Optimal locations for GNSS measurements in constraining Glacial Isostatic Adjustment

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Vertical Rates Symposium Plenary
International GNSS Service workshop
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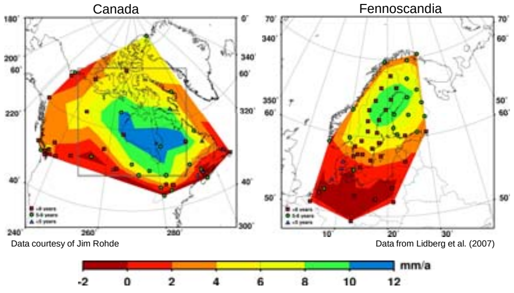
GPS stations and determined uplift velocity in Canada and northern Europe



Introduction

- GGOS workshop in Ottawa May 31, 2010
- Objectives:
    - to discuss how Canada can actively contribute to GGOS
    - to explore possible future collaboration with North American agencies involved in Earth and Atmospheric sciences

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Optimal locations for GPS measurements in North America and northern Europe for constraining Glacial Isostatic Adjustment

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Motivation (1)

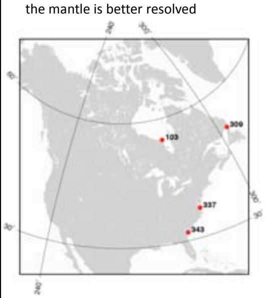
- To constrain GIA models and improve our current knowledge of GIA, more relative sea-level data and geodetic observations are desirable to resolve the parameters of GIA such as:
    - *Ice history,*
    - *Lithospheric thickness & lateral variation*,
    - *Radial viscosity profile* (background viscosity profile for modeling),
    - *Lateral viscosity changes* in view of thermal versus chemical origin of the 3D structures in the mantle.

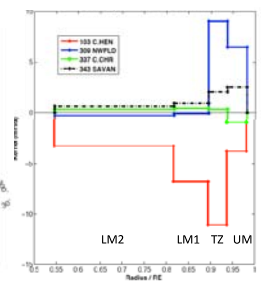
Motivation (2)

- **Aim:** find the optimal locations for GNSS observations that are most sensitive to the four GIA parameters above
- Note: an optimal location is defined by where sensitivity lies above the observational accuracy of GPS measurements

Sensitivity kernels

For laterally homogeneous Earth, location of the site determines which part of the mantle is better resolved





UM = Upper Mantle (115-400 km) LM1= Shallow Lower Mantle (670-1171km)
TZ = Transition Zone (400-670 km) LM2= Deep Lower Mantle (1171km–CMB)

Sensitivity kernels

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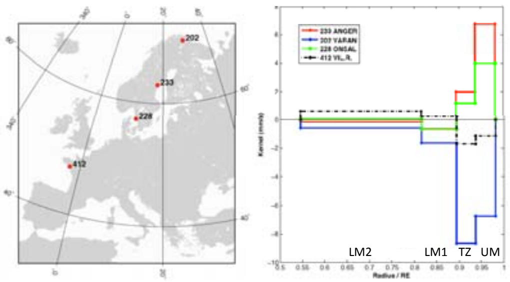

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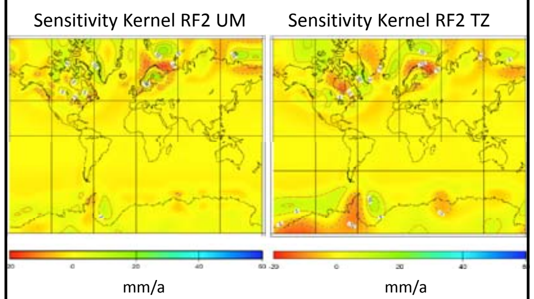
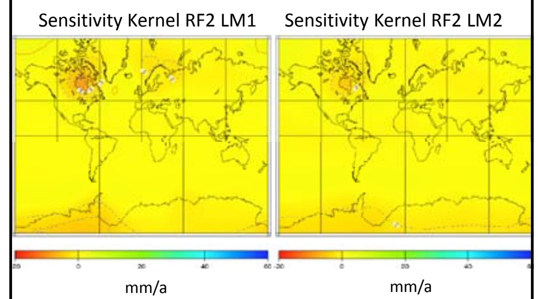
Accuracy of GPS observations

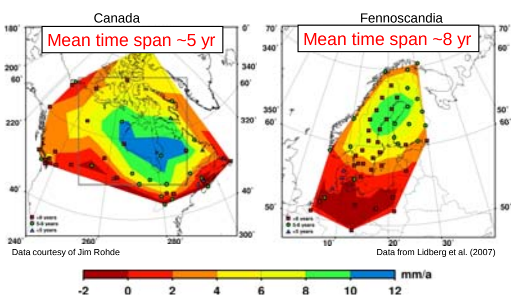


Accuracy of GPS observations



Only sites around Hudson Bay have high enough sensitivity for deep lower mantle viscosity!

GPS stations and determined uplift velocity in Canada and northern Europe



Data courtesy of Jim Rohde

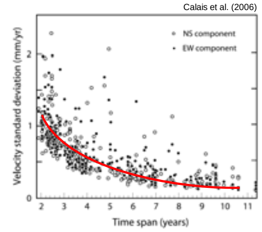
Data from Lidberg et al. (2007)

Accuracy of GPS observations

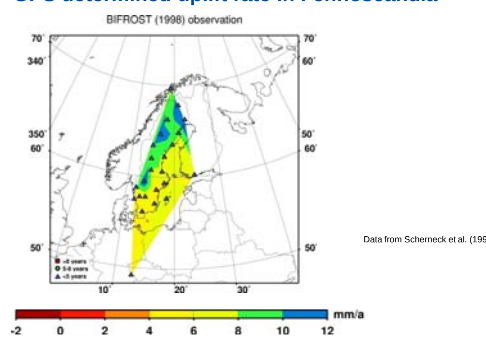
- Accuracy depends on the time span of all instruments in a network,
- A longer time span generally decreases the errors.

- 5 years: 0.6 mm/a for tangential velocities
  2.0 mm/a for vertical velocities
  (Calais et al. 2006),
- 8 years: 0.2 mm/a for tangential velocities
  0.5 mm/a for vertical velocities
  (Calais et al. 2006, Lidberg et al. 2007).

Calais et al. (2006)

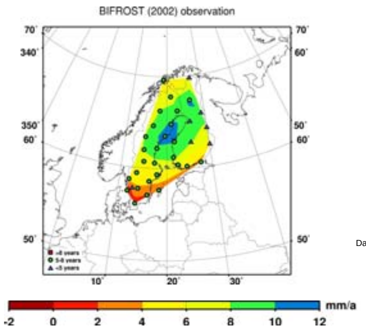


GPS determined uplift rate in Fennoscandia



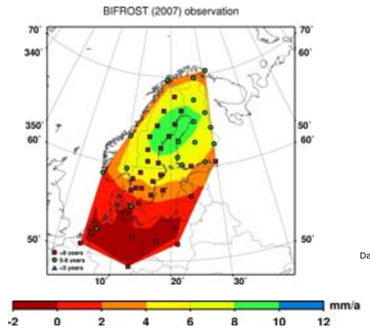
Data from Scherneck et al. (1998)

GPS determined uplift rate in Fennoscandia



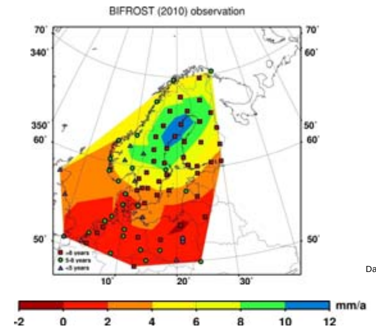
Data from Johansson et al. (2002)

GPS determined uplift rate in Fennoscandia



Data from Lidberg et al. (2007)

GPS determined uplift rate in Fennoscandia



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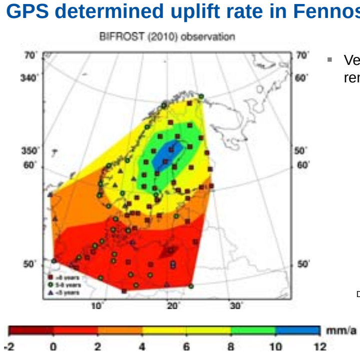
GPS determined uplift rate in Fennoscandia



- Velocities at 5 sites removed

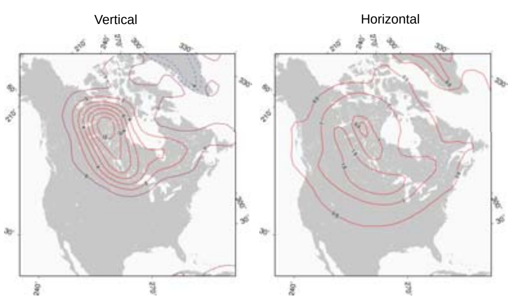
Data from Lidberg et al. (2010)

Modeling approach

- Coupled Laplace-Finite Element method (Wu 2004)
- Non-rotating, spherical, self-gravitating, Maxwell visco-elastic earth with material compressibility and self-gravitating oceans
- Sensitivity of uplift rate or tangential velocity to a certain model parameter is obtained from the difference between the predictions of two models which only differ in the parameter under consideration

Sensitivity to	Ice model	h_{Lith} [km]	η_{UM} [x 10^{20} Pa s]	η_{LM} [x 10^{21} Pa s]	Lateral heterogeneity
Reference model	ICE-4G	115	6	3	None
Ice history	RSES (Fennoscandia) ICE-5G (North America)	115	6	3	None
Lithospheric thickness	ICE-4G	*	6	3	* Varying h_{Lith}
Background viscosity profile	ICE-4G	115	7	10	None
Lateral heterogeneity	ICE-4G	115	6	3	S20A seismic tomography model with β=0.6

Sensitivity to ice sheet thickness in North America

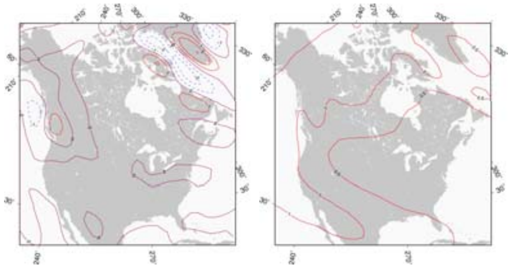


Unit: mm/a

Sensitivity to lateral lithospheric thickness variations in North America

Vertical

Horizontal

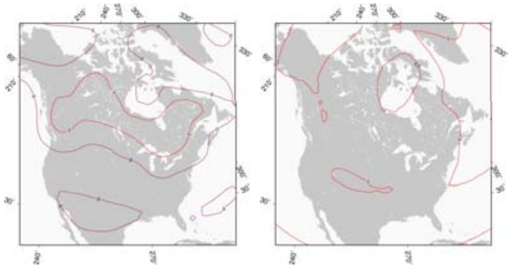


Unit: mm/a

Sensitivity to background viscosity in North America

Vertical

Horizontal

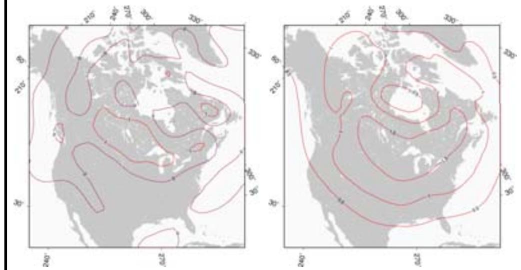


Unit: mm/a

Sensitivity to lateral viscosity variations in North America

Vertical

Horizontal

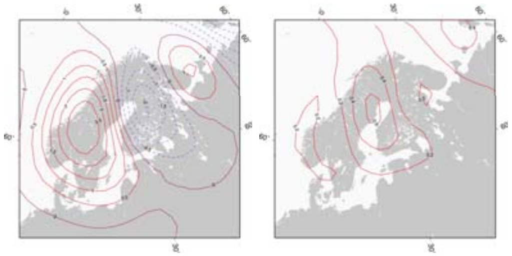


Unit: mm/a

Sensitivity to ice sheet thickness in Fennoscandia

Vertical

Horizontal



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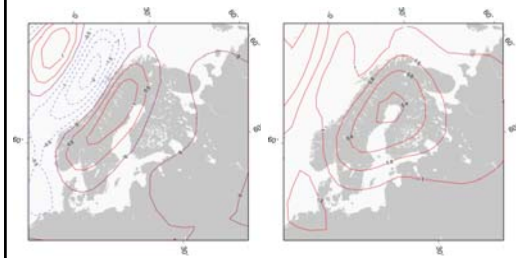
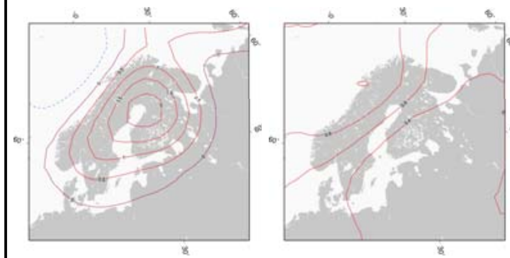


Unit: mm/a

Sensitivity to background viscosity in Fennoscandia

Vertical

Horizontal



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Sensitivity to lateral viscosity variations in Fennoscandia

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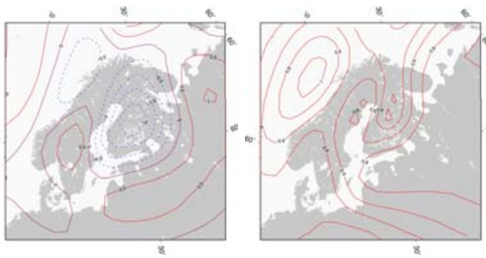


Unit: mm/a

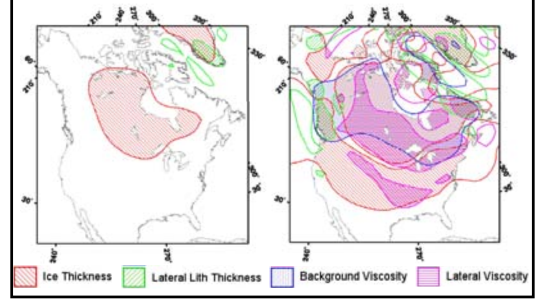
Results (2/2)

- Sensitivity kernels for horizontal and vertical velocities to the 4 chosen parameters dependent of the GPS accuracy,
- Accuracies of two representative mean time spans of
  - 5 years: 2.0 mm/a for radial and 0.6 mm/a for tangential velocities (Calais et al. 2006), ~ 500 m in ice thickness
  - 8 years: 0.5 mm/a for radial and 0.2 mm/a for tangential velocities (Calais et al. 2006, Lidberg et al. 2007). ~ 120 m in ice thickness

Sensitivity in North America for Vertical Velocity

5 year (2 mm/a)

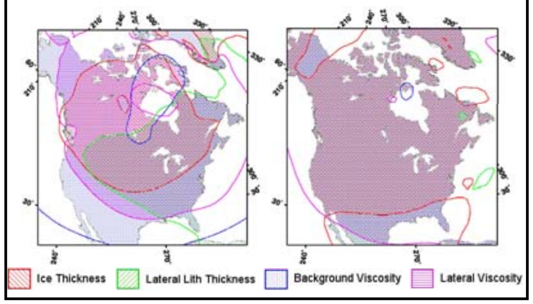
8 year (0.5 mm/a)



Sensitivity in North America for Horizontal Velocity

5 year (0.6 mm/a)

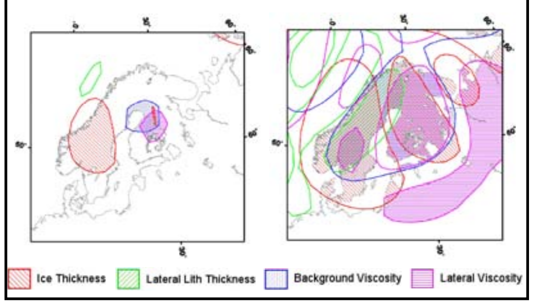
8 year (0.2 mm/a)



Sensitivity in Northern Europe for Vertical Velocity

5 year (2 mm/a)

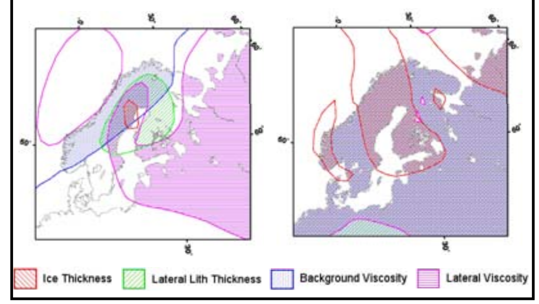
8 year (0.5 mm/a)



Sensitivity in Northern Europe for Horizontal Velocity

5 year (0.6 mm/a)

8 year (0.2 mm/a)



Conclusion

- **North America:** more permanent GPS stations are needed in northern Canada especially around Hudson Bay and west of it to the Rocky Mountains.
- **Fennoscandia:** the GPS network is almost adequate, but it should be extended to the last known GIA-affected areas in the Russian part of East Europe and to Central Europe.

For more information see:

Wu, P., Steffen, H., Wang, H. (2010), Optimal locations for GPS measurements in North America and northern Europe for constraining Glacial Isostatic Adjustment, **Geophys. J. Int. 181 (2), 653-664**, doi:10.1111/j.1365-246X.2010.04545.x

Thank you for your attention!

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