NKG General Assembly 2014
Chalmers University of Technology
Göteborg 1-4 September 2014

A New Fennoscandian Crustal Thickness Model

Mohammad Bagherbandi [1, 2], R. Tenzer, L. E. Sjöberg, M. Abrehdary

[1] Division of Geodesy and Geoinformatics ,Royal Institute of Technology, Stockholm, Sweden.

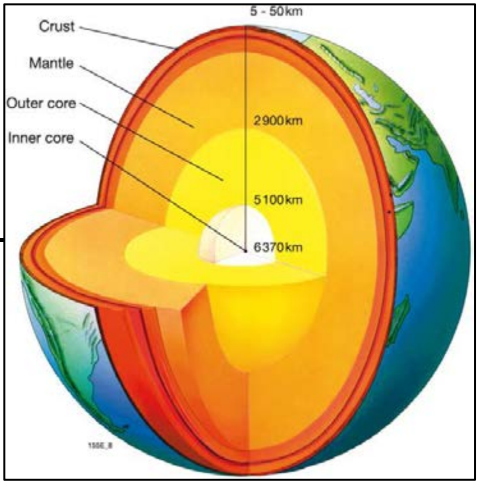
[2] Department of Industrial development, IT and Land Management, University of Gävle, Gävle, Sweden.

Introduction

The volumes of the layers are: crust 2 %, mantle 80 %, outer core 17 %, and inner core 1 % of the Earth's volume.

The Earth's crust covers the mantle and is the Earth's hard outer shell.

Compared to the other layers of the Earth, it is much thinner and floats upon a softer layer, which is the mantle.



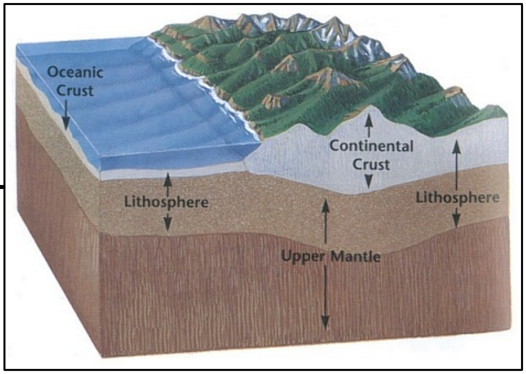
Why is crustal thickness modelling important to study?

A good knowledge of the Moho brings clues for understanding the dynamics of the Earth interior.

Mohorovičić discontinuity (Moho).

Oceanic (6-13 km) and continental crust (up to 90 km).

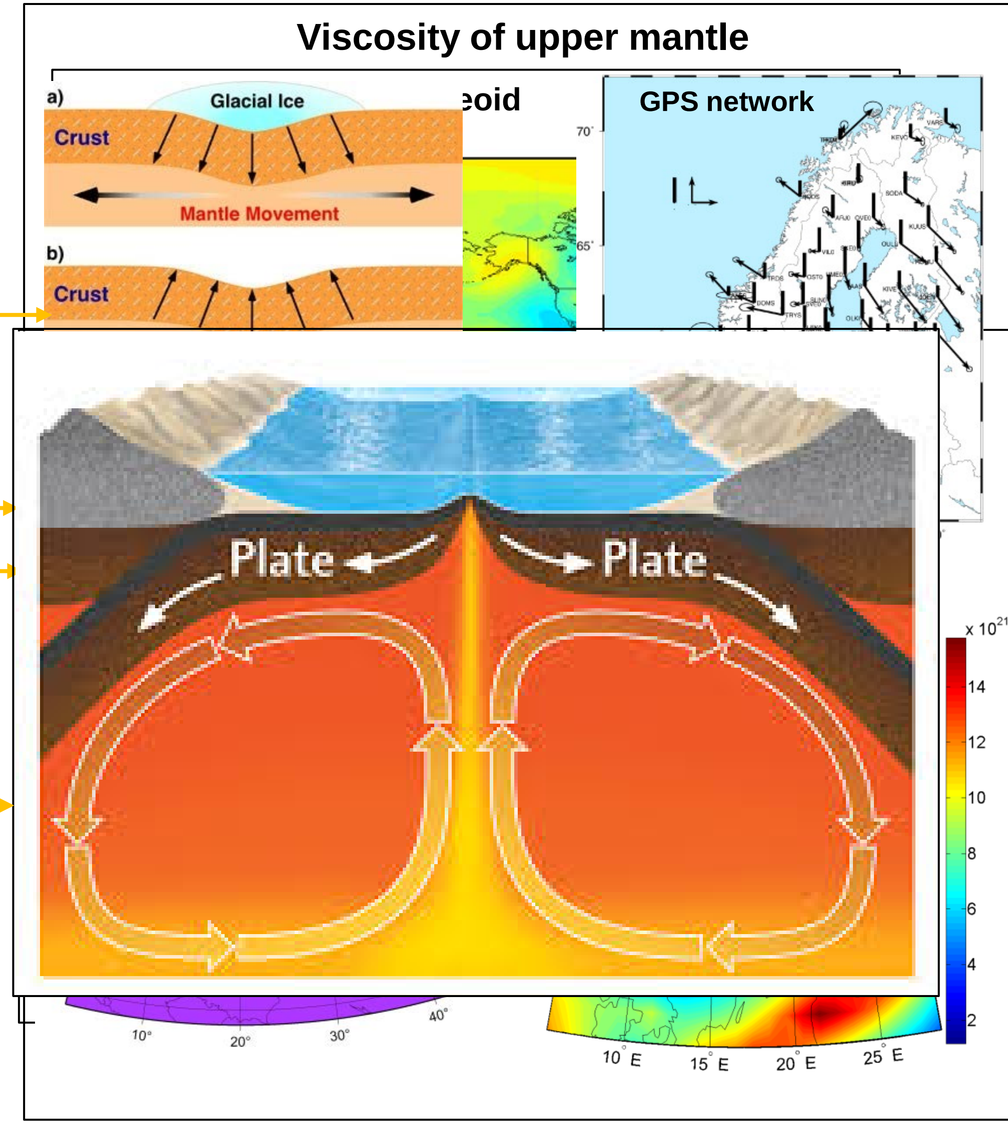
A physical/chemical boundary.



Importance of Moho in geoscience

Applications of Moho

- Geoid: Remove-Restore Technique
- Glacial isostatic modeling and viscosity determination
- Mantle convection and plate tectonics



Methods for determining Moho

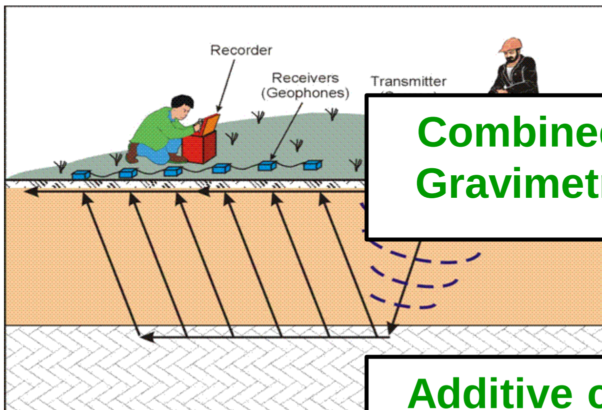
Seismic methods

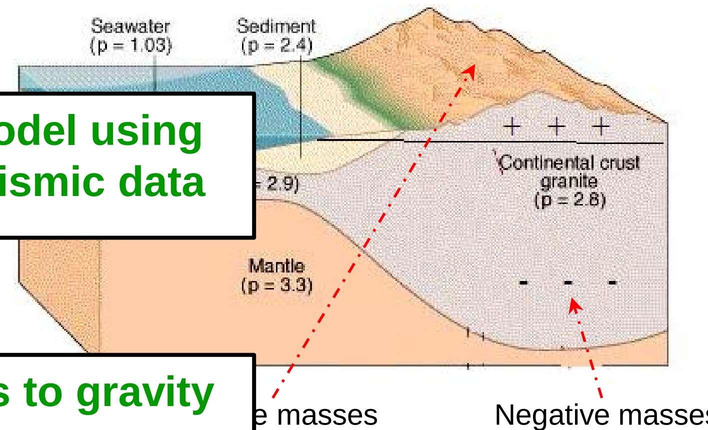
How: Measuring time travel of seismic waves.
Advantages: Direct observation.
Disadvantages: gaps.

+

Gravimetric methods

How: Gravity data and isostatic hypotheses.
Advantages: coverage of gravity data.
Disadvantages: disturbing gravity signals.

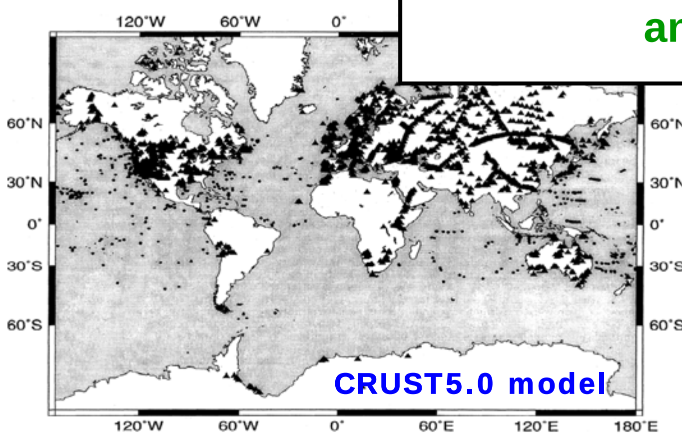


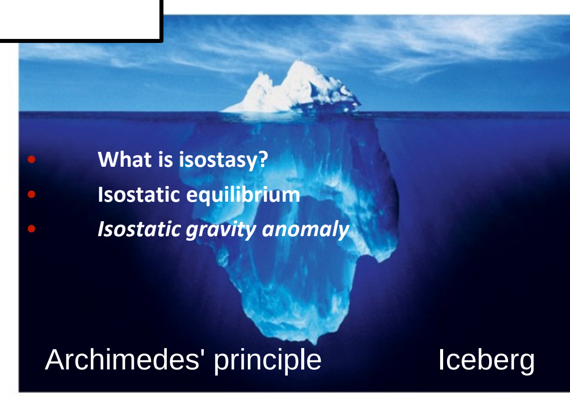


Combined Moho Model using Gravimetric and Seismic data

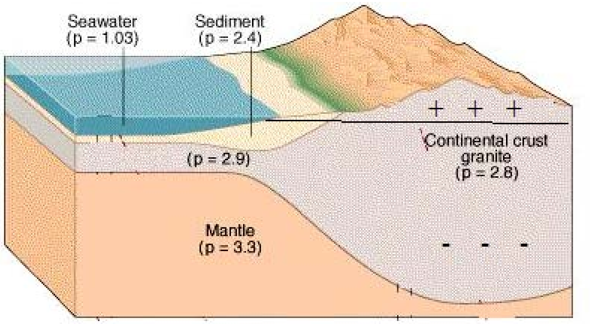
and

Additive corrections to gravity anomalies





VMM-method for crustal thickness determination



$$\delta g_I = \delta g_B + A_C = 0$$

$$V_C(P) = G\Delta\rho \iint_\sigma \int_{R-T}^{R-T_0} \frac{r^2 dr}{l_P} d\sigma \rightarrow A_C = -\frac{\partial V}{\partial r_P}$$

$$\delta g_I = \delta g_B + A_C \approx 0$$

Corrections to the gravity data

Corrections from different crust layers

$\Delta\rho = \rho - \rho_m$

- Ice
- Water
- topography
- Sediment
- Upper crust
- Middle crust
- Lower crust
- Upper mantle

$$\delta g^{TBIS} = g^t + g^b + g^i + g^s$$

Corrections due to non-isostatic effects

- Mantle convection
- Thermal compensation
- Postglacial rebound
- Motion tectonic
- Deeper masses

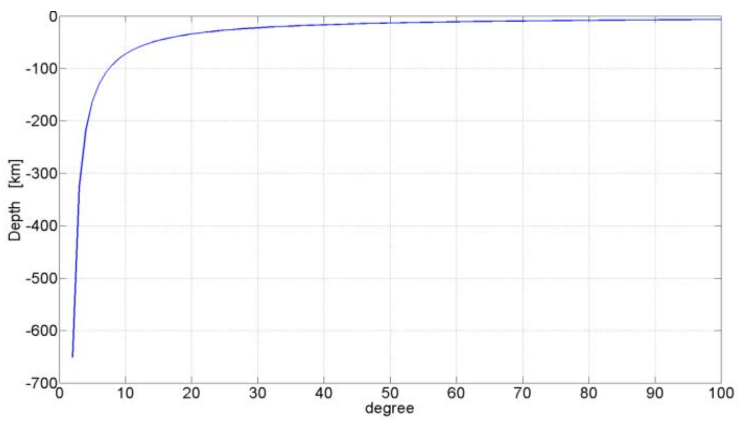
$$g^{NIE} = A^{tm} + A^{GIA} + A^{mc} + A^{\varepsilon}$$

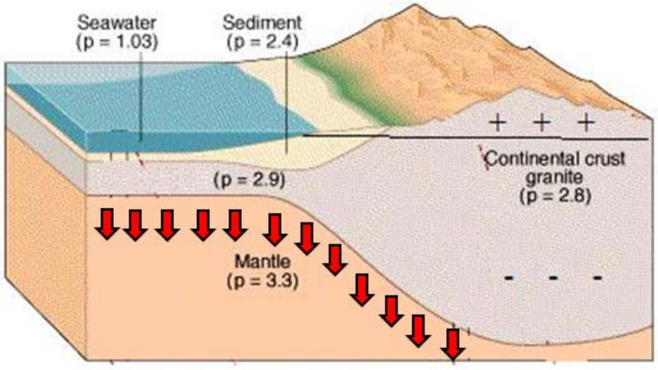
$$\delta g_I = \left[\delta g - g^{topo} - g^{bathymetry} - g^{ice} - g^{sediment} - \ldots\right] + A_C - g^{NIE} = 0$$

Methods to determine the non-isostatic effects

- Correlation analysis to find a best harmonic window in GGMs (cf. Sjöberg 2009; Bagherbandi and Sjöberg 2012).

$$d_n \equiv \frac{N_n}{\Delta g_n} = \frac{\gamma(n-1)}{R}$$

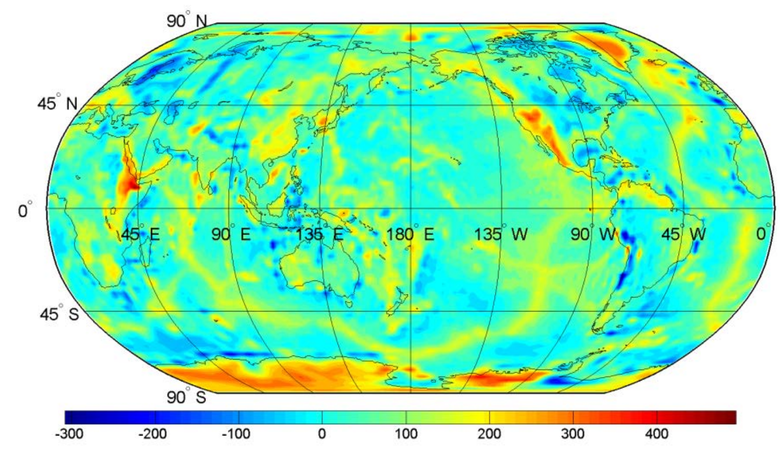




- Assuming that the crustal thickness is known
- **Scenario 1:**

$$\delta g_I = \left[\delta g - g^t - g^b - g^i - g^s\right] + A_C - g^{NIE} = 0$$

$$g^{NIE} \approx \delta g^{TBIS} - 4\pi G \Delta\rho T_0 + 2\pi G \Delta\rho T$$



Units: mGal

Methods to determine the non-isostatic effects

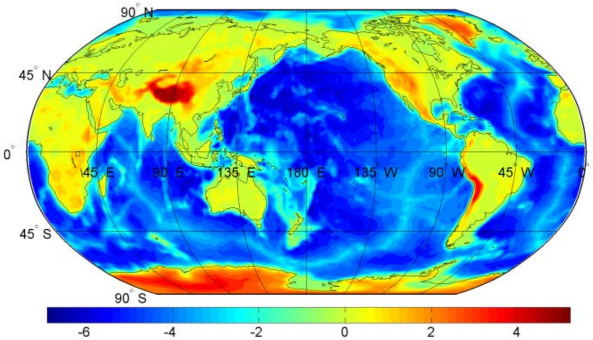
- Assuming that the crustal thickness is known

- **Scenario 2: Residual Isostaic Topography**

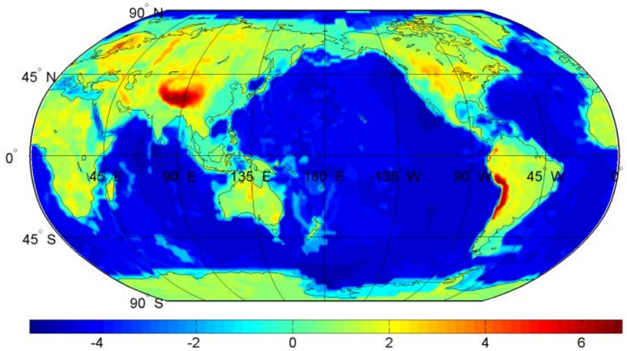
$$RIT = H_{DTM} - H_{isostasy}$$

$$H_{isostasy} \cong \frac{1}{2\pi G \rho_c}\left[\delta g + \frac{4\pi G \Delta\rho R}{3}\left[\left(1 - \frac{T_0}{R}\right)^3 - 1\right] + 2\pi G \Delta\rho R\left(\frac{T + T_0}{R}\right)\right]$$

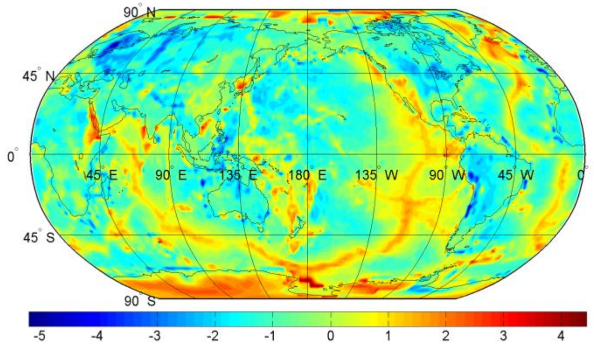
$$g^{NIE} = g^{RIT} = 4\pi G R \sum_{n=0}^{\infty}\left(\frac{R}{r_P}\right)^{n+2} \frac{n-1}{2n+1} \sum_{m=-n}^{n} c_{nm}^{RIT} Y_{nm}(P)$$



H_{DTM}



$H_{isostasy}$



RIT

Units: km

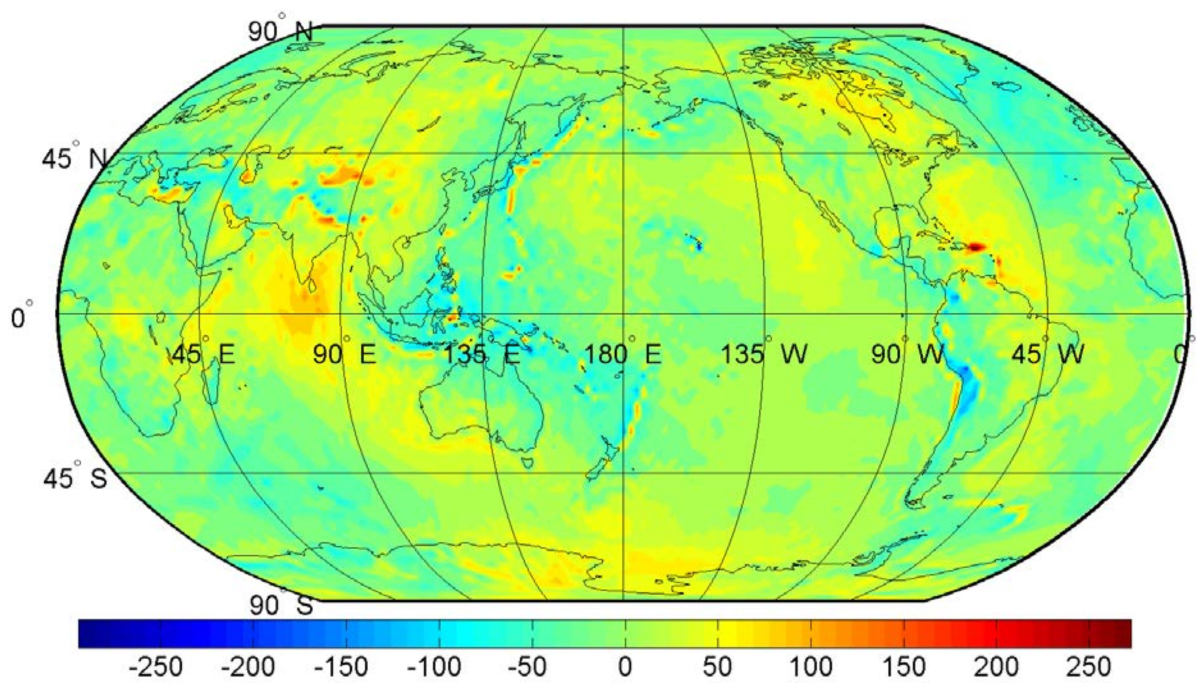
Numerical studies

Data:
GOCO-03S ; ETOPO1 ; CRUST1.0;
LITHO1.0; DTM2006.

Corrections to gravity data

Crustal thickness and comparisions with others models

$$\delta g_I = \left[\delta g - g^t - g^b - g^i - g^s \right] + A_C - g^{NIE} = 0$$



The gravity disturbances computed globally on a 1×1 arc-deg surface grid using the GOCO-03S coefficients complete to degree 180 of spherical harmonics. [mGal]

Data

- The gravitational contribution of **seawater** was computed using the **ETOPO1** bathymetric depths (National Geophysical Data Center (NGDC)).

- Instead of using a uniform seawater density model we used:

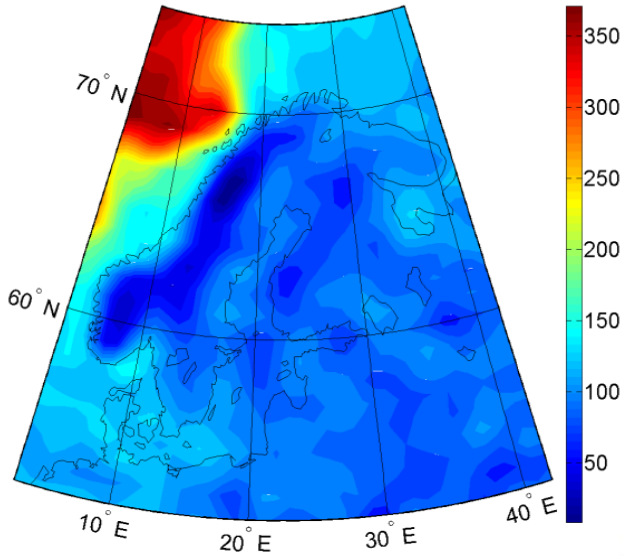
$$\rho_w(D,\phi) = 1000 + \alpha(\phi) + \beta(\phi) D^{\vartheta(\phi)}$$

- The gravitational contribution of **sediments** calculated using **CRUST1.0** (Laske et al. 2013).

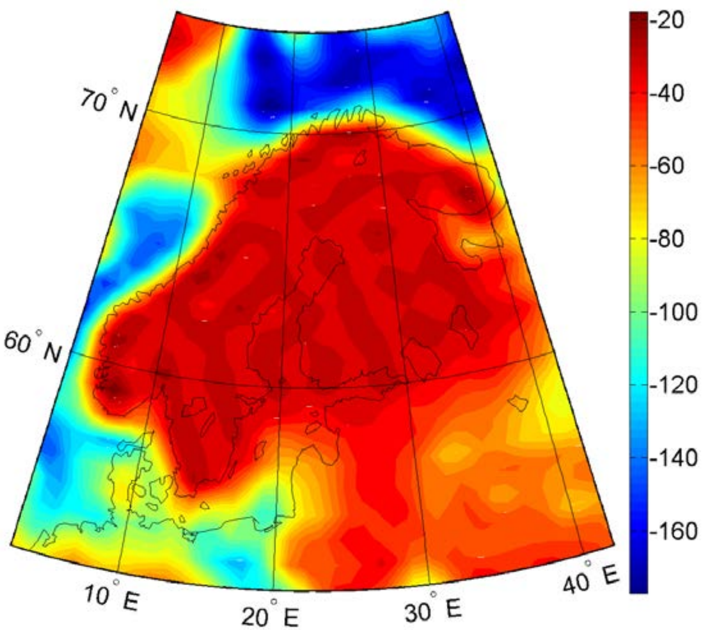
- **Non-isostatic effects** was derived using CRUST1.0 and LITHO1.0 (Laske et al. 2013).

The gravity effect of the crust different layers

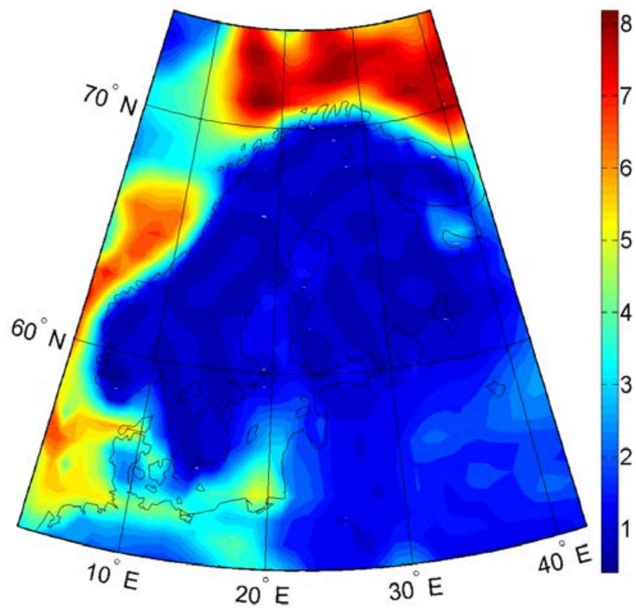
$$\delta g_I = \left[\delta g - g^t - g^b - g^i - g^s \right] + A_C - g^{NIE} = 0$$



Topography-bathymetry effect , Unit: mGal

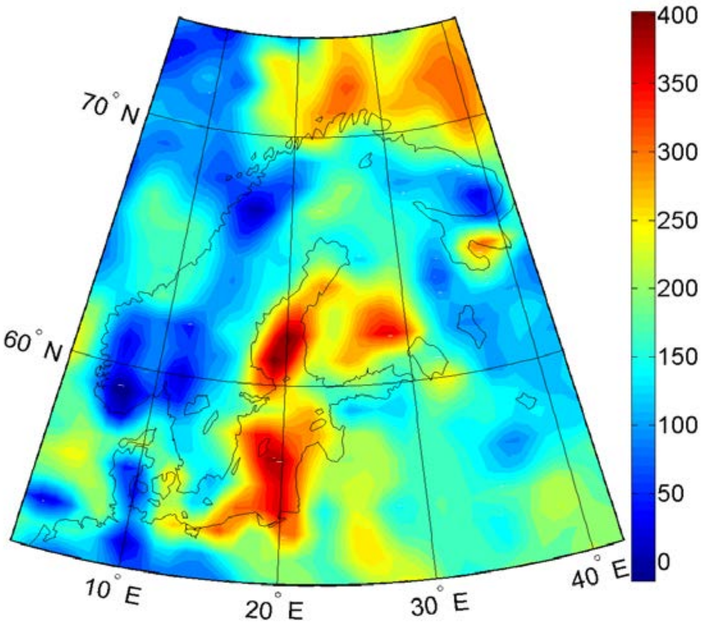


Sediment effect on gravity disturbance, Unit: mGal

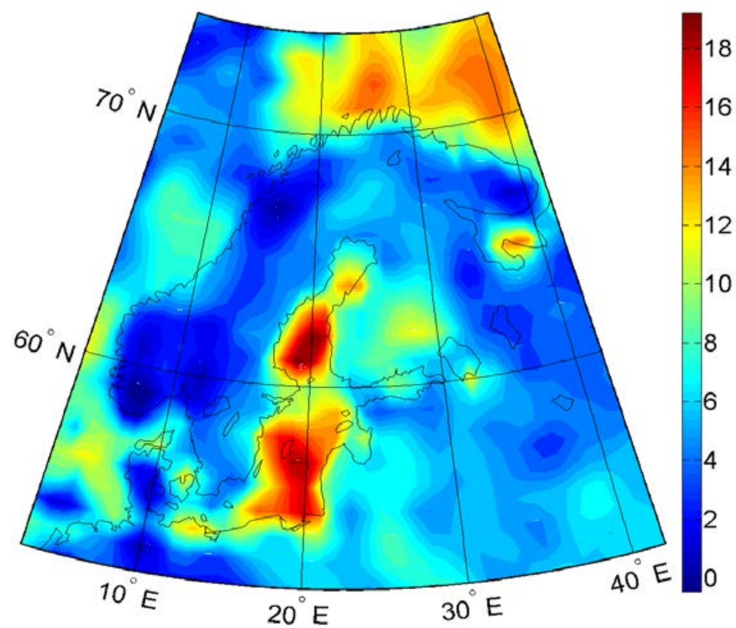


Sediment effect on Moho depth, Unit: km.

Non-isostatic gravity effect



Non-isostatic effect on the gravity disturbance.
Unit: mGal



Non-isostatic effect on Moho depth.
Unit: km

Additive corrections to gravity data

Gravity data

+

TBIS

+

Non-isostatic effect

$$\delta g^{I} = \left[\delta g - g^{t} - g^{b} - g^{i} - g^{s}\right] - g^{NIE}$$

Crustal thickness determination using KTH method

$$\delta g_I = \left[\delta g - g^{topo} - g^{bathymetry} - g^{ice} - g^{sediment} - \ldots\right] + A_C - g^{NIE} = 0$$

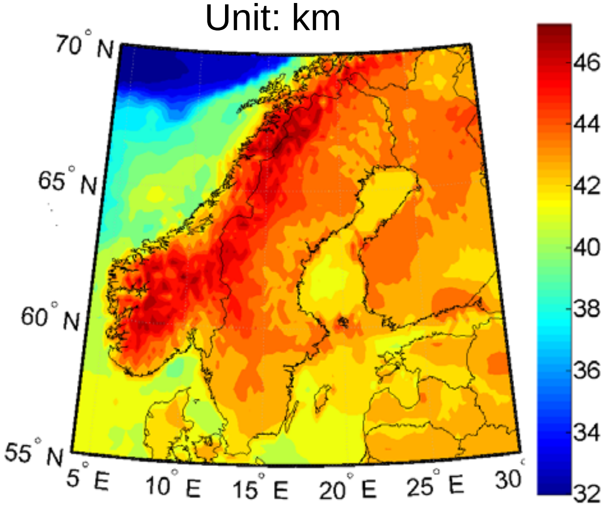
$$-\mathrm{G\,R\,\Delta\rho^{c/m}} \iint_{\Phi} \mathrm{K}(\psi, s)\, d\Omega' = f(r,\Omega)$$

$$T(\Omega) = T_1(\Omega) + \frac{T_1^2(\Omega)}{\mathrm{R}} - \frac{1}{32\pi \mathrm{R}} \iint_{\Phi} \frac{T_1^2(\Omega') - T_1^2(\Omega)}{\sin^3(\psi/2)}\, d\Omega' \qquad T_1(\Omega) \cong -\frac{f(r,\Omega)}{2\pi \mathrm{G}\, \Delta\rho^{c/m}}$$

$$f(r,\Omega) = \delta g_B(r,\Omega) - 4\pi G \Delta\rho T_0$$

Before NIE and TBIS corrections

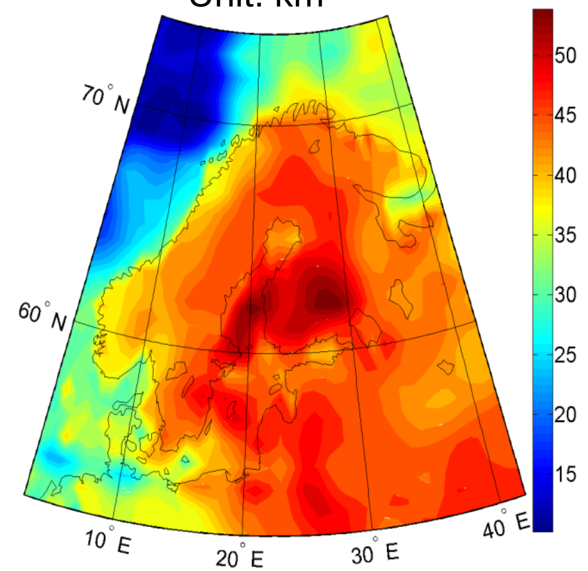
Unit: km



$$f(r,\Omega) = \delta g^{TBIS}(r,\Omega) - 4\pi G \Delta\rho T_0 + g^{NIE}(r,\Omega)$$

After NIE and TBIS corrections

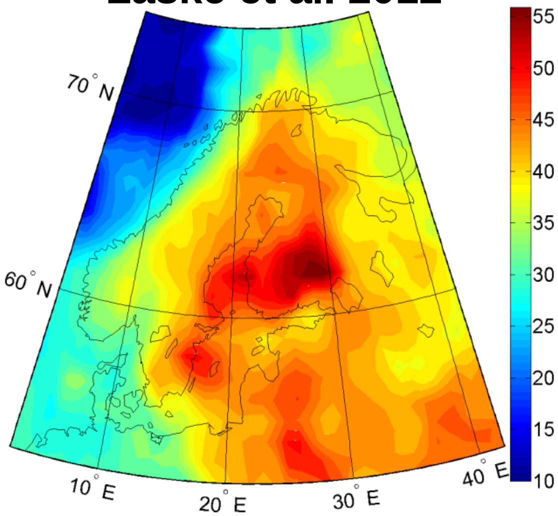
Unit: km



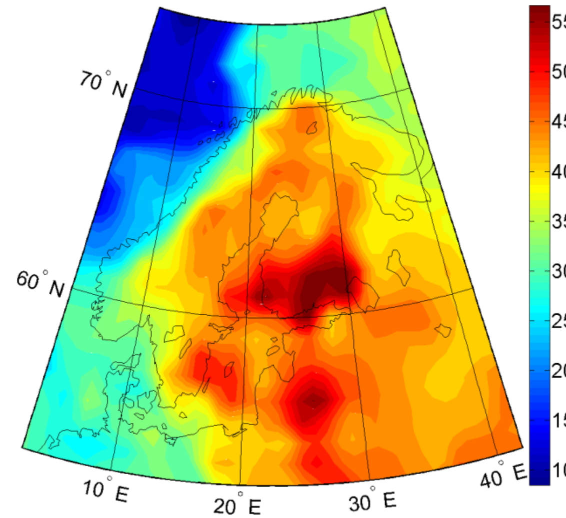
Comparison with seismic models

CRUST1.0

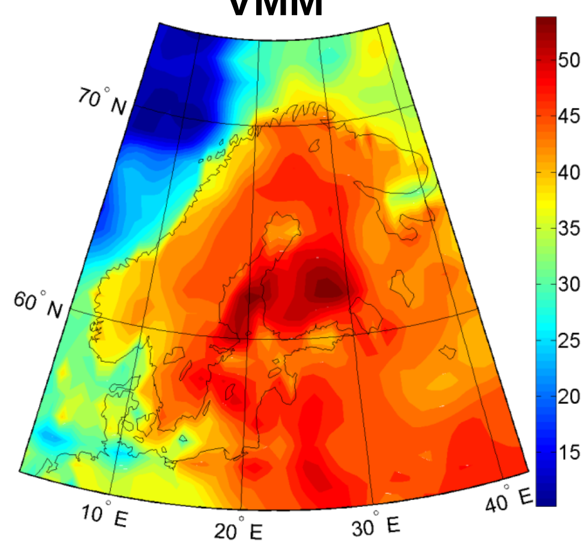
Laske et al. 2012



Moho depth of the European plate (MDEP)
Grad et al. 2009



KTH_FenMoho2014
VMM

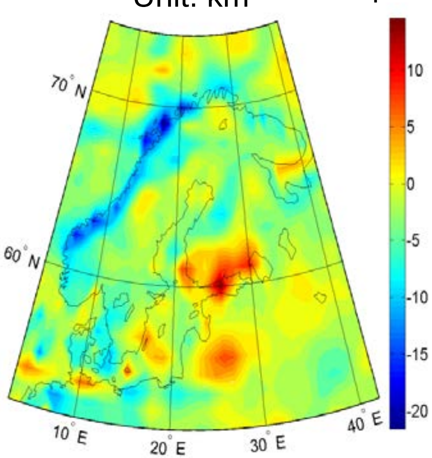


Units: km

Statistics of crustal thickness models and comparisons of the models after taking into account both crust density variation correction (TBIS) and NIE corrections. Unit: km

		Max	Mean	Min	Std	Rms
Crustal thickness	KTH_FenMoho2014	55.3	38.1	10.2	10.5	----
	CRUST1.0	57.4	36.1	10.0	10.2	
	MDEP	58.3	36.0	8.5	11.1	
Differences	CRUST1.0 – KTH_FenMoho2014	7.7	-1.9	-12.1	2.4	3.1
	MDEP - KTH_FenMoho2014	15.7	-2.1	-21.5	3.8	4.3
	MDEP – CRUST1.0	15.3	-0.1	-11.3	2.8	2.8

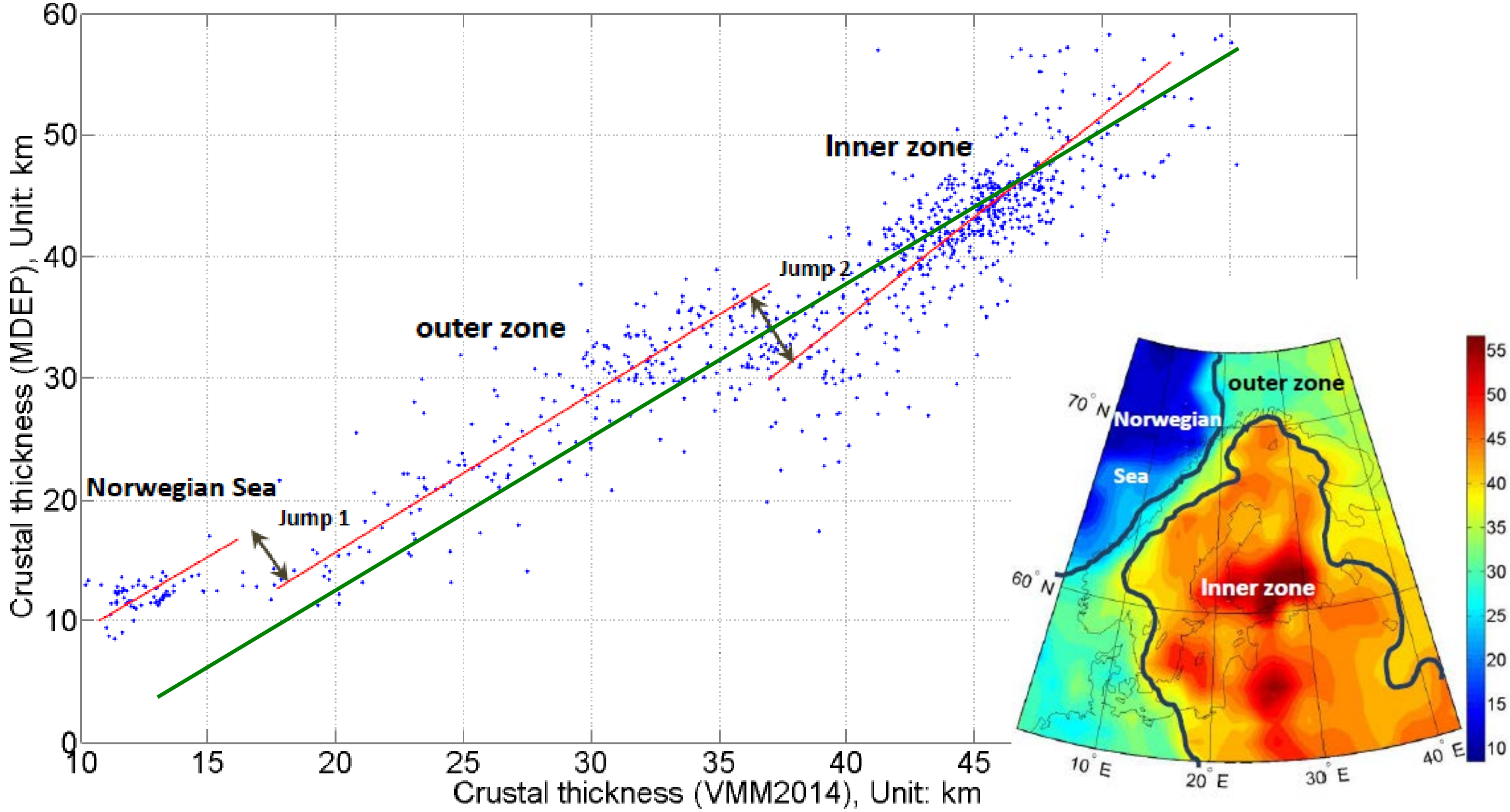
Unit: km



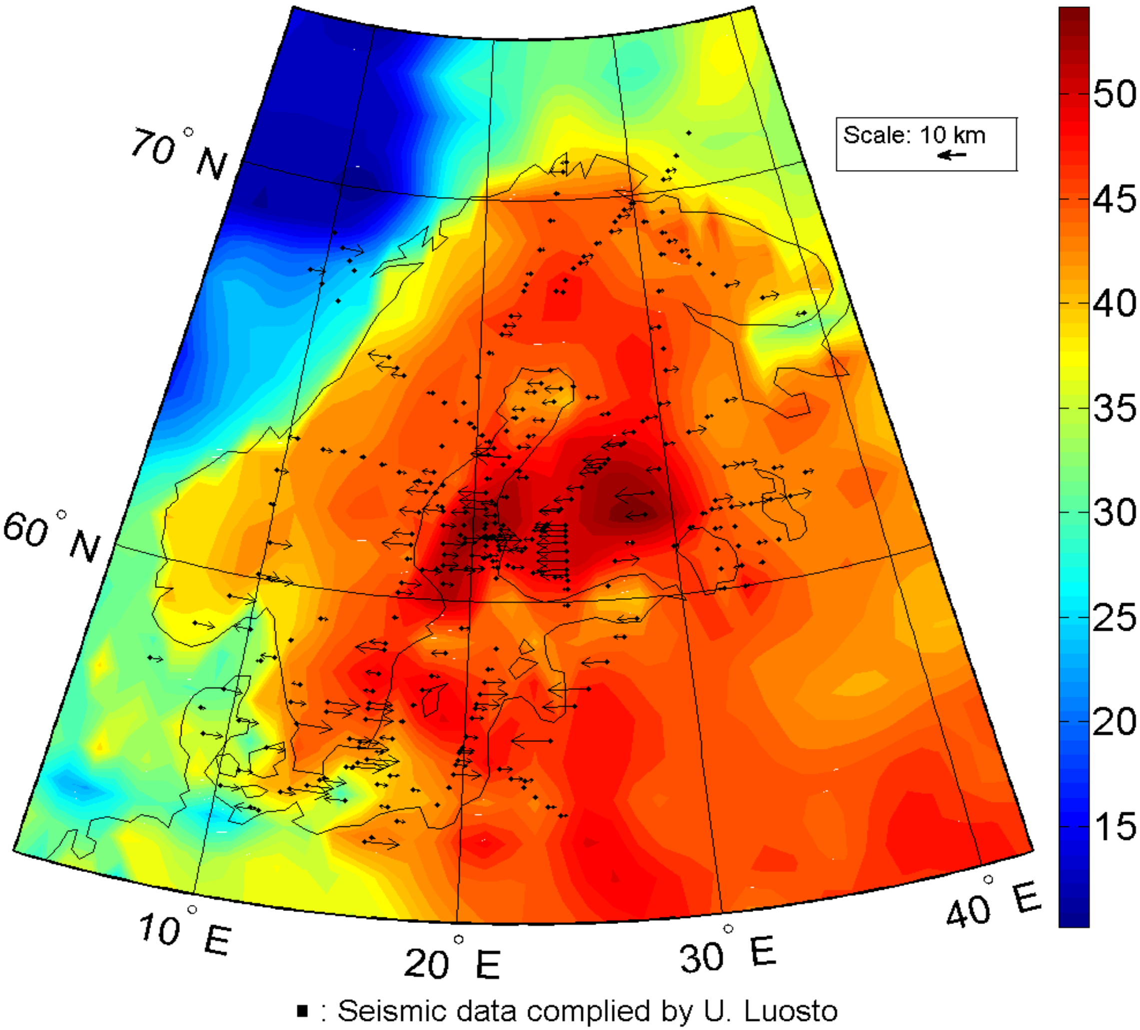
before taking into account of TBIS and NIE corrections = rms 7.3 km

Scatter plot of MDEP and KTH_FenMoho2014 crustal thickness models. Unit: km.

The correlation between these two quantities is 0.94.

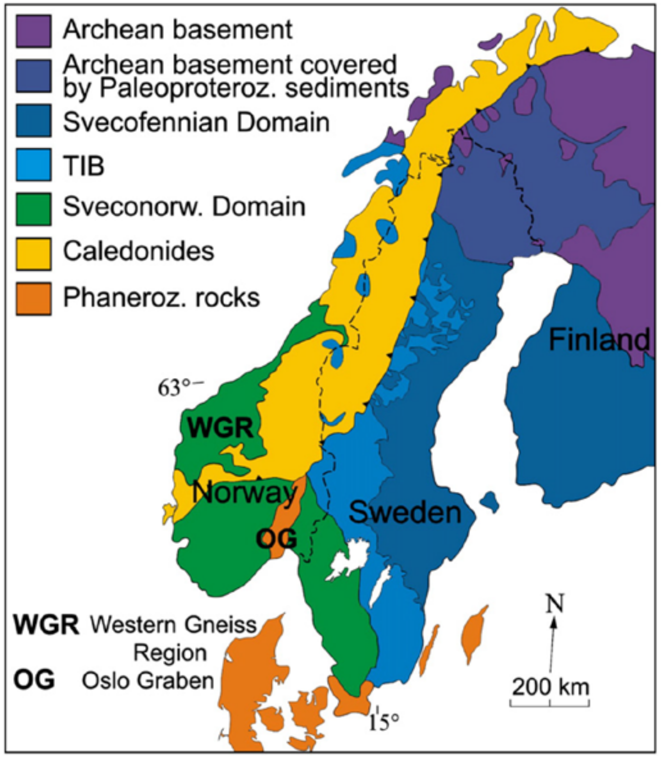


The main reason of the three jumps is because of the missing geological parameters and the effect of the masses below the crust.

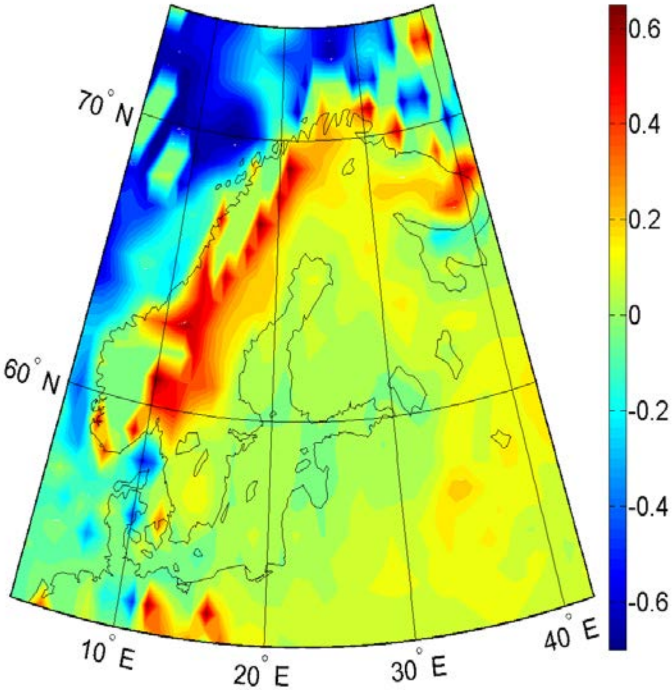


Difference between crustal thicknesses in VMM14_FEN (this study) and the seismic data compiled by U. Luosto 1991. Arrows denote on the difference. The background map shows the Moho depth VMM14_FEN model. Unit: km.

Comparison of geological units vs. isostatic equilibrium



Simplified geological map of Fennoscandia after Gorbatchev (2004).



Compensation-ratio

$$CR_l = \frac{\rho H}{\Delta\rho t}$$

$$CR_o = \frac{(\rho - \rho_w) H'}{\Delta\rho t'}$$

Conclusion

- The effects of **major known crustal density structures** and the other **geophysical phenomena** on the Moho geometry investigated.

- The agreement between the seismic and gravimetric Moho depths improved after using **a more realistic crustal density model** and **deeper masses** effects.

- More accurate sediment data should be used for future studies (National Geophysical Data Center (NGDC)).)

- Study on other geological parameters (e.g. thermal compensation effect).

Thank you for your attention

and

also thanks for financial support from SNSB (Swedish National Space Board).