UKESM1 science configuration complete and CMIP6 simulations started

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In April 2018 we completed the scientific and technical development of UKESM1 and started a number of baseline simulations as part of the 6th Coupled Model Intercomparison Project (CMIP6). This newsletter outlines early results from UKESM1 covering the CMIP6 DECK and a number of historical simulations (Eyring et al. 2016), as well as a range of more targeted experiments used to characterize the model's fundamental behaviour. Specifically, one article describes the overall coupled behaviour of UKESM1, followed by a set of papers that look more closely at the model's representation of atmospheric, marine and terrestrial processes and the global carbon cycle. The newsletter concludes with an article outlining plans for the release of UKESM1 to the UK research community in the coming months.

UKESM1 is now being actively run in the first set of simulations in CMIP6, known as the DECK (Eyring et al. 2016). This is a set of baseline experiments designed to characterize the unforced behaviour of a coupled Earth system model and its sensitivity to increased/increasing atmospheric CO_2 concentrations. The DECK consists of:

(i) A pre-industrial (PI) control simulation (natural emissions only), termed *piControl*, which is run for a minimum of 500 years started from a spun up PI model state.

(ii) A simulation forced by a 1%yr^{-1} increase in atmospheric CO_2 concentrations from PI values (referred to *1pctCO$_2$*) and run for 150 years.

(iii) A simulation where atmospheric CO_2 concentrations are abruptly increased to 4 times pre-industrial values, referred to as *abrupt-4xCO$_2$* and run for 150 years.

(iv) An atmosphere-land only simulation, using prescribed, observation-based fields of sea surface temperatures (SST) and sea ice concentration (SIC), referred to as *amip* and run for the period 1979 to 2015.

In addition to the DECK, CMIP6 also include an historical simulation, spanning the period of scientific observations (1850 to present). These experiments, referred to as *historical,* use observed estimates of atmospheric CO_2 concentrations over the historical past, as well as estimates of anthropogenic emissions of aerosol and aerosol-precursors, human-induced land use change and emissions of other important trace gases. The historical simulations provide an important opportunity to evaluate UKESM1 against a range of observations. The historical simulations also provide a stepping-stone for using UKESM1 to make Earth system projections for the coming century. These projection use a range of plausible future greenhouse gas and aerosol emission pathways, combined with different assumptions about future land use. Future projections all start from the end state of a UKESM1 historical simulation and are organized within the scenarioMIP activity in CMIP6 (O'Neill et al. 2017).

The UKESM1 DECK and an ensemble of historical simulations are presently running and we aim to start a first set of scenarioMIP projections in the time-window October to December 2018. UKESM1 will also be extensively used over the coming months in a range of Model Intercomparison Projects (MIPs), addressing different aspects of climate and Earth system science. For more details on individual MIPs see Eyring et al (2016) and accompanying, MIP-specific papers, in the same special issue.

Some top level performance metrics from the UKESM1 piControl

As a brief introduction to the scientific performance of UKESM1, we present a few high-level, global mean metrics from the piControl simulation that are important indicators of whether a

coupled model has attained a stable and realistic pre-industrial climate, with the caveat that observational constraints on model PI performance are limited. Figure 1 plots the global mean, annual mean top of atmosphere (TOA) net radiation balance from the UKESM1 piControl, which has now run slightly more than 300 simulated years. For a stable PI control climate a long-term net TOA radiation balance of 0Wm^{-2} is required. Figure 1 shows this has been realized with UKESM1. While there is interannual variability of ~+/-0.5Wm^{-2} the long-term mean of the TOA radiation budget is essentially zero meaning that long-term thermal drift in the model's piControl climate is likely to be minimal.

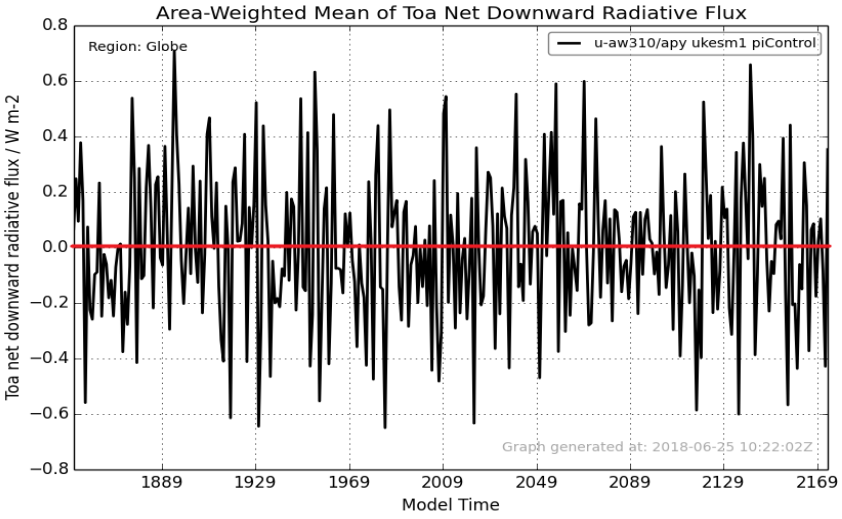

Figure 1: Global mean, annual mean TOA net radiation UKESM1 piControl. While the piControl started with a date of Jan 1st 1850, for such a simulation model dates bear no similarity to the real calendar.

In figure 2 we show the global mean, annual mean surface temperature from the UKESM1 piControl covering the same period as the TOA net radiation figure. While a 0Wm^{-2} TOA net radiation balance will, eventually, lead to a coupled climate in long-term thermal equilibrium, due to the ocean's overturning circulation there will be periods when the global mean surface temperature is colder or warmer than the long-term average. For a significant period of the UKESM1 spin-up the model exhibited such variability in surface temperature, on timescales of ~70-120 years. This was linked to periodic overturning of the ocean column off Antarctica, bringing relatively warm deep waters to the surface resulting in significant heat loss from the ocean. Such phenomena have been observed in the real climate, most notably associated with the Weddell Sea polynya of 1974-1977 (Gordon and Comiso 1988).

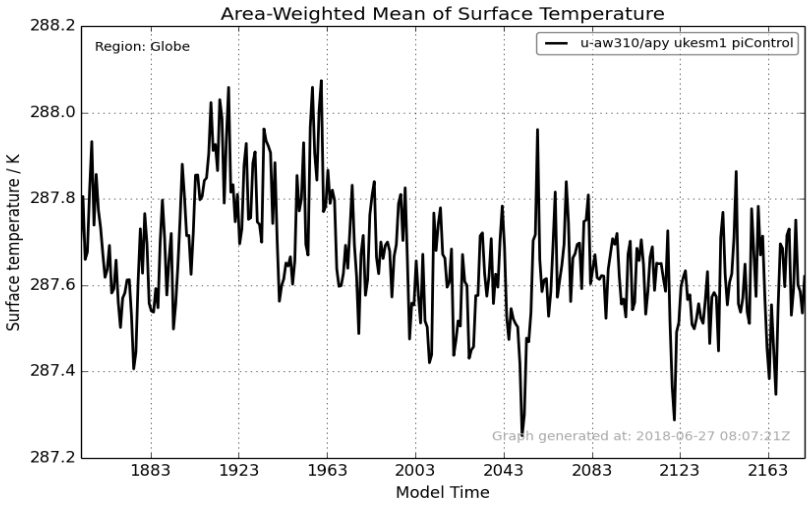

Figure 2: Global mean, annual mean surface temperature from the UKESM1 piControl.

After some variability in surface temperature over the first ~150 years of the piControl, the last ~170 years show a rather stable global mean surface temperature of around 287.6K (~14.5°C), with some short period deviations, most of which are associated with periodic changes in ocean circulation in the North Atlantic.

As a final measure of the piControl being well equilibrated, figure 3 shows the global mean, annual mean net CO_2 flux between the ocean and land reservoirs and the atmosphere. Positive values indicate a flux of CO_2 into the atmosphere. Again, over a sufficiently long averaging period we should expect a PI climate, with no external emissions of CO_2, to reach an equilibrium in exchange between the 3 connected carbon reservoirs, land, ocean and atmosphere. This is clearly the case for the UKESM1 piControl, with interannual variability, driven by both the land and marine fluxes, oscillating around the zero flux value.

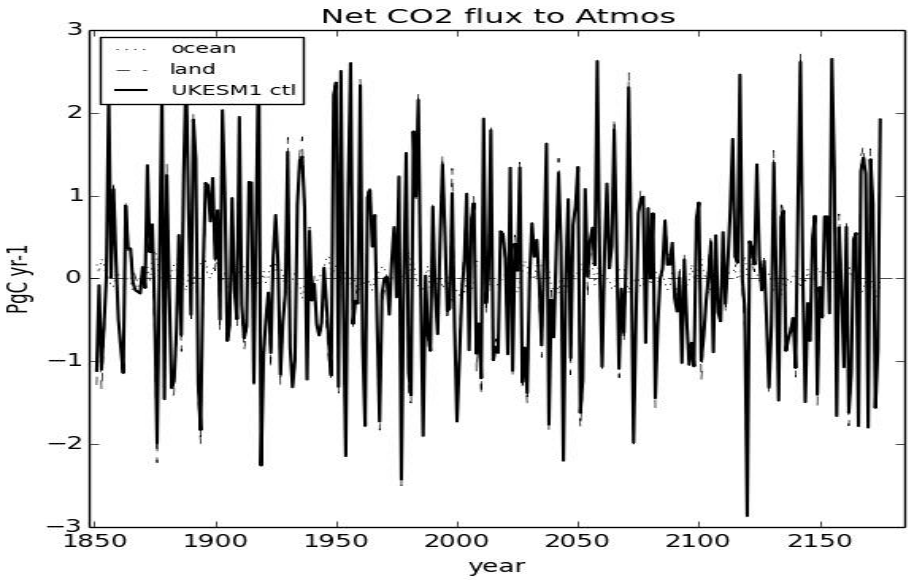

Figure 3: Global mean, annual mean net CO_2 flux into the atmosphere in the UKESM1 piControl. The full black line shows ocean and terrestrial fluxes combined.

From this brief analysis we conclude that the piControl climate simulated by UKESM1 is in radiative, thermal and carbon equilibrium and is therefore a suitable reference for the numerous experiments planned with UKESM1 in CMIP6, in particular the historical and future projection experiments targeted for completion in 2018.

REFERENCES

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