High resolution Post Glacial Rebound over the European Alps.

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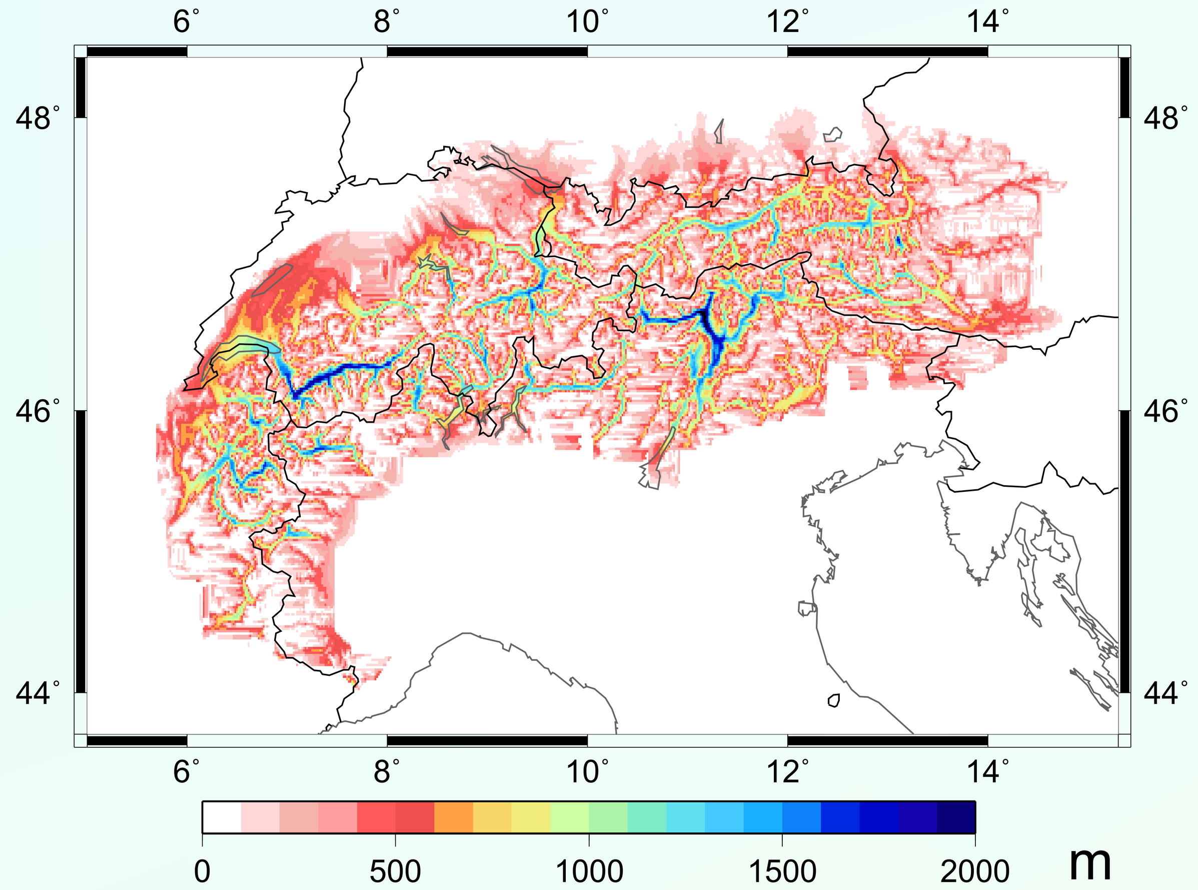
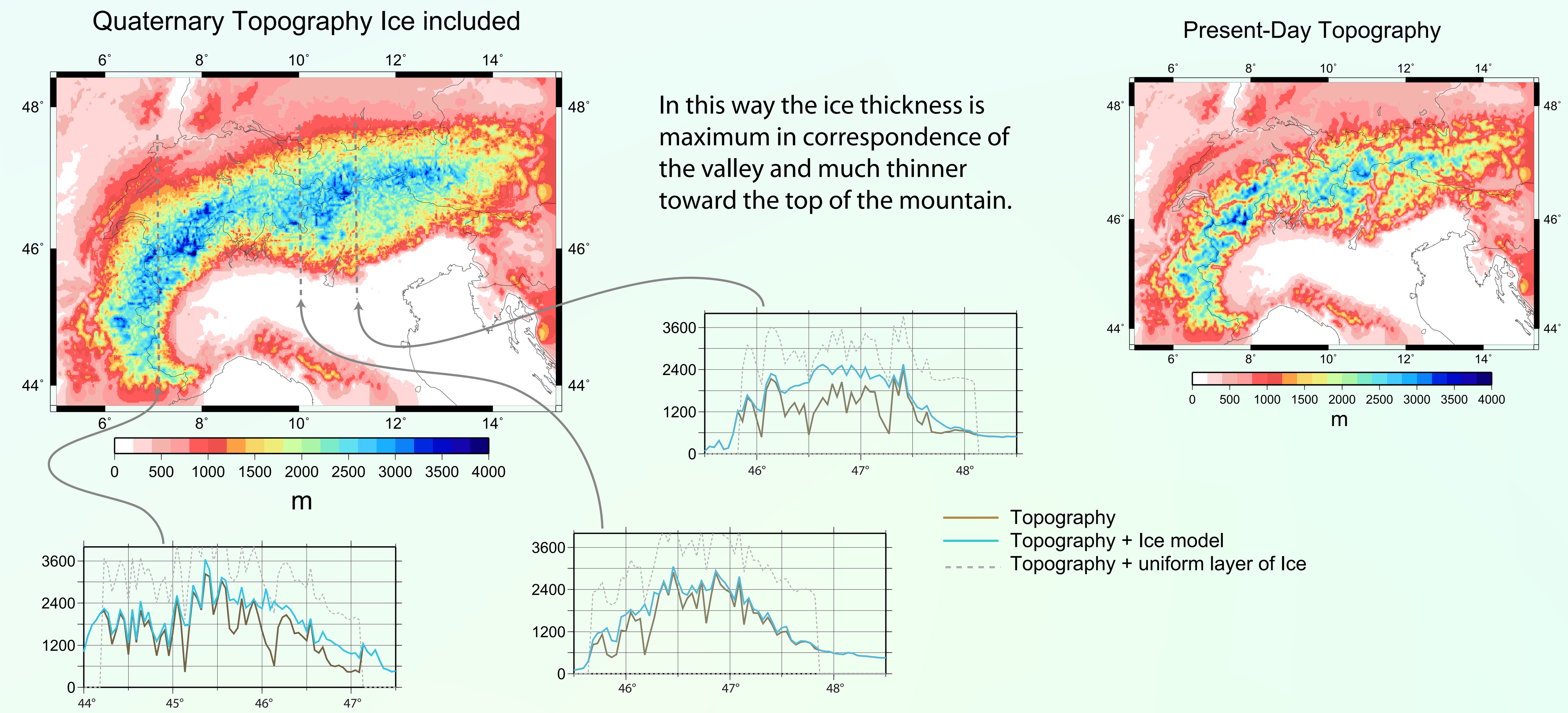
Abstract

We implemented an ice model with both glaciation and deglaciation phase starting from a very realistic ice distribution. The latter is calculated on the basis of trim-line of the ice during the LGM (Last Glacial Maximum) and the real topography. In this way the ice thickness is maximum in correspondence of the valley and much thinner toward the top of the mountain. The deglaciation process is set between 21 and 15 kyr ago.
The glaciation phase ended 26 kyr ago and it reasonably lasted three times more than the deglaciation phase. We chose to implement a linear behaviour with different rates for the accumulation and the deglaciation phase. We used the high resolution technique and the Earth model as in Barletta et al. 2006, to calculate over the European Alps the uplift rate and the gravity anomaly contribution from all the ice elements. We also tested the sensitivity of the PGR results with respect to ice model and with respect to Earth model, layering in particular.

1. Ice Thickness 21 kyrs ago



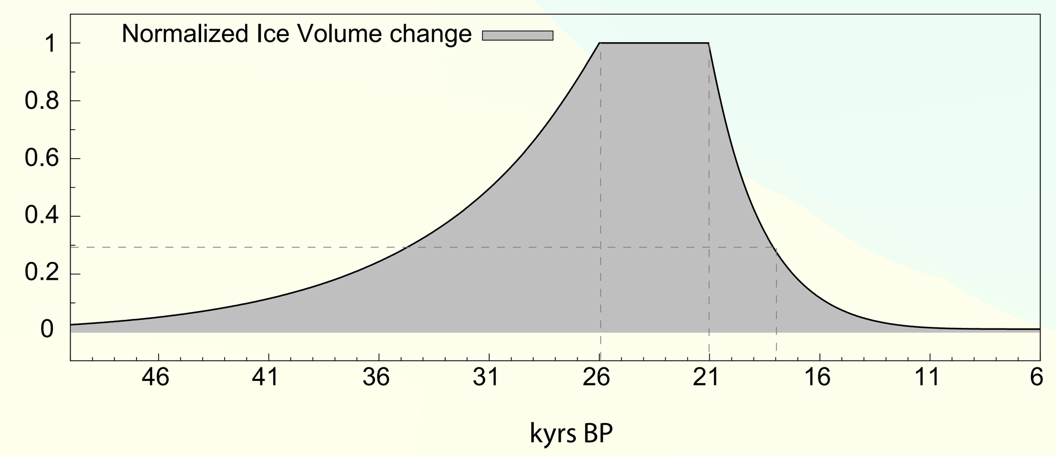
Digital model of Ice thikness during LGM (Last Glacial Maximum) used in Norton and Hampel (2010) based on the elevation of trim-lines and the position of the ice margin, which together constrain the ice surface (Jäckli, 1970; Florineth and Schlüchter, 1998; Kelly et al., 2004; Ivy-Ochs et al., 2006). The ice distribution was then calculated by subtracting the ground elevation from the altitude of the ice surface.



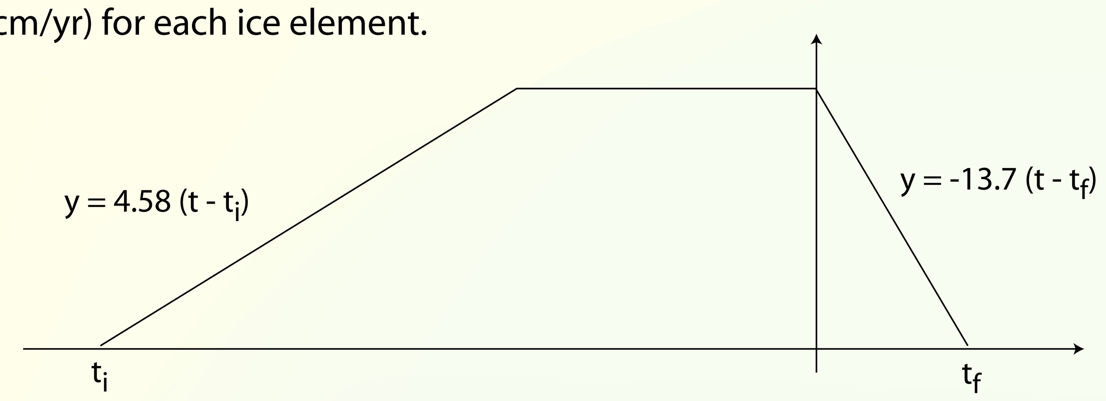
Since trimlines are not necessarily the top of the ice, the big assumptions is that they should at worst mark the boundary between ductile and brittle flow, and given that temperatures were not too cold during the LGM, that this is probably less than 100 m or so deep (Kevin Norton personal communication).

2. Ice Model

We implemented an ice model with both glaciation and deglaciation phase starting from the ice thickness described in Box 1.
One issue is the choice of the timing in the melting process.
We chose to implement a linear behaviour with a rate for the accumulation and another for the deglaciation phase.



The deglaciation process is set between 21 and 15 kyr ago. We calculate a melting rate of about 13.7 cm/yr equal for each element of the ice distribution in such a way that the 70% of the total ice volume is lost in the first 3 kyr and the remaining in the subsequent 3 kyr from the beginning of the deglaciation.
The glaciation phase ended 26 kyr ago and it reasonably lasted three times more than the deglaciation phase, so we assumed an accumulation rate of one third of the melting rate (4.58 cm/yr) for each ice element.



For every ice element a time behaviour like the one depicted is assumed, where t_i and t_f depend on the mass of the individual element..

3. The high resolution technique

For each element of the ice we calculate (up to harmonic degree 1536) a different green function to take into account the different time of the ice exhaustion, given the fixed accumulation/melting rate.
We used the high resolution technique and the Earth model as in Barletta et al. 2006, to calculate over the European Alps the uplift rate and the gravity anomaly contribution from all the ice elements.

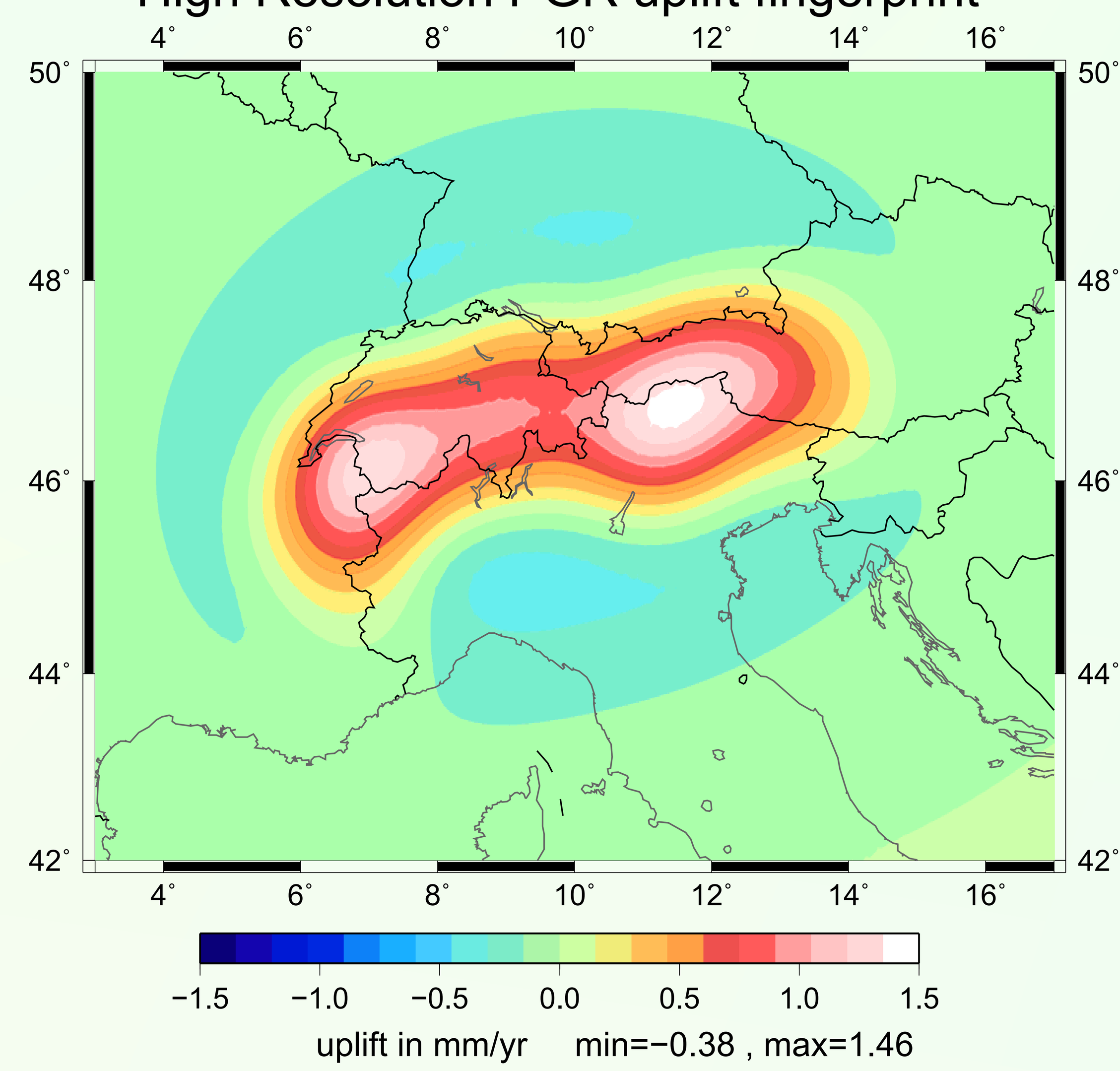
4. Sensitivity to Earth Model

Table 2. Rheologic Structure

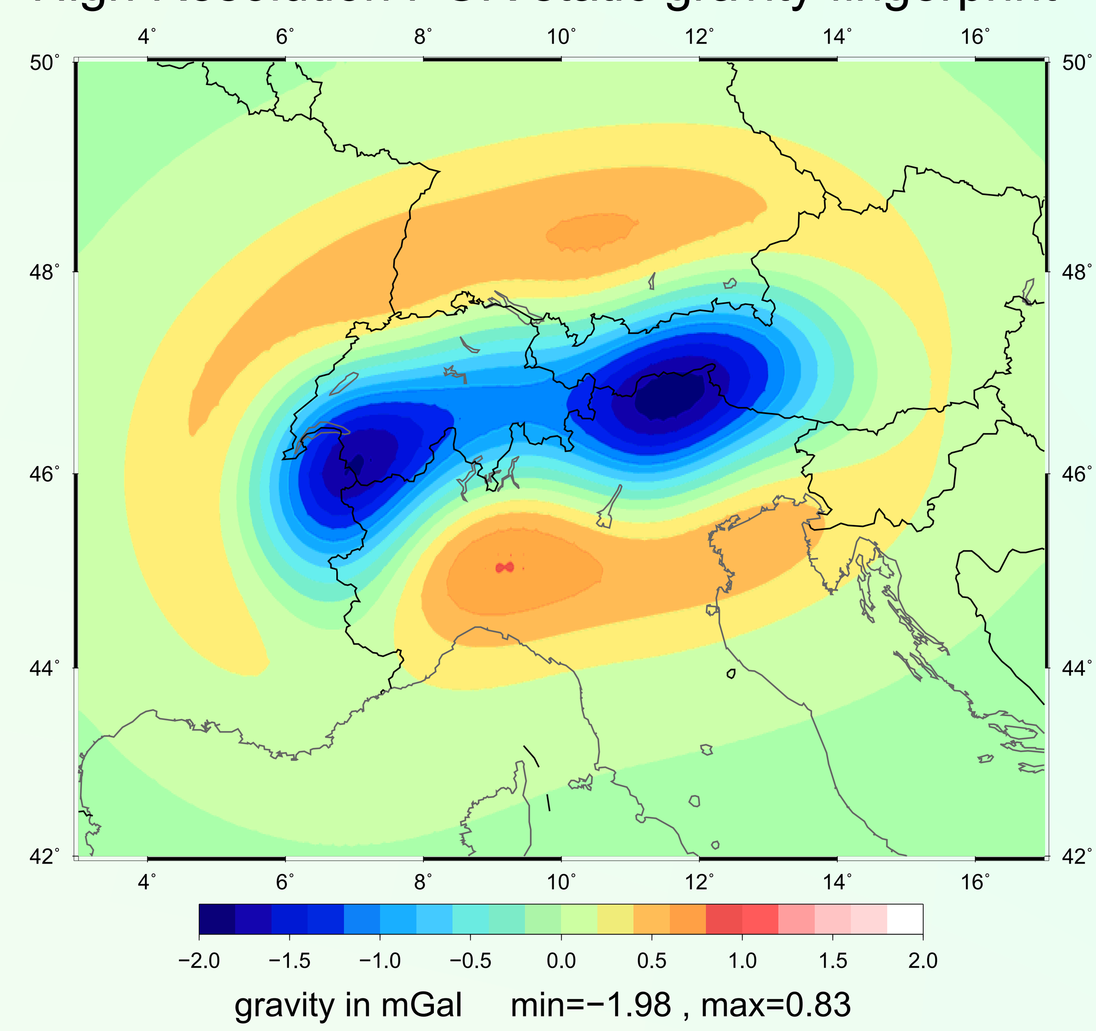
Layer	r, km	ρ, kg/m³	μ, Pa	ν, Pa s
1	6371.0	2650.0	2.97×10^{10}	1.00×10^{35}
2	6352.5	2750.0	5.58×10^{10}	2.15×10^{19}
3	6341.0	2900.0	6.81×10^{10}	5.00×10^{21}
4	6331.0	3439.3	7.27×10^{10}	4.64×10^{20}
5	5951.0	3882.3	1.09×10^{11}	4.64×10^{20}
6	5701.0	4890.6	2.21×10^{11}	1.00×10^{21}
7	3480.0	10932.	0.00	0.0

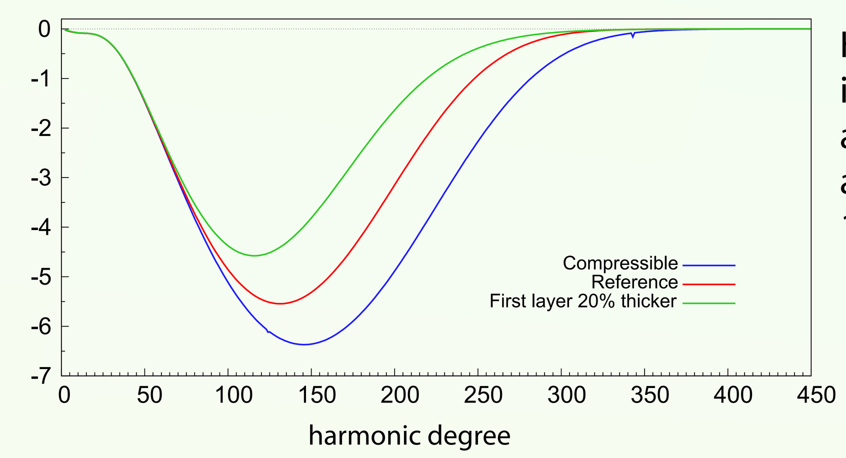
We also tested the sensitivity of the PGR results with respect to ice model and with respect to Earth model, layering in particular.
We made two tests
1) increasing by 20% the first elastic layer
2) using a compressible rheology as done in Tanaka et al. 2011.
In both cases we obtained at most, in corrispondence of the maximum uplift, a +/- 15% difference.

High Resolution PGR uplift fingerprint



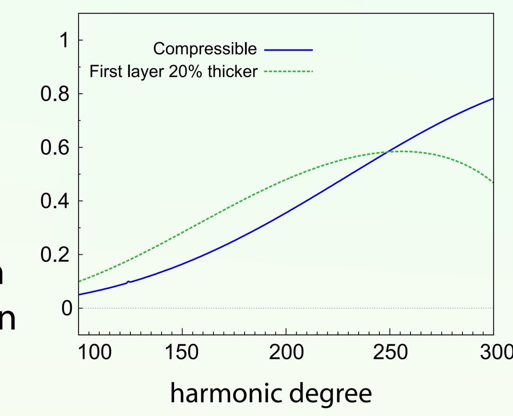
High Resolution PGR static gravity fingerprint





Here the Green Functions calculated for a sample ice element which ends the deglaciation 18 kyr ago. The difference in the use of the 3 models are concentrated between the harmonic degree 100 and 300.

Normalized differences with the reference Green function



References:
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Norton, K. P. and Hampel, A. (2010), Postglacial rebound promotes glacial re-advances – a case study from the European Alps. Terra Nova, 22: 297–302. doi: 10.1111/j.1365-3121.2010.00946.x
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