Earth Systems and Climate Change Hub

National Environmental Science Programme

Delving deeper into Australia’s national climate model: The Australian Community Climate and Earth System Simulator (ACCESS)

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March 2020

Earth Systems and Climate Change Hub Report No.12

Australian Government

National Environmental Science Programme

The Earth Systems and Climate Change Hub is supported by funding through the Australian Government's National Environmental Science Program. The Hub is hosted by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), and is a partnership CSIRO, Bureau of Meteorology, Australian National University, Monash University, University of Melbourne, University of New South Wales and University of Tasmania. The role of the Hub is to ensure that Australia's policies and management decisions are effectively informed by Earth systems and climate change science, now and into the future. For more information visit www.nespclimate.com.au.

Citation

Rashid HA, 2020. *Delving deeper into Australia's national climate model: the Australian Community Climate and Earth System Simulator (ACCESS)*, Earth Systems and Climate Change Hub Report No. 12. Earth Systems and Climate Change Hub, Australia.

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Published in March 2020

This report is available for download from the Earth Systems and Climate Change Hub website at www.nespclimate.com.au.

Contents

REPORT SUMMARY

The Australian Community Climate and Earth System Simulator (ACCESS) is Australia's national weather and climate model, developed through a collaboration between CSIRO, the Bureau of Meteorology and Australian universities.

The Earth Systems and Climate Change Hub has supported improvements and application of ACCESS through *Project 2.5: Improving Australia's climate model (ACCESS)*, which ran from June 2016 to June 2019. The Hub continues to support ACCESS through the current *Project 5.1: ACCESS evaluation and application*.

While ACCESS is a state-of-the-science climate model, like other climate models, it experiences systematic errors (or biases) in its simulations of the climate. Project 2.5 undertook research to understand the sources of some of the prominent model biases, especially around tropical rainfall and convection. Researchers then worked to reduce or rectify these biases through refinements of the model's existing convection scheme, as well as designing a new convection scheme.

As a result of this research, Hub Project 2.5 has led to an improved version of ACCESS, resulting in better representation of tropical rainfall and convection processes in the model simulations. This provides greater confidence in the simulations of Australia's current and future climate, which will in turn better inform policy development and decision-making outcomes for Australian industries, sectors and across all levels of government.

For more information

Publications, reports, webinars, related information and a summary video of the research and outcomes from Hub Project 2.5 can be found on the project webpage < http://nespclimate.com.au/improving-access/>.

Publications and related information developed under the current Project 5.1 will be shared on the current Hub Project 5.1 webpage <http://nespclimate.com.au/access-evaluation-and-application-5-1/>.

1 Introducing Australia's national climate model (ACCESS)

The Australian Community Climate and Earth System Simulator (ACCESS) is a state-of-the-science comprehensive climate model developed through a collaboration between CSIRO, the Bureau of Meteorology and Australian universities.

Just as the Earth's climate system is the result of interactions between the atmosphere, oceans, land and sea ice (among others), ACCESS comprises atmosphere, ocean, land surface and sea-ice models that are 'coupled' to communicate the relevant information between them. Each component model numerically represents the physics of the respective climate sub-systems. The ACCESS coupled climate model also allows for the interactions *between* the climate sub-systems, and so produces more realistic simulations of the climate system.

Climate models represent the world in a series of three-dimensional grid cells. The smaller the grid cell, the higher the model resolution. Ideally, the higher the model resolution the better the model simulation should be. However, in practice, models cannot always be run at high resolutions due to the high computational costs. Modelling a complex system like the climate in fine detail takes a lot of computer time. For example, to simulate the climate over a 100-year period can take over half-a-million hours. Although in practise, this time is shortened by running the climate model on hundreds or thousands of computer processors on a supercomputer.

However, higher model resolution alone does not guarantee improved simulations for all variables and regions. This is because while the models represent the 'large-scale' (larger than the grid size) physics pretty accurately (such as those associated with synoptic weather systems, appearing as Highs and Lows on weather charts), uncertainties still remain in the representations of many weather and climate processes at the scales smaller than the grid size (the 'sub-grid' scale). To make matters more complicated, these sub-grid scale processes interact with the well-represented large-scale processes, making their accurate representations (or 'parametrisations') in climate models an important topic of research.

Thanks to decades of research, the representation of important small-scale climate processes in climate models, such as those associated with cloud, rain and temperature, has come a long way since their beginning in the sixties and seventies. These developments have made the state-of-the-science comprehensive climate models (such as ACCESS) a very useful tool to study weather and climate, as the models can now simulate the major climatic features with great realism. ACCESS is now ranked among the top performing international climate models participating in the Coupled Model Inter-comparison Project Phase 5 (CMIP5).

2 Improving ACCESS

Like all other climate models, ACCESS experiences systematic errors (or biases) in its simulation of the climate. Most of these errors arise from imperfections in the representation of sub-grid scale processes and their interactions with large-scale processes. The best ways to further improve the simulation performance of ACCESS are through continued development and improvement of representation of climate system physics in ACCESS, and through increasing the model's resolution.

What we did

With this in mind, the main objectives of research on ACCESS under the Earth Systems and Climate Change (ESCC) Hub Project *2.5: Improving Australia's climate model (ACCESS)* were to:

- undertake scientific research to understand the sources of some of the prominent model biases, focusing on errors in representing tropical rainfall and convection,
- rectify (or reduce) those biases through refinements of the model's existing convection scheme, as well as designing a new convection scheme.

2.1 Impacts of the improved ACCESS atmospheric model

Climate models such as ACCESS have become uniquely useful tools for studying climate variability and change. However, model development is a difficult process and progress comes at a slow pace. Despite being one of the top performing CMIP5 models, ACCESS still faces many challenges in realistically simulating some important features of the climate.

Research performed under Hub Project 2.5 has significantly enhanced our understanding of some of the biases within ACCESS and has reduced their severity to further improve the model's performance in tropical rainfall and circulation simulations.

The key benefits of this research include:

- Significantly advancing understanding of the causes of tropical rainfall errors in the ACCESS climate model.
- Improving simulations of tropical rainfall and intra-seasonal variability.
- Adoption of some of our model improvements by the UK Met Office for use in their climate model, which is used by many modelling groups around the world.
- Development of a new convection scheme and a new experimental framework for Single Column Models to study convection, which is expected to be used in an international model inter-comparison study.

As a result of research under this Hub project, the improved ACCESS model will enhance Australia's climate change science capability and contribute to future Climate Model Inter-comparison Project initiatives. This model will also contribute to all other ESCC Hub projects and many projects across the Australian climate change research community by providing improved climate simulations to underpin their research activities.

Model improvements made through this project enhance our confidence in Australian rainfall simulations in current and future climates. More reliable ACCESS model projections will ultimately lead to better informed policy development and decision-making outcomes for Australian industries, sectors and across all levels of government.

A high-level description of the various experiments performed by project researchers and the enhanced understanding, reduction in model errors, refinement of the convection scheme and development of a new convection scheme resulting from these experiments is provided below

2.2 ACCESS experiments performed in Hub Project 2.5

Model improvements through enhanced understanding

Rainfall in the real-world results from a complicated set of physical processes involving surface heating, upward motion and low-level convergence of moist air, and the condensation at the cooler middle to upper troposphere (part of the atmosphere extending up to a height of about 12 km). Many of these processes take place at spatial scales of a few kilometres, which are smaller than the model's horizontal grid spacing. There are also two-way couplings between these sub-grid scale processes and the large-scale processes resolved by the models. In order to simulate realistic rainfall and atmospheric circulations, the models mathematically represent these complicated processes and the associated interactions, as realistically as possible, in a part of the model code called the convection parametrisation scheme.

Under Hub Project 2.5, researchers have conducted experiments to understand the nature of ACCESS model biases in tropical rainfall, convection and cloud feedbacks. To identify and understand the sources of the biases, researchers compared model outputs with observational and reanalysis datasets (obtained by combining models with observations).

Understanding the source of rainfall bias over the Maritime Continent

The tropical Maritime Continent is the region between the Indian and Pacific Oceans including the archipelagos of Indonesia, Borneo, New Guinea, the Philippine Islands, the Malay Peninsula, and the surrounding seas. The Maritime Continent region, surrounded by the warmest sea-surface areas, experiences some of the heaviest rainfalls in the world and is an important energy source for global weather, including that in Australia. It is therefore critical that ACCESS simulates realistic rainfall amounts in the Maritime Continent region.

However, like many other climate models, the ACCESS atmospheric model shows a dry bias over the Maritime Continent region. This means that the ACCESS simulated rainfall amount is lower than the observed amount there. To understand the causes of this rainfall bias, two model experiments with different horizontal resolutions (with 135 km and 60 km grid spacing) were performed and analysed. It was found that the Maritime Continent dry rainfall bias was significantly reduced in the high-resolution model experiment.

A further experiment with the model confirmed that about half of the increased rainfall in the high-resolution model occurred due to a more realistic representation of the surface elevation associated with mountains in this model. This highlights the importance of increased horizontal resolution in realistic simulations of rainfall.

Understanding the sensitivity of cloud feedbacks to small changes in cloud parameters

Cloud feedback is an important climate process which determines the net changes in the radiative energy input (positive or negative) to the climate system resulting from the cloud response to global warming. This is closely related to climate sensitivity, which is the amount of warming in the atmosphere due to a doubling of the concentration of carbon dioxide from its pre-industrial value.

Uncertainty in the knowledge of cloud feedback has been the largest source of uncertainty in climate projections made by comprehensive climate models. To understand the sensitivity of cloud feedback (and hence climate sensitivity) to small changes in cloud parameters (numerical values representing the magnitudes of cloud processes), Hub researchers have conducted experiments with a version of the ACCESS atmospheric model. Their results show that the model’s cloud rapid response and feedback are not significantly affected by modest changes in ACCESS’s cloud parameters. This is an important finding, as small cloud parameter changes or ‘tuning’ are a common practice of model development, and so it confirms that this tuning process doesn’t significantly impact the model’s projections of future climate.

Refining the existing convection scheme and developing a new scheme

Guided by the enhanced understanding of model biases, Hub researchers have corrected some of the shortcomings of the existing convection scheme and developed an entirely new convection scheme. They tested the new scheme in the single-column model version of ACCESS. Single-column models are a useful model development tool in which a full-blown climate model is reduced to a vertical column over a single grid cell. The single-column models are particularly useful for testing the results of changes in physics parametrisation schemes or implementing new schemes. As a result of this research, the ACCESS model’s simulations of tropical rainfall, convection and intra-seasonal variability (with time periods between 30-90 days) are now much improved and better match the relevant real-world observations.

Implementing the modified melting-layer physics

The ACCESS atmospheric model simulations also showed a narrow cooling and drying spike at the freezing-level of the atmosphere. This incorrect feature, arising from convection parametrisation, had previously been overlooked in the broader modelling community. One solution to this was to allow a mix of liquid and frozen precipitation across a certain depth of the model’s vertical layers. Hub researchers implemented this change in the ACCESS atmospheric model’s convection scheme and found that the rainfall bias in the tropics was significantly reduced as a result, and the model’s representation of the most important mode of tropical intra-seasonal variability (the Madden-Julian Oscillation, MJO) was also improved.

Implementing the convective memory scheme

A further modification to the ACCESS model's convection scheme was made by introducing what is called 'convective memory' to improve the coupling between model convection and the large-scale dynamics. Introduction of the convective memory scheme improved the model's diurnal cycle of convection. It also significantly reduced the magnitude of the rainfall dry bias over the Maritime Continent. However, the impact on the MJO simulation is negative, probably due to the change of the coupling between convection and large-scale dynamics, and over-supressing of shallow convection over the Tropical warm ocean. To overcome the problem with shallow convection, Hub researchers made some further changes to the trigger of convection so that the shallow convection can be easily triggered over the warm Tropical oceans. As a result, the modelled MJO is improved due to the enhanced pre-moistening associated with shallow convection for the intense rainfall events.

Designing a new stochastic multi-cloud model (SMCM)

Climate models perform simulations by time marching the climate state over many short time steps (~20-30 minutes), a process called time integration. A common limitation of model simulated rainfall is the on-off behaviour of convection (at the time-step level) and the associated large peaks in instantaneous rain rates.

To address this limitation, a new convection scheme, the stochastic multi-cloud model (SMCM), was implemented in the single-column version of the ACCESS atmospheric model. Single-column model simulations (with the new and existing convection schemes) were performed and compared with observations collected during the Tropical Warm Pool International Cloud Experiment (Darwin, Jan-Feb 2006). The result shows that the on-off behaviour of convection is largely eliminated due to the SMCM closure, and the associated extreme rain rates have been moderated. The latter allowed for the development of some persistent large-scale precipitation during the organised convective event observed on the 23rd January 2006. The mitigation of the on-off behaviour is related to a decrease in the convective mass flux, which prevents convection from over-stabilising the environment in a single time step, which is a known issue with the existing scheme in ACCESS.

3 Next steps in improving ACCESS

While Hub Project 2.5 was completed at the end of June 2019, further research to evaluate and apply ACCESS climate simulations is being conducted under the current Hub *Project 5.1: ACCESS evaluation and application* <http://nespclimate.com.au/access-evaluation-and-application-5-1/>.

The focus of this current project is on enhancing the utility of ACCESS by using multiple versions of ACCESS to develop multiple model runs (called ‘ensembles’) of past and future climates. This will result in the provision of better estimates of changes in future extreme rainfall and temperature over Australia.

Glossary

ACCESS	Australian Community Climate and Earth System Simulator
CMIP	Coupled Model Inter-comparison Project
MJO	Madden-Julian Oscillation
SMCM	Stochastic multi-cloud model

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