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.

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ESMValTool : An Evaluation Tool for Earth System Models

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The Coupled Model Intercomparison Project (CMIP), now in its sixth phase (CMIP6) provides the climate and impact assessment community with a wide range of simulation output from Earth System Models (Eyring et al., 2016b). These simulations help us better understand past climate and also provide estimates for the future under different greenhouse gas emission scenarios. It is crucial to evaluate these simulations to better understand systemic biases in the models and the magnitude of uncertainty in future projections before using them to provide policy advice and in impact assessment studies.

There is also a need for a comprehensive framework to perform baseline aspects of model evaluation in a consistent and efficient manner. This will prevent waste of valuable time and effort by scientists individually re-implementing well established evaluation diagnostics instead of using readily available tools. A tool that implements basic metrics and diagnostics for model output evaluation, but also has the flexibility of allowing newly developed science-based evaluation measures is therefore the need of the hour. We present the Earth System Model Evaluation Tool (ESMValTool) as a tool compatible with current and future phases of CMIP, possessing many desirable features for comprehensive model evaluation (Eyring et al., 2016a).

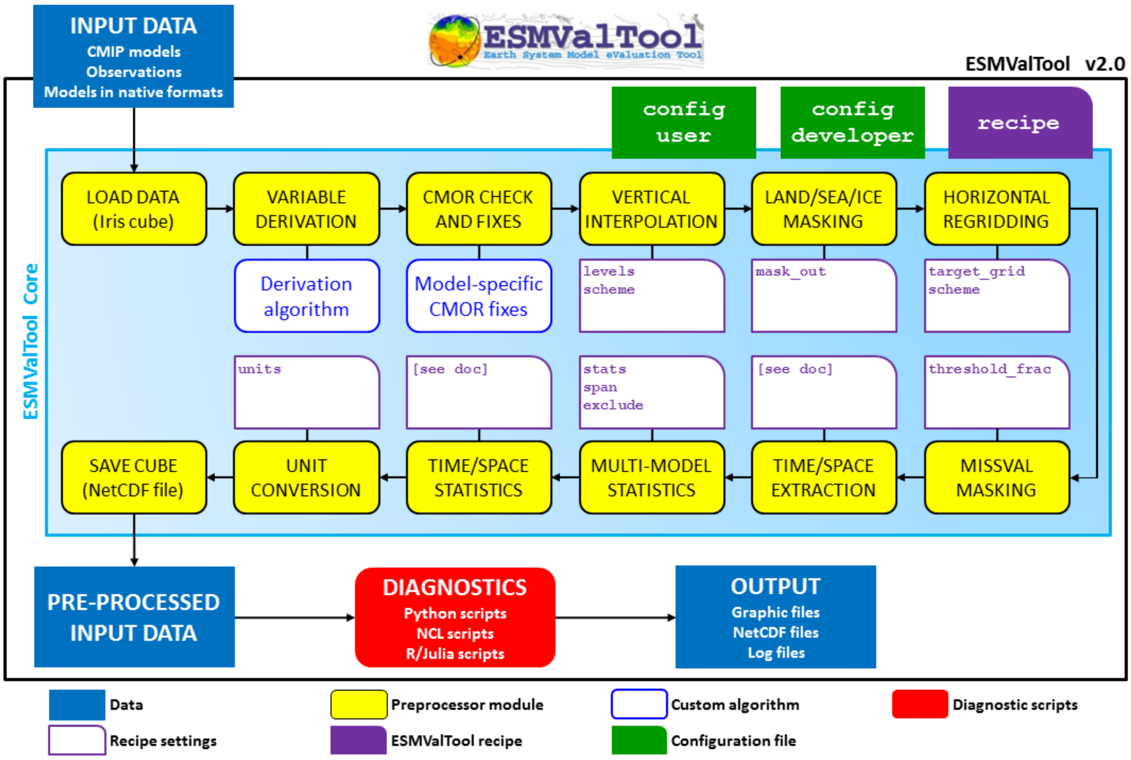

Figure 1: Overview of ESMValTool's workflow starting with user input (configuration and recipe files), data retrieval and ingestion, compliance checks and fixes, standardized preprocessing steps that are freely chosen by the user diagnostic run and final output.

ESMValTool is an open source community diagnostics and performance metric tool allowing comparison between multiple CMIP models, against different versions of these models, as well as against observations. The tool provides a versatile and highly optimized *preprocessor core* to perform standardized data operations such as re-gridding, vertical level selection, masking as well as temporal and spatial extraction capabilities. Standard recipes for scientific topics reproduce specific diagnostics and performance metrics considered important for ESM evaluation from the peer-reviewed literature (Lauer et al., 2017); integration of existing metrics and diagnostics from other packages is also possible due to the tool's modular structure. The tool is currently at version 2.0 and the most recent release allows new analyses and recipes to be written in one of many open source languages such as Python, R, NCL or Julia. Figure 1 shows a high-level overview of ESMValTool.

Some key advantages of ESMValTool are:

1. **Community shared and Open-source:** In-built powerful preprocessor functionalities with diagnostics that can be reused or adapted from existing ones. An example is Figure 2, showing a standard plot diagnostic adapted from the IPCC's Fifth Assessment Report to analyze average surface temperature and biases against reanalysis (ERA-Interim) data in the more recent CMIP6 models.
2. **Scientific Validation and Reproducibility:** Extensive documentation, log files for improved traceability and code sharing via GitHub enables the wider scientific community to reproduce and verify results from published diagnostics, as well as develop and share new diagnostics.
3. **Scope and Flexibility:** Wide scope with standard recipes covering different aspects of ESMs such as dynamics, clouds, radiation, aerosols and sea ice. The tool is also flexible, with diagnostics written in one of several open source languages (Python, NCL, R or Julia).
4. **Central Installation:** on the Centre for Environmental Data Analysis's (CEDA's) JASMIN infrastructure, with CMIP model data retrieval and a large selection of compliant observation datasets automatically facilitated.
5. **Convenient Output Formats:** Diagnostic outputs produced in a whole host of convenient formats such as plots (pdf, png etc.) and netcdf files.

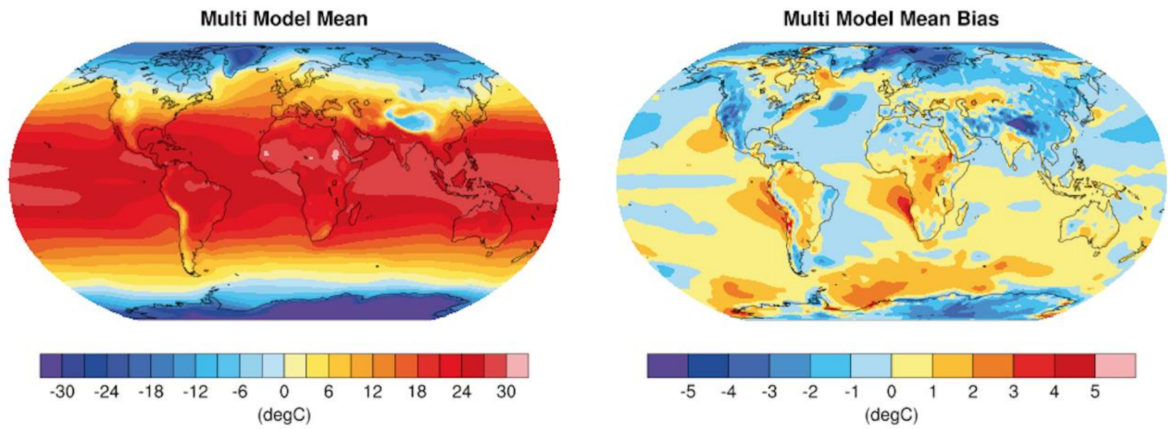

Figure 2: Annual-mean near surface (2m) air temperature (°C) for the period 1980 -2014. On the left is the multi-model ensemble mean constructed with one realization each for a selection of CMIP6

models available on CEDA-JASMIN and on the right is the multi-model-mean difference from the ECMWF reanalysis (ERA) - Interim data.

ESMValTool v2.0 continues to evolve with diagnostics ported from the previous release, relevant diagnostics ported from other assessment tools (see Figure 3 produced with the AutoAssess Stratosphere diagnostic, ported into ESMValTool v2.0) as well as new ones being added. Figure 4 shows the Atlantic Meridional Overturning Circulation (AMOC) at 26°N in some CMIP5 models. The AMOC is an important circulation feature, used to gauge the performance of models in representing ocean circulation (Cheng 2013).

The tool can be accessed from the ESMValTool GitHub page and a sample of CMIP results produced with ESMValTool is available from the German climate modelling center at DKRZ. ESMValTool is a powerful, optimised, documented, modular, and well-supported tool and we strongly encourage the climate modelling community to actively adopt it for their evaluation and analysis work.

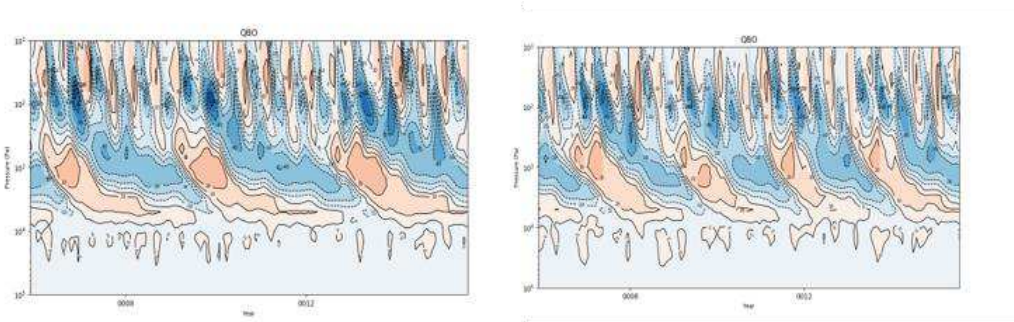

Figure 3: Quasi-Biannual Oscillation (QBO): vertical cross-section versus time for zonal mean equatorial (5N to 5S) zonal wind speed. Comparison between UKESM1-00-LL and HadGEM3-GC31-LL; plots made using the Autoassess Stratosphere assessment area, which has been ported to ESMValTool and is available part of the diagnostics library of ESMValTool version 2.0.

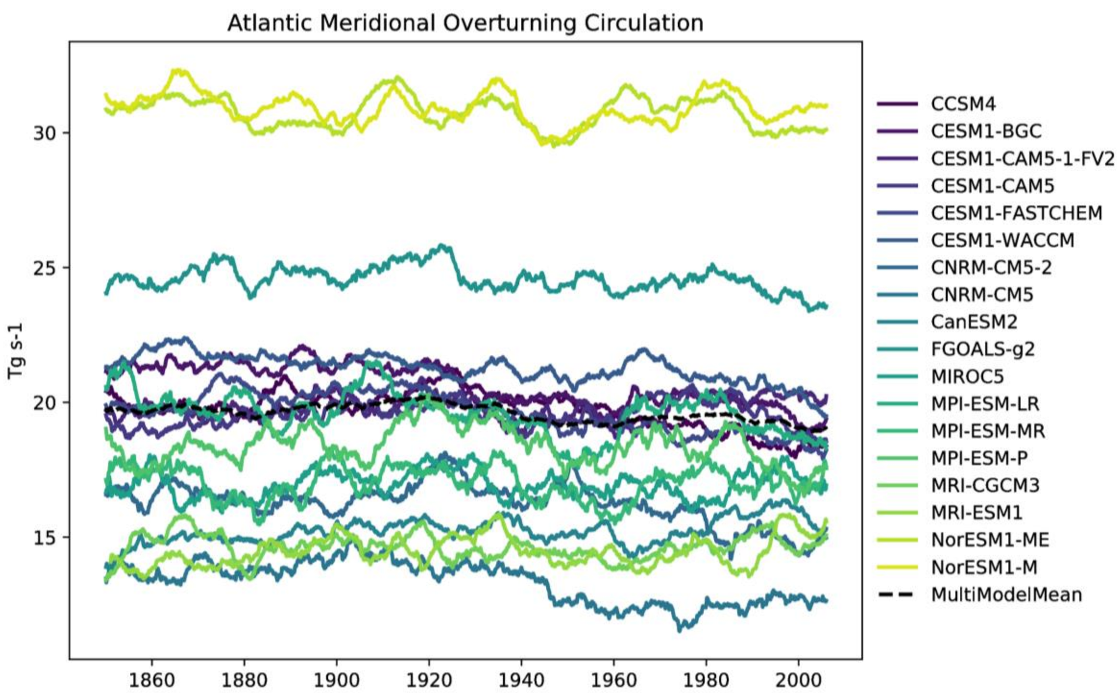

Figure 4: Figure showing the Atlantic Meridional Overturning Circulation in a range of CMIP5 models.

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A marine biomes analysis of UKESM1

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Biomes are ecosystems adapted to the specific constraints of the environment they live in. Biomes have been studied extensively on land, where the existence of natural borders and obvious geographical features helps to identify them. Defining biomes is more challenging in the ocean, where identifying and separating one ocean biome from another cannot be done simply by looking at them. Several attempts to partition the ocean into regions of broadly equivalent ecosystems have already been undertaken, typically based on observations. It is important work, both since it helps improve our understanding of the underlying marine biogeochemistry, but also because it is needed by policy makers, to help with the management of marine areas by defining "biologically significant" areas, vulnerable areas, or climate change hot-spots.

In the context of UKESM1, our study has multiple aims:

First, we aim to provide a regional evaluation of the model simulated marine physics and biogeochemistry. Typically, model evaluations are done at the large scale, effectively "bulking-up" the model's average performance everywhere. This can be a good way to characterise a model, especially when reducing the complexity of analysis, but such budgets and trends at basin scale (or larger) overlook ocean physical or biogeochemical features. Some information, which could be highlighted and improve our understanding of model behaviour, is instead diluted and lost. This is the first reason why we decided to perform a biome-based evaluation of the model.

Second, while we now know about "real" ocean biomes, based on observations, what about our models? Do they reproduce all of the observed biomes? Are they correctly located? Do they have the same ecological properties? If not, why not?

First, how do we define our biomes? There are plenty of ways to divide the ocean, most of which are tested and validated on observational data:

1. Use expert knowledge-based predefined regions to apply as a mask to the observed and modeled ocean;
2. Define biomes based on the intervals of specific key ocean variables;
3. Use an "unsupervised or automated" objective approach based on statistical tools (like clusters) applied to one or more key ocean variables.

The way we describe this problem helps to decide how best to proceed. One of our main aims is to evaluate how well the model is able to reproduce the observed biomes, which excludes the use of observationally-predefined regions whose boundaries are unlikely to map perfectly onto those of the model. Also we want to make sure that the biomes we compare, are actually comparable. This is something that is difficult to be sure of with automated methods, since the biome definition (i.e. what it represents), as well as the number of biomes, are data-dependent, something not well suited for model-observation intercomparison. The best solution in our case seems to be to define biomes based on the intervals of key-variables. This avoids the use of fixed boundaries that likely vary and is a transparent method that is straightforward to interpret.

In our study, biomes are defined based on annual maximum surface chlorophyll (CHL) and mixed layer depth (MLD) as follows:

Table 1: Chlorophyll and mixed layer depth criteria for defining ocean biomes.

Biome	Chlorophyll	Mixed layer depth
Shelves	-	-
Oligotrophic (olig)	Chl < 0.075 mg m^{-3}	-
Submesotrophic (sm)	0.075 <= Chl < 0.25 mg m^{-3}	-
Mesotrophic (m)	0.25 <= Chl < 1.0 mg m^{-3}	MLD > 100 m
Low mixing meso- (m100)	0.25 <= Chl < 1.0 mg m^{-3}	MLD < 100 m
Eutrophic (e)	1.0 < Chl	MLD > 100 m
Low mixing eu- (e100)	1.0 < Chl	MLD < 100 m

The use of annual maximum MLD enables us to disentangle productive biomes with high seasonal mixing (typically at high latitudes) from those with low seasonal mixing (typically low latitude upwelling regions). Applying these rules to both observational data and UKESM1 output results in the geographical pattern of biomes shown in Figure 1 (see also Table 2's biome areas).

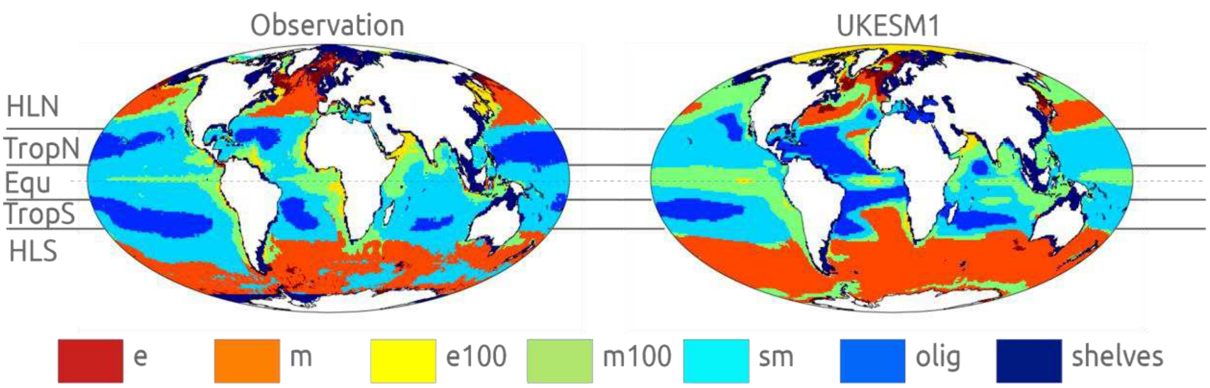

Figure 1: Present-day (2000-2009) biomes based on observations (left) and UKESM1 (right). Observations used are monthly average SeaWiFS ocean colour data, and de Boyer Montégut et al. (2004) climatology.

Figure 1 shows the model accurately simulated the main marine biomes, comparable in terms of location and size to those derived from observations, although it some model biases are evident. Oligotrophic biomes (dark blue) in the Atlantic of UKESM1 cover a wider area, at the expense of submesotrophic (light blue) and low mixing productive biomes (green). By contrast, in the Pacific Ocean, the oligotrophic biomes cover a smaller area, while the low mixing productive biome (which corresponds here to equatorial upwelling) covers a much larger area. Meanwhile, in the Southern Ocean, we find that a greater area of the model is productive (orange). This general bias is already known from our model evaluation at the global scale, but using biomes enables a more geographically resolved comparison, helping us understand what is happening to the model in this important region.

Table 2: The first two columns compare the biomes areas calculated from observational data and model output (in Mkm^2, i.e. million km^2) for the present-day (2000-2009) presented in Figure 1. The final two columns report the relative change (as a percent) of each biome area by 2090-2099 for two future scenarios whose biomes are shown in the Figure 2. Also note the model and observation-based biomes total area cannot match, because of missing data in polar regions of the observed chlorophyll fields.

Biome	Obs. area	UKESM1 area	SSP1 2.6 (low CO_2)	SSP5 8.5 (high CO_2)
Oligotrophic (olig)	39.5	38.6	+15.5%	+102.6%
Submesotrophic (sm)	145	102	+6.9%	-2.1%
Mesotrophic (m)	75.9	105.8	-8.6%	-19.7%
Low mixing meso- (m100)	43.5	74.5	+1.3%	-10.1%
Eutrophic (e)	5.4	4.8	-12.1%	-59.5%
Low mixing eu- (e100)	10.3	10.1	-62.4%	-79.6%

With the biomes defined this way, ongoing work is using them in a more regional analysis of the performance of UKESM1. This includes using them to help evaluate the model's performance across a wide range of biogeochemical properties, such as nutrient availability, productivity and carbon cycle variables, such as surface ocean pCO_2. In particular, how the modelled seasonal cycles of these properties relate to those we see in nature. This analysis is helping to provide a more complete understanding of where our model's weaknesses are and what properties of the model most require improvement in the future.

A further analysis that the biome approach can help us with is in characterizing how marine productivity may change in the future. In the same way we apply the biome criteria across both models and observations, we can apply them to model simulations at different times into the simulated future to assess how biomes may change in response to global warming. Here, we use two different ScenarioMIP simulations of the future: SSP1 2.6, a scenario with low CO_2 emissions and relatively low warming and SSP5 8.5, a scenario with high, "business-as-usual" CO_2 emissions and strong warming. Figure 2 shows the resulting biomes for these two extreme cases.

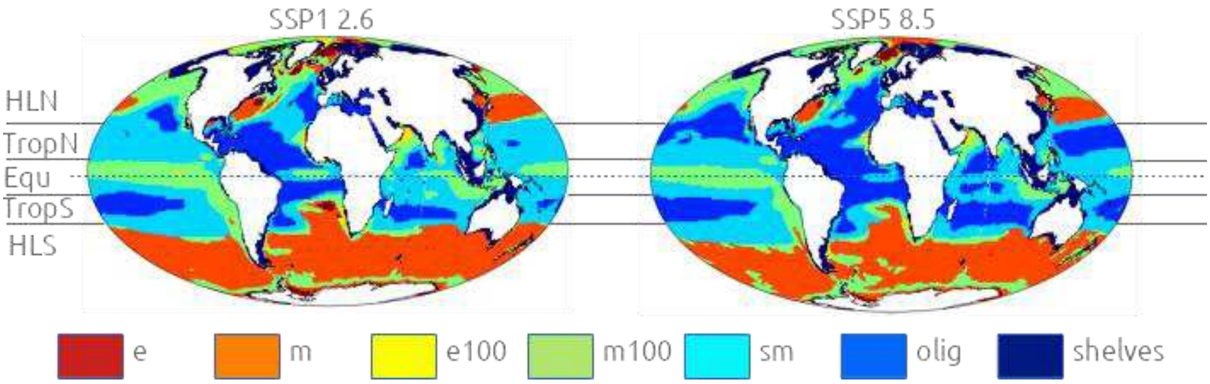

Figure 2: Future (2090-2099) biomes under two different scenarios: SSP1 2.6 (left; low CO_2 emissions) and SSP5 8.5 (right; high CO_2 emissions).

Table 2 also lists the percentage changes in the areas of the biomes across the 21st century. In both scenarios, there is a common evolution from productive / high mixing to low production / low mixing biomes. But the scenario results differ in the scale of this evolution.

In the low CO_2 emission scenario (SSP1 2.6), the eutrophic (-46%; both classes) and mesotrophic (-4.5%; both classes) biomes generally shrink and are supplanted by the submesotropic (+6.9%) and oligotrophic (+16%) biomes. However, in the high CO_2 emission scenario (SSP5 8.5), the changes are much greater, with the unproductive oligotrophic biome more than doubling its area (+102%), and the eutrophic biome collapsing (-73%; both classes). Under SSP5 8.5, the last remains of the eutrophic biomes are tiny regions east of Greenland. Given that the mesotropic and eutropic biomes are the source of most of the open ocean's productivity, including its fisheries, these large changes point to the importance of reducing CO_2 emissions.

Conclusion

Biomes are a promising tool to help us understand our model's performance. They enable us to evaluate the model according to regions that share common biogeochemical features rather than simply a common location, and to understand whether biases in different regions have the same root cause. Furthermore, they provide a handle for quantifying how different future scenarios may change the ocean's living communities.

More to come about this very soon in the UKESM1 special issue.

Preliminary results from some fully interactive UKESM1-Antarctic coupling configuration

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In the previous newsletter (Newsletter #8, https://ukesm.ac.uk/portfolio-item/coupling-greenland-and-antarctic-ice-sheets/), we briefly described two UKESM1 variations that have interactive ice sheets: one with only Greenland coupled (referred to as UKESM1-is1), and a prototype model where both Greenland and Antarctica are coupled (referred to as UKESM-is2). Here we discuss in a bit more detail the latter. UKESM-is2 has been developed to allow coupling between the BISICLES ice sheet and UKESM1 models via land-ice interaction (over Greenland & Antarctic) and ocean-ice interaction (Antarctica only).

In the aforementioned article, we mentioned that we were working on a UKESM-is2 configuration with a model resolution of N96-ORCA025 (a higher ocean model resolution than the standard UKESM1). Recently, we decided to deliver two UKESM1-is2 configurations, i.e. in addition to the N96-ORCA025 resolution, we also implement an N96-ORCA1 (ocean model resolution the same as in UKESM1). Like the ocean model component of UKESM1, both of these configurations use GO6 settings (Storkey et al. 2018) in the global ocean. The traceability hierarchy in GO6 requires that the lower resolution ORCA1 use higher horizontal viscosity, as well as the Gent-McWilliams (GM) parameterisation describing mixing due to unresolved ocean eddies. Extending the ocean into the cavities under ice shelves in ORCA1 is a challenging task. For stability reasons, we reduced the horizontal viscosities and switched off the GM parameterisation under ice shelves.

Basal melt rates under ice shelves are calculated explicitly, using the three-equation model of Jenkins (1991). The coupling frequency between BISICLES and the NEMO ocean in the fully coupled run is 1 year, therefore after the coupled model runs for 1 year, the resulting mean basal melt rate and the surface mass balance (SMB) are fed into BISICLES which is then run to update the ice-sheet geometry. The coupling becomes two-way (full) when the new ice sheet geometry is passed back into the coupled model for a subsequent 1-year period of run. While numerical stability during the geometry change has been maintained, tracer conservation issues related to this geometry change are not yet covered by this work.

We run both model configurations for 40 years under present-day climate forcing. The BISICLES ice-sheet model, with mesh refinement down to 1.2km, was initialised using an Antarctic ice-sheet geometry obtained from a standalone BISICLES spin-up run forced by a similar present-day climate. The initial temperature and salinity in the global ocean are taken from EN4 data, which are then extrapolated from Antarctic coasts into the cavities.

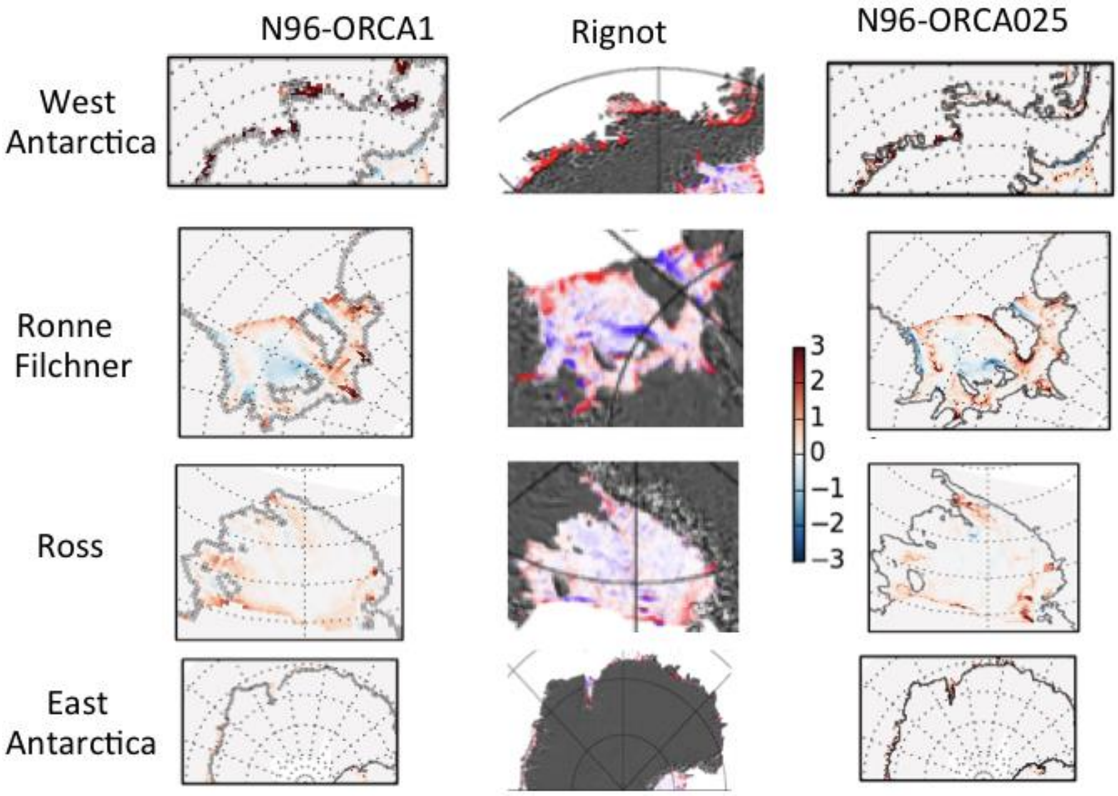

Figure 1: Melt rate (in m/year) in four Antarctic regions. The middle panel is the observation data, whereas the left and right panel are from the UKESM-is2 runs.

One of the most important ocean-ice sheet interactions to capture in a coupled model is basal melting. Figure 1 shows the spatial pattern of the Antarctic basal melt rate in the two configurations, compared to estimates from observational data (Rignot et al., 2013). We divide the continent into 4 well-known regions: West Antarctica (covering ice shelves near the Amundsen & Bellinghausen Sea, known as warm shelves), the East Antarctica (cold shelves), and the two large ice shelves Ross and Ronne-Filchner (in the Ross & Weddell sea respectively). The regional pattern of melt in both N96-ORCA1 & N96-ORCA025 configurations follows that seen in the observations in the way that melting (red colours) and freezing (blue colours) occur in largely the same areas and that larger the major melt rates also occur in almost the same areas.

The main difference between the observations and the two configurations is the colour intensity, where the observations looks darker, indicating total melt rate is higher in the observations. This is confirmed in Figure 2a, which displays total basal melt rate across the continent, where the solid red line and the two red dashed lines are the mean, upper and lower limit of observations respectively. In the last 30 years of the run, both the N96-ORCA1 (blue) and N96-ORCA025 (green) are below the observation limit.

Pine Island Glacier (PIG) is a location of major importance as it is among the fastest melting glaciers in Antarctica and may therefore give an indication of how warm West Antarctica is becoming. Its average temperature and total melt flux are shown in Figure 2b and 2c, both figures show similar time-series patterns as the total melt flux.

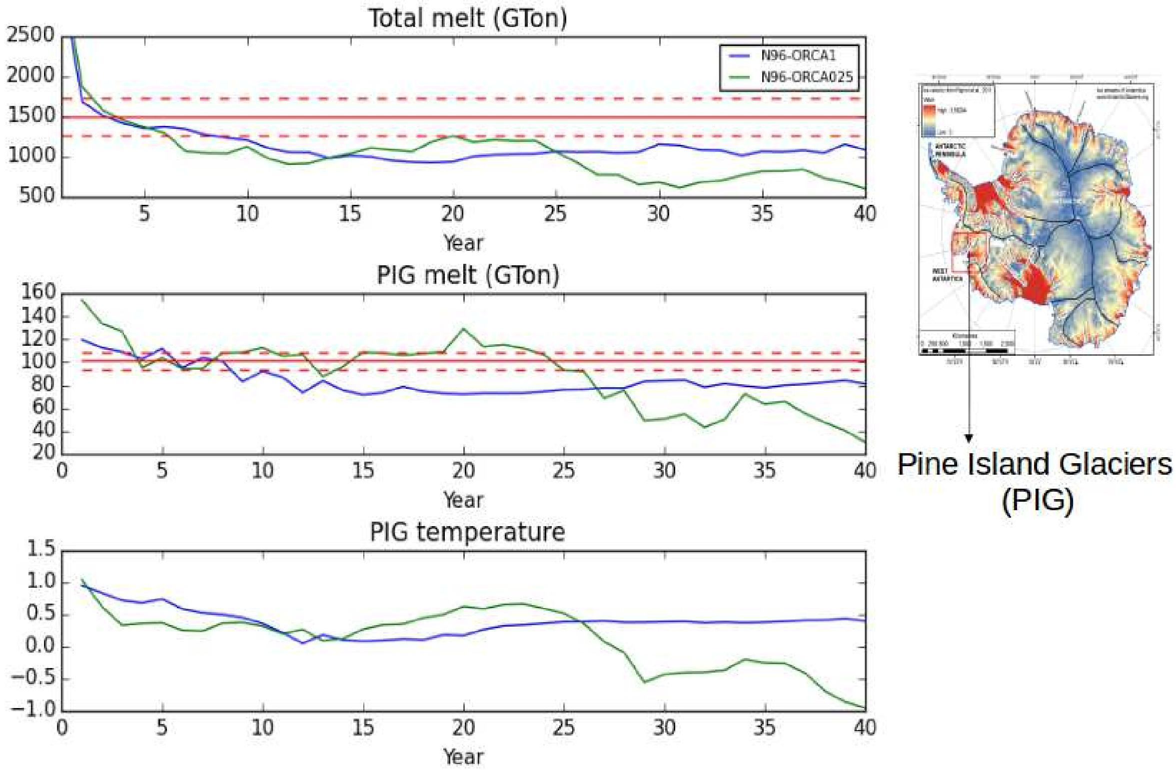

Figure 2: (a) Total basal melt flux (Gton/year) across the Antarctic continent, (b) total basal melt flux (Gton/year) from the Pine Island Glacier, (c) Average temperature in the Pine Island Glacier cavity.

Despite the lower melt rate in the two UKESM1-IS2 configurations, they show different behaviours in the last 25 years of the simulations. The N96-ORCA1 melt flux is very steady and it is only slightly lower (50-100 GTon/year) than the lower limit of observation. With further tuning and approximations available in the 3-equation model, we expect an improvement of the N96-ORCA1 results. The opposite is the case in the N96-ORCA025 simulation, where the time series melt flux shows a decreasing pattern, falling to less than half the observed melt flux. The lower average PIG temperature gives an indication that warm deep water does not reach the continental shelf in this model run. This is confirmed in Figure 3 (the last 10 years mean of 300-1000m depth averaged temperature), where the N96-ORCA025 Amundsen Sea average temperature decreases rapidly from the open ocean to the continental slope. In the same figure, the average temperature anomaly also shows that a cold bias in the West Antarctic coast is higher in N96-O25.

Further analysis shows the Drake Passage transport in UKESM-is2 N96-ORCA1 and N96-ORCA025 configurations is similar to that seen in the HadGEM3- GC3.1 N96-ORCA1 and N216-ORCA025 simulations (Kuhlbrodt, T., et al, 2018), where the transport in the higher resolution ocean drops quickly below 100 Sv whereas the lower resolution stays above 140 Sv (much closer to observational estimates). This gives us a hint that coupled models with ORCA025 ocean model (regardless of the resolution of the atmospheric model) has significant deficiencies in the Southern Ocean. Further investigations we carried out suggest almost all available ORCA025 ocean models (coupled as well as standalone) have a tendency to expand the Ross gyre further east as far as into the Bellinghausen Sea. This is generally not found in

UKESM1's N96-ORCA1 ocean models or many other coupled or standalone ocean models that use ORCA1.

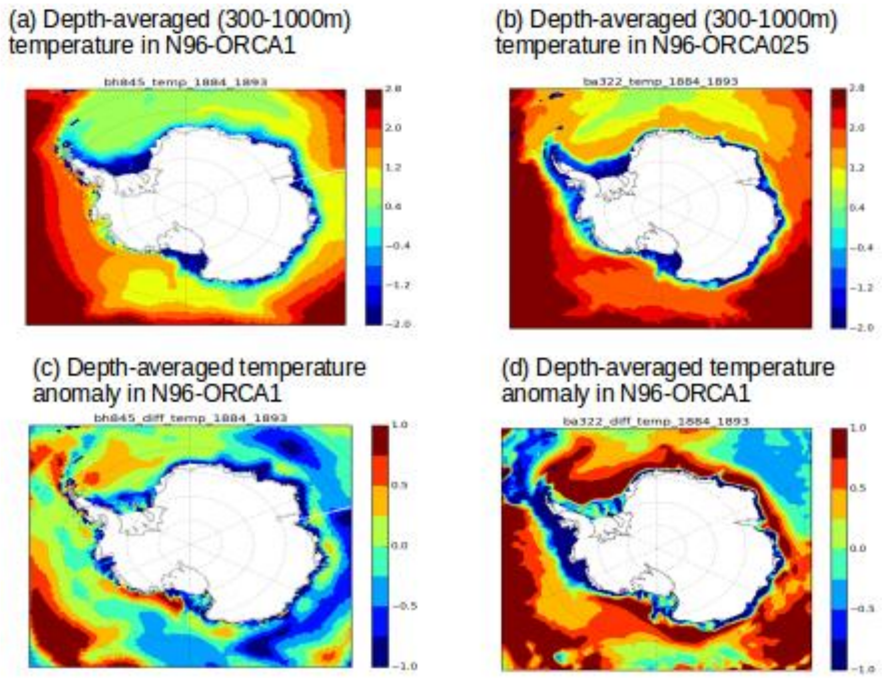

Figure 3: Depth averaged (300-1000m) temperature (average over the last 10 years of the simulation) in (a) N96-ORCA1, (b) N96-ORCA025. The lower panel shows the depth averaged temperature bias (minus EN4 data) in (c) N96-ORCA1, (d) N96-ORCA025.

These preliminary analyses have given us some details that the UKESM1-is2 with lower ocean resolution (N96-ORCA1) looks promising and hence its challenging developments are worth exploring and testing. As for the UKESM1-is2 N96-ORCA025, with its higher computational cost, before a fully interactive coupling is continued it will be important to improve the simulation of the main Southern Ocean thermohaline and circulation features.

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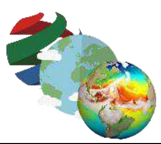
Upcoming events

18-21 July 2019 - UKESM at the Blue Dot Music and Science Festival - Macclesfield:

The 2019 Blue Dot Festival (https://www.discoverthebluedot.com/) at Jodrell Bank Observatory, in Macclesfield, is about to open its doors this July from 18th to 21st. Celebrating fifty years since the Moon Landings this July with a four-day spectacular combining music, science, cosmic culture and more beneath the Lovell Telescope.

The UKESM team will be there over the festival weekend, with our exhibit entitled 'A MODEL EARTH', to deliver an engaging activity to help the public understand climate change and learn more about Earth System science across the UK. Visitors will be able to watch and touch recent and future climate simulations in our Projecting Globe (Puffersphere) and learn about different aspects of the Earth's climate and its evolution over this century, have a go at our 3D puzzle or take our quiz and find out who knows the most amongst your friends about the Earth's climate and climate change.



Follow the link below to take our Quiz and find out if you really are a 'Master Climate Modeller'!!

https://ukesm.typeform.com/to/Q4prOa

1-3 October 2019 – CRESCENDO General Assembly 2019 - Sorbonne University Conference Centre, Paris:

This year the CRESCENDO General Assembly 2019 is taking place in Paris at the Centre International de Conférences Sorbonne Universités (CICSU), organised by Project Partner IPSL-CNRS, between the Tuesday 1st and Thursday 3rd of October 2019.

The EU H2020 CRESCENDO project aims to progress on the next generation of European earth systems models; by (1) Improving the representation of key processes in European Earth System Models, (2) Evaluating thoroughly the scientific performance of these models, (3) Using the models to generate a new set of Earth system projections for the coming century, and (4) Ensuring the knowledge developed in the project is communicated to key stakeholder communities.

Recent past events

27th February 2019 - 1-day UK CMIP6 workshop - Said Business School, Oxford

The workshop aimed to cover topics such as: Update/inform the community on progress with UK model CMIP6 simulations; Update/inform the community on timelines for UK model data being available on the CEDA Earth System Grid Federation (ESGF); Inform/discuss with the community preferred/optimal ways to access and analyse CMIP6 data; Begin discussions on (UK community) scientific analysis of CMIP6 data (UK models and the wider CMIP6 multi-model ensemble); and

Discuss and (possibly) define non-UK model CMIP6 data to be mirrored at the CEDA ESGF.

Follow this link to see a summary of notes and minutes with links to all presentations from this past UK CMIP6 workshop in Oxford.

Further information about CMIP6 workshops and UK preparations for CMIP6 can be found at **https://ukesm.ac.uk/cmip6/**.

11-12 June 2019 - UKESM LTSM annual meeting - NOC, Southampton:

During June 2019, the annual science meeting of the LTSM ESM project took place at the National Oceanography Centre in Southampton. The meeting was attended by more than 50 scientists from across the UK, drawn from all eight of the participating NERC research centres as well as the Met Office Hadley Centre (**download the meeting agenda with links to presentations here**).

Day one of the meeting began by updating the community on the science performance of UKESM1 in CMIP6 simulations performed during 2018-2019. This included overview talks on its land, atmosphere and ocean components, its global carbon cycle, and a summary of the fully coupled model. This was followed by a series of contributed talks that described evaluation of the model on a range of more focused topics. These included its sea-ice, Arctic and Antarctic dynamics, ocean heat content, wetland methane, interactive land ice, and marine methane hydrates and biomes. Representatives of sister LTSM projects, ORCHESTRA and ACSIS, also presented analyses of UKESM1 relevant to their respective Southern Ocean and North Atlantic domains. Chris Jones of the MOHC also presented a summary of results from the zero-emissions commitment model intercomparison project (ZECMIP), a key focus for policymakers in light of the Paris Agreement of 2015.

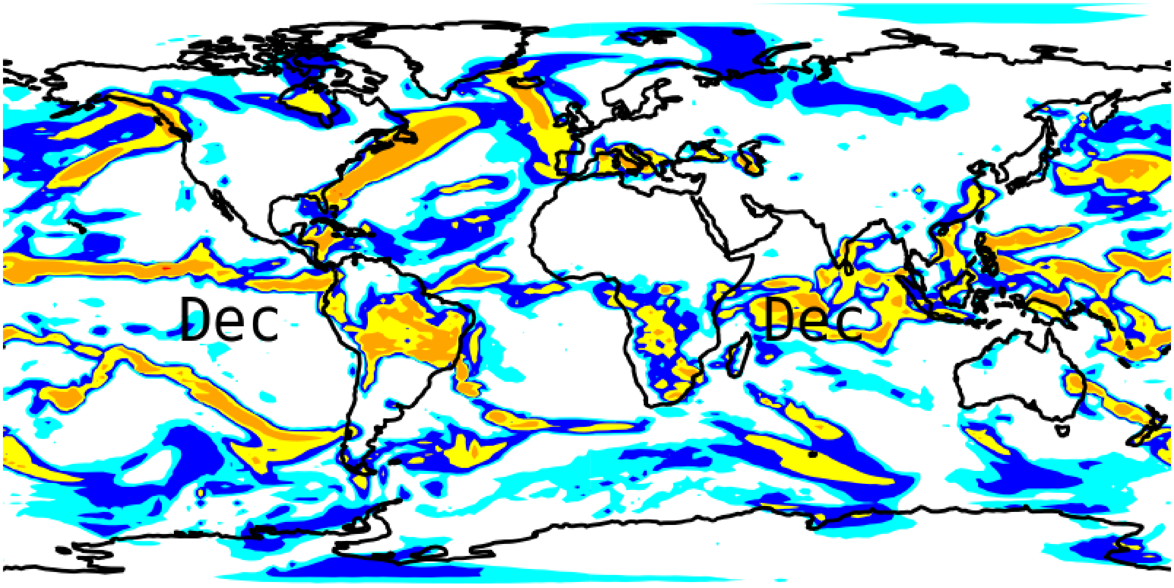
Day two of the meeting continued with further contributed talks exploring UKESM1 evaluation and development. These included fire modelling, atmospheric composition, aerosols and nitrate radicals in the atmosphere. A presentation was also made of the availability of Earth system observational data held by the European Space Agency Climate Change Initiative (ESA-CCI). These presentations were followed by a series of breakout groups the aimed to communicate ongoing analysis and to discuss existing and potential collaborations both within the LTSM project and beyond.

Following on from the main meeting, a workshop introducing users to the ESMValTool suite for model comparison took place. This included hands-on activities assisted by UKESM1 members of its development team, Val Predoi, Ranjini Swaminathan and Lee de Mora.

Team News

June 24-July 3, 2019 - Visualization of UKESM1 output: a work experience project:
by Harry List and Jeremy Walton

Following the release of UKESM1 earlier this year, the model is being extensively used for climate simulations. The display and analysis of its output for various experiments is receiving considerable attention, and visualization can be a useful tool in this context. Recently, Harry List, a 15-year-old student from Blundell's School in Tiverton, joined the UKESM core group for a work experience project (Harry has just completed his GCSEs). Working in python, and using the Iris library (see https://scitools.org.uk/iris/docs/latest/index.html), Harry was able to create a range of visualizations from UKESM1 output in a remarkably short time. Below is a one example of his work, taken from an animation of daily precipitation, as modelled by UKESM1.



This figure shows local precipitation for a day in December. The colourmap goes from white to blue to yellow to orange (orange is wettest).

Commenting on his experience in the core group, Harry said, "*The eight days I spent in the Met Office were both productive and enjoyable. I managed to complete a few projects, making my time spent there feel very worthwhile. I must thank Jeremy Walton for being very helpful and patient with me. This experience was better than I could ever have hoped for from a work experience placement, and so I am very grateful to Dr Walton, the UKESM team and the Met Office for making this work.*"

For our part, we greatly enjoyed collaborating with Harry, finding him to be a skilled and thorough worker who was able to quickly produce useful results – indeed, we are aiming to use some of Harry's visualizations on the globe display on our stand at the Bluedot festival later this month (see https://www.discoverthebluedot.com/profile/ukesm:-a-model-earth).