

PREVIOUS TRACK RECORD

The proposed project “**Shared frameworks for next-generation ice sheet modelling**”, involves researchers from three of the leading glaciology groups in the UK, and the UK’s national climate research centre. It will enable these researchers to deepen and expand their collaboration with leading US groups, and, in so doing, it will allow them to develop a next generation framework for ice sheet modelling. The PI, Co-Is and researcher Co-I all have strong track-records in coupled ice-sheet/climate modelling, and bring a diverse portfolio of relevant experience and expertise to the project.

Ian Rutt (PI, Swansea) was appointed Lecturer in Glaciology at Swansea University in March 2007, having previously worked as a PDRA with Co-I Payne at the University of Bristol (2003-7). During his time at Bristol, he was responsible for developing Glimmer-CISM (Rutt et al. 2009) as the ice sheet component of GENIE (<http://www.genie.ac.uk>), and for coupling Glimmer-CISM to FAMOUS for the Hadley Centre, as part of the CPOM NERC Centre of Excellence (now the National Centre for Earth Observation, Cryosphere theme). He was instrumental in releasing Glimmer-CISM as an open-source, community model, a decision which precipitated the present international collaboration. He is Co-I on a current £880k NERC Network of Sensors grant (NE/I007148/1), in which he leads the glacier modelling component, using the finite element code Elmer. He is a founding Executive Editor of the EGU journal *Geoscientific Model Development*, reflecting a long-held interest in promoting best practice in scientific software development.

Tony Payne (Co-I, Bristol) is Professor of Glaciology in Bristol and co-director of the National Centre for Earth Observation, Cryosphere theme. He is a work package leader in a €10M EU project called ice2sea, which aims to predict the contribution of ice sheets and glaciers to global sea level over the next 200 years. The project involves 24 European and international partners. He is a Lead Author on the Sea level chapter of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change; he also acted as a contributing author on ice-sheet modelling for the 3rd (2001) and 4th (2007) Assessment Reports. Since 1997, he has been awarded a total of seven NERC non-thematic grants (4 as P.I. and 3 as Co-I.), and seven research/thematic programme grants (Joint Climate and Weather Research Programme JCWRP; National Centre for Earth Observation NCEO; Centre for Polar Observation and Modelling CPOM; QUEST; RAPID; ARCICE; and e-science), as well as a Joint Research Councils Supercomputing Grant and two Leverhulme Trust grants. He was also deeply involved in the European Science Foundation’s Ice Sheet Model Inter-comparison exercise (EISMINT). He was a member of the International Council of the International Glaciological Society 2003 to 2006, and was a member of NERC’s peer review college (to 2006). He is currently a co-chair of NERC’s expert group on Ice Sheet Stability. In 2004, he organized a Royal Society Discussion Meeting entitled “Evolution of the Antarctic ice sheet: new understanding and challenges” and is chief editor of the associated *Philosophical Transactions of the Royal Society A* volume.

Nick Hulton (Co-I, Edinburgh) is a Senior Lecturer in Glaciology and has been developing and using ice sheet models for over twenty years, in particular focusing on glacier-climate linkages and paleo ice sheet prediction, particularly applied to South America. He supervised Hagdorn’s PhD thesis, a collaboration which in part led to the instigation of Glimmer. He has developed erosion model components for Glimmer which were utilised by NERC-funded student Stewart Jamieson for his PhD (Jamieson et al. 2008, Jamieson et al. 2011). This work has shown the significance of accurately predicting subglacial conditions, and relating glacial thermodynamics to basal melt, drag, and sliding mechanisms. Most recently, another PhD student (Karatay) has implemented sub-glacial hydrological modules for Glimmer-CISM, which are being released to the wider community. He is currently working with a consortium of oil companies aiming to predict permafrost development under the Barents Sea.

Magnus Hagdorn (researcher Co-I, Edinburgh) is a scientific programmer working within the School of Geosciences, University of Edinburgh. His PhD and postdoctoral work was concerned with modelling ice sheet evolution over the last glacial cycle. He has been a key developer of Glimmer-CISM since 2004 (Rutt et al. 2009), and is a member of the model’s international steering committee. Hagdorn developed the sediment erosion and transport extension for Glimmer-CISM. His current Glimmer-CISM work is mostly focused on infrastructure, code refactoring and visualisation tools. In addition to academic work, he spent three years working in the oil and gas industry. Overall, he has over ten years experience of developing numerical models on UNIX workstations and High Performance Computing (HPC) systems. Additionally, he is one of the lead

developers of a commercial 2.5D marine Controlled Source Electromagnetic (CSEM) finite element model.

SELECTED PUBLICATIONS BY THE TEAM:

- Bougamont M *et al.* inc **AJ Payne** and **IC Rutt** (2007) Impact of model physics on estimating the surface mass balance of the Greenland ice sheet, *Geophysical Research Letters* 34, L17501
- Boulton GS, Hagdorn M, NRJ Hulton (2003) Streaming flow in an ice sheet through a glacial cycle, *Annals of Glaciology*, 36, 117-128
- Benn DI, **NRJ Hulton**, RH Mottram (2007) 'Calving laws', 'sliding laws' and the stability of tidewater glaciers, *Annals of Glaciology*, 46, 123-130
- Boulton G, **M Hagdorn** (2006) Glaciology of the British Isles Ice Sheet during the last glacial cycle: form, flow, streams and lobes, *Quaternary Science Reviews*, 25 (23-24), 3359-3390
- Hagdorn M** (2008) *Simulation of the European Ice Sheets*, VDM Verlag Dr. Mueller
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- Jamieson, SR, Sugden DE and **Hulton NRJ** (2010) The evolution of the sub-glacial landscape of Antarctica, *Earth and Planetary Science Letters*, 293, 1-27
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- Stone EJ *et al.* inc. **IC Rutt** (2010) Investigating the sensitivity of numerical model simulations of the modern state of the Greenland ice-sheet and its future response to climate change, *The Cryosphere*, 4, 397-417
- Vieli A and **AJ Payne** (2005) Assessing the ability of numerical ice sheet models to simulate grounding line migration, *Journal of Geophysical Research*, 110, F01003.
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Shared frameworks for next-generation ice sheet modelling

Developing a next generation ice sheet modelling framework through international collaboration and community building

SUMMARY AND OVERALL MOTIVATION

Ice sheets respond to and influence the global climate on a variety of spatial and temporal scales. Their future evolution, with its consequences for global sea level, is of great societal importance, and consequently numerical ice sheet models (ISMs) comprise a growing area of interest. The technical and scientific challenges inherent in ice sheet modelling are substantial, and are compounded by the need to couple ISMs to Global Circulation Models (GCMs) in a physically-consistent and scientifically-useful way. The expense and fragility of bespoke coupling code makes the development of flexible, generic couplers attractive. While this requires greater initial effort, there are longer-term efficiencies to be gained by devising common model interface standards. It will also enable new types of experiment to be conducted, leading to a deeper understanding of the effects of numerical and scientific uncertainties in these coupled models. For instance, it would be easier to conduct experiments to identify the cause and scale of uncertainty in future sea-level predictions, whether stemming from different component climate or ice sheet models or from the way they are coupled. This challenge requires a coordinated, international approach, with a high degree of participation from the broader academic and stakeholder communities.

We aim to address the deficiencies in current approaches to coupling ISM to GCMs, and in doing so augment UK leadership in this rapidly developing field. We will build on an existing unfunded international collaboration centred on an established ISM (Glimmer-CISM), but will involve a far greater part of the glaciological and climate modelling communities to establish a more coherent approach. Our overall objectives are threefold:

OBJ1. *Development and dissemination of a generic, sustainable technical and scientific framework for ISM-GCM coupling. This will define a standard Application Programming Interface (API) for ISMs and their coupling to climate models.*

OBJ2. *Implementation of the ISM part of the API within Glimmer-CISM, and the GCM part within the US Community Earth System Model (CESM) and the Hadley Centre climate models.*

OBJ3. *Enhancing access to and use of Glimmer-CISM by developing an API-compliant architecture for the model, and basing new documentation and training opportunities upon this.*

The framework developed in OBJ1 aims to promote the coupling of ISMs to climate models in a transparent and flexible fashion. OBJ2 will provide exemplars of the interface in operation. It is also directed at maintaining the position of Glimmer-CISM as an internationally-leading ISM, and is crucial for safeguarding future UK ice sheet modelling capability. OBJ3 will capitalise on the preceding technical advances and bring about a step-change in use of Glimmer-CISM in the ISM and GCM communities. All three objectives contribute strongly to the delivery of the NERC strategy themes *Climate System* and *Earth System Science*, since they will strengthen and augment capacity to understand and predict cryospheric change in the polar regions.

International community participation is essential if the potential benefits and impact of this proposal are to be maximised, and so we focus on activities which will foster deep engagement of the scientific user community in the project. These activities will allow the community to leverage further sources of funding to support future code maintenance and development; they will provide a clear strategy for the application of ice sheet components within climate models.

The project will be delivered by substantially strengthening an existing collaboration between groups in the UK (the Universities of Bristol, Edinburgh and Swansea, and the Hadley Centre) and the US (Los Alamos National Laboratory and the University of Montana), based around the Glimmer-CISM ice sheet model. It will also draw in groups from across the US and Europe in a network of global significance. The team assembled for this project is of international standing, and brings an unrivalled set of skills and insight to this difficult and important problem. The aims are of high importance for international climate science capability. Throughout, our focus is on capacity-building and providing value-for-money: pledged in-kind support is valued at greater than £3M: more than 10 times the FeC value of this project. The impact will consequently be very substantial in relation to the cost of the project.

1. INTRODUCTION

Prediction of the sea level change which will result from climate change is a key scientific challenge with major public policy implications. Numerical modelling of the global climate system using coupled Global Climate Models (GCMs) is the primary predictive tool used by climate scientists. GCMs need to incorporate the behaviour of the cryosphere, in particular the dynamics of the Earth's large ice sheets (Greenland and Antarctica), but although numerous stand-alone ISMs exist, ISM-GCM coupling has historically been problematic for a number of scientific and technical reasons. In addition, ice sheet modelling is a rapidly-evolving field, and so the software architecture of ISMs themselves needs to be able to accommodate the addition of new or alternative model components if they are to remain scientifically-relevant. The goal of this proposal is to deliver a long-lasting software framework for ice sheet modelling and ISM-GCM coupling, through a vigorous international collaboration, informed by substantive community participation.

2. ISM-GCM COUPLING

The scientific and technical challenges of coupling ISMs and GCMs are formidable. Coupling entails an exchange of model fields between the ISM and GCM over the course of the integration period. Scientifically, the most important problem is that the spatial and temporal scales concerned differ substantially between the two types of model. Ice sheets respond to climate change on timescales from decades to millennia: substantially longer than the timescales of interest in climate modelling, even considering the response of the deep ocean (typically a few thousand years).

Spatial scales also differ, with the narrow ablation region around the edge of an ice sheet typically being small compared to a GCM grid box. Similar scaling-process mismatches occur where ice sheets connect to the oceans. The detail of calving, ice shelf melting and grounding-line stresses are very important to ice sheets, but are seldom resolved in ocean-scale models. In addition, interpolation may be necessary between different ISM and GCM grid schemes; in these circumstances, achieving mass and energy conservation requires care. There are also decisions to be made about where quantities such as mass-balance are calculated, and how the ISM should interact with the land surface model in the GCM. Pollard¹ discusses in detail the various techniques previous workers have used to address these issues, including various types of temporally asynchronous coupling and statistical climate downscaling.

The software implementation of ISM-GCM coupling is also complex, and comes with its own range of technical difficulties. Primarily, these are concerned with making the coupling code flexible enough to handle a useful range of coupling scenarios, while being structured to be robust and maintainable. ISMs and GCMs are technically diverse codes: a generic coupler needs to take into account the possibility of different parallelisation strategies, different hardware/operating system platforms, and different grid definitions. Some complexity in coupling code is therefore inevitable, and consequently requires sound software engineering if a long-lasting solution is to be devised.

3. SOFTWARE ARCHITECTURE CONSIDERATIONS

The key to the way a computer model can be used and re-used is its *interface* (often known as the *Application Programming Interface*, or API), which is a description of how other pieces of code communicate with it, in whole or in part. The purpose of a standardised API is to provide predictability and interoperability to users of a piece of code.

For simplicity, we divide ISM APIs into two distinct types: *internal* and *external*. An *internal API* defines how components within the ISM (such as those which deal with stress, temperature and form evolution) should be packaged. An internal API makes it possible to design new modules such that, provided they conform to the API, they can be used with other existing ice sheet code without need for substantial internal code redesign. An internal API may also define interfaces for processes which may be dealt with inside a given ISM – for instance hydrology at the ice bed or the isostatic adjustment of the lithosphere – but which for some applications a separate (external) module is sometimes used instead.

By contrast, an *external API* defines how the ISM as a whole interacts with the rest of the climate system, in particular linkages to external models such as atmospheric and oceanic GCMs. In this case, a standardised API makes it easy to couple different ISMs to a given climate model, and vice versa.

The provision of a standardised API brings obvious benefits of flexibility and reusability, as well as facilitating model intercomparison and sensitivity studies. It also means that time spent learning to use a particular model framework is not wasted when new, compliant models are developed. We address the need for a standard external API for ISM-GCM coupling in OBJ1, and for an internal API for our chosen ISM in OBJ3. To bring these about, it will be necessary to engage deeply with all those involved in the design of ISMs and ISM-GCM coupling.

4. GLIMMER-CISM

Our starting point for this project is Glimmer-CISM, an ISM with an international profile. The model's origins lie in an ISM developed prior to 2003 by Payne. From 2003, the model was developed as an open-source community model (Glimmer), initially funded as part of GENIE (Payne, Rutt: NERC eScience ref. NER/T/S/2002/00221), and later through the National Centre for Earth Observation (NCEO), with significant unfunded contributions from Hagdorn and Hulton. Rutt *et al.* (2009)² provides a full description of model physics, numerical methods and validation/verification exercises. Glimmer-CISM has been used in many published studies.^{e.g. 3-11}

From 2006, Glimmer was adopted as the ice sheet model component of the Community Earth System Model (CESM¹², formerly CCSM), and subsequently renamed Glimmer-CISM. This work has been funded primarily by the US Department of Energy (DOE), and this comprises the majority of funding supporting present development of the model. While the US support has delivered significant benefits to the global ISM community, it is nevertheless understandably driven by the needs of CESM and US funders.

Development of Glimmer-CISM is conducted on a public-access website¹³, and is coordinated by a steering committee comprising Rutt (chair), Hagdorn, Johnson, Lipscomb, Payne and Price. However, UK involvement in model development, and the provision of functionality and support for non-CESM users (e.g. the Met Office, University of Reading), is presently hampered by a lack of funds.

The scientific and numerical specification of Glimmer-CISM reflects the changing nature of contemporary ice sheet modelling. The model was initially based on the established Shallow Ice Approximation¹⁴, solved using the Finite Difference method. Thermomechanical coupling and a simple treatment of basal melt/sliding were also included in the model described in Rutt *et al.*². However, Glimmer-CISM has recently gained a higher-order stress balance module developed by Price and Payne, using the approaches of Blatter¹⁵ and Pattyn¹⁶, as well as other enhancements.

Glimmer-CISM has a relatively modular architecture; it can be embedded within other codes with comparative ease. For example, the code can be coupled to a variety of climate drivers and landscape evolution models. It also allows multiple regional ice sheet instances within the same overall model. Model configuration can be controlled flexibly using standardised configuration files, including determining which numerical methods, ice physics and bed parameterisations are selected. Glimmer-CISM uses NetCDF¹⁷ for file IO, and there is significant freedom in the variables and frequency of output.

However, Glimmer-CISM was not originally designed around a standardised API; instead, the code base has grown organically. While the code runs well as a whole, the interface between components is weakly specified, process modules are not always well encapsulated (they have embedded dependency with other parts of the code). An ISM-GCM coupling module is provided with Glimmer-CISM, but it has quite limited functionality, so where external coupling has taken place, it has been crafted for a specific application rather than considered (or defined) in abstract. Existing coupling of Glimmer-CISM to HadCM3 and CESM is of this form.

Glimmer-CISM is the leading ISM with a UK provenance. The most prominent alternatives are PISM¹⁸, developed by groups at University of Alaska Fairbanks and Potsdam Institute for Climate Impact Research, and Elmer¹⁹, a multiphysics finite element code developed by the CSC, Espoo, Finland. There is a substantial potential European user group comprising scientists coupling ISMs to GCMs in FP7 who currently use PISM, in part because of concerns over Glimmer-CISM's coupling environment. Glimmer benefits from its 3D higher order scheme whereas PISM uses a simpler hybrid scheme. A further open-source code is provided via NASA, being a joint development between the Jet Propulsion Laboratory and University of California at Irvine²⁰. Whilst

a number of ice sheet codes are available, some are provided piecemeal and are not truly open-source.

5. PROJECT PARTNERS

Our project partners fall into three categories:

Major developers. These are groups currently making major continued developments to Glimmer-CISM and its incorporation into other Earth System Models. There are two major partner groups which have been instrumental in developing Glimmer-CISM over the last four years: those at LANL (Lipscomb and Price) and the University of Montana (Johnson). In particular, the LANL group have provided significant sustained investment in the development of parallel, higher-order ice-flow models (in collaboration with participants in the DOE Ice Sheet Initiative for Climate ExtremeS (ISICLES)) and in the coupling of Glimmer-CISM to CESM. Total DOE investment in these projects is currently in excess of \$4M/year, the majority being specifically applied to Glimmer-CISM. The work by these groups on the code base will continue (see letters of support) and is directly complementary to what is proposed here. We will continue to work closely with these partners as part of the framework development process (see below), and to assist their implementation of the framework in CESM. We will also work closely with the Hadley Centre and University of Reading (Ridley/Gregory) to conduct parallel work for the suite of Hadley Centre models derived from the Met Office Unified Model (HadGEM3-ES and FAMOUS).

Wider ISM/GCM users. This is a group (e.g. Colleoni, Clark, Benn, Rea: see Letters of Support) which comprises scientists who use Glimmer-CISM to solve scientific problems, and who are interested in continuing to use ice sheet codes as they develop. This is the group who are likely to benefit most directly from the proposed work. We need to ensure that this user community gains genuine benefits from the way the code is operated and can be interfaced, and from the supporting materials provided. Through a series of Framework Development Workshops (see below), their role is to inform us of their experience of using ISMs, what they perceive as desirable, the best kind of interfaces, and how the code can be improved to solve the problems they are interested in. The principle is to have a deeper conversation with the typical users of the code, and to identify shared aspirations and experiences.

Developers of other ice sheet codes. (e.g. Zwinger, Nowicki, Aðalgeirsdóttir, Ritz: see Letters of Support. Ayako Abe-Ouchi, University of Tokyo and Anders Levermann, Potsdam Institute for Climate Impact Research have also expressed support and agreed to participate in project workshops) The current core of Glimmer-CISM and other ice sheet codes will eventually become obsolete. Already there are new ice sheet codes (e.g. Elmer) which bring improvements in how the ice physics are solved, yet arguably are less easy to use than Glimmer-CISM. What is important for the wider community is to avoid having to re-invent how models can be operated and coupled as these underlying codes evolve. By involving this group of partners, we will seek ways of standardising the ISM-GCM interface such that it can be operated in a similar way. This could lead to benefits now, since it would mean that different ice sheet models could be swapped in and out of larger models comparatively easily. In the future, it would mean that if there were an agreed interfacing standard, new models could be developed to conform to it. Consequently, it is essential to involve other model developers in this discussion.

6. PROJECT OVERVIEW

There are seven primary work packages (WP1-WP7) proposed:

WP1. Definition of scientific and technical requirements

WP2. Specification of ice sheet model internal and external coupling APIs

WP3. Architecture modification and API implementation for Glimmer-CISM

WP4. API implementation in CESM GCMs and Hadley Centre models

WP5. Improvements to Glimmer-CISM accessibility and usability

WP6. Creation and delivery of training materials and courses

WP7. Establishment of a longer-term community network to advance API development.

A detailed work plan follows below. We emphasise that the work outlined is targeted at providing better infrastructure and supporting use of the existing code in the wider community. We aspire to continue to provide scientific enhancements to the core of Glimmer-CISM, but funding will be sought from other sources to allow this to happen, as well as falling within the scope of activities by our international partners.

Community engagement and participation is essential to achieve the goals listed above. Our approach to gaining community-wide consensus on these requirements as they evolve is to convene two *Framework Development Workshops* involving ourselves and each of our partner communities previously outlined. The two workshops are intended to be formative, in as much as we intend that they should lead to the agreement on (at least) a prototype interface standard for ice sheet models. The workshops broadly map into WP1 and WP2, but will be used to further other aspects of project, in particular in helping form a longer-term community network (WP7)

7. DETAILED WORK PLAN

The objectives (OBJ1-3, section 1) that are tackled by each work package (WP1-WP7) are indicated. Specific resultant Deliverables D1-D12, are also indicated.

WP1 Definition of scientific and technical requirements (OBJ1)

Before commencing on a practical framework for ISM-GCM coupling, we will undertake work to understand and define the range of functionality it is to have. The scientific aspects will include: the possible coupling fields and their calculation, interaction with the atmosphere, land surface and ocean components of the GCM, asynchronous coupling strategies, and interpolation/downscaling techniques. The technical aspects will include computing platforms, compilers, language choice, parallelism, file IO, and restart mechanisms.

We will use *Framework Development Workshop 1* to explain the overall concept behind the project, to engage participants in aspects of current practice, to identify core data-model needs, to permit key scientific problems to be addressed, and to discuss technical solutions.

Work will be undertaken by the project team to identify and consider key primary aspects of a potential interface within a scoping document (D1) feeding in to Workshop 1, in order to provide a structure for discussion. Following the workshop, the team will draw up a full technical and scientific specification of requirements that will be distributed to all the project participants (D2)

WP2 Specification of ice sheet model internal and external coupling APIs (OBJ1)

Having determined what the ISM and ISM-GCM APIs should be capable of doing, we will next write a full API for internal ISM use and ISM-GCM coupling (D3), sufficiently detailed that it can be used by other modellers to implement compatible interfaces in their own models. This will be done by the project team following Workshop 1, in particular forming part of the major role of Hagdorn.

The initial API will be presented to the community prior to and for discussion at *Framework Development Workshop 2*. At Workshop 2 we will invite reflections on and refinements to this API. We will hold sessions that allow discussion on detailed aspects of the interfacing and its needs as specified in the requirements and API generated from Workshop 1.

WP3 Architecture modification and API implementation for Glimmer-CISM (OBJ2)

Following the work completed in WP1 and WP2 on API specification and design, we will modify the interface and structure of Glimmer-CISM to conform to the API (D4). This will provide a working example of how the API should be implemented, and will demonstrate the practicability and usefulness of the approach. We will use the Workshop 2 to review and refine the outcomes available at this point. This part will be carried out by the UK project team, particularly Hagdorn, in collaboration with Project Partners at LANL and University of Montana,

This work will likely be conducted in tandem with WP2: that is, a real implementation of the API will be developed in parallel with the specification. We will report on how the API is implemented within Glimmer-CISM at Workshop 2.

WP4 API implementation in CESM GCMs and Hadley Centre models (OBJ2)

We will implement the GCM side of the coupling API in CESM and Hadley Centre models (Famous, HadCM3, HadGEM3-ES) (D5). This part will be carried out by Project Partners at LANL, University of Montana, Met Office/Hadley Centre and University of Reading, in consultation with the core UK project team. In particular, ongoing projects led by Partners Gregory and Ridley already aim to couple Glimmer-CISM to Hadley Centre models, and the API will provide them access to better specified and better supported ways of achieving this.

WP5 Improvements to Glimmer-CISM accessibility and usability. (OBJ3)

The most recent developments to Glimmer-CISM have tended to focus on improvements to the underlying physics, and have to some extent incurred further complexity in the use of the code. By contrast, the documentation and front-end accessibility to the code has lagged behind. For a specialist, use of Glimmer-CISM is not particularly complex, and permits relatively easy access to ice sheet models. However, for non-specialists or new users there is quite a technical hurdle to overcome. Connected to WP3, we will regularise the code into two main branches, one for stable code and one for development, and a number of feature branches. This will assist stable evolution of the code. Secondly, the code will be fully documented, and user-guides for non-specialists will be developed (D6). Third, we will employ a dedicated programmer (Swansea) to build a graphical 'front-end' to some versions of the code that will allow it to be driven for simple scenarios where the base topography, and climate options can be selected from particular options, or user-specified data (D7). This will be done to support both Windows and Linux platforms. This latter functionality is particularly targeted at non-expert and student use so that we can extend awareness and use of the code. All of these will be released through an enhanced, more user-friendly instance of the existing Glimmer-CISM website (D8)

WP6 Creation and delivery of training materials and courses. (OBJ3)

This element extends that provided in A5 but is more directly targeted at pro-active engagement of the user-community so that we can extend expertise in the use of the code, once the tools that enhance the code accessibility are prepared. The development of a new ISM/GCM modelling framework will have maximum impact only if ice sheet and climate modellers are aware of it and know how to use it. To make sure these goals are achieved we will generate structured training materials (D9) in support of three training events (D10) aimed at a broad constituency of scientific ISM users but targeted to graduate student/postdoctoral level. These users will mainly comprise the wider ISM/GCM user-community referred to above. The training events will be run over two full days, and will provide a comprehensive introduction to the coupling framework in general, and its implementation in Glimmer-CISM in particular. Hands-on experience for the participants will be a central part of these events. Training materials and model documentation will be provided, which will also be published on the project website. We aim to educate users about the principles of utilising the standard interfaces, such that if they go on to work with other codes, they will be aware of this opportunity. We will also ensure that these training events persist beyond the time of the grant and be funded from additional sources (D10), in part via the establishment of a longer-term community (WP7). We will thus create a cadre of individuals trained in the use of Glimmer-CISM and as a specific instance of the API (D11)

WP7 Establishment of a longer-term community network to advance API development (OBJ1)

Glimmer-CISM is a community code operating under a public licence (currently the GNU GPL²¹, but soon to be released under GNU LGPL²²). It is therefore not 'owned' by anyone. The way in which it is used and is developed by various interest groups is in part dictated by those that have an interest in and resource to make it happen. The kind of development that is proposed in WP1&2 also necessitates mutual agreement and benefits to those that participate in the further development of the code. For the most part, those interested in furthering ice sheet models do not want to get bogged down in huge bureaucracies or management systems; they want to get on and do the next bit of science. However, if an agreed specification of an API, and the efficient development of models is desirable, then the collegiate and consensual activity that implies requires a level of steerage and governance. We will explore via both workshops and beyond longer-term ways of establishing networks, centred on the existing Glimmer-CISM Steering

Committee, which can continue to provide consensus on how ice sheet models can be more easily interfaced and accessible. We aim to create a longer term network of API users (D12), subject to mutual agreement of participants, and for which we will aim to generate continued support.

8. PROJECT MANAGEMENT PLAN

The overall progress of the project will be managed by the existing Glimmer-CISM steering committee (Rutt, Hagdorn, Payne, Lipscomb, Price and Johnson), with the addition of Co-I Hulton. Overall operational responsibility rests with PI Rutt, but decisions will be taken on a consensus basis within the group. Responsibility for individual work packages is given below, with specific deliverables in each case.

The structure and mechanics of the two **Framework Development Workshops** (WP1, WP2) is similar. Each workshop requires a planning phase, where participants are invited, practical arrangements made, and a detailed schedule devised to facilitate best use of available time. *Milestones*: First and second circulars; detailed programme, event takes place; follow-up with participants; workshop report.

WP1 Definition of scientific and technical requirements [Hulton/Hagdorn]

This includes organisation of Workshop 1 (Hulton), but also includes initial scoping of the requirements that will provide information for the planning of the workshop (Hulton). In addition to Hulton, Hagdorn will have a major role in this work package. *Deliverables*: D1 - scoping document for technical and scientific requirements; D2 - full draft of technical and scientific requirements.

WP2 Specification of ice sheet model internal and external coupling APIs [Rutt/Hagdorn]

This work package depends on WP1, and includes further refinement in the course of Workshop 2. The main task in this work package is to turn the technical and scientific requirements into a detailed API specification. This task will be largely carried out by Rutt and Hagdorn, in consultation with other Co-Is and project partners. *Deliverable*: D3 - full draft of API specification document.

WP3 Architecture modification and API implementation for Glimmer-CISM [Rutt/Hagdorn]

This work package will run alongside WP2, and will deliver outputs to WP1 and WP4. Glimmer-CISM will provide a testbed for API development, and the experience will inform decisions in WP2 as to which approaches are most practical and beneficial. Rutt and Hagdorn will deliver this work package in consultation with other Co-Is and project partners. *Deliverable*: D4 - working implementation of API in Glimmer-CISM, including a suite of regression tests.

WP4 API implementation in CESM GCMs and Hadley Centre models [Payne]

This work package depends on WP3 and WP4. The parts of the API specification which relate to ISM-GCM coupling will be implemented in CESM and the Hadley Centre models. These changes will primarily be made by project partners Lipscomb and Price (CESM), with and Ridley and Gregory (Hadley Centre and Univ. Reading), coordinated by Payne. *Deliverable*: D5 - Working coupling between Glimmer-CISM and these two GCMs.

WP5 Glimmer-CISM usability changes and documentation [Rutt]

This work package depends on WP3, and provides outputs to WP6. In the light of any concerns raised in Workshops 1 and 2, changes to Glimmer-CISM will be made to enhance usability. Full documentation of the model will be generated, and a graphical front-end to the model will be written. The Glimmer-CISM website will be redesigned and improved to provide easy access to documentation, and to support the building of the community network of stakeholders. Programming tasks will be undertaken by a graduate programmer, under direction from Rutt. Website developments will be commissioned from commercial providers. *Deliverables*: D6 - full documentation delivered (web/PDF); D7 - GUI front-end delivered, including relevant documentation; D8 - new website.

WP6 Creation and delivery of training materials and courses [Hulton/Rutt/Hagdorn]

This work package depends on all the other activities in the project. Nevertheless, to leverage maximum engagement and impact during the life of the project, we will initiate training events before the other work packages are complete. Three training events will be provided, one in the second year of the project, and two in the third. These will be led by Hulton, Rutt and Hagdorn, with input from Payne and project partners. *Deliverables*: D9 - Training materials on website; D10 -

training events advertised and successfully organised. D11 - Secured long-term support further training beyond the grant period.

WP7 Establishment of a longer-term community network [Rutt/All]

This package lasts for the duration of the project but is inherently harder to manage practically and relies on community willingness which we can foster but not directly command. Time will be set aside at each workshop to discuss the best format for forming a longer term network, and the best governance structures to enable that to happen. The Glimmer-CISM steering group steer API developments within its own code, but to be successful the network will require more extended community membership. D12 – Invigorated stakeholder network

Work Package Schedule

The GANTT chart shows how the WP1-7 will be scheduled across the 36 months of the project:

Year	2012		2013				2014				2015	
Quarter	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
WP1		WK1										
WP2							WK2					
WP3												
WP4												
WP5												
WP6												
WP7												

9. DELIVERABLES SUMMARY

There will be tangible and long-lasting outcomes (Deliverables D1-12) from the project:

D1 Scoping document on current model interface design and broad interface requirements.

D2 Published specification of scientific and technical requirements of the API

D3 A published interface standard (API) that ice sheet and climate modellers can work to

D4 Upgrades to Glimmer-CISM to adhering to the API and improving internal modularity

D5 Addition to Hadley centre models to allow coupling via the API

D6 Creation and release of code documentation and user Guides for Glimmer-CISM

D7 Development of a GUI front-end to Glimmer-CISM to improve access to some versions

D8 New website to promote and release Glimmer-CISM upgrades, and API specification

D9 Structured training materials to introduce user to the API and Glimmer-CISM

D10 Three specific training events within the grant period

D11 Securing longer term support for further training events

D12 A long-term network to support API development and ISM-GCM coupling in general

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