Global and regional scale modeling of dynamic processes in the Earth's mantle
Ph.D. thesis by Marie Běhounková
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Information about structures in Earth's mantle can be obtained by studying their images resulting from seismic tomography or by simulating the processes that cause them. This thesis is concerned with both approaches. This makes the thesis very versatile while at the same time it shows a mature and in-depth understanding of both fields. The first part of the thesis investigates how well results of a geodynamic model could be seen by tomographic techniques. Because both input (the geodynamic model) and output (from the inversion) are known, the results can be checked against each other. The results bring new insight into the role of the parameterisation of Earth into cells. This is of importance for tomographic studies that need to choose a parameterisation and also points out to non-seismologists how assumptions in the tomographic procedure influence the visibility of plumes and subducting plates. In this sense it is very interesting that the results show that models with $Ra = 10^6$ do not do well at depths at the base of the upper mantle and top of the lower mantle. The second part examines the conditions that would lead to wide seismic anomalies associated with subduction through the 670 km discontinuity. A numerical code was specially written for this, based on a paper by Gerya and Yuen (2003). It is a welcome scientific contribution that shows that phase transitions, the strength of the plate, the viscosity increase at the upper-lower mantle interface and the strength of a decoupling layer are important factors in causing slab thickening in the lower mantle by folding or by thickening due to compression. It is demonstrated that only weak plates and a limited viscosity increase over the 670 km discontinuity lead to seismic anomalies of a width that is comparable to seen in seismic observations. This again provides a nice link between geodynamics and seismology and the results are of importance to any discipline concerned with subduction processes.

I find that the thesis is written well, with clear outlines of the research motivation, complete descriptions of the methods that were used and systematic model studies. It is also well balanced with a clear eye for extracting the relevant information and conclusions. Two papers are already published and I hope that a third based on part two of the thesis is in preparation, since this most certainly should be published as well. In summary, the thesis clearly demonstrates mature scientific results and proves the scientific creativity of the author.

I would like to ask Ms Běhounková a few questions which are mainly to clarify some of the findings in her thesis or even try some speculations beyond it:

1) In Chapter 3, real sources and receivers are used for ray tracing through a geodynamic model. The sources are, therefore, related to plate movements and show the subduction zones and mid-ocean ridges. Subduction and plate spreading at ridges are also processes that cause earthquakes, and thus the sources. Therefore, there is normally a relation between sources on one hand and the structures that are to be imaged on the other hand. We expect high hit counts where the structures are. The geodynamic model does however not have this correlation and does not have higher hit counts where structures are. Could you comment on this? Could you predict if your results would change if a geodynamic model driven by plate motions were used (e.g., Bunge and Davies, Geophysical Research Letters 28, 2001)?

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2) The first part of the thesis shows that the correlation between input and output models for Ra = 10^6 is not particularly good in the depth interval 400-1600 km (or an even larger interval for an irregular parameterisation). The hit count at a depth of 1000 km seems reasonable. Could you speculate on what is causing the limited resolution in the inversion? In the second part you show that slabs may look thicker in this depth interval. Would that help in visualising them?

3) The numerical method described in Chapters 5 and 6 is well tested against analytical solutions and the Blanckenbach convection benchmark. These test the solutions for velocity, viscosity, temperature and buoyancy driven flow. The numerical code is special in that it solves directly for velocities and dynamic pressure. Could you describe a possible test for dynamic pressure?

4) The subduction models in Chapter 7 are driven by internal density differences and boundary conditions. The density differences are caused by composition, phase changes and temperature differences. Could you describe (or show) an example of the density difference field for one of the subduction models?

5) The numerical models in Chapter 7 focus on conditions that would cause slab folding and thickening. Could you use the results of your models to speculate on the conditions that would favour the opposite scenario, that is, a slab that goes straight through the 670 km discontinuity (e.g., as in the Java subduction zone)?

6) Some numerical models in Chapter 7 with free-slip at the surface of the subducting plate, a low stress limiter and a strong decoupling layer (e.g. Tsy8d21C10_fs10) show trench advance during their evolution, that is, the trench moves to the right. However, for x > 5000 km the overriding plate is held fixed at the surface. How is the trench advance into this no-slip domain achieved?

7) In simple models that only simulate the slab itself, Housemans and Gubbins (Geophysical Journal International 131, 1997) use, among others, a buoyancy number F to characterise their slab shapes. F measures the ratio of stresses generated by the density anomaly of the slab and the stress associated with viscous deformation of the slab. Houseman and Gubbins also obtain slab folding at the base of the upper mantle. Would it be possible to use their buoyancy number to characterise your models?

To Marie I would like to pass my congratulations for a very nice thesis. I wish her best of luck in her new post-doc position!

19 November 2007

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