FUTURE CLIMATE FOR AFRICA

GUIDE

September 2017

How to understand and interpret global climate model results

Climate modelling approaches projecting future changes to the Earth's climate vary widely, generating different types of dataset. These results are often displayed visually in a variety of formats, such as statistical graphs, maps and increasingly innovative presentations. This guide explains why there are so many climate model results, and how to interpret the various ways in which they are presented, in order to understand what models tell us about likely future climate. It is targeted primarily at technical staff in the government and non-government sectors, to offer an introduction to what can be a confusing and highly technical subject area.

What are global and regional climate models?

Global climate models (GCMs) are the most widely used method to understand what the climate may be like in the future as a result of emissions of greenhouse gases (global warming). They are run on supercomputers that attempt to simulate the complex atmospheric and oceanic processes that determine the climate conditions we experience. Because they work at a global scale, the resolution of GCM results is typically quite coarse. Each grid cell is roughly 200 × 200 km.

Regional climate models (RCMs) are applied to smaller spatial areas to produce results with greater local detail. However, RCMs still rely on GCMs for input data and therefore are not necessarily more reliable or more accurate.

A variety of GCMs and RCMs exist around the world, housed in scientific centres concentrated in high-income countries, such as the Max Planck Institute for Meteorology (Germany), the Met Office Hadley Centre for Climate Science and Services (UK), and the National Oceanic and Atmospheric Administration (USA). GCMs and RCMs are run under different scenarios of future greenhouse gas emissions – from a best-case scenario (if extensive action is taken to reduce emissions levels) to the worst-case (if emissions keep rising with no action taken to reduce them). They generate a number of possible climate futures (projections). For example, the fifth phase of the Coupled Model Intercomparison Project[1] (CMIP5) compares findings of the different GCMs run under the same set of four different emissions scenarios, known as the Representative Concentration Pathways (RCPs).

Given the variety of GCMs and RCMs – all run under a range of different scenarios – a wide range of climate model results are now available.

Figure 1 explains some of the reasons why there are a variety of results and ways to present them, in order to understand climate change. More information about how to use climate models can be found in the FCFA guide *Climate models: What they tell us and how they can be used in planning*.[2]

Processing and summarising model results

Climate models produce numerical values for key climate parameters, such as temperature, humidity and wind speed, for specific points and at different levels on the Earth's surface and in the atmosphere and oceans. These results are stored by climate modelling groups as large data files in standardised formats, and require technical skill to use. Climate model portals allow the climate science research community to compare model results, assess errors and identify improvements as part of ongoing model development (such as CMIP5 for the global level and CORDEX[3] for the regional level).

About FCFA

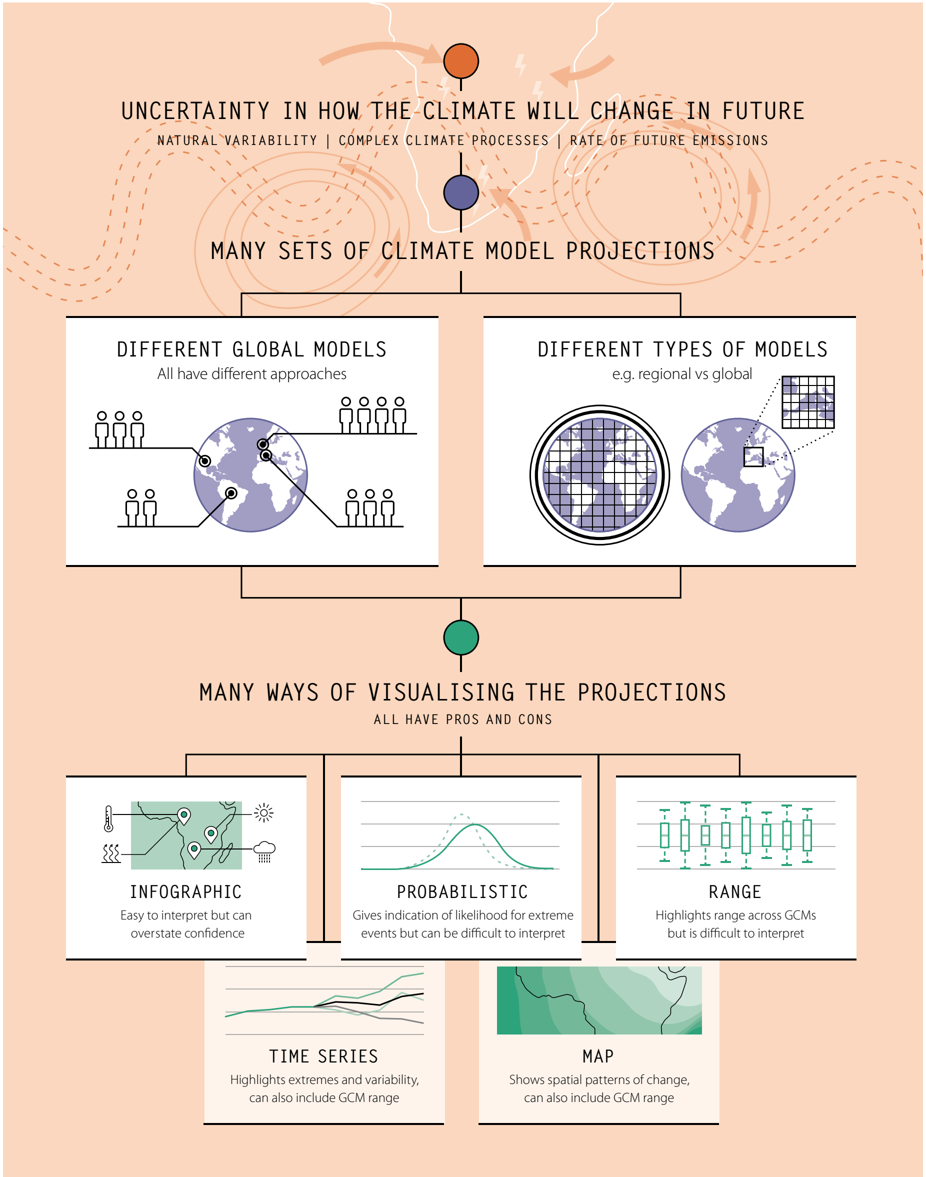
Future Climate for Africa (FCFA) aims to generate fundamentally new climate science focused on Africa, and to ensure that this science has an impact on human development across the continent.

www.futureclimateafrica.org

To produce projections, the data files need to be processed and critical decisions have to be made about which aspects of the data are most relevant for the audience. These decisions relate to the:

- future time period of interest (e.g. 2016-2035, or 2046-2065, or 2081-2100)
- spatial scale (e.g. regional, national or subnational level)
- choice of climate parameters (most commonly temperature and rainfall)
- number of climate models to be used (it is good practice to use multiple models)
- greenhouse gas emission scenario (from best-case to worst-case)
- format and level of technical detail of the information (e.g. maps, tables, time series).

Figure 1. Why are there so many climate projections (GCMs) and ways of visualising them?



Understanding model datasets

What models tell us

Models project the extent of difference (or anomaly) of various climate parameters – typically temperature and rainfall – relative to the long-term average. With temperature, for example, projections tell us how much of an increase in temperature we expect to see relative to the global average temperature (all models project an increase in temperature). Rainfall projections typically show percentage (%) change, or change in millimetres per year.

Timescales of future projections

Climate models can project out to 2100, but the time periods used in the CMIP5 models are generally 2016-2035 (for near term); 2046-2065 (for medium term); and 2081-2100 (for long term).

GCM results are available on daily time steps (data are generated in daily increments) and can be aggregated into monthly, seasonal and annual values. Daily time steps give more information about changes in the frequency and intensity of specific climate hazards such as droughts and floods (often causing the greatest socioeconomic impacts), but they are associated with higher levels of uncertainty.

Comparing averaged climate model results for a given time period and area

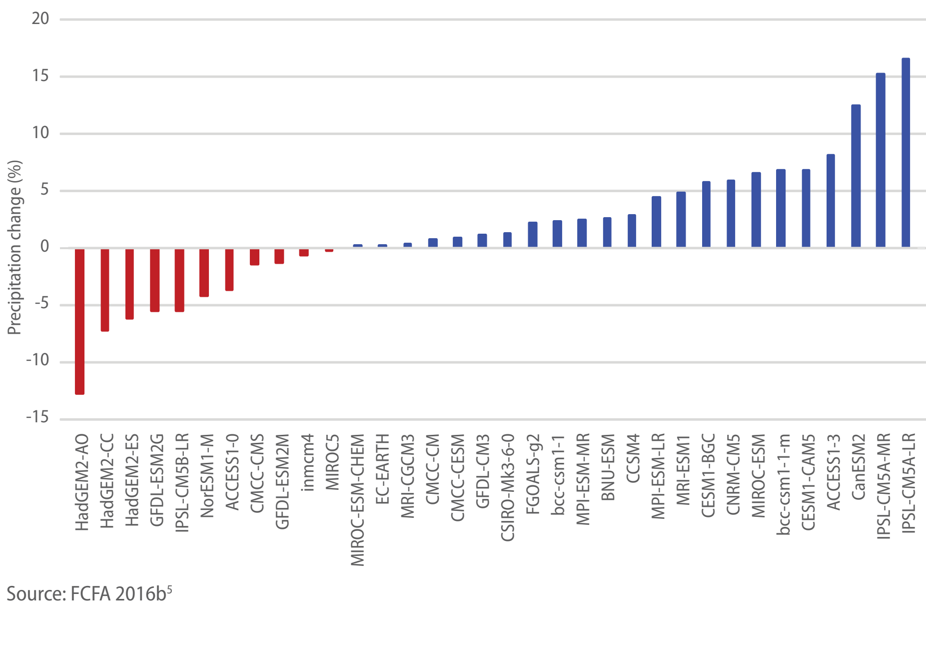
For any given time period and area, it is important to use projections from multiple GCMs (or ensembles) to capture the range of results. Employing just one GCM output, or the average or median of a group of GCMs, can disguise important information. Ranges can be shown in a variety of ways.

What to remember about climate models

- Climate model results are not predictions or forecasts. Because of the uncertainties in GCM results, we refer to them as 'projections' (plausible descriptions of future climate).
- The rate at which greenhouse gases are emitted in the future can also lead to differences in climate model projections. Models are run under different scenarios in order to capture this. Higher emissions lead to faster rates of warming, but the differences are generally not very large until at least the 2050s.
- The inherent variability in the climate system (periods that are particularly warm or cool, or wet or dry) also leads to differences between GCM results.
- Climate model projections are not final. Models are constantly being refined as new understandings of the climate system come to light.
- All climate models show continued warming of surface air temperatures in the future. But for rainfall, which shows much greater variations across space and through time, there is less agreement between climate models. In some cases, the models do not even agree on whether a place will become drier or wetter.
- The reliability of model results generally decreases at finer scales. As we move from larger to smaller areas, the ability of climate models to represent local climatic influences decreases. Hence, although RCMs may produce projections with higher resolution, they are not necessarily more reliable.
- The differences between climate models and scientific uncertainties are often larger for less widely used climate parameters, such as wind speed, humidity and radiation (sunshine).

Figure 2. Change in rainfall (precipitation) for the whole of Tanzania between the present (1976-2005) and the future (2021-2050) projected by 34 global climate models

Each bar on the x-axis represents one GCM.



Source: FCFA 2016b[5]

Different climate models can project drier or wetter conditions for the same location. Figure 2 shows projections of change in rainfall from 34 GCMs averaged across the whole of Tanzania, highlighting marked divergence in the direction of change (11 models project drying and 23 project wetting); see the brief *Future climate projections for Tanzania* for more details.[4] Each bar represents one climate model; red bars project drier conditions and blue bars project wetter conditions.

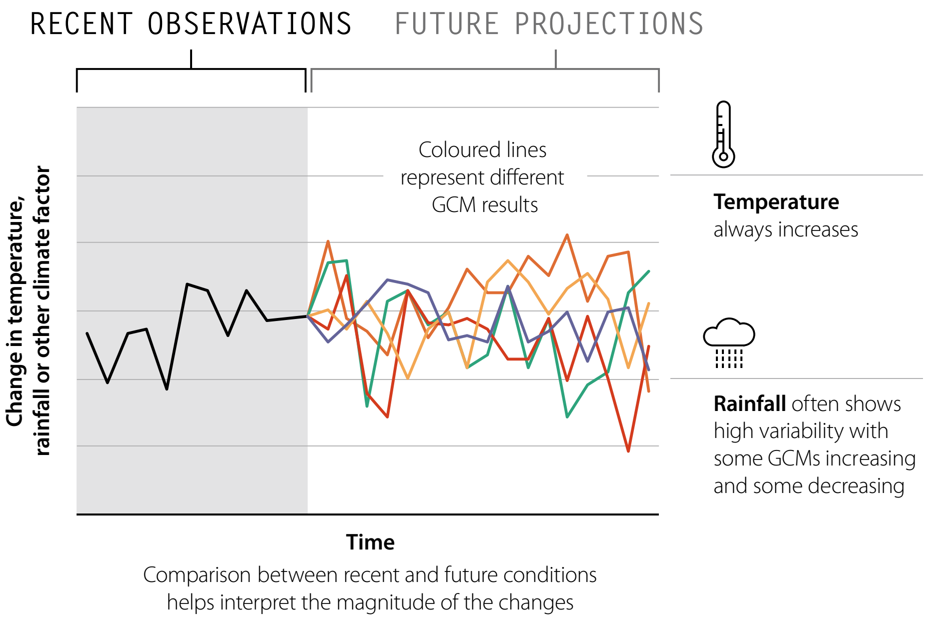
Presenting model data

Model datasets are most commonly presented in a time series graph or map. The reasons for different presentations are twofold: first, there are many different aspects of climate that we want to know about; second, we are unsure of the most helpful way to represent the uncertainty. Time series graphs show changes over time relating the extent of difference (or anomaly) of the parameter (e.g. rainfall) relative to the long-term average (see Figure 2 for an example). Maps show changes averaged over a given time period (often 20 or 30 years) but presented spatially, making it easy to see what is projected in different locations.

Time series graphs

Time series show variation in parameters such as temperature and rainfall, and can portray annual, seasonal or monthly values for the recent past and projecting into the future. Time series may be for one climate model grid box (which tends to be between 100 and 300 km, although attempts are under way to make them higher resolution), or they may be averaged across a specific area such

Figure 3. A hypothetical example of time series change in temperature, rainfall or other climate factor for the recent past and into the future



as a river basin or a country. Figure 3 shows some of the main features of a typical time series presented in climate change reports. Time series are useful for showing changes in climate extremes and variability, and how the rate of change varies over time.

Changes in the mean

Information about changes in the monthly pattern of climate, for example temperature (°C) or rainfall (mm), is useful for informing adaptation decisions. Figure 4 shows a hypothetical example of monthly changes that could represent the results from different GCMs. The format, known as a box-whisker plot, uses a vertical box to show the 50% of values lying closest to the median (the value lying at the middle of the sample), and vertical lines from the box to show the full extent of the upper and lower 25% of values (known as quartiles). Because some models do not even agree on the direction of future change in rainfall (whether there will be an increase or decrease), it is important not to rely just on the average (mean) of model results. If two models project an increase and two models project a decrease, this would be hidden in the mean. If the quartiles are shown, this variation becomes apparent. The range reflects differences in climate model results.

Frequency distributions (probabilistic)

A frequency distribution shows the likelihood of occurrence (probability) of events of a certain magnitude (which can be absolute, or a difference from the mean) that occur over a certain period. Such distributions generally form a bell-shaped curve with the mean (average) located in the middle. Figure 5 shows an idealised example for past observations of temperature. The jagged line represents the variation around the long-term mean for observations of temperature. In the majority of years between 1951 and 1980, the temperatures are similar to the mean (unshaded, in white), but in a smaller number of years they may be substantially cooler (blue) or warmer (red) than the long-term average. Very extreme years occur rarely (darker blue/red).

The bottom graph in Figure 5 shows how such a frequency distribution changes for the period 2005 to 2015. Since 45 years of warming have occurred, the average temperatures are higher, the probability curve shifts, and thus the probability of temperatures exceeding the previous high range is now much higher (the red area is much larger).

Figure 4. A hypothetical example showing change in the monthly pattern of a climate variable between present and future

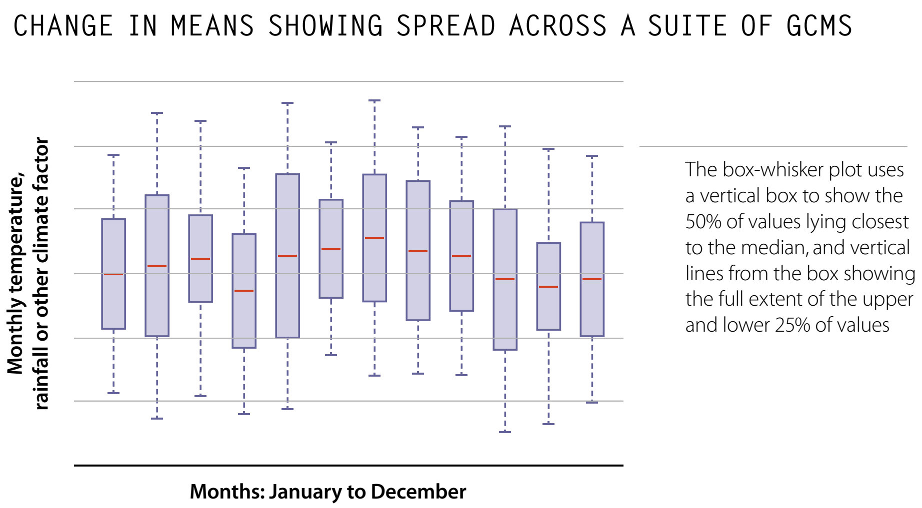
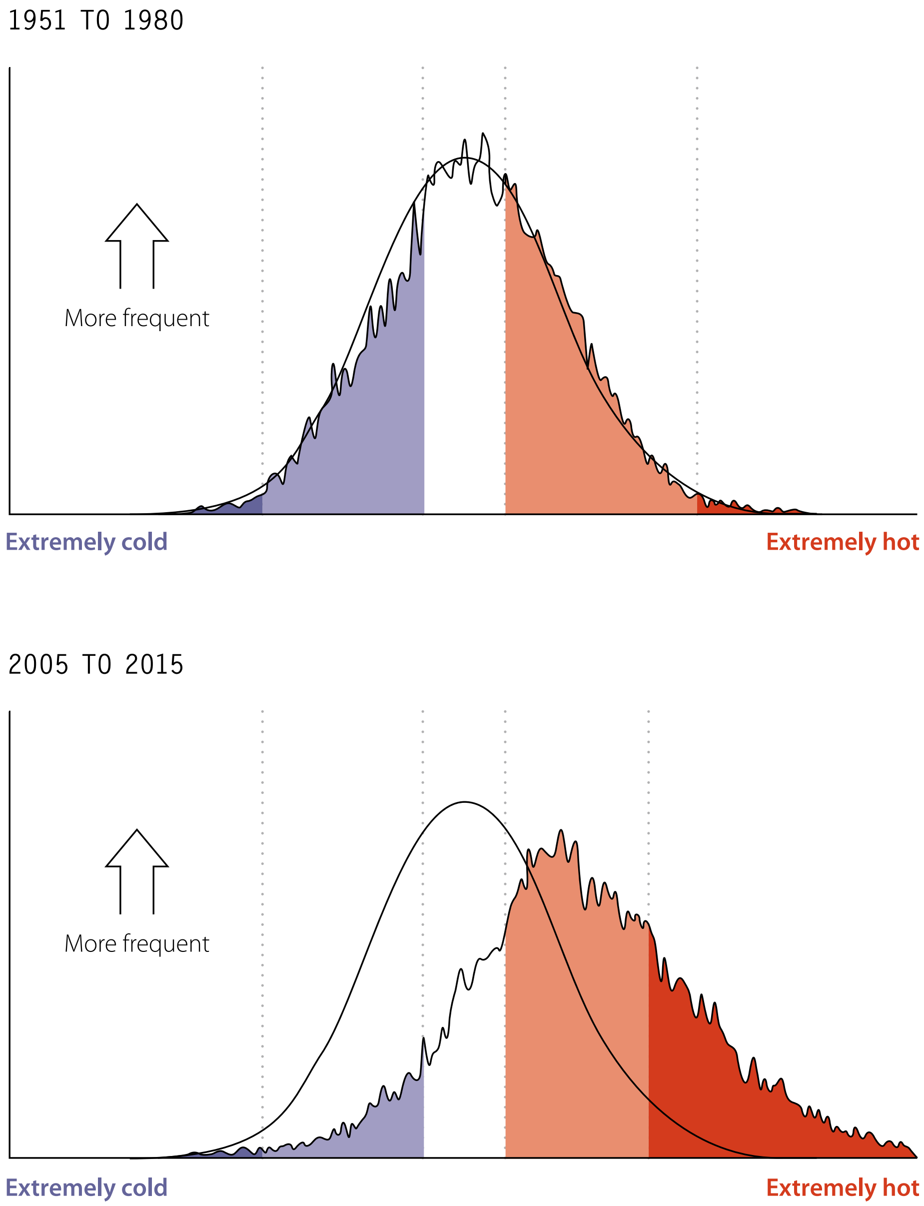


Figure 5. A hypothetical example showing the change in probability of certain temperatures between the 1950s and the 2000s



Extremely hot years also occur much more frequently, and extremely cold years less frequently. The same figures can be produced for the future using GCM projections of temperature (or other climate parameters). Such shifts will continue into the future with global warming.

Figures showing frequency and probability distributions can be very difficult for untrained readers to understand, and there are no effective shortcuts for visual displays to improve understanding.

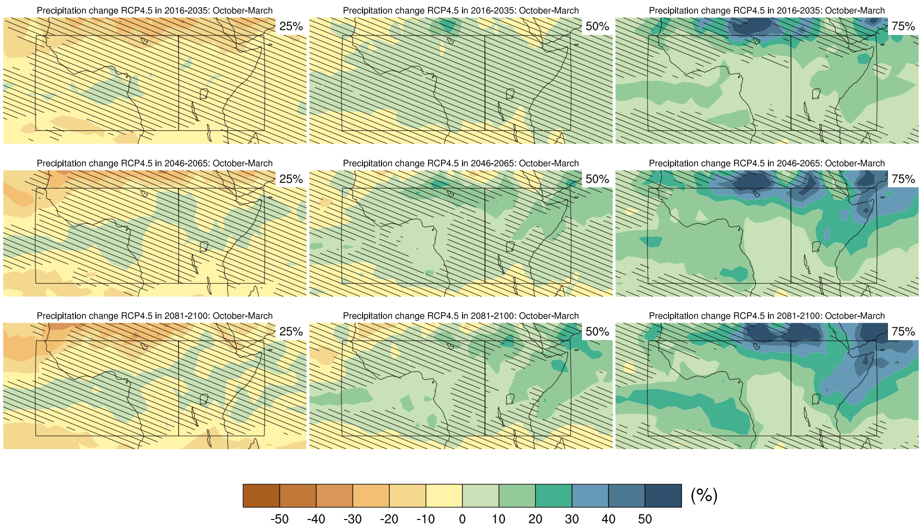
Maps

While maps offer an excellent format for displaying spatial patterns of change, their resolution (the amount of detail they can show) is limited by the rather coarse resolution of GCMs. Multiple maps can be used to show patterns of change for different seasons, time periods and scenarios of greenhouse gas emissions.

Figure 6 shows changes in rainfall for western and eastern Africa for three periods into the future from the Intergovernmental Panel on Climate Change's (IPCC) *Fifth Assessment Report*. In this case, the periods are 2016-2035, 2046-2065 and 2081-2100, shown as a percentage change from the period 1986-2005 with a low greenhouse gas emissions scenario (RCP4.5) and focused on a six-month period from October to March. For each time period, the 25th, 50th and 75th percentiles of the distribution of the CMIP5 climate model ensemble are shown. It is important to show these percentiles because an average (mean) could disguise variation in results between models (known as inter-model spread). For example, if two models project an increase of 10%, and two models predict a decrease of 10%, then the mean would be 0% change – which would be misleading. In these maps, an additional level of detail is shown through the hatching (black diagonal lines). Here, hatching shows areas where the projected change in future variability is not significantly different from current levels of variability – these would be areas where relatively small changes are projected.

Another way of showing how well models agree when projecting rainfall is to use colour. Some maps use colour to represent future changes in rainfall, often for an average of multiple GCMs; no colour to represent disagreement

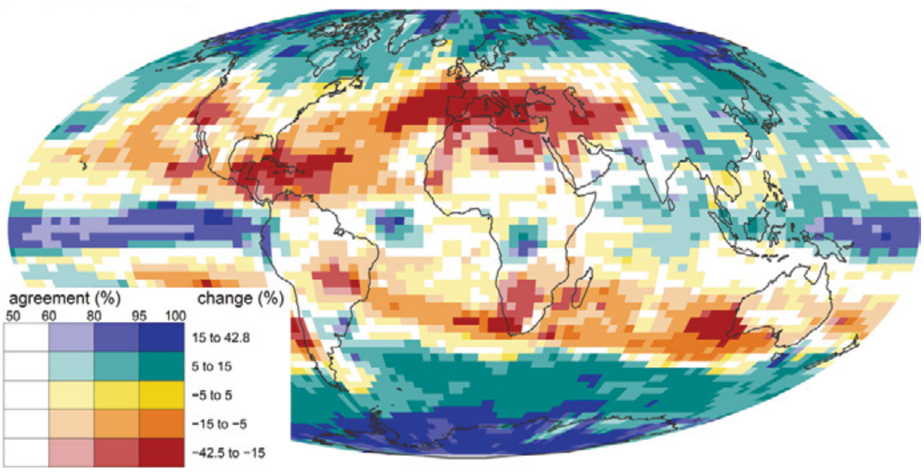
Figure 6. Change in monthly pattern of rainfall between present and future



Source: van Oldenborgh et al., 2013[6]

in models (known as divergence); and stippling (small dots) to represent high levels of agreement between models. This can make it easier to determine where the model findings are uncertain (white) and robust (stippling). Alternatively, Figure 7 uses colour hues to show whether there is a projected increase or decrease, and by how much; colour saturation to show how much agreement there is between models in the projection; and no colour to represent areas of model divergence (where fewer than 60% of models agree on the direction of change in rainfall). So the areas with darkest colour are where we have robust projections for the percentage change in rainfall indicated.

Figure 7. Change in spatial pattern of rainfall between present and future



Source: Kaye et al., 2012[7]

Innovative presentation of GCM data for non-scientific audiences

New and innovative ways of visualising and presenting climate information now exist. These typically provide greater context, not just showing what the change is, but also highlighting what impacts it may have.

Infographics

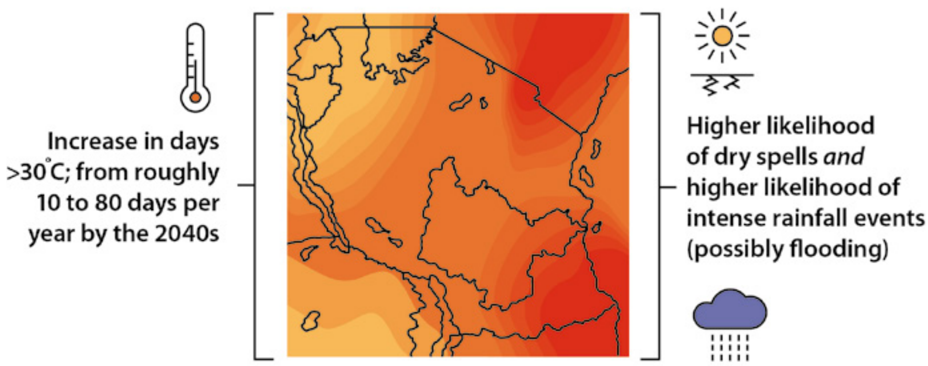
For non-scientific audiences and readers with limited time to absorb text, infographics can highlight key information. However, summary information must be derived responsibly to accurately reflect levels of uncertainty and avoid alarming messages. It is often useful to provide more detailed supporting information to explain how the information has been derived.

The example in Figure 8 highlights projected changes in extreme temperature for Tanzania by using a background map to illustrate warming throughout the country, and text to summarise a key example of how temperature extremes might increase. The right-hand side highlights two other aspects of extreme climate that are likely to interest readers. The icons help to orientate the reader. There is no mention of confidence in the projections in the infographic itself, but this is included in the accompanying text in the original source.

Iconic figures

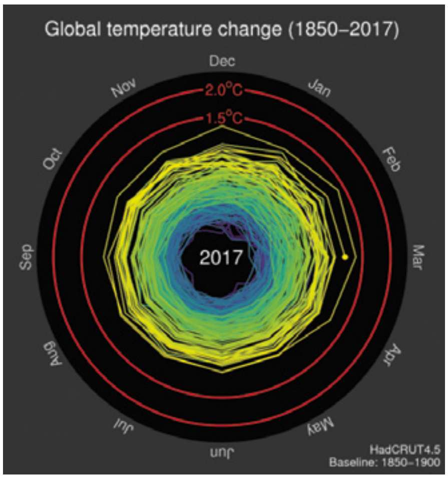
In 2001 the IPCC first introduced a 'reasons for concern' graphic, more recently termed a 'burning embers' diagram (Figure 9). It highlights risks identified in the IPCC assessment reports that may be considered 'dangerous':
(1) risks to unique and threated systems;
(2) risk of extreme weather events;

Figure 8. An infographic summarising the main changes from GCM projections related to temperature and rainfall extremes in Tanzania



Source: FCFA 2016b[8]

Figure 10. Global temperature change by month from 1850 to 2017



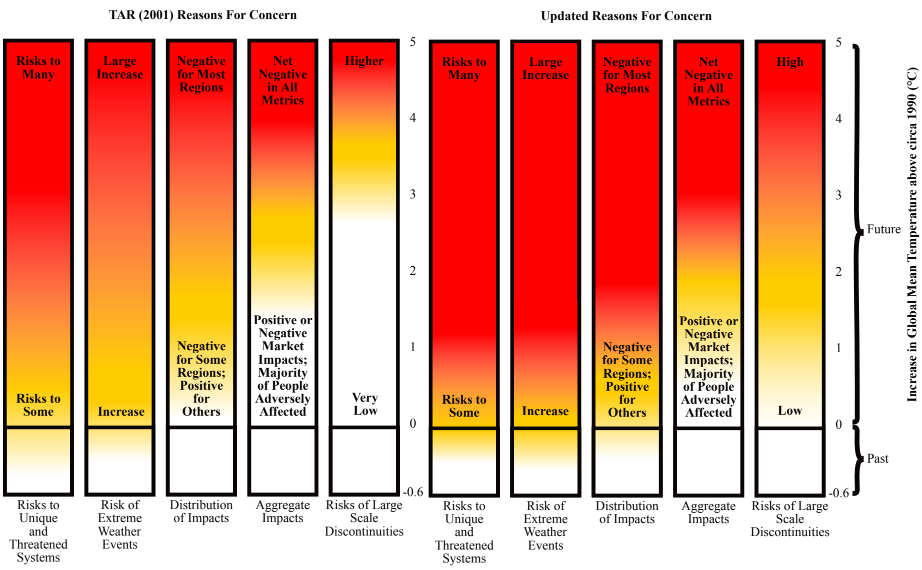
Source: Hawkins, 2017[11]

(3) distribution of impacts; (4) aggregate impacts; and (5) risks of large-scale discontinuities. Colour transitions from white to red in the vertical columns show where the risk shifts from neutral to somewhat negative or low risk, and then to more negative or high risk. However, the lack of clarity in the diagram may give the illusion of being a visual representation based on an objective assessment of climate risk, when it is actually a subjective appraisal.

Climate spirals

Temperature varies from month to month. Showing this intra-annual variability, together with inter-annual variability (change from year to year), can be complicated. Ed Hawkins, from the University of Reading in the UK, has created 'climate spiral' animations (Figure 10)[10] that show global average temperature change by month from 1850 to 2016, relative to the 1850-1900 average. He highlights the 1.5°C and 2°C thresholds, widely believed to be critical thresholds for temperature change (and reflected in political instruments such as the Paris Agreement under the United Nations Framework Convention on Climate Change). Animated versions can be viewed on the Climate Spirals webpage.

Figure 9. 'Reasons for concern' about climate change



Source: Smith et al., 2009[9]

Conclusion

There are a range of ways to present projections from climate models: graphs, maps, and innovative visual displays such as infographics, iconic figures and animations. Each approach has positives and negatives, and the choice of presentation should reflect the intended use of the information. This guide highlights what is being represented in different presentations to enable effective understanding and interpretation of GCM results.

Endnotes

1 CMIP5: http://cmip-pcmdi.llnl.gov/cmip5

2 FCFA (2016a) *Climate models: What they tell us and how they can be used in planning.* Cape Town: Future Climate for Africa. www.futureclimateafrica.org/resource/climate-models-what-they-show-us-and-how-they-can-be-used-in-planning

3 CORDEX: www.cordex.org

4 FCFA (2016b) *Future climate projections for Tanzania.* Cape Town: Future Climate for Africa.

5 Ibid.

6 van Oldenborgh, G.J., Collins, M., Arblaster, J., Christensen, J.H., Marotzke, J., Power, S.B., Rummukainen, M. and Zhou, T. (2013) 'Annex I: Atlas of global and regional climate projections', in Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V. and Midgley, P.M. (eds) *Climate change 2013: The physical science basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK and New York, USA: Cambridge University Press, Figure AI.46, p. 1360. www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_AnnexI_FINAL.pdf

7 Kaye, N.R., Hartley, A. and Hemming, D. (2012) 'Mapping the climate: guidance on appropriate techniques to map climate variables and their uncertainty', *Geoscientific Model Development* 5(1): 245–256, Figure 10b, p. 254. http://doi.org/10.5194/gmd-5-245-2012

8 FCFA (2016b) Op. cit.

9 Smith, J.B., Schneider, S.H., Oppenheimer, M., Yohe, G.W., Hare, W., Mastrandrea, M.D., Patwardhan, A., Burton, I., Corfee-Morlot, J., Magadza, C.H.D., Füssel, H.-M., Pittock, A.B., Rahman, A., Suarez, A. and van Ypersele, J.-P. (2009) 'Assessing dangerous climate change through an update of the Intergovernmental Panel on Climate Change (IPCC) "reasons for concern"', *PNAS* 106: 4133–4137, Figure 1, p. 4134. www.pnas.org/content/106/11/4133.full.pdf

10 Hawkins, E. (2017) 'Climate spirals' (animated GIF). *Climate Lab Book.* www.climate-lab-book.ac.uk/spirals

11 Ibid.

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About Future Climate for Africa

Future Climate for Africa (FCFA) aims to generate fundamentally new climate science focused on Africa, and to ensure that this science has an impact on human development across the continent. This guide was written by members of the UMFULA research team: Declan Conway, Katharine Vincent, Sam Grainger, Emma Archer van Garderen and Joanna Pardoe. You can find out more about their work under 'research teams' on www.futureclimateafrica.org

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