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Atmospheric Blocking and Greenland melt

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Atmospheric blocking occurs when near-stationary high-pressure systems divert westerly flow for a week or more. It can cause extreme regional weather such as heatwaves in summer and cold spells in winter. In this article we explore the connection between blocking over Greenland and enhanced surface melting of the ice sheet in UKESM1.ice N96 ORCA1 present-day run. UKESM1.ice is based on a modified version of GC3.1 (Kuhlbrodt *et al.*, 2018) that allows a two-way coupling to the ice sheet model BISICLES (Cornford *et al.*, 2013). In particular, the modified land-surface model JULES (Best *et al.* 2011) uses a more sophisticated representation of the ice sheet surface on multiple elevation bands to downscale atmospheric forcing and an improved albedo scheme (Shannon *et al.*, 2019). The run, which forms part of the UKESM contribution to Ice Sheet Model Intercomparison Project for CMIP6 (ISMIP6) (Nowicki *et al.*, 2016), starts from 1970 and finishes at the end of 2014.

We measure blocking over Greenland using the Greenland blocking index (GBI) which is defined as the 500 hPa geopotential height averaged over the region 60-80°N, 20-80°W (Hanna *et al.*, 2013, 2016). The advantages of using GBI are that it is simple to calculate and daily NCAR/NCEP reanalysis data is available at NOAA from 1948 to present-day. We compare monthly means of GBI rather than daily means because global climate models, particularly low resolution models such as ours, underestimate the frequency and persistence of synoptic blocking events (Woollings *et al.*, 2018 and Schiemann *et al.,* 2020). Figure 1a suggests that the model run can capture Greenland blocking from 1980 to 2014 reasonably well on averaged over a month, where the mean GBI is 5317 m in the model and 5301 m for the reanalysis and the root-mean-square-error between the two is 83 m.

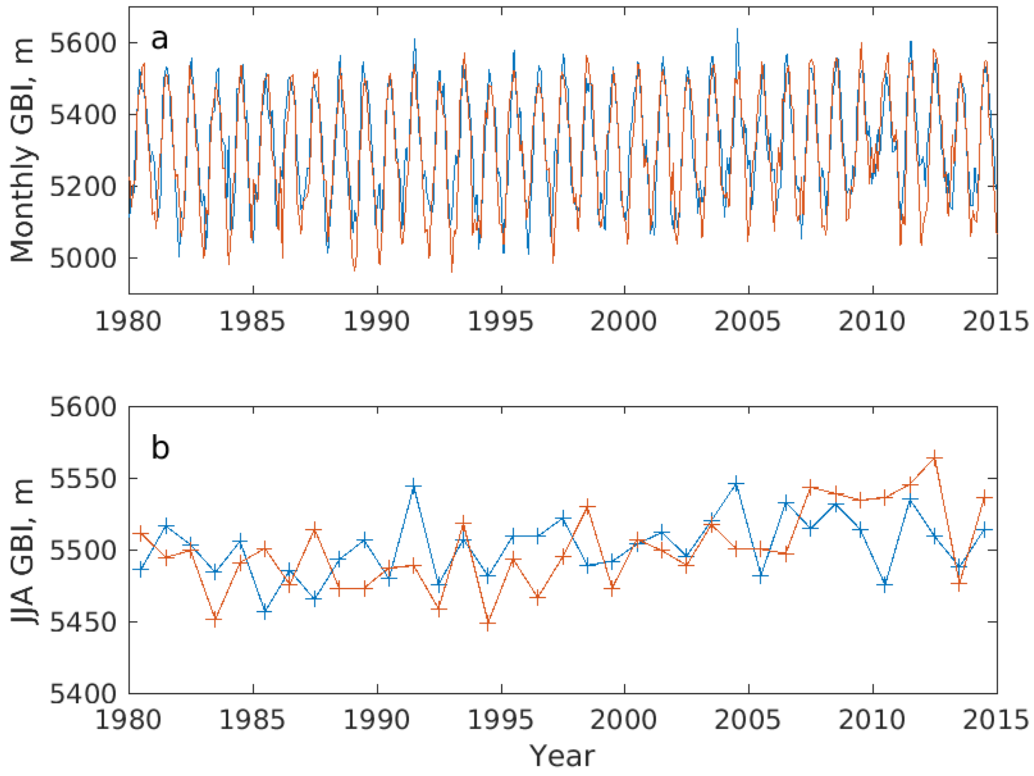

Figure 1: Comparison of Greenland blocking index (GBI) between present-day model (blue) and NCAR/NCEP reanalysis data (red) for monthly means (a) and summer means (b).

Summer GBI is of interest because anomalously high pressure over Greenland has been linked to accelerated surface melting on the ice sheet in recent summers (Hanna *et al.*, 2013, 2016). Theory suggests that blocking can advect relatively warm air masses from the subtropics, disperse cloud cover and bring drier weather. Comparing the modelled summer GBI, where the index is averaged between June and August (JJA), with the reanalysis (see figure 1b) the mean of timeseries match where values are 5502 m and 5501 m, respectively, but the model has less variability than the reanalysis, where the standard deviations are 21.6 m and 28.2 m, respectively. The reanalysis time series has a positive trend from the mid-1990s, whereas the modelled times series has no significant trend. The model does show warming over the ice sheet, where the annual air temperature 1.5 m above the ice surface is increasing at 0.12 ◦C/y since 1995. CMIP5 models also fail to capture the positive blocking trend (Hanna *et al.*, 2018), although Woollings *et al.* (2018) argues that the trend is not distinguishable from natural internal variability.

The top three summer GBI values in the model run occur in years 2004, 1991 and 2011, which correspond to maxima in the mean surface meltrate over the ice sheet (see figure 2). Positive anomalies in GBI also correspond to positive anomalies in meltrate in the 2000s and there is a linear correlation for the whole timeseries with a coefficient of 0.76 and p-value < 1.0e-6. How is blocking increasing ice sheet melt?

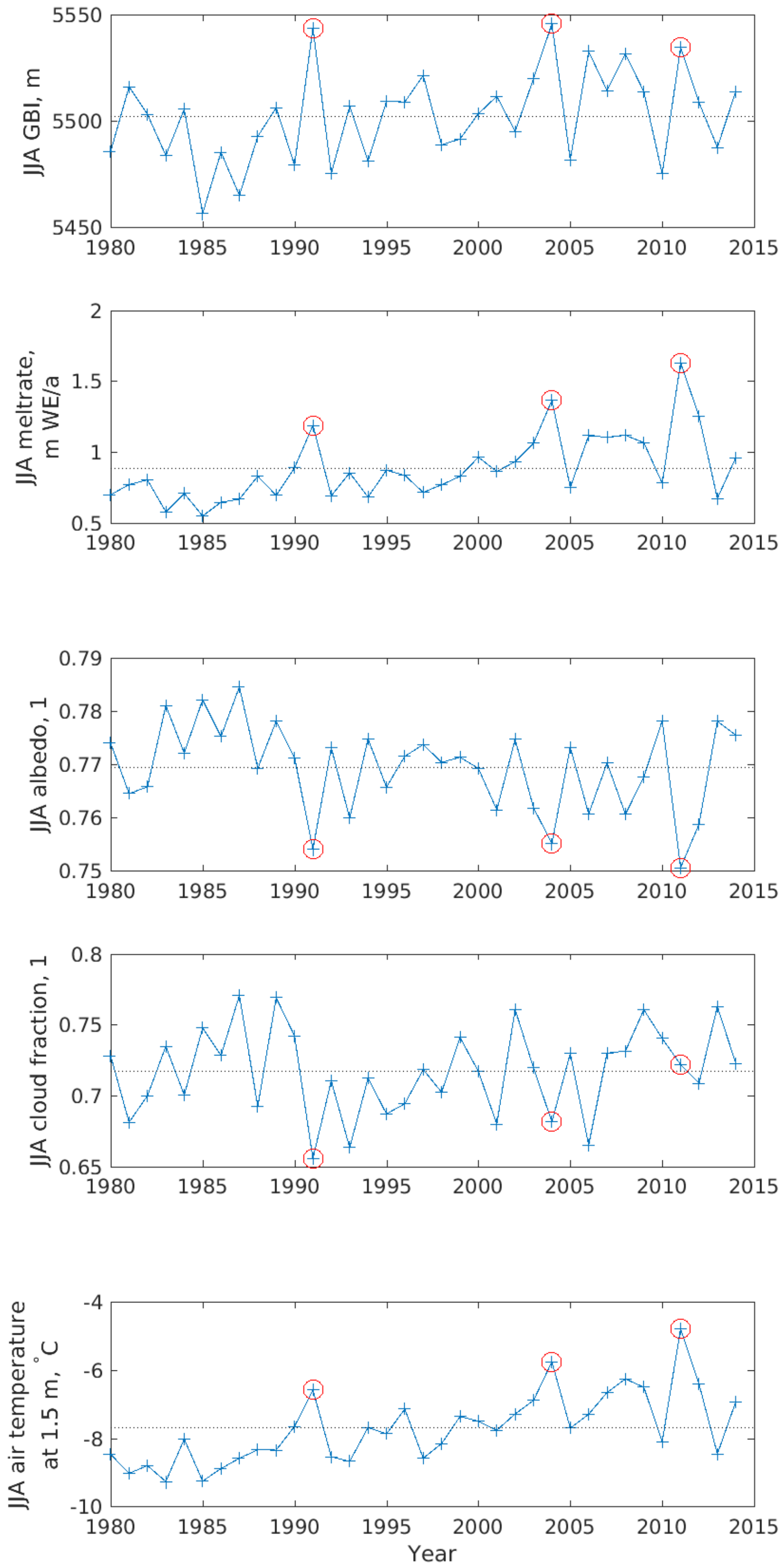

Figure 2: Timeseries of summer means of Greenland blocking index and surface meltrate, albedo, cloud fraction and air temperature at 1.5 m averaged over the ice sheet with the timeseries mean (dotted black line). Red circles mark the years for the 3 top GBI values.

Ice sheet melt is calculated using the energy balance fed by air temperature, humidity, wind speed, precipitation and downward shortwave and longwave radiation in a multilayer snowpack model (Best *et al.*, 2011, Shannon *et al.*, 2019). Albedo, which represents the ratio of reflected to incoming solar radiation on the surface of the ice, is parameterised in the model using the density, age and grain size of the snowpack and varies in value between that of ice and fresh snow. The three years where the summer GBI is highest coincide with those of the three lowest albedo values (see figure 2). There is also a strong correlation between the two with a coefficient of –0.81 and p-value < 1.0e-6.

Atmospheric blocking can affect cloud cover which impacts solar radiation reaching the ice sheet. This may explain the correlation between GBI and albedo and is backed up by a study by Hofer *et al.* (2017) that found a strong, negative correlation between GBI and cloud cover since the mid-1990s using a combination of satellite observations of clouds and regional climate modelling. They suggest increased summer blocking is reducing cloud cover over southern Greenland allowing more shortwave radiation to reach the surface. Longwave radiation also increases from cloud cover over the northeast. Both of which drive the observed accelerated ice sheet melt since the mid-1990s (Hahn *et al.*, 2020). In the present-day model run the cloud fraction anomaly is negative for 1991 and 2004 (see figure 2) with reduced cloud over most of the ice sheet, but in 2011 there is increased cloud over the interior and west in the northern half and over the southern tip. Also, in 2004 incoming shortwave radiation is not anomalous, but the longwave radiation anomaly is positive everywhere. Clearly, there is no consistent pattern with cloud in the model run. There is only a weak correlation between GBI and cloud fraction timeseries with coefficient –0.52 and p-value = 0.001 and there is a positive trend in cloud fraction since 1990 that contradicts satellite observations showing decreasing cloud. More importantly, there is no significant correlation between meltrate and cloud fraction timeseries in the model. It may be that the location of cloud cover is more relevant rather than the average amount over the whole ice sheet.

How is albedo related to GBI if not through cloud cover? The connection between albedo and GBI could be made indirectly through melt as GBI is correlated to net shortwave radiation, the amount of shortwave radiation absorbed by the ice, with coefficient 0.72 and p-value < 1.0e-5 rather than to incoming shortwave radiation. The mean summer meltrate and albedo have a strong correlation with coefficient of –0.83 and p-value < 1.0e-6. This can be explained by melt-albedo feedback where meltwater decreases albedo by increasing the grainsize of the ice and surface melt increases when the ratio of absorbed solar radiation increases (Box *et al.*, 2012).

Atmospheric blocking, depending on the location of the block, can also advect warm air on to the ice sheet that will drive surface melting. Figure 2 shows that the three peaks in meltrate correspond to peaks in air temperature 1.5 above the surface of the ice. There is a very strong positive correlation between two with a coefficient of 0.92 and a p-value < 1.0e-6, although the correlation between summer air temperature and GBI is weaker with a coefficient of 0.67 and p-value < 1.0e-4. Figure 3 shows the mean summer 500 hPa geopotential height for 1985, when both the GBI and mean meltrate are both a minimum, 1991, 2004 and 2011. In 1985 there is low pressure off the northwest coast of Greenland bringing air down from the north in cyclonic (anti-clockwise) flow, where the flow moves along the pressure contours. In the high melt years there is a high over southern Greenland in 1991 which migrates off the southeast coast in the other two years leaving anti-cyclonic flow to the west to advect air from the south.

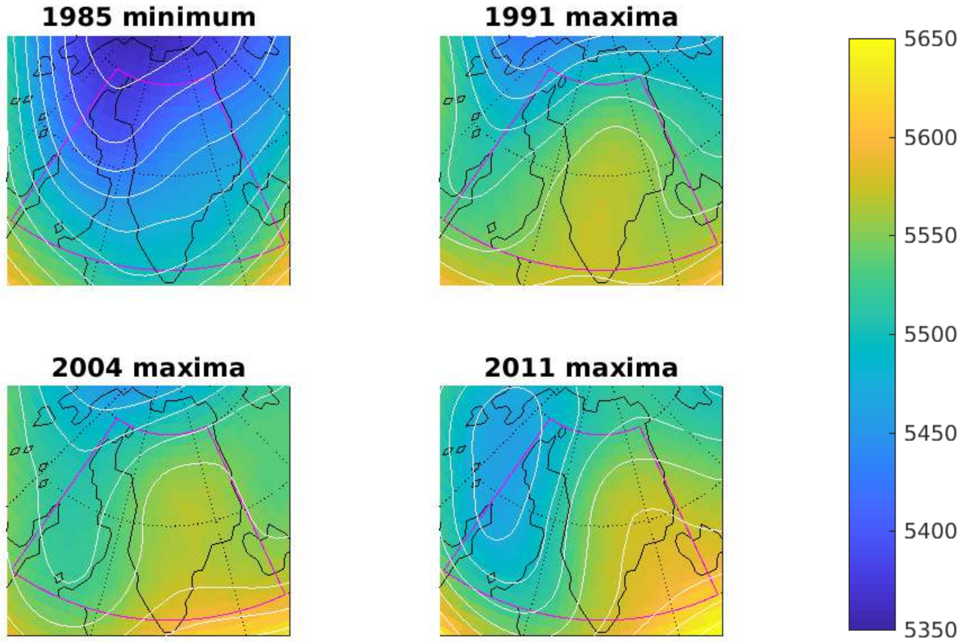

Figure 3: Mean summer geopotential height at 500 hPa in metres with white contours every 25 m for years 1985, 1991, 2004 and 2011. GBI is calculated inside the region marked by magenta lines. Black contours mark the edge of land.

It is perhaps not surprising that GBI is high when the air over the ice sheet is relatively warm given that geopotential height can be expressed as a function of virtual temperature of the air column. However, the air temperature at 1.5m and meltrate in 2011 appear to be outliers when plotted against GBI. The meltrate and temperature are much higher than the linear fit with GBI predicts. In 2011 the ice sheet is relatively warm almost everywhere and the meltrate is also above average in the interior and not just at the margins. Clearly, warm air is the dominate driver of melt, but the anti-cyclonic flow brings cloud and rain, and alters the sensible heat flux that increases melt too. Rain has a positive trend since the 1990s and reaches a maximum in 2011 where the anomalies are located over the ablation zone along the western margin in the northern half of the ice sheet and southern tip. Sensible heat flux is enhanced along a section of southern half of the ablation zone.

Anomalous atmospheric blocking in summer is linked to enhanced surface melt over Greenland in the UKESM1.ice present-day run. We have rejected the idea that clearer skies due to blocking are responsible for the enhanced melt. We found that GBI is most strongly correlated to albedo. It is likely that albedo is at its lowest when GBI is highest simply because there is more meltwater around, though this does not explain why the correlation is higher than the correlation between GBI and meltrate. Near surface air temperature is the dominant driver of meltrate and it appears that atmospheric blocking is bringing it on to the ice sheet. Blocking also modifies spatial patterns of cloud cover, rain and sensible heat flux that can contribute to the enhance melt. The findings in this article are based on one model run. We need to analyse more runs to demonstrate that the link is more than a happy coincidence. We also need to separate out the recent warming to identify the natural variability of the model using long control runs with and without coupling to the ice sheet. Should the link between blocking and melt prove robust in the model then we can investigate its effect along with possible orographic effects (Hahn *et al.*, 2020) from an evolving ice sheet on sea-level rise projections from emissions scenarios. Some caution is needed though as projected total melt from Greenland is very sensitive to cloud microphysics (Hofer *et al.* 2019). Almost every aspect of the phenomenon may change in the future: the frequency and/or the location of the block, the temperature of the air and the shape of Greenland.

REFERENCES

Best, M. J., Pryor, M., Clark, D. B., Rooney, G. G., Essery, R. L. H., Ménard, C. B., Edwards, J. M., Hendry, M. A., Porson, A., Gedney, N., Mercado, L. M., Sitch, S., Blyth, E., Boucher, O., Cox, P. M., Grimmond, C. S. B., and Harding, R. J.: The Joint UK Land Environment Simulator (JULES), model description – Part 1: Energy and water fluxes, *Geosci. Model Dev.*, **4**, 677–699, https://doi.org/10.5194/gmd-4-677-2011, 2011.

Box, J. E., Fettweis, X., Stroeve, J. C., Tedesco, M., Hall, D. K., and Steffen, K.: Greenland ice sheet albedo feedback: thermodynamics and atmospheric drivers, *The Cryosphere*, **6**, 821–839, https://doi.org/10.5194/tc-6-821-2012, 2012.

Cornford, S. L., Martin, D. F., Graves, D. T., Ranken, D. F., Le Brocq, A. M., Gladstone, R. M., Payne, A. J., Ng, E. G., & Lipscomb, W. H.: Adaptive mesh, finite volume modeling of marine ice sheets. *Journal of Computational Physics, 232*(1), 529-549. https://doi.org/10.1016/j.jcp.2012.08.037, 2013.

Hahn, L. C., T. Storelvmo, S. Hofer, R. Parfitt, and C. C. Ummenhofer: Importance of Orography for Greenland Cloud and Melt Response to Atmospheric Blocking. *J. Climate*, **33**, 4187–4206, https://doi.org/10.1175/JCLI-D-19-0527.1, 2020.

Hanna E., J.M. Jones, J. Cappelen, S.H. Mernild, L. Wood, K. Steffen, P. Huybrechts: The influence of North Atlantic atmospheric and oceanic forcing effects on 1900–2010 Greenland summer climate and ice melt/runoff. *International Journal of Climatology*, **33**(4), 862-880, https://doi.org/10.1002/joc.3475, 2013.

Hanna, E., T. E. Cropper, R. J. Hall and J. Cappelen: Greenland Blocking Index 1851-2015: a regional climate change signal. *International Journal of Climatology*, **36**(15), 4847-4861, https://doi.org/10.1002/joc.4673, 2016.

Hanna, E., X. Fettweis, and R.J. Hall: Brief communication: Recent changes in summer Greenland blocking captured by none of the CMIP5 models. *The Cryosphere*, 12, 3287–3292, https://doi.org/10.5194/tc-12-3287-2018, 2018.

Hofer, S., A. J. Tedstone, X. Fettweis and J. L. Bamber: Decreasing cloud cover drives the recent mass loss on the Greenland Ice Sheet. *Science Advances,* **3**, no. 6, e1700584 DOI: 10.1126/sciadv.1700584, 2017.

Hofer, S., Tedstone, A.J., Fettweis, X. and Bamber, J.L.: Cloud microphysics and circulation anomalies control differences in future Greenland melt. *Nat. Clim. Chang.* **9,** 523–528, https://doi.org/10.1038/s41558-019-0507-8, 2019.

Kuhlbrodt, T., Jones, C., Sellar, A., Storkey, D., Blockley, E., Stringer, M., Hill, R., Graham, T., Ridley, J., Blaker, A., Calvert, D., Copsey, D., Ellis, R., Hewitt, H., Hyder, P., Ineson, S., Mulcahy, J., Siahaan, A., Walton, J.: The Low-Resolution Version of HadGEM3 GC3.1:

Development and Evaluation for Global Climate. *Journal of Advances in Modeling Earth Systems*, **10**(11), 2865-2888, https://doi.org/10.1029/2018MS001370, 2018

Nowicki, S. M. J., Payne, A., Larour, E., Seroussi, H., Goelzer, H., Lipscomb, W., Gregory, J., Abe-Ouchi, A., and Shepherd, A.: Ice Sheet Model Intercomparison Project (ISMIP6) contribution to CMIP6, *Geosci. Model Dev.*, **9**, 4521–4545, https://doi.org/10.5194/gmd-9-4521-2016, 2016.

Schiemann R., P. Athanasiadis, D. Barriopedro, F. Doblas-Reyes, K. Lohmann, M.J. Roberts,D.V. Sein, C.D. Roberts, L. Terray, and P.L. Vidale: Northern Hemisphere blocking simulation in current climate models: evaluating progress from the Climate Model Intercomparison Project Phase 5 to 6 and sensitivity to resolution. *Weather Clim. Dynam.*, 1, 277–292, https://doi.org/10.5194/wcd-1-277-2020, 2020.

Shannon, S., Smith, R., Wiltshire, A., Payne, T., Huss, M., Betts, R., Caesar, J., Koutroulis, A., Jones, D., and Harrison, S.: Global glacier volume projections under high-end climate change scenarios, *The Cryosphere*, 13, 325–350, https://doi.org/10.5194/tc-13-325-2019, 2019.

Woollings, T., Barriopedro, D., Methven, J. *et al.* Blocking and its Response to Climate Change. *Curr Clim Change Rep* 4, 287–300. https://doi.org/10.1007/s40641-018-0108-z, 2018.

First Analysis of ScenarioMIP Projections from UKESM1 in the Context of Global Warming Thresholds

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The sixth Coupled Model Intercomparison Project (CMIP6) Scenario Model Intercomparison Project (ScenarioMIP) coordinates future climate projections, sampling a range of emission scenarios produced by integrated assessment models [O'Neill et al. 2016]. ScenarioMIP simulations are identified by a combination of an underpinning Shared Socioeconomic Pathway (SSP) number, which ranges from 1 for a sustainable future to 5 for a fossil fuel intense future, and the RCP (Representative Concentration Pathway) value, denoting the global mean top of the atmosphere radiation perturbation (in units of Wm^{-2}) for the year 2100 (specifically, 1.9, 4.5, 7.0, 8.5). More detail on the RCPs can be found in Moss et al. 2010 and Taylor et al. 2009. UKESM1 [Sellar et al. 2019] ScenarioMIP simulations for SSPs 1-2.6, 2-4.5, 3-7.0 and 5-8.5 are already available on the Earth System Grid Federation (ESGF) node, comprising at least 5 members for all SSPs and 13 members for SSP3-70 and (shortly) SSP1-26. We analyse when UKESM1 ScenarioMIP ensemble members will exceed key global warming thresholds. We then assess the patterns of regional climate change simulated in UKESM1, centred on these "exceedance dates" to give a snapshot of how the future Earth System might look when we reach these GWTs. We present some early results from this analysis.

We define a Global Warming Threshold (GWT) as a specific value of Global Mean Surface Air Temperature (GSAT), calculated as an anomaly with respect to the GSAT value averaged over the period 1850-1900. To limit the influence of short-term variability, we apply a 21 year centred running mean to the ScenarioMIP GSAT values from each UKESM1 ensemble member. A GWT exceedance year is calculated for individual ensemble members (as well as the ensemble mean) as the year at which the 21 year mean GSAT anomaly exceeds a given GWT (e.g. a GSAT value 3°C warmer than 1850-1900 mean – see Figure 1). We use GWTs and years of exceedance to help answer questions such as (*a) What is the regional pattern and magnitude of climate change at different levels of global mean warming? (b) What regional changes and associated impacts can we avoid if we restrict warming to a given GWT compared to warmer values?* Our initial focus is on changes at specific GWTs in several key climate variables such as surface temperature, precipitation and soil moisture that are of particular importance for human activities.

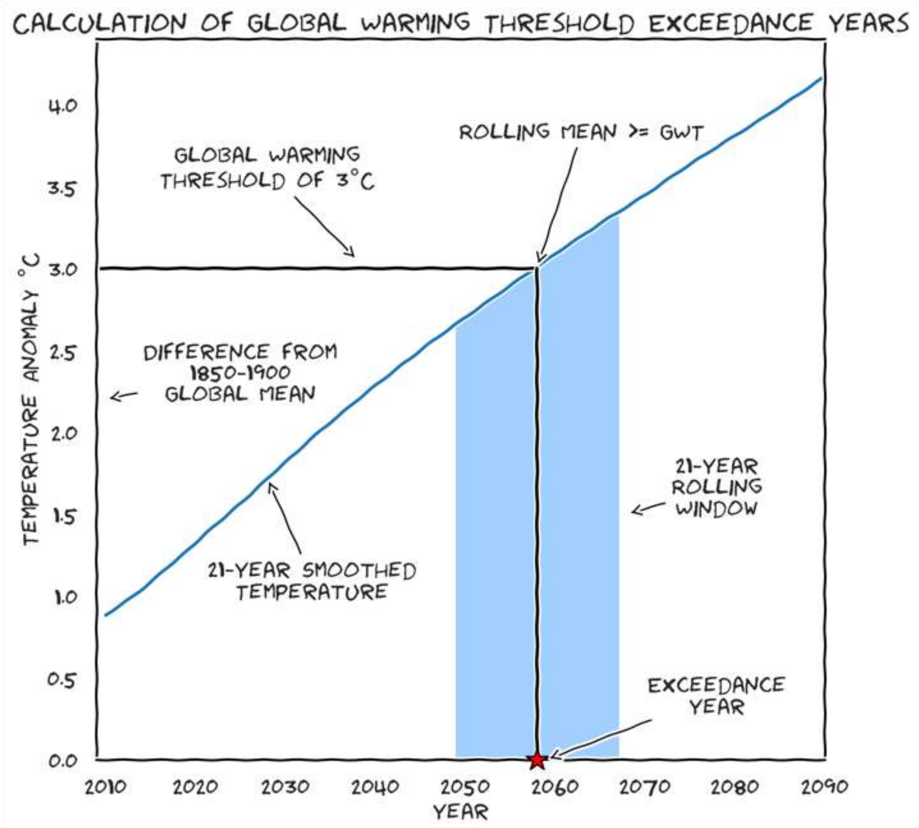

Figure 1. Global Warming Threshold (GWT) exceedance year computation: For each UKESM1 historical member and subsequent SSP, a 21 year centred running mean GSAT anomaly is calculated with respect to 1850-1900 mean GSAT. The first year this anomaly exceeds a given threshold temperature value for a given ensemble member (or ensemble mean) is taken as the year of exceedance for that ensemble member (or ensemble mean). Calculation of the exceedance year for a 3°C GWT is shown in the figure.

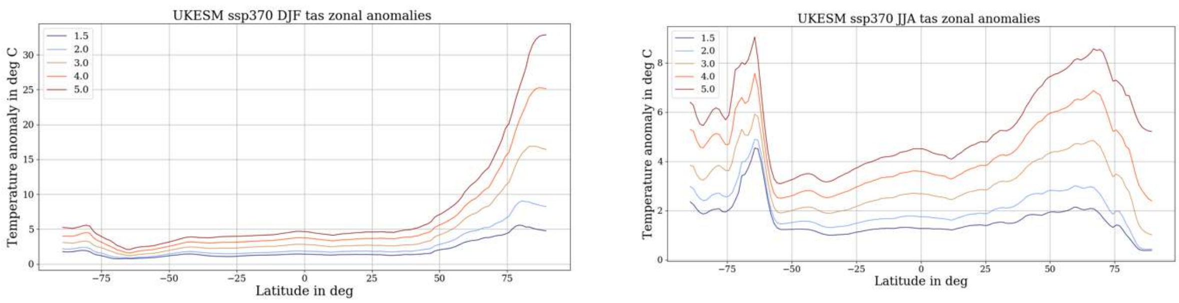

Figure 2. Zonal mean surface temperature anomalies shown for the European winter (DJF) and summer (JJA) seasons under SSP3-7.0 and for different warming thresholds.

The zonal mean surface temperature anomalies in Fig. 2 highlight the significant Arctic amplification we can expect to see in the boreal winters of the future. While there is amplification at both poles, the magnitude of increase in the Arctic is much higher and also increases with increasing warming thresholds. One important reason for this is sea ice loss in the summer months – Arctic sea ice melts in the summer, increasing the area of open ocean exposed to the atmosphere [Dai et al. 2019]. Regions with extensive sea ice or snow cover have high values of surface albedo and reflect away most of the sun’s radiation, keeping temperatures low. When sea-ice melts, this cover is lost and the exposed ocean with a lower albedo, absorbs significantly more solar radiation, warming the surface further. As the climate warms to higher temperature thresholds, increasing loss of Arctic sea-ice drives a substantial amplification of winter warming, in excess of 25°C in the central Arctic for a GWT of 5°C. Arctic amplification will begin to decrease once the majority of sea ice has melted, and the strength of the sea-ice albedo feedback decreases. However, amplified Arctic warming may still occur, mainly as a result of increased water vapour absorption of terrestrial radiation.

As the primary goal of the 2015 Paris Climate Agreement was to limit the increase in global mean surface temperature to well below 2°C above pre-industrial levels [Rhodes, C.J 2016], we explore the state of the Earth System at GWT = 2°C in greater detail (Figures 3 and 4). We plot land temperatures only to help focus attention onto changes that impact human activities on land.

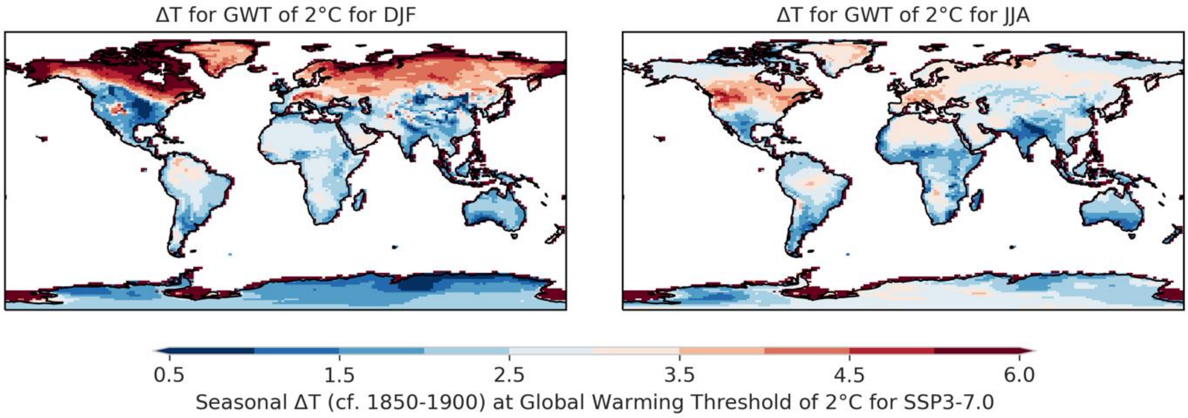

Figure 3. Seasonal mean surface temperature anomaly averaged across the UKESM1 SSP3-70 ensemble and centred on the year of exceedance at GWT = 2°C. Anomalies are calculated with respect to 1850-1900 mean and shown for the northern hemisphere winter (DJF) and summer (JJA) seasons.

The primary signal is a strong amplification of winter warming across the high latitude Northern Hemisphere, with most areas north of 60°N warming in excess of 4°C. Over central Europe and North America summer warming exceeding 3°C, and summer precipitation decreasing by 20-30% will lead to major impacts on human activities in these two critical agricultural regions. Meanwhile, local warming in the Amazon is amplified relative to the global mean value by 50-75% which, combined with projected drying of the wet season (~30% in DJF) may have negative impacts on the long-term health in a rainforest already experiencing savannafication and deforestation.

Conversely, looking at areas with projected increases in precipitation, we see a significant increase in monsoon rainfall over the Indian subcontinent, likely explaining the relatively smaller seasonal increase in temperature across this region. While increased monsoon rains can be favourable for agriculture, such increases may also be associated with significant flood risk.

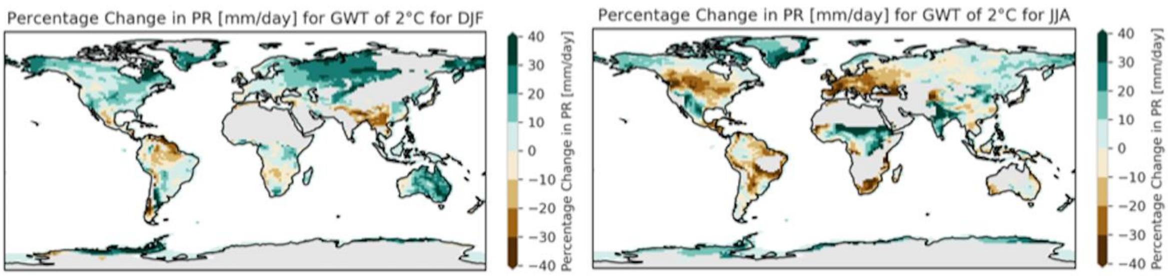

Figure 4. Projected seasonal changes in precipitation at 2°C global mean warming under SSP3-7.0. Changes are shown as a percentage change relative to the 1850-1900 period and for northern hemisphere winter (DJF) and summer (JJA) seasons. Values below 0.5mm/day in the 1850-1900 period are greyed out.

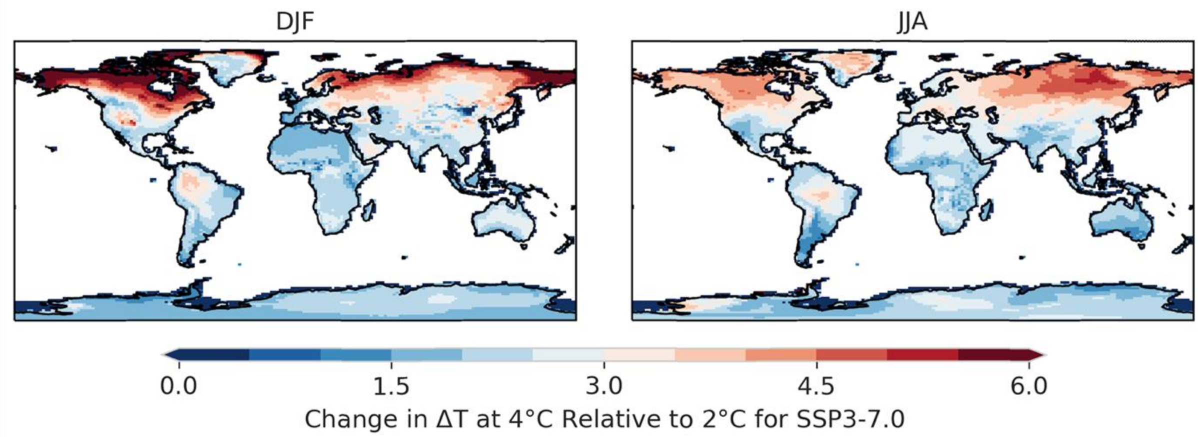

Figure 5. Absolute change in seasonal surface temperature anomalies between 2°C and 4°C mean warming under SSP3-7.0 for norther hemisphere winter (DJF) and summer (JJA) seasons.

In order to motivate the scale of mitigation required to stay below 2°C global warming, it is useful to consider the scale of regional changes seen across different global warming thresholds. In Figure 5, for example, we plot the increase in seasonal mean surface temperatures as mean global warming increases from 2°C to 4°C and see that some of the earlier patterns of regional change continue to be visible. In particular, the high Northern latitudes continue to experience an amplified warming rate, as does the Amazon region.

A similar analysis extended to a broader range of climate variables will provide a more complete picture of the benefits of restricting global warming to 2°C. We will also expand our analysis to include other models from CMIP6, focusing on sensitive regions such as the Mediterranean, Amazon and studying the co-variability of changes across different components of the coupled Earth System.

REFERENCES

O'Neill, Brian C., Claudia Tebaldi, Detlef P. Van Vuuren, Veronika Eyring, Pierre Friedlingstein, George Hurtt, Reto Knutti et al. "The Scenario Model Intercomparison Project (ScenarioMIP) for CMIP6." (2016).

Moss, Richard H., Jae A. Edmonds, Kathy A. Hibbard, Martin R. Manning, Steven K. Rose, Detlef P. Van Vuuren, Timothy R. Carter et al. "The Next Generation of Scenarios for Climate Change Research and Assessment." *Nature* 463, no. 7282 (2010): 747-756.

Taylor, Karl E., Ronald J. Stouffer, and Gerald A. Meehl. "An Overview of CMIP5 and the Experiment Design." *Bulletin of the American Meteorological Society* 93.4 (2012): 485-498.

Sellar, Alistair A., Colin G. Jones, Jane P. Mulcahy, Yongming Tang, Andrew Yool, Andy Wiltshire, Fiona M. O'connor et al. "UKESM1: Description and Evaluation of the UK Earth System Model." *Journal of Advances in Modeling Earth Systems* 11, no. 12 (2019): 4513-4558.

Dai, Aiguo, Dehai Luo, Mirong Song, and Jiping Liu. "Arctic Amplification is Caused by Sea-ice Loss Under Increasing CO 2." *Nature communications* 10, no. 1 (2019): 1-13.

Rhodes, Christopher J. "The 2015 Paris climate change conference: COP21." *Science progress* 99.1 (2016): 97-104.

3D visualization of CMIP6 data

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The UKESM1 earth system model has been used to run the climate experiments prescribed by the CMIP6 project, including a simulation of the historical period (1850-2014) and a range of projections (2015-2100) which explore ways in which the Earth's climate could evolve in the future. The output from each simulation has been converted to data in the standard format prescribed by CMIP6 and uploaded to the Earth System Grid Federation (ESGF) for access by climate scientists worldwide.

Partly because of the broadened scope of CMIP6, our investment in the project is much greater than for previous rounds, and the experiments have consumed several person years' effort and CPU core centuries. More specifically, we expect to upload around 5 PB of data to ESGF, which is more than three times the size of the *entire* CMIP5 data archive. The scale of this investment is one of the reasons we are keen to take more opportunities to exploit our model data by ensuring it is used not only in contributions to climate research and policy-making, but also in public outreach and dissemination efforts.

For example, results for near-surface air temperature – a variable of interest for climate change studies – from the historical and future projections are plotted in Figure 1. The data is plotted as an anomaly – that is, the difference from the global average mean near-surface temperature between 1850 and 1900 – thereby focusing attention on changes in temperature since that period, which is conventionally used as a pre-industrial reference.

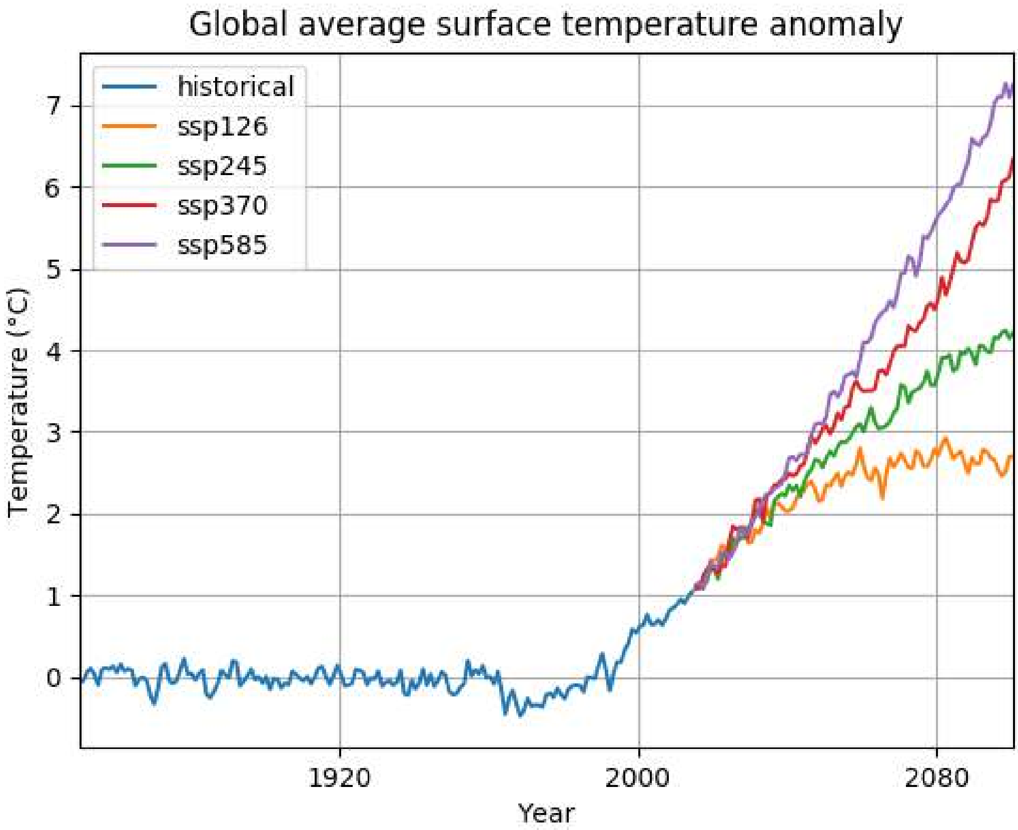


Figure 1. Global average annual mean near surface temperature, as determined by UKESM1, for the CMIP6 historical experiment and four future projections.

Each of the four projections in Figure 1 corresponds to an assumed so-called *shared socio-economic pathway* (SSP), prescribing how – amongst other things – greenhouse gas emissions and land use could change in the future. They range from SSP126 – a future where emissions are constrained in order to try and limit temperature rise to around 2 °C – to SSP585, which assumes a “business as usual” pathway in which the rate of increase in emissions stays constant for many decades, resulting in a very large rise in atmospheric greenhouse gas concentrations. UKESM1 simulates the response of the Earth’s climate to these different conditions, which includes increases in global average near-surface temperature in 2100 which range between circa 2.5 °C (in the case of SSP126) to around 7 °C (for SSP585).

The temperature data plotted in Figure 1 has been averaged over both time (as an annual mean) and space (as an area-weighted spatial average). Hence, although it provides a compelling illustration of some of the differences between the future projections, it does not contain any information about spatial distribution of temperature change. This can be displayed using a 2D contour plot, but, inspired by our experience at public outreach events where we displayed our contour plots on a 3D spherical projection system, we have opted instead to mimic the physical globe by wrapping 2D temperature contours around the surface of a sphere.

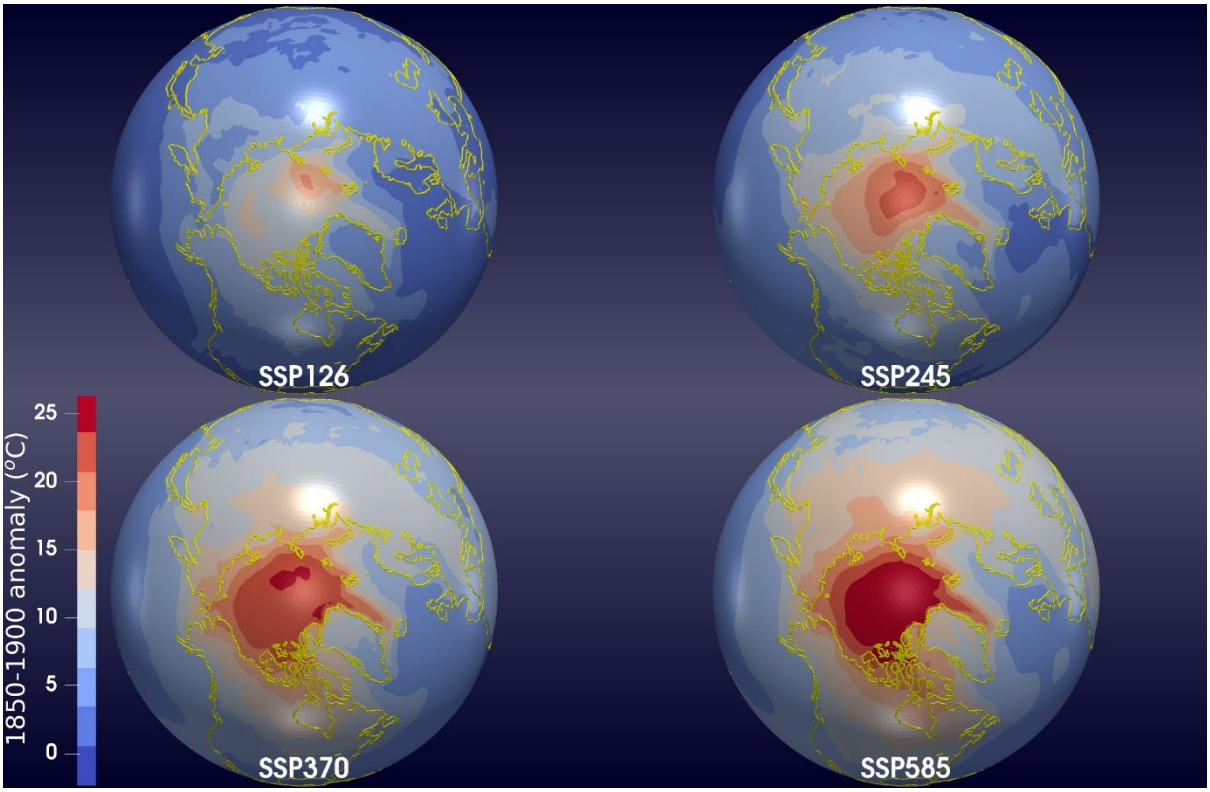


Figure 2. Annual mean near-surface temperature anomaly in the Arctic, as determined by UKESM1, at the end of the four CMIP6 future projections; land areas are represented by yellow coastlines.

Figure 2 shows solid contour plots of the annual mean near-surface temperature anomaly wrapped around a sphere for each of the four future projections in the year 2100 (i.e., at the end of the experiment). The differences between the temperature change for the projections which is a feature of Figure 1 can still be seen be in Figure 2, but this also displays the spatial variation of temperature change. For each future projection, the Arctic region warms most strongly, and this warming is greatest for SSP585 (corresponding to the largest rise in emission levels) – specifically, it shows an increase in temperature of around 25 °C for the year 2100 – that is, around three times the global average displayed in Figure 1.

We note in passing that an in-depth investigation of a climate change signal would not be based solely on the annual mean results for one year from a single realization of a climate experiment, as depicted here. Instead, a rolling average of the results for several ensemble members would be used – see, for example, the article from Swaminathan *et al.* elsewhere in this edition of the Newsletter.

We have also produced animations of our CMIP6 data, reflecting the evolution of climate variables over the course of the experiment. For example, Figure 3 is a dynamic visualization of near-surface temperature, showing how this evolves over the surface of the globe during the time period covered by the future projection experiments (i.e. 2015-2100).

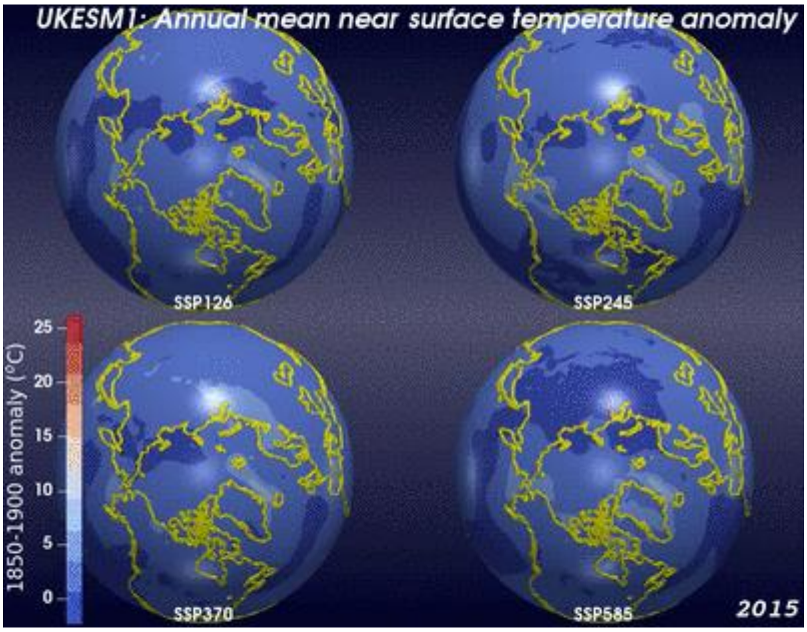


Figure 3. Dynamic visualization of near-surface temperature, as determined by UKESM1, for the four CMIP6 future projections; land areas are represented by yellow coastlines.

We are using images such as Figure 2 and 3 in our dissemination work, and associated efforts to engage with a non-specialist audience. The study of climate change is a scientific activity which – partly because of its connections to human activities and implications for society – excites a degree of interest from the general public which is unusual when compared to other fields of science. The scale of the problem, coupled with the degree of commitment required to mitigate its effects, can be daunting, necessitating a sustained level of engagement and understanding from the public. There is a concomitant requirement for specialists to explain and disseminate their work to a broad audience in an accessible and compelling fashion – such as, for example, Figure 2. Further work in this area will look at the creation of images using other variables of interest produced by the model, including precipitation and wind vectors in the atmosphere, carbon content in the ocean and ice extent on sea and land.

For further information, please contact Jeremy Walton (jeremy.walton@metoffice.gov.uk).

Recent events

UKESM - LTSM General Assembly, Online - 16-17 June 2020

The 2020 UKESM General Assembly went fully online for our two day meeting. Whilst we may have missed out on meeting face-to-face this year, it did mean that we had between 80 to over 100 participants in the sessions – from as far as New Zealand, Australia and South Korea.

Day 1 included: a review of the progress of the UKESM project over the past year (Colin Jones & UKESM team), the 2nd NERC Long Term Science Multi Centre (LTSM) programme (Rowan Sutton) and policy related science talks

- *Investigating abrupt, potentially irreversible changes in the Earth system.* **Tim Lenton**
- *Allowable carbon budgets for meeting key policy targets.* **Chris Jones**
- *The mitigation potential of non-CO_2 Short Lived Climate Forcers and potential co-benefits for regional air quality.* **Fiona O'Connor**
- *Assessing aggressive climate mitigation strategies.* **Cat Scott**

An international perspective on Earth system modelling was provided by Olivier Boucher (IPSL) and **Jean-François Lamarque** (NCAR/CESM). Day 1 was rounded off by a summary by Jane Mulcahy (UKESM).

Most of Day 2 was dedicated to short science talks related to UKESM developments or using the generated datasets in the Coupled Model Intercomparison Projects (CMIPs). 20 short talks were given by a mixture of the UKESM team, collaborators and researchers in other institutions. A full list is available at the link below.

Further details, slides and a link to recordings of all the sessions on YouTube can be found on our website: https://ukesm.ac.uk/ukesm-general-assembly-16-17-june-2020/

CMIP6 Analysis Seminars – Online in April and May 2020

Five online seminars were held over the 20, 21 April & 15 May involving 25 scientists presenting their work on the analysis of CMIP6 simulations. We were particularly pleased to involve a number of Early Career Scientists in the programme of talks. The full list of presentations and slides are available for each session at:

https://ukesm.ac.uk/cmip6/uk-cmip6-analysis-workshop-20-21-april-2020-met-office-exeter/

Publications

UKESM1 in the research literature

The Journal of Advances in Modeling Earth Systems has a special issue on: The UK Earth System Models for CMIP6. Recent updates to this issue include:

- Andrews et al. 2020: Historical Simulations With HadGEM3-GC3.1 for CMIP6

- Bodas-Salcedo et al. 2019: Strong dependence of Atmospheric Feedbacks on Mixed-Phase Microphysics and Aerosol-Cloud interactions in HadGEM3 (explains high ECS & cloud feedbacks in UKESM1)
- Andrews et al. 2019: Forcings, Feedbacks and Climate Sensitivity in HadGEM3-GC3.1 and UKESM1

In Atmospheric Chemistry and Physics online journal:

- Fiona O'Connor et al. 2019: Assessment of pre-industrial to present-day anthropogenic climate forcing in UKESM1

Papers coming soon:

- Kuhlbrodt et al. 2020: Ocean heat uptake in the UK model historical simulations
- Yool et al 2020: Evaluation of the ocean component of UKESM1 CMIP6 historical simulations
- Kelley et al 2020: Evaluation of the land component of UKESM1 in CMIP6 historical simulations

News

July 2020 – I'm A Scientist, Stay At Home

by Andrew Yool

Since 2010, "I'm A Scientist, Get Me Out Of Here" has run an annual fortnight of online outreach events in which school students from around the UK chat with scientists about anything and everything science. With the advent of lockdown across the UK in response to the COVID-19 pandemic, an expanded programme of "I'm A Scientist, Stay At Home" events has been running since May. The format for "I'm A Scientist" is primarily online chat sessions – sometimes themed, sometimes completely open – in which students and scientists come together to pose and answer questions. In addition, the website hosts "Ask A Scientist", allowing questions to be posted for everyone in the community to answer.

Taking part in this summer's events has been Andrew Yool, one of UKESM1's marine biogeochemists. He joined the coding, environment and "Summer 2020" zones of the event, and has taken part in a number of chatroom sessions. In each of these, around 10-15 scientists took part in fast and furious conversations sparked by questions from up to 30 students. Typically these questions are posed by students at particular scientists (of whom, potted biographies are available), but many are open to @all for anyone to answer. Questions can be broken out into separate chat threads for scientists and students alike to follow-up on and dig deeper. As well as questions on particular science topics, many questions touch on why people became scientists, what it's like to be a scientist day-to-day, and how students can make science their career.

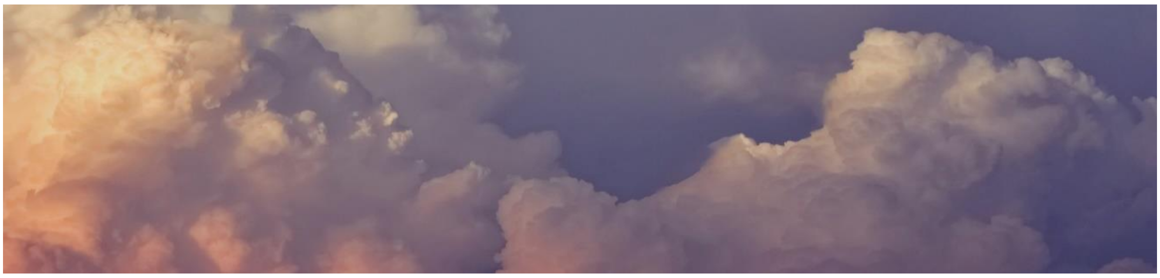
During his time in the chatrooms so far, Andrew has been asked questions about how he models plankton in UKESM1, how the ocean's carbon cycle works, and what nutrient cycles are. He has also fielded questions on topics as wide ranging as why cats eyes are reflective, why we produce toxic waste, and why hearing aids are not what animals need to understand human language. On the chatrooms, he remarked, "Although frenetic at times, the enthusiasm from the students is very infectious, and it's a real buzz to be able to help students with their questions – I'd definitely recommend taking part to my colleagues".

"I'm A Scientist, Stay At Home" continues to the end of July 2020.

Andrew Yool is a researcher at the National Oceanography Centre, Southampton.

Weblinks:

- https://imascientist.org.uk/
- https://coding20.imascientist.org.uk/
- https://environment20.imascientist.org.uk/
- https://summer20.imascientist.org.uk/
- https://summer20.imascientist.org.uk/ask/



United Kingdom Chemistry and Aerosol (UKCA) model – Community Survey

The United Kingdom Chemistry and Aerosol (UKCA) model is a widely used atmospheric composition model. UKCA is the composition model of choice in UKESM. The UKCA user community has grown significantly over time necessitating a more robust management structure. To respond to this need the UKCA Science Management Group (SMG) has been created. Currently, the SMG is drawing up a new strategy to guide science and development for the next few years. However, the SMG strongly feels that the forthcoming UKCA science and development strategy should reflect the interests and needs of the community rather than the opinions of its management alone. Therefore, the SMG needs to understand better those needs and priorities of the community. We have designed a community survey and we ask you all for your help. Please follow the link to the survey below or go to the UKCA website (https://www.ukca.ac.uk/wiki/index.php/UKCA) and follow the link on the landing page.

Link to the survey: https://docs.google.com/forms/d/e/1FAIpQLSe6fFb3lnSTyEXv5oxPFp3wTkvG8FI6duQYYWWvnaoMGdDrNA/viewform?usp=send_form"

ESGF user feedback survey 2020

The ESGF user feedback survey 2020 has been launched. This infrastructure-focused survey aims to collect feedback from a broad range of ESGF users, including the broad community of CMIP data users and stakeholders. The results of the survey will focus the development priorities for the next-generation ESGF software stack and website, along with the ESGF computing capabilities to be launched soon alongside the data.

This infrastructure-focused survey is being led by the Earth System Grid Federation (ESGF) in collaboration IS-ENES with the WCRP WGCM Infrastructure Panel to "take the temperature" of how CMIP data contributors, users, and stakeholders are working with ESGF to search, access and download data. We expect another science-focused survey led by the CMIP panel and focused on the possible design of CMIP7 will follow in a number of months.

The survey will take 10-15 minutes of your time, and is available at https://www.surveymonkey.com/r/3RZFPG7

We appreciate it if you can respond before Monday 20th August 2020.

We invite you to forward the details far and wide so that we can collate the most representative feedback for ESGF's broad contributor and user communities.

ESGF

Team News

Recent additions to the UKESM Core Group:

Stephen Pring joined the UKESM core group in February 2020 as a scientific software engineer. Prior to this Stephen worked in Dynamics Research at the Met Office between 2015-2019. During this time Stephen worked on developing the next-generation dynamical core called GungHo. Designed to be more scalable than the current dynamical core ENDGame within the UM, GungHo uses a cubed-sphere mesh rather than a latitude-longitude mesh to avoid singularities at the poles. Before this Stephen worked in Data Assimilation between 2010-2014, where Stephen worked on developing the ensemble-variational ensemble generation system which is now being used operationally at the Met Office for generating the forecast ensemble members.