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A 3D Moho depth model for the Tien Shan from EGM2008 gravity data

Overview

The Tien Shan, a high mountain range in Central Asia (Fig. 1), is one of the most interesting regions in the world due to its evolutionary history and the position in the Eurasian lithosphere plate. With a distance from 1500 km to the collision-zone of the Indian and Eurasian plate, the Tien Shan is the largest intracontinental mountain range in the world. In addition, it is one of the most seismically active regions globally. So far, mainly seismological data have been used to explore its origin and ongoing seismic activity. There has only been one study by Burov et al. (1990) investigating terrestrial gravity data.

In this study, a new gravity dataset, the EGM2008 (Pavlis et al., 2008), is used in order to determine the Mohorovičič discontinuity (Moho, CMB) of the Tien Shan by inversion of gravity data. Additionally, an isostatic CMB was calculated with topographic data. Comparing the isostatic CMB to the results of the gravity inversion illuminates the effects of isostatic compensation.

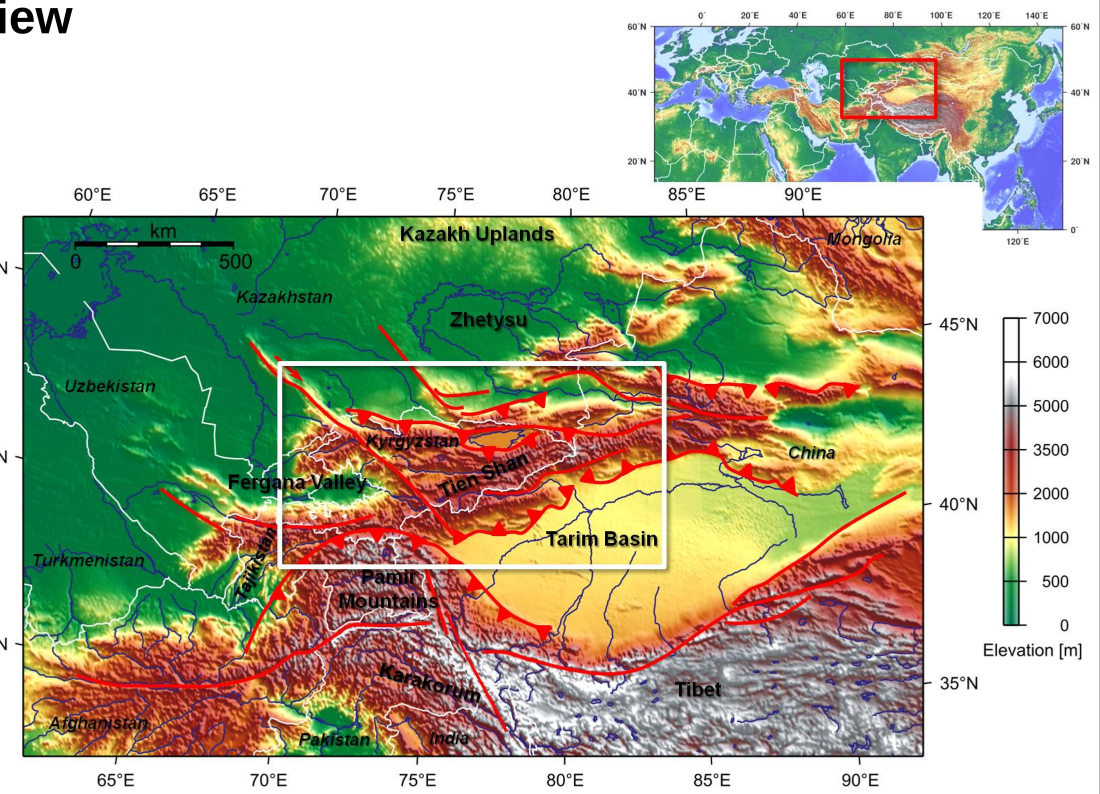


Fig. 1: Geographical and tectonic overview of Central Asia. The investigation area for this study is shown as white rectangle in the large picture. Red lines mark faults (thrust faults and strike-slip faults; T. Voigt, pers. comm., 2009), white lines borders.

Data

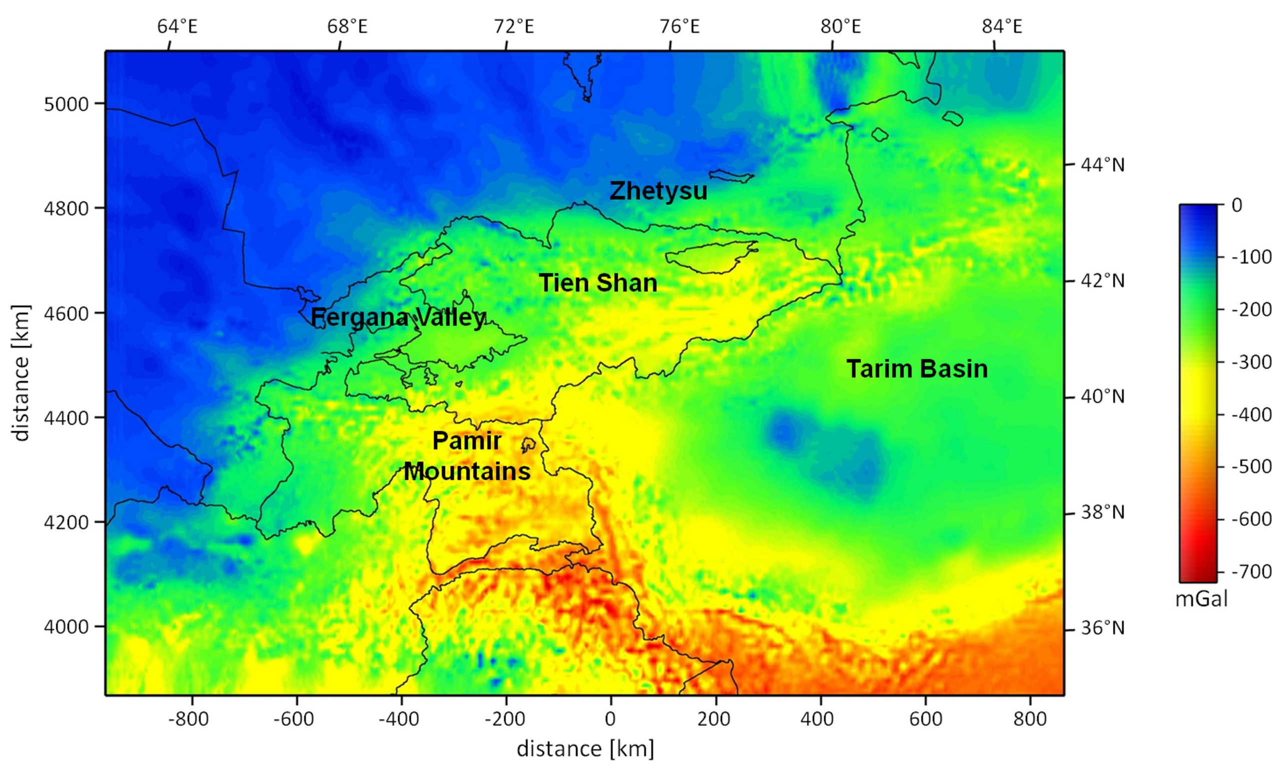


Fig. 2: Bouguer anomaly of the Tien Shan calculated from the EGM2008 and the SRTM heights. The important basins and mountain ranges are displayed. Black lines represent borders and lakes.

- Bouguer anomaly (Fig. 2) calculated from the free-air anomaly of the EGM2008 (resolution of 5 arcmin) and from the SRTM elevation dataset
- Lowest values in the highest mountain ranges such as the Pamir mountains and Karakorum
- Highest values in the Zhetysu
- In the Tien Shan values between -200 and -400 mGal and in the Tarim basin -100 to -200 mGal
- Small-scale anomalies generated by low density contrasts, which are located in the upper crust
- Large-scale distribution, with the maxima in the Tarim and Zhetysu and the minima in the Tien Shan and Pamir mountains, generated by the distribution of the CMB

Data Analysis

- Analysis of the Bouguer gravity field after the method of Spector & Grant (1970) to get a rough estimation of the CMB depth (Fig. 3a) and the cut-off wavelength of 332 km (Fig. 3b) for filtering of gravity field with a Hannig-lowpass filter to eliminate Bouguer anomalies at a small scale
- Calculation of the elastic thickness T_e = 20 km from the coherence between topography and Bouguer anomaly, which agrees with the values of Burov et al. (1990) of T_e < 25 km for the Tien Shan (Fig. 3c)
- Calculation of the gravity effect of sediments to eliminate the effect of sediment basins in the estimation of the CMB (Fig. 4)

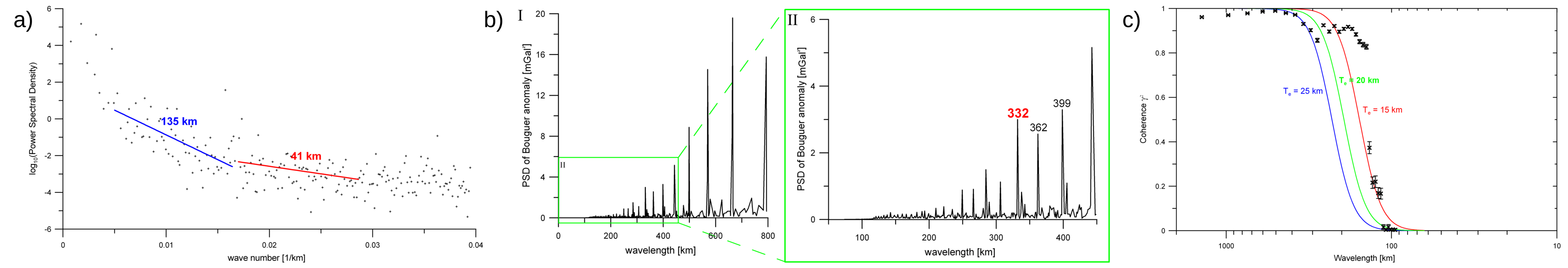


Fig. 3: Spectral analysis of the gravity field: **a)** Natural logarithmic of the Power Spectral Density (PSD) of wave numbers in the Bouguer anomaly [1/km]. The reference depths for the boundary between lithosphere and asthenosphere and the CMB in the first iteration step of the following gravity inversion are highlighted in blue and red, respectively. **b)** PSD of wavelengths in the Bouguer anomaly [km]. The cut-off wavelength of 332 km for filtering the Bouguer anomaly is marked in red. **c)** Coherence between Bouguer anomaly and topographic load compared to the wavelength [km]. The theoretical coherence is indicated for three different elastic thicknesses of 20 km (green), 15 km (red) and 25 km (blue). Calculated coherence are black crosses with error bars.

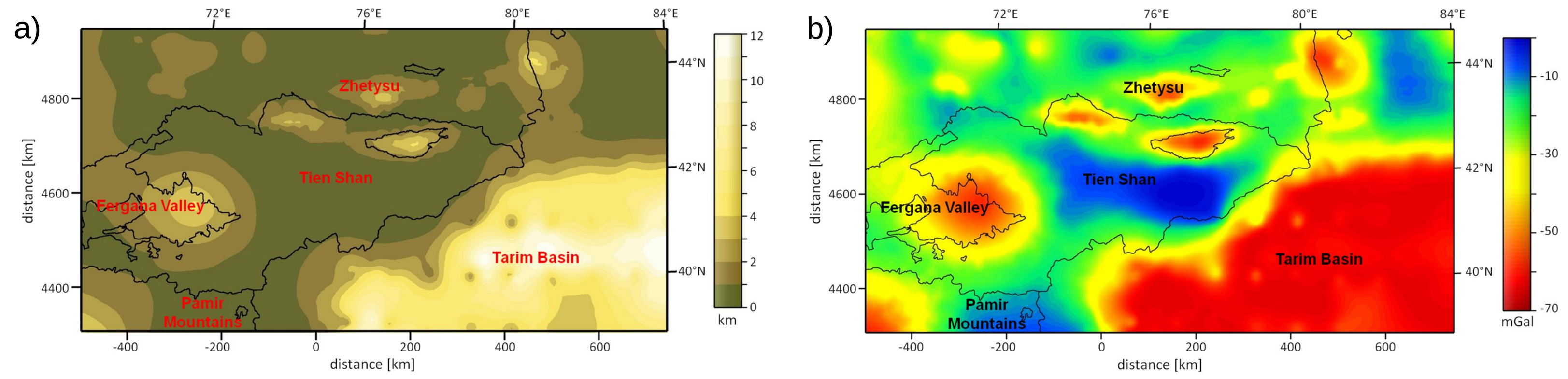


Fig. 4: a) Combined sediment thickness in the investigation area of the Tien Shan from the global sediment thickness map (Laske & Masters 1997), data from the Tarim Basin (Braitenberg et al. 2003) and from the southern Zhetysu (Geological Survey of Kazakhstan 2001; Kostenko 2001, T. Voigt, pers. comm., 2009). **b)** Gravity effect of the sediments in a) in the investigation area. Lines as in Fig. 2.

Results

Method

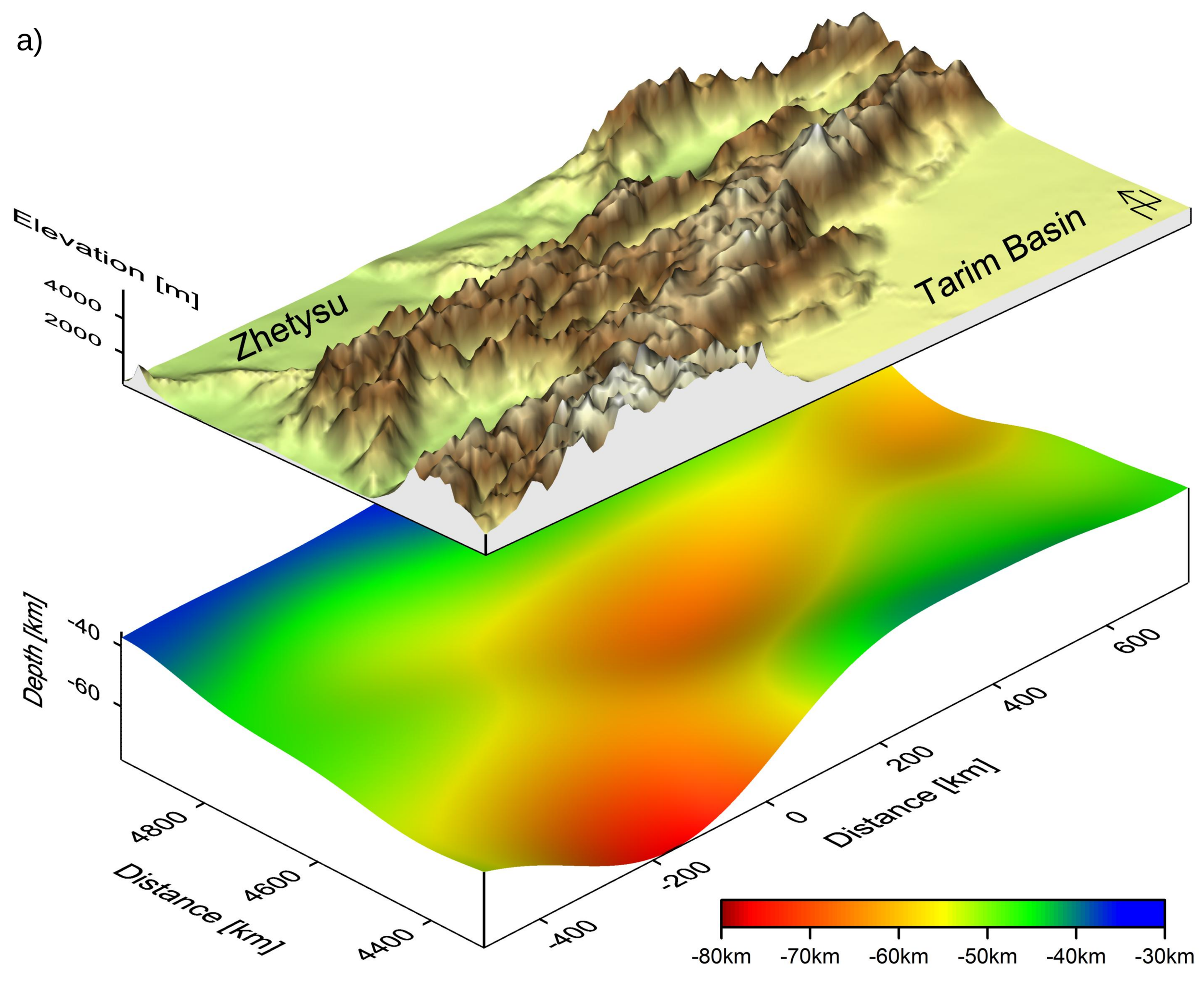
- 10 times larger investigation area to avoid boundary effects
- Reduction of the gravity effect of the sediments
- Application of a Hanning lowpass-filter with the estimated cut-off wavelength of 332 km
- Application of Parker-Oldenburg (Parker, 1972) algorithm to calculate the CMB
  → necessary initial start values: - Reference depth CMB: 41 km
  - Density contrast between mantle and crust: 351 kg/m³ (Wang et al., 2004)

CMB for the Tien Shan (Fig. 5, 6a)

- Variation of CMB between 30 km and 80 km below sea level
- Below the Tien Shan crust more than 55 km thick, highest values below the Pamir Mountains
- CMB of the Central Tien Shan, which corresponds to the highest mountains in this range, about 65 km
  → This shows clearly that the Tien Shan has a mountian root!
- Shallower CMB below the Zhetysu and the Tarim Basin
- Topography correlates well with crustal thickness (Fig. 5):
  - Large elevation change in the north at the border of the Tien Shan → corresponds to a steep decrease in the crustal thickness
  - Lower elevation change at the Tarim Basin → decrease in thickness not so steep

Isostatic compensation for the Tien Shan (Fig. 6b,c)

- Isostatic CMB calculated from the topographic load (SRTM elevation data) and an elastic thickness of 20 km
- In isostatic CMB mountain root clearly visible beneath the Central Tien Shan with values of 65 km
- Difference between the first CMB (Fig. 6a) and the isostatic one (Fig. 6b) shows the isostatic compensation (Fig. 6c) which is given in percent
- Area almost compensated (compensation is defined between 90 and 110%) besides some undercompensated areas in the south of the Tarim Basin and in the north of the Zhetysu
- Mountain areas and especially Tien Shan are **100%** isostatically compensated



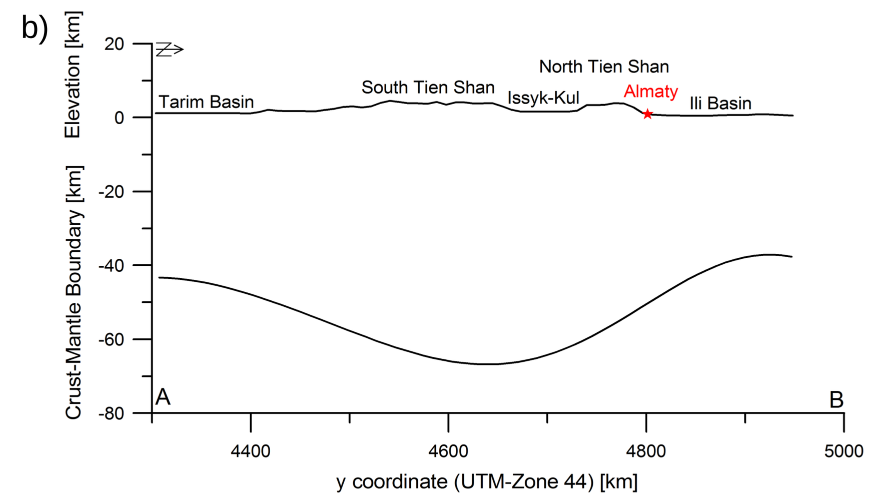
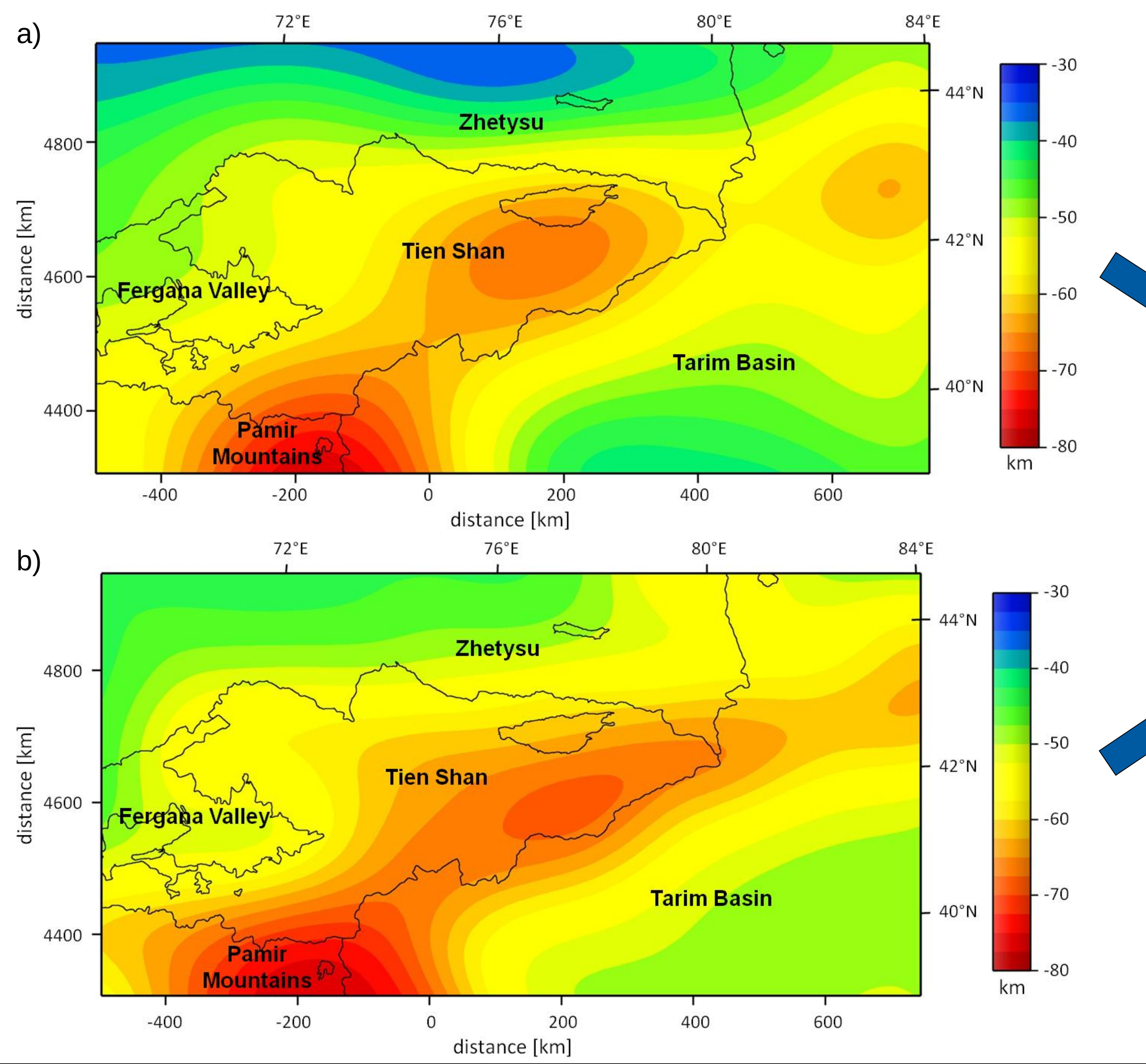


Fig. 5: a) 3D view of the CMB and corresponding topography of the Tien Shan mountains. The minima of the CMB are beneath the high mountain ranges. **b)** Comparison of elevation and CMB along the profile that runs from south (A) to north (B) and is located at 77°E, which is equal to 200 km in a).



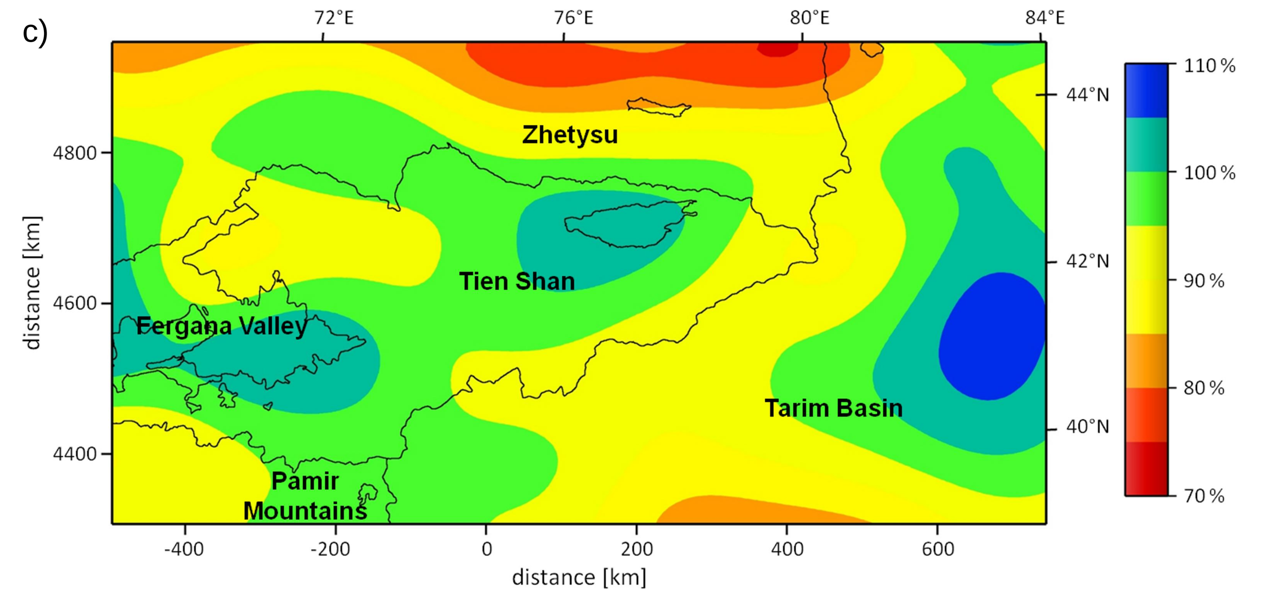


Fig. 6: a) CMB of the Tien Shan and surrounding areas obtained from the gravity inversion. **b)** Isostatic CMB of the Tien Shan and surrounding areas obtained from the topographic load and an elastic thickness of 20 km. **c)** Isostatic compensation estimated as difference between a) and b) in percent. Lines as in Fig. 2.

Conclusion

- CMB of the Tien Shan determined with inversion method
- Mountain root clearly visible below the Tien Shan
- EGM2008 for this kind of investigation applicable
- Tien Shan isostatically compensated
- Gravity inversion is a very good alternative to the receiver function method to estimate the CMB of a region

Acknowledgements

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