EGSIEM

European Gravity Service for Improved Emergency Management

Task 3.8 – GIA (correction) for hydrology Status January 2017

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Glacial Isostatic Adjustment model

- Once developed to determine mantle viscosity for convection models and to describe sea-level variations, nowadays quite complex
- Two major parts: (I) Earth (Rheology) model and (II) ice model
- Other information: Topography model (for time-dependent ocean function)
- Mathematical-physical theory relating the physics of the ice-earth-ocean changes to observational quantities
  - Earth and ice models are coupled via the sea-level equation
- Needs (III) observations for tuning
- Can take different processes/effects into account:
  - Deformation
  - Mass redistribution (ice, water, earth, (sedimentation))
  - Earth rotation
  - Geoid & sea-level changes
  - Stress changes
- A well-fitting GIA model for one quantity may NOT fit another quantity well!

Task 3.8 (from the proposal)

T3.8: GIA for Hydrology LM (covered by SLA, see Sect. 3.3.4) M11-M36
Input: *D2.1, Gravity field solutions from T2.3, combined solution from T4.2, NRT solutions from T5.2 and T5.3, regional solutions from T5.4*
Efficient monitoring tools of the available water resources on regional and local scales need to take global interactions into account. In northern latitudes, e.g. in Fennoscandia, the tilting due to the GIA will be modelled by applying the latest GIA models. This is necessary because it strongly affects groundwater flow and lake surface control. The consortium will benefit from the latest developments in GIA modelling through the associated member Lantmäteriet.
Output: *GIA models; When?*

Sect. 3.3.4 (from the proposal)

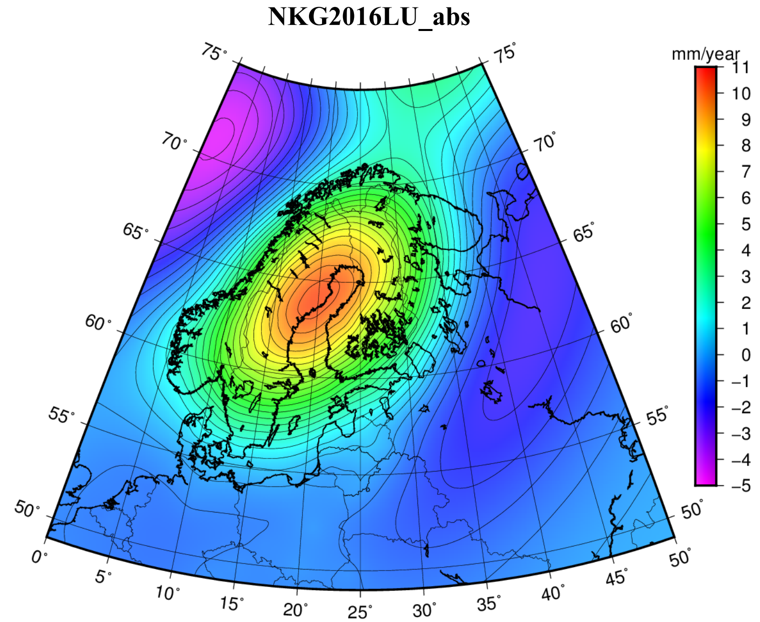
LM will provide a sophisticated global GIA model to the project, whose Fennoscandian part will be used at LM for corrections of the Swedish reference network (SWEREF99), and national height (RH2000) and gravity models (RG2000). This model part will be publicly released by 2015 as part of LM's strategic geodesy plan for the decade 2010-2020. It will include station and grid values (1x1 degree or finer) of velocities, geoid, geoid changes, and gravity changes. A global velocity field of 1x1 degree grid will substitute a 2x2 degree grid field that was made accessible to the GIA community through the COST action ES0701. (…)

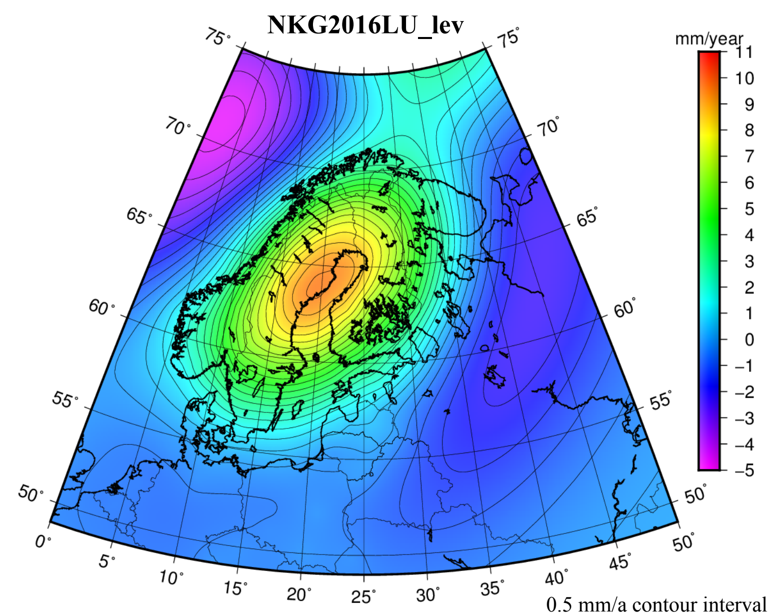
Status of Fennoscandian part

- Uplift model NKG2016LU released June 2016, GIA model part NKG2016GIA_prel0306 available on request
- Geoid model NKG2015 released October 2016
- Velocity model NKG_RF17vel to be processed this year, release hopefully summer 2017, GIA model part NKG2016GIA_prel0907 done
- NKG2016LU_gdot gravity change model to be processed this year, release end of 2018
- No official geoid change model planned, but geoid change component of NKG2016GIA_prel0306 available on request

NKG2016LU

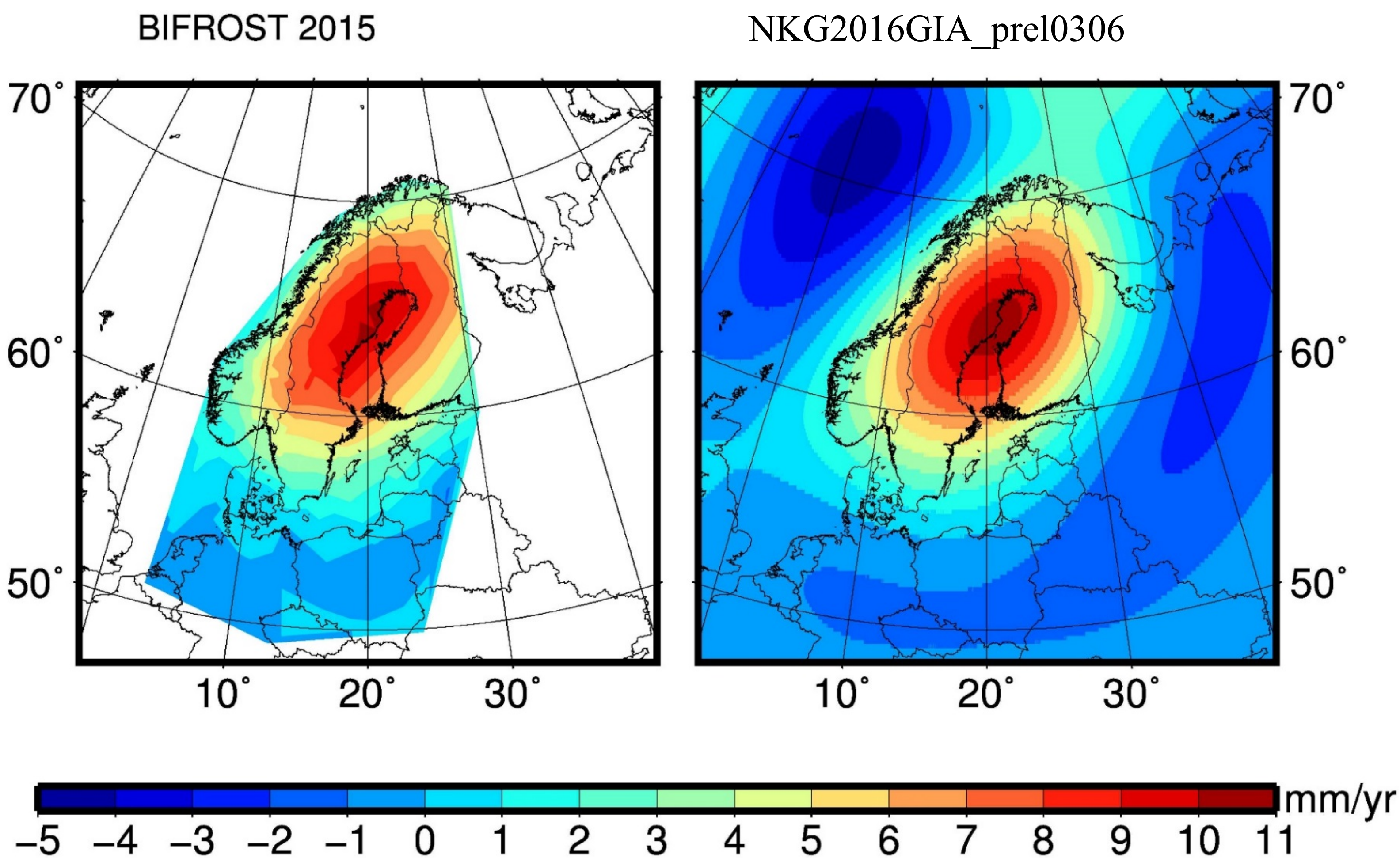
- Semi-empirical land uplift model computed in Nordic-Baltic cooperation in the NKG Working Group of Geoid and Height Systems
- Vertical land uplift rate in two different ways (high resolution of 10′ long./5′ lat.):
  - **NKG2016LU_abs**: Absolute land uplift in ITRF2008 (i.e. relative to the Earth's centre of mass)
  - **NKG2016LU_lev**: Levelled land uplift, i.e. uplift relative to the geoid
- NKG2016LU has been computed based on
  - An **empirical land uplift model** computed by Olav Vestøl based on geodetic observations
  - The preliminary geophysical GIA model **NKG2016GIA_prel0306** (next slide) computed by Steffen et al. (2016) in the NKG WG of Geodynamics



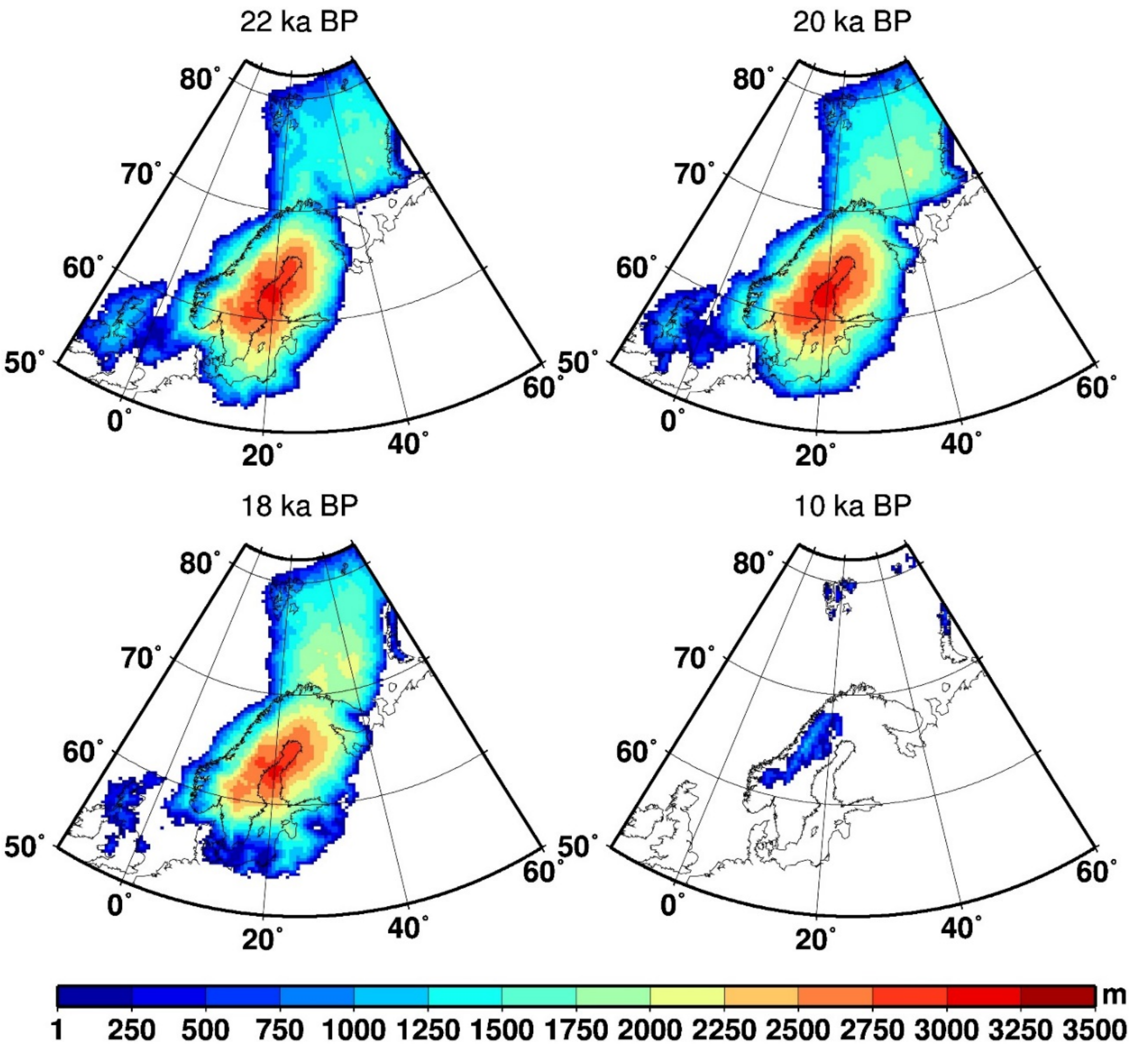


Best fitting model to GNSS and RSL observations

160 km lith. thick., 7 x 10^{20} Pa s upper mantle visc., 7x10^{22} lower mantle visc.

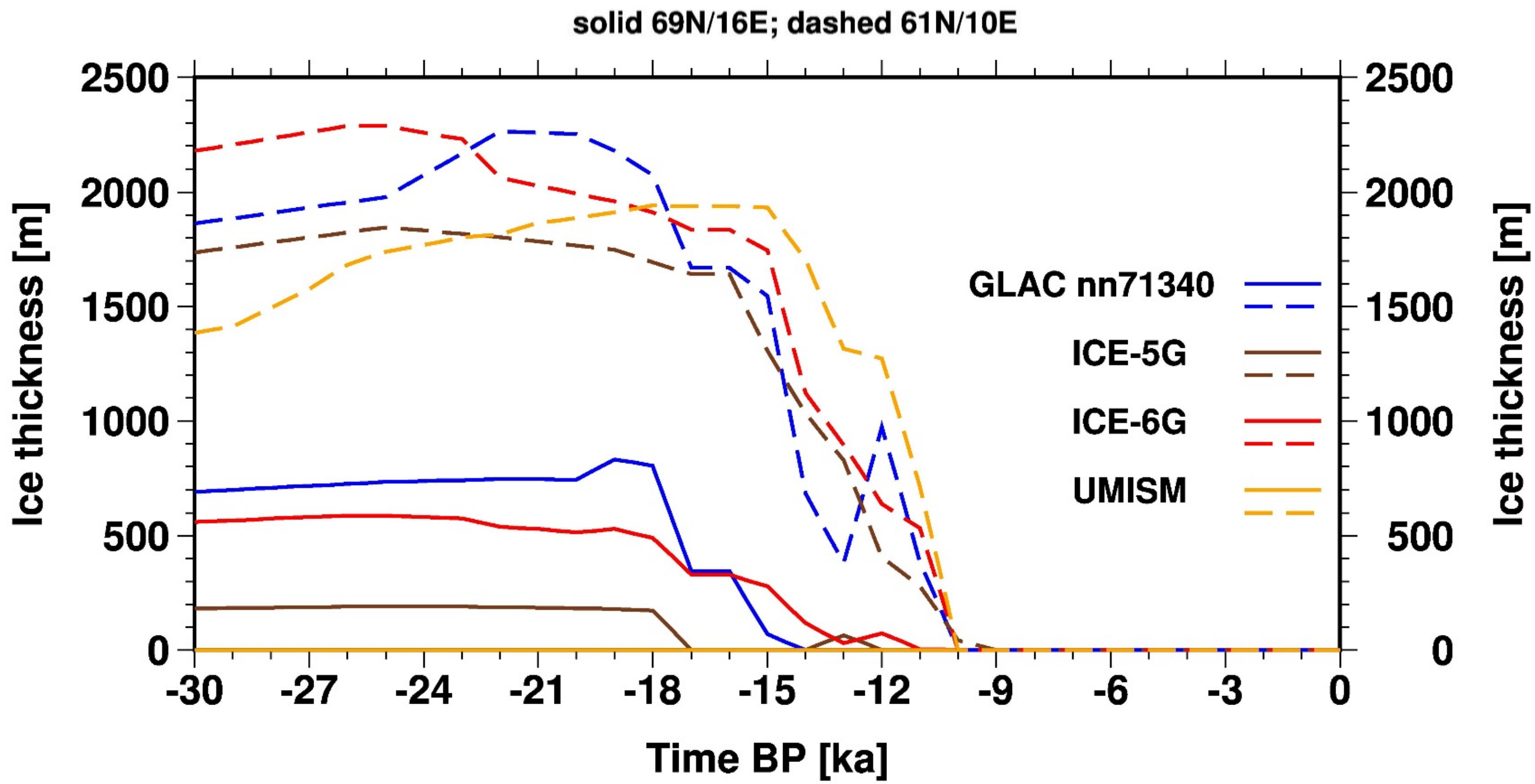


Best ice model GLAC-71340



- Glaciological Systems Model (GSM) results kindly provided by Lev Tarasov, Memorial University of Newfoundland, Canada, to NKG
- 3D thermo-mechanically coupled glaciological model calibrated against ice margin information, present-day uplift, relative sea-level records
- 39 ensemble parameters (the majority related to the climate forcing) subject to Bayesian calibration
- Calibration done with Peltier's VM5a earth model
- Takes uncertainties in the constraints into account → generates posterior probability distributions for past ice sheet evolution (Tarasov et al., 2012)

GLAC vs. other ice models



Model set-up for first EGSIEM GIA correction

- Ice models:
  - Best GLAC (#71340) for Fennoscandia/Barents Sea, GLAC for North America, GLAC for Antarctica, HUY3 for Greenland, *IJ04 for Patagonia*, rest (Iceland, HMA, Siberia, Tibet) from ANU-ICE
- Earth model:
  - *Dedicated earth model for each region*, Maxwell rheology, using Wu (2004) 3D spherical FE model approach
  - Other model parameters (ice/water density, Earth radius, moments of inertia, π, etc.) as used in COST benchmark activity (see Spada et al. 2010)
- Observations (to be done):
  - Global RSL data
  - GNSS in North America and northern Europe
  - EGSIEM GRACE result (?)

Ice models

A series of regional ice models was kindly provided by colleagues for this purpose:

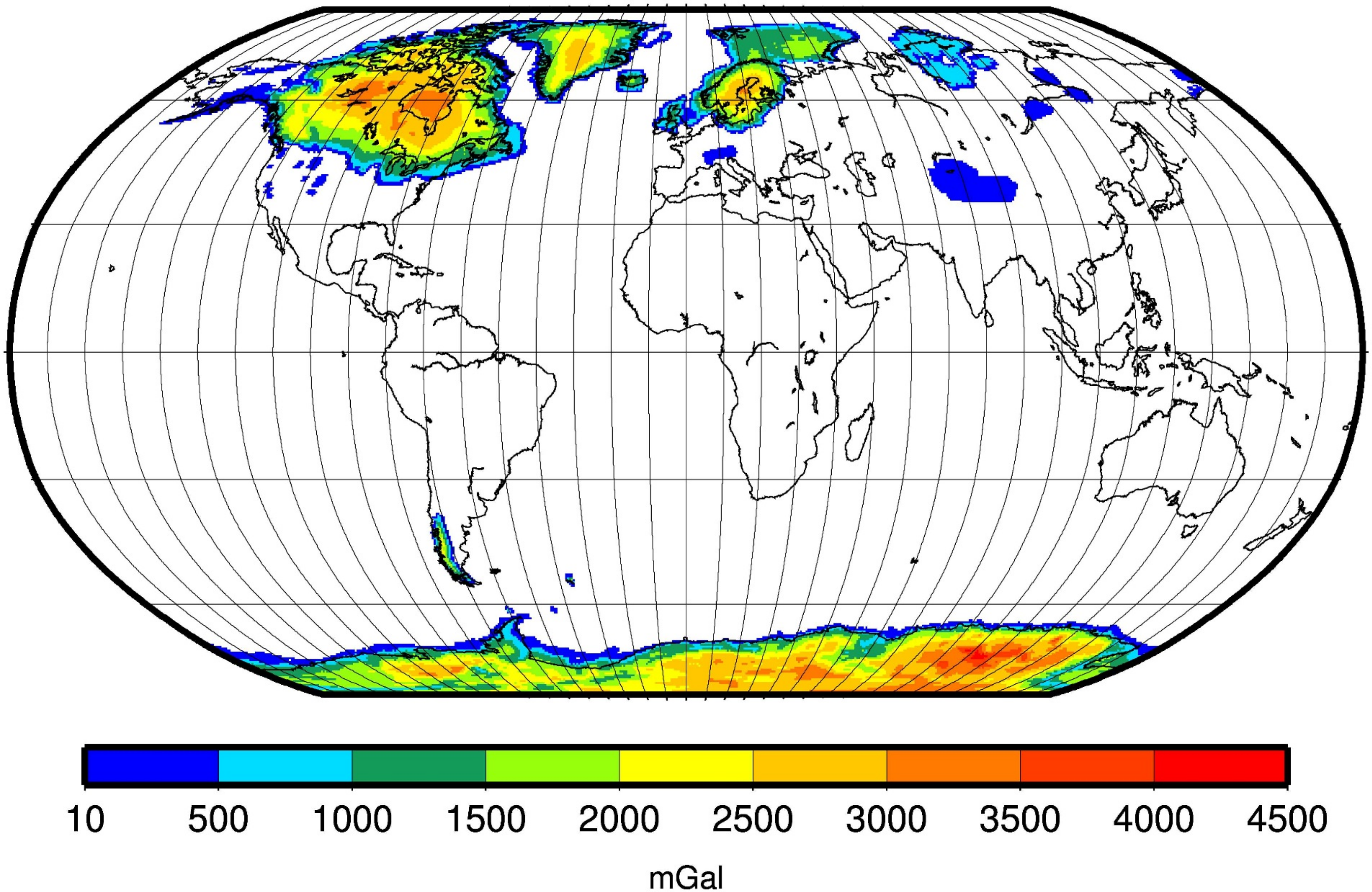
- Greenland (2): HUY3 (Lecavalier et al. 2014), ANU-ICE (Lambeck et al. 2014)
- Fennoscandia and Barents Sea (2): GLAC (Hughes et al. 2015, Nordman et al. 2015, Root et al. 2015; updated chronologies from Lev Tarasov), ANU-ICE (Lambeck et al. 2010)
- North America (3): GLAC (Tarasov et al. 2012), NAIce (Gowan et al. 2016), ANU-ICE (Lambeck et al. 2017)
- Antarctica (including Antarctic Peninsula) (4): W12 (Whitehouse et al. 2012), IJ05_R2 (Ivins et al. 2013), GLAC (Briggs et al. 2014), ANU-ICE (unpublished)
- Patagonia (2): updated IJ04 (Ivins & James 2004), ANU-ICE (Lambeck et al. 2014)
- High Mountain Areas, Iceland, Siberia, Tibet & small SH glaciers (1): ANU-ICE (Lambeck et al. 2014)

Ice model combination is not easy

- Different grids (e.g. 0.5x0.25 vs. 0.7x0.7)
- Different start & end times, # time steps and time intervals
- **The global combination will most likely not fit the expected sea-level equivalent of at least 120 m at LGM (missing ice problem)**

Model			ANU_ICE					GLAC			NAICE	HUY3	W12	IJ05_R2	ICE-6G_C
Region	skan+bar	brit	na+green	nh_glac	sh_glac	ant	skan+bar+ brit	na	ant	global	na	green	ant	ant	global
Version/ Number	16	10	19	12	12	12	71340	9894	4041	skan90227 +na9894 +ant6005 +green	2	(3)	(1)	(2)	(6)
Resolution Grid	0.5x0.25	0.25x0.125	0.5x0.25	1x0.5	1x0.5	1x1	0.5x0.25	0.5x0.25	1x0.5	1x0.5	0.5x0.25	0.7x0.7	0.7x0.7	0.7x0.7	1x1
Start-End-Grid (lon/lat/lon /lat)	0/83/ 115/50.25	-10.25/58.75/ 4/51.5	-139/84.5 / -7/38	-179/80.5 / 180/35	-75/-38/ -36/-62.5	-179/-61.5/ 180/-89.5	-12.75/48.125/ 119.25/83.125	-172.5/34.75/ -42.5/84.75	0.5/-89.75/ 359.5/-52.75	global	-166/83/ -51.5/37.5	global	global	-180/-57.2/ 179.3/-89.5	global
Start-End Time	240000-9650	195000-6000	240000-6800	240000-0	240000-0	250000-0	120000-0	120000-0	200000-0	120000-0	200000-5000	122000-+500	122000-+500	21000-2200	26000-0
Timesteps	76	74	64	48	48	49	97	97	117	391	40	68	57	9	48
Reference	Lambeck et al. 2010, Boreas	?	Lambeck et al. 2017, QSR	unpubl.	unpubl.	unpubl.	Nordman et al. 2015, GJI	Tarasov et al. 2012, EPSL	Briggs et al. 2013, Cryosphere	unpubl.	Gowan et al. 2016, GMD	Lecavalier et al. 2014, QSR	Whitehouse et al. 2012, QSR	Ivins et al. 2013, JGR	Peltier et al. 2015, JGR

First model: Ice thickness at 22 ka BP



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- Observations (to be done):
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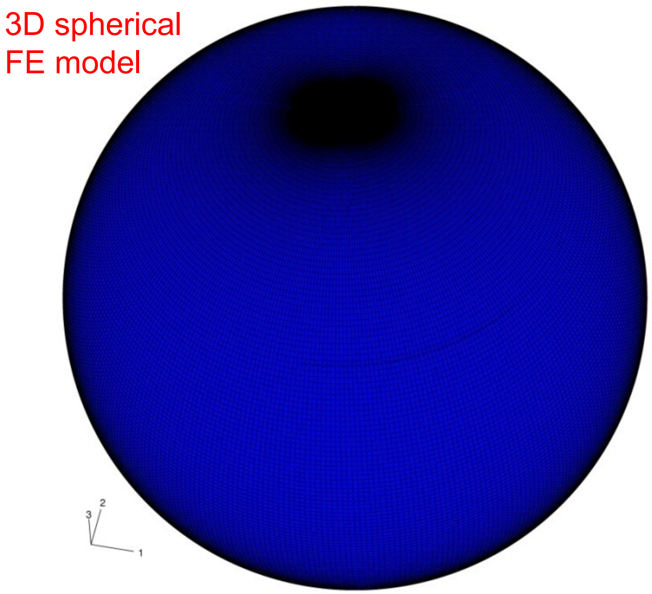
3D modelling

- Using model approach by Wu (2004)
- Global model, 0.5x0.5 degrees
- Lateral variations in lithospheric thickness and mantle viscosity possible
- Rotational feedback (in test mode)
- Compressibility (in test mode)
- Time-dependent coastlines

- Problems:
  - Sea-level equivalent from ice model
  - Run time (reduces time steps)



Earth model combination is not easy either

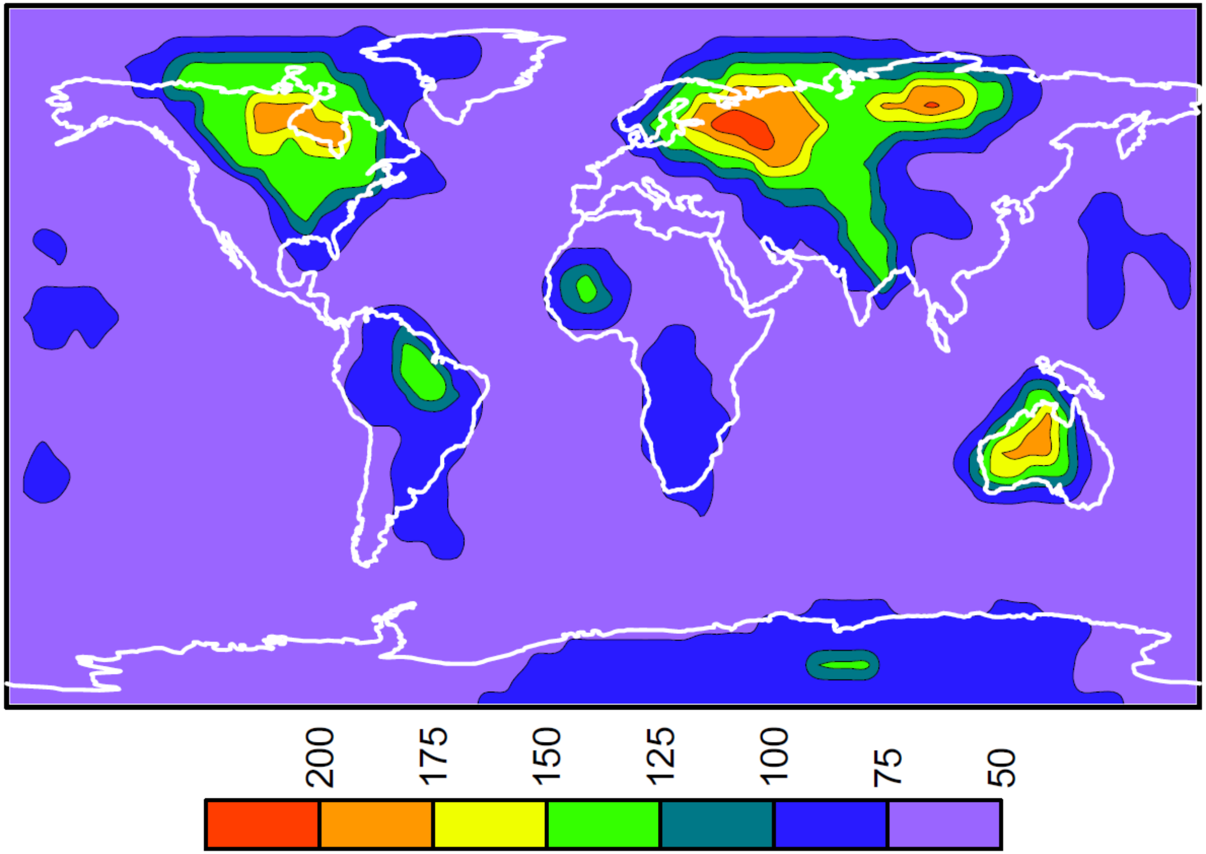
Corresponding Earth models to the ice models:

- Different lithospheric thicknesses
- Different mantle viscosities, different layers (number and/or depth interval)

Plan: Each model will be implemented in the GIA model with its ~corresponding Earth model → lateral variation in lithospheric thickness and mantle viscosity!

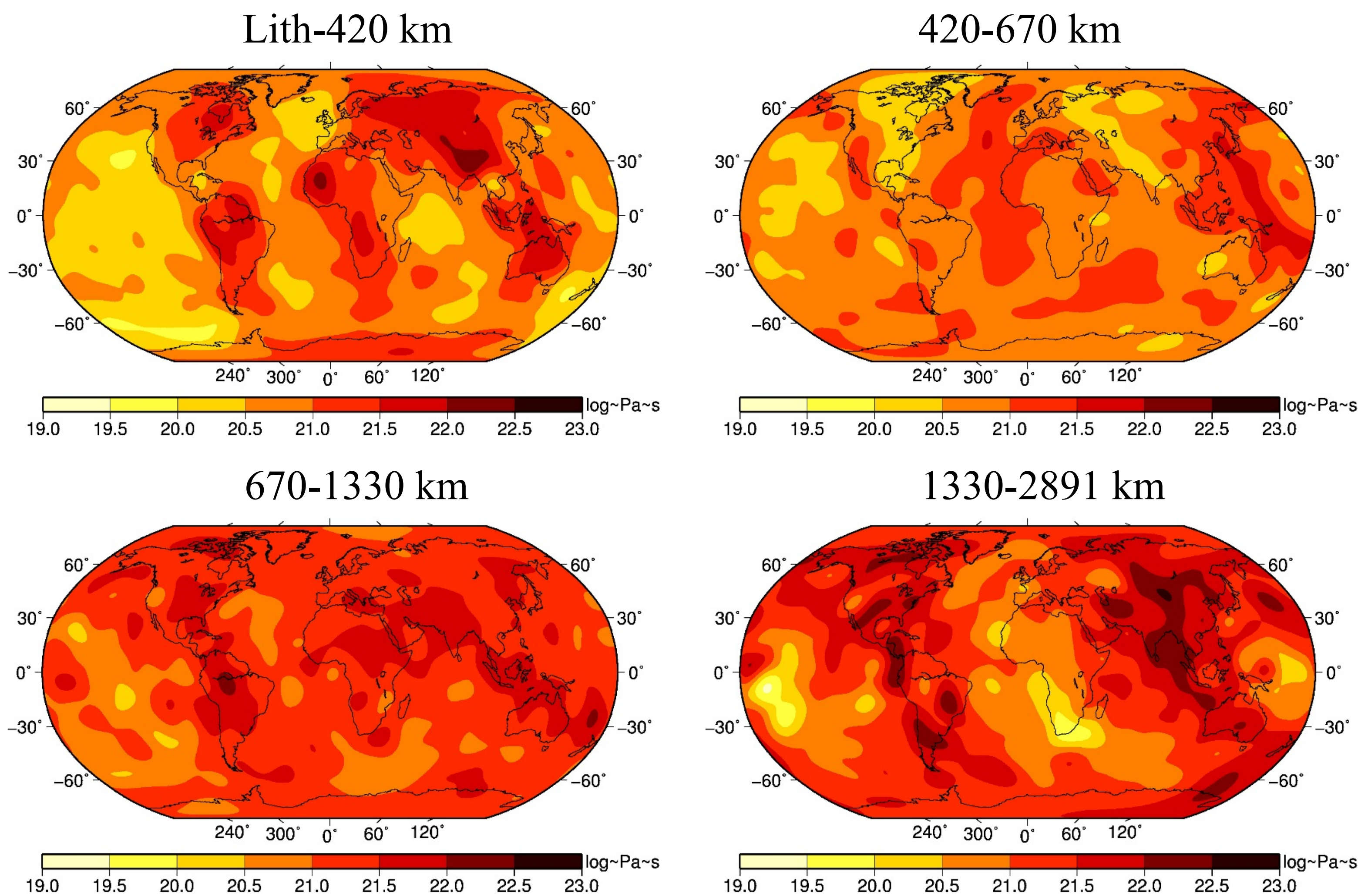
- Which thicknesses and viscosities for the rest of the world?
- Shall we treat oceanic lithosphere separately?
- Inclusion of plate boundaries?
- Shall we use Maxwell rheology only?

3D modelling alternative: 3D lithosphere



(Wang & Wu 2006, EPSL)

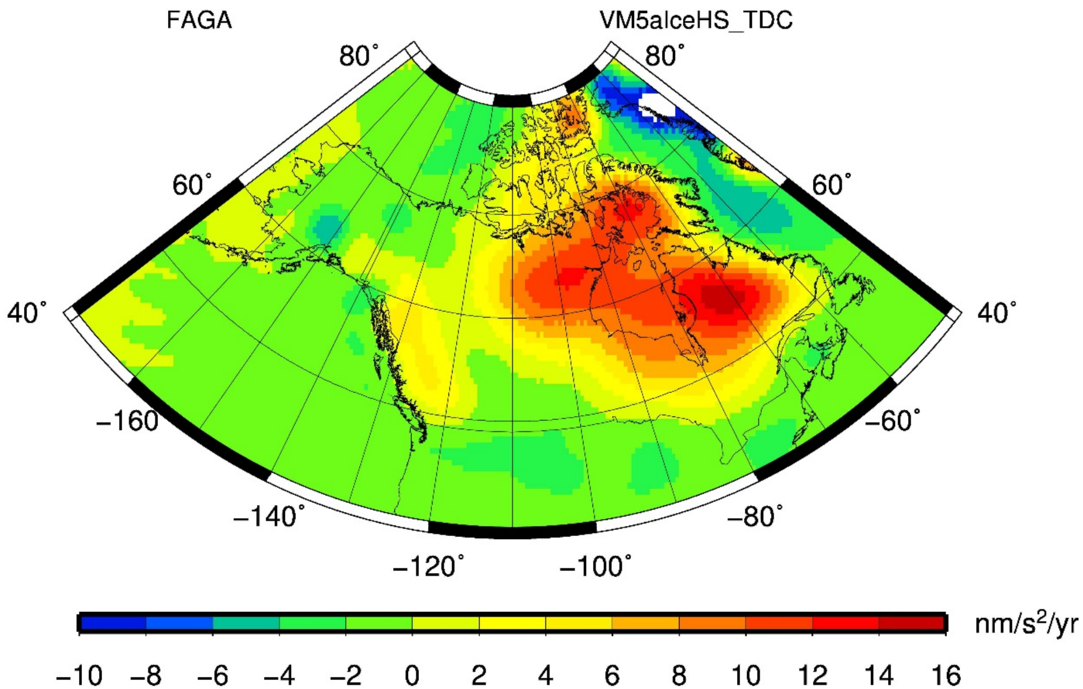
3D modelling alternative: 3D viscosity

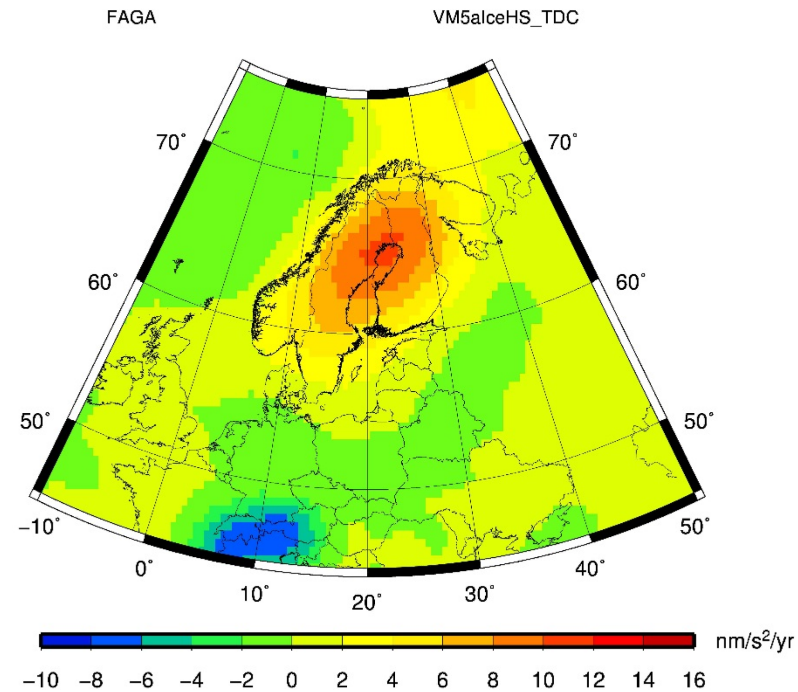


(Based on Grand et al. 1997)

First results (to be continued in 2017)

- Ice model as outlined except Patagonia from ANU-ICE, 0.5x0.5 deg resolution, 53 time steps
- VM5a Earth model





Work in progress (a bit delayed)!