Welcome to UK Earth System Model (UKESM) News from the Joint Weather and Climate Research Programme (JWCRP).

The UK Earth system modelling project is a joint venture between the Met Office and the Natural Environmental Research Council (NERC) to develop and apply a world-leading community Earth System Model.

If you like to get in touch, please email us at **ukesm@ncas.ac.uk**.

For more information visit our website **www.ukesm.ac.uk**.

INSIDE THIS ISSUE:

1. Final steps to UKESM1

Colin Jones, NCAS and UKESM core group

The UKESM core group

INTRODUCTION

As discussed in the 5th UKESM Newsletter (Sellar et al.2017, Parameter tuning for UKESM1, newsletter no. 5), over the past 12 months we have been working intensively on the scientific calibration of UKESM1, an important and necessary final step when a set of complex component models are coupled together into a fully coupled Earth system model (ESM). This calibration effort is now largely complete and the 1st version of UKESM1 will be ready for scientific use in January 2018. At this point the UKESM core group will launch the first set of UKESM1 simulations contributing to the 6th Coupled Model Intercomparison Project (CMIP6). These simulations, referred to as the CMIP DECK (Eyring et al. 2016), have already begun with the physical core of UKESM1, namely HadGEM3-GC3.1 at N96/ORCA1 resolution (referred to as GC31 hereafter) and are reported elsewhere in this newsletter (Kuhlbrodt et al. 2017). Subsequent to starting the CMIP6 DECK, the core group will then ensure UKESM1 is made available to the wider UK research community for their individual research use.

Here we follow up on where the report of Sellar et al. 2017 ended to illustrate the type of (calibration/tuning) challenges we have been addressing in the final stages of developing UKESM1. We discuss how the radiation bias, presented and un-remedied at the time of that article, has now been corrected (or rather reduced). Combined with the remedying of other, similar biases that appeared as the UKESM1 component models were progressively coupled together, we have now reached a position where the present UKESM prototype model (UKESM0.9.4) is performing sufficiently well to be released for active scientific use by the UK research community.

AN EXAMPLE BIAS FROM UKESM0.6, FINALLY REMEDIED AT UKESM0.9.1

Below we reproduce figure 1 from the Sellar et al. 2017 article, which shows one of the biases in UKESM0.6 being addressed at the time that article was written. This bias manifested itself as a broad area of the continental Northern Hemisphere mid-latitudes not reflecting sufficient amounts of solar radiation in the winter months, compared to both the parent physical model (GC31) and satellite observations. This lack of solar reflection was traced to the land surface in these regions being not sufficiently reflective and was thought to be a result of one important difference between UKESM and GC31; namely UKESM dynamically predicts the surface vegetation type and cover, whereas these are externally prescribed based on observations in GC31. In particular, it was thought that differences in predicted vegetation type and cover in UKESM0.6, and their interaction with accumulating winter snow in the regions in question, was the cause of the large differences in winter surface reflectivity seen between the 2 models. This bias in reflectivity leads to excess absorption of solar radiation at the surface and a warm bias in winter and spring surface temperatures.

The bias is self-amplifying through the fact that excess absorption of solar radiation at the surface also causes snow to melt more rapidly than observed, further reducing the surface reflectivity. Furthermore, the large spatial extent of the energy bias associated with this error was shown to impact a number of other, planetary scale, phenomena in UKESM0.6. As an example, tests running UKESM0.6 with vegetation prescribed to be the same as GC31 indicated that this surface radiation bias caused a ~20% reduction in the strength of the Atlantic Meridional Overturning Circulation (AMOC) in the model. Hence it was deemed critical to reduce this surface reflectivity bias before UKESM could be deemed fit for purpose.

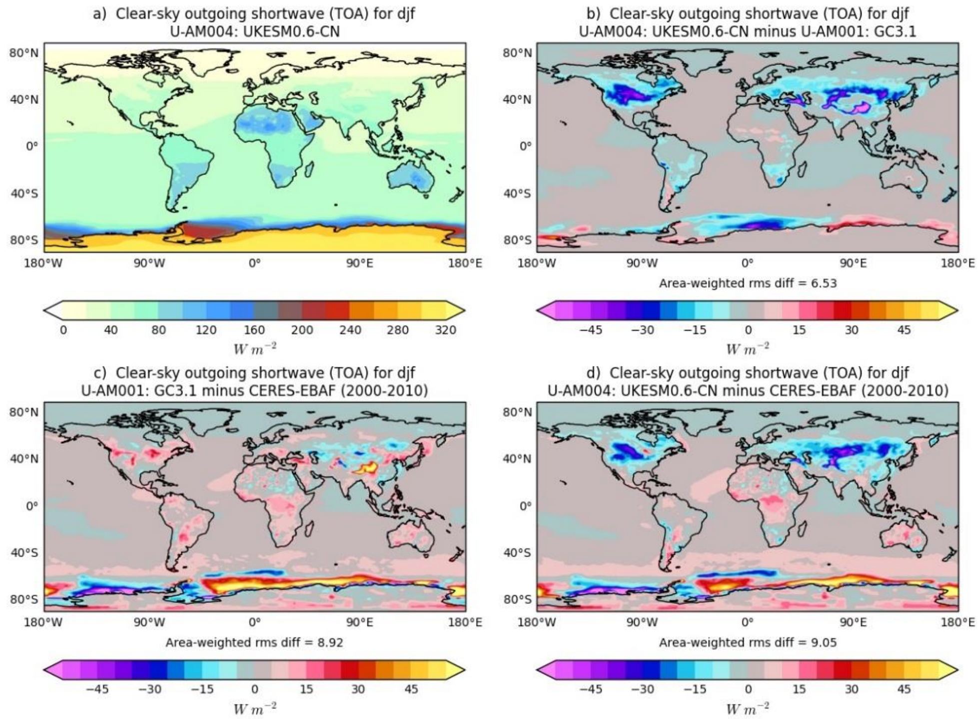


Figure 1. *Top of atmosphere clear-sky outgoing shortwave radiation (Dec-Jan-Feb average) for UKESM0.6 and HadGEM3-GC3.1. a) UKESM0.6. b) Difference between UKESM0.6 and GC31. c) GC31 errors against CERES-EBAF satellite observations. d) UKESM0.6 errors against the same observations.*

DIAGNOSING THE UNDERLYING CAUSE OF THE BIAS

After a large amount of analysis the cause of the difference in Figure 1 was narrowed down to the definition of a model parameter, known as "the Leaf Area Index" or LAI and the interaction of LAI with snow accumulating through the model simulated winter. LAI is largely a model-based parameter that describes the degree to which a given simulated vegetation type interacts with model energy fluxes, such as solar radiation. Roughly speaking, the larger the value of LAI, the greater amount of foliage a vegetation type is assumed to have and the greater its interaction with solar radiation (e.g. reflection or absorption). The total reflectivity (or albedo) of vegetation varies by type and growth through the annual cycle, but lies in the approximate range ~10 to

30%. As snow accumulates on the ground (in both the real and model world), vegetation is gradually buried and the surface reflectivity rapidly increases towards much higher snow values, going from an initial surface vegetation value, through one that is a mixture of snow and protruding vegetation (~30-60%) to finally reach the high snow albedo values (~70-90%). The rate of this transition depends both on the amount of snow accumulating on the ground and the type of vegetation on to which the snow falls.

In GC31 vegetation type and distribution are externally prescribed, combined with this an annual cycle of LAI is assigned to each prescribed vegetation type. These LAI values are based on satellite observations. Hence, in regions and periods of the year that are snow covered, the prescribed LAI implicitly includes the impact of accumulating snow cover on the seasonal variation of LAI. Thus, in GC31 the parameterization that describes the impact of accumulating snow on the grid box mean surface albedo in vegetated regions is not required (or is largely inactive), as the impact of snow cover is already included in the prescribed LAI. One can argue that the prescribed LAI in GC31 is not really an LAI for vegetation, rather in regions and periods of snow cover, it is an LAI representative of the combined snow cover and (progressively buried) vegetation. In UKESM0.6, vegetation type, spatial cover and foliage are all dynamically predicted. Hence, in winter the LAI of a given vegetation is the model's best estimate of that vegetation's actual LAI, without any inclusion of the impact of snow cover. In UKESM0.6, therefore, the parameterization describing the impact of accumulating snow on the total grid box mean (combined vegetation and snow cover) surface albedo becomes critical for an accurate simulation of the annual cycle of total surface reflectivity. As a result of the implicit inclusion of snow effects on vegetation in GC31, this particular parameterization which is also used in UKESM, is not sufficiently active in terms of the impact accumulating snow has on surface reflectivity when more realistic vegetation LAI values (as simulated by UKESM0.6) interact with the model's snow scheme. The result in UKESM0.6 is a negative bias in surface reflectivity (too low reflectivity) due to an underestimate of the impact of accumulating snow in vegetated areas on total surface reflectivity.

SOLVING THE PROBLEM AND REDUCTION OF THE BIAS

Modifications of this parameterization, particularly with respect to the interaction of accumulating snow with broadleaf trees and shrubs, increasing the rate at which vegetation, in terms of its interaction with downwelling solar radiation, is buried by snow, led to a dramatic reduction in the model solar reflectivity bias. This can be seen in figure 2, which plots the same quantity as in figure 1 (top of atmosphere outgoing solar radiation (OSR) in clear sky conditions during boreal winter). The top right panel shows the increase in OSR when the parameterization for the impact of accumulating snow on vegetated LAI is modified versus prior to this modification. To a large extent the area of increased clear sky OSR in figure 2 (red coloured areas in the mid latitude

Northern Hemisphere with increased OSR values of ~20Wm^{-2}) is a mirror image of the UKESM0.6 error in figure 1. The lower panels in figure 2 show the bias in clear sky OSR compared to satellite-based observations. The lower left shows UKESM0.9 before the snow-LAI modification and lower right (UKESM0.9.1) after the modification. While not all of the OSR bias is removed, there is a very significant improvement in the regions of of concern. Improvements of a smaller magnitude are also seen in the Northern Hemisphere autumn and spring, again due to an improved representation of the interaction between accumulating snow and vegetation and their combined impact on downwelling solar radiation.

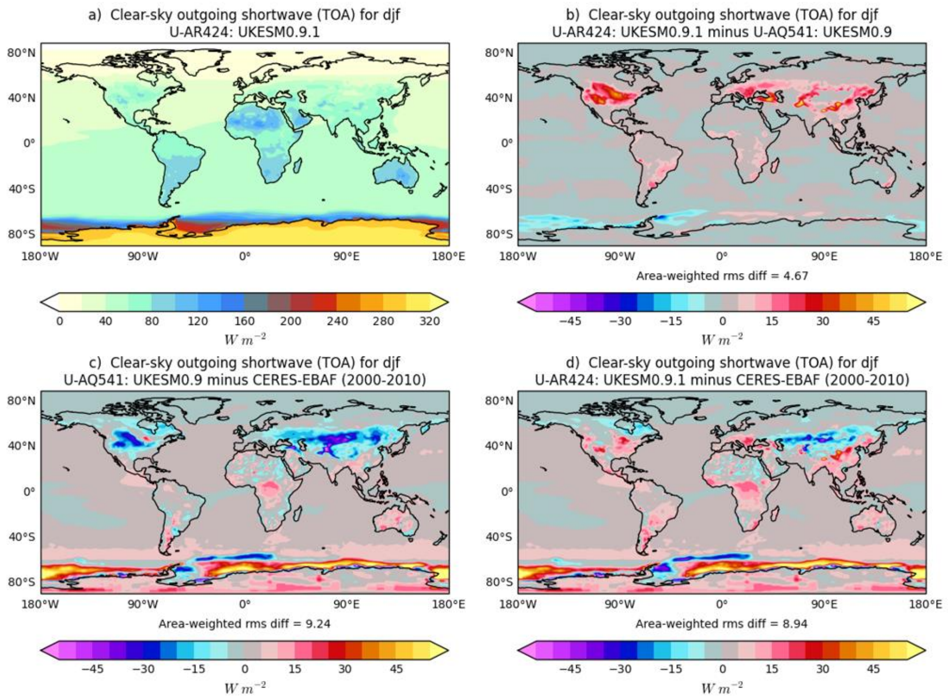


Figure 2. *As Figure 1, but (b) UKESM0.9.1 – UKESM0.9, (c) UKESM0.9 - EBAF (d) UKESM0.9.1 – EBAF.*

KNOCK ON EFFECTS OF ONE BIAS REDUCTION ON OTHER MODEL BIASES.

Reduction of the winter surface reflectivity bias in UKESM0.9.1, as expected, led to near surface temperatures across wide swathes of the Northern Hemisphere becoming warmer, particularly in boreal winter and summer. This was deemed an improvement. Perhaps more surprisingly, the ~20% reduction in the strength of the AMOC between GC31 (~16 Sverdrups in strength) and UKESM0.6 (~13 Sverdrups strength) was also remedied by correcting the surface reflectivity problem, with the AMOC in UKESM0.9.1 now of similar strength to GC31. Improvements to the AMOC also had a significant (and positive) impact on Arctic sea ice thickness as simulated in UKESM0.9.1.

REFERENCES

- Eyring, V., S. Bony, G. A. Meehl, C. A. Senior, B. Stevens, R. J. Stouffer, and K. E. Taylor (2016), Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization, *Geoscientific Model Development*, *9*(5), 1937-1958, doi: 10.5194/gmd-9-1937-2016.
- Alistair Sellar et al. Parameter tuning for UKESM1, UKESM Newsletter no. 5, June 2017.
- Till Kuhlbrodt and Colin Jones. Starting the CMIP6 simulations with HadGEM3 GC3.1. UKESM Newsletter no. 6, December 2017.

2. Progress towards interactive Ice Sheets in UKESM1

Robin Smith, National Centre for Atmospheric Science (NCAS) and UKESM core group

There is currently an intense focus in the UKESM development group on finalising the 1st version of UKESM that will be used for the majority of CMIP6 runs that start early next year. But there will be more than one configuration of UKESM, each with different strengths, designed to explore different science questions. One of these alternative configurations will have fully interactive, dynamic ice sheets – a new frontier in climate modelling, and one that will give UKESM unique capabilities amongst Earth system models.

An overview of this version, UKESM1-IS, was presented in our previous Newsletter No 2: April 2016 (https://ukesm.ac.uk/an-overview-of-the-land-ice-in-ukesm1). Since then a great deal of progress on coupling the ice sheets to UKESM has been made through a fruitful cross-centre collaboration between the Met Office, British Antarctic Survey and Reading and Bristol Universities, led by the UKESM core team. Ice sheets have significant interactions with many other parts of the Earth System, so as well as developing mechanisms for passing information to and from the ice sheet model we have also had to make major scientific and technical developments in other parts of UKESM, introducing new subgrid scale surface and snow physics into JULES and enabling NEMO to simulate the ocean under floating Antarctic ice shelves.

We now have a working prototype of UKESM-IS with a fully interactive, dynamic Greenland ice sheet that is being used to tune and evaluate the coupled system. To reduce the computational overhead and enable long simulations, UKESM1-IS will run without interactive atmospheric chemistry and ocean biogeochemistry found in UKESM1 - this prototype suite setup uses about the same resources as a normal HadGEM3 GC3.1 simulation.

Greenland is not the only ice sheet on Earth, of course, and some of the most interesting questions - and potentially the ones with most impact on sea-level - are centred around Antarctica. Around half of the mass loss from Antarctica occurs under the floating ice shelves that extend from the continent, so including -ice shelf interaction between NEMO and the ice sheet model is essential for simulating a dynamic Antarctica in UKESM1-IS. Not only does this require significantly higher ocean model resolution than used in the standard UKESM1, in order to represent the ice shelf regions in the first place, there is also a requirement to allow the boundaries of the ocean to change during the model simulation as the ice shelves change in physical extent. This latter point is both technically and numerically very challenging. While the scheme we have developed to address this performs well in idealised test cases, it has so far proven less robust in a more realistic domain and this part of the coupling is still being developed.

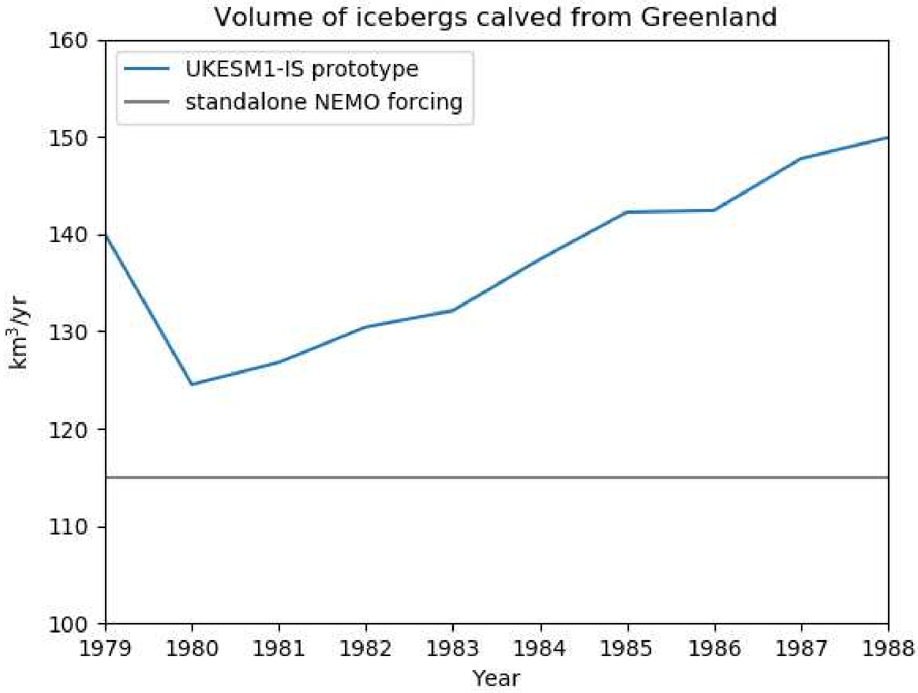


Figure 1. *In UKESM1-IS, ice that BISICLES has calved from the edge of the ice sheets is used to seed NEMO's Lagrangian iceberg scheme, affecting both the magnitude and distribution of iceberg melt in the ocean. The Greenland-only UKESM1-IS is still being tuned, but the volume of ice being calved from Greenland is in the right ballpark - higher than what is used in standalone NEMO runs at this resolution, but lower than observational estimates.*

UKESM1-IS will be used to produce results for the coupled climate-ice sheet runs specified by ISMIP6 as part of CMIP6, which focus on the climate feedbacks from a dynamic Greenland. In order that we can finish these for the IPCC AR6 deadline, we will release a version of UKESM1-IS and start these runs in the summer of 2018, pending a decision on the science-readiness of the Antarctic coupling.

3. Starting the CMIP6 simulations with HadGEM3 GC3.1

Till Kuhlbrodt and Colin Jones, National Centre for Atmospheric Science (NCAS) and UKESM core group

Following finalization of the scientific evaluation of HadGEM3 GC3.1 (see UKESM newsletter no.4), the first set of “production” runs for the CMIP6 model intercomparison (Eyring et al., 2016) have now begun. These are being performed at the two spatial resolutions of HadGEM3 GC3.1: N96ORCA1 (CMIP6 tag: HadGEM3-GC31-LL) and N216ORCA025 (HadGEM3-GC31-MM). The former of these 2 constitutes the coupled physical model core of UKESM1.

Preceding the start of the production runs, the two model versions were spun up in order to transition them form an observation-based “present-day” (PD) initial climate state to a climate state in equilibrium with pre-industrial (PI) radiative forcing. The length of this spin-up phase was 615 years for N96ORCA1 and 224 years for N216ORCA025. For these spin-up runs, the pre-industrial (1850 AD) forcing was used as far as available. This comprises greenhouse gas concentrations, three-dimensional ozone forcing, solar forcing and the influence of land use on vegetation cover. The final version of the forcing datasets for volcanic emissions and aerosol emissions were released only recently. The final coupled model state from each of the 615/224 year spin up runs was then used as initial condition to start the formal pre-industrial forced control run (piControl) for CMIP6. The same initial conditions were also used to begin the first CMIP6 historical simulations of each model version. These run from 1850-2014 using observed, time-varying forcing data.

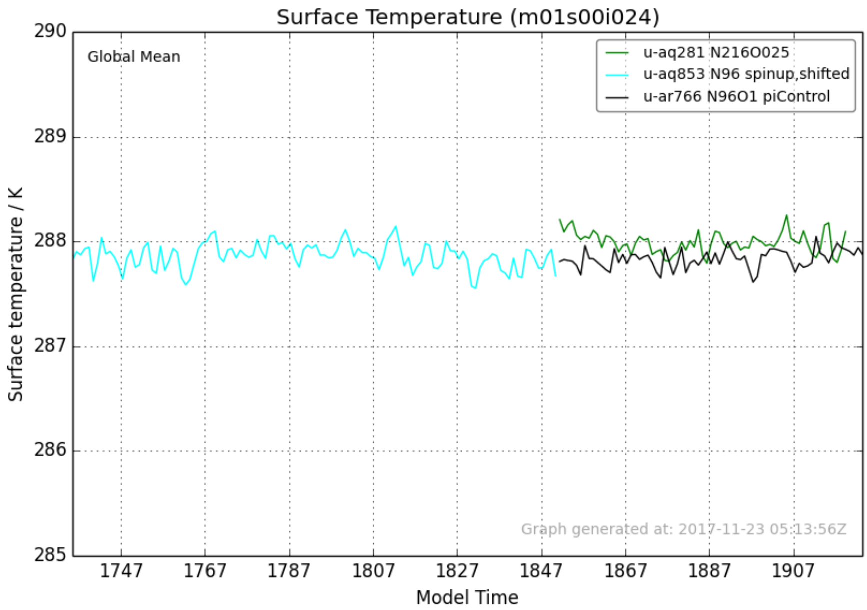


Figure 1. *Time series of global annual mean surface temperature from the end of the N96ORCA1 PI spin-up (cyan), the N96ORCA1 pre-industrial control (black) and the N216ORCA025 pre-industrial control (green). The year count is nominal since all simulations have a fixed 1850s forcing.*

An example output from the two pre-industrial spin-ups and the N96ORCA1 piControl run is shown in Figure 1. For N96ORCA1, the global annual mean surface temperature is around 287.8 K (14.7°C), with some interannual variability. In N216ORCA025, the surface temperature is on average a few tenths of a degree higher.

The CMIP6 production simulations have started with the pre-industrial control runs (piControl), followed by the idealised, 150-year long CO2-increase experiments; 1%CO2 transient increase and 4xCO2 abrupt increase. These three experiments form the core of the CMIP experiments, called the CMIP-DECK. As mentioned above, simulations of the historical climate (1850 AD to 2014 AD) have also begun. Projection simulations of the climate throughout the 21st century, based on shared socio-economic pathways (SSPs) and representative concentration pathways (RCPs) for the greenhouse gases, will begin using 2014 simulation data from the end of the respective historical simulations.

The two versions of HadGEM3 GC3.1 used for CMIP6 will be documented in papers to be published in the Journal of Advances in Modeling Earth Systems. For N96ORCA1, the paper is in preparation (Kuhlbrodt et al., 2017) while for N216ORCA025 the paper has been submitted and is already under review (Williams et al., 2017).

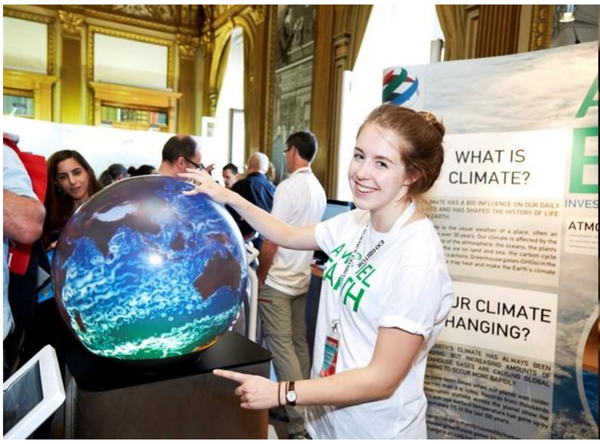
REFERENCES

- Eyring, V., S. Bony, G. A. Meehl, C. A. Senior, B. Stevens, R. J. Stouffer, and K. E. Taylor (2016), Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization, *Geoscientific Model Development*, 9(5), 1937-1958, doi: 10.5194/gmd-9-1937-2016.
- Kuhlbrodt, T., et al. (2017), The low-resolution version of HadGEM3 GC3.1: development and evaluation for global climate, *Journal of Advances in Modeling Earth Systems*, to be submitted
- Williams, K. D., D. Copsey, E. W. Blockley, A. Bodas-Salcedo,, R. C. D. Calvert, P. Davis, T. Graham, H.T. Hewitt,, P. H. R. Hill, S. Ineson, T.C. Johns, A. Keen, , A. M. R.W. Lee, S.F. Milton, M.J. Roberts, J. G. L. Rae, M.J. Roberts, A. A. Scaife,, D. S. R.K. Schiemann, L. Thorpe,, D. N. W. I.G. Watterson, A. West, R. Wood,, and T. W. a. P. K. Xavier (2017), The Met Office Global Coupled model 3.0 and 3.1 (GC3 & GC3.1) configurations, *Journal of Advances in Modeling Earth Systems*, Under review

4. A) UKESM at the Royal Society Summer Science Exhibition, 3-9 July 2017 London

Alice Booth, NCAS and summer internship in CRESCENDO and UKESM

In the first week of July 2017, The Royal Society held their annual flagship Summer Science Exhibition, in the society's home in London. Consistently attracting tens of thousands of curious visitors each year, the exhibition remains as prestigious as it was at its creation, and an incredible opportunity for members of the scientific community to show off their work to the public and develop public understanding of the amazing work that these teams do. This year the UKESM project was lucky enough to be one of the 22 exhibits at the event, and the only one in the field of climate science. Our stand, 'A Model Earth' consisted of a brilliant display, puzzles, an interactive quiz, climate oriented games, information, and our crowd-pleaser: the interactive puffersphere globe, where we alternated in displaying 6 different videos to provide s visual explanations of different aspects of the Earth system. Members from all areas of the project pitched in to help on the stand throughout the week and although completely exhausting, I've yet to come across someone who didn't have an amazing and enjoyable experience.

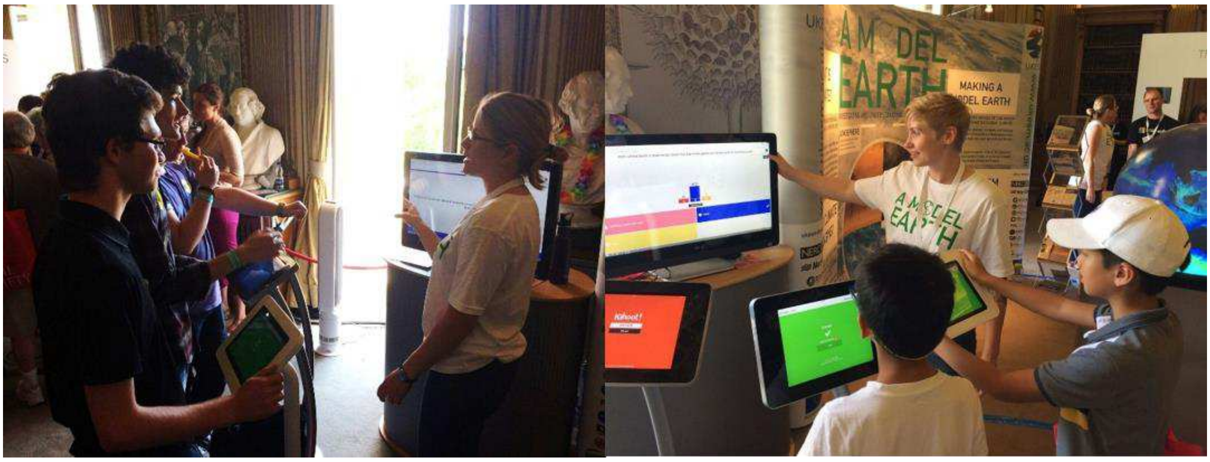


Top: Alice Booth with the Puffersphere during the exhibition. Bottom: Team photo at the Royal Society exhibition on day 7. From left to right: Alice Booth, Shannon Mason, Till Kuhlbrodt, Lucia Hosekova, Lee de Mora, Colin Jones and Alberto Muñoz.

Bigger that previous events we have attended, the Royal Society exhibition was exceptionally well organised. Shannon Mason from NCEO and a new addition to UKESM, noted that the exhibition was 'flashier' than other conferences he had attended, showcasing 'the best of UK science'. As a higher profile event, the range of visitors was much broader, and whilst all had a general science interest and were clearly curious and intelligent, the 'general understanding of climate modelling or climate change science was relatively low probably due to the low exposure to research most people receive in their day to day lives', noted Jane Mulcahy, a Met Office member of the UKESM Core Development Team. Jane also noted how, although many visitors were not climate scientists themselves, their background in other sciences meant they understood far more thanan average member of the public might be expected to. After all, 'its's all the same physics'. For Jane, engagement with younger audiences is a priority, and the Schools Day at the exhibition gave the team a brilliant opportunity to engage with children of all ages. 'If they learn even one thing then I'm happy' said Jane on the topic. Shannon also spoke about the satisfaction of speaking to A Level students about careers in science and knowing that he might have encouraged them to become scientists themselves.

> *'I thought the interactive quiz was brilliant. You were able to start a conversation withpeople ; ask them questions; and get them to think about what they do know about climate change. People don't realise the breadth and depth of the research that we do. They've had limited exposure to the concepts of modelling or climate science beyond what they hear on the news. They don't see the work that goes into producing those results and predictions. I think helping at these events and being able to communicate your research to the public is really important. You're forced to explain in simpler terms, think outside your normal box, and have a good understanding of all areas of the project as you could be asked anything. I think it definitely makes you a better scientist'. – Jane Mulcahy.*

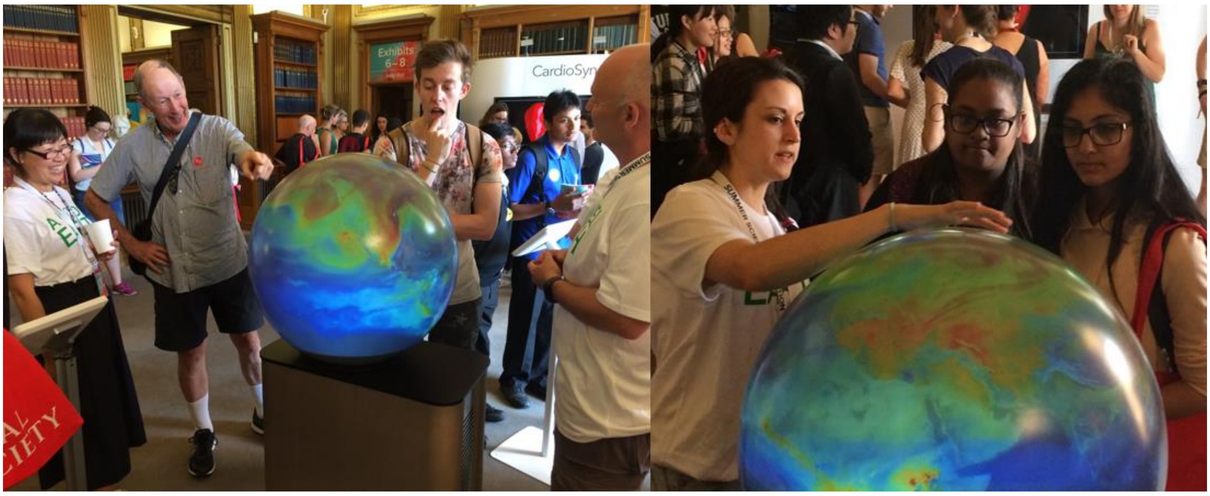
The variety of visitors meant we were also able to spend time talking to those outside our normal bubbles of similar-minded people and see contrasting viewpoints on the both the politics and science of climate change. 'People know about the concept of 2°C of warming, but they often haven't considered the spatial variation that this involves. It was amazing to see people's eyes light up at the complexity [of temperature change in the simulation of global warming on the Globe]' noted Shannon Mason. The challenge of answering difficult questions such as 'How do you know that your models are right and are actually representing the processes correctly?', a question we often ask ourselves, was also part of the excitement for many of the team as it forced them to think hard about their explanations in order to justify their research to someone who may need some convincing.



Jane Mulcahy (left) and Emma Suckling (right) during the exhibition playing the interactive quiz with visitors.

I myself was lucky enough to be one of the team who helped on the stand, spending the full week there as part of my summer internship with the project. Having just finished my second year of an undergraduate degree at the University of St Andrews, I'd had very little real experience with climate scientists or the work that they do, outside of the lecture hall. My internship was based around science communication and public engagement, an area I'm keen to be more involved in my future career, an intention encouraged by my time with the UKESM team and at the Royal Society. I'm not sure what I'd expected before going to the exhibition. I certainly hadn't expected talking to people or being on my feet 12 hours a day to be as tiring as it was. I also don't think I'd comprehended just how many interesting people I'd get to meet, from all areas of science and the public. My confidence in public speaking, particularly in explaining research to non-experts, has never improved as quickly as it did at the Royal Society exhibition. It was a pleasure to meet and talk to the rest of the UKESM team throughout the week, and an exciting, albeit daunting, experience to meet the fellows of the Royal Society, including the Vice President of the Royal Society, Professor Halliday, who turned out to have taught one of my own lecturers. Science is a smaller world than I'd expected!

My main role at the exhibition was to collect responses to a survey I'd prepared before the event, the aim of which was to gauge how effective we were at communicating the project's research to the general public (to see the results visit the article Results from the visitor's survey, in Newsletter no.6). I did this by asking questions on climate knowledge and opinions to visitors who had been to our stand, and those who had not, along with some feedback, and then later comparing their answers to see if there was a trend. Whilst sometimes repetitive saying 'hello! Would you mind filling out this survey on climate change really quickly?' over and over, this did give me the opportunity to explore the rest of the exhibition, meet other exhibitors, and to advertise our stand. My wanderings also prompted several interesting conversations with cheery visitors, often very outspoken with their views on the politics of climate change. There were many who insisted we send our research to President Trump, several more who discussed the problems of short-termism in politics, and even one who, completely seriously, suggested that a cull on a proportion of the population was needed in order to avoid the worst effects of climate change. To this I pointed out that this policy was unlikely to be popular with voters.



Yongming Tang and Rich Ellis (left) and Cat Scott (right) explaining the simulations and movies shown at the Puffersphere to members of the public.

When I wasn't surveying, I joined the other members of the team at our stand. This was an extremely enjoyable experience and it was wonderful to see such a range of people engaging in climate science research. I spent a while early on in the week explaining the videos on the globe to an extremely enthusiastic 5 year old who amazed me with her curiosity and interest – certainly a budding climate scientist in the making! A half hour debate with a mild-mannered climate sceptic and a lively discussion with a knowledgeable war veteran, were also among the highlights.

A big thank you to all who helped make the event possible – it was incredibly well-organised and a huge skills-builder for myself in particular. My time there and during the rest of my internship has certainly cemented my interest in outreach and making science accessible to the public. One of the main obstacles in making effective climate change mitigation and adaption possible is the lack of public understanding of the causes, mechanisms, and impacts of climate change. Fewer still understand the methodology behind modelling or prediction, making effective communication of research to non-experts really important. I would highly recommend attendance of the exhibition next year.

Chris Wilson (left) and Colin Jones (right) talking and playing with the younger visitors at our 'climate games' table.

For more information on the Royal Society and its events see https://royalsociety.org/.

To see the results and read more about the survey undertaken at the exhibition visit the article: Results from the visitor's survey, in Newsletter no.6.

4. B) Results from the Royal Society Summer Science Exhibition visitors' survey

Alice Booth and Alberto Muñoz, National Centre for Atmospheric Science (NCAS)

In order to evaluate the effectiveness of communication at our stand, 'A Model Earth', at the Royal Society Summer Science Exhibition (3rd to 9th July 2017) and to observe trends in opinions and knowledge of climate science amongst exhibition visitors, a survey was conducted over the course of the exhibition week. The aim was to compare answers to a selected number of questions on climate change, what we called '*opinion questions*' (example question included; what role have humans played in climate change?, how will climate change affect humans?, and what is society doing to combat climate change?) with a second set of questions that tested the knowledge of exhibition visitors about the science of Earth system modelling and current levels of global warming, what we called '*knowledge-based questions'*. These questions were compared stratified by age, level of education, and whether they had visited our stand, 'A Model Earth' at the point when the questions were answered. Such a study was party conducted due to interest and partly to help determine whether our method of communicating our research at the stand was effective and appropriate to the knowledge level of the general public.

RESULTS

175 respondents completed the survey, 164 above the age of 14 (see age distribution in Fig. 1A). Because of the low number of people under 14 who took our survey, the subsequent analysis and conclusions are based on those surveyed above the age of 14.

Regarding the first set of '*opinion questions*', there was a strong majority of 94.5% who believed climate change was occurring as a result of human activity (Fig. 1B). The age distribution was slightly more diverse in answer to the question '*Do you think that you will be directly affected by climate change within your lifetime?*' (Fig. 1C). Whilst 93.9% of respondents believed that they would be affected in some respect, there was variation between those who thought they 'would be affected in some ways', and those who thought that climate change would 'have a major impact' on their life. Markedly, the 60+ age group were less likely to believe that they would feel major impacts of climate change within their lifetimes. The proportion of over 60s who answered '*Yes, I think it will have a major impact on my life*' was greater than 10% lower than any other age group (20.7% of the +60 group compared to 33.3% and 37.3% for 14-29 and 30-59 age groups, respectively). Likewise, the proportion who answered '*No, I don't think climate change will have an effect for some time to come*', was over 10% higher than other age groups (13.8% of the +60 group compared to ~2.5% for 14-29 and 30-59 age groups).

A slightly lower majority of 76.8% believed society could do more to combat climate change. The opinion, '*No, I think we can do more'*, was the preferred answers by all age groups (Fig. 1D). However, the group of +60 again showed a marked difference with the other groups when choosing '*Yes, I think we're doing the best we can for the time being*', with higher number of answers than all other groups (20% of the +60 group compared to 4.9% and 2.0% for 14-29 and 30-59 age groups, respectively).

Whilst also a representation of age and therefore individuals foreseeing less time for the climate to change within their lifetimes than, for example, a 15 year old, this could also suggest a more widespread belief that climate change is a future concern rather than something that is affecting humans in the present day. Moreover, the increased number of responses in the +60 group feeling that efforts currently being made by society to address climate change are not that bad, could also be attributed to life expectancy, as this group may be more likely to consider other aspects where they feel society should focus more , such as health care or pensions.

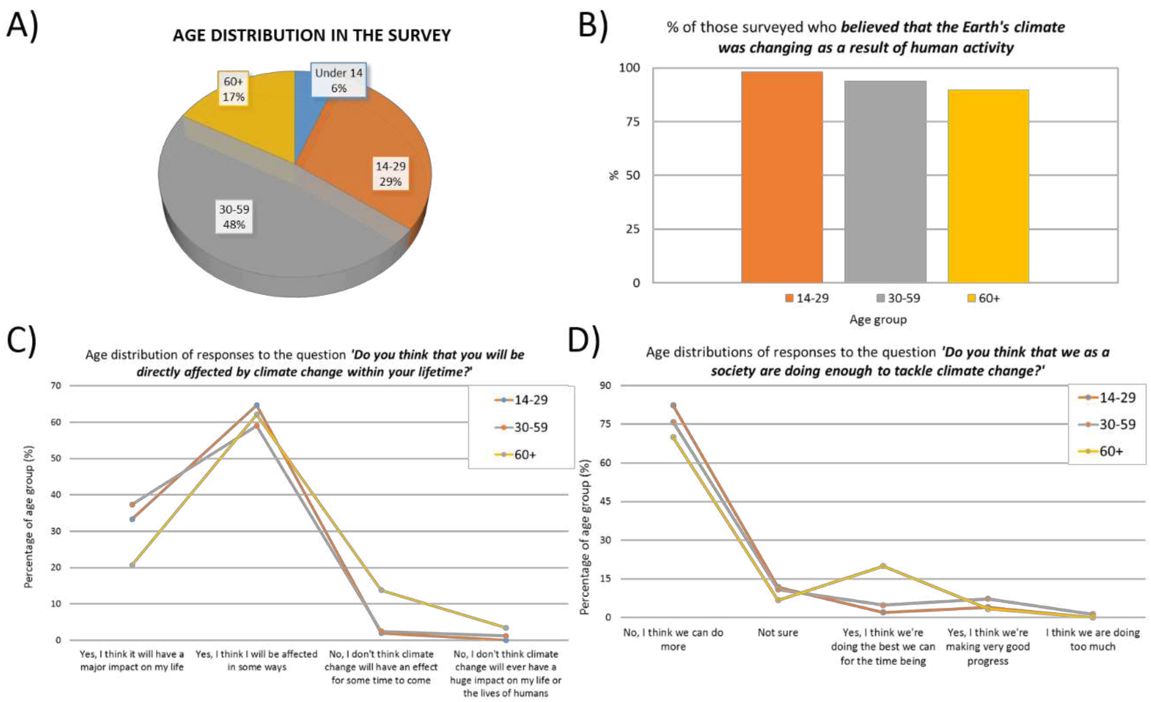


Figure 1. A): Age distribution of the 175 visitors who took the survey. B): Percentage of positive answers to the question '*Do you believe that the Earth's climate is changing as a result of human activity?*' C) and D): Age distribution of the responses to the questions '*Do you think that you will directly affected by climate change within your lifetime?*' and '*Do you think that we as a society are doing enough to tackle climate change?*', respectively.

Meanwhile, certain knowledge-based questions showed a higher proportion of correct answers. 75.6% of respondents correctly answered that the Earth had seen approximately 1°C of warming over the past 100 years. In contrast, only 28.7% of respondents correctly answered which components of the Earth were included in an Earth system model. This suggests that whilst the public is relatively well exposed to the facts of global warming, their understanding of climate science and the methodology behind the research, in particular climate modelling, is much lower (Fig. 2A).

Whilst the survey results show no significant difference between opinions expressing concern about climate change, of those who had visited the stand and those who had not, there is a slight improvement in the proportion of respondents who answered all of the knowledge-based questions correctly (Fig. 2B). 60% of those who had not visited the stand answered 2 or more questions correctly, with 17% answering all 3 correctly. This compares to 65% of those who had been to the stand receiving 2 or more right answers, and 22% with all 3 correct. While this is only a small increase, the knowledge and scientific understanding of the visitors to the exhibition was already high prior to arriving at the exhibition, hence their interest in attending. An example of this was when we compared the correct number of answers to our knowledge-based questions based on Educational level of the respondent. Results showed how the number of people who answered 2 or more questions right increased with their level of education, with higher numbers of correct answers in the groups of respondents with postgraduate and undergraduate degrees (Fig. 2C).

Whilst 'A Model Earth' may not have significantly influenced the opinions of many exhibition visitors, the results suggest that communication was effective enough to have slightly improved average understanding of climate science.

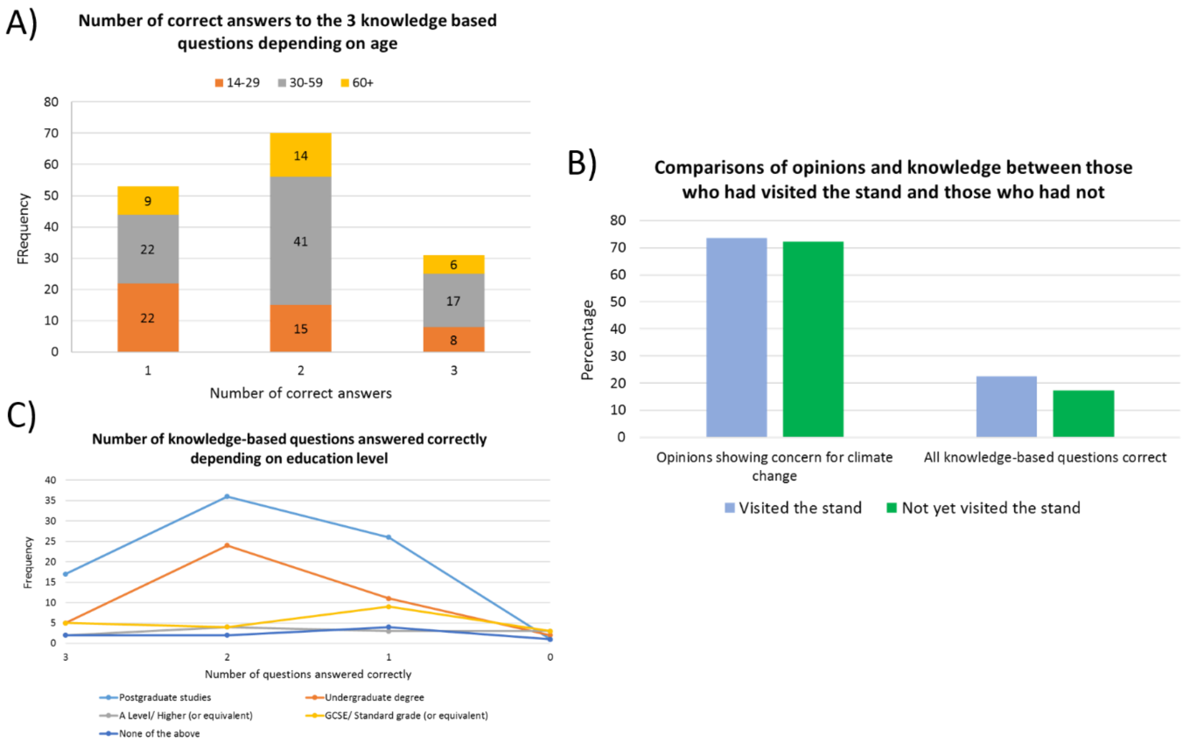


Figure 2. A): Cumulative number of correct answers to the 3 knowledge-based questions across age groups. B): Differences between the responses of those who had visited 'A MODEL EARTH' stand compared to those who had not. C): Comparison of the number of correct answers to the knowledge-based questions depending on the educational level of the exhibition visitors.

CONCLUSIONS

The results of this survey suggest the public have a relatively good understanding of global warming and have concerned opinions surrounding climate change, although the sample was biased towards a more educated audience due to the nature of the Royal Society exhibition (i.e. those likely to attend such an event are likely to have an interest in, and therefore a certain level of understanding of science in general and potentially a decent exposure to climate science). However, the results do show a difference in opinions over how rapidly the impacts of climate change will occur, depending on age, and also suggest that public understanding of climate modelling or Earth system models is very low. The feedback from the survey shows that visitors found our stand enjoyable and the slight improvement in answering the knowledge-based questions after visiting the stand suggest that communication of concepts was good and that the team was engaging. A limitation of the methodology could potentially be the presence of multiple-choice that may mean respondents had an opportunity to guess and still get the answer right, meaning that the total number of correct answers may have been affected as a result. If the survey was repeated then a larger, more diverse sample size might be preferable as it may be more representative of the whole population. A greater number of questions would also allow better analysis of public understanding, although due to the nature of the event this is likely unwise as visitors are unlikely to want to answer a long survey.

METHODOLOGY

The survey was carried out on a mobile tablet using an app called ‘Quick Tap Survey’, which worked offline and then collected the results in a single database. In order to cater for different ages and whether respondents had visited our stand, the survey used branching, where different answers to certain questions, determined which question followed. Respondents under the age of 14 were also offered an alternate set of questions which were more appropriate for their level of understanding. As well as ensuring that no-one was excluded from the survey, it also maximised the number of visitors who were likely to answer the survey as parents are more likely to join in if their children can also be involved. Respondents were selected randomly from the visitors to the exhibition, both in the building and in the queue outside. All ages, genders and ethnicities were approached for the survey.

The following questions were asked:

1. What is your age? - Under 14 - 14-29 - 30-59 - 60+	
2a. Do you believe that the Earth's climate is changing as a result of human activity? - Yes - No - Not sure	**2b. In the next 50 years do you think that the Earth will…** - get warmer - get colder - stay the same
3a. Do you think that you will directly affected by climate change within your lifetime? - Yes, I think it will have a major impact on my life - Yes, I think I will be affected in some ways - No, I don't think climate change will have an effect for some time to come - No, I don't think climate change will ever have a huge impact on my life or the lives of humans	**3b. How will climate change affect our environment? Click all the ones you think are right** - Some wildlife will lose their habitats - There will be fewer storms - The sea level will rise - We will have longer summer holidays because it will be so warm
4a. Do you think that we as a society are doing enough to tackle climate change? - I think we are doing too much - Yes, I think we're making very good progress - Yes, I think we're doing the best we can for the time being - Not sure - No, I think we can do more	**4b. What ways can we help protect the environment?** - Recycling our rubbish - Walking or riding our bikes to school instead of going in the car - Turning off lights when we leave the room - Going on more holidays abroad - Cutting down trees
5a. Approximately, how much do you think the Earth's temperature has increased by in the last 100 years? - 0°C - 1°C -11°C -0.5°C	**5b. Have you visited the 'A Model earth' stand yet?** - Yes - No
6a. Which of the following best describes an 'Earth System Model'? - Mathematical equations describing current global weather patterns - A computer simulation that uses equations to describe every part of the earth system in the past, present, and future - Kate Moss speaking out about climate change - A prediction of future global warming	**6b. How interesting did you find the stand?** (Sliding scale) **End**

7a. Which of the following components are included in an earth system model? Select all that apply - Land and sea ice - Birds - Oceans - The moon - Fish - Vegetation	
8a. What is the highest academic qualification you have completed/ received? - GCSE/ Standard grade (or equivalent) - A Level/ Highers (or equivalent) - Undergraduate degree - Postgraduate studies - None of the above	
9a. Have you visited the 'A Model Earth' exhibit yet? - No - Yes	
10a. How enjoyable did you find the stand? (sliding scale)	**10b. What are you most hoping to learn more about at the 'A Model Earth' exhibit?** - How climate models works - How humans will be affected by future climate change - How we can help to minimise future climate change - How much the climate is likely to change in the future - The difference between weather and climate - The research of the scientists at the stand - I really don't know!
11. If you could add one thing to make the exhibit better, what would it be?	
End	

5. Recent past events

16 November 2017. Earth System science at COP23 - Bonn, Germany:

Colin Jones, head of the UKESM project, together with Jason Lowe (Met Office and University of Leeds) and Matthew Gidden (International Institute of Applied Systems Analysis), presented at a side event, organised by the Met office, at the UK Pavilion in COP23. The event, entitled: 'From science to policy: applying Earth system models', showcased the policy relevance of Earth system models and addressed some of the high profile questions, such as: How can information from these models inform and support policy making in the areas of mitigation and adaptation to global change?; How the next generation of Earth system models will contribute to the next IPCC 6th Assessment Report; or What future human emission of greenhouse gases is compatible with realizing the Paris Accord?

11-14 November 2017. Representing UKESM at CERN, by Lee de Mora, PML and UKESM core group:

Before I started working in the UKESM project, I worked on an entirely different project: the ATLAS experiment at CERN. CERN is the European Organization for Nuclear Research: it is the largest particle physics laboratory in the world and hosts the Large Hadron Collider, as well as many significant physics experiments. Between 2006 and 2010, I completed a PhD working on B-physics with the ATLAS detector, including two years at the CERN site just outside Geneva. I was quite lucky to be on site for the excitement of the first beam, the first collisions and the early results.

Perhaps because of the contrast between my PhD and my current work with the UKESM, the CERN alumni network invited me to participate in a panel discussion at their annual careers event this November. The target audience for this event was current PhD students and early career scientists at CERN, who for whatever reason want to leave the field of particle physics or who are unable to remain. The goal of the event was to put them in contact with CERN alumni in other fields and to demonstrate that life is indeed possible for physicists outside the world of high energy physics.

The panel discussion was led by Sebastian Bott of the alumni network, and consisted of Sarah Livermore, from the UK committee for climate change; Xavier Rouby, a consultancy entrepreneur; Jacopo Nardulli, an international baccalaureate science teacher; and myself, representing the UK's earth system modelling project. The panel discussion covered numerous topics, notably what skills we developed at CERN, how we apply the skills learned there to our current work, what the main differences are between high energy physics and our current positions, and how we got from our PhD to where we are now. The event also included several opportunities for questions from the audience and breaks for informal discussions. I was lucky to meet many young scientists who were interested in potentially studying climate change.

In addition to the panel discussion, the event had several fantastic talks showing off a range of career paths available to physicists, including software development at google, particle physics in medical applications, working in the energy sector, or in high-tech software application, such as facial recognition software.

The invited alumni were also taken on a guided tour of the Anti-matter factory, which houses the new anti-proton decelerator, ELENA. We saw many experiments studying the properties of anti-matter. We also had the chance to visit the CMS experiment's control room, the microcosm and the Globe of Science and Innovation visitor centres.

Image Captions: **A**) The AntiMatter Factory, which houses several experiments testing the nature of anti-matter, the anti-proton decelerator (AD) and the ELENA Decelerator. **B**) The ELENA anti-proton decelerator. This hexagonal storage ring slows down the anti-protons produced by the AD before sending them to the experiments. **C**) A Large Hadron Collier dipole magnet. This is a functional spare LHC magnet, and is one of many on display scattered around CERN and the greater Geneva area. **D**) The Wandering the Immeasurable sculpture, sitting outside the Globe of Science and Innovation visitor centre. **E**) The CERN alumni event panel; left to right: Sarah Livermore, Lee de Mora, Sebastian Bott, Jacopo Nardulli and Xavier Rouby.

21-22 November 2017. UKESM core group annual meeting and retreat in Bristol:

The UKESM core group recently met for a day at the annual team retreat in Bristol. The group analysed, reviewed and discussed the following topics: UKESM1 status, plans for the 1st set of CMIP6simulations, diagnostics and data for CMIP6 and a range of outstanding model development tasks for 2018. During their time in Bristol, the group also embarked on a team-building afternoon in the form a graffiti workshop (photo below) where the artistic flair of some of the core group members finally came to the fore.

6. Team News

Recent additions to the UKESM Core Group:

Valeriu (V) Predoi, National Centre for Atmospheric Science (NCAS): V joined the NCAS CMS group as a UKESM Core Member based at the University of Reading in April 2017. He previously worked in gravitational waves research and computational analyses, as part of the LIGO collaboration at Cardiff University. Prior to this V worked in the area of computational virology at Ryerson University in Toronto, Canada. He obtained a PhD in gravitational waves data analysis from Cardiff University in 2012. He will be working on a number of computationally-oriented projects including diagnostic pipeline development, data acquisition and processing, MIP conversion tools and general integration and optimization of both existing and future model evaluation tools. V is also contributes to the development of the interactive ice sheet version of UKESM1; UKESM-IS.