Structure of the uppermost mantle beneath the North American Continent

Stephanie Godey,[1] Frederic Deschamps, Jeannot Trampert and Roel Snieder [2]

Faculty of Earth Sciences, Utrecht University, The Netherlands.
1 Now at EMSC, c/o LDG, DASE, Bruyeres le Chatel, France, email: godey@emsc-csem.org
2 Now at CSM, Golden, Colorado, USA

Utrecht University

Introduction

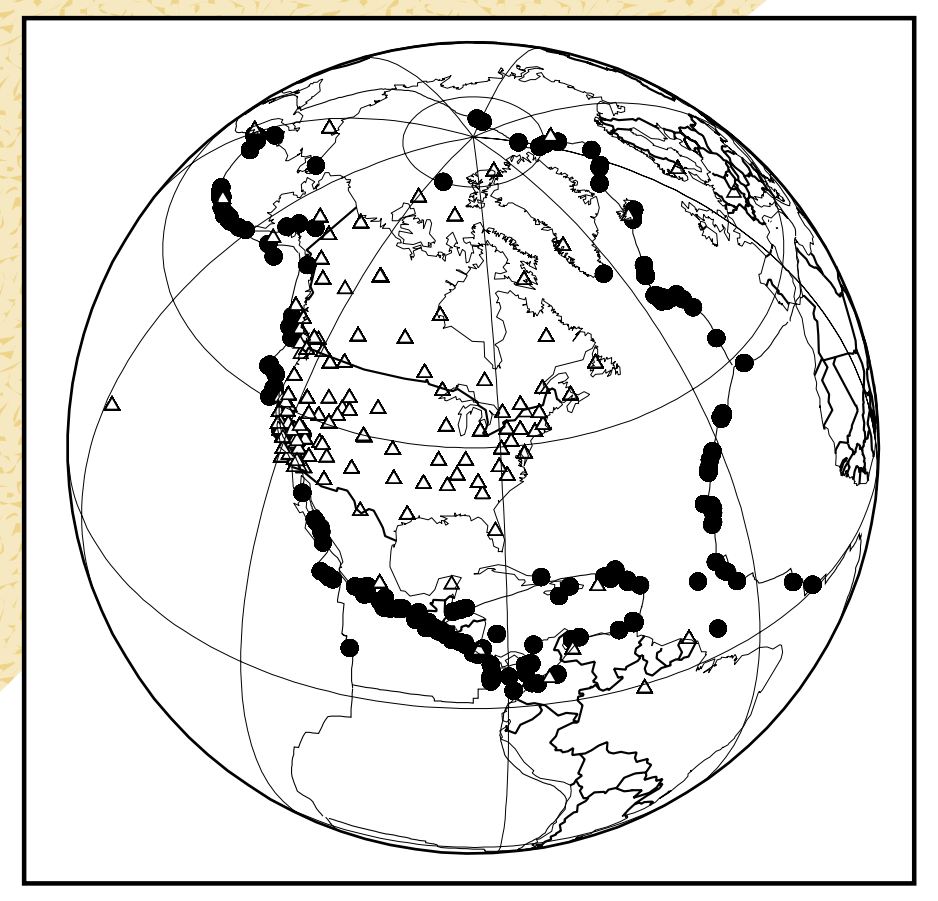
Nowadays, large high-quality seismological dataset are available for various regions of the world. Improved ray path coverages are obtained allowing the construction of velocity models displaying high resolution. It is therefore possible to infer the parameters to which seismic velocities are sensitives. Temperatures and composition variations in the uppermost mantle have the predominant influence on the shear velocity. Knowing such variations can provide explanations on the stability of cratonic areas in comparison with tectonically active regions.

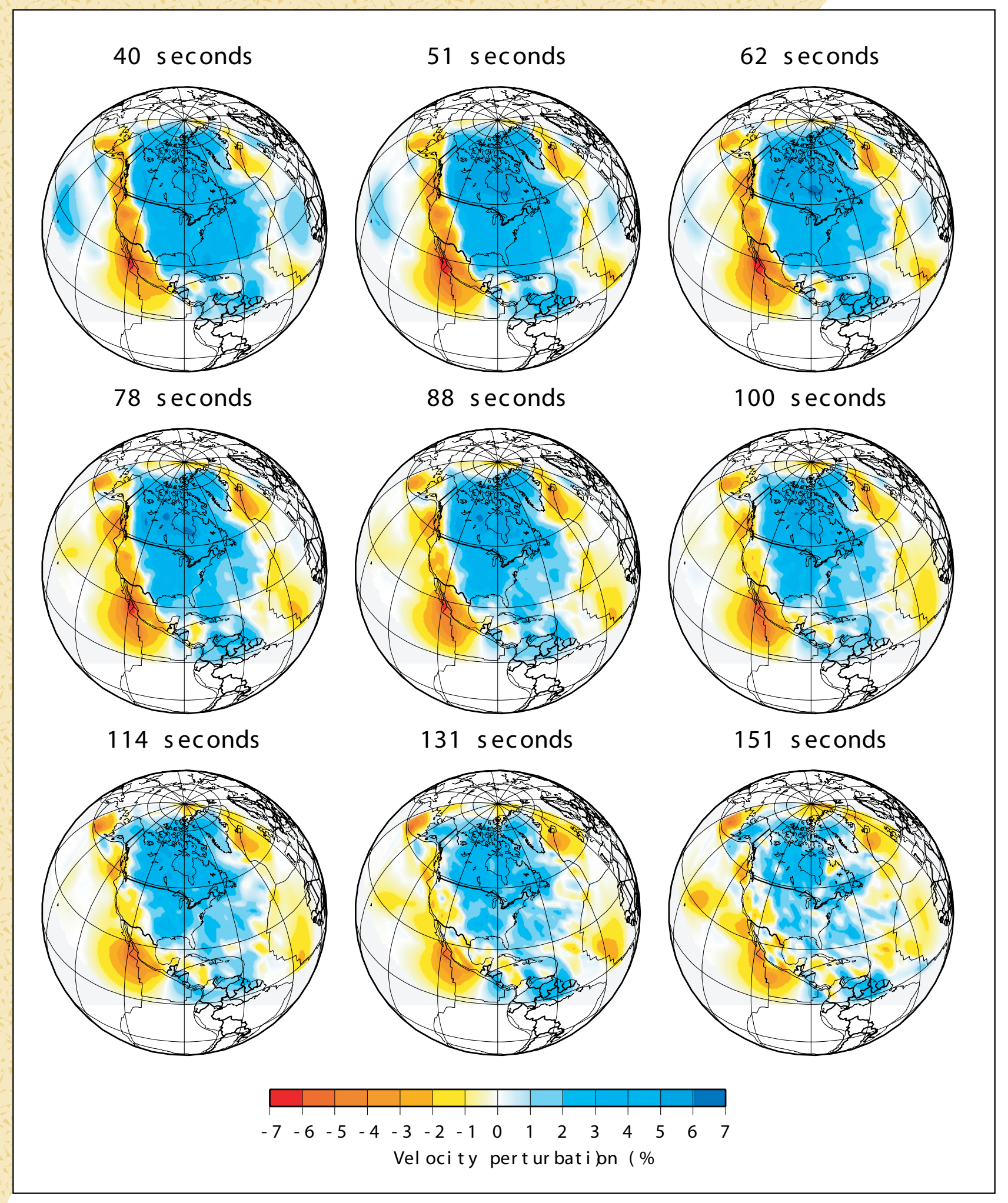
In this study, phase velocity measurements of fundamental mode Rayleigh waves were collected over the North American Continent from 1995 to 1999. The dataset is inverted to construct a new shear velocity model using ray theory for the uppermost mantle. In a second step, gravity measurements are associated to shear velocity to resolve temperature and composition variations.

Data

We use a regional dataset (Figure 1) derived from:
- -207 events
- -recorded by 142 global (GSN) and regional stations (CNSN,USNSN,BDSN,Terrascope, Geoscope)
- -between 1995-1999
- -7700 phase velocity measurements of the Rayleigh wave fundamental mode,

calculated using a non linear waveform inversion method (Trampert and Woodhouse, 1995)
- -magnitude between 4.7 and 7





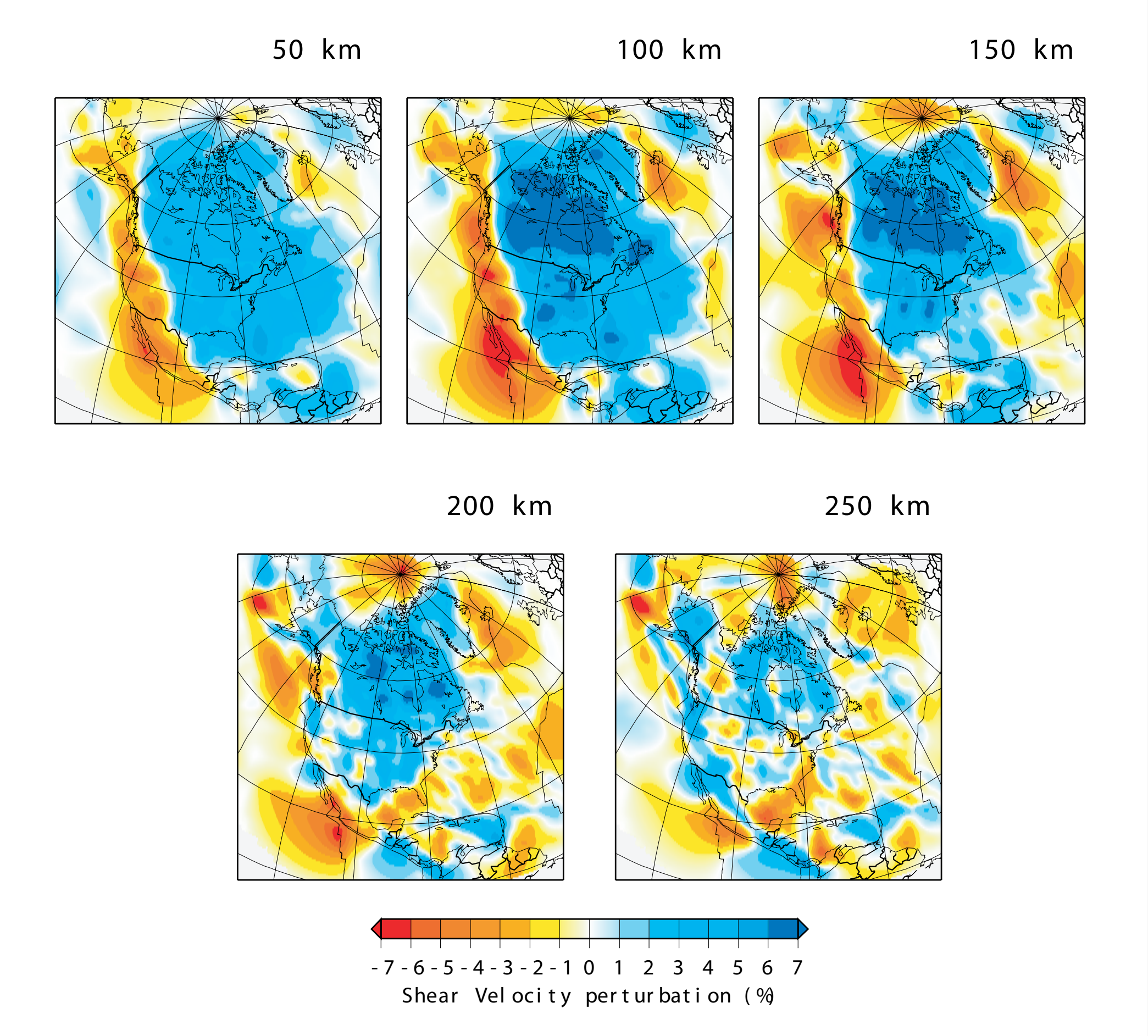
Phase velocity maps

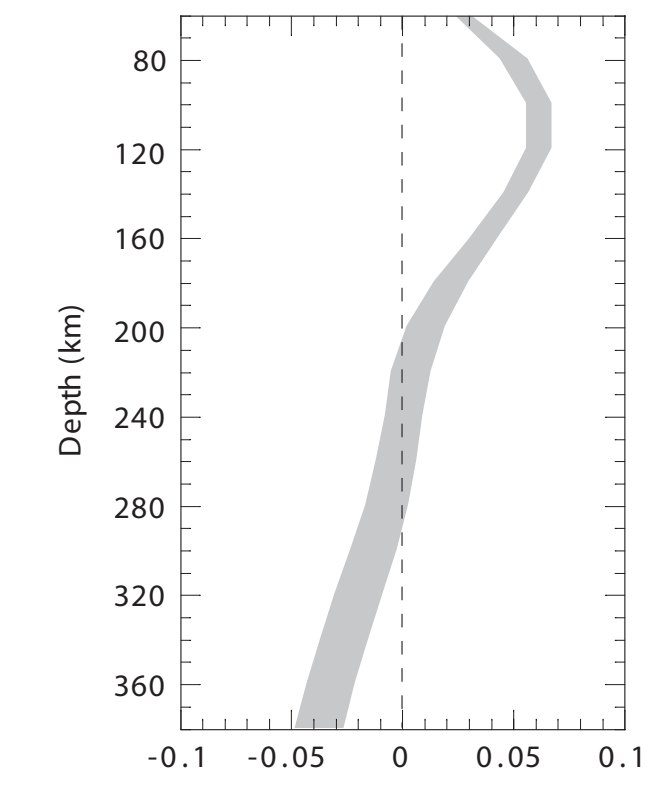
We define 10 period range between 40 and 150 secons to construct phase velocity maps, showing the same data coverage. We apply crustal thickness corrections using CRUST5.1.

We use the method of Barmin et al. (2001) to compute phase velocity maps using the geometrical ray theory. A grid of 2 by 2 degrees spacing is defined. Over the inversion region, the cell area does not vary by more than 10%. To obtain equal resolution in all phase velocity maps, we applied the same Laplacian regularization at all periods and therefore avoid artefacts in the depth inversion.

Shear velocity model

The Earth's shear velocity structure as a function of depth is derived by a standard linear inversion applied on the computed phase velocity maps. The model is defined in terms of spline functions on which we apply a second derivative smoothing. The two prominent features imaged in our model are the high velocities beneath the North American craton and the lower velocities associated with the western active Cordillera, as frequently reported in other studies.These structures extend down to depths of 200 km and 150 km, respectively. But it is interesting to see that they do not decrease significantly at larger depths.





Scaling factor ξ for the sub-continental upper mantle

Density Data

To resolve thermal and compositional variations from our Vs model, another set of data is needed. We propose to add density variations as additional constraint. We follow a classical approach, which infers density anomalies from observed gravity anomalies using an appropriate scaling factor computed for continents which relates density to shear velocity (Deschamps 2002):

$$\xi(r,\theta,\phi) = \frac{\partial \ln \rho(r,\theta,\phi)}{\partial \ln v_s(r,\theta,\phi)}$$

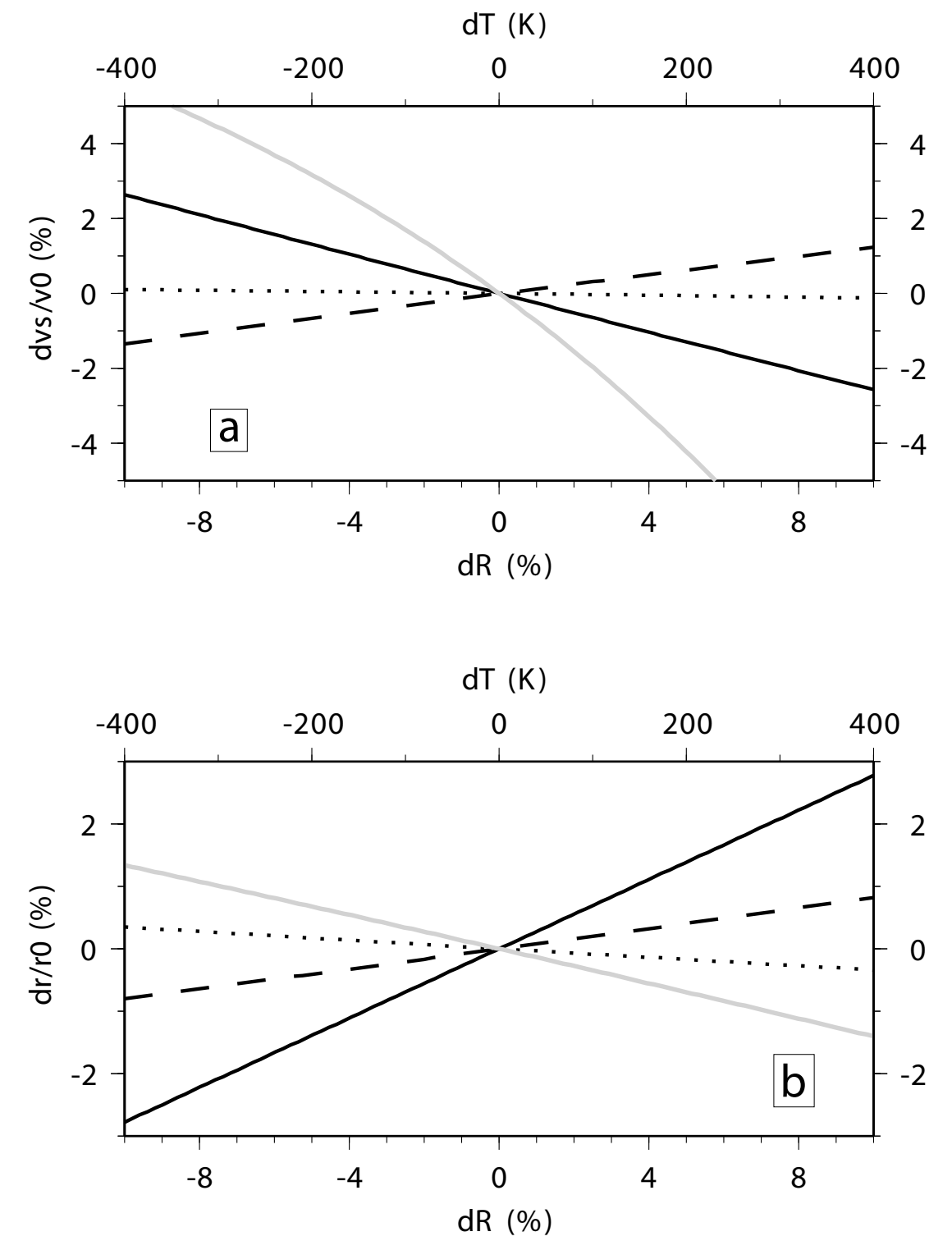
Thermo-chemical model

Relative velocities are mainly sensitives to thermal anomalies and to a lesser extent to variations in composition. To decide of the most relevant chemical parameter, we have computed the velocity and density perturbations for temperature and three different compositional parameters: iron, garnet, and olivine content (see figure to the right). We can see that density is mainly sensitive to iron content variations in iron content. An enrichment of 3.5% in iron induces a 1% increase in density. The same density variation is obtained with a decrease of 400 K in temperature.

We define the inversion system by:

$$\frac{\delta v_s}{v_0} = A\delta T + B\,\delta Fe$$

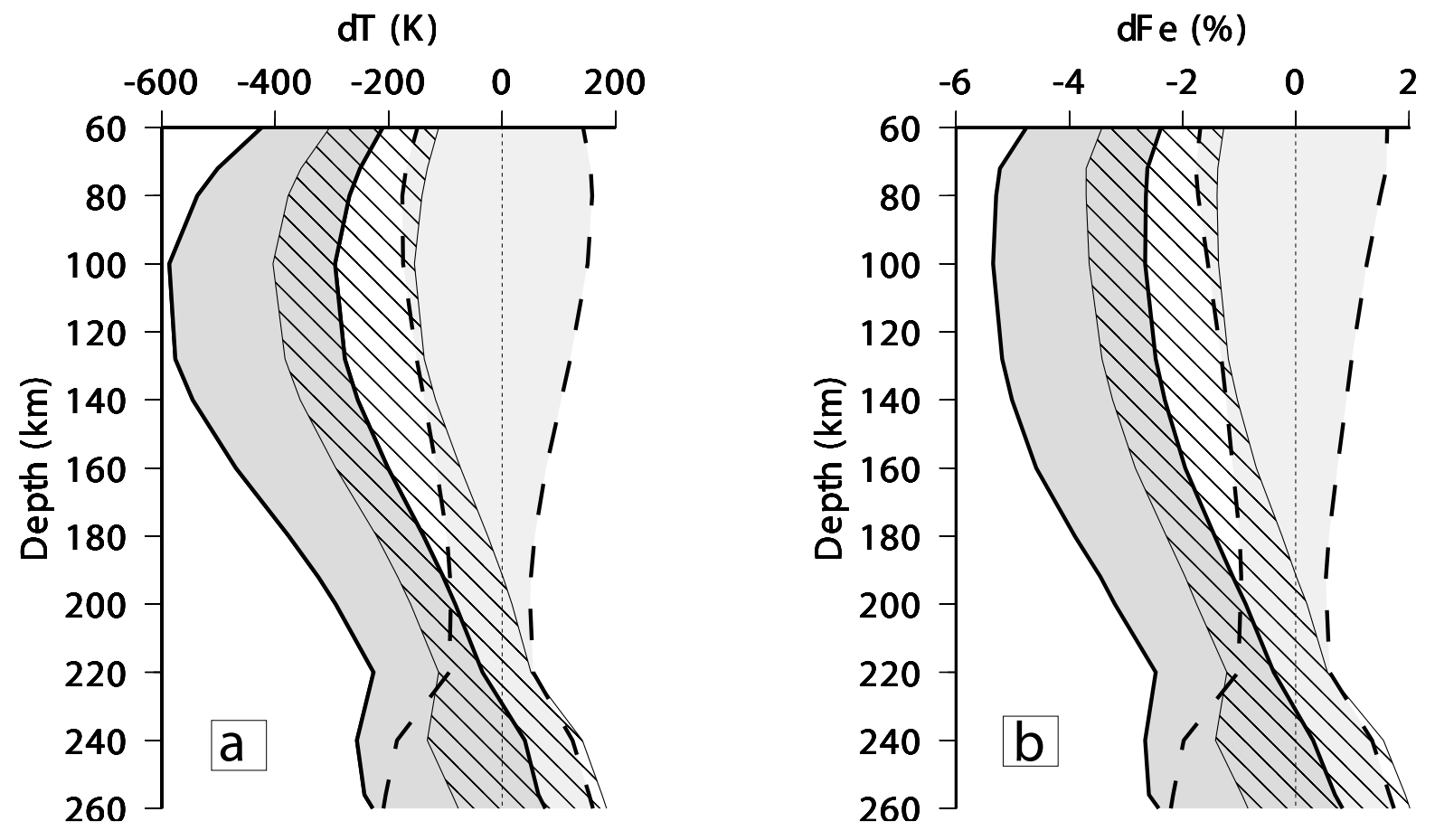
$$\frac{\delta\rho}{\rho_0} = C\delta T + D\delta Fe$$



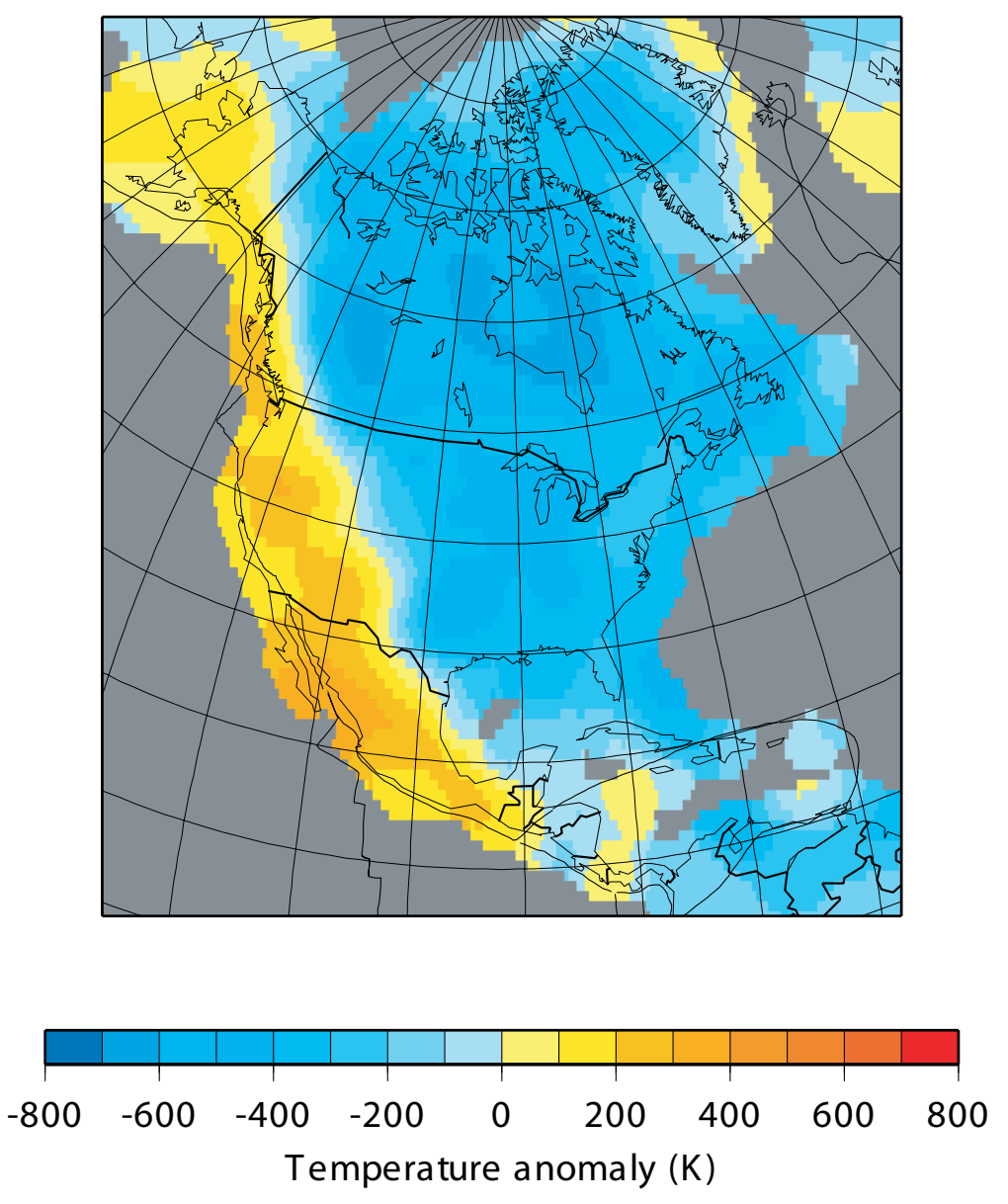
Relative variations of velocity and density for temperature (grey line), global volumic fraction of iron (solid line) and volumic fraction of olivine (dotted line).

The system is resolved following an iterative Newton-Raphson method to minimize the residuals for temperature and composition. We use a range of mineralogical reference models for which we vary the average mantle temperature and chemical composition. Therefore, the results are given in terms of mean temperature and composition and standard deviation.

The figure below displays the mean anomaly of temperature and iron and their variance (shaded area) as a function of depth and surface tectonics. We have computed profiles of dT and dFe for cratons, stable platforms and tectonically active continent, as defined by 3SMAC (Nataf96). The distributions of temperature and iron anomalies are clearly related to tectonic provinces for depth shallower than 200 km. These results agree with previous global scale studies. Down to a depth of 230 km (+/- 50 km), cratonic roots are significantly colder and depleted in iron, compared to the average mantle. The positive buoyancy induced by chemical depletion may balance the negative buoyancy due to the cooling of the continental root. This may explain the longevity of the Archean craton, by preventing the lithosphere from sinking into the asthenosphere. The tectonic Cordillera is underlained by low S-velocities following well the tectonic regionalization, consistent with an average mantle, and with slightly positive thermal anomalies.



Profile of temperature (left) and iron (right) anomalies for different tectonic regions: Archean craton (dark grey), Stable platform (hatched) and Tectonic continent (light grey)



Map of mean temperature anomalies at 110 km depth obtained by inversion of the Shear-velocity model. A similar map would be obtained for iron content. We see clearly the difference in temperature between tectonic regions (western Cordillera) and the cratonic area (eastern North

Conclusion

The use of a new regional tomographic model improves our image of the thermal and chemical structure of the uppermost mantle, in particular compared to previous global scale studies. Next steps will include to refine the distribution of the scaling factor by estimating finer lateral variations of this ratio. In particular, we expect that the depth at which the scaling factor goes to zero vary with the tectonic province. The use of different scaling factors, one for each province, will therefore determine more accuretely the depth at which the regional differences in terms of temperature and composition are cancelling.