



Supplement of

UKESM1.1: development and evaluation of an updated configuration of the UK Earth System Model

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1 Introduction

This Supporting Information contains a number of additional, supplementary figures and table to support the findings in the main article. All figures are referenced in the main article and the reader is directed to the main text for more information.

2 Figures



Figure S1: Total aerosol optical depth at 550nm from (a) UKESM1, (b) UKESM1.1, and satellitederived AOD from (c) MODIS and (d) MISR. Dust optical depth (DOD) in (e) UKESM1 and (f) UKESM1.1-UKESM1 change in dust optical depth. Simulated AOD and DOD are a 20 year annual mean from 1980 to 2000. Satellite AOD represent annual means over the years 2003 to 2012 inclusive.



Figure S2: Histograms of the period of the quasi-biennial oscillation (QBO) from (top, black) MERRA reanalysis, (middle, blue) UKESM1 and (bottom, red) UKESM1.1. Dashed lines indicate the mean and dotted lines the standard deviation. Each period is calculated as a sum of the duration of the easterly and westerly wind phases between 5° S and 5° N at 30 hPa.



Figure S3: Historical evolution of the anthropogenic emissions of SO_2 in CMIP6.



Figure S4: Annual mean AOD at 440 nm from (a) UKESM1.1 and (b) UKESM1. Groundbased AOD retrievals from the global AERONET network are overlaid at their respective locations and use the same colour scale; scatterplots of simulated co-located AOD with the AERONET measurements are shown for (c) UKESM1.1 and (d) UKESM1.



Figure S5: Timeseries of simulated (blue, UKESM1; red, UKESM1.1) and observed (black, HadISST; grey, NSIDC) sea ice extent in the Antarctic for the months of March and September over the full historical period (1850-2014). The seasonal trends in the more recent period are shown for each dataset on the right-hand side. Model data represents the ensemble mean for UKESM1 (6 members) and UKESM1.1 (6 members) with ± 1 standard deviation also shown.



Figure S6: Timeseries of simulated (blue, UKESM1; red, UKESM1.1) sea ice volume in the Antarctic for the months of March and September over the full historical period (1850-2014). Model data represents the ensemble mean for UKESM1 (6 members) and UKESM1.1 (6 members) with ± 1 standard deviation also shown.



Figure S7: Global net (left) air-sea CO2 flux and (right) primary production for the UKESM1.0 (blue) and UKESM1.1 (red) ensembles. Solid lines denote the ensemble mean, with shaded areas illustrating ± 1 standard deviation. Observed estimates of CO₂ flux are shown in black.



(a)) UKESM1.1 Total Anthropogenic Clear-sky ERF (Wm^{-2})

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Figure S8: Comparison of the anthropogenic clear-sky effective radiative forcing (ERF) in (left) UKESM1 and (right) UKESM1.1; (top) the clear-sky total anthropogenic ERF, (middle) clear-sky aerosol ERF and (bottom) clear-sky land use change ERF. The ERFs are calculated for the year 2014 relative to an 1850 pre-industrial control.



Figure S9: Regional climate feedbacks in (left) UKESM1.1, (middle) UKESM1 and (right) UKESM1.1-UKESM1 difference. The rows show (from top to bottom) the net, SW clear-sky, LW clear-sky, and cloudy-sky feedbacks.



Figure S10: Global mean sea ice extent anomalies 2070-2100 mean minus 1850-1900 mean for SSP126 and SSP370. UKESM1.0 is in blue and UKESM1.1 in red. Thick lines are the respective three member ensemble means and the thin lines are the individual ensemble members. 5-year running means have been applied in all cases.



Figure S11: Zonal mean precipitation anomalies (2070 to 2100 mean) minus (1850 to 1900 mean) for SSP126 (left) and SSP370 (right). UKESM1.0 is in blue and UKESM1.1 in red.



Figure S12: Annual mean timeseries of (top) the aerosol optical depth at 550nm, (middle) cloud droplet number concentration and (bottom) cloud droplet effective radius from UKESM1 (blue) and UKESM1.1 (red) historical simulations. Both the ensemble mean (thick lines) and individual ensemble members (faint lines) are plotted. A 5 year running mean has been applied.



Figure S13: Annual mean timeseries of the top-of-atmosphere (from top to bottom) net radiation, outgoing SW radiation, outgoing LW radiation, SW cloud forcing and cloud fraction from UKESM1 (blue) and UKESM1.1 (red) historical simulations. Both the ensemble mean (thick lines) and individual ensemble members (faint lines) are plotted. A 5 year running mean has been applied.

3 Tables

Table S1: Values for the short-wave snow metric^a used in the tuning of the snow burial of vegetation parameter, $n_{lai_exposed}$. The metric is calculated for both atmosphere-only (AMIP) and coupled historical simulations.

Model	$\frac{1}{\text{AMIP (W m}^{-2})}$	Historical (W m^{-2})
UKESM1	53.1	54.3
UKESM1.1	48.1	47.9
Observed range		50.5 - 53.6

 a Defined as the DJF mean clear-sky outgoing SW radiation at TOA over land between 30° N-60° N.