Summary Report of the MOCA Joint Model-data workshop for the Late Pleistocene evolution of the Greenland and Antarctic ice sheets

LGGE, Grenoble, May 22nd-24th, 2014

The aim of this workshop was to bring together scientists from across the disciplines of field- and modelling-based ice-sheet reconstruction, in particular those working on the Greenland and Antarctic ice sheets, in order to identify outstanding issues in each field and identify how different communities could work together to make progress in resolving these issues. Participants were encouraged to consider both the type of information that they would like to see exchanged between the two communities (e.g. data, meta-data, model output) as well as issues within each discipline that end users of the data need to be aware of.

An overarching theme of the 2-day workshop was the quantification of uncertainty, in particular, how to quantify different sources of error and represent these in terms of a statistical distribution. It was highlighted that numerical models that assimilate, or are tuned to fit, field data should be adapted to take into account the error model associated with the data, and this error model should account for interpretative, spatial, and temporal uncertainties. On the flip side, there needs to be clear communication with regard to model uncertainty: this can arise from (i) the neglect or parametrization of certain physical processes, (ii) issues associated with model resolution, and (iii) uncertainties associated with the input forcing.

To facilitate cross-disciplinary understanding of key debates within each field, the workshop consisted of a series of review talks interspersed with extensive discussion. With regard to terrestrial field-based studies, it is clear that dating continues to be problematic in both Greenland and Antarctica. Relevant issues include: a lack of dateable material, the presence of recycled carbon, and the difficulty of interpreting cosmogenic isotope data where there is potential inheritance from multiple glacial cycles. Attribution of landform ages based on weathering characteristics is often difficult because processes and rates can be very different to those observed in more temperate regions. We also know from present-day observations that local topography and ice dynamics at scales below those resolved by most current palaeo ice-sheet models can play an important role in determining local ice extent. To what extent do such processes need to be resolved in modelling efforts, for example using adaptive grids, in order for the field data to play a useful role in constraining models of ice-sheet reconstruction?

Near-field relative sea-level data record the isostatic response to loading and hence provide information on regional-scale ice-sheet thickness evolution. However, such data are still sparse for current ice sheets, particularly in Antarctica. Historical photogrammetry surveys in Greenland are enabling us to push back the period over which we have direct observations of ice-sheet changes, but longer records will always be needed to interpret present-day processes and place the current changes in a wider context.

Reviews of offshore information relating to past ice extent highlighted different problems; many landforms relating to past ice extent are undated and sediment cores are often only acquired from trough regions, where ice dynamics may be very different to the inter-trough regions. Dating is again problematic due to a lack of reliably dateable material. This is compounded by the need to account for marine reservoir effects and interpret the stratigraphy 'remotely' using underwater imagery. Marine sediments are often used to determine when a location became free from grounded ice, but it was highlighted that reconstructing ice-shelf retreat is also important for constraining the forces acting on an ice sheet. The implications of the presence of ice-rafted debris were also discussed, along with the role of the ocean, for example, with regard to sediment transport and post-depositional sediment erosion.

In both terrestrial and marine regimes, the issue of how to scale up what are largely point-based observations, e.g. from individual outcrops or marine sediment cores, to ice-sheet scales remains a fundamental challenge. Depending on the regional topography and flow configuration, palaeo indicators for ice flow direction (with basal ice flow also indicating warm-based ice), can provide larger-scale constraints relevant to model resolution. Moving away from looking at the imprint of ice on the landscape, a new kriged radar dataset that traces layers within the Greenland Ice Sheet offers a constraint on past ice-sheet configurations and flow regimes over much larger spatial and temporal scales than can be obtained from point measurements. Radar layers and ice cores provide evidence of where ice was present, even prior to the Last Glacial Maximum (LGM). However, aside from sparse marine and lake cores, there is little field data that can constrain ice-sheet margin locations prior to the LGM and it remains difficult to quantify rates of ice-sheet growth or re-advance. New proxies for ice extent and new or improved dating methods were high on the collective wish-list.

From a modelling point of view, much discussion focussed on the need to understand and better represent the forcing factors and boundary conditions that govern past ice dynamics. With regard to climate forcing, constraints on past precipitation rates and air temperatures can be obtained from ice cores, although the interpretation of such records relies on the development of a reliable chronology for both the ice phase and the gas phase of the core, and the ability to separate signals due to competing processes, e.g. changes in temperature versus changes in elevation. Ice cores are also spatially sparse and generally located well into the interior of the ice sheets near ice divides, it was therefore recognized that the heavy reliance of palaeo ice-sheet models on ice-core records as the primary forcing agent needs to be superseded. Air and marine temperatures in the marginal regions of ice sheets largely control ice margin location but lack significant palaeo constraints. Such quantities are also poorly resolved by climate models, especially those run at a coarse enough resolution to enable transient modelling.

The importance of accurate dating when determining the relative timing of different climate events was also emphasized. While ice cores do provide us with a method to link northern and southern hemisphere changes, much progress is still need to understand global climate feedbacks. As an example, we still lack a robust understanding of north-south phasing even during the Holocene.

In addition to quantifying external forcing factors, models require information relating to conditions at the ice-bed and ice-ocean interface, yet basal topography is poorly resolved in extensive regions. The uncertainties in such boundary conditions are very difficult to quantify, particularly with regard to past conditions. There is a dearth of direct observations of basal conditions, and hence very little quantitative information against which to test model representations of e.g. till rheology and subglacial hydrology. Bed conditions have been inferred during attempts to model the present-day ice sheet. However, such inferences are ambiguous; there is a difference between being able to reproduce present-day observations and being confident that they were reproduced for the correct reasons. To further complicate matters, bed properties evolve over time, as they act on and in turn are acted upon by ice flow.

At the ice-ocean interface, models continue to lack well-constrained representations of ice calving and sub-shelf melt. The latter are especially limited due to our lack of knowledge on past ocean conditions. Past variations in both ocean temperatures and open ocean circulation patterns have the potential to strongly alter melt rates beneath the ice shelves, which in turn will alter the shape of the cavity beneath the ice shelves and hence the pattern of melt. Large-scale predictions can be produced using global and regional climate models but the uncertainties are large, especially for palaeo time scales. Furthermore, the challenge remains of how to pass this information down to higher-resolution ice-sheet models and represent the spatial-temporal variability that we know exists at smaller scales.

Spatial resolution is obviously a key issue with regard to ice-sheet modelling, and it was discussed whether higher spatial resolution or the inclusion of more complete model physics was more important. The use of adaptive grids can reduce the computational expense of modelling at high resolution to some degree, but a trade-off still exists, particularly when it is necessary to factor in the time scale over which simulations are to be run. It is becoming clear that different models are suited to different tasks, but this brings with it the problem of how to usefully compare results from models that are run at different spatial and temporal scales. A key point was the need for more cognizance of model resolution when interpreting model results and comparing against palaeo records.

The basic physics included in ice-sheet models is now fairly well standardised, largely due to community inter-comparison exercises, but challenges remain with regard to the modelling of grounding line dynamics, ice-ocean coupling, and feedbacks associated with glacial isostatic adjustment. This last factor may be particularly important in Greenland where the evolution of the adjacent

Laurentide Ice Sheet will have influenced solid Earth deformation across Greenland (as well as regional climate and oceanic conditions).

The diversity of factors outlined above highlights the need for improved collaboration between disciplines. As an aid to improving such collaboration, the development of open access databases – containing both field data and model output – was discussed. The initiative received strong community support, but it was highlighted that barriers often exist on a more personal level, particularly amongst early career researchers who are trying to get their foot on the academic ladder. Other issues which would need to be addressed are the collation of already-published data, the standardisation of information and file formats, and the ongoing stewardship of the database. As funding bodies move towards a requirement for outputs to be made open access, the development and adequate funding of such databases will become a necessity. A key outcome of the meeting was an undertaking to develop protocols for database standardisation and promote these among major Quaternary journals. The protocols will consider required meta-data, uncertainty specification, and search keys to facilitate data-base identification by standard search engines.

The success of the workshop was due in good part to a diverse mix of 22 junior and 32 mid to late career scientists. This in turn was only possible due to the generous sponsorship provided by: IACS (International Association of Cryospheric Sciences), IUGG (International Union of Geodesy and Geophysics), LGGE (Laboratoire de Glaciologie et Géophysique de l'Environnement), PAIS (Past Antarctic Ice Sheet Dynamics), and SCAR (Scientific Committee on Antarctic Research).

Pippa Whitehouse and Lev Tarasov, on behalf of the organizing committee