SERCE

SOLID EARTH RESPONSE AND INFLUENCE ON CRYOSPHERIC EVOLUTION

2017 GIA and Elastic Deformation Workshop, Reykjavik

Two overarching themes were felt to be crucial for advances in the field to take place:

a. Development of a culture of sharing of codes and numerical outputs, as well as geological and geodetic data
b. Continued collaboration across disciplines, allowing modellers to understand the nuances of field data, and observational scientists to understand the strengths and weaknesses of models.

Top 10 questions

More specific issues that were discussed included:

1. What are the feedbacks between solid Earth deformation and ice dynamics, especially in regions with low viscosity upper mantle?
2. What is the rheological nature of the lithosphere/asthenosphere at timescales from hours to decades and what is the rheological nature of the mantle from years to millennia? Can processes across these time scales be explained by a single rheological model?
3. How should geodetic time series be interpreted in the presence of time-varying mass changes and varying rheologies? In particular, what approach should be taken in low viscosity regions where quite recent (decades to centuries), but poorly quantified, mass changes may have excited a viscous response?
4. To what degree do inferences of ice history and earth rheology depend on the type and distribution of the constraining data, such as relative sea-level constraints and GPS data? To what degree is it possible to determine ice history independent to Earth rheology?
5. When do lateral variations in rheology need to be considered and what are the consequences of using a simplified 1D rheology? Issues to be considered include computational efficiency and the sensitivity of GIA to lateral variations in rheology.
6. What are the uncertainties associated with determining the 3D viscosity distribution of the mantle, e.g. from seismic velocities, and how should we determine realistic uncertainties on 3D GIA models?
7. How should we compare models and observations in the presence of poorly quantified reference frame errors and uncertainties (including the effects of loosely-constrained lower mantle viscosity)?
8. What is the ongoing deformation of the ocean floor and the land beneath ice sheets (in regions with no outcrops)? How can deformation in these areas be observed?
9. How does dynamic topography affect our understanding of relative sea-level curves?
10. What can the horizontal surface velocity field tell us about GIA processes?

2018 TACtical Workshop, Hobart
(taking the Temperature of the Antarctic Continent)

a) Research activities

- Cross comparison of Heat Flux (HF) results, e.g.
  - HF inferred from point measurements
  - HF inferred from ice observations/water
  - HF inferred from magnetic data
  - HF inferred from electrical admittance
  - HF inferred from seismic tomography
  - HF inferred from geology
- Plan for understanding/reconciling discrepancies in the above and which methods are most reliable under what circumstances
- Understand the strengths/weaknesses of each form of data
- Understand the best way to interpolate/extrapolate HF values to create continent or plate-scale HF maps
- Establish the basis for prioritising locations for new HF measurements, optimised for benefit in terms of variable density of future measurements

b) Research products

Everything below to have quantified uncertainty, and alternate models and probabilistic models encouraged

- Geomap (ongoing)
- Rock Heat Production values database
- HF measurements database
- Ice temperature profiles database
- 3D lithosphere+ crust reference model (including lithospheric thickness for GIA,crust for HF) from which to generate 2D HF maps
- 2D HF maps derived from alternate methods
- 2D gridded HF maps with spot points and uncertainties
- Guide to HF products
- Rheology model of Antarctica

c) Modelling

- A small Model Intercomparison Project (MIP)
- A MIP of ice sheet models in inverse mode designed to infer geothermal flux
- To understand what situations would lead to the biggest contribution to sea level rise from HF
- To understand how big an HF anomaly would have to be to have an impact
- To understand how much laterally varying HF influences ice sheet behaviour
- To understand what spatial scale of lateral variability in HF matters
- To understand what accuracy/resolution of HF measurement is needed
- To find the locations in new HF measurements that are most significant to improve modelling
- To find conditions where melt rate can be upper/lower bounded
- To assess equilibrium vs non-equilibrium modelling in full 3D Stokes

d) New observations

- HF measurements
  - In ice
  - In rock (e.g. RAID) including sediment or bedrock, avoiding hydrothermal

  - Focussed on West Antarctica
  - Marine measurements on the continental margin
- Samples of bedrock
  - Geochronology
  - Geochemistry
  - For petrophysics to correlate with airborne geophysics
- Sub ice observations where the bed isn't frozen
  - Better understanding of accuracy near pressure-melting point
- Ground observations
  - Seismic in East Antarctica, Aurora and Wilkes Basins
  - Active source seismology in the interior
  - UAV hyperspectral
  - UAV radiometrics
  - Gamma ray surveying
- Airborne observations
  - Geomagnetic
  - Ice radar mapping of internal ice structure, englacial layers
  - Phase sensitive radar

e) Other comments/ required knowledge

- Note also importance to ice sheet modeller of other factors, e.g. physics of ice, ocean forcing, basal topography inc. coast, atmospheric forcing, HF, GIA and feedback
- Map connections between subglacial lakes
- Better knowledge of basal hydrology
- Better knowledge of permeable nature of ice bed
- Better knowledge of groundwater
- Effect of groundwater storage on ice dynamics
- Complications for subglacial lakes away from the ice divide, ice flow, sliding, advection by water flow
- Better knowledge of sedimentary basins, basement distribution, structures therein
- Role, possibly a variable influence, of HF in paleo ice sheet modelling
- Variation in HF over time for paleo ice sheet model inputs
- Possible influence on HF of ice sheet history
- Possible influence on HF of tectonic history
- Variability of HF in different tectonic provinces
- Evolution of thermal topography over the Cenozoic
- Water content and grain size in the mantle beneath Antarctica
- Relation between mantle volatiles, temperatures, viscosity and seismic velocity
- Ambient seismic noise shear velocity structure to estimate crustal heat production
- Other proxies for temp at depth, e.g. Bouguer gravity spectra and crustal thickness
- Advection effects in borehole measurements
- Neutrino detector

2019 Ottawa GIA workshop

- **Sea-level data**
  - How do we account for the subtleties of assessing uncertainty in field data when comparing with model predictions?
  - How do we avoid skewing parameter inferences with poor data? When tuning or scoring a model, how should we weight the data to deal with data redundancy, correlation, or non-uniform distribution in time and space?
  - Where do we need new sea-level data, and how good does it need to be to be useful? Sensitivity analyses could indicate the locations and nature of data required to address specified model features.
- **Geodetic data**
  - How can horizontal crustal velocities measured by Global Navigation Satellite System (GNSS) be employed to constrain processes related to GIA and ice sheet change?
  - Can changes in rates or phase information of geodetic time series be used to determine whether there is a transient (viscous) response to contemporary ice loss? GNSS time series are critical to understand rheology over decadal timescales, but this resource will become more limited in key regions within the next decade due to the anticipated termination of several large projects.
  - How should we account for non-physical signals in GNSS time series, e.g. due to seasonal ice build-up?
- **Novel data and information from other fields** that could be used to constrain ice sheet and GIA model predictions:
  - Solid Earth deformation rates from beneath ice sheets and the ocean.
  - The age structure of the ice within the major ice sheets from radar reflection profiling.
  - Evidence relating to recent glacier and ice sheet advances.
  - Analysis of ice-marginal marine sediment cores.
  - New exposure ages constraining the evolution of ice margins and the thickness (surface elevations) of ice sheet interiors.
- **Projections:**
  - What will be the contribution of ongoing GIA to future sea-level change? What are the uncertainties on these projections?
  - How should we draw together our understanding of GIA over different timescales to make more robust projections?
  - How will coupled ice-sheet/solid-Earth models affect projections of sea-level change?
- **Consideration of additional processes**
  - How should we account for non-GIA processes when interpreting evidence for past sea-level change? Sea-level data record the response to sediment loading, ocean density/circulation changes, and tectonics.
  - How should we account for non-GIA processes when interpreting geodetic data? GNSS and satellite gravity data record the response to hydrological and atmospheric loading and contemporary ice mass change.

- **Coupled modelling**
  - What are the relative impacts of feedbacks between solid Earth deformation and ice dynamics, especially in regions with low viscosity upper mantle?
  - How can we feasibly develop coupled climate–GIA–ice sheet models and what are the most important applications of these models?
- **Earth structure and rheology**
  - What are the influences of plate boundaries on the modelled solid Earth response to surface loading?
  - What are realistic uncertainties in three-dimensional mantle viscosity structure?
  - Explore the influence of more complex rheologies in GIA modelling, such as those used to understand post-seismic deformation, and determine if they provide a superior explanation of GIA observables.
  - What can be learnt from parallel efforts to constrain mantle rheology in the fields of mantle convection modelling and laboratory deformation experiments?
- **Smart modelling**
  - Are there smarter, or more rigorous, ways to search model parameter space, in particular, in relation to past ice sheet configuration?
  - What can be learnt from employing sophisticated statistical techniques, or approaches used in joint inversions, machine learning, adjoint methods, and so on?
  - How should we account for structural uncertainty when running GIA and ice sheet models? Can an improved understanding of structural uncertainty bridge the gap between data and model predictions?
  - Encourage the provision of rigorous uncertainty assessment to accompany model predictions or scientific inferences.
- **Open resources**
  - Work towards producing open access repositories of data, code, and model output relating to GIA and ice sheet modelling, for elements such as sea-level data, GNSS rates, GIA model output, and three-dimensional mantle viscosity models.
  - Carry out a benchmark of three-dimensional GIA modelling.