

Towards an improved Glacial Isostatic Adjustment model for Fennoscandia: Quantifying Earth model uncertainty using decay time estimates from Ångermanland

Maaria Nordman, Finnish Geodetic Institute

Glenn Milne, University of Ottawa

Lev Tarasov, Memorial University of Newfoundland



FINNISH GEODETIC
INSTITUTE

NKG General Assembly 2.9.2014

Introduction

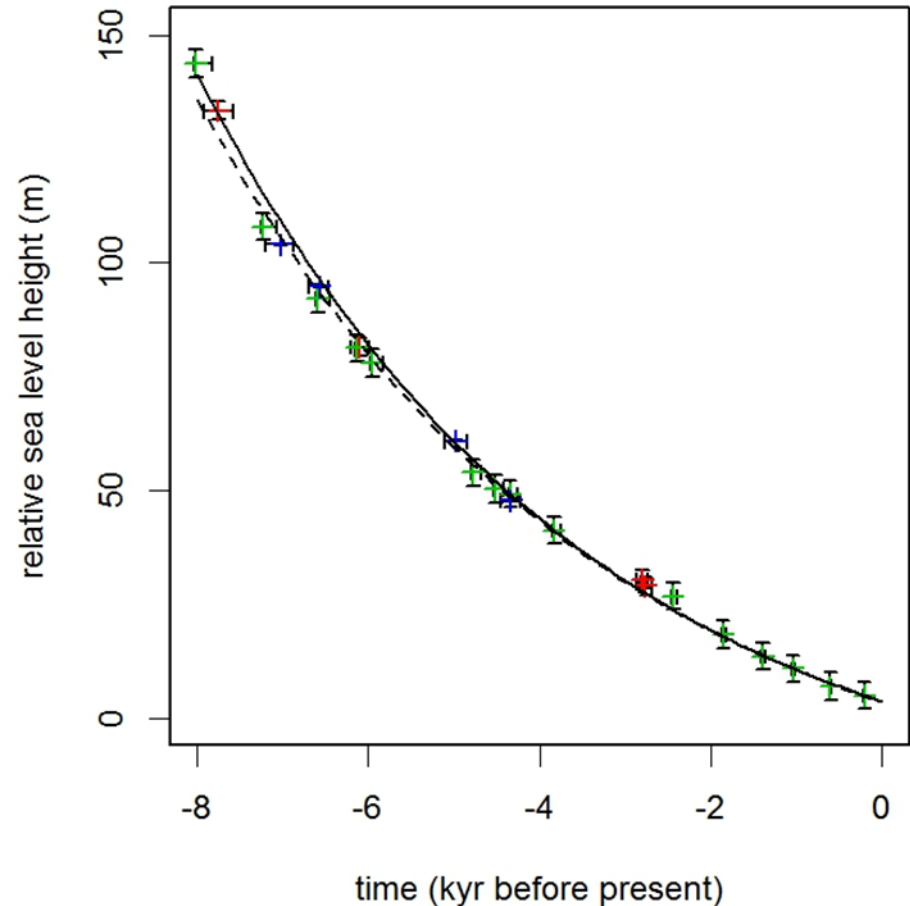
- GIA is the dominant geodynamic process in Fennoscandia, controlling land motion and relative sea level change
- GIA models have no uncertainties
- Ice models use certain Earth model (VM2/VM5)
- 3D Glacial Systems Model (GSM)
- Relative sea level curve for Ångermanland
- Decay time analysis

Decay time: one solution for ice model – earth model coupling problem

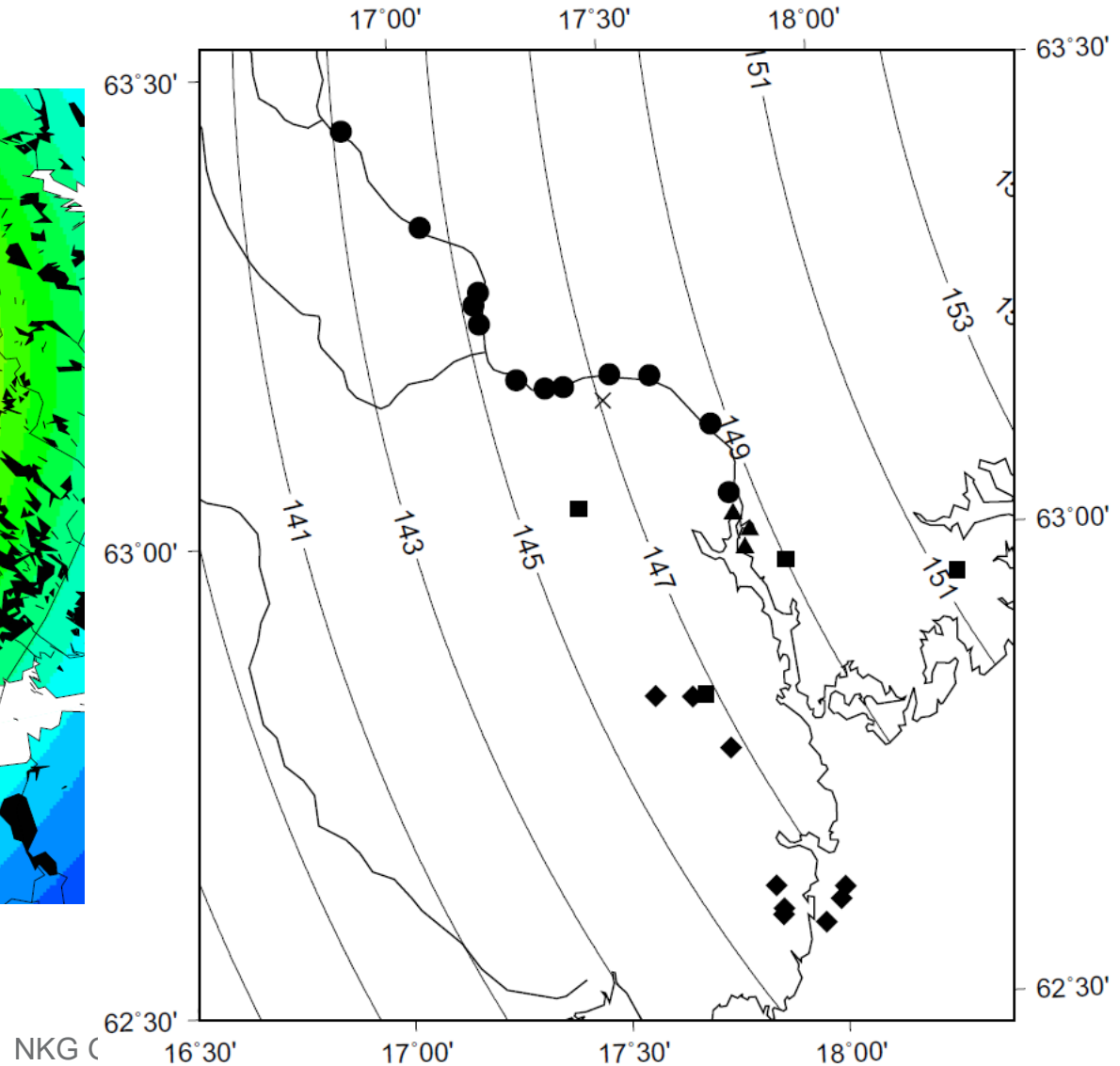
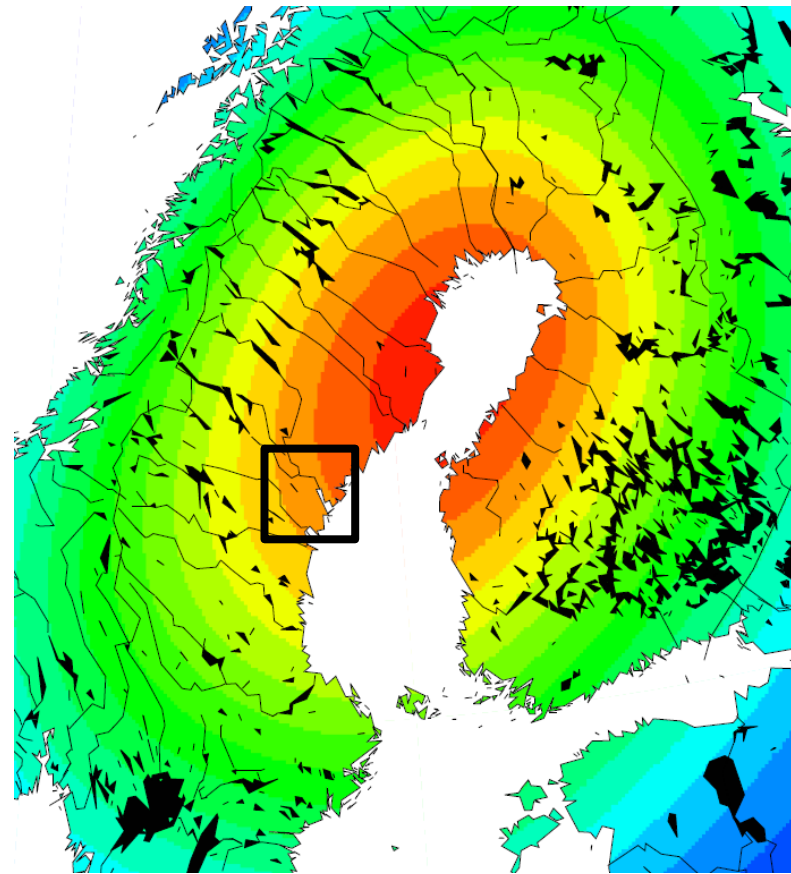
- Relative sea level curve can be fitted with exponential curve

$$RSL(t) = A(e^{-t/\tau} - 1) + c$$

- $RSL(t)$ relative sea level height over time (m)
- τ decay time (kyr)
- A and c constants (m)



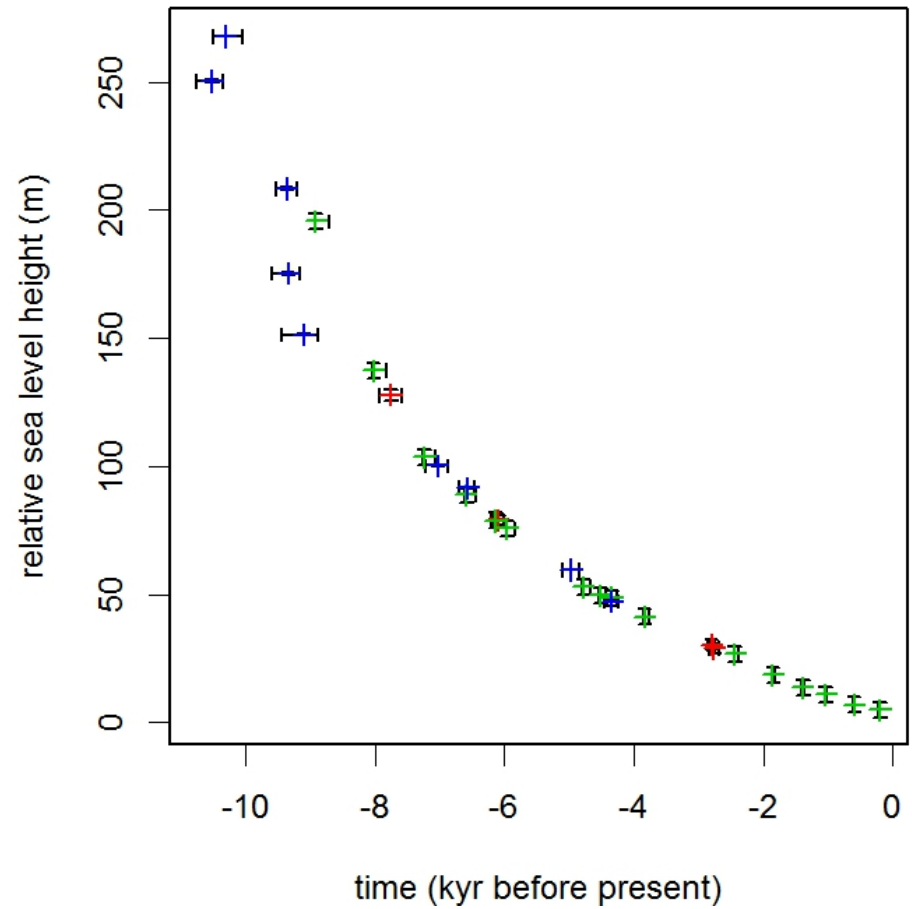
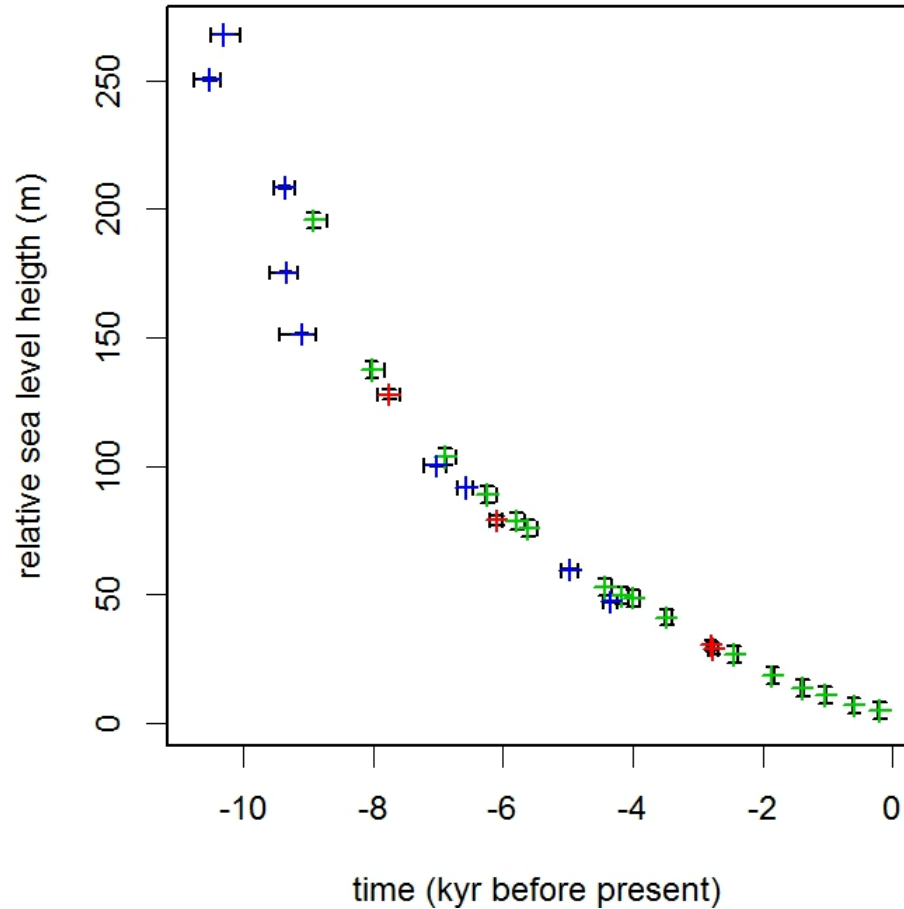
Study area: Ångermanland, Sweden



Relative sea level data: table

| Site | Lat | Long | ¹⁴ C yr BP | | cal yr BP | | | meters | | | | | Height reference | Type | Source |
|---------------------------|--------|--------|-----------------------|--------------|-----------|---------|---------|--------------|-----------------------|--------------------|-----------|--------------------|------------------|-------|----------------|
| | | | Age | σ Age | Age | Min age | Max age | Delta height | σ delta height | Original SL height | SL height | σ SL height | | | |
| Gårelehöjden | 63.6 | 16.817 | - | - | 8917 | 8907 | 9130 | 189.1 | 1 | 194.1 | - | - | RH00 | varve | Lidén (1938) |
| Nämforsen | 63.443 | 16.887 | - | - | 8022 | 8012 | 8214 | 133.9 | 1 | 138.9 | 136.9 | 3 | RH00 | varve | Lidén (1938) |
| Myre | 63.338 | 17.067 | - | - | 6890 | 6880 | 7055 | 100.1 | 1 | 104.1 | 103.1 | 3 | RH00 | varve | Lidén (1938) |
| Forsmobron | 63.267 | 17.200 | - | - | 6246 | 6236 | 6395 | 85.4 | 1 | 90.4 | 88.4 | 3 | RH00 | varve | Lidén (1938) |
| Sand (Ed socken) | 63.253 | 17.188 | - | - | 5791 | 5781 | 5930 | 75.2 | 1 | 80.2 | 78.2 | 3 | RH00 | varve | Lidén (1938) |
| Ön (Ed socken) | 63.233 | 17.200 | - | - | 5613 | 5603 | 5747 | 72.2 | 1 | 76.2 | 75.2 | 3 | RH00 | varve | Lidén (1938) |
| Risövikén (Sollefteå) | 63.172 | 17.283 | - | - | 4432 | 4422 | 4538 | 49.4 | 1 | 54.4 | 52.4 | 3 | RH00 | varve | Lidén (1938) |
| Nyland (Multrä s:n) | 63.162 | 17.350 | - | - | 4172 | 4162 | 4272 | 46.1 | 1 | 51.1 | 49.1 | 3 | RH00 | varve | Lidén (1938) |
| Färjastället (Multrä s:n) | 63.163 | 17.393 | - | - | 3996 | 3986 | 4092 | 45.2 | 1 | 48.2 | 48.2 | 3 | RH00 | varve | Lidén (1938) |
| Sågån | 63.175 | 17.503 | - | - | 3486 | 3476 | 3569 | 37.7 | 1 | 40.7 | 40.7 | 3 | RH00 | varve | Lidén (1938) |
| Björkä bruk | 63.172 | 17.598 | - | - | 2443 | 2433 | 2501 | 23.3 | 1 | 26.3 | 26.3 | 3 | RH00 | varve | Lidén (1938) |
| Undrom | 63.118 | 17.737 | - | - | 1857 | 1847 | 1901 | 15 | 1 | 18 | 18 | 3 | RH00 | varve | Lidén (1938) |
| Prästmon | 63.044 | 17.773 | - | - | 1395 | 1385 | 1428 | 10.2 | 1 | 12.2 | 13.2 | 3 | RH00 | varve | Lidén (1938) |
| Gistgårdsön | 63.021 | 17.781 | - | - | 1039 | 1029 | 1064 | 7.5 | 1 | 9.5 | 10.5 | 3 | RH00 | varve | Cato (1992) |
| Danero | 63.003 | 17.818 | - | - | 600 | 590 | 614 | 3.5 | 1 | 5.5 | 6.5 | 3 | RH00 | varve | Cato (1992) |
| Kungsgårdsfjärden | 62.984 | 17.805 | - | - | 204 | 194 | 209 | 1.5 | 1 | 3.5 | 4.5 | 3 | RH00 | varve | Cato (1992) |
| Filitjärnen | 63.033 | 17.417 | - | - | 7775 | 7605 | 7945 | - | - | - | 127.8 | 2 | RH00 | lake | Cato (1992) |
| Judesjön | 62.833 | 17.700 | - | - | 6098 | 5998 | 6198 | - | - | - | 79 | 2 | RH00 | lake | Cato (1992) |
| Koltjärnen | 62.950 | 18.300 | - | - | 2799 | 2739 | 2859 | - | - | - | 30.4 | 2 | RH00 | lake | Cato (1992) |
| Ödstjärn | 62.967 | 17.900 | - | - | 2761 | 2691 | 2831 | - | - | - | 29 | 2 | RH00 | lake | Cato (1992) |
| Stormomyren | 62.772 | 17.753 | 9120 | 105 | 10310 | 10120 | 10570 | - | - | - | 268.4 | 0.1 | RH70(?) | lake | Berglund(2004) |
| Frättentjärn | 62.830 | 17.582 | 9320 | 70 | 10520 | 10290 | 10700 | - | - | - | 251 | 0.5 | RH70(?) | lake | Berglund(2004) |
| Orrmyran | 62.828 | 17.669 | 8360 | 80 | 9360 | 9190 | 9520 | - | - | - | 209 | 0.5 | RH70(?) | lake | Berglund(2004) |
| Lomtjärn | 62.592 | 17.859 | 8350 | 105 | 9340 | 9090 | 9530 | - | - | - | 176 | 0.5 | RH70(?) | lake | Berglund(2004) |
| Värptjärn | 62.598 | 17.861 | 8145 | 95 | 9100 | 8770 | 9330 | - | - | - | 152 | 0.1 | RH70(?) | lake | Berglund(2004) |
| Betlehemsmyran | 62.623 | 17.845 | 6135 | 65 | 7030 | 6850 | 7180 | - | - | - | 100.9 | 0.2 | RH70(?) | lake | Berglund(2004) |
| Mårtenmyran | 62.606 | 17.994 | 5770 | 55 | 6570 | 6440 | 6680 | - | - | - | 92.3 | 0.2 | RH70(?) | lake | Berglund(2004) |
| Lapptjärnsmyran | 62.619 | 18.004 | 4370 | 75 | 4970 | 4830 | 5090 | - | - | - | 60.3 | 0.2 | RH70(?) | lake | Berglund(2004) |
| Brattåsmöran | 62.582 | 17.957 | 3910 | 60 | 4340 | 4220 | 4450 | - | - | - | 48 | 0.2 | RH70(?) | lake | Berglund(2004) |

Relative sea level data: plotted



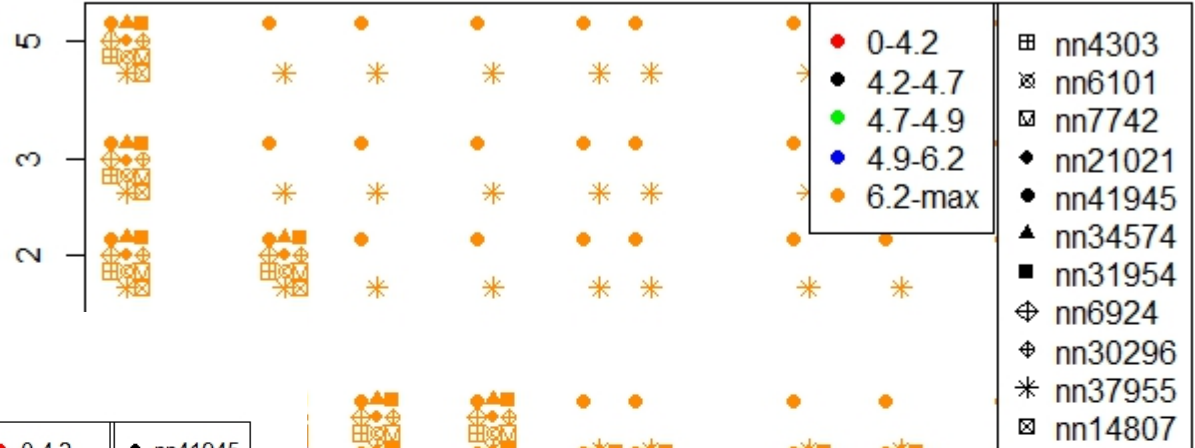
$$RSL(t) = A(e^{-t/\tau} - 1) + c$$



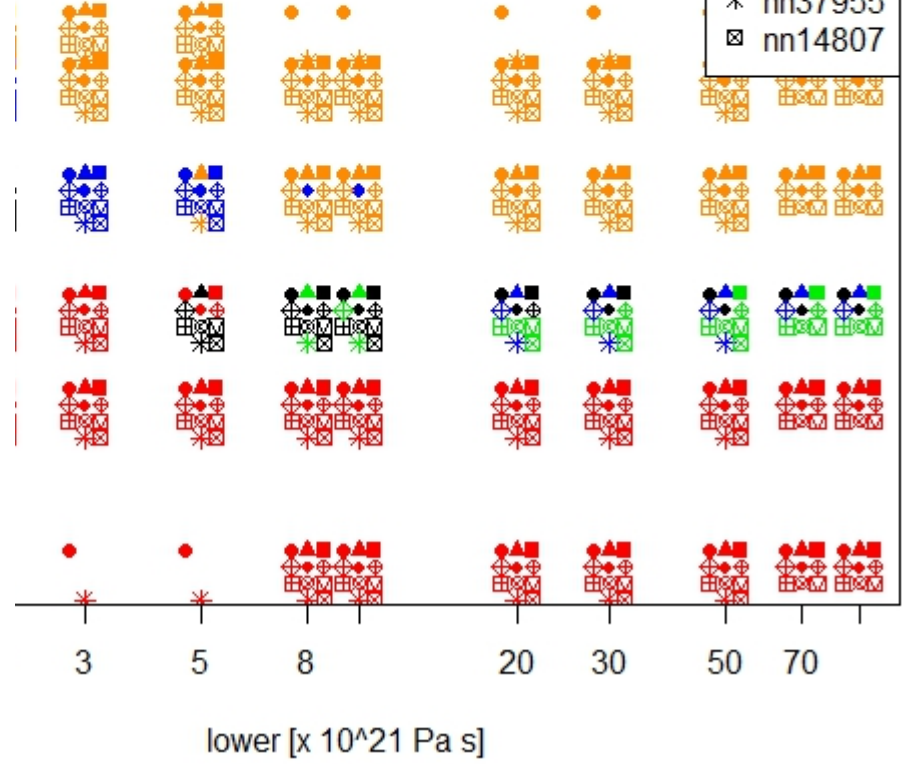
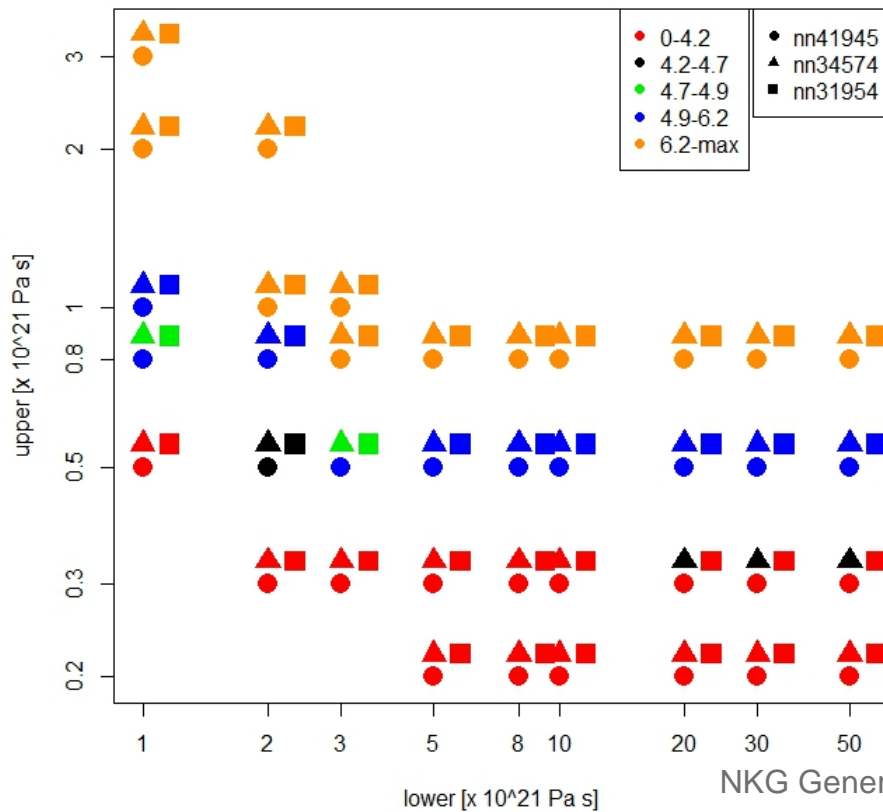
| data | | A | 95% | | tau | 95% | | c | 95% | | N |
|-------------------------------------|------------|--------|-------|-------|--------|-------|-------|--------|-------|-------|-------|
| row # in table 2. | correction | median | lower | upper | median | lower | upper | median | lower | upper | |
| 2 - 13 original varves | none | 19.7 | 14.0 | 28.3 | 4.0 | 3.5 | 4.8 | 8.1 | 4.7 | 11.4 | 163 |
| | eust | 16.1 | 10.8 | 23.8 | 3.6 | 3.1 | 4.3 | 9.0 | 5.4 | 12.6 | |
| | all | 15.9 | 10.7 | 23.8 | 3.6 | 3.1 | 4.3 | 9.2 | 5.5 | 12.8 | |
| | limit c | 27.7 | 23.2 | 32.4 | 4.6 | 4.2 | 5.0 | 3.5 | 1.9 | 4.0 | |
| 2 - 20 varves 1992 | none | 23.9 | 18.9 | 30.3 | 4.3 | 3.9 | 4.9 | 5.7 | 3.9 | 7.5 | 720 |
| | eust | 19.8 | 15.0 | 26.3 | 3.9 | 3.4 | 4.4 | 6.2 | 4.2 | 8.2 | |
| | all | 19.7 | 14.9 | 26.3 | 3.9 | 3.4 | 4.4 | 6.3 | 4.3 | 8.4 | |
| | limit c | 26.9 | 23.4 | 30.9 | 4.5 | 4.2 | 4.8 | 3.7 | 2.9 | 4.0 | |
| 17 - 20, 26 - 29 lakes | none | 16.5 | 9.5 | 27.7 | 3.7 | 3.0 | 4.7 | 11.8 | 6.6 | 16.7 | 311 |
| | eust | 13.3 | 7.8 | 24.4 | 3.3 | 2.7 | 4.3 | 13.1 | 7.1 | 17.9 | |
| | all | 13.7 | 7.8 | 27.1 | 3.4 | 2.7 | 4.5 | 12.9 | 6.3 | 18.0 | |
| | limit c | 37.4 | 29.6 | 49.3 | 5.3 | 4.6 | 6.2 | 3.1 | 0.6 | 4.0 | |
| 2 - 20, 26 - 29 varves and lakes | none | 25.2 | 20.5 | 31.4 | 4.5 | 4.0 | 5.0 | 5.5 | 3.7 | 7.2 | 1302 |
| | eust | 20.9 | 16.0 | 27.3 | 4.0 | 3.5 | 4.5 | 6.1 | 4.0 | 8.1 | |
| | all | 21.0 | 16.0 | 27.8 | 4.0 | 3.5 | 4.6 | 6.1 | 4.1 | 8.2 | |
| | limit c | 27.9 | 24.5 | 32.8 | 4.5 | 4.2 | 4.9 | 3.7 | 2.7 | 4.0 | |
| 3-16, 18-20, 26-29 7kyrs | all | 33.8 | 25.5 | 45.2 | 5.1 | 4.4 | 6.1 | 3.9 | 1.9 | 5.9 | 32292 |
| | limit c | 36.8 | 30.3 | 47.0 | 5.3 | 4.7 | 6.2 | 3.3 | 1.6 | 4.0 | |
| 5-16, 18-20, 28-29 6kyrs | all | 38.1 | 26.4 | 56.2 | 5.5 | 4.5 | 7.0 | 3.6 | 1.5 | 5.7 | 39060 |
| | limit c | 41.3 | 31.6 | 58.5 | 5.8 | 4.9 | 7.2 | 3.1 | 1.3 | 4.0 | |

Fitting the models

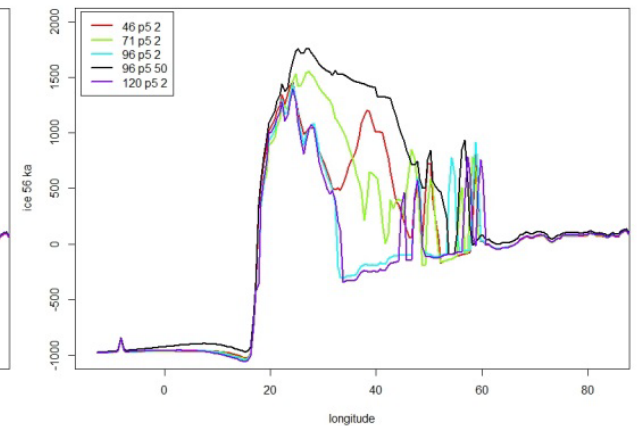
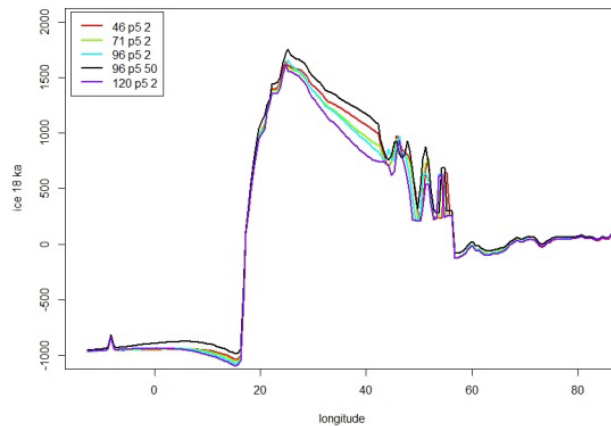
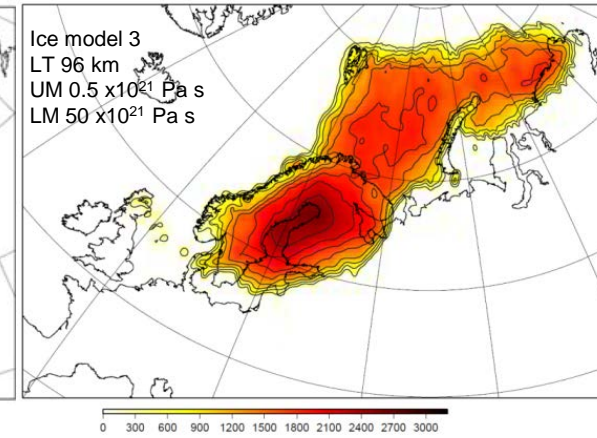
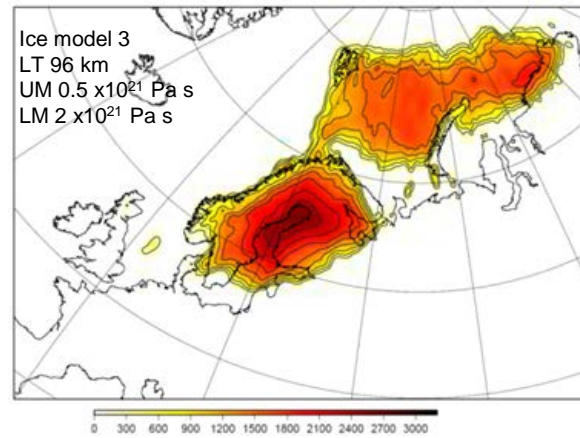
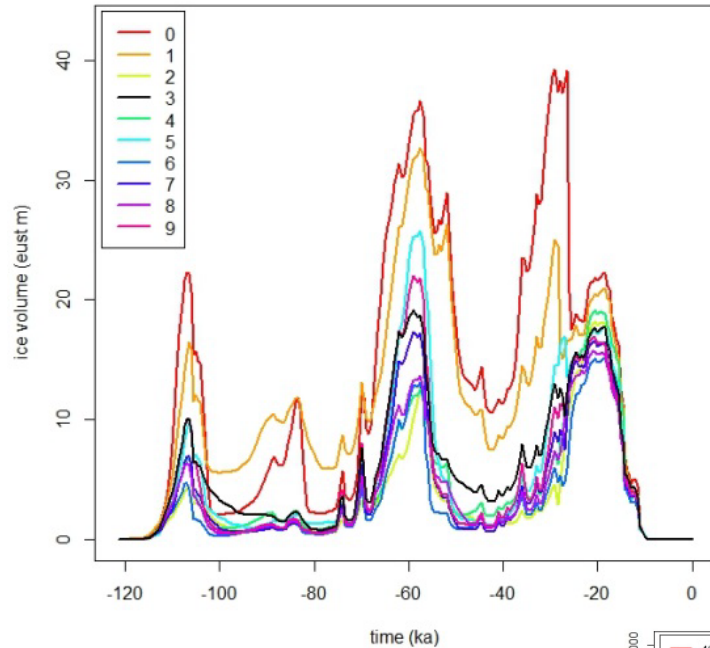
Lithosphere 120 km



Lithosphere 46 km



How does this affect the ice model?



Conclusions

- Decay time analysis is insensitive to ice load model
- About 10 Earth models match the tighter constraint per LT
- About 17 Earth models match more conservative constraint per LT
- Earth model has an effect on ice model

Thank you! Questions?