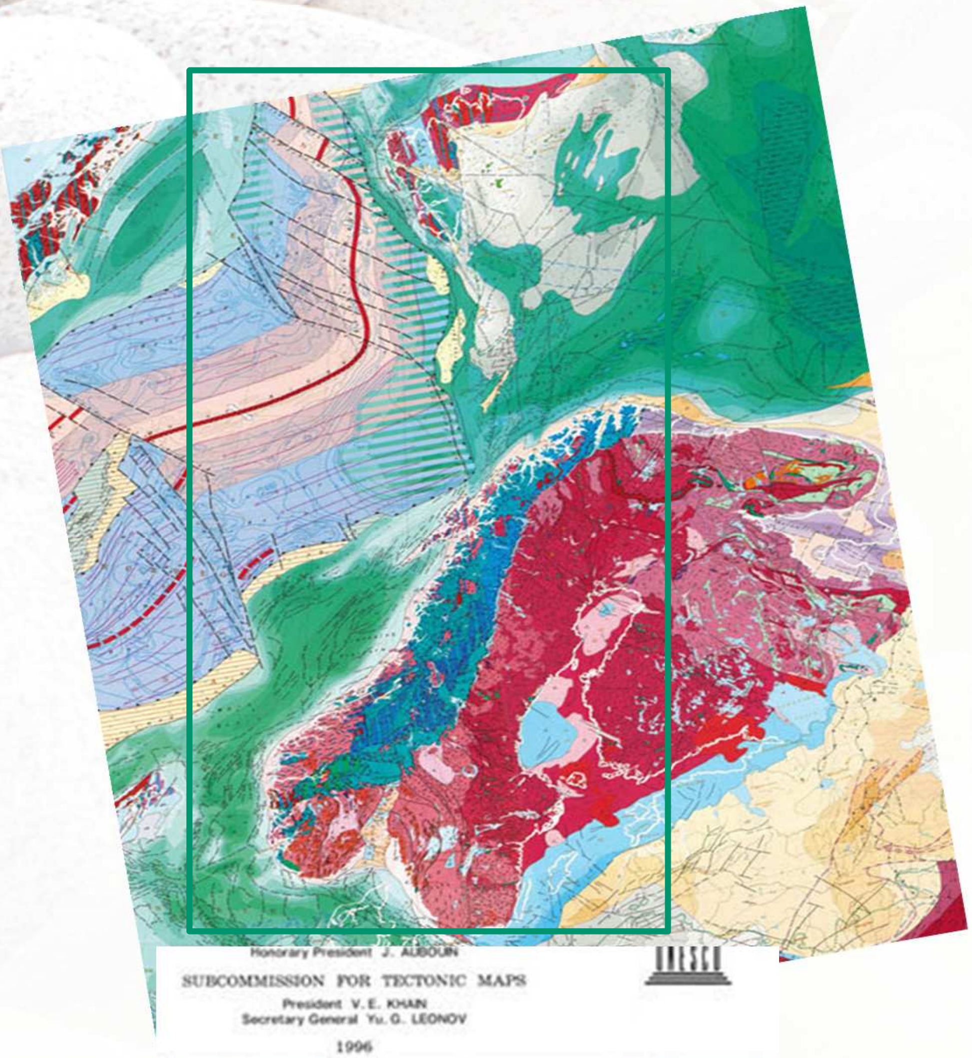
=> Impact assessment NE Atlantic

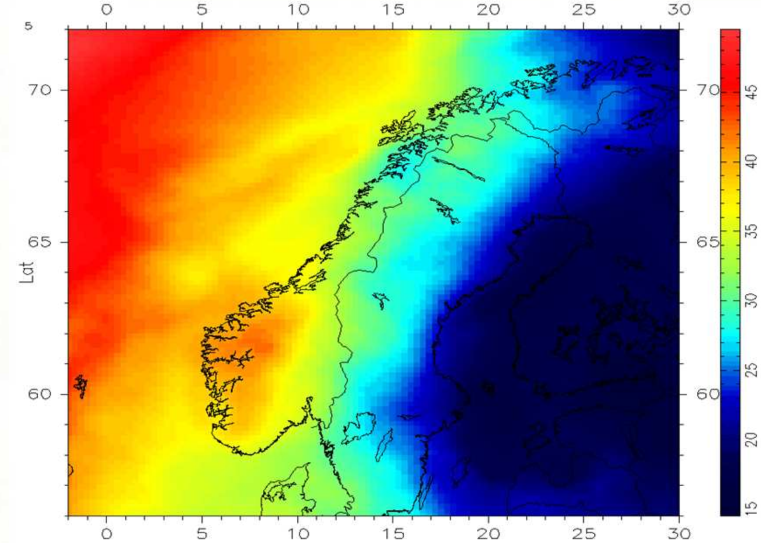
Impact Assesment Strategy

- Compile 3D model
- Forward calulate potential field response
- Compare calculation to GOCE gradients
  - Sensitivity for individual lithologies/bodies
  - Residual maps for individual components
- Invert model geometries to minimize residuals
  - Individual components/invariants
  - Weighted joint inversion
- Document model improvement

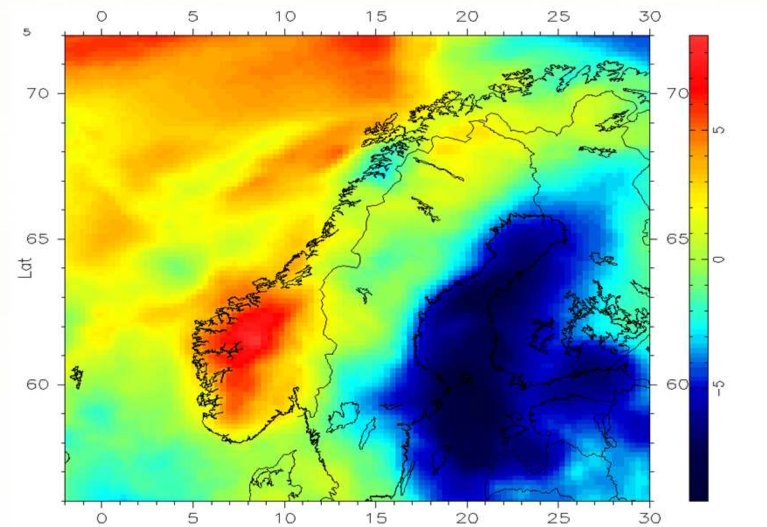
NE Atlantic margin



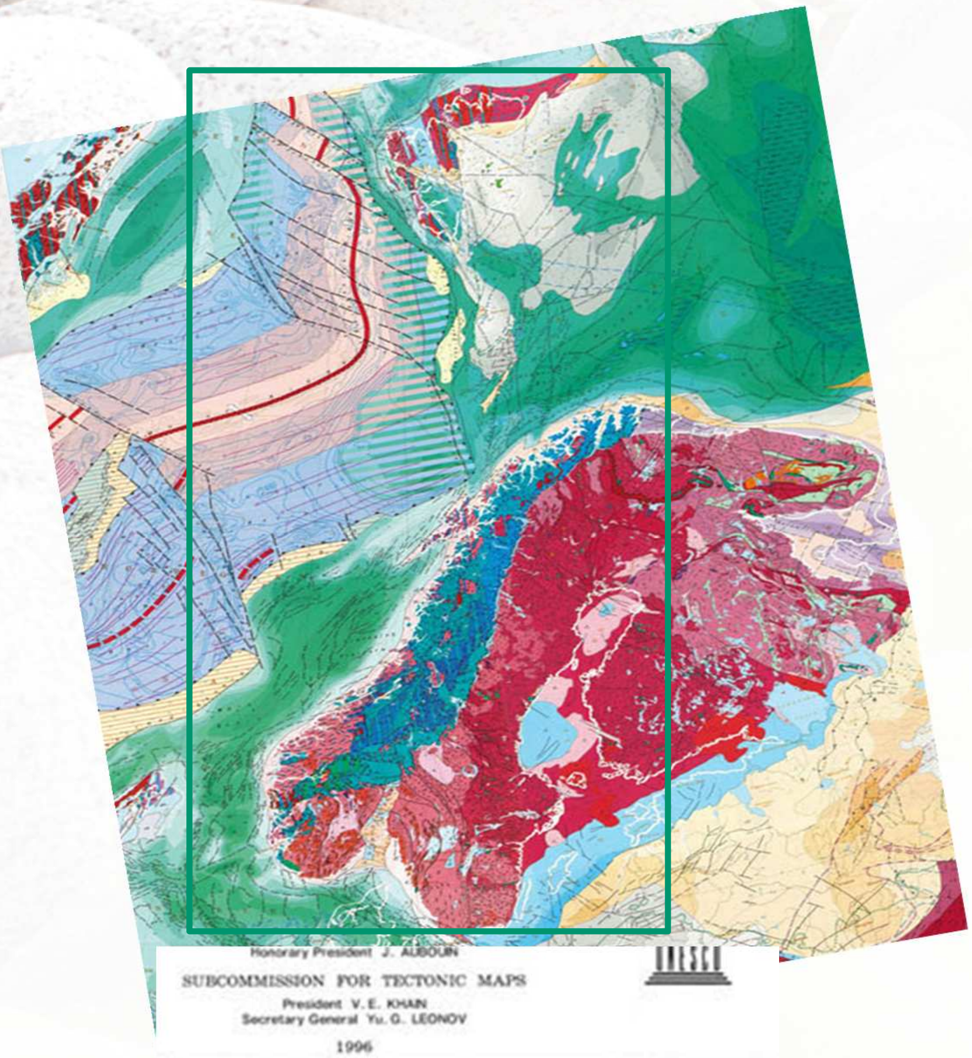
Geoid

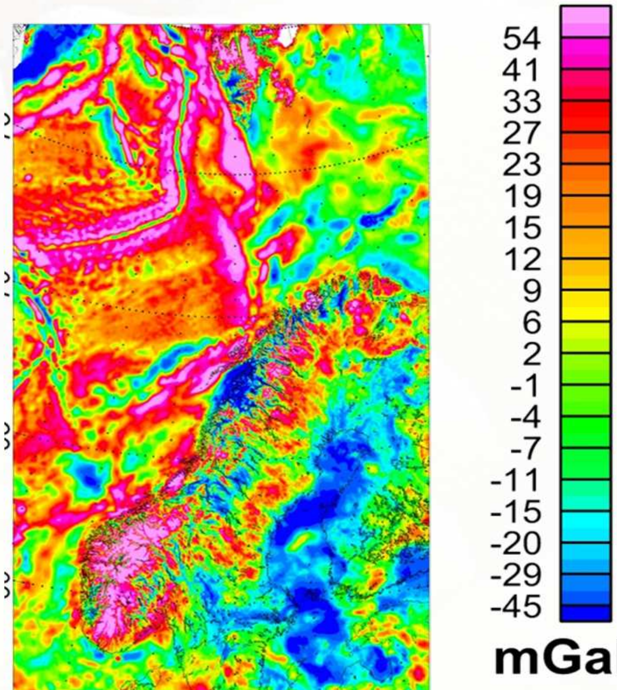


Geoid >degree and order 10

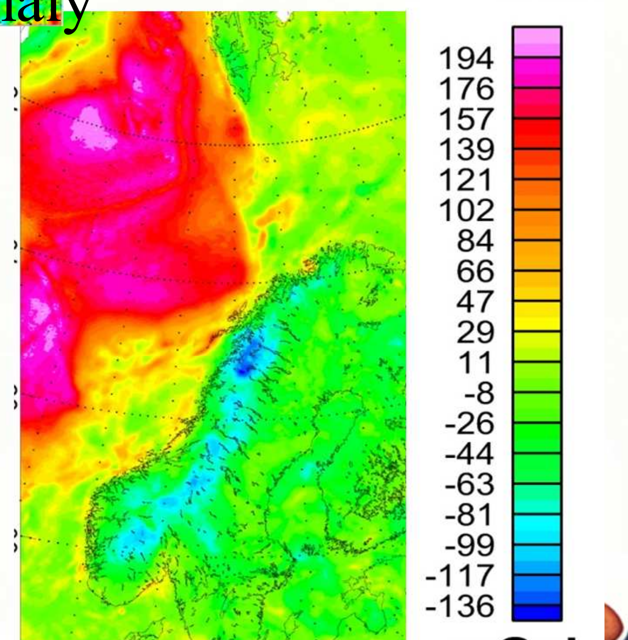


NE Atlantic margin



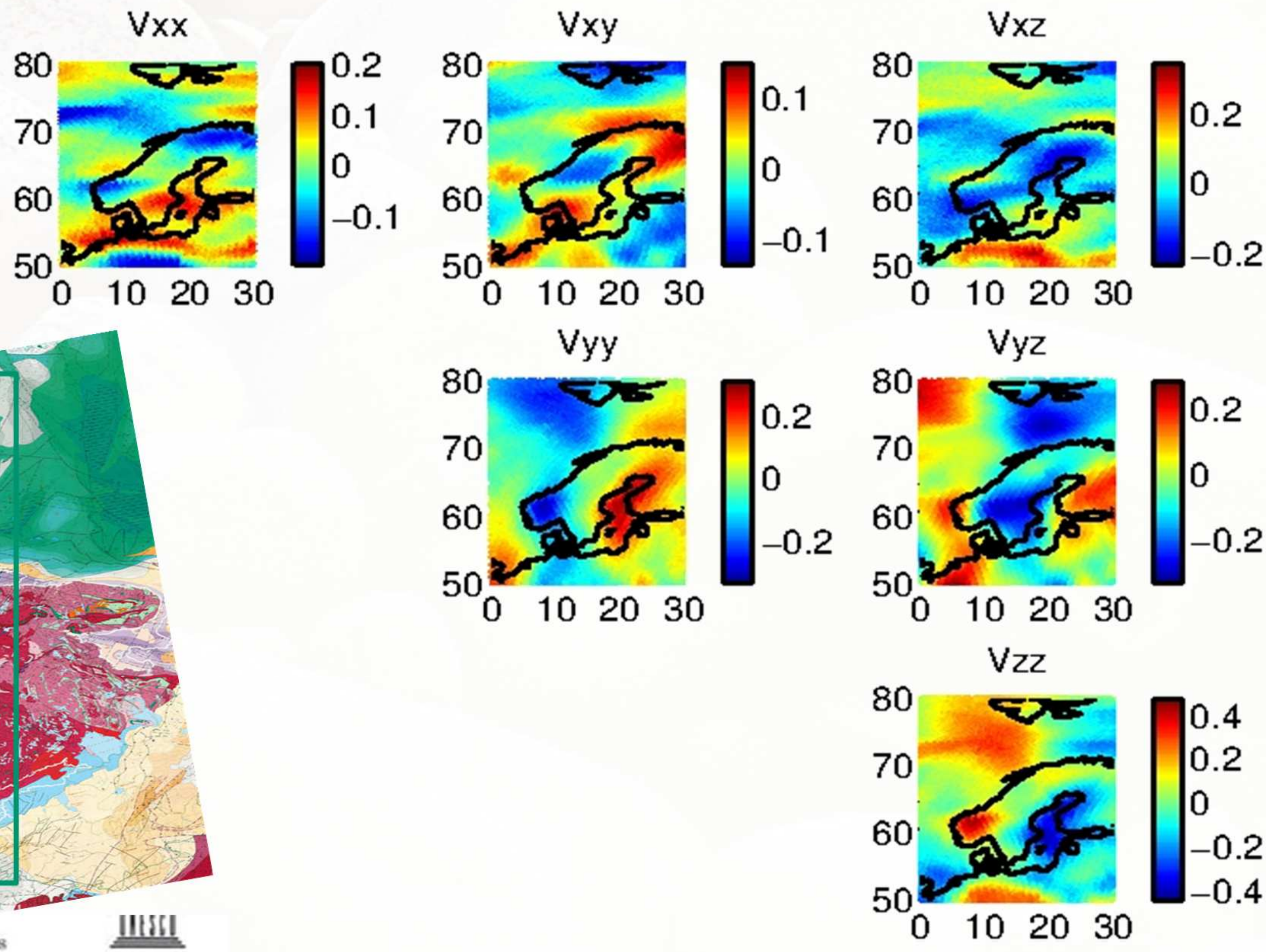


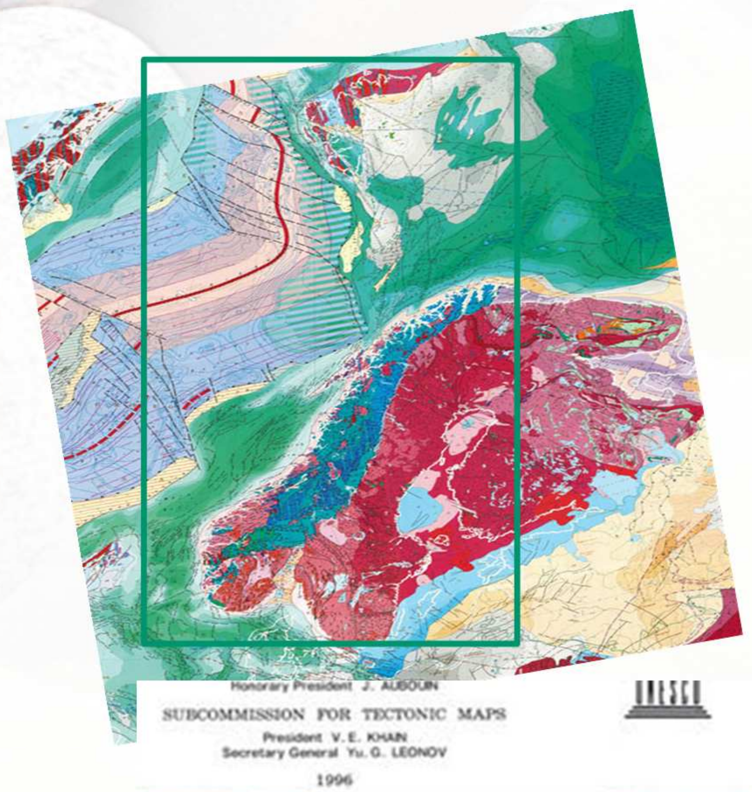
Free-air anomaly



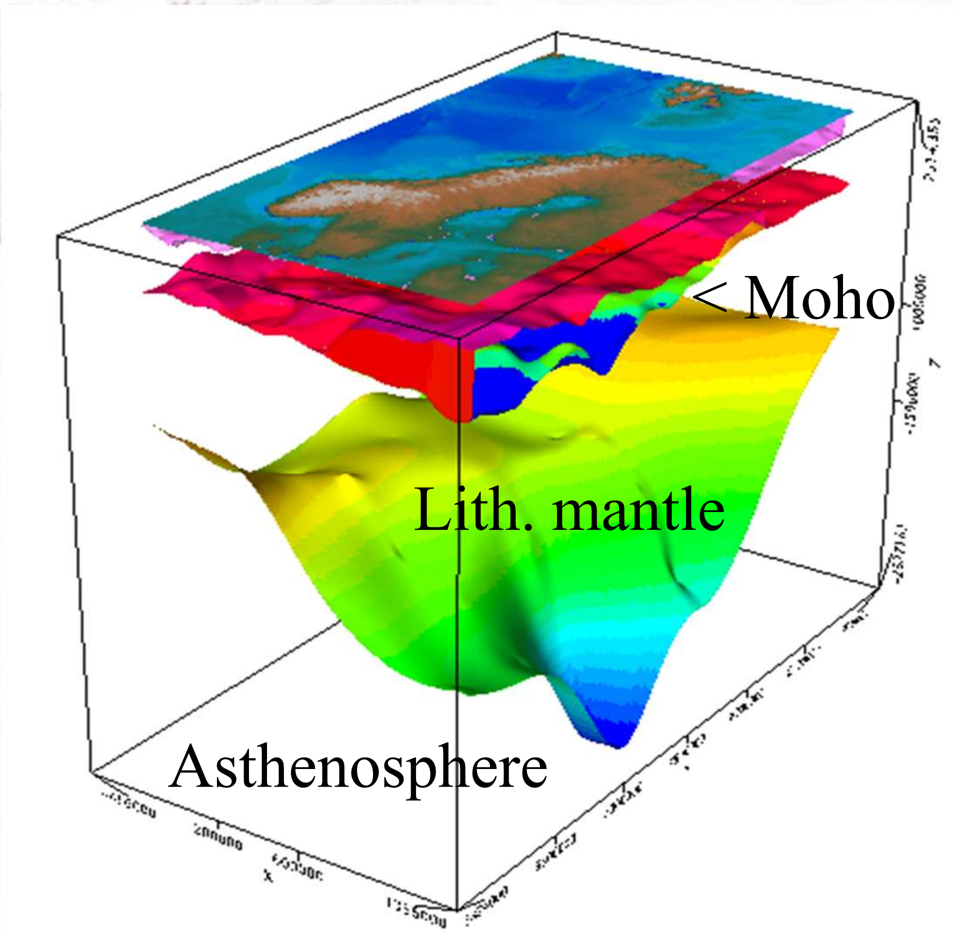
Bouguer anomaly

NE Atlantic margin - GOCE gradients





Model set-up



Model Name: 3D_NEAtlantic.g3d
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- Vertical Density Function
- Gravity
- Magnetic
- Layer 1: .\3DMod_Topography10.grd(GRD)
  - Density: 2.67
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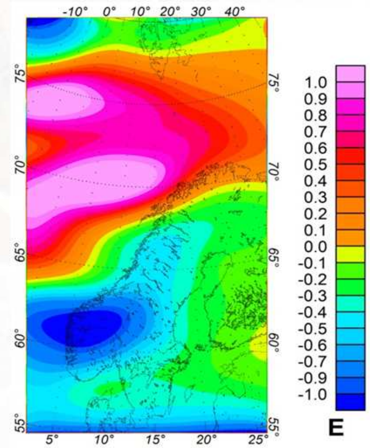
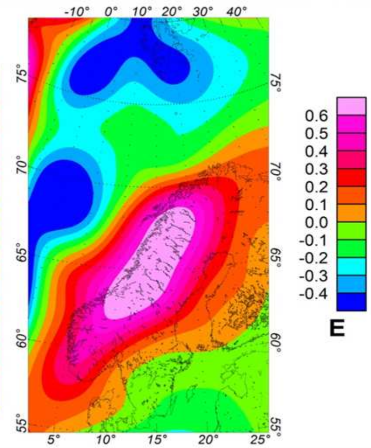
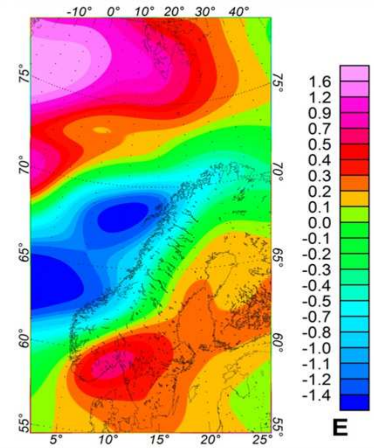
1st model: Topography only

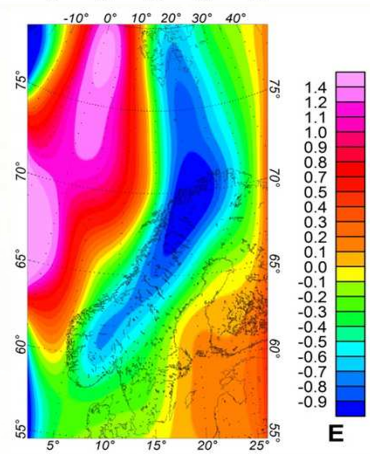
Topographic-bathymetric effect on gravity gradients at satellite height (255 km)

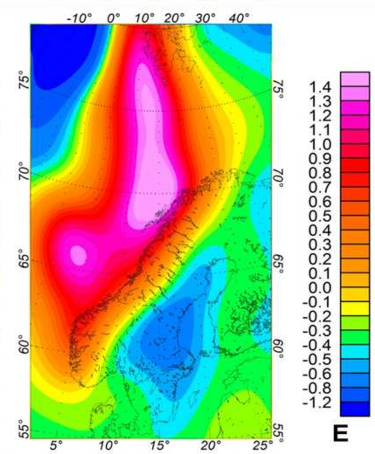
Constant surface density



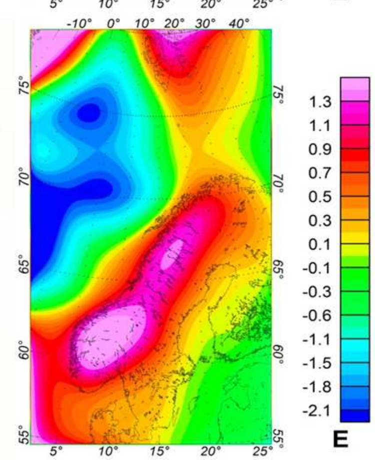






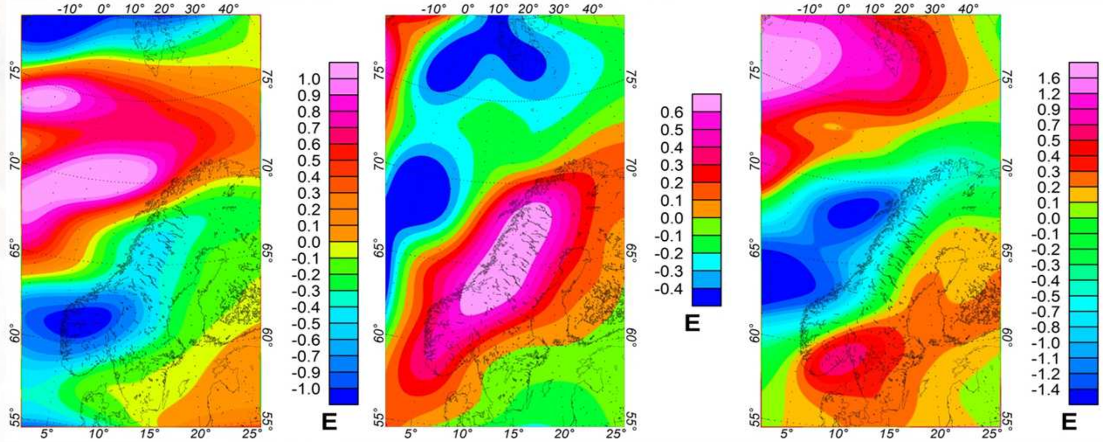


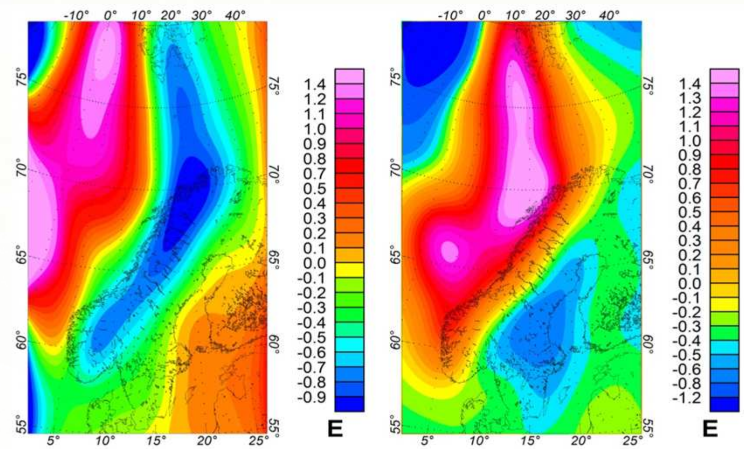
$$\begin{bmatrix} G_{xx} & G_{xy} & G_{xz} \\ & G_{yy} & G_{yz} \\ & & G_{zz} \end{bmatrix}$$

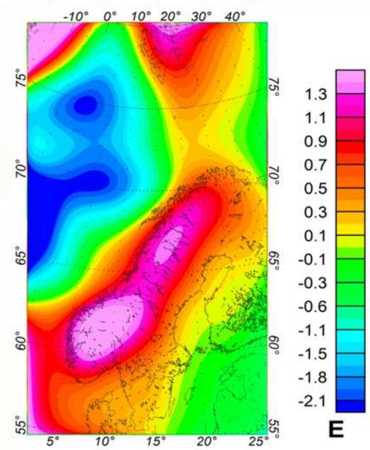


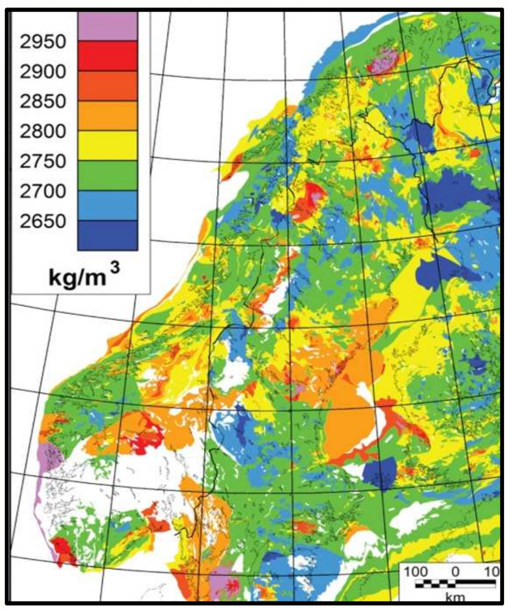
Topographic-bathymetric effect on gravity gradients at satellite height (255 km)

Variable surface density



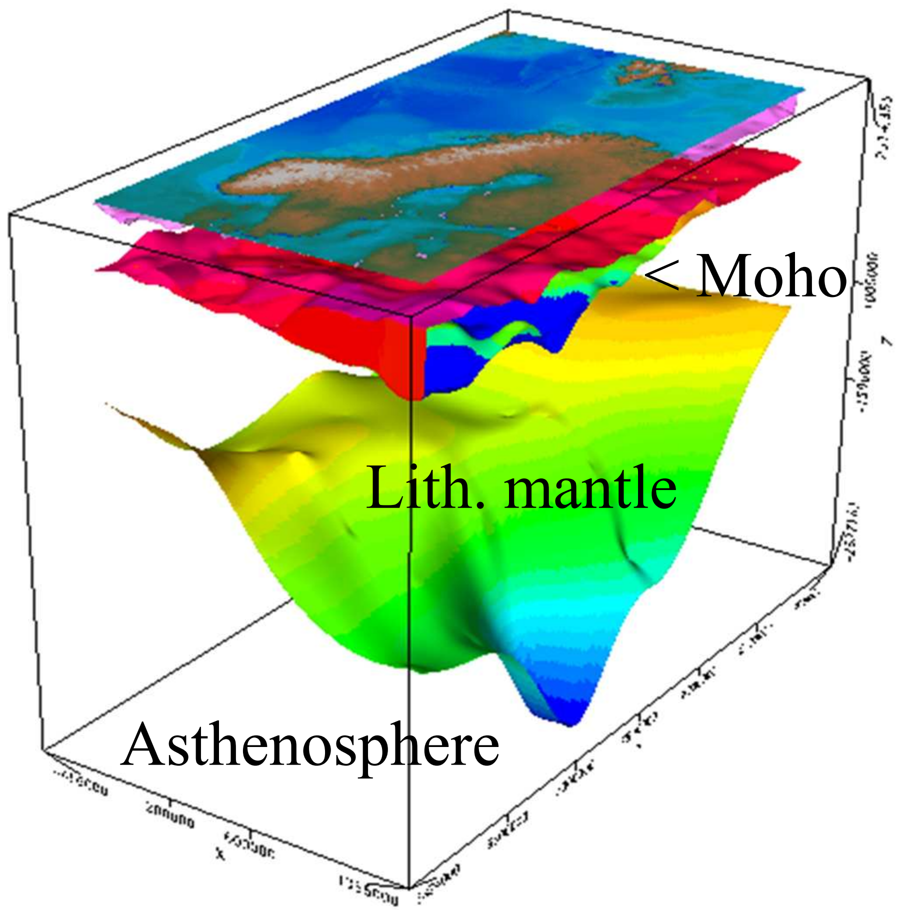






Surface density model after Ebbing et al. (2012)

Lithospheric model set-up



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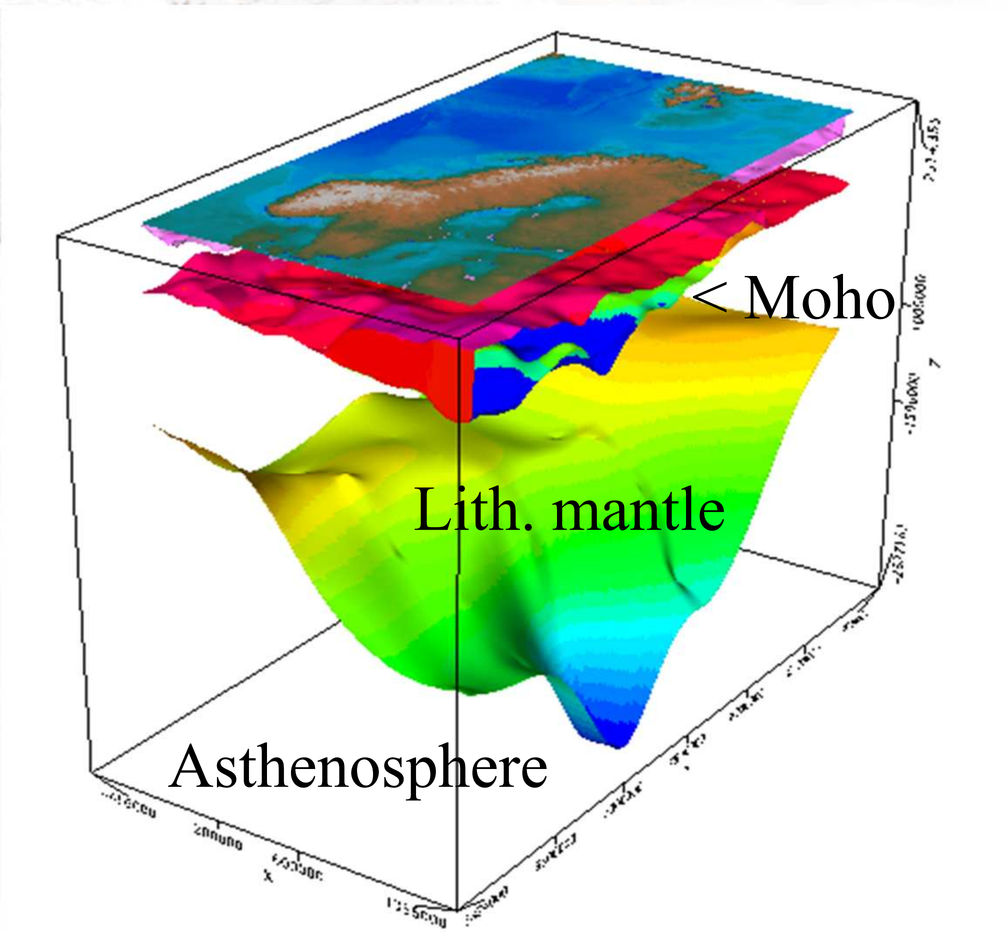

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- Layer 4: .\BaseSed_NGU_NOAA_Laske.grd
  - Density: .\D_UC1.grd
  - Susc: Constant
- Layer 5: .\UCMC.grd
  - Density: 2.8
  - Susc: Constant
- Layer 6: .\UCLC.grd
  - Density: 2.95
  - Susc: Constant
- Layer 7: .\3DMod_IsoTopLCBClipped.grd(GRD)
  - Density: 3.1
  - Susc: Constant
- Layer 8: .\3DMod_Moho_Grad.grd
  - Density: .\MantleDensityGP250km.grd
  - Susc: Constant
- Layer 9: .\LAB_Artemieva2.grd
  - Density: 3.3

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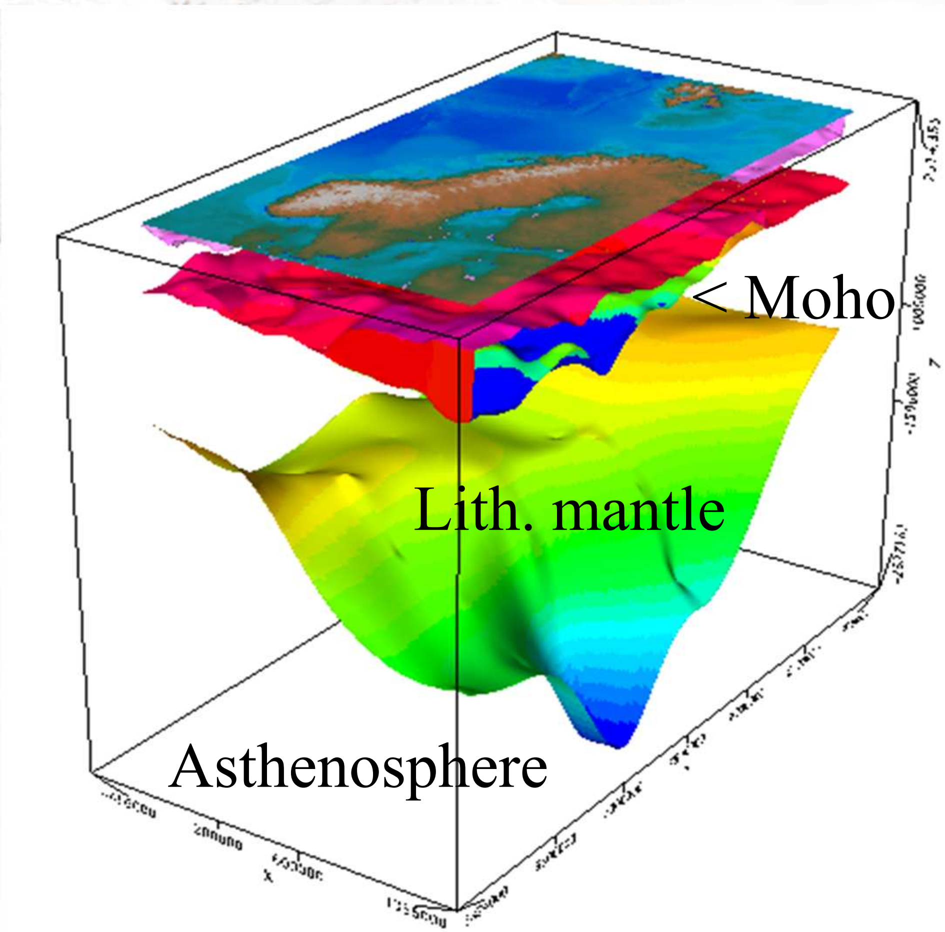

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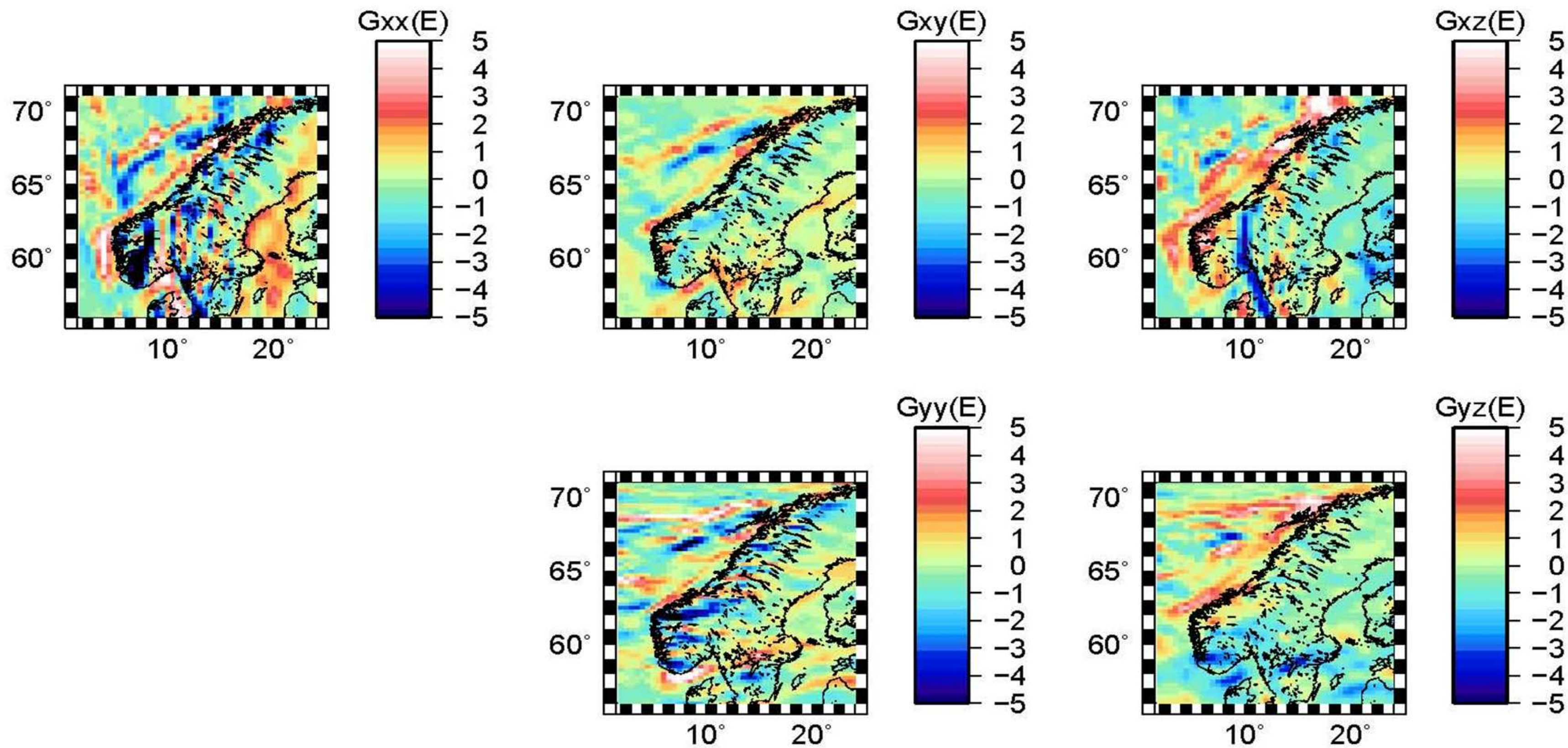
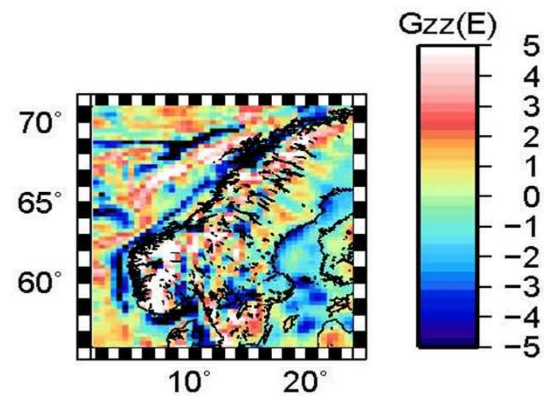
Sediment compaction

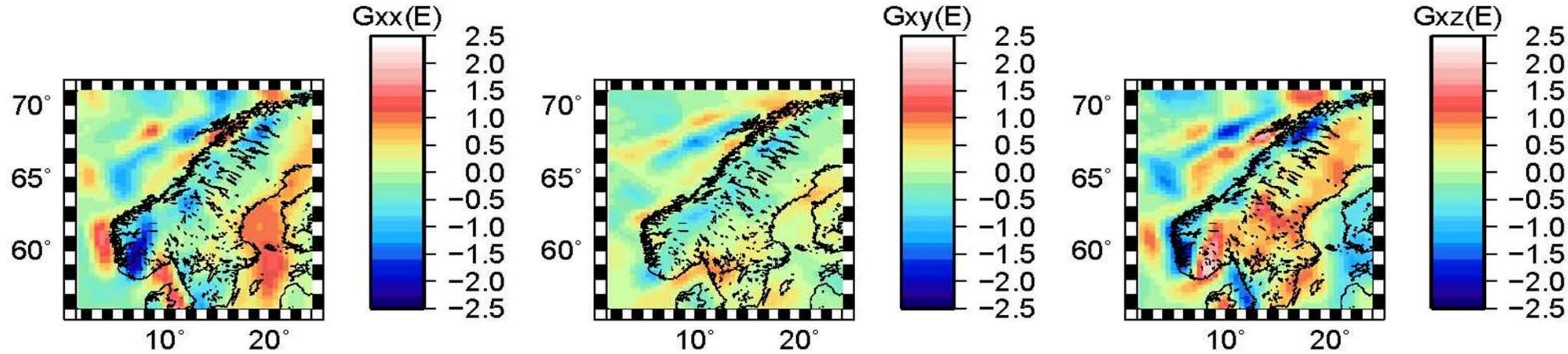
Laterally temperature dependent

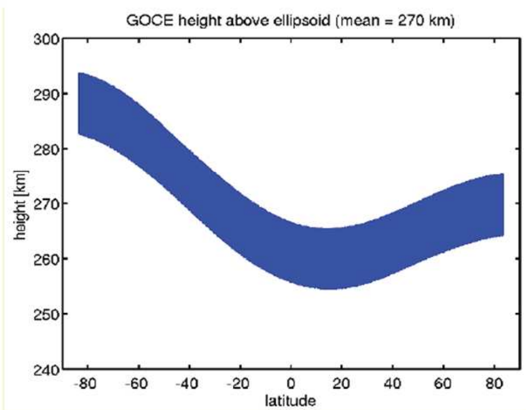


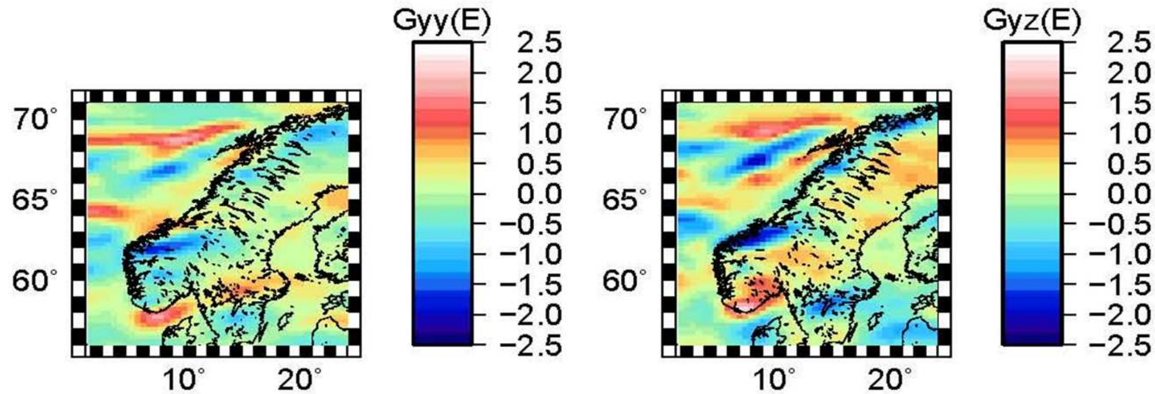
LitMod 5km

$$\begin{bmatrix} G_{xx} & G_{xy} & G_{xz} \\ & G_{yy} & G_{yz} \\ & & G_{zz} \end{bmatrix}$$



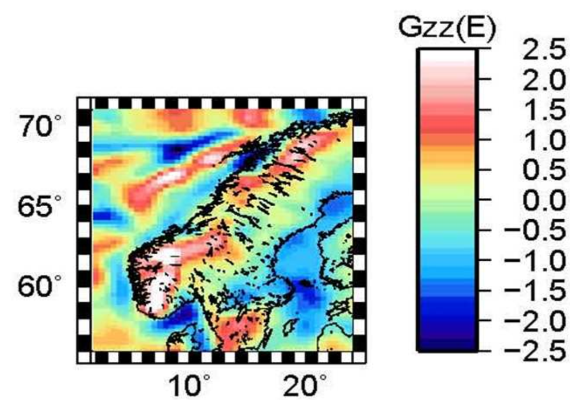


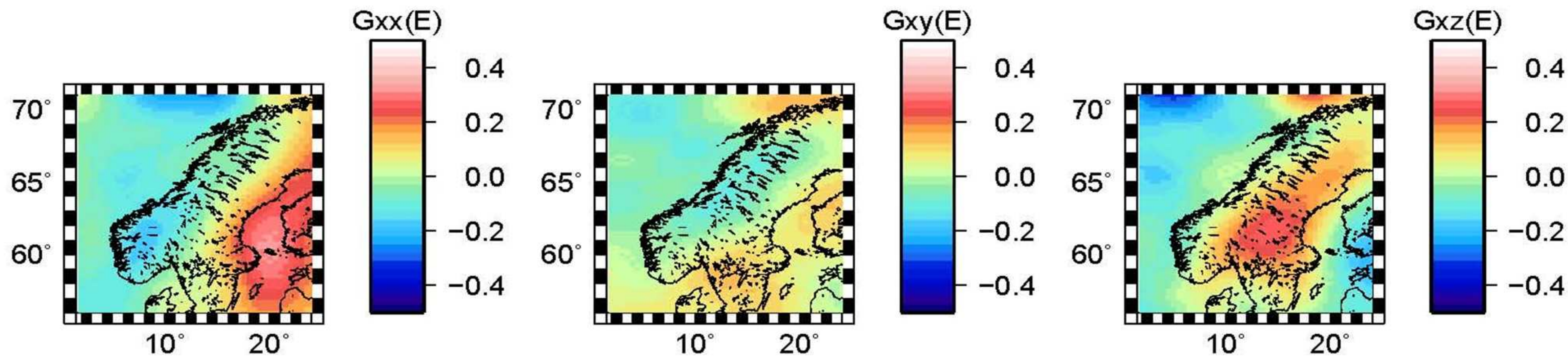


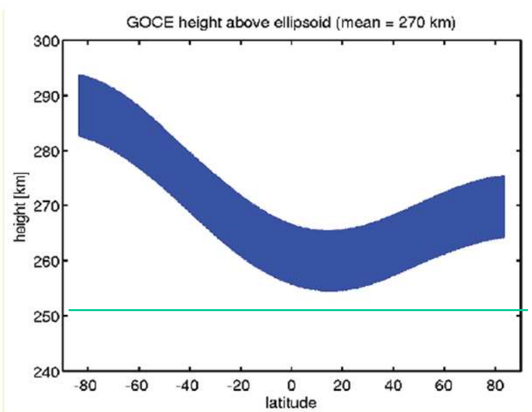


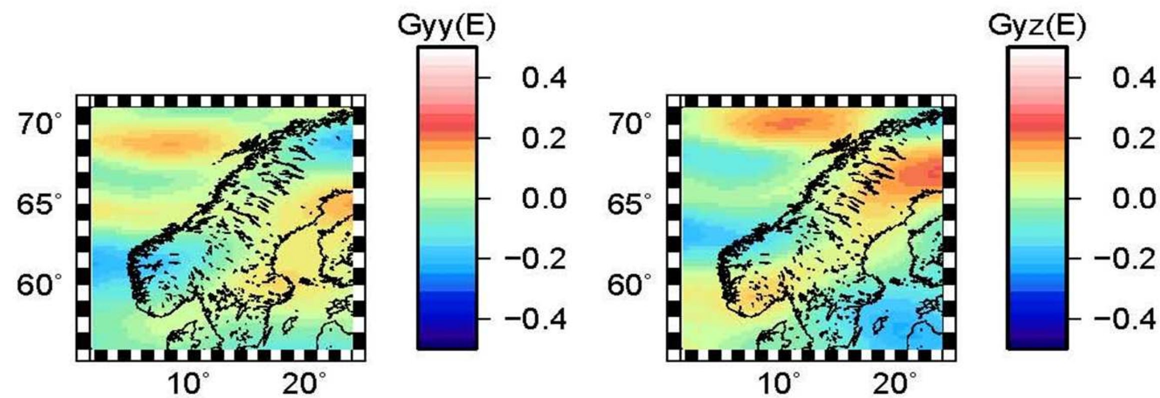
LitMod_50km

$$\begin{bmatrix} G_{xx} & G_{xy} & G_{xz} \\ & G_{yy} & G_{yz} \\ & & G_{zz} \end{bmatrix}$$



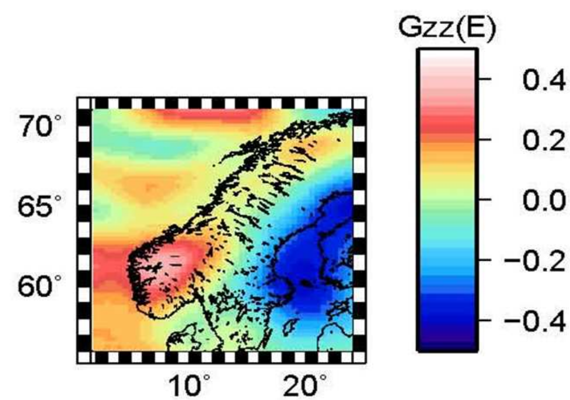


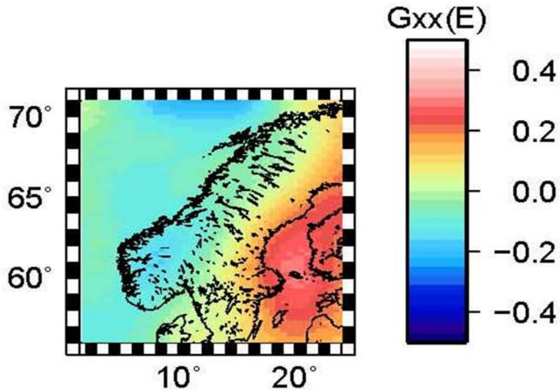


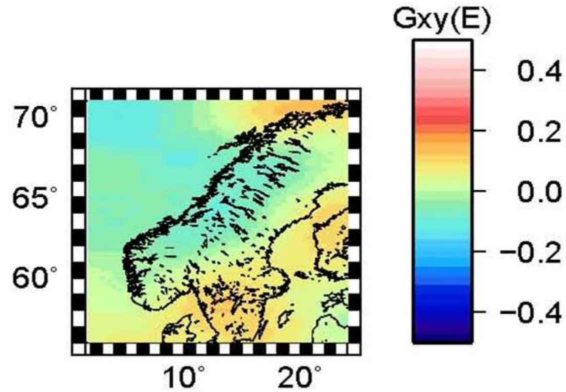


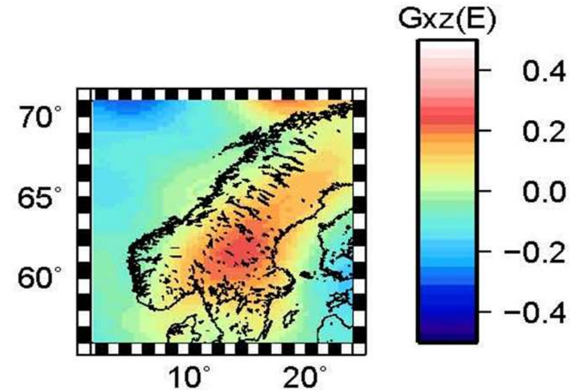
LitMod_250km

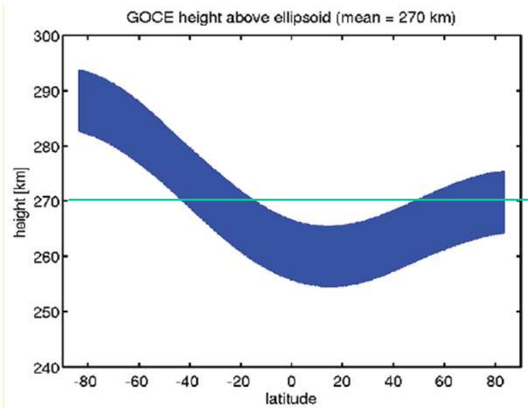
$$\begin{bmatrix} G_{xx} & G_{xy} & G_{xz} \\ & G_{yy} & G_{yz} \\ & & G_{zz} \end{bmatrix}$$

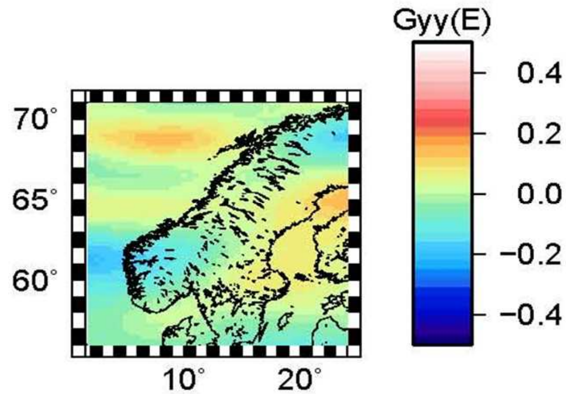


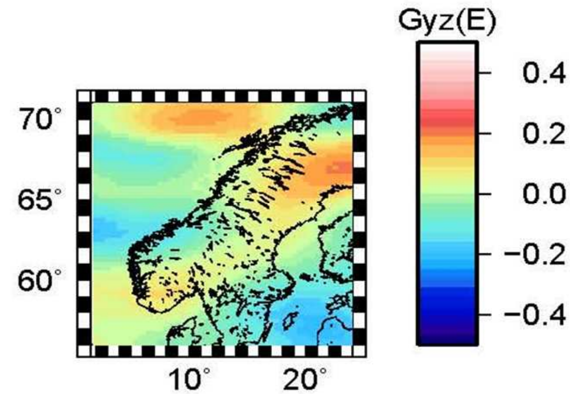






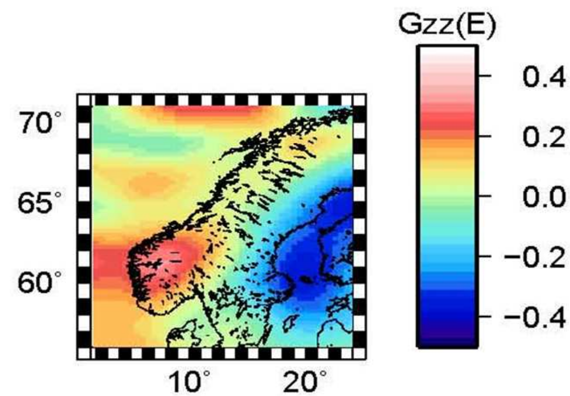






LitMod_270km

$$\begin{bmatrix} G_{xx} & G_{xy} & G_{xz} \\ & G_{yy} & G_{yz} \\ & & G_{zz} \end{bmatrix}$$

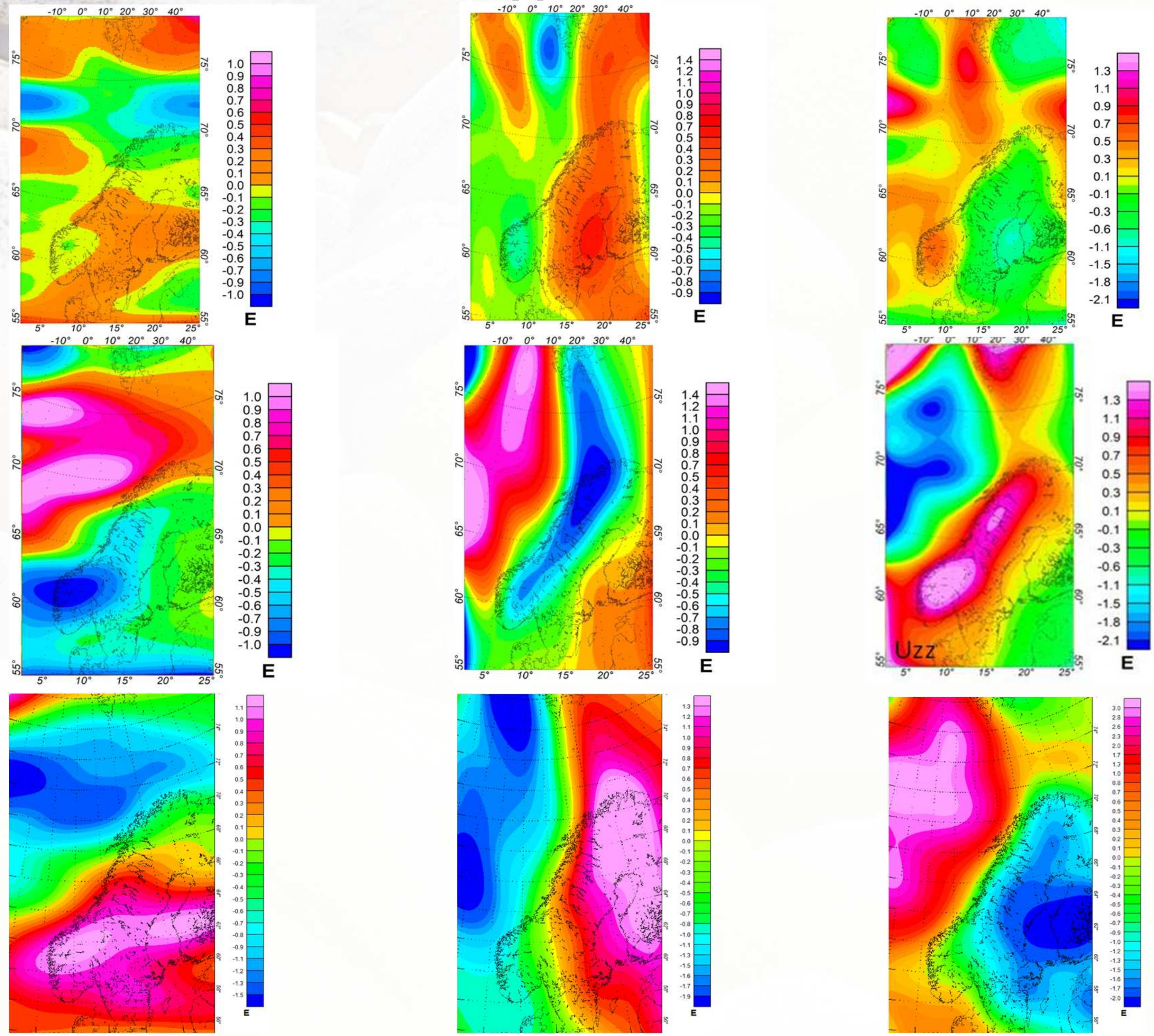


Uxx | Uyy | Uzz

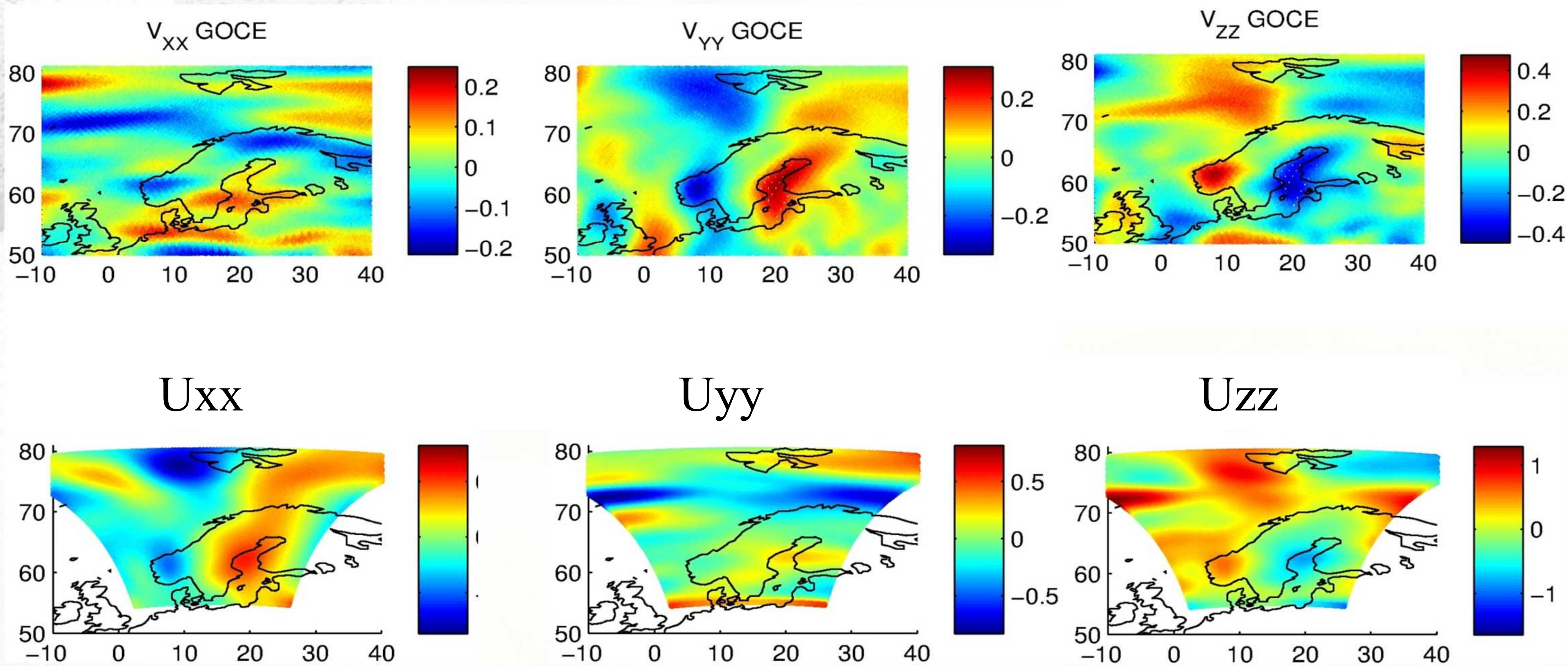
Lith. Model

Topogr. Model

Moho boundary

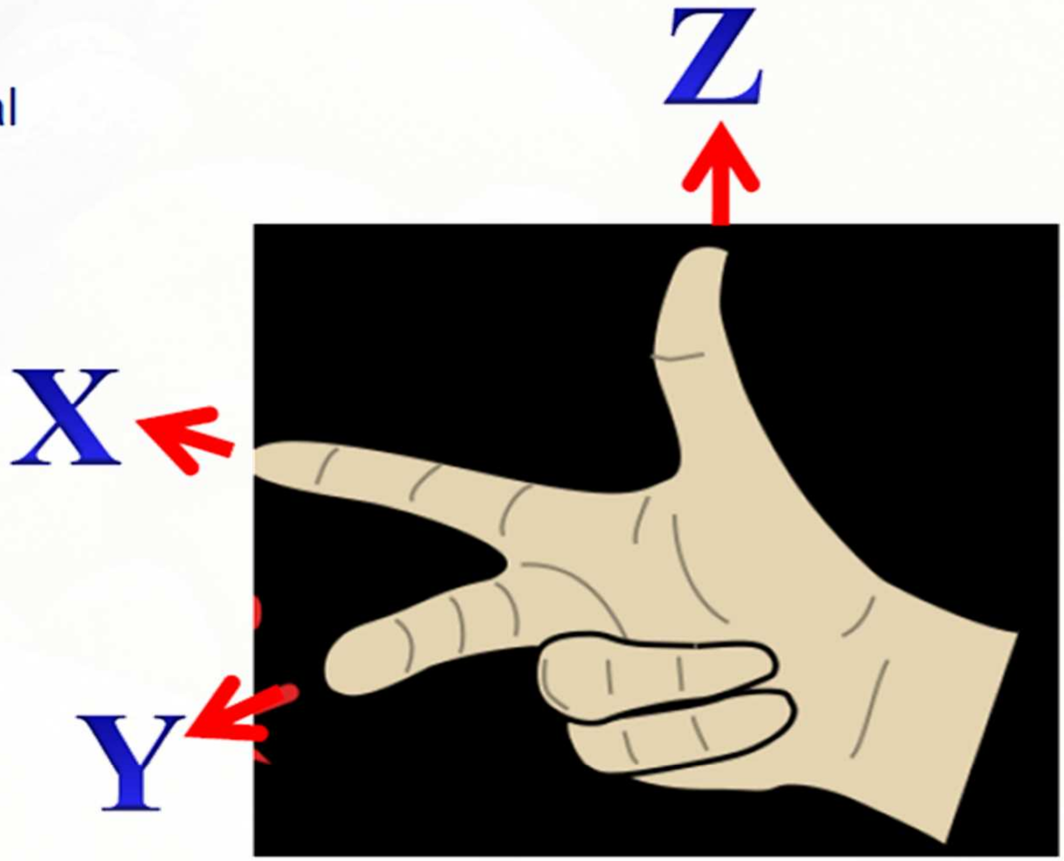


Comparison to GOCE data



Storing the Gradient Fields

- Gravity
  - Down positive is normal convention for Gz
- Bell FTG
  - END (east,north,down)
- Falcon
  - NED(north,east,down)
- Magnetics/IGRF
  - NED(north,east,down)
- IPHT tensor
  - ENU(east,north,up)
- GOCE
  - NWU (north, west, up)



(Des FitzGerald, 2011)

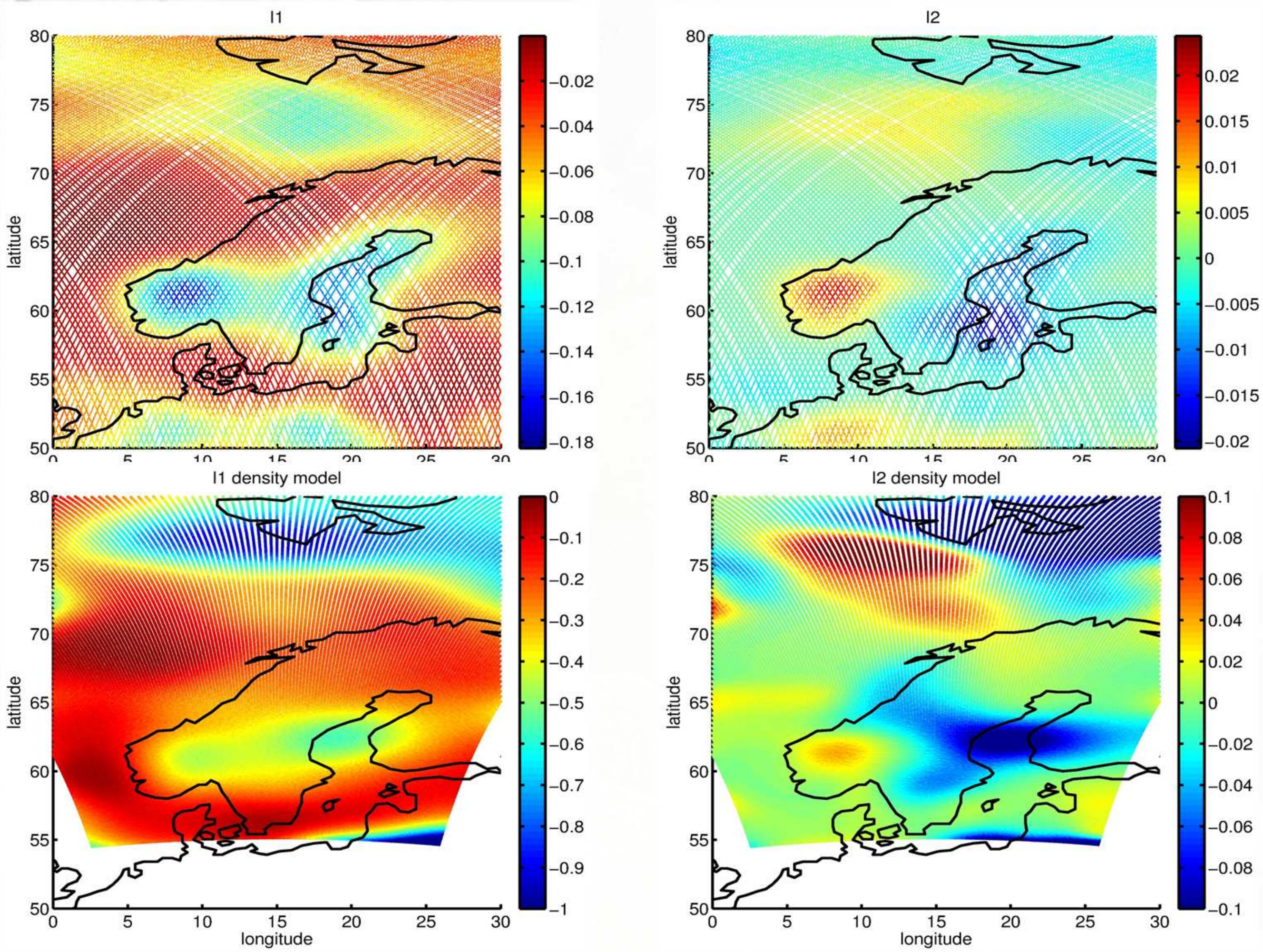
Gradient data and rotational invariants

- Gradients are dependent on the orientation of the coordinate system, which may differ from the orientation of *random* geological features

- Pedersen and Rasmussen (1990) demonstrated the use of rotational invariants of the gravity tensor:

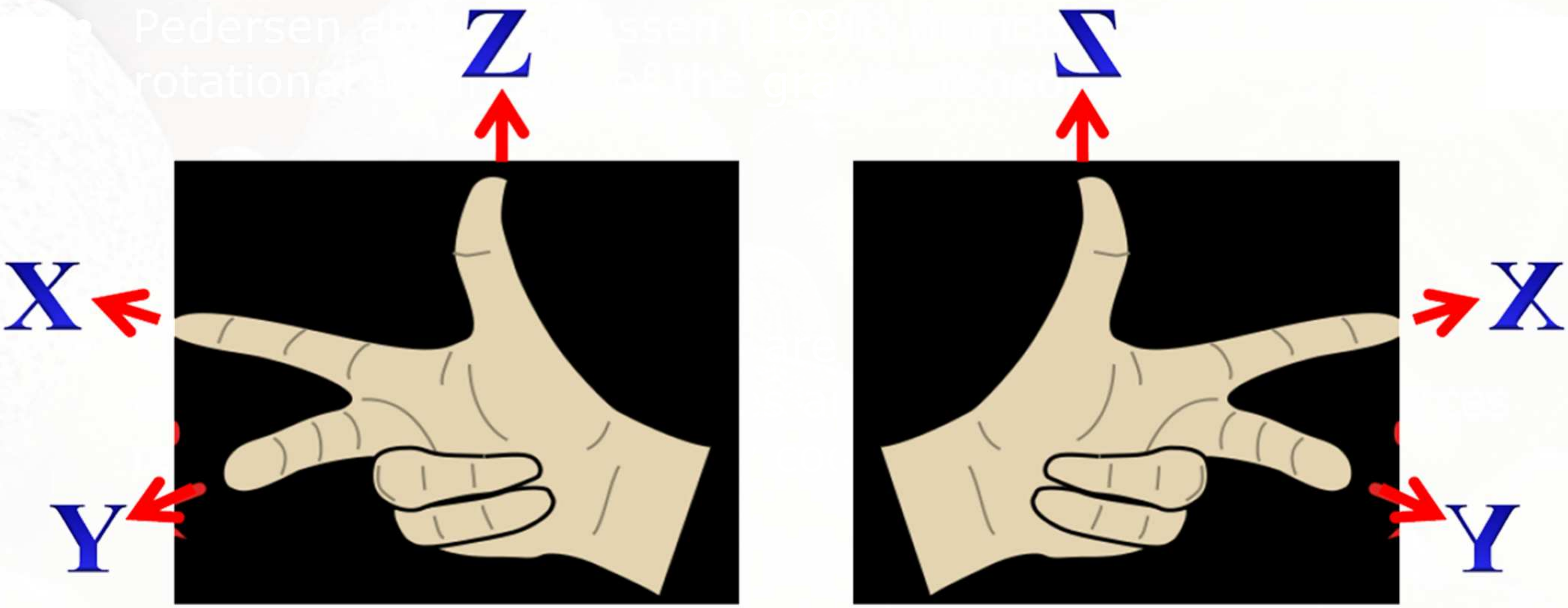
$$\begin{aligned}
I_0 &= trace\left(\tilde{G}\right) = \sum_{i=1}^{3} G_{ii} \equiv 0 \qquad \text{since } \Delta U = 0 \\
I_1 &= G_{xx}G_{yy} + G_{yy}G_{zz} + G_{xx}G_{zz} - G_{xy}^2 - G_{yz}^2 - G_{xz}^2 \\
I_2 &= det\left(\tilde{G}\right) \\
&= G_{xx}\left(G_{yy}G_{zz} - G_{yz}^2\right) + G_{xy}\left(G_{yz}G_{xz} - G_{xy}G_{zz}\right) + G_{xz}\left(G_{xy}G_{yz} - G_{xz}G_{yy}\right)
\end{aligned}$$

Rotational invariants



Gradient data and rotational invariants

- Invariants have the advantage to be independent from the coordinate system and help to delineate the outline of density contrasts
- Useful to combine different airborne and satellite gradient surveys



Conclusion and outlook

Preliminary sensitivity analysis

- Large effect by topography, but not near-surface density distribution
- GOCE gradients are sensitive to deep crustal/lithospheric structure

Comparison of calculated and observed GOCE gradients

- Shape of anomlies similar
- Amplitudes differ
- Height of observation is important

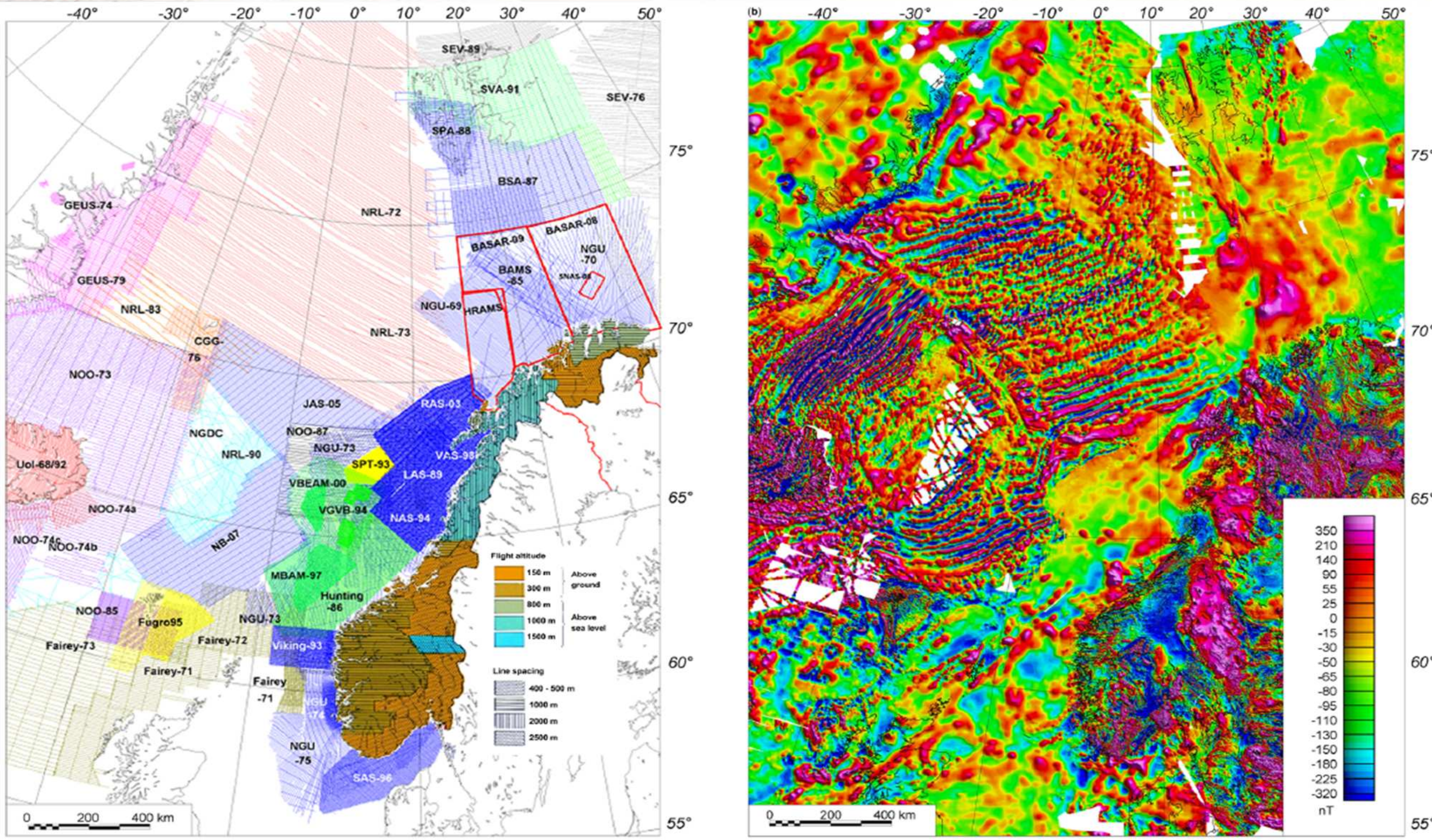
Next step: Model optimiziation

- Forward modelling of 5(9) tensor components is time-consuming
  - Sensitivity for the entire lithospheric structure has to be developed => see my afternoon talk
- Application to constrain the regional background for geophysical exploration

  => see talk by R. Abdul Fattah

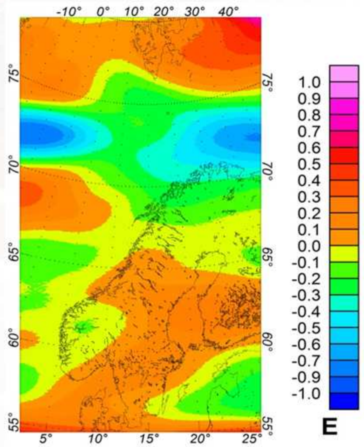

Thank you for your attention!

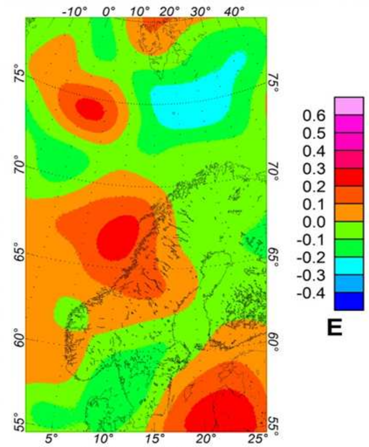
Magnetic data base

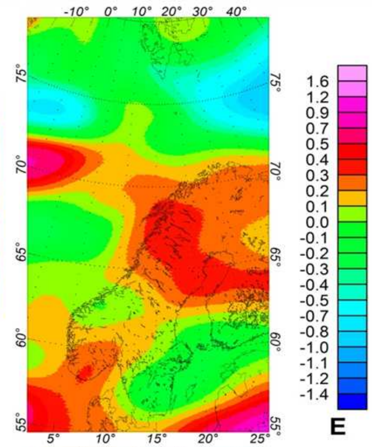


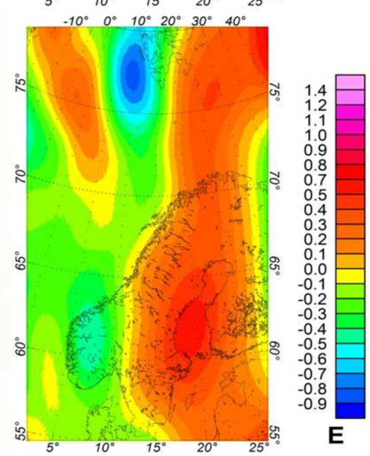
Olesen et al. 2010

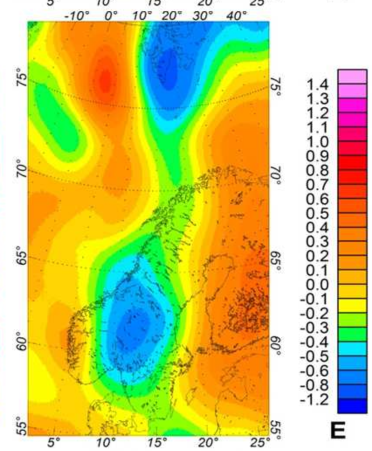
NE Atlantic lithospheric model: Calculated gradients

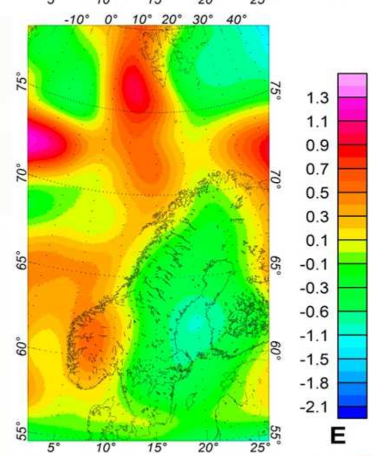












$$\begin{bmatrix} G_{xx} & G_{xy} & G_{xz} \\ & G_{yy} & G_{yz} \\ & & G_{zz} \end{bmatrix}$$