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3D Numerical modeling of glacial isostatic adjustement with lateral heterogeneities

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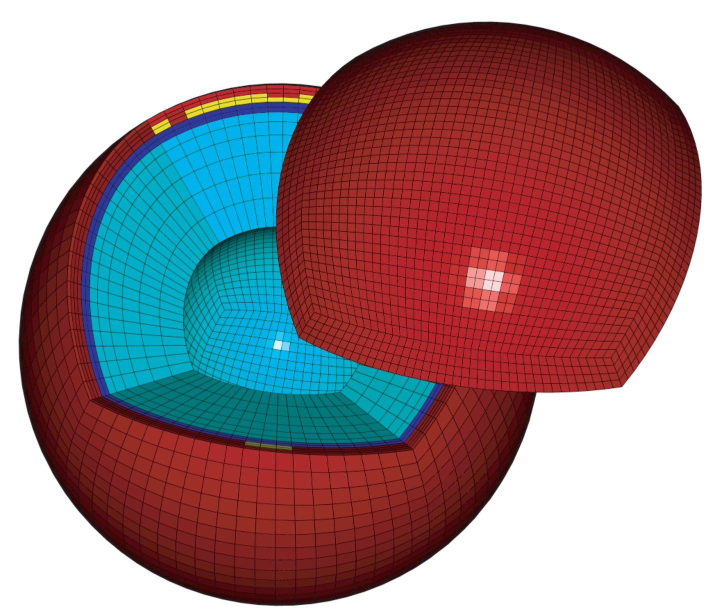
Abstract

The Earth response to the melting of the late-Pleistocene ice-sheets has been mainly studied using spherically layered models, based on well established analytical methods. In the last few years new approaches have been developed, based on numerical techniques and massive computer resources. These methods allow to evaluate the effects of non-Newtonian rheologies (Wu, 1992) and lateral viscosity variations (Giunchi & Spada, 2001) on glacial isostatic adjustment (GIA) and relative sea level (RSL) changes. In this framework, we use a 3D Finite Element (FE) code to include laterally varying structures both in the elastic lithosphere and in the Newtonian viscoelastic upper mantle and we directly compare the outcomes of these models with RSL data selected from a publically available global data set. Our spherical models reproduce the global structure of the cratons and account for a low-viscosity layer beneath the oceanic lithosphere (Nataf & Ricard,1996).

Model

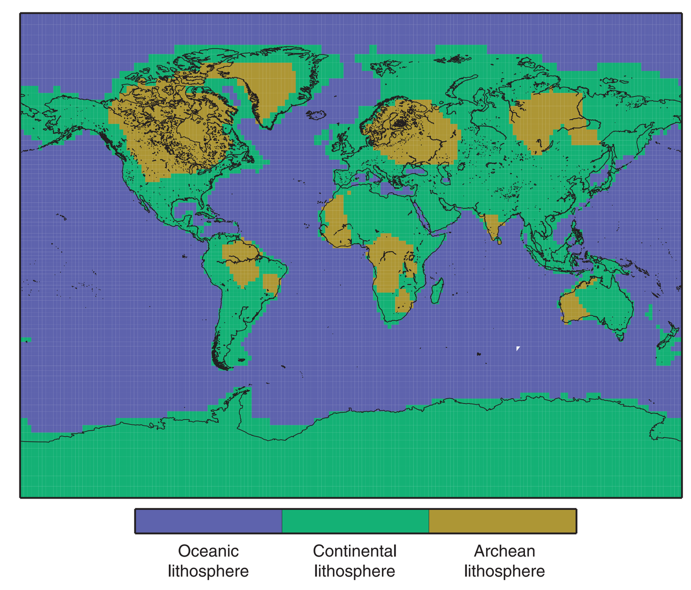
FE mesh



Homogeneous and heterogeneous models considered in the paper. Themechanical parameters of each layer are given in Table~\ref{layers}}

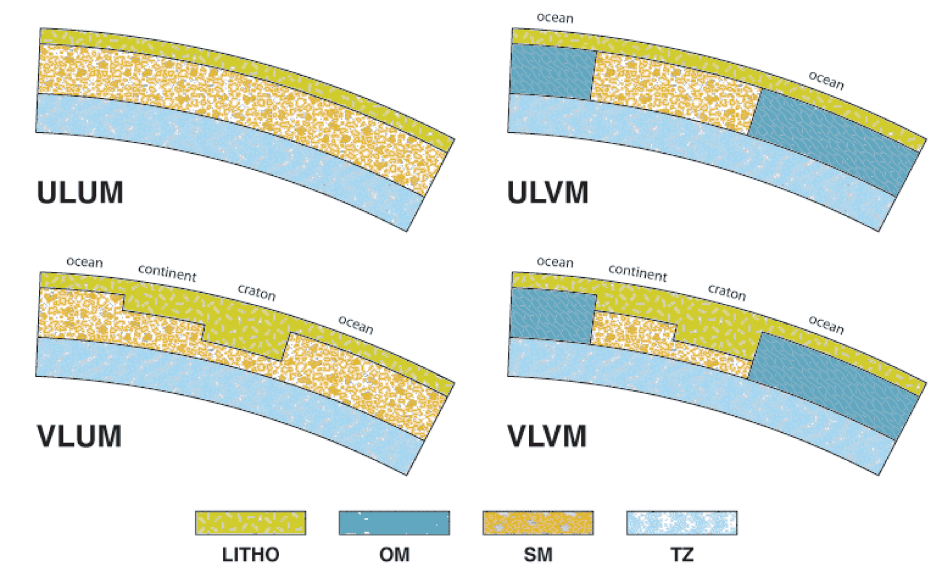
Lithospheric thickness according to 3SMAC model\citep{natafricard96},used in the heterogeneous models. The thickness of the oceanic, continental andcratonic lithosphere is assumed to be 100, 200 and 300 km, respectively.}

3SMAC tectonic provinces



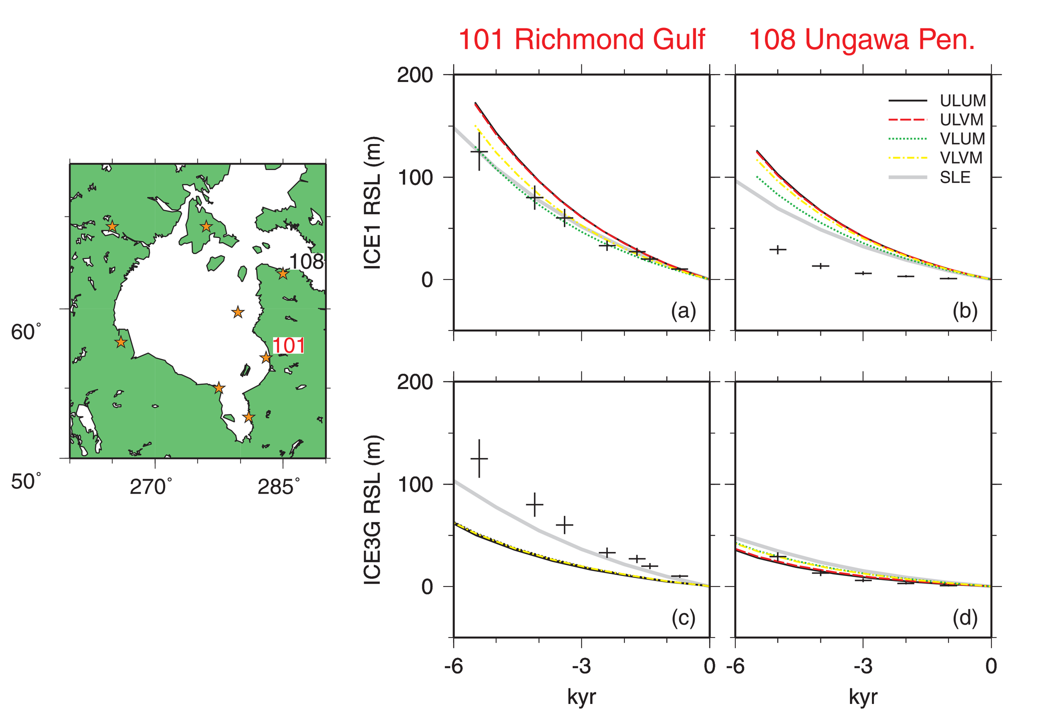
Layer	Radius km	Density kg m^{-3}	Rigidity GPa	Viscosity Pa.s	Gravity m s^{-2}
LITHO	6371	4120	73	∞	9.71
UM	6271	4120	95	1.0×10^{21}	9.66
OUM	6271	4120	95	1.0×10^{19}	9.66
TUM	5951	4220	110	1.0×10^{21}	9.57
LM	5701	4508	200	2.0×10^{21}	9.51
CORE	3480	10925	0	0.0	10.62

Earth models

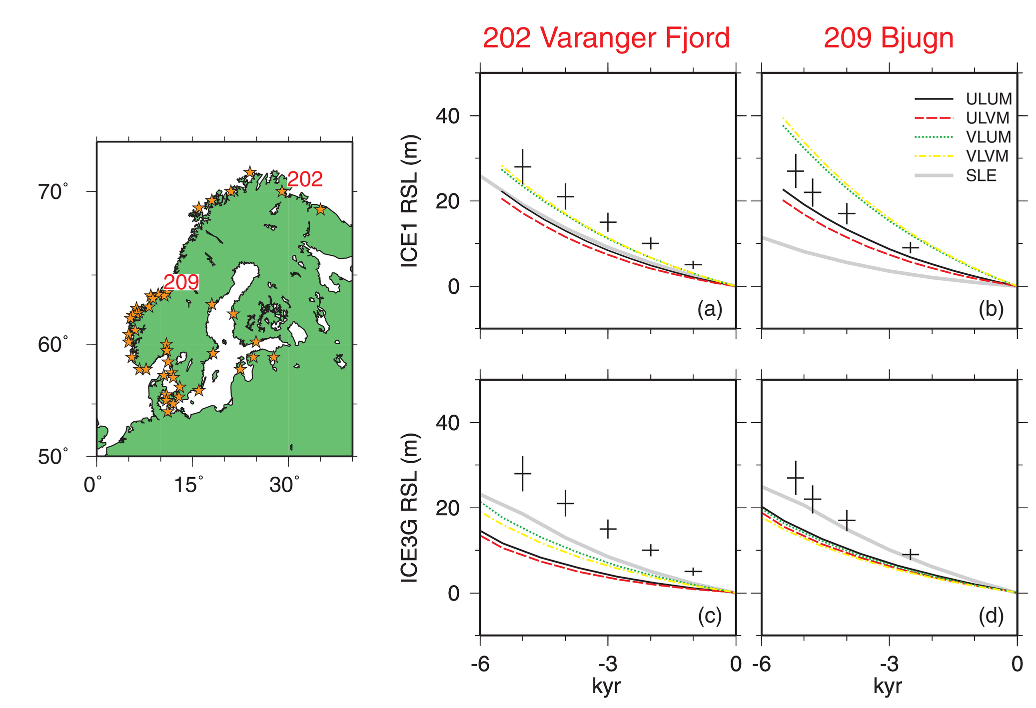


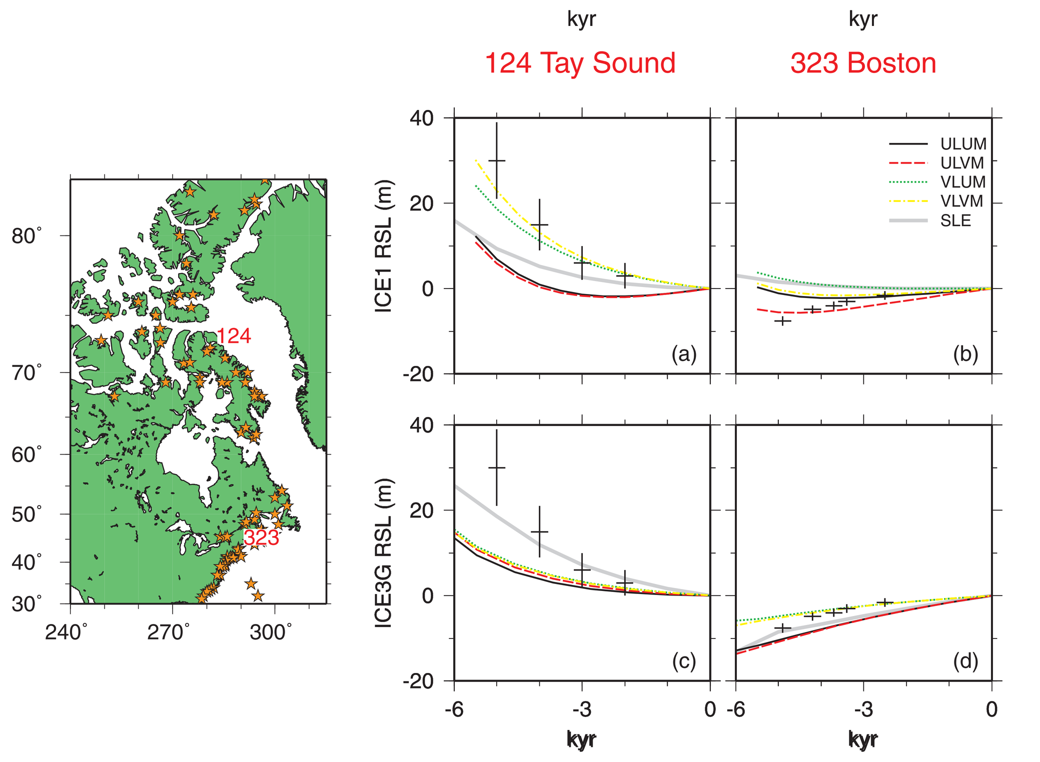
the mesh is ensured by contact elements. The lithospheric thickness variations are taken from the 3SMAC model (*Nataf & Ricard,1996*). In the heterogeneous models, the upper mantle viscosity variations are limited to the depth of 420 km.

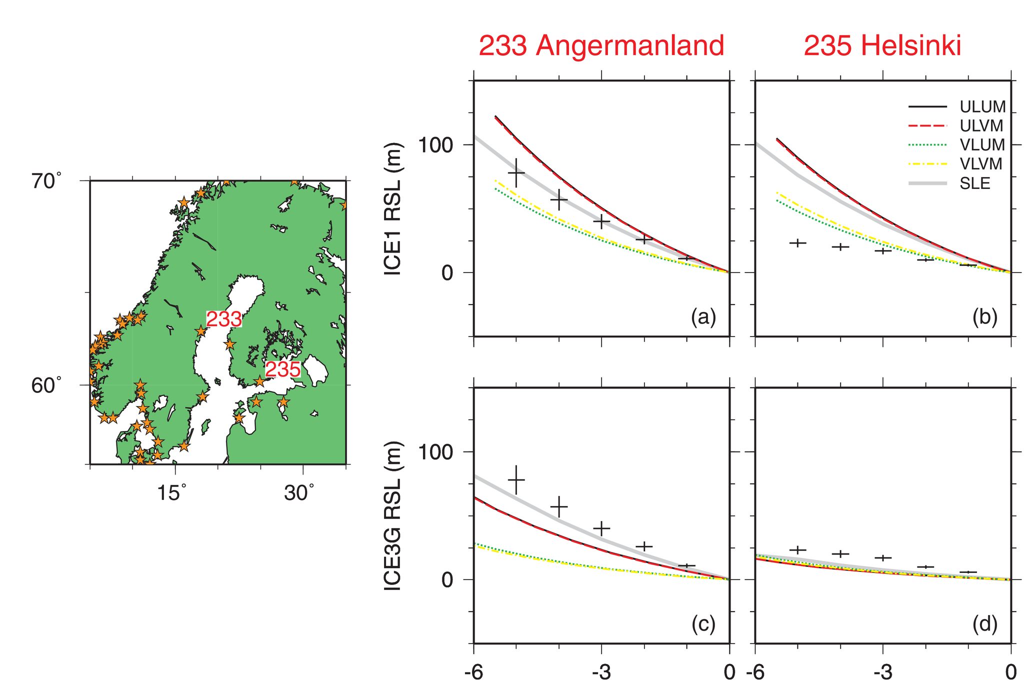
RSL in selected areas

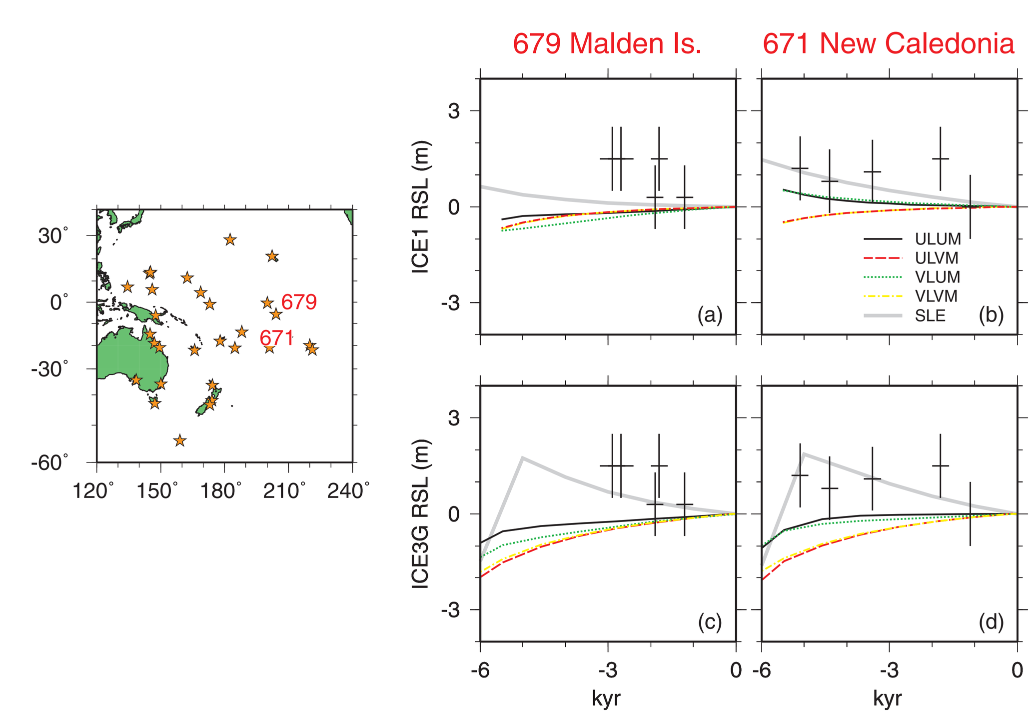


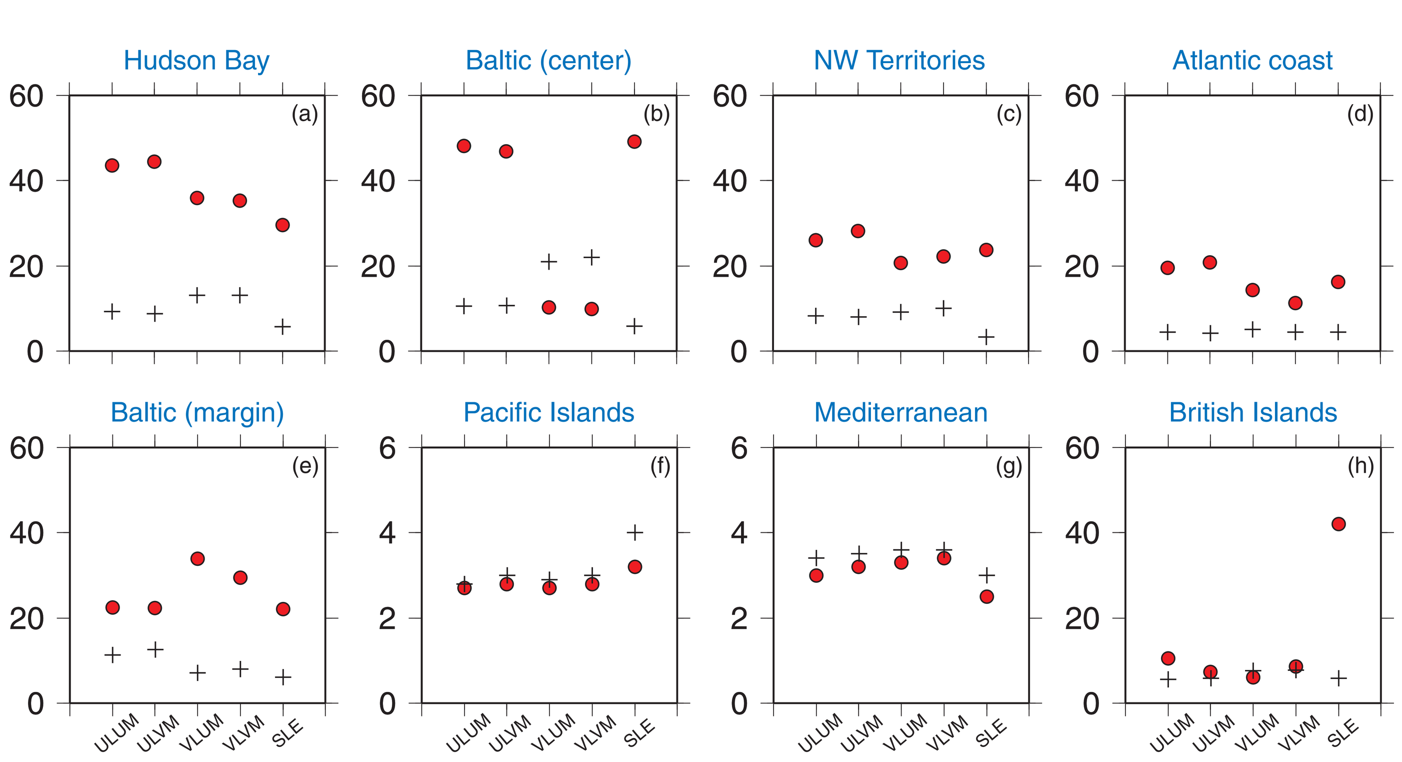
Predictions from ULUM, ULVM, VLUM, VLVM, and SLE models RSL predictions at selected sites belonging to areas characterized by broadly similar postglacial RSL trends, that have been chosen according to their location with respect to the former ice–sheets.
They include i)regions close to the center of the loads (the Hudson Bay and the Baltic regions), ii)regions located at the periphery of the ice–sheets (Northwestern Territories, the Eastern coast of the United States, and the coasts of Fennoscandia), and iii) the extreme far field eld region of the Pacfic Islands.
For every homogeneous region, results are shown in panels a), b) for the ICE1 and c), d) for the ICE3G models, respectively. Crosses show data and associated 1s errors from the Tushingham and Peltier (1993) dataset. The maps show the locations of the RSL sites.



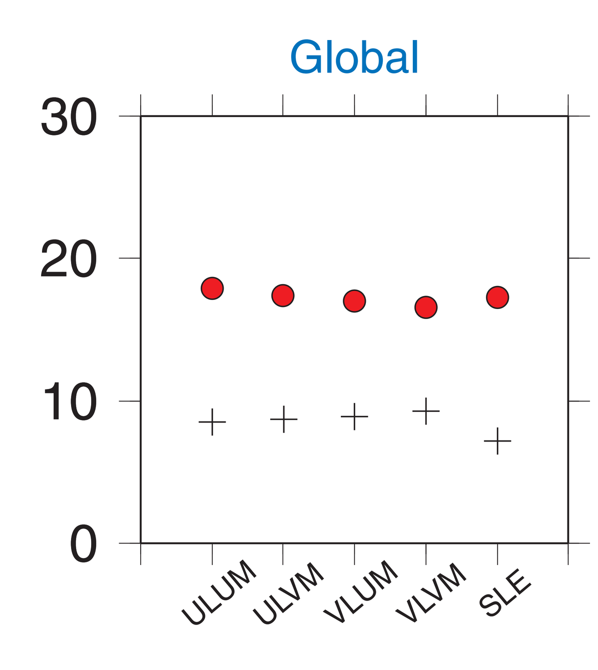








Regional misfits M_r for eight selected regions. Red circles and crosses indicate the misfits between RSL observations and model predictions when the glaciation chronologies of ICE1 and ICE3G are employed, respectively. The labels on the x axis indicate the forward model employed. SLE shows the results obtained when the self-consistent SLE is emplo employed.



Global misfit computed using all of the data from the 392 RSL sites included in the Tushingham & Peltier (1991) database (ICE1, red dots; ICE3G ,crosses).

Conclusions

We have shown that homogeneous and laterally heterogeneous models have comparable global performances for both the ice chronologies studied. This finding suggests that the effect of lateral viscosity variations cancel out globally, so that the radially stratified models still may be a useful tool for GIA predictions on a large scale. When specific subsets of the global RSL data set are considered, such as the regions which have directly experienced the glacial melting (e.g. Hudson Bay), we find that the RSL can be better reproduced by heterogeneous models. This indicates that further refinements of the laterally varying structures on a regional scale may lead to a better agreement between RSL observations and model predictions.