Assessment of surface solar radiation projections in Australia

Lea Wollensack, u5866405

Supervisor: Nicholas Engerer

The Australian National University

Fenner School of Environment & Society

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SUMMARY

This Independent Research Projects assesses the change in surface solar radiation for the 20-year time periods 2020-2040 and 2040-2060 compared to the baseline period 1990-2010. In order to do so, the Climate + Weather Science Laboratory is used as a tool to generate maps for surface solar radiation and total cloud amount from the simulation data output generated by the ACCESS1.0 and ACCESS1.3 models. The Relative Concentration Pathways RCP4.5 and RCP8.5 are considered. The ACCESS models were among Australia’s contribution for the Climate Model Intercomparison Project 5 used in the latest assessment report by the Intergovernmental Panel on Climate Change. Concluding that there will be no significant change in surface solar radiation in the future, the limitations and challenges of climate models are discussed, namely both temporal and spatial resolution and model skill.

LIST OF ABBREVIATIONS

AOGCM: Atmosphere-Ocean General Circulation Model

AR: Assessment Report

BOM: Bureau of Meteorology

CCIA: Climate Change in Australia

CLT: Total Cloud Amount

CMIP5: Climate Model Intercomparison Project 5

CNN: Cloud Condensation Nuclei

CSIRO: Commonwealth Scientific and Industrial Research Organisation

CWSlab: Climate + Weather Science Laboratory

ENSO: El Niño Southern Oscillation

ESM: Earth System Model

GCM: Global Circulation Model

GHG: Greenhouse gas

IPCC: Intergovernmental Panel on Climate Change

PET: Potential Evapotranspiration

RCP: Relative Concentration Pathway

RSDS: Short-wave radiation down at surface

SSR: Surface Solar Radiation

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1. INTRODUCTION

Climate change is a global issue affecting Australia: the continent has been warming and this trend will continue substantially over the 21st century (CSIRO & BOM 2015).

To avoid the further emission of greenhouse gases (GHG) and to mitigate global warming, renewable energy technologies like solar power will be needed. This report will focus on Australia, where the solar industry has a high potential. It will look at the amount of sunlight that reaches the earth’s surface (surface solar radiation) which is essential for solar power production. This leads to my research question:

Do climate models project a significant change in surface solar radiation in Australia from 2020 to 2040 and from 2040 to 2060 compared to a current baseline?

This question is important for the solar industry: The gained knowledge might remove the uncertainty from investment within the different climate change scenarios. This report assesses three distinctive time spans of 20 years, with a special focus on seasons.

1.1 Hypothesis and assumptions

Hypothesis: There will be little change in surface solar radiation in Australia for the future.

In the near future (2030), it is projected with high confidence that Australia will experience little change in surface solar radiation (CSIRO & BOM 2015). There is only medium confidence on the fact that there will be more sunshine in winter and spring in Southern Australia. Hypothesizing that this will also be shown in the model output, I expect the conclusion that solar power will remain to have a huge potential in Australia even under climate change conditions.

Assumption: Climate models are a useful tool to evaluate future changes in surface solar radiation in respect to solar energy production.

In order to conduct this research project, it is assumed that climate models are a useful tool to assess future changes in solar radiation and that this assessment will be useful for the solar industry.

2. BACKGROUND

2.1 Solar radiation and climate change

The sun is the driver of the earth's climate system. Incoming solar radiation is either reflected by clouds, absorbed or scattered by the atmosphere (see Figure 1). Shortwave radiation that reaches the earth's surface directly is called beam radiation. The surface re-emits the absorbed solar energy as longwave radiation, which is again absorbed, re-emitted and reflected by gases and particles in the atmosphere. If the incoming solar radiation is scattered and its direction has been changed, this is called diffuse radiation. The total solar radiation received on a surface is the sum of beam and diffuse radiation.

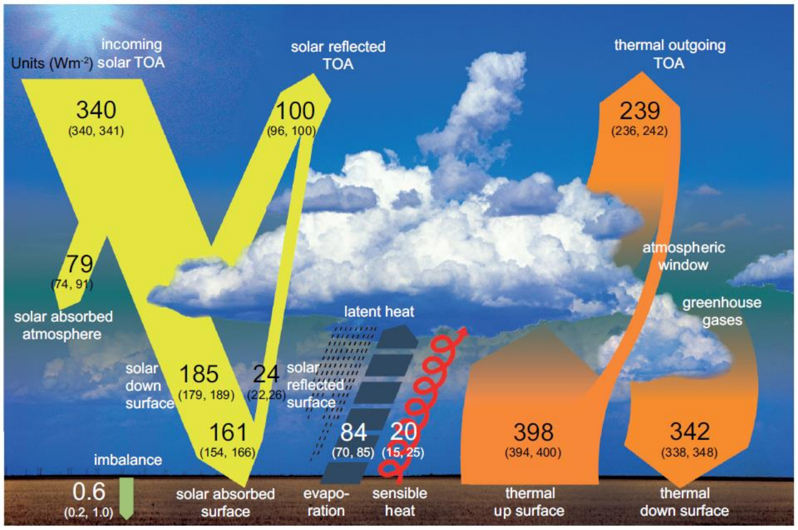

Figure 1: Global energy budget (Hartmann et al. 2013: Figure 2.11).

The amount of sunlight that reaches the earth's surface is called surface solar radiation (SSR). At land-based sites, SSR underwent changes in the past: there was dimming from the 1950s until the 1980s, followed by increases (Hartmann et al. 2013).

SSR variations come from changes in the transparency of the atmosphere, which is determined by the presence of clouds, aerosols and radiatively active gases (Hartmann et al. 2013). These are three of the six main drivers of climate change, among natural fluctuations in the sun's output, ozone, and surface albedo changes. While the sun is external to the earth's climate system, the other five global climate drivers are coupled by feedbacks (Cubasch et al. 2013).

Alterations in cloud cover explain the SSR variations throughout the year. On longer timescales, cloud cover cannot explain the SSR trends, which points to an important role of atmospheric aerosols. They scatter and absorb solar radiation and they act as cloud condensation nuclei, impacting cloud reflectivity and lifetime (Boucher et al. 2013).

2.2 Climate change in Australia

For Australia, average surface air temperature has been warming 0.9°C since 1910, and anomalously warm months were more frequent than anomalously cold months (CSIRO & BOM 2015). The mean, daily minimum and daily maximum temperatures are projected to increase in all of Australia with very high confidence.

In Eastern Australia, the mean, maximum and minimum temperature increase will be continued in all seasons with very high confidence (CCIA 2007-2015b). There is medium confidence about projected decreasing average rainfall in winter and spring for the East Coast, while confidence about precipitation decrease in winter and spring in the inland is high. There is high uncertainty about changing seasonal rainfall patterns because there is a high difference between Global Circulation Models (GCMs) and downscaling approaches. The reason for this could be that there are different drivers for precipitation: for example at the East Coast, the coastline plays a major role which is difficult to simulate.

For all seasons, relative humidity is projected to decline while potential evapotranspiration (PET) will increase. Warming temperatures and an increased PET point to potentially more clouds because of a higher availability of moisture in the air. At the same time, a decline in RH and rainfall indicate the opposite, reducing the atmosphere's moisture.

2.3 Climate Models

In order to understand the climate system and project its changes under the influence of anthropogenic greenhouse gas emissions, climate models are used. They are a numerical simulation of the climate system, based on mathematical equations and run on super computers (Park & Allaby 2013; CCIA 2007-2015a). This mathematical representation is derived from our knowledge of the physical and chemical interactions between the climate system's components (atmosphere, ocean, land surface and cryosphere). It is challenging to develop these Earth System Models (ESMs) because of scale issues: most processes that govern the Earth's climate operate on different temporal and spatial scales and they interact with each other on different temporal and spatial scales, ranging from a few meters and seconds to thousands of kilometers and years, see Figure 2 (CCIA 2007-2015a). Global climate models used for decadal-to-century long projections thus aim to incorporate as many small-scale and short-term processes as possible. Global climate models have a limited spatial and temporal scale (about 200km and 30 minutes up to 3 hours), which means that processes that happen on shorter time scales and smaller spatial scales must be parameterised.

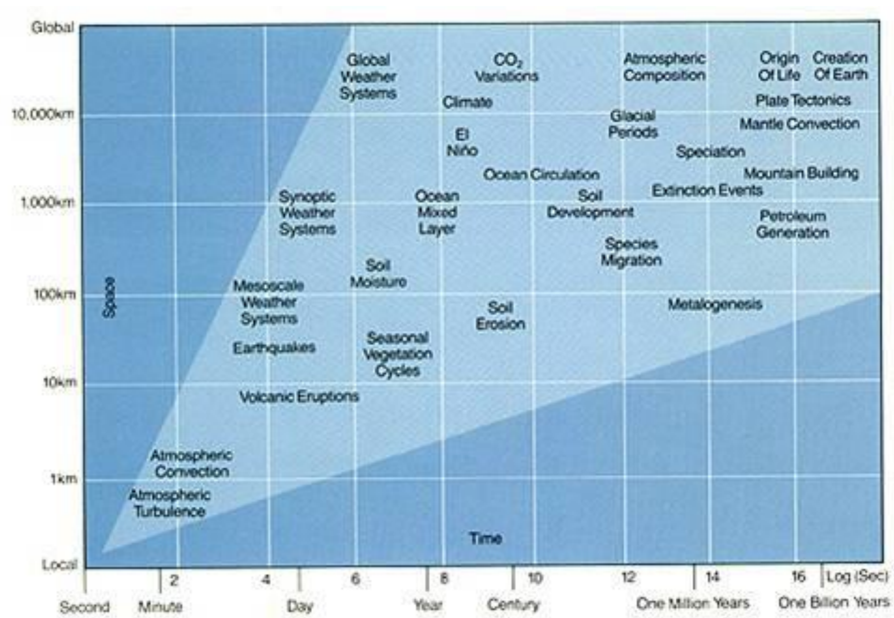

Figure 2: Different Earth system processes and their temporal and spatial scale (CCIA 2007-2015a).

The Intergovernmental Panel on Climate Change (IPCC) is an international body reviewing and assessing the latest climate science. For its Fifth Assessment Report (AR5) climate models from the Climate Model Intercomparison Project 5 (CMIP5) were used.

CMIP5-generation models are either Atmosphere-Ocean General Circulation Models (AOGCMs) or Earth System Models (ESMs). AOGCMs are made to understand the physical dynamics of the climate system, namely the atmosphere, ocean, and land and sea ice. They are also used to make future projections based on aerosol and GHG forcing (Flato et al. 2013). ESMs are AOGCMs which have biogeochemical cycles added into their system.

3. METHODS

3.1 Climate + Weather Science Laboratory

For this Independent Research Project, access could be gained to the Climate + Weather Science Laboratory (CWSlab) (BOM 2015). The CWSlab was developed by the Bureau of Meteorology, CSIRO and the National Computational Infrastructure to facilitate collaboration and information-sharing among Australian weather and climate researchers. It is a virtual laboratory which provides access to climate modelling software products and analysis and visualisation tools. The CWSlab is the main platform for accessing, analysing and visualising the data from the ACCESS models for this research project (see Figure 3). For more information on the CWSlab, please visit http://nectar.org.au/labs/climate-and-weather-science-laboratory/ .

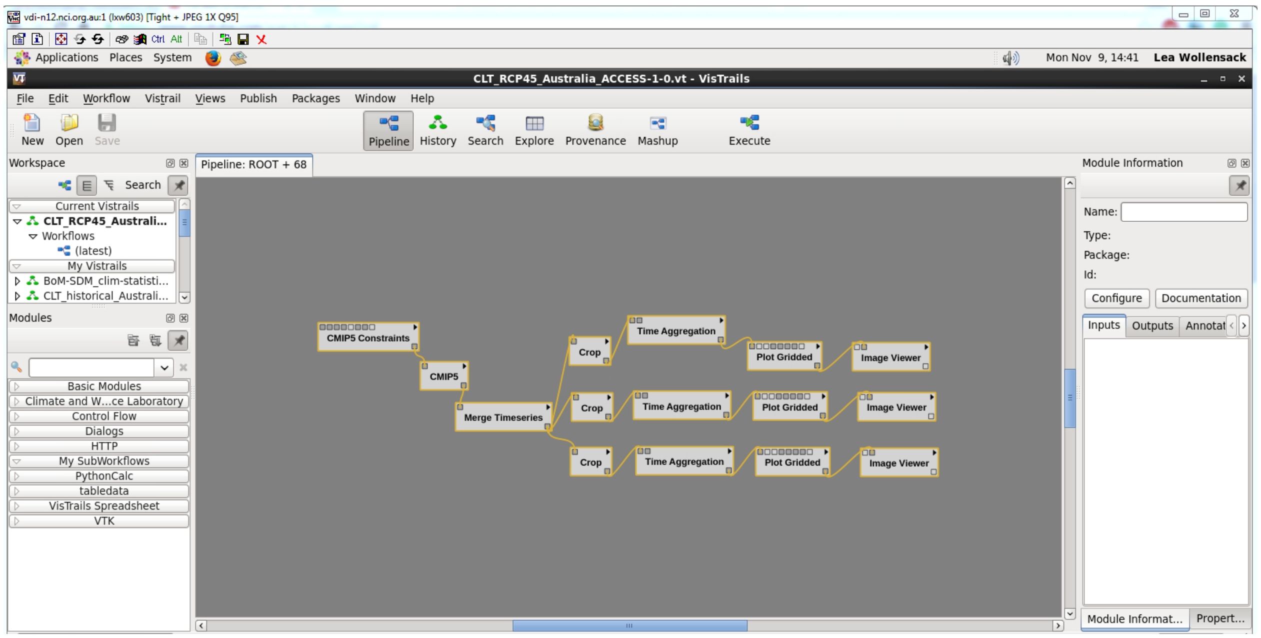

Figure 3: The CWSlab platform.

3.2 ACCESS models

Australia contributed to CMIP5 with three different models: ACCESS1.0, ACCESS1.3, and CSIRO-Mk3.6.0 (Flato et al. 2013: Table 9.1). For this Independent Research Project, access to both ACCESS model data could be gained which is why these two models will be assessed. They are AOGCMs with intermediate resolution atmosphere and ocean components and an added fully interactive aerosol component. The two ACCESS models share essentially the same ocean and sea ice components but they differ in their land surface and atmospheric components (CSIRO 2014). A very important difference between ACCESS1.0 and ACCESS1.3 is their parameterisation, and their atmosphere and land surface components (Bi et al. 2013). While both the ACCESS1.0 and ACCESS1.3 model have principally the same atmospheric configuration, their physical parameterisations differ. This means that small scale physical processes on short time scales regarding clouds are represented differently in the two models. ACCESS1.0 uses a diagnostic cloud scheme developed by Smith (1990), and ACCESS1.3 uses a modified radiation scheme which includes the ‘Tripleclouds’ scheme developed by Shonk and Hogan (2008) (Bi et al. 2013). This scheme represents horizontal inhomogeneity in clouds. The location and frequency of clouds modulate both regional and global climate. They are particularly interesting for this research project because they interact with incoming solar radiation. A different approach to cloud modelling might lead to different outcomes in surface solar radiation.

The ACCESS models have a horizontal resolution of 1.25° latitude by 1.875° longitude and 38 vertical levels (Bi et al. 2013). This corresponds to ~40km height, and a spatial resolution of about 208 km x 139 km at the Equator and 120 km x 139 km at 55° latitude (Met Office 2014).

3.3 Time periods

The annual seasonal mean of daily solar radiation (rsds) and total cloud amount (clt) is assessed for three distinct time periods: 01/01/1990 – 31/12/2010, 01/01/2020 – 31/12/2040, and 01/01/2040 – 31/12/2060. 20-year periods are chosen because they are also used by the IPCC to analyse trends and changes in climate. A second reason for 20-year time periods is that the projections by climate models are made for decadal-to-century long timespans (CCIA 2007-2015a), which implies that it would not be meaningful to analyse shorter timespans.

3.4 Relative Concentration Pathways

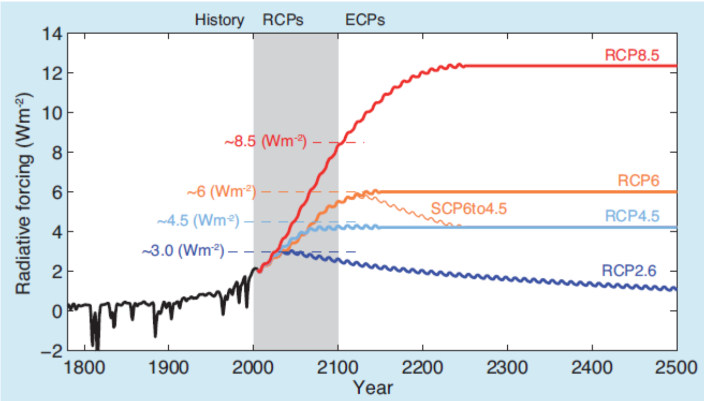

Figure 4: Relative Concentration Pathways (Cubasch et al. 2013: Box 1.1: Figure 1).

The IPCC uses Relative Concentration Pathways (RCPs) in AR5 (see Figure 4). There are four RCPs, listed in the order of magnitude of radiative forcing: RCP2.6, RCP4.5, RCP6, and RCP8.5. These four scenarios are defined by their radiative forcing peak or stabilization value by the end of the 21st century (Cubasch et al. 2013).

Simulation based on historical data is compared to the RCP4.5 and RCP8.5 for the first 20-year time period. For the projected time periods, RCP4.5 and RCO8.5 are compared. RCP8.5 translates to a high radiative forcing coming from high CO_2 emissions, while RCP4.5 contains an intermediate radiative forcing and thus intermediate GHG emissions. These two RCPs are chosen to assess moderate and extreme scenario and their consequences on surface solar radiation.

For the time period 1990-2010 I also looked at historical simulations from the two ACCESS models. Historical simulations are initialised in 1850 and are then run with prescribed forcings (both anthropogenic and natural) to simulate the climate of the past as well as possible (CCIA 2007-2015a). However, historical simulations do not represent weather and climate accurately from year to year. The goal of historical simulations is rather to tune the climate models in order to reproduce long-term climate statistics and averages.

3.5 Variables

Based on physical parameterisations and governed by a numerical representation of the climate system, the global climate models calculate the different variables for each time step (CCIA 2007-2015a). For each model step, a new state of the Earth's atmosphere and ocean is calculated, and this state is then used as the initial state for calculating the next time step. One could say that for each time step, the model reproduces the global energy budget (see Figure 1).

Solar radiation: I analysed the surface down-welling shortwave flux in air, in other words the shortwave radiation down at surface, which represents the surface solar radiation in the models.

Total cloud amount: Looking at the Earth's radiation budget (Figure 1), a substantial amount of incoming solar radiation is reflected back into space by clouds, precisely 100 out of 340 W/m^-2. Also, changing cloud cover explains SSR alterations over the year. This is why I analysed the total cloud amount, represented as percentages. Unfortunately, this variable only informs us about the total amount of clouds present, but not their type. High, thin clouds are transparent to incoming solar radiation while they reflect outgoing longwave radiation back to Earth and contribute to greenhouse warming (Graham 1999; Kump et al. 2010). On the other hand, low, thick clouds primarily reflect incoming solar radiation and thus impact the amount of surface solar radiation substantially.

4. LIMITATIONS

4.1 CWSlab as a tool

The CWSlab is a relatively new tool for climate research in Australia. Documentation is limited due to the virtual laboratory's novelty. There is a Wiki for the CWSlab on the platform GitHub, including instructions for set-up and a tutorial for a sample workflow (GitHub 2014). Further sample workflows can be downloaded from the site. Additionally, there is a Gitter room for getting help and asking questions (Gitter 2015). Apart from that, I found documentation rather sparse, especially when building new workflows. It was often not clear to me which information and variables I could put into the modules. For example for the CMIP5 Constraints Module, I had to consult other sources to know which variables (like total cloud amount and surface solar radiation) I could use for the models (see Figure 5).

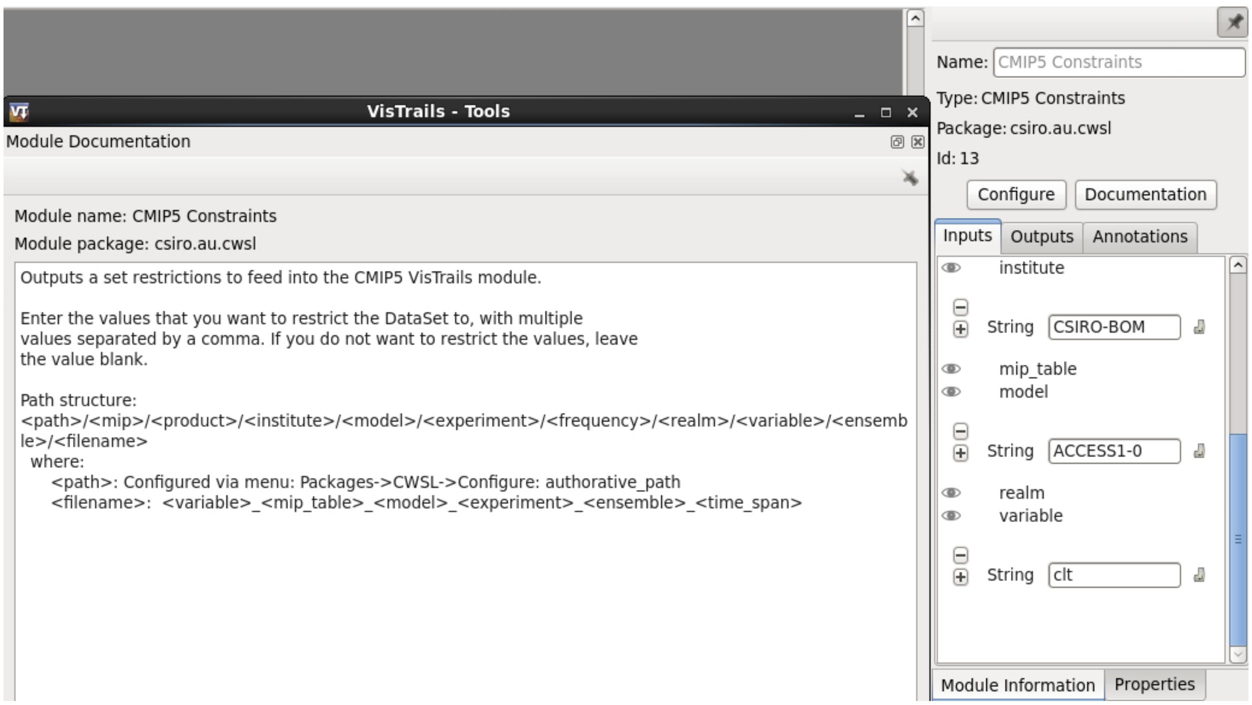

Figure 5: Sparse documentation on the CMIP5 Constraints Module.

Furthermore, the CWSlab only provides limited options for analysis. It might be that I did not discover all analysis options the laboratory supplies due to missing documentation and limited time for learning to navigate the tool. Potentially, there would be further analysis options if I would add modules and components programmed by myself. However, this would go beyond the scope of an Independent Research Project.

The CWSlab gave me a useful tool to visualise climate model outputs in maps. Because this is a qualitative tool for beginners, I also conducted a qualitative analysis.

4.2 Climate models

4.2.1 Resolution

Both ACCESS models are general circulation models. They have a spatial resolution of about 120km x 140km. While they might include some synoptic scale meteorological features, they do not simulate local climate phenomena. For example, mesoscale weather systems happen on a spatial scale of about 100km and a temporal scale of hours to days (see Figure 2). This means that the ACCESS models are only able to simulate mesoscale weather processes on a limited extent if at all, and these weather systems would mostly be represented by parameterisations. However, for the solar industry it is crucial to know what will happen to climate on a local scale because solar farms will be installed in one specific place. For example meteorological phenomena like orographic lifting or sea breeze will not be represented in global circulation models, nevertheless they could influence local climate substantially. Especially small-scale processes like atmospheric convection and turbulence are not simulated by general circulation models.

Furthermore, temporal resolution is limited. Climate models do not meticulously forecast the climate of each year. In fact, they are a tool to analyse long-term climate statistics and averages. To sum up, climate model outputs are useful to evaluate trends. But I would recommend against using them as a management or planning tool for the solar industry.

4.2.2 Model skill

Climate models have been improved and extended since the last IPCC Assessment Report. Global climate models successfully reproduce major climate systems affecting Australia (CSIRO & BOM 2015). For example, global climate models capture broad-scale temperature, rainfall and surface wind well over Australia, while they show deficiencies in simulating finer details around pronounced topography and coastlines. Other remaining challenges include the simulation of clouds (Flato et al. 2013), the El Niño Southern Oscillation (ENSO) and resulting teleconnections to Australian rainfall, and the monsoon (CSIRO & BOM 2015). The IPCC reports biases in cloud simulations which lead to regional errors of the cloud radiative effect (Flato et al. 2013). This could affect the correct simulation of SSR.

A climate model's skill is evaluated by comparing model output for the present climate to observations and then a skill score is derived from this comparison. There are standardised inter-comparisons between models and observations for CMIP5. Among the CMIP5 models, ACCESS1.0 scores the highest overall skill (727) for the full Australian region (CSIRO & BOM 2015). ACCESS1.3 has a skill score of 691 for Australia, and 463 for Eastern Australia. ACCESS1.3 scores 514 compared to 640 of the CMIP5 top model for the Eastern Australia region. This means that the ACCESS models are highly skilled relative to other CMIP5 models. However, it is important to note that a perfect skill would be represented by 1000.

Regarding the simulation of solar radiation (rsds: surface down-welling shortwave flux in air), the ACCESS1.0 and ACCESS1.3 models score a skill of 604 and 606 respectively, compared to a top result of 812 (CSIRO & BOM 2015: Table, 5.2.4). This indicates a relatively high level of skill for simulating incoming solar radiation. The report did not directly assess the models' skill score for clouds, however the score for modelling rainfall (pr: precipitation) is indicated: ACCESS1.0 scores 552 while ACCESS1.3 is slightly less skilled with 544, compared to a maximum skill of 701. This indicates that both models might struggle with simulating clouds.

Box: The cloud feedback

Clouds are critically important for the climate system and climate change (Boucher et al. 2013). The **cloud feedback** is likely to be positive. Scientists are uncertain about its sign and magnitude because there exists a continuing uncertainty on how warming impacts low clouds. Cloud changes can lead to reflective cooling as well as greenhouse warming effects.

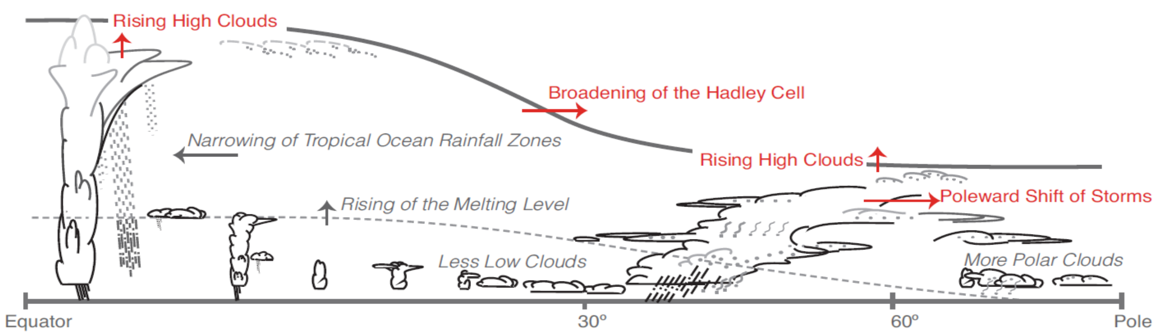

Figure Box 1: Cloud responses to greenhouse warming (Boucher et al. 2013: 592).

The figure shows how clouds respond to greenhouse warming; robust positive feedbacks are in red while uncertain or small feedbacks are indicated grey. In the tropics high clouds rise as troposphere deepens. Consequently, the difference between the high cloud top and the surface temperature grows. Also, high clouds trap infrared radiation more effectively which leads to further warming of the surface. In the mid-latitudes, mid- and low-level clouds are reduced, storm tracks migrate poleward, and rainfall zones like the Intertropical Convergence Zone are reduced. Because less sunlight is now reflected back to space by clouds, this contributes to an increased surface warming.

Most climate models do not resolve nor parameterize cloud regimes particularly well (Boucher et al. 2013).

5. ANALYSIS & RESULTS

5.1 General patterns

When looking at the historical simulations for 1990-2010, some general patterns can be identified. First of all, general circulation patterns are represented in the patterns of solar radiation shown by the models.

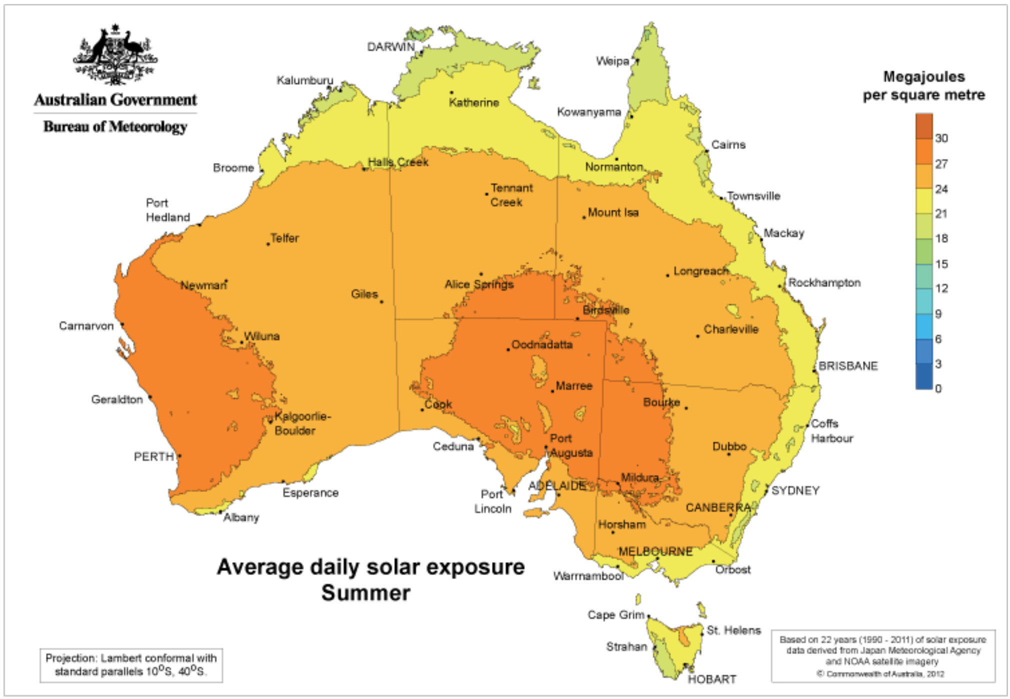

Figure 6: Average daily solar exposure in summer (BOM 2013).

I use average daily solar exposure maps from the Bureau of Meteorology to compare the climate model output to observations. They have a different unit (MJ/m^2) than the generated maps but are still useful to analyse patterns qualitatively. However, I advise against numerical comparisons.

In **summer**, one can observe high surface solar radiation over central and Western Australia. One major difference between the models is that ACCES1.0 models two patches of high SSR amounts, one at the west coast and one in southern Australia, while ACCESS1.3 shows a continuous patch. ACCESS1.0 is thus closer to observations when one compares Table 1 to Figure 6. Interestingly, this difference in pattern is not reproduced by the maps showing total cloud amount.

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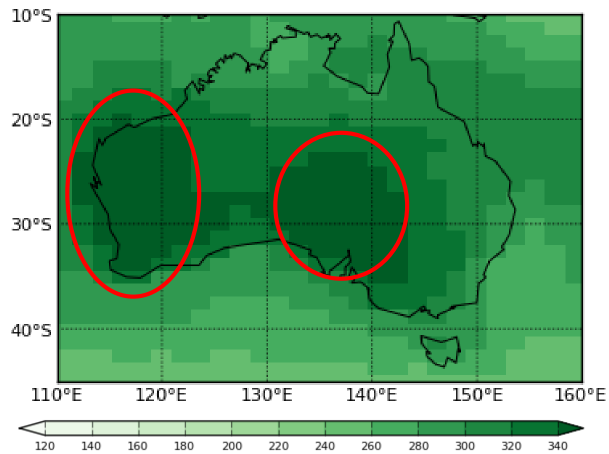
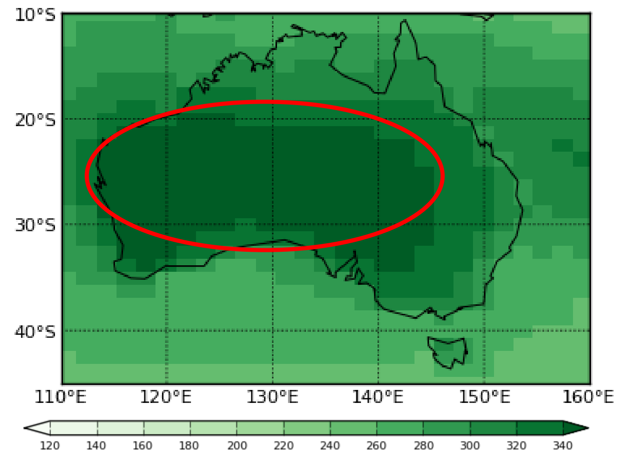


Surface solar radiation [W/m²]</td><td>


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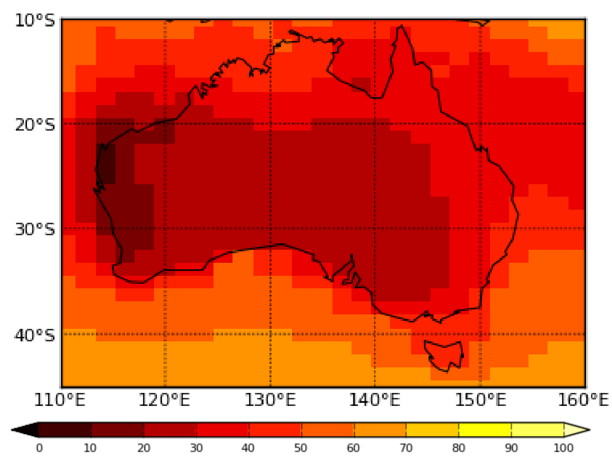
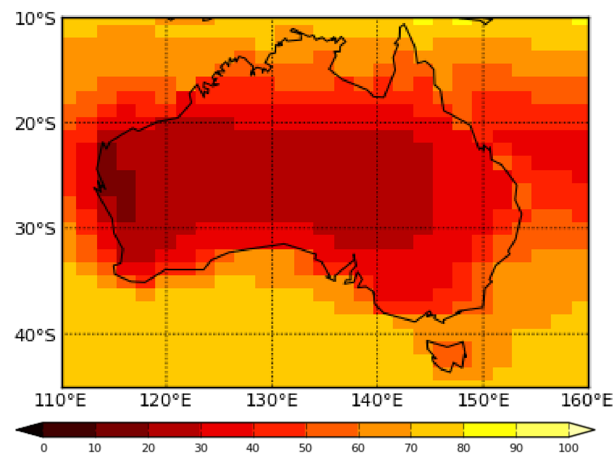


Total cloud amount [%]</td><td>


Total cloud amount [%]</td></tr>
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Table 1: 1990-2010 Historical simulation summer.

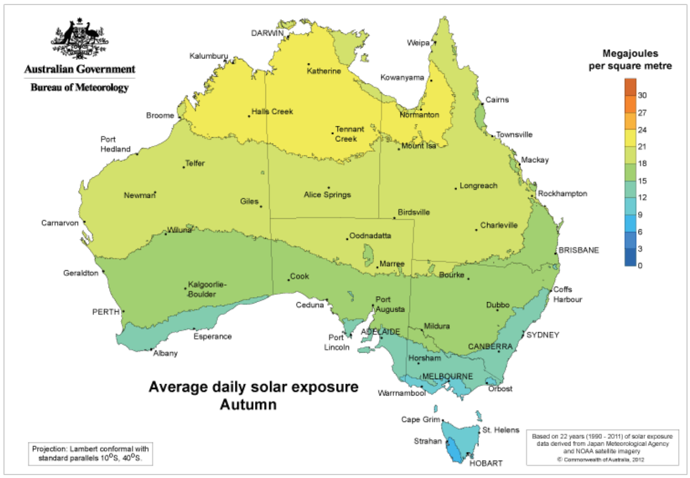

Figure 7: Average daily solar exposure in autumn (BOM 2013).

In **autumn**, surface solar radiation is generally lower than in summer. Both models manage to reproduce the surface solar radiation patterns well compared to observations (Figure 7). The major difference being that ACCESS1.0 models higher radiation amounts for northwestern Australia than ACCESS1.3.

It is important to note the substantial difference in patterns for the cloud simulations. ACCESS1.0 tends to model lower total cloud amounts especially over the whole continent but also over ocean. Interestingly, this big difference in cloud simulation does not seem to influence the surface solar radiation.

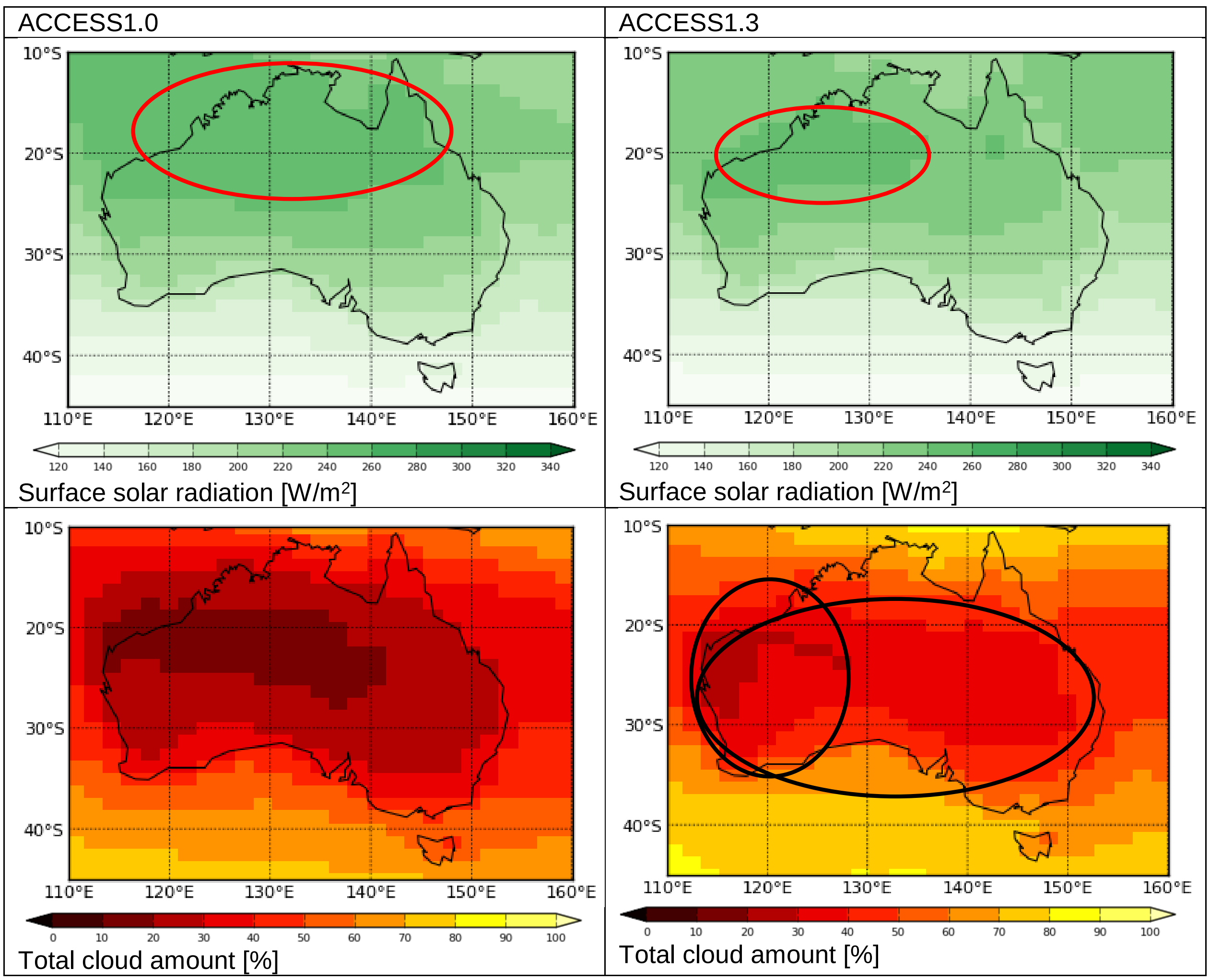

Table 2: 1990-2010 Historical simulation autumn.

In **winter**, the models show similar differences like in autumn. ACCESS1.0 tends to model higher surface solar radiation amounts for northeastern Australia. Again, both models capture the general patterns well. Like in autumn, the difference between cloud simulations is greater than for incoming solar radiation. What is interesting to observe is that ACCESS1.3 models high cloud amounts for southeastern Australia (up to 80%).

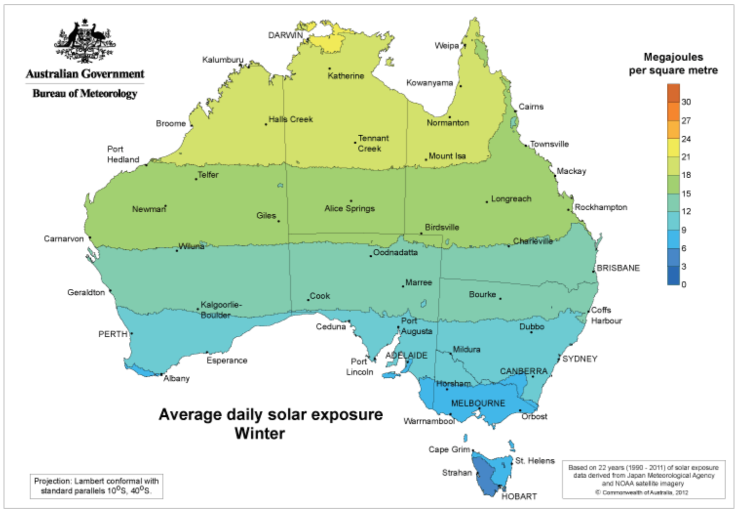

Figure 8: Average daily solar exposure in winter (BOM 2013).

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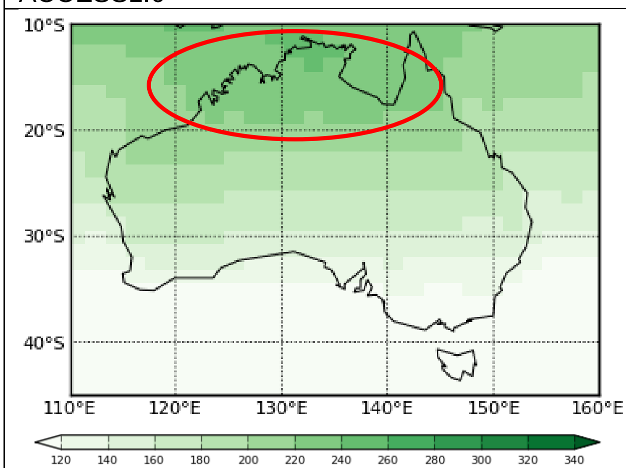
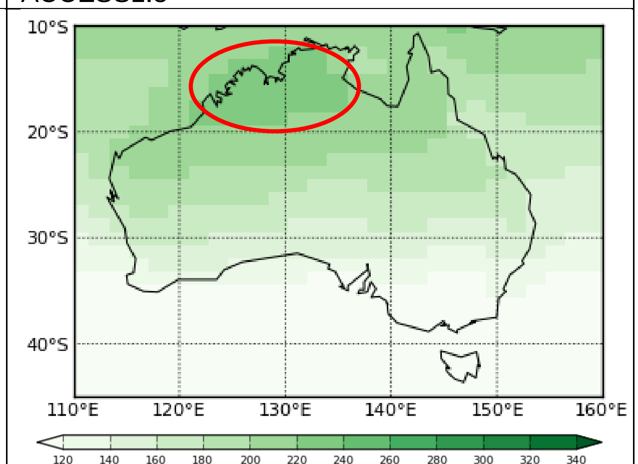
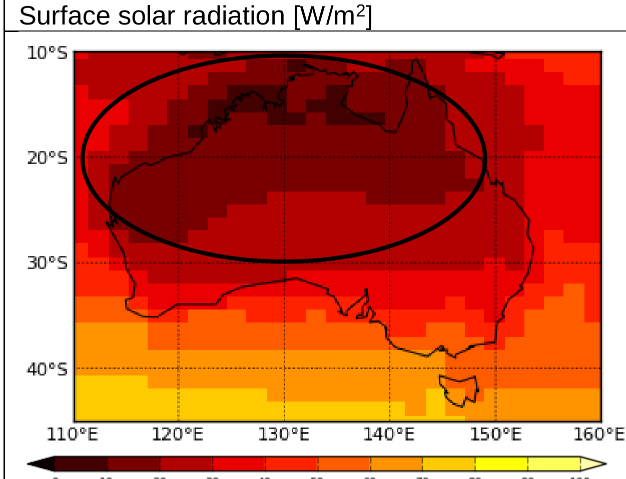
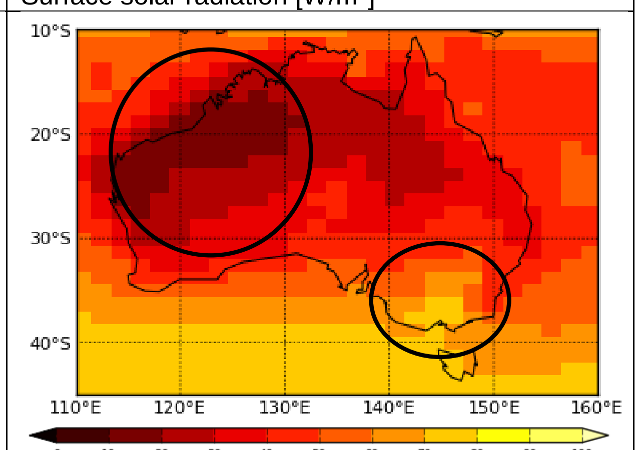
 Surface solar radiation [W/m²]	 Surface solar radiation [W/m²]
 Total cloud amount [%]	 Total cloud amount [%]

Table 3: 1990-2010 Historical simulation winter.

In **spring**, ACCESS1.0 only models higher incoming solar radiation at the surface for Western Australia while ACCESS1.3 does so for all of central Australia. It is important to note that ACCESS1.3 models lower SSR and a higher total cloud amount for the region around Darwin and the far northeastern coast. Because of this and the higher radiation amounts in central Australia it is closer to observations than ACCESS1.0.

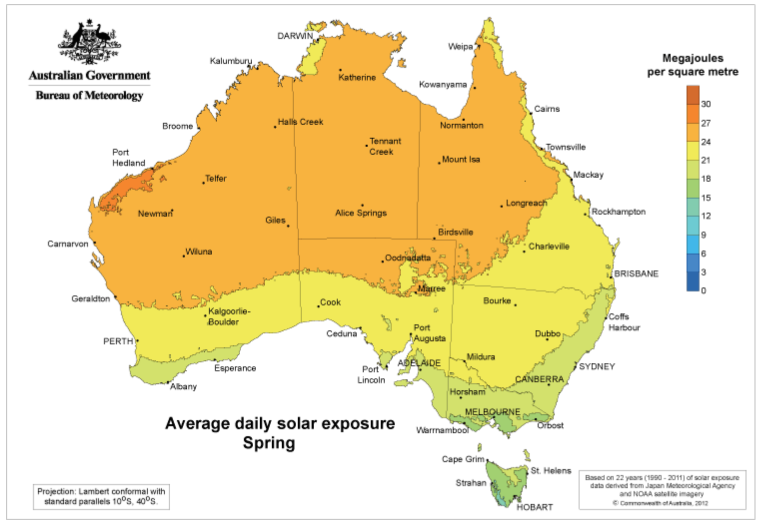


Figure 9: Average daily solar exposure in spring (BOM 2013).

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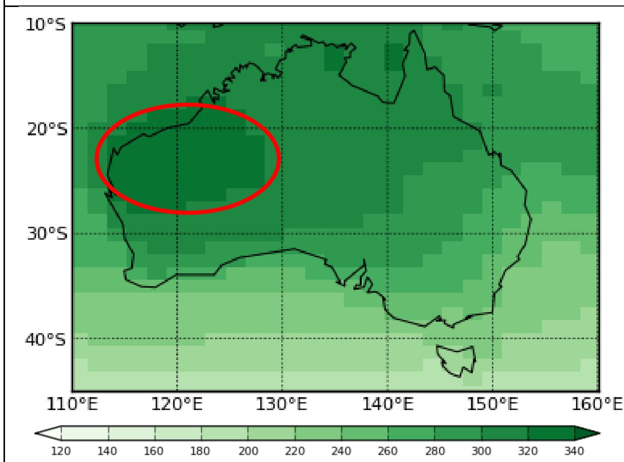
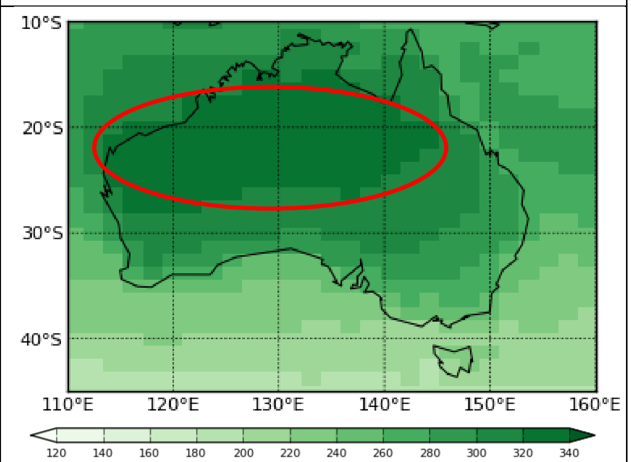
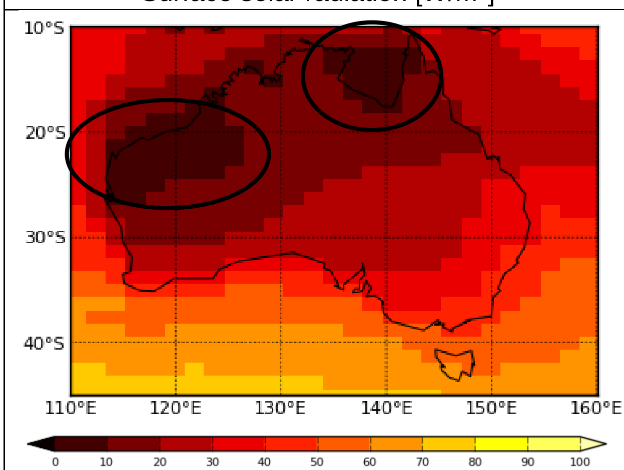
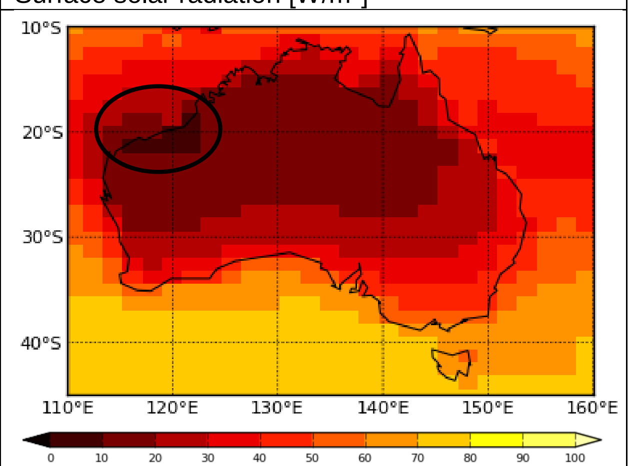
 Surface solar radiation [W/m^2]	 Surface solar radiation [W/m^2]
 Total cloud amount [%]	 Total cloud amount [%]

Table 4: 1990-2010 Historical simulation spring.

5.2 Australian climate influences

Australia's climate is influenced by the general circulation and both regional and local climate phenomena, see Figure 10 (BOM 2010).

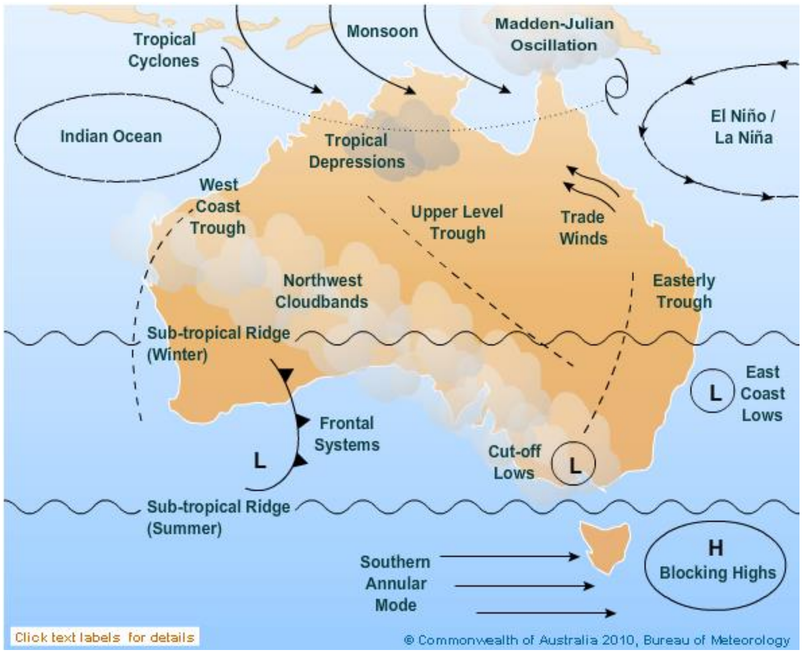


Figure 10: Australian climate influences (BOM 2010).

The ACCESS models are general circulation models which means that they simulate aspects of the general circulation. For Australia specifically this would be the subtropical ridge, the trade winds, and tropical cyclones. The subtropical ridge is south of Australia in summer which can be seen on the maps which show high surface solar radiation in southern Australia in summer (see Table 1). In winter the subtropical ridge is situated more northward over central Australia which is shown by higher surface solar radiation amounts over northern Australia in winter (see Table 3). The trade winds mostly affect northern and northerly parts of eastern Australia: they bring rainfall to the east coast and dry conditions to northern Australia. On the maps one can observe the influence of the trade winds with generally lower surface solar radiation and higher total cloud amounts along the east coast in all seasons. Tropical cyclones affect Australia's northerly coastal areas, especially in summer. On the maps, this can be seen by lower surface solar radiation rates at the north coast in summer, for example around Darwin (see Table 1).

Climate oscillations like the El Niño-Southern Oscillation, the Madden-Julian Oscillation, the Southern Annular Mode, and the Indian Ocean Dipole do affect Australia's climate. Because the climate oscillates between two distinctive phases this will not be shown on a map representing averages.

Challenges remain for climate models to simulate the monsoon which brings heavy precipitation to northern Australia in summer. While ACCES1.3 simulates very high total cloud amounts for northern Australia in summer (for example around Darwin), this is not as well reproduced by ACCESS1.0.

Influences that affect climate in southeastern Australia are east coast lows and the easterly trough. East coast lows are areas of intense low pressure which bring heavy rainfall and strong winds.

They are most common in autumn and winter. ACCESS1.3 shows significantly high total cloud amounts over southeastern Australia in winter (see Table 3) which could be related to east coast lows. However, if ACCESS1.0 simulates this weather phenomena needs to be determined. Easterly troughs on the other hand bring rainfall to eastern parts of central Australia in summer. I did observe lower surface solar radiation and higher total cloud amounts along the east coast for both models in summer. However, I am uncertain whether the ACCESS models simulate these comparatively short-lived climate phenomena or if they just show these patterns because they are related to the general atmospheric circulation.

On the west coast, west coast troughs can form during the warmer months of the year. When formed they are a dominant influence on the west coast weather. Because they can bring both hot days and thunderstorms I doubt that their influence is seen on the surface solar radiation and total cloud amount maps.

5.3 Looking at time periods separately

The above identified patterns and differences between models tend to be true for all simulations, regardless of scenario. For the time period of 1990-2010, there seem to be higher differences between models than between scenarios. Most differences between models and scenarios are seen in central and northern Australia and have been observed for summer and spring. One reason for that could be that there are many different climate influences active in summer.

Generally, ACCESS1.0 tends to model higher surface solar radiation amounts in autumn and winter compared to ACCESS1.3. At the same time, ACCESS1.3 tends to model higher surface solar radiation amounts in summer and spring compared to ACCESS1.0.

ACCESS1.0 tends to model a patch of higher surface solar radiation in central Australia for summer and spring, while ACCESS1.3 only shows a patch of high radiation at the west coast for the same seasons.

Regarding cloud simulation, differences in total cloud amount tend to be greater between models than between scenarios in all seasons. The biggest differences in total cloud amount between the two models can be observed in summer. General patterns identified for surface solar radiation are also shown for the total cloud amount (more clouds > less surface solar radiation and vice versa). It is important to note that the differences between maps tend to be greater total cloud amount compared to surface solar radiation.

ACCESS1.3 calculates more clouds over southeastern Australia in winter while ACCESS1.0 tends to show less cloud cover than ACCESS1.3, especially over the ocean in summer. In general, ACCESS1.3 tends to have more distinguished cloud amounts between ocean, coast and land. This has an effect on the surface solar radiation simulations: ACCESS1.3 has a tendency to model higher surface solar radiation over the oceans compared to ACCESS1.0, especially in autumn and winter.

Differences between scenarios tend to become greater for 2020-2040 and 2040-2060 compared to 1990-2010.

5.4 Future projections

Because differences tend to be greater between models than between scenarios, I assessed the development of surface solar radiation and total cloud amount for each model and scenario separately. Generally, most differences between time periods have been observed in central Australia for both models.

For the surface solar radiation simulations of ACCESS1.0, the greatest difference between time periods can be observed in summer. There tends to be lower incoming solar radiation over the western part of central Australia in the future. RCP8.5 generally tends to show higher surface solar radiation in the future than RCP4.5.

For ACCESS1.3, the same general patterns are shown in the future. Only slight differences between time periods could be observed.

For both models the total cloud amount tends to slightly decrease over the century while surface solar radiation tends to slightly increase (bigger patches of high surface solar radiation). For ACCESS1.3, very similar patterns of total cloud amounts are observable for now and the future. Patterns of low total cloud amounts tend to become bigger and spread towards eastern Australia. However, these differences are too small to identify a trend. Differences between all time periods tend to be greater for RCP8.5 than for RCP4.5. Also, differences tend to be greatest when comparing the time period 1990-2010 to 2040-2060.

To conclude I can say that my hypothesis turns out to be correct. Indeed there will be little change in surface solar radiation under climate change scenarios for the future.

6. DISCUSSION

In line with the assessment by the IPCC and the Climate Change in Australia Technical Report (CSIRO & BOM 2015), the two climate models ACCESS1.0 and ACCESS1.3 project no significant change in surface solar radiation in Australia for 2020-2040 and for 2040-2060 compared to the baseline period 1990-2010. This suggests that non-climate variables like technological development, political measures and economic factors will be more important when considering the return of investment for installing solar panels or building solar farms.

During this research project I learned that my methods have essential limitations in regards to my research question. These are discussed in section 4. One option to overcome these limitations would be to choose a tool other than the CWSlab to analyse climate model outputs. If one were to still use the CWSlab, training for this software product could prove useful in order to add modules and to conduct a quantitative analysis.

Furthermore, climate models generally might be of limited use to remove the uncertainty of investment for the solar industry. Firstly, one major problem is the temporal resolution. Climate models only produce averages and long-term climate statistics. They should not be consulted when the goal is to find out what the weather will be like for a specific year. General trends produced by climate models only become meaningful when analysed for a time period of 20 years or more. This might not correspond to the time horizon for management plans by the solar industry.

Secondly, there is the added problem of limited spatial resolution. General circulation models like the ACCESS models only produce data for a resolution of roughly 120kmx140km – this corresponds to an area of 16800 km^2! A way to resolve this problem would be to consider regional climate models with a higher spatial resolution. In addition, downscaling methods could be used to improve the spatial resolution of the ACCESS model data. Because ACCESS1.3 tends to show a greater skill in cloud simulations I would suggest to dynamically downscale from this model to obtain further information for specific regions of Australia. For example, one could assess the development of surface solar radiation at the east coast specifically since this is the most populated region and energy need will be great for cities like Sydney or Melbourne.

In addition to the challenges of limited resolution, one should also consider that the climate model's skills are limited. Primarily, this comes from a limited understanding of the climate system. For example, there is uncertainty about the magnitude and sign of the cloud feedback. This presents a major obstacle to improve climate change prediction, especially for surface solar radiation. About one third of the incoming solar radiation is reflected back to space by clouds. Thus it is of major importance that further research will be undertaken to improve our understanding of clouds and their representation in climate models.

Further challenges remain in the simulation of phenomena affecting Australia's climate, like the El Niño-Southern Oscillation (ENSO) and the monsoon. Both the ENSO and the monsoon affect rainfall in Australia which is tightly related to cloud cover. Therefor it is also of great significance to further research these climate phenomena to improve future climate projections.

Finally, my assumption that consulting climate models is the right tool to assess surface solar radiation projections for reducing the uncertainty of investment for the solar industry remains doubtful because of the limitations and challenges listed above.

ACKNOWLEDGEMENT

Especially, I would like to thank my wonderful supervisor, Nick Engerer, for his support and constructive feedback throughout the process of writing this report. I am grateful to have had the opportunity of working on an Independent Research Project, from which I learned a lot.

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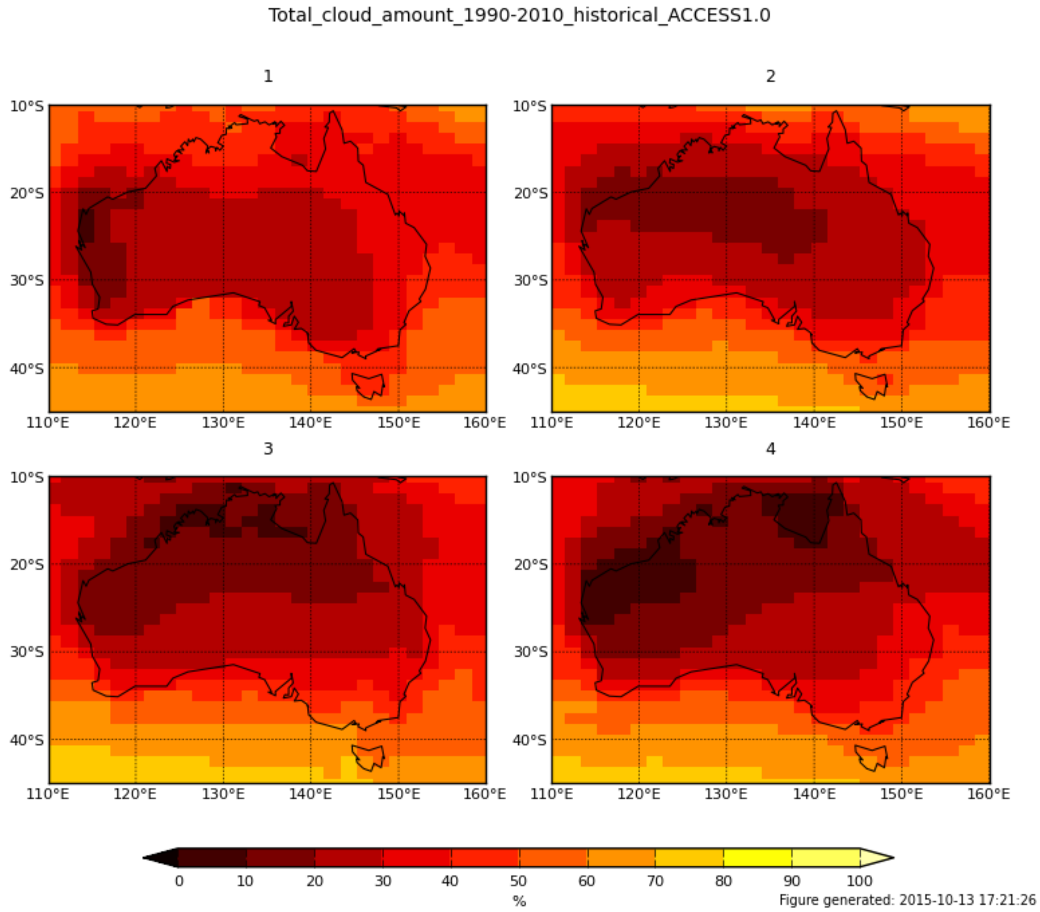
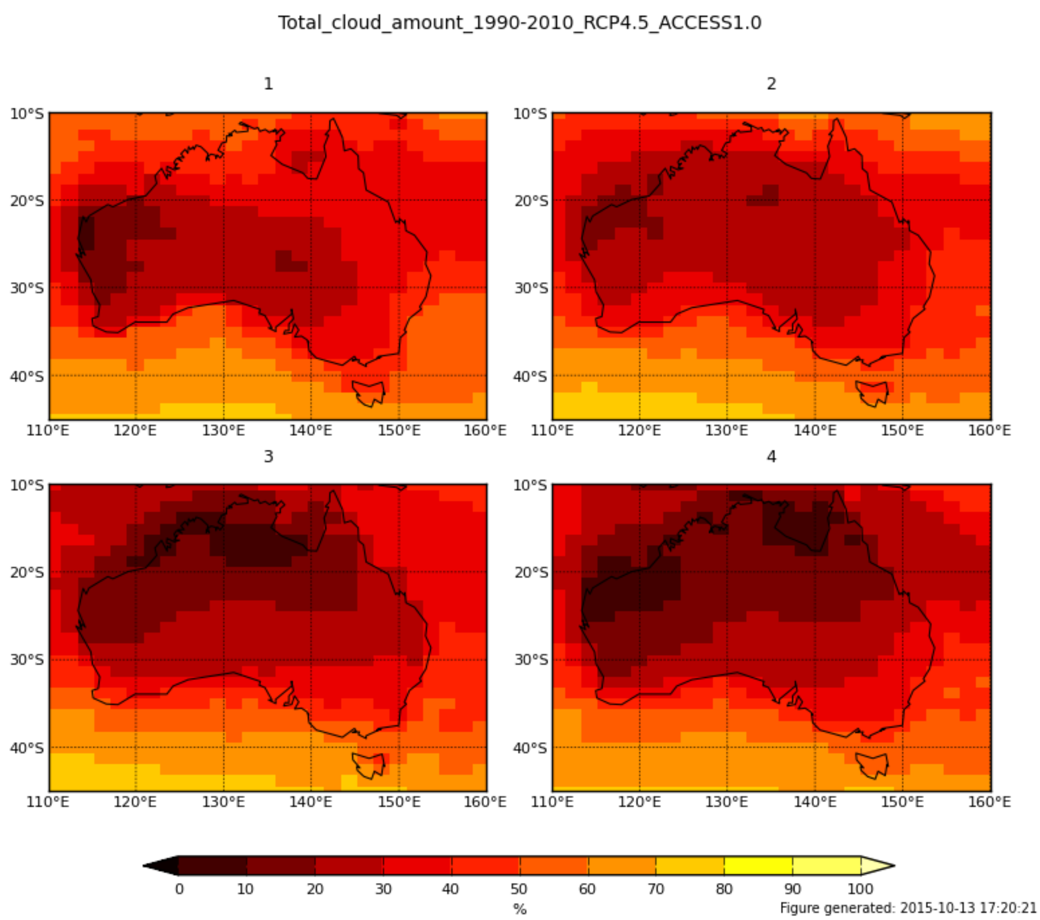
APPENDIX A: MAPS





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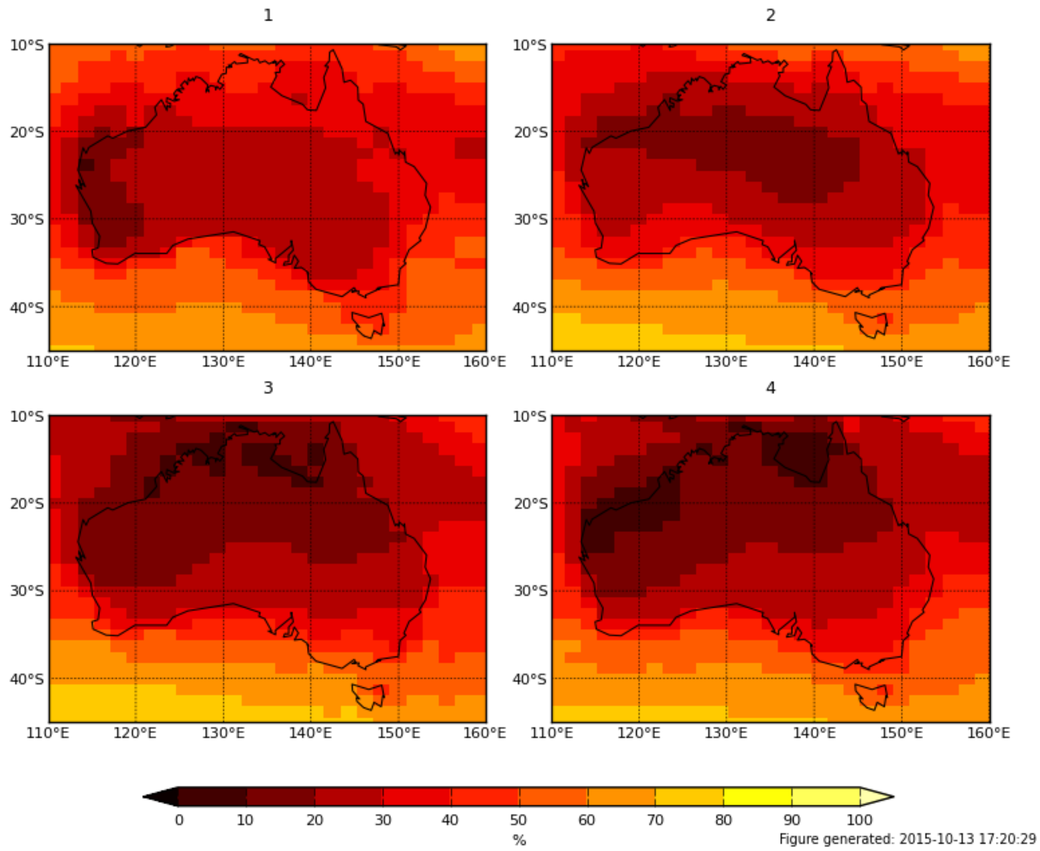

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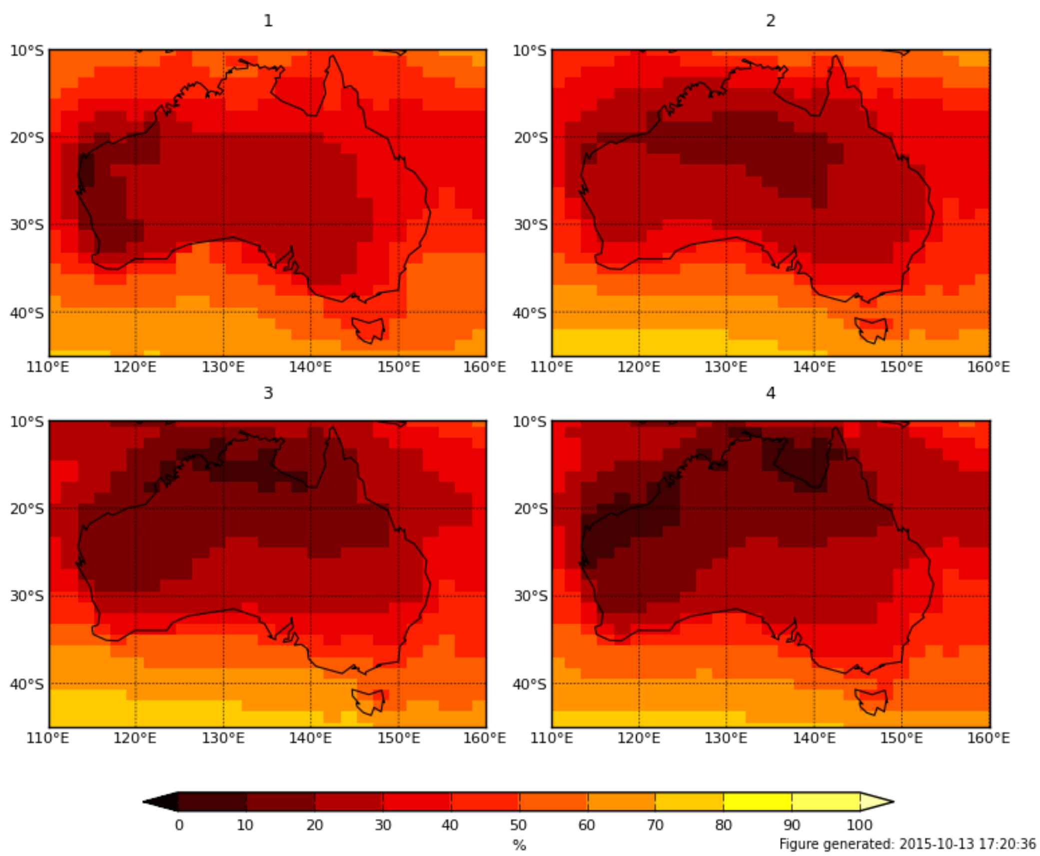

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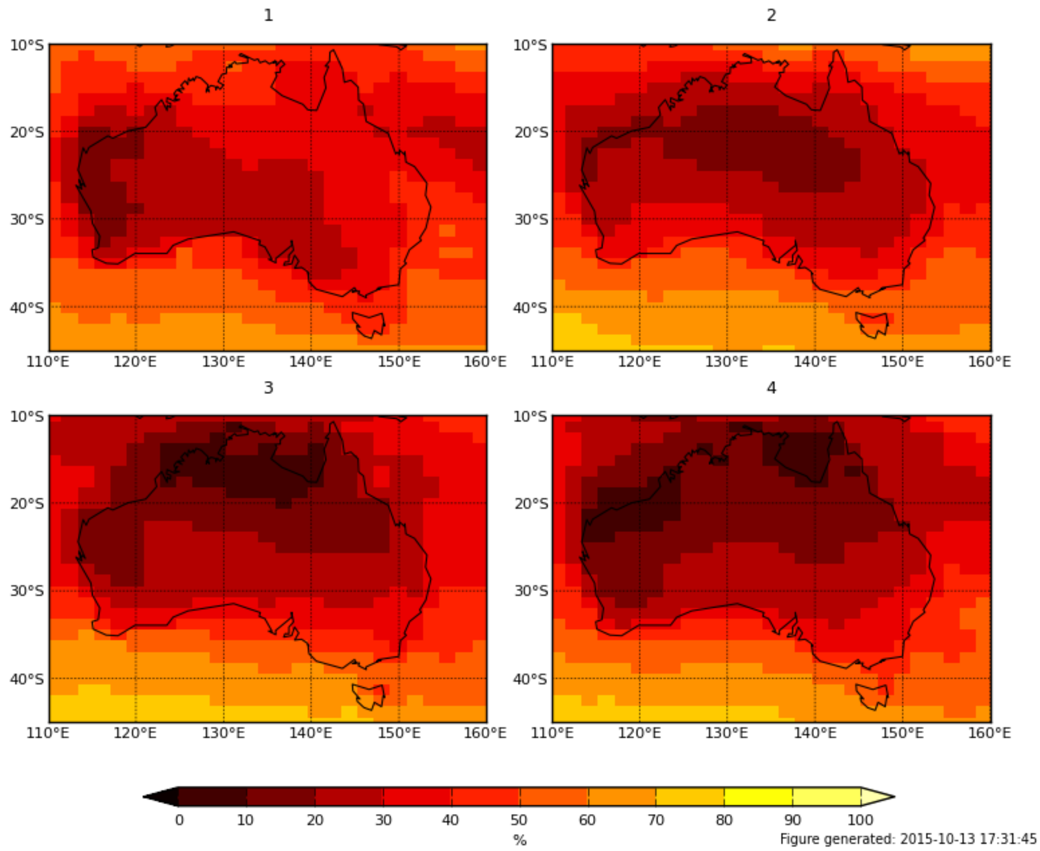

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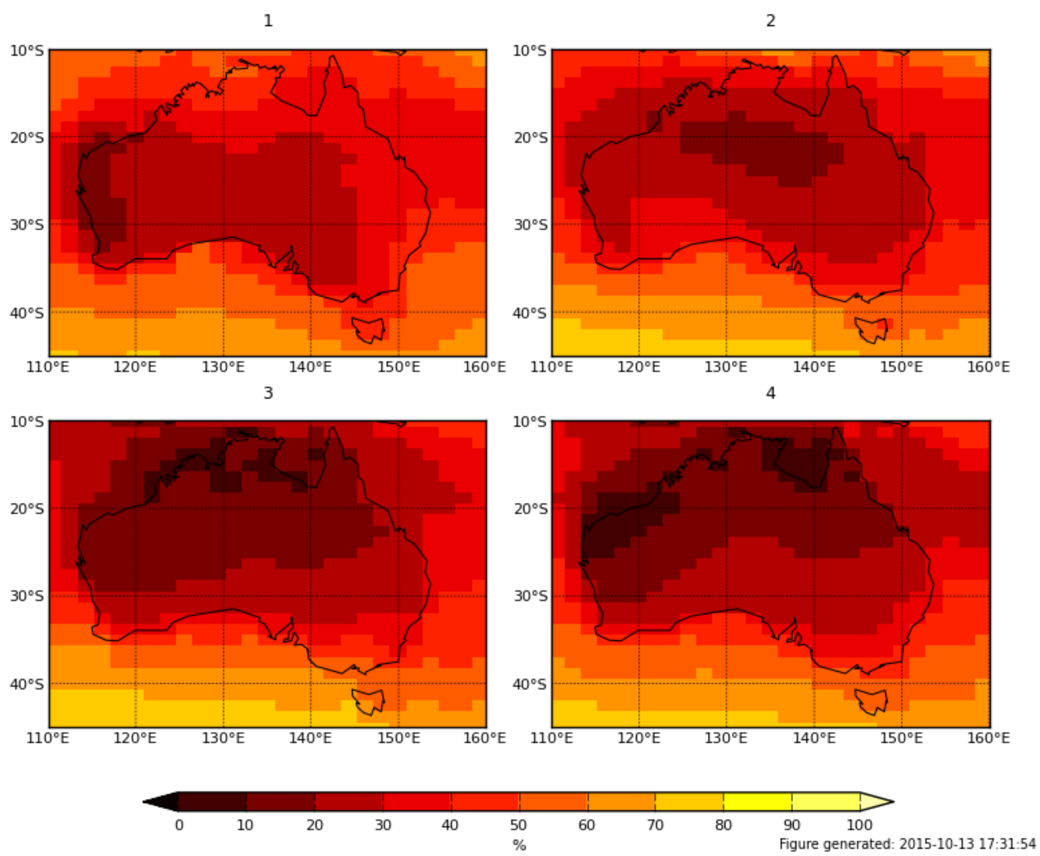

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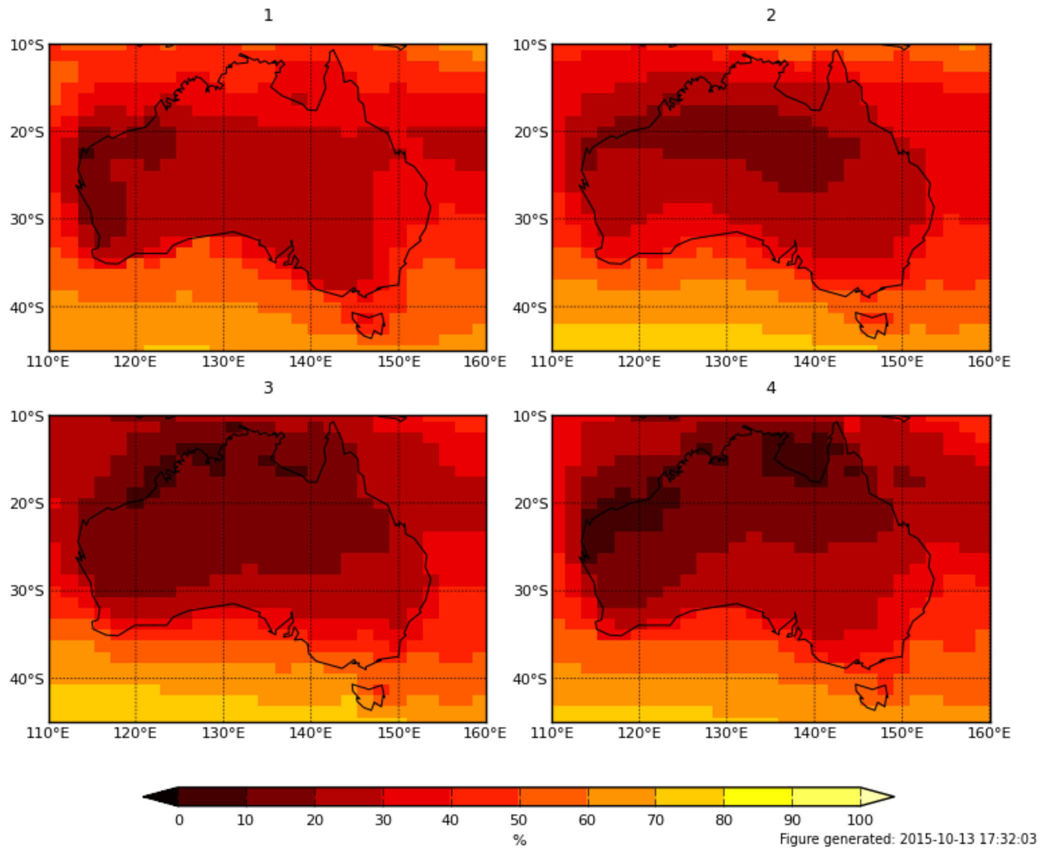

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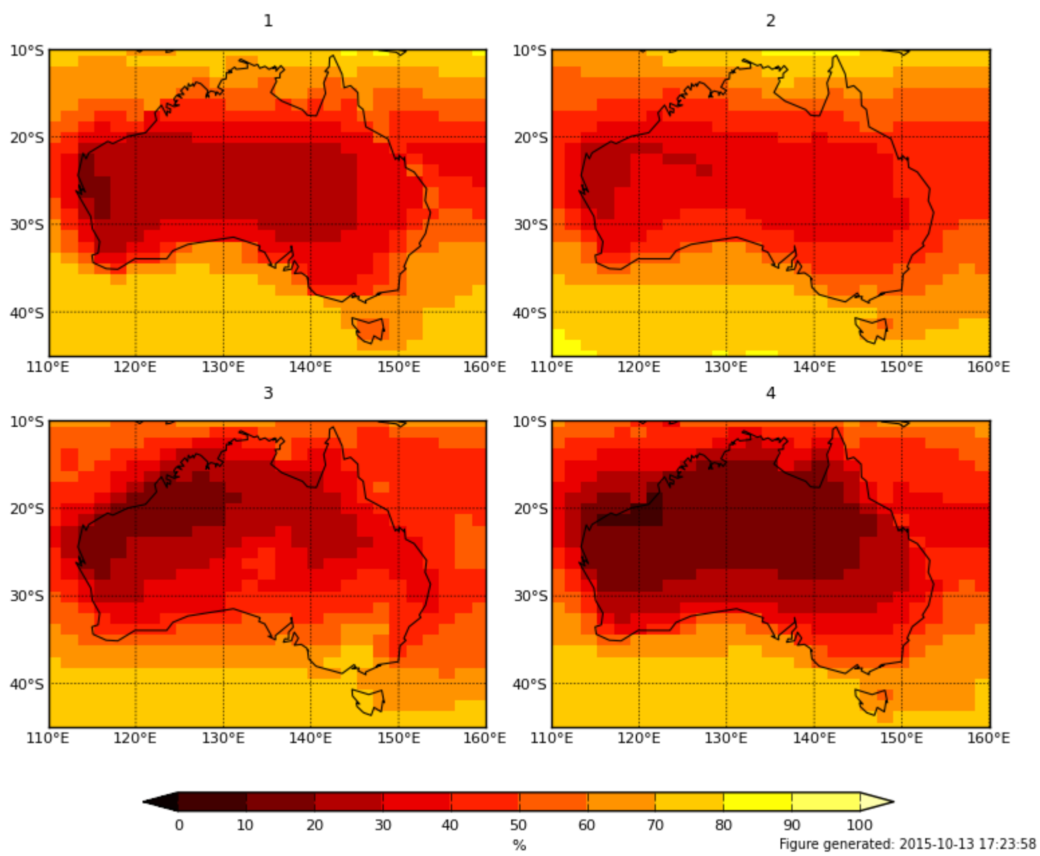

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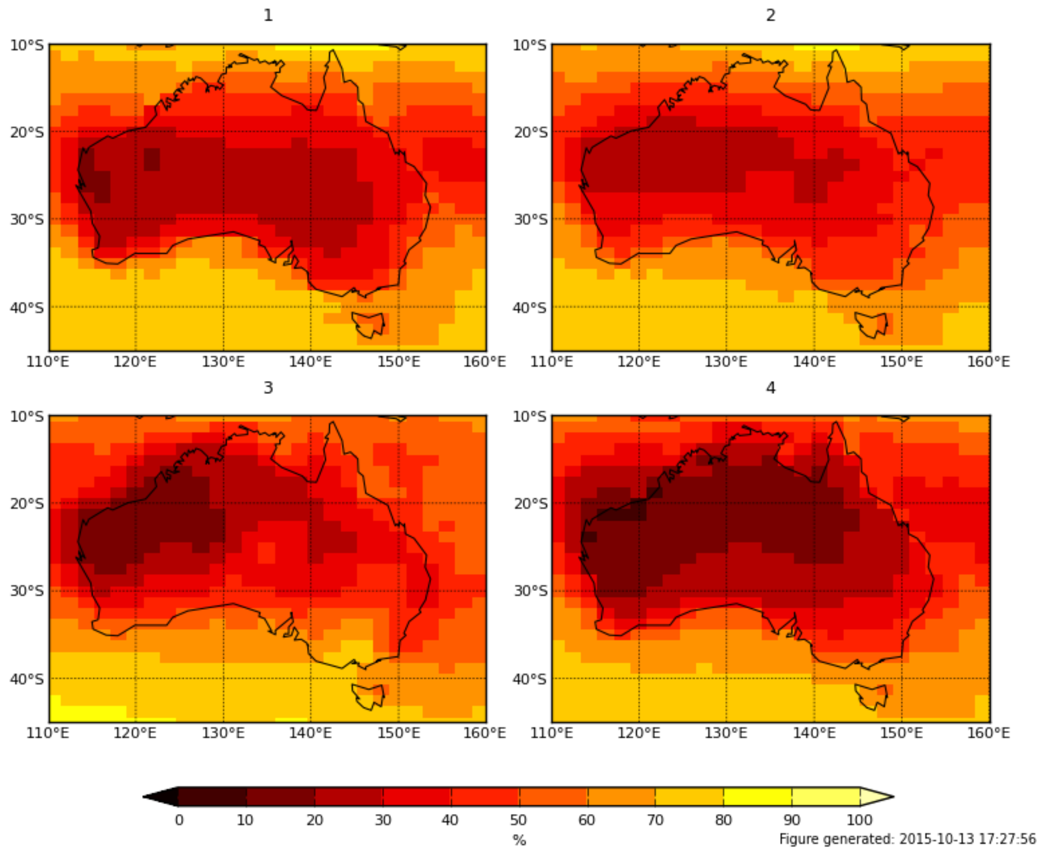

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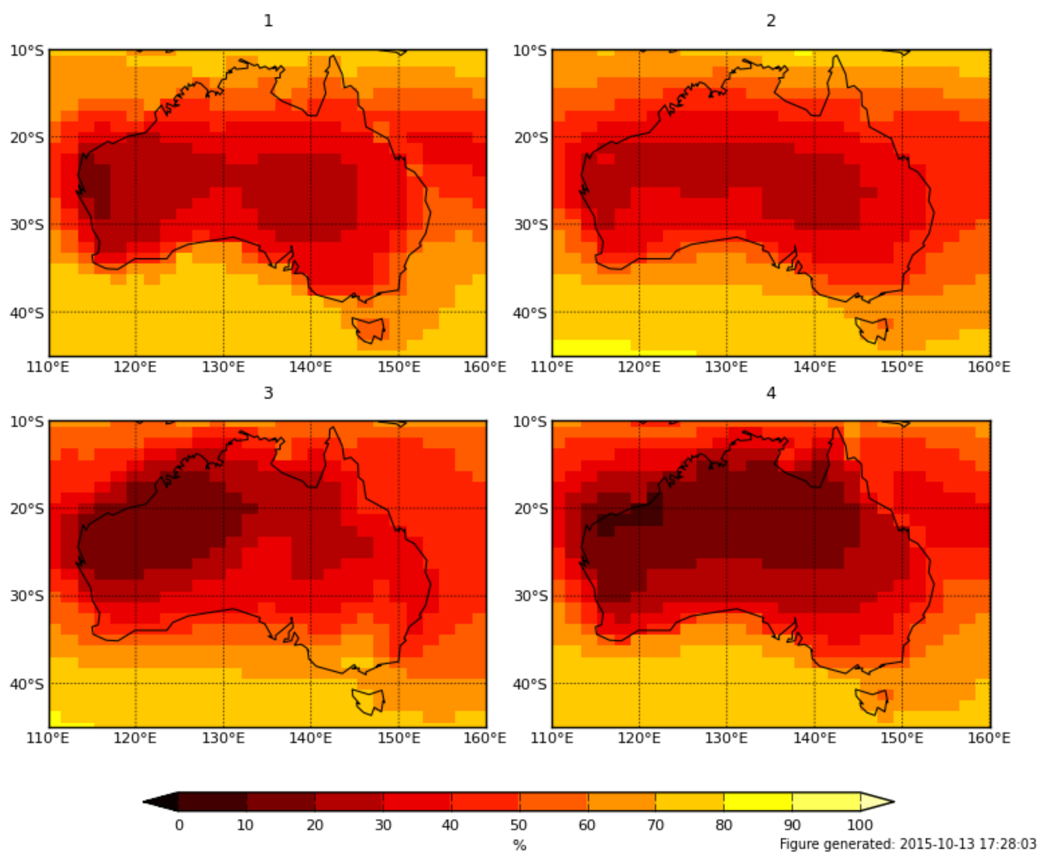

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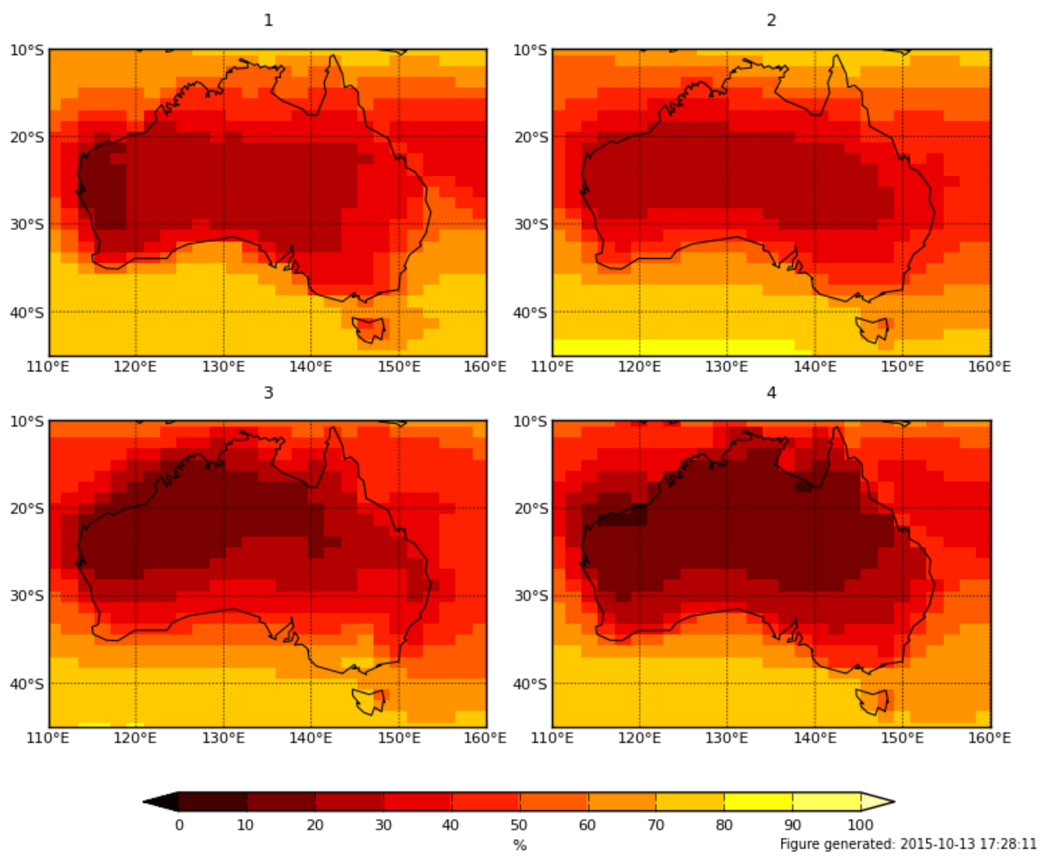

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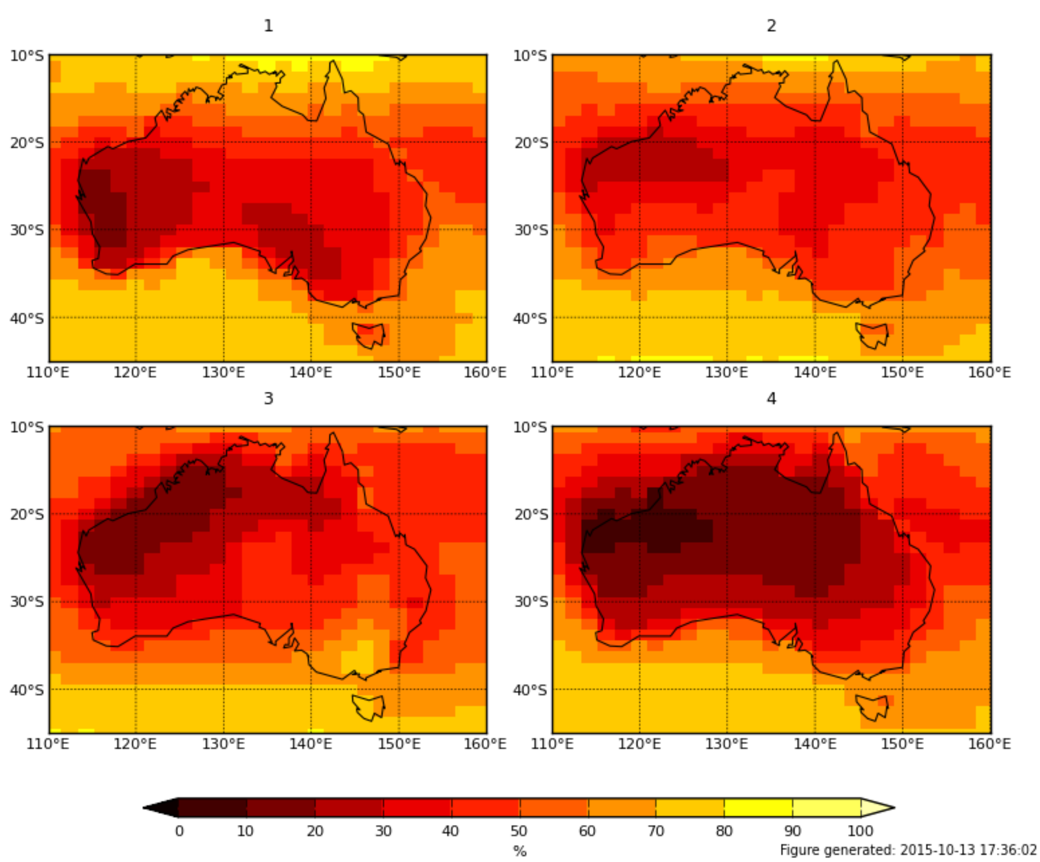

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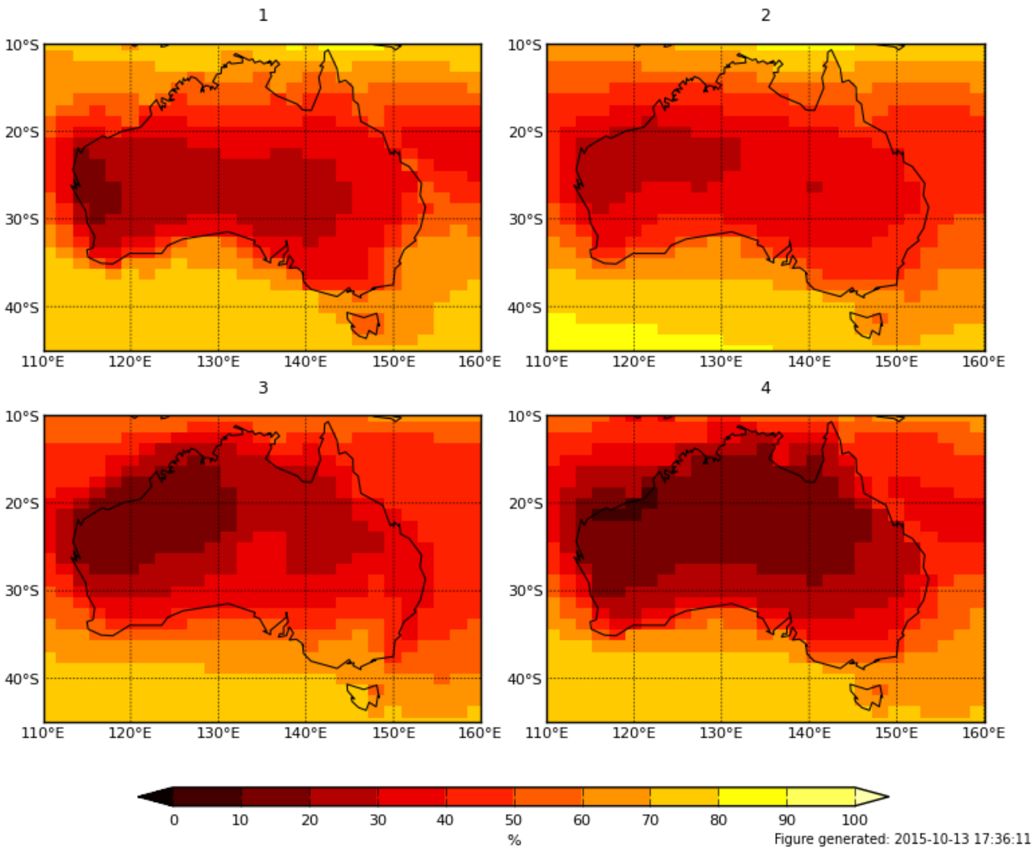

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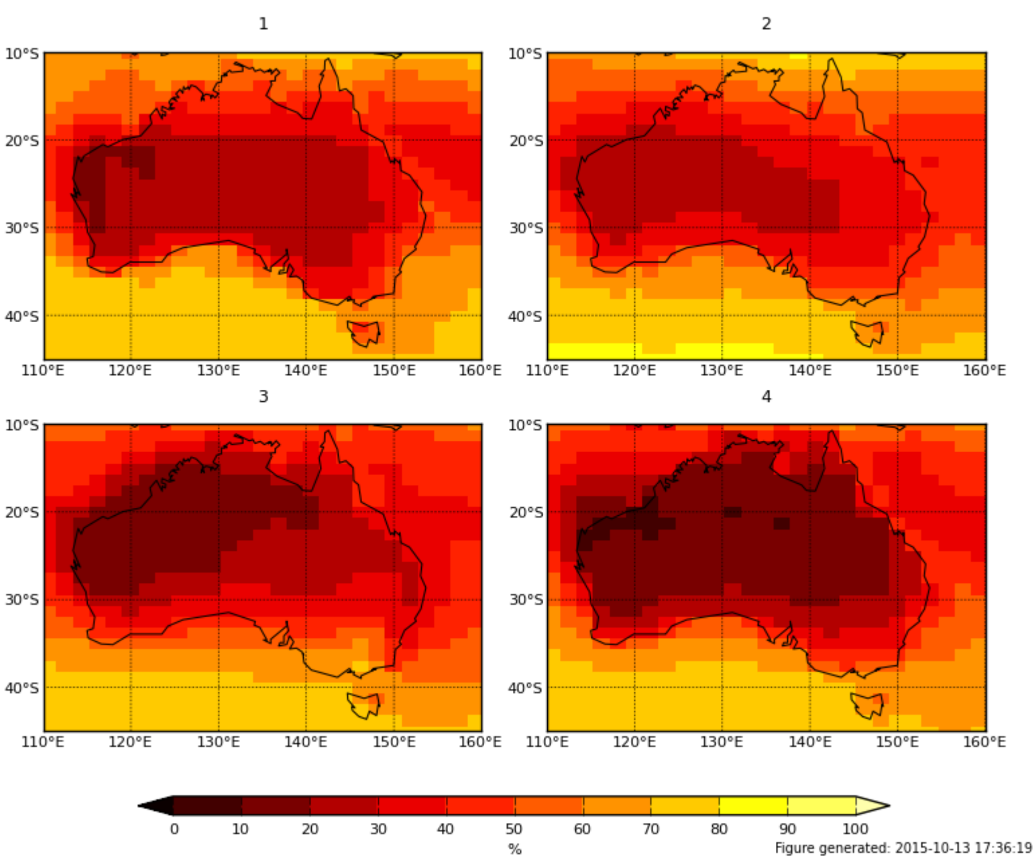

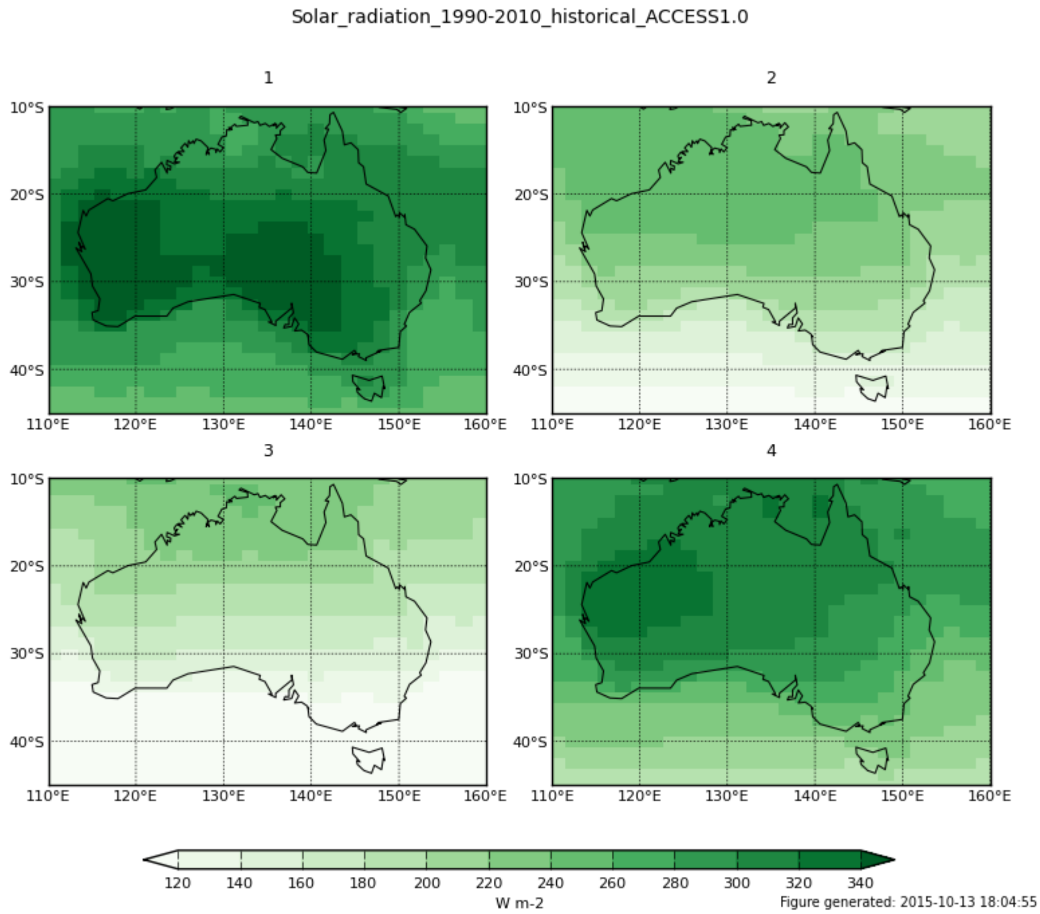
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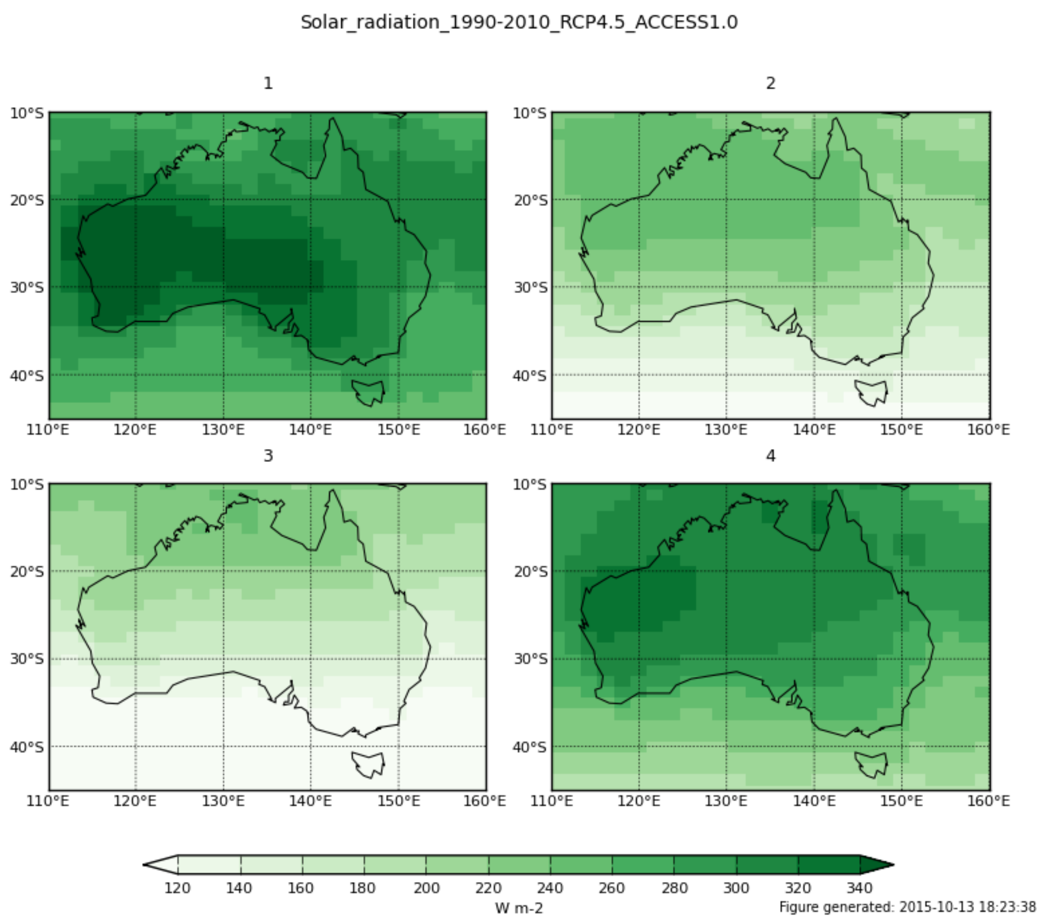
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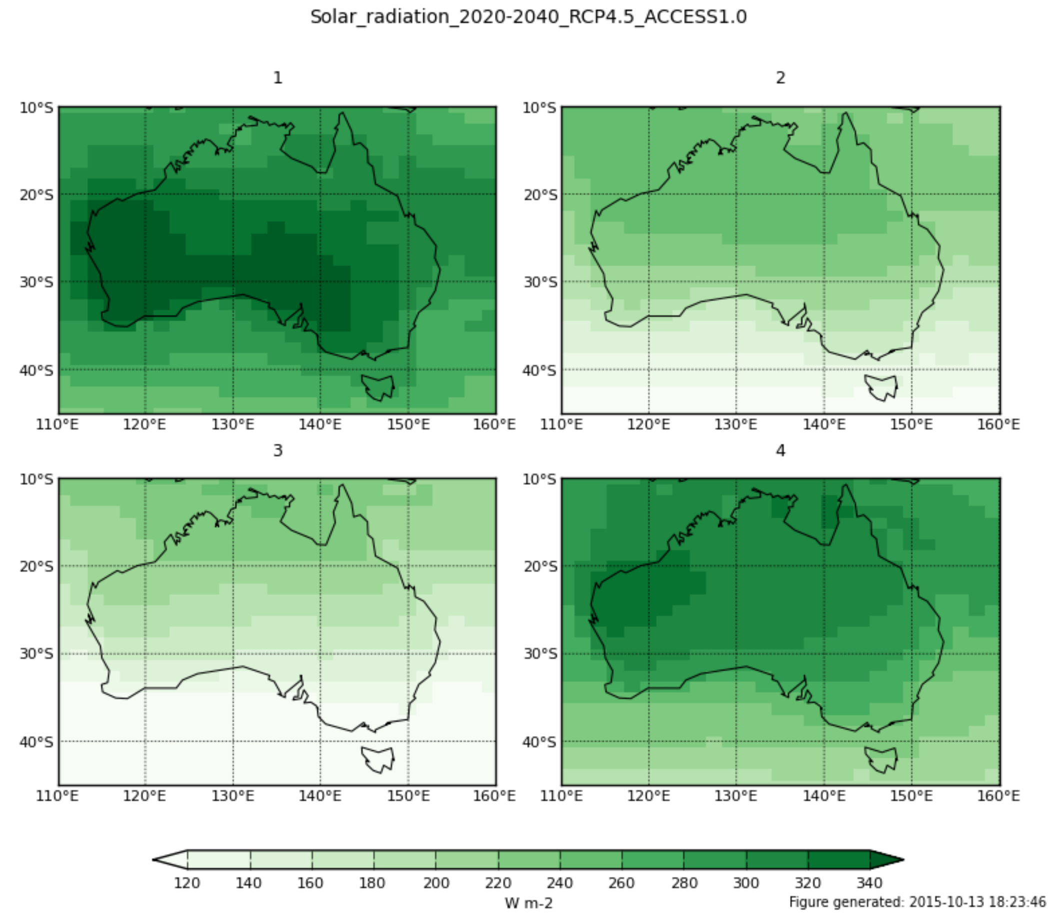
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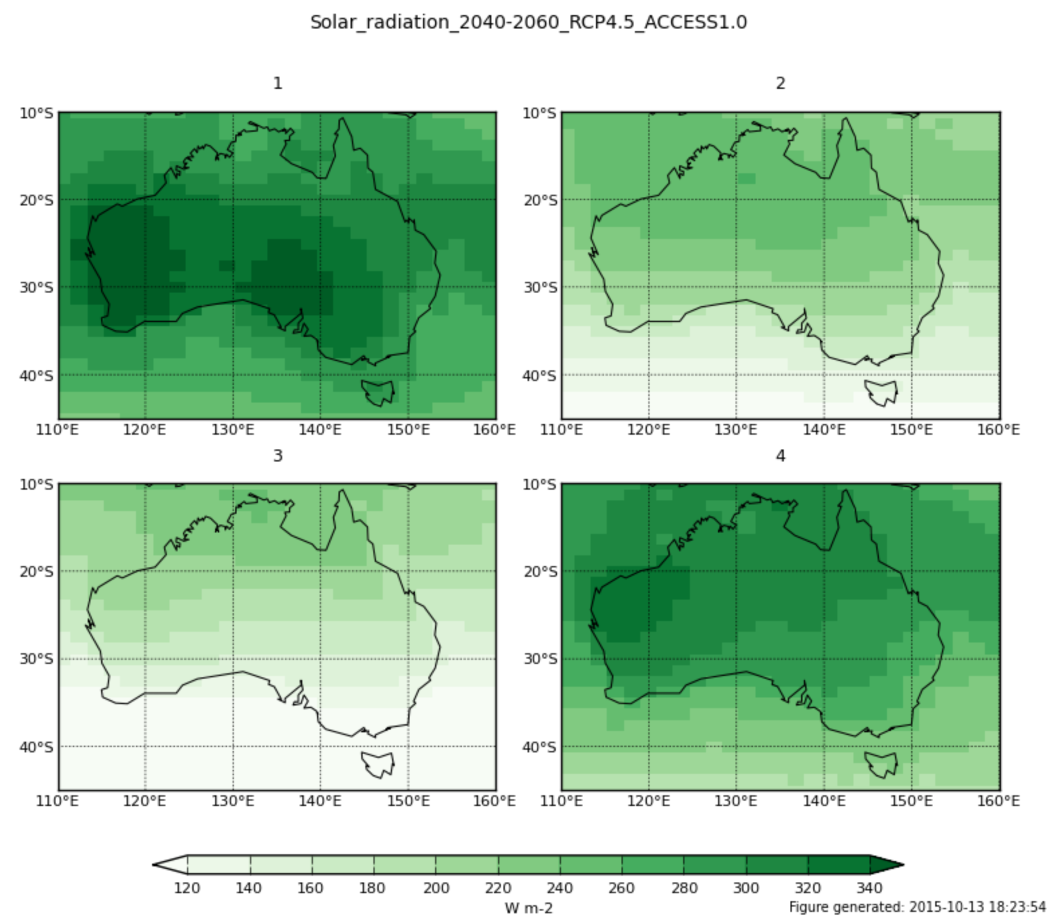
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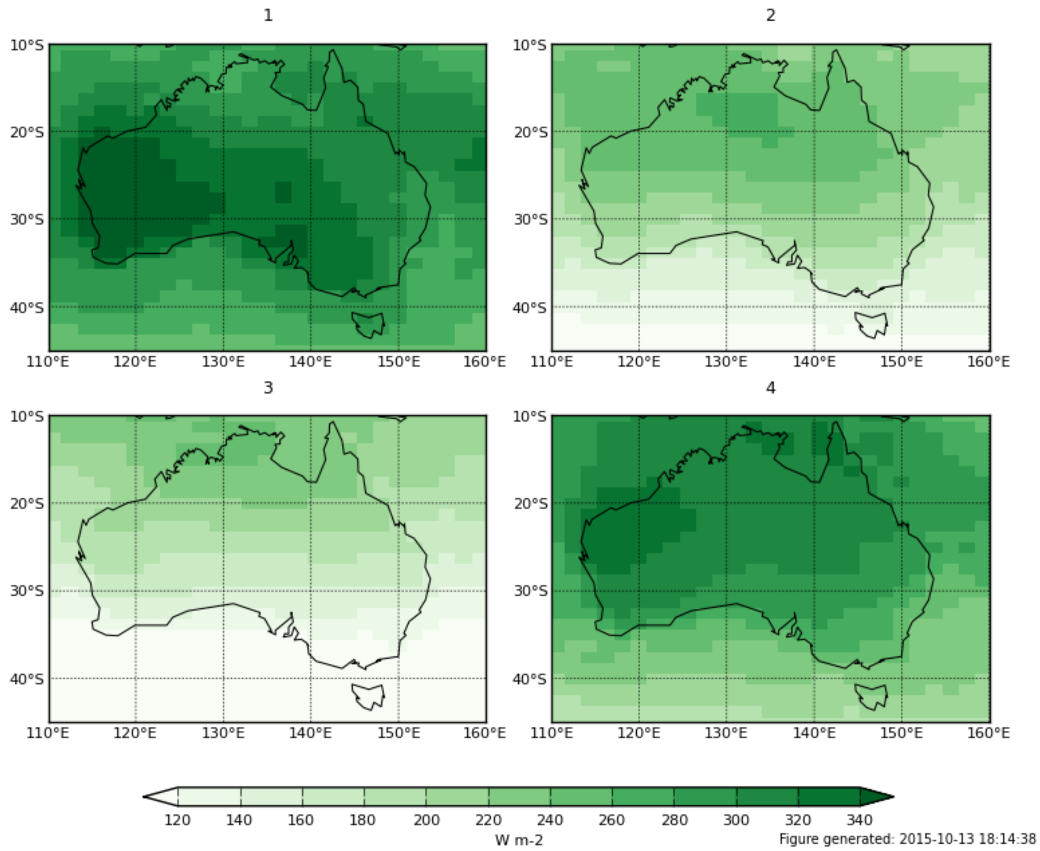

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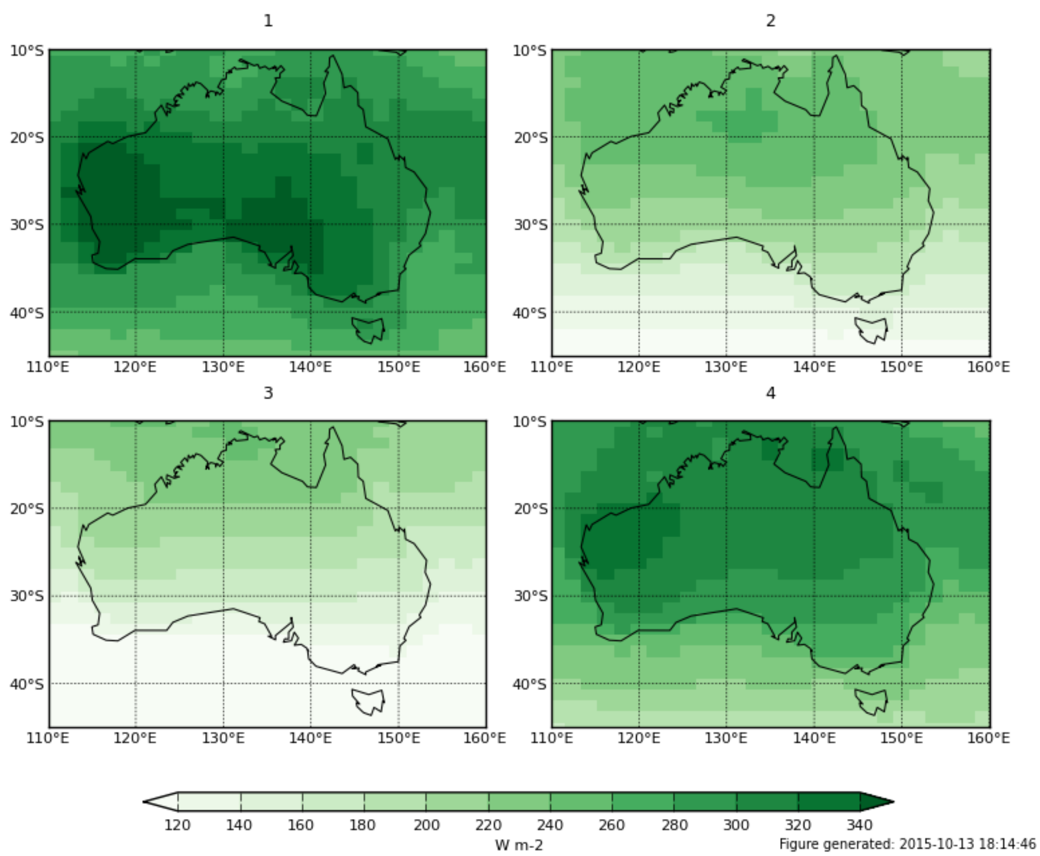

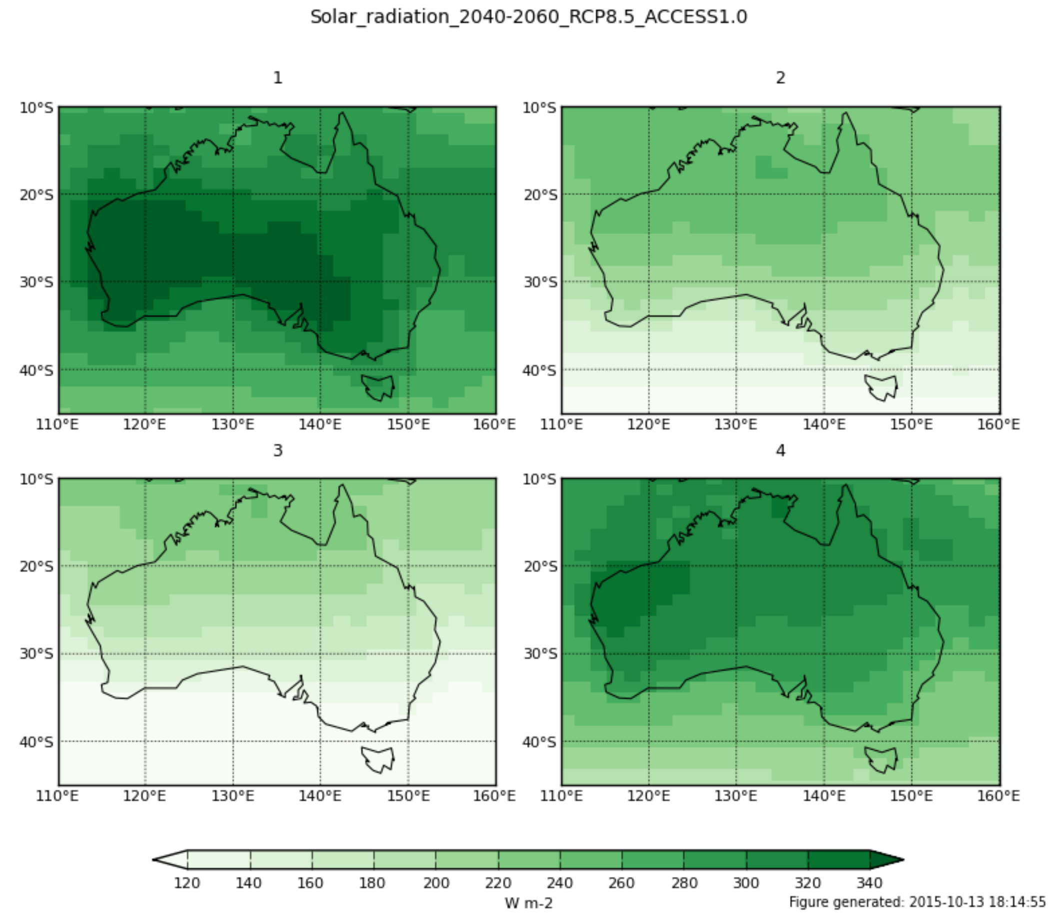
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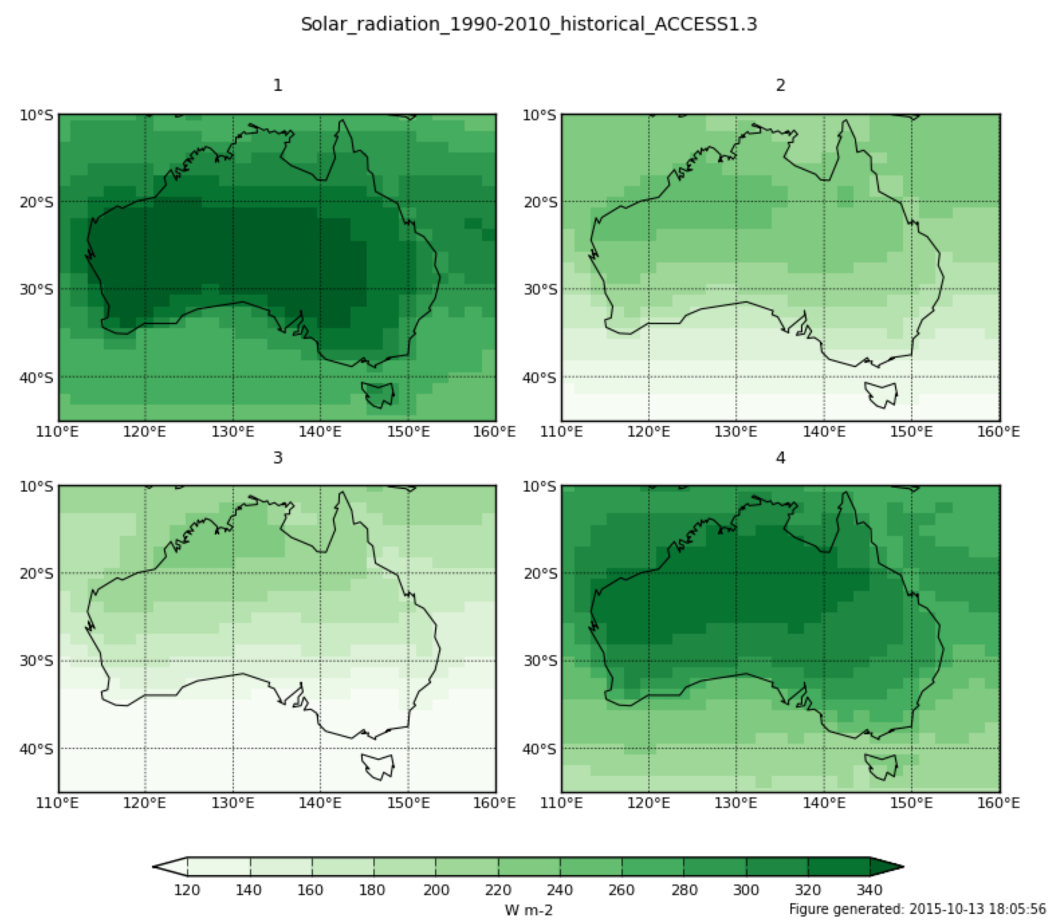
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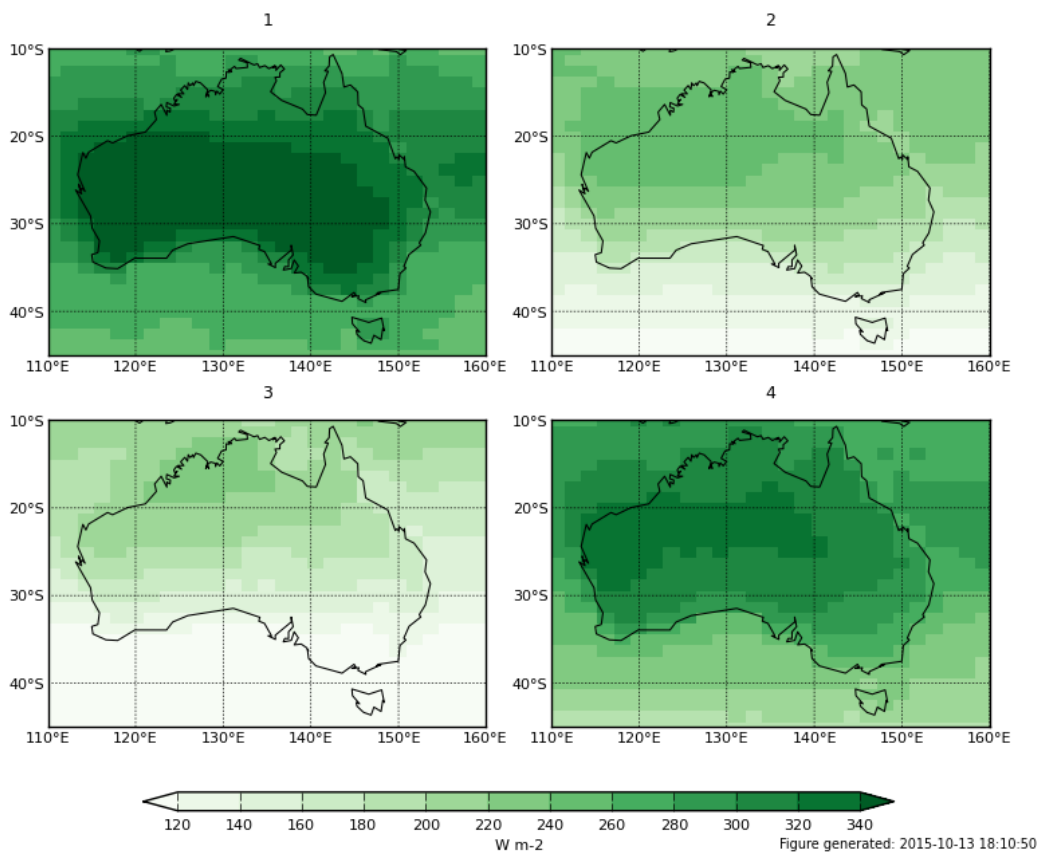

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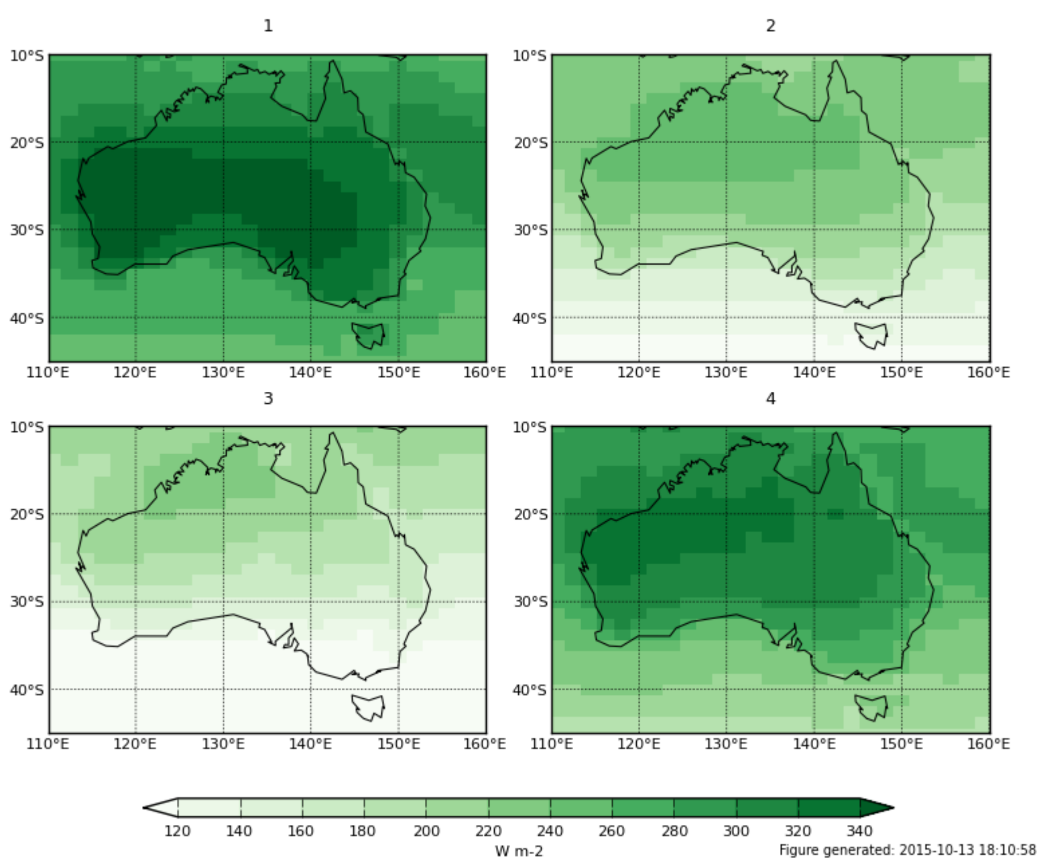

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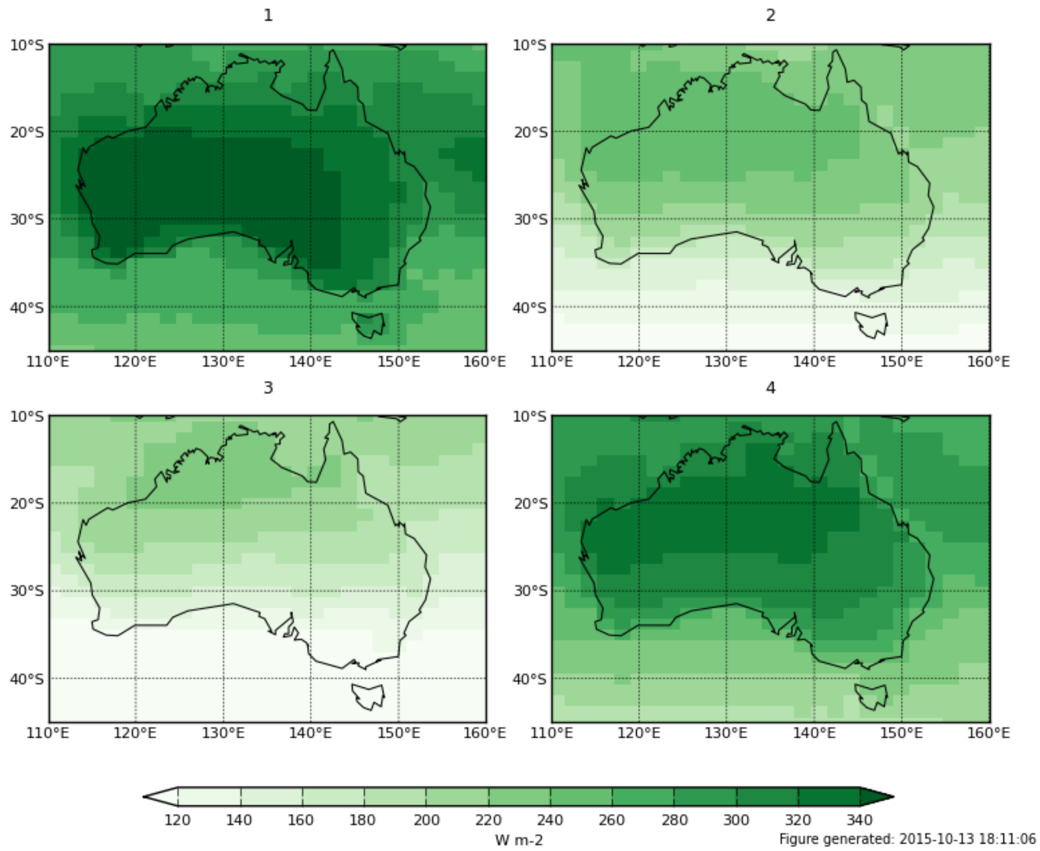

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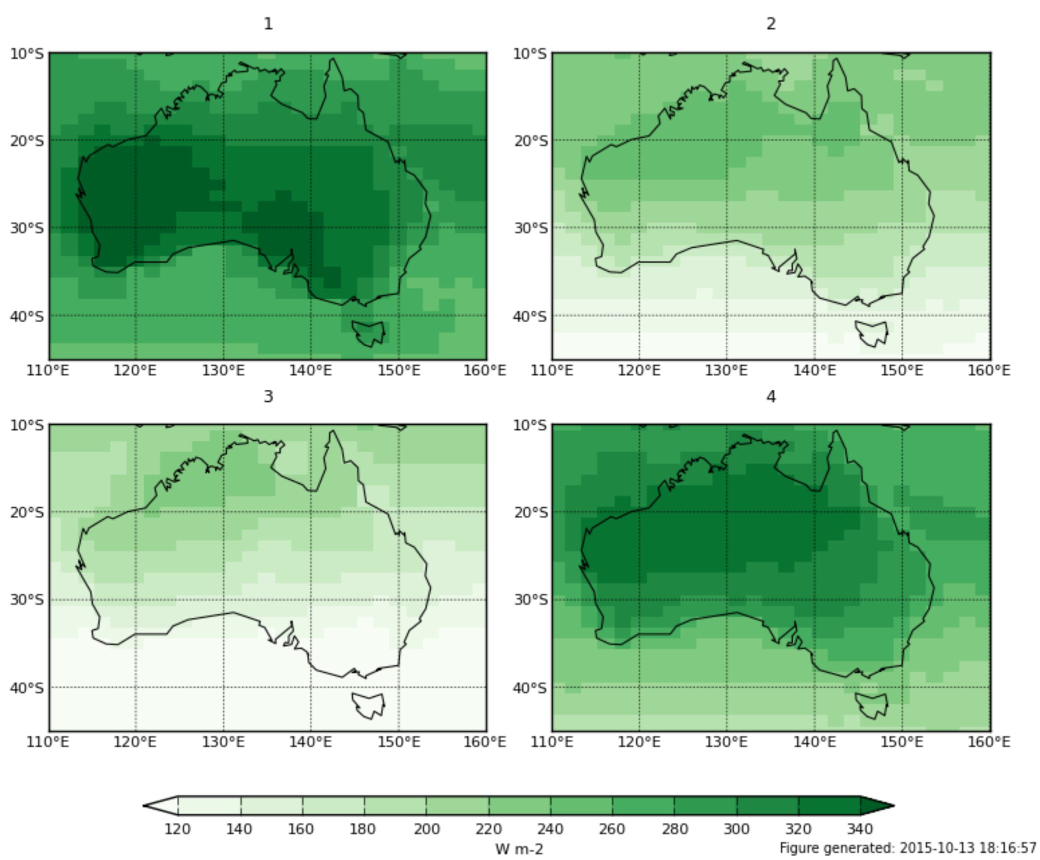

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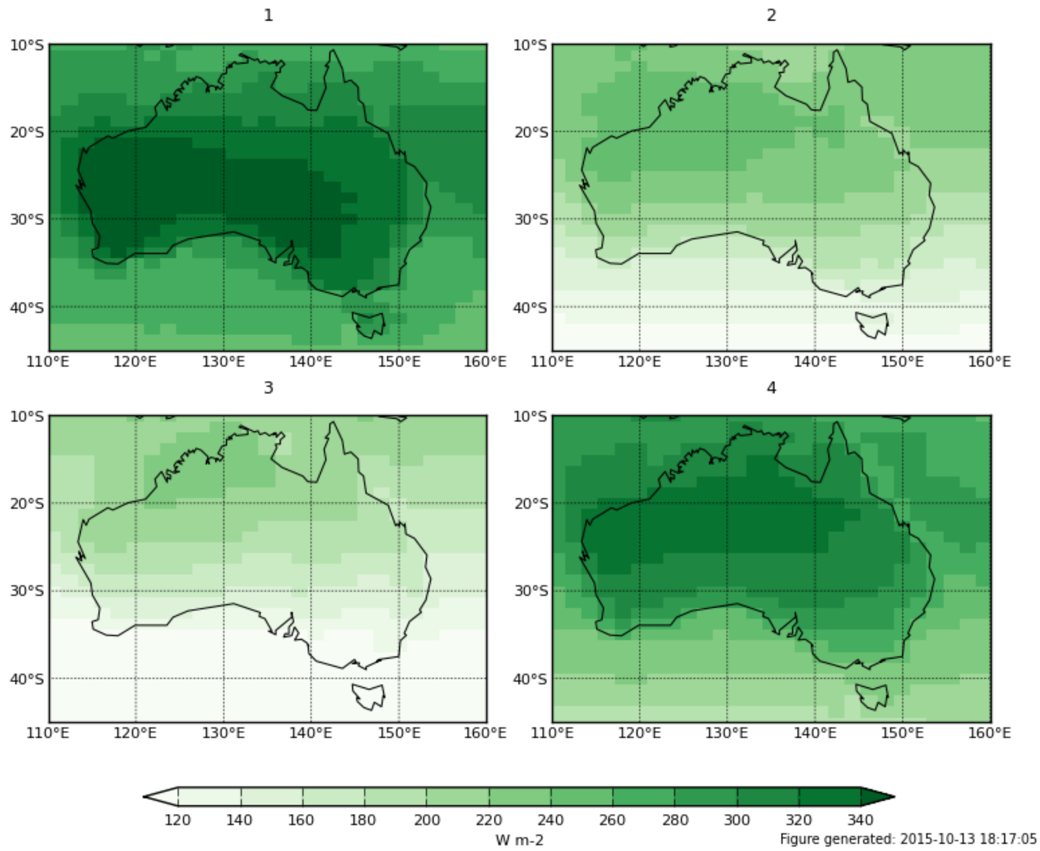

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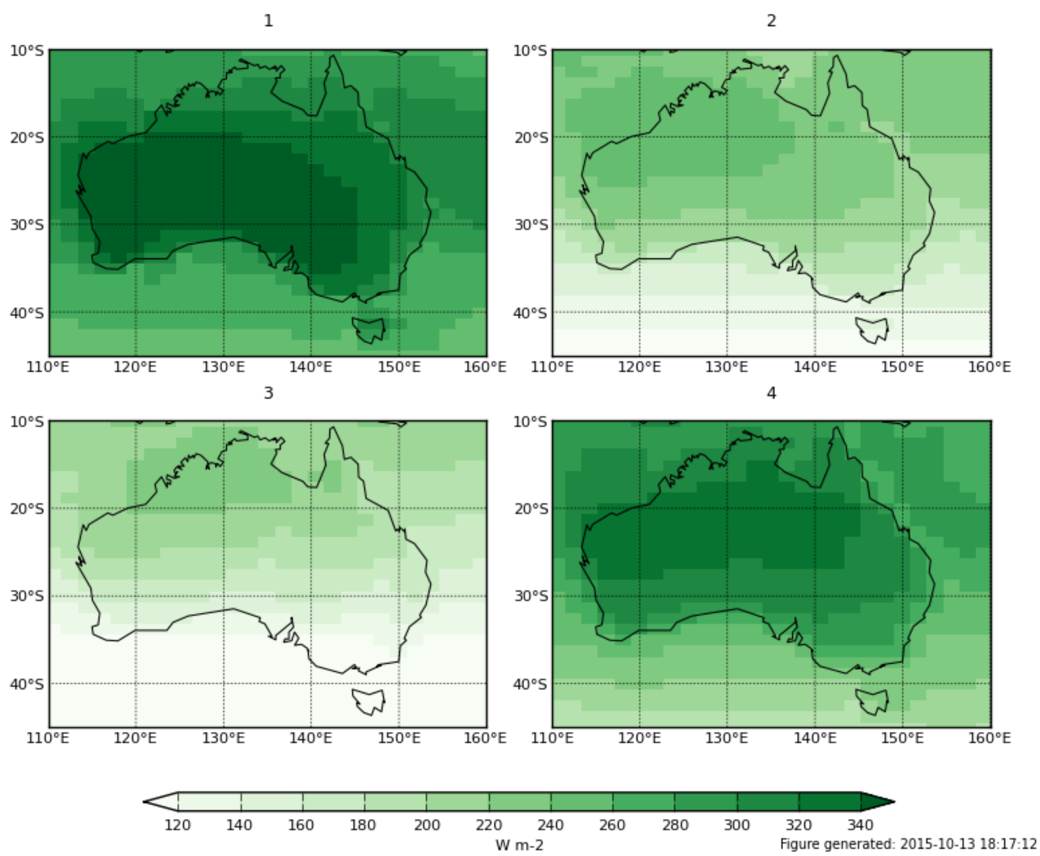
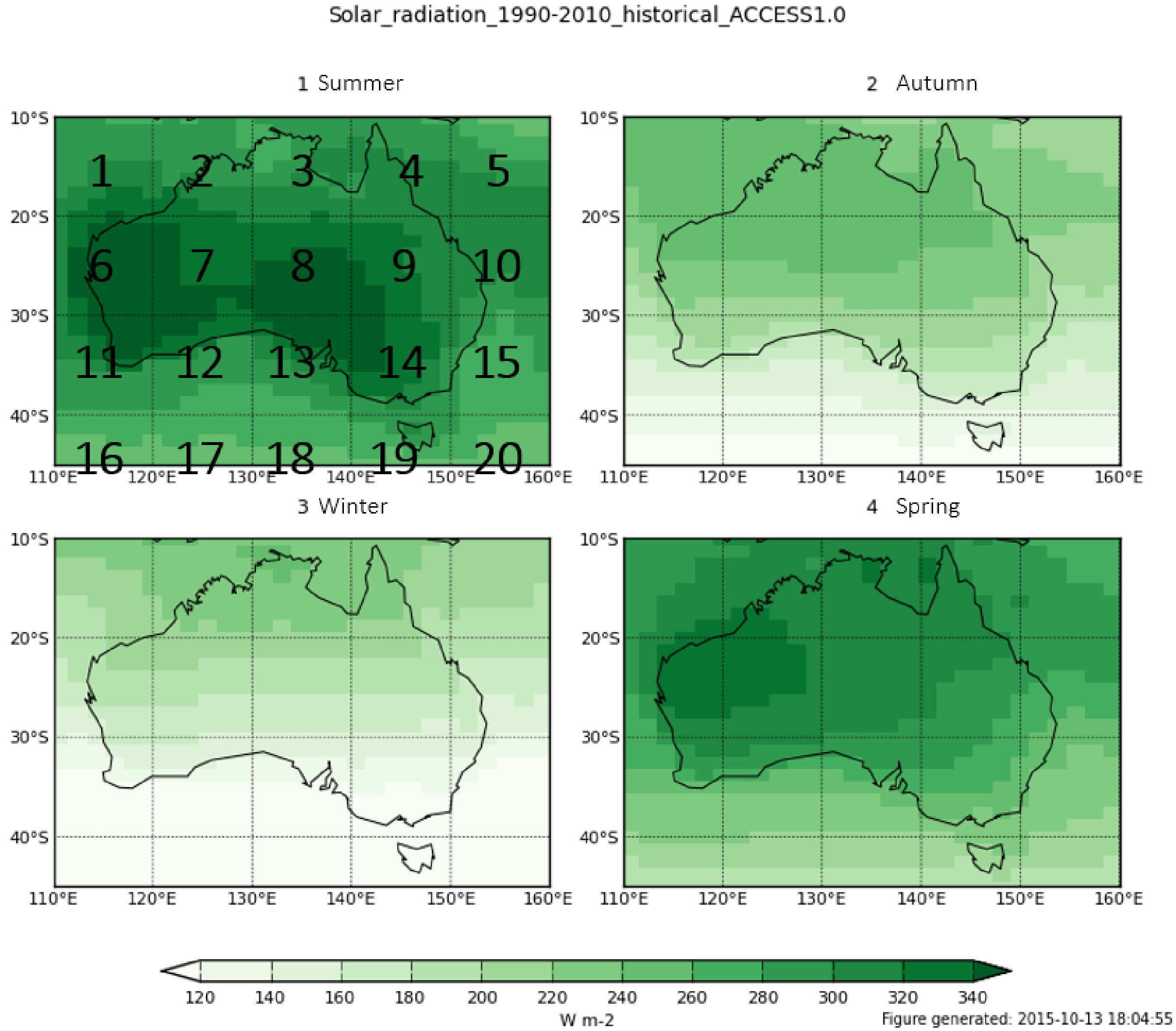


APPENDIX B: ANALYSIS



For a clear analysis that is as objective as possible, the maps are divided into 20 rectangles as seen below.

Legend:

1	Summer
2	Autumn
3	Winter
4	Spring
R1 – R20	Rectangle 1 to Rectangle 20
A1.0	ACCESS1.0
A.13	ACCESS1.3
SSR	Surface solar radiation
CLT	Total cloud amount

Evaluation of solar radiation

Time period 1: 1990-2010

	Historical ACCESS1.3	RCP4.5 ACCESS1.0	RCP4.5 ACCESS1.3	RCP8.5 ACCESS1.0	RCP8.5 ACCESS1.3
Historical ACCESS1.0	1: more SSR in A1.3, especially in R7 and R8.SSR more homogenous over ocean in A1.3, see R12, R13. 2: More SSR in A1.0 over northern Australia, see R1, R2, R3, R4, R6, R7, R8, R9. 3: More SSR from A1.0 in R3. A1.0 has more linear borders going south, A1.3 models SSR in a more patchy way. 4: Higher SSR over central/northern Australia, see R2, R3, R7, and R8. A1.3 shows higher SSR at the East Coast, see R9, R10. General: Same general patterns, most differences over central / northern Australia.	1: High SSR patch in western Australia slimmer and more consistent in RCP4.5 (R7, R13). 'Hole' in historical in R7. Historical more heterogeneous in southeastern Australia (R14). 2: No major differences. 3: No major differences. 4: No major differences. General: Only major differences in Summer.	1: Patch of high SSR very pronounced over central/ southern Australia in RCP4.5 A1.3- 'Hole' in historical A1.0 in R7, generally patch of high SSR less developed. 2: Historical A1.0 shows higher SSR in the north, see R1, R2, and R4. 3: Less SSR in RCP4.5 A1.3 around Darwin, R2, R3, R4. SSR amounts over central/eastern Australia more homogenous in historical A1.0. 4: Patch of high SSR in central Australia more pronounced in RCP4.5 A1.3 (see R7, R8). General: A1.3 shows higher SSR in summer and spring, while A1.0 shows higher amounts in autumn and winter.	1: Patch of high SSR over mid-southern Australia bigger in historical, see RR8, R9, R14. 2: Higher SSR over northern Australia in historical, while patch of same W/m^-2 in R2, R4 in RCP8.5. 3: No major differences. 4: Patch over western Australia bigger in historical, see R7. General: Higher SSR in historical compared to R8.5.	1: Very big patch of high SSR over southern Australia in R8, R9, R13, R14 in historical compared to RCP8.5 (patch in RCP8.5 almost non-existent). 2: Higher SSR over northern Australia in historical and RCP8.5, RCP8.5 shows small high patch in R3. 3: Patch in R3 in historical A1.0 slightly bigger in RCP8.5, spreading R2 and R3. 4: High SSR over northwestern Australia bigger in historical, see R7 General: Most discrepancies in summer and spring.
Historical ACCESS1.3		1:A1.3 shows higher SSR over central Australia in R7, R8, and R9. SSR is more homogenous at East Coast in A1.0 (R9, R14). 2: Higher SSR over northern Australia in A1.0 (R1, R2, R3, R4, R6, R7, R8, R9). 3: high patch in A1.0 in R3. 4: Higher SSR over north-central Australia in A1.3 (R2, R3, R7, R8, R9). General: Same general patterns, most differences over central / northern Australia.	1: No major differences. 2: Patch of high SSR over northern Australia in RCP4.5, ranging over R1, R2, R3, R4, R6, R7, R8, R9,; only in R1, R2, R3, R6, R7, R8 in historical. 3: Patch in R2, R3 bigger in RCP4.5 (northern Australia). Lower SSR in southeastern Australia in historical (see R14). 4: Form of high SSR patch slightly different, but roughly same area.	1: Patch of high SSR over central Australia less developed in RCP8.5 A1.0 (see R7, R8). 2: Patch of high SSR (260 W/m^-2) much bigger in RCP8.5 A1.0 (see R1, R2, R3, R4, R6, R7, R8, R9). 3: Still higher SSR over northern Australia in RCP8.5 A1.0 (from R1 to R4), while only R2, R3 in historical A1.3. 4: Patch of high SSR in central Australia in historical A1.3 (R1-R4, R6-R9), almost not developed	1: Patch of high SSR over central Australia less developed in RCP8.5, especially in R7, R8, R9. 2: Patch of high SSR over northern Australia bigger in RCP8.5, especially towards the east. 3: No major differences. 4: No major differences. General: RCP8.5 shows higher SSR in central Australia in summer and autumn compared to historical run. Same model.

			General: Biggest difference in autumn over northern Australia.	in RCP8.5 A1.0 (R7, R8 only). General: Higher SSR over central Australia in A1.3 in summer and spring, higher SSR over northern Australia in A1.0 in autumn and winter.	
RCP4.5 ACCESS1.0			1: Higher SSR in A1.3 generally. High patch over central Australia very pronounced in A1.3 (R7, R8, R9, and R14). 2: Higher SSR in the northwest in A1.0, see R1, R2. Higher SSR in northeast in A1.3, see R5. 3: A1.0 has high patch in R3, higher SSR in the north in general (R2, R3, and R4). 4: Patch of higher SSR more distinct in A1.3 (see RR7, R8). General: A1.3 has higher SSR in summer and spring, while A1.0 has higher SSR in autumn.	1: Patch of high SSR over central Australia more pronounced in RCP4.5, especially in R8. 2: RCP8.5 again shows higher SSR in R2, R3. 3: Patch in R3 slightly bigger in RCP8.5. 4: No major differences. General: Very similar (same model), greatest difference in summer.	1: Higher SSR over northeastern Australia in RCP4.5 A1.0. Different pattern of patch over central Australia, see R7, R8. 2: There is a higher SSR over northern Australia in both models. Patch more pronounced in RCP4.5 A1.0 (see R1, R2 especially). 3: Higher SSR over northern Australia more pronounced in RCP4.5 A1.0, especially in R2, R3, and R4. 4: Big patch of higher SSR over all central Australia in RCP8.5 A1.3 (R1-R4, R6-R9), while only in R6 and R7 in RCP4.5 A1.0. General: Much higher SSR in spring for RCP8.5 A1.3, while RCP4.5 A1.0 shows larger area of high SSR in northern Australia in autumn.
RCP4.5 ACCESS1.3				1: High SSR over central Australia very pronounced in RCP4.5 A1.3 compared to RCP8.5 A1.0 (see R7, R8, R9). In RCP8.5 A1.0 the patch of high SSR is mainly over northwestern Australia. 2: High SSR in R3 for RCP8.5 A1.0 and patch of higher SSR in northern Australia bigger.	1: RCP4.5 shows higher SSR over all of central Australia (R6, R7, R8, R9), while this patch is less developed in RCP8.5 (see R7, R8, R9). 2: High SSR over ocean at northeast coast in RCP4.5, not shown in RCP8.5 3: No major differences. 4: Patch of high SSR over northern/central Australia

				3: Higher SSR in the north forRCP8.5 A1.0 again, especially in R2, R3. 4: Patch of high SSR in northwest for RCP8.5 A1.0, while higher SSR over central Australia in RCP4.5 A1.3. General: Higher SSR in RCP4.5 A1.3 in summer and spring, while RCP8.5 A1.0 shows higher SSR in autumn and winter.	more pronounced in RCP8.5, spreading in latitude. General: RCP4.5 shows more SSR over central/southern Australia in summer, while RCP8.5 generates higher SSR in over northern Australia in autumn and spring.
RCP8.5 ACCESS1.0					1: Higher SSR over central/eastern Australia (especially in R8) for A1.3. 2: Higher SSR over ocean at north coast for A1.0, not for A1.3 (see R1, R2). The patch of high SSR is bigger in A1.0. 3: Higher SSR in A1.0 in the north, especially over ocean (R1, R2). 4: Patch of higher SSR in A1.3 over northern/central Australia, not for A1.0 (here, patch of higher SSR only in R7, R8). General: A1.0 shows higher SSR in summer and autumn, A1.3 has higher SSR over central Australia in spring.

General observations:

- General circulation patterns are represented in the patterns of solar radiation shown by the models.
- ACCESS1.0 tends to model higher surface solar radiation amounts in autumn and winter compared to ACCESS1.3.
- ACCESS1.3 tends to model higher surface solar radiation amounts in summer and spring compared to ACCESS1.0.
- Most differences between models and scenarios are seen in central and northern Australia.
- For the period 1990-2010, there seem to be higher differences between models than between scenarios.
- Most differences have been observed for summer and spring.

Time period 2: 2020-2040

	RCP4.5 ACCESS1.3	RCP8.5 ACCESS1.0	RCP8.5 ACCESS1.3
RCP4.5 ACCESS1.0	1: High SSR in central Australia, less pronounced in A1.0 which shows ‘hole’ in R7. A1.3 generally models less SSR along the coast (see R9, R10) especially. 2: High SSR in northern Australia for both models, however A1.3 shows decrease along coast (R3, R4), while A1.0 shows higher SSR over ocean (R1, R2). 3: High SSR in northern Australia for both models, however A1.3 shows decrease along coast (R3, R4), while A1.0 shows higher SSR over ocean (R2). 4: A1.0 shows higher SSR over ocean (R1, R2, R3), while SSR is higher for A1.3 over central Australia (R7, R8). General: More solar radiation over central Australia in summer and spring for A1.3, while A1.0 tends to model higher RSDS amounts over ocean generally.	1: RCP4.5 shows slightly higher SSR over parts of central Australia (R7, R8). 2: RCP8.5 shows patch of high SSR in R2, R3. 3: No major differences. 4: No major differences. General: Same model, very similar.	1: ‘Hole’ in high SSR pattern in A1.0 (R7, R8). A1.3 also shows higher SSR towards eastern Australia (see R9). 2: Higher amounts of incoming solar radiation over northwestern ocean in A.10 (R1, R2). A1.3 shows lower SSR over Darwin region (R3, R4). 3: Lower SSR over southeastern Australia for A1.3, while A1.0 has higher SSR amounts in northern Australia, especially over ocean and near Darwin (R3). 4: A1.0 shows higher SSR over ocean (R1, R2, R3), while SSR is higher for A1.3 over central Australia (R7, R8). A1.0 only represents this high SSR patch at west coast (R6, R7). General: More solar radiation over central Australia in summer and spring for A1.3, while A1.0 tends to model higher RSDS amounts over ocean generally.
RCP4.5 ACCESS1.3		1: High SSR in central Australia, less pronounced in A1.0 which shows ‘hole’ in R7 and R8. A1.3 generally models less SSR along the coast (see R9, R10) especially. 2: A1.0 shows bigger patch of SSR in northern Australia, especially over ocean (R1, R2) and over land in R2, R3. 3: A1.0 has higher SSR over ocean in the north, higher SSR around Darwin especially (R3). 4: A1.0 has higher SSR over ocean, patch of high SSR over central Australia in A1.3 (R7, R8). General: A1.0 generally shows higher incoming solar radiation over ocean while A1.3 shows higher amounts over central Australia in summer and spring.	1: No major differences. 2: RCP8.5 shows slightly higher SSR over ocean in northwest, see R1. 3: No major differences. 4: RCP8.5 shows bigger patch of high SSR over central Australia (R3, R8, and R9). General: Only slight differences, differences especially in autumn in spring.
RCP8.5 ACCESS1.0			1: ‘Hole’ in high SSR patch in R7, R8 over central Australia for A1.0. A1.0 also shows higher SSR for central east coast (R9, R10). 2: A1.0 shows bigger patch of SSR in northern Australia, especially over ocean (R1, R2) and over land in R2, R3.

			3: A1.0 has higher SSR over ocean in the north, higher SSR around Darwin especially (R3). 4: A1.0 has higher SSR over ocean, patch of high SSR over central Australia in A1.3 (R7, R8). General: A1.0 generally shows higher incoming solar radiation over ocean while A1.3 shows higher amounts over central Australia in summer and spring.

General observations:

- The same patterns of differences are shown between models, regardless of scenario.
- ACCESS1.0 tends to model a patch of higher surface solar radiation in central Australia for summer and spring, while ACCESS1.3 only shows a patch of high radiation at the west coast for the same seasons.
- ACCESS1.3 has a tendency to model higher surface solar radiation over the oceans compared to ACCESS1.0, especially in autumn and winter.

Time period 3: 2040-2060

	RCP4.5 ACCESS1.3	RCP8.5 ACCESS1.0	RCP8.5 ACCESS1.3
RCP4.5 ACCESS1.0	1: A1.3 shows higher amounts over Australia in general, especially for central Australia in R7, R8. 2: Both show high SSR over northern Australia, while A1.3 has less high values over northeast coast (R3, R4). 3: A1.3 shows less over northeast coast, especially R4. 4: A1.3 shows higher amounts over Australia in general, especially for central Australia in R7, R8, and R9. General: A1.3 shows patch of high SSR over central Australia in summer and spring, this is only pronounced on the west coast for A1.0.	1: High SSR consistent over central Australia for RCP8.5, while 'hole' for A1.0 in R7, R8. RCP4.5 generally shows slightly lower incoming solar radiation amounts. 2: No major differences. 3: No major differences. 4: No major differences. General: Only differences in summer where SSR is generally higher for RCP8.5.	1: A1.3 RCP8.5 shows higher SSR over continent, especially central/northwestern Australia (R7, R8). 2: A1.0 RCP4.5 shows higher SSR over northern Australia + ocean (R1, R2, R3, R4). 3: A1.0 RCP4.5 has higher amounts over northern ocean. 4: A1.3 RCP8.5 has patch of higher SSR over north-central Australia, see R7, R8, and R9. General: Biggest differences over land in summer and spring.
RCP4.5 ACCESS1.3		1: Pattern of high SSR over south-central Australia more distinct in A1.3 RCP4.5, while this patch is slimmer for A1.0 RCP8.5 (R7, R8). 2: A1.0 shows higher SSR over northern ocean (R1, R2) and around Darwin (R3, R4). Otherwise no major differences over land. 3: A1.0 shows higher amounts in R2, R3, and R4. 4: Pattern of high SSR over north-central Australia very distinct in A1.3 RCP4.5, while this high is only on west coast for A1.0 RCP8.5 (R5, R6). General: Greatest differences over land in summer and spring. Only slight differences for east coast.	1: No major differences. Slightly higher SSR amounts towards east coast in RCP8.5. 2: Patch of high SSR over northern Australia bigger in latitude for RCP4.5 (R3, R4, R8, R9). 3: No major differences. 4: No major differences. General: Same model, only slight differences.
RCP8.5 ACCESS1.0			1: A1.3 shows higher amounts over Australia in general, especially for central Australia in R7, R8. 2: Both show high SSR over northern Australia, while A1.3 has less high values over northeast coast (R3, R4). 3: A1.3 shows less over northeast coast, especially R4. 4: A1.3 shows higher amounts over Australia in general, especially for central Australia in R7, R8, and R9.

			General: A1.3 shows patch of high SSR over central Australia in summer and spring, this is only pronounced on the west coast for A1.0.

Evaluation across time periods

	1990-2010 vs. 2020-2040	2020-2040 vs. 2040-2060	1990-2010 vs. 2040-2060
RCP4.5 ACCESS1.0	1: Higher SSR in R7 for 1990-2010 compared to 2020-2040. 2020-2040 shows higher radiation for southeastern Australia (R9, R14), but the difference is only in the range of 20 W/m^2. 2: No major differences. 3: No major differences. 4: No major differences. General: Greatest difference in summer, where 1990-2010 shows higher SSR over central Australia while 2020-2040 shows higher SSR in (south-) eastern Australia.	1: 2020-2040 shows continuous patch of high SSR over central Australia while 2040-2060 shows two distinct patches in western and southern Australia (R7, R8). 2020-2040 also shows slightly higher radiation in south eastern Australia (R9, R14). 2: No major differences. 3: No major differences. 4: No major differences. General: Greatest difference in summer.	1: Lower SSR over western central Australia for 2040-2060 (R7, R8). 2: 2040-2060 shows slightly higher SSR in northern Australia (R4). 3: No major differences. 4: 2040-2060 shows small patches of lower SSR in northwestern Australia (R2, R3). General: Greatest difference observed in summer, 2040-2060 shows lower SSR for central Australia.
RCP4.5 ACCESS1.3	1: Patch of high solar radiation over central Australia more pronounced in 1990-2010 (R7, R8, R9, and R14). 2: No major differences over the continent. 3: No major differences. 4: Slightly higher SSR in R8 for 1990-2010. General: Very similar, same general patterns, only slight differences.	1: Bigger patch of high SSR in 2040-2060(R7, R8). 2: No major differences for the continent. 2040-2060 shows higher SSR over ocean for R1, R2. 3: Both show patch of high SSR over northwestern Australia, however this is more pronounced in 2040-2060 (R3). 4: Patch of high SSR over central Australia more pronounced in 2040-2060 (see R8, R9). General: 2040-2060 tends to show bigger patches of high SSR over central Australia in summer and spring. Greatest difference observed in spring.	1: 1990-2010 shows higher SSR in eastern Australia (R9, R14). 2: 2040-2060 shows higher SRR along central north coast (R3) and in east-central Australia (R8, R9). 3: 2040-2060 shows higher SSR in northern Australia (R2, R3). 4: 2040-2060 shows bigger patch of high solar radiation in northern/central Australia (R3, R4, R8, and R9). General: 2040-2060 generally shows higher SSR, however differences are not more than around 20 W/m^2.
RCP8.5 ACCESS1.0	1: 2020-2040 shows higher SSR in southern Australia, see R8, R13. 2: No major differences. 3: 1990-2010 shows higher SSR along coast in R2. 4: No major differences. General: 2020-2040 shows higher SSR over central Australia in summer.	1: For 2040-2060 we have a continuous patch of high SSR over central Australia, this is much less pronounced in 2020-2040, especially in R7, R8. Also, 2040-2060 shows higher SSR in eastern Australia (R9). 2: 2020-2040 shows high RSDS in R3, this is less pronounced in 2040-2060. 3: Slight difference in R3, with 2020-2040 producing bigger patch of high SSR than 2040-2060. 4: No major differences. General: Greatest difference in summer for central Australia.	1: While 2040-2060 shows high solar radiation in eastern/central Australia (R8, R9, R13, R14), this is not shown in 1990-2010. 2040-2060 also shows higher SSR for eastern Australia (R9. 2: 1990-2010 shows higher RSDS over northern Australia (R3). 3: Higher SSR at northern coast for 1990-2010 (R2, R3). 4: 1990-2010 shows higher SSR amounts at coast in R1, R2. General: 2040-2060 shows higher SSR amounts, especially compared to RCP4.5 there is a greater difference between the two time periods.
RCP8.5 ACCESS1.3	1: 2020-2040 shows greater SSR over central Australia, see R7, R8, R9, R14. It also produces higher radiation amounts for	1: Patch of high SSR over western & central Australia bigger in 2040-2060 (R7,	1: 2040-2060 shows greater SSR over central Australia, see R7, R8, R9, R14. It also produces higher radiation amounts for

	eastern Australia (patch of high SSR moving closer towards coast), see R9. 2: Only slight differences: 1990-2010 shows higher SSR in R4, while 2020-2040 shows higher SSR between R3 and R8. 3: No major differences. 4: No major differences, patch of high SSR in 1990-2010 goes slightly more south. General: Greatest difference in summer where 2020-2040 shows higher SSR over central Australia.	R8, R9) and spreading more towards east (R9, R14). 2: Higher SSR for R4 in 2020-2040. 3: Higher SSR for R4 in 2020-2040. 4: No major differences. General: Very similar, 2040-2060 tends to show slightly bigger patches in general.	eastern Australia (patch of high SSR moving closer towards coast), see R9. 2: 1990-2010 shows higher SSR in R4, while 2040-2060 shows higher SSR in R8. 3: No major differences, 2040-2060 shows higher in R4. 4: No major differences. General: Greatest difference in summer with 2040-2060 showing more SSR in central Australia.

General observations:

- For ACCESS1.0, the greatest difference between time periods can be observed in summer. There tends to be lower incoming solar radiation over western part of central Australia in the future.
- For ACCESS1.3, the same general patterns are shown in the future. Only slight differences between time periods could be observed.
- For ACCES1.0, RCP8.5 generally tends to show higher surface solar radiation in the future than RCP4.5.
- Differences between time periods tend to be greater for RCP8.5 than for RCP4.5.

Evaluation of total cloud amount

Time period 1: 1990-2010

	Historical ACCESS1.3	RCP4.5 ACCESS1.0	RCP4.5 ACCESS1.3	RCP8.5 ACCESS1.0	RCP8.5 ACCESS1.3
Historical ACCESS1.0	1: 50% CLT almost everywhere in A1.0, less clouds over central Australia, minimum cloud amount on west coast for A1.0 (R6). Same pattern smaller in A1.3 (see R6), patch of fewer clouds over central Australia slimmer, extending less southwards. Higher cloud amounts (70-80%) over ocean in 1.3. 2: Patch of low cloud cover over central/northern Australia in A1.0 (R1-R4, R6-R9), not pronounced in A1.3. Generally fewer clouds over continent in A1.0 compared to A1.3. More clouds over southern ocean in A1.3 (R16, R17, and R18). Clouds along coastlines in A1.3. 3: Generally fewer clouds for both models in northwestern Australia, however more pronounced in A1.0. Patch of increased cloud amount in southeastern Australia (R14) for A1.3. 4: Both models show fewer clouds over central and northern Australia, while A1.3 has increase in clouds along the coast (R2, R3, and R4). A1.0 shows low	1: Same general pattern, low cloud amount in western Australia more pronounced by RCP4.5 (R6, R7). Lower cloud amounts in central/eastern Australia for historical (RR9, R14), patch of very low cloud amount in R8 for RCP4.5. 2: Strip of low cloud amounts over central Australia in historical (R1-4, R6-8), while there is only few clouds on west coast for RCP4.5. 3: Cloud pattern slightly different at north coast (R2, R3), otherwise no major differences. 4: Slightly more cloud cover along east coast in RCP4.5 (R9, R10, R14, and R15). General: Generally, the historical run shows less cloud cover and a more homogenous distribution of cloud amounts across Australia. Also, there is a higher difference between land and ocean /coast for RCP4.5.	1: Generally fewer clouds in historical A1.0. Difference between land and ocean more pronounced in RCP4.5 A1.3 (more clouds over ocean and along coast, see especially southern Australia). Patch of low cloud amounts at west coast more pronounced in historical A1.0 (R6). 2: Patch of fewer clouds in central Australia more pronounced in historical A1.0, see R1-4, R6-8. Fewer clouds over continent in historical A1.0. 3: Low CLT at west coast for RCP4.5 A1.3 (R1, R2, R6, R7). This is more pronounced in historical A1.0, showing fewer clouds in northern Australia. RCP4.5 A1.3 shows more clouds over southeastern Australia (R14). Historical A1.0 shows the same phenomena, but less pronounced. 4: Generally lower cloud amounts over central/northern Australia, more pronounced in historical A1.0. A1.0 shows two patches of low cloud amounts at the west (R1, R2, R6, R7) and north (R3, R4) coast,	1: RCP8.5 shows more cloud cover in central/eastern Australia (R8, R9, and R14). RCP8.5 shows low amount of clouds over ocean east of Australia (R5, R10). Historical run has more pronounced absence of clouds at west coast (R6). 2: RCP8.5 shows slightly less cloud amount at west/north coast (R2, R6), otherwise no major differences. 3: More low cloud amounts in the north by RCP8.5 (R2, R3), while RCP8.5 also shows more clouds over central Australia (R7, R8). 4: Same pattern, fewer clouds at west coast for historical (R1, R2, R6, R7). General: Generally both runs show the same pattern, only minor differences at the coast and over central Australia.	1: Generally more clouds in A1.3, especially over ocean and along coast. Few clouds (40%) over all central Australia in A1.0, while only patch of few clouds at west coast (R7, R8) and in the south (R9, R13, R14) for A1.3. 2: Much fewer clouds in A1.0 over central Australia (<30% vs. <50%). Patch of particularly low cloud amount (<20%) in northern part of central Australia for A1.0. 3: High cloud cover in southeastern Australia (R14) for A1.3. All of northern Australia has few clouds in A1.0, while only northwest coast shows the same amount of clouds in RCP 8.5. A1.3 (see R1, R2, R5, R6). 4: Fewer clouds over northern Australia in A1.0, while RCP8.5 has more clouds along north coast (R3, R4) and only shows fewer cloud amounts at northwest coast (R6, R7). General: RCP8.5. A1.3 has a more varied cloud cover, distinctions between land and ocean tend to be clearer than

	cloud amounts along west coast (R1, R2, R6, and R7) and in the north (R3, R4). More cloud cover over ocean in A1.3 (R16, R17, and R18). General: A1.3 generally shows more cloud cover over ocean and along the coast compared to A1.0. A1.0 has more homogenous cloud cover overall and shows less cloud cover than A1.3, especially in spring.		while RCP4.5 A1.3 shows more cloud cover along coast in the north. General: Historical A1.0 shows more homogenous and generally lower cloud amounts than RCP4.5 A1.3, in all seasons. A1.3 distinguishes more between land and ocean. Both models show generally more cloud cover in southeastern Australia and fewer cloud amounts over central/western Australia.		for historical A1.0. RCP8.5 A1.3 tends to show less clouds for all of Australia, especially the southeast.
Historical ACCESS1.3		1: Historical A1.3 shows generally higher cloud amounts over the ocean and along the coast. Low in cloud amounts at west coast more pronounced in RCP4.5 A1.0 (R6, R7). 2: RCP4.5 A1.0 has lower cloud amounts over northern/central Australia. Fewer clouds at west coast more pronounced in RCP4.5 A1.0 (R7). 3: Historical A1.3 shows high cloud cover over southeastern Australia (R14). RCP4.5 A1.0 generally shows fewer clouds, particularly over northeast (R3, R4, R8, and R9). Low cloud amount in the north more pronounced by RCP4.5 1.0. 4: RCP4.5 A1.0 shows two patches of almost no clouds at the west and north coast, while	1: Same pattern, no major differences. 2: Fewer clouds over central Australia (R7, R8, R9) for RCP4.5. 3: Same pattern, no major differences. 4: Same pattern, no major differences. General: The two runs generally show the same pattern: more clouds over the ocean and at the coast, more clouds in summer, and fewer clouds over central Australia in winter and spring.	1: Fewer clouds over ocean in RCP8.5 A1.0, especially in northern parts. Pattern of low cloud amounts at west coast (R7) more pronounced in RCP8.5 A1.0. More clouds along southern coast in historical A1.3 (R12, R13). 2: Historical A1.3 shows patch of fewer clouds at west coast (R7), while RCP8.5 A1.0 shows lower cloud amounts over all of northern and central Australia, particularly in R8 and around. Both models show more clouds along south coast, especially historical A1.3. 3: Both show lower cloud amounts at west coast (R7, R2). Historical A1.3 shows more clouds in southeast (R14), while RCP8.5 shows fewer	1: RCP8.5 shows more clouds in central Australia (R7, R8, and R9), while the low cloud amount at the west coast (R6) is more pronounced in RCP8.5 than historical. 2: Generally the same pattern, slightly fewer clouds in historical for R7. 3: Few clouds at northwest coast, while higher cloud amount in southeastern Australia. Pattern almost the same for historical and RCP8.5, only RCP8.5 shows more clouds over central Australia (R8, R9). 4: Lower cloud amounts over central/northern Australia for both runs, fewer clouds at west coast more pronounced in RCP8.5 (R6, R7). General: Only minor differences, RCP8.5

		historical A1.3 only shows the same phenomena less pronounced for the west coast (R6, R7). General: Historical A1.3 generally shows more clouds, especially over southeastern Australia in winter, and over the oceans in all seasons.		clouds in northern Australia, especially in R2, R3, and R4. 4: Fewer clouds over northern Australia for both, but historical A1.3 shows more clouds at northeast coast (R3, R4), while RCP8.5 A1.0 shows two patches of no clouds at west coast (R1, R2, R6, R7) and northeast coast (R3, R4). General: Both models show fewer clouds in winter, A1.3 particularly over the ocean.	shows more clouds over central-east Australia in autumn and winter.
RCP4.5 ACCESS1.0			1: Fewer clouds over ocean for all rectangles except R16-20 for A1.0 compared to A1.3. Fewer clouds in central-eastern Australia in A1.3 compared to A1.0 (R9). 2: A1.0 shows fewer clouds over north central Australia, especially around west coast. 3: A1.3 has more clouds over the ocean south of Australia (R11, R12, R13), and more clouds over southeastern Australia in particular (R14). On the other hand, the low cloud amounts over northwestern Australia are more pronounced in A1.0 (especially in R3). 4: The phenomena of fewer clouds over northwestern Australia is more pronounced in A1.0. A1.3 shows higher cloud amounts along	1: RCP8.5 has less clouds over ocean south of Australia (R11, R12), but more clouds in central-eastern Australia (8, R9). 2: RCP8.5 shows a distinctive pattern of low cloud cover over central Australia (R2, R3, R7, R8, and R9) which is not really present in RCP4.5. Otherwise very similar pattern, especially along coast. 3: Slightly more clouds in RCP8.5 for R7 and less clouds at northeast coast (R4, R5), otherwise no major differences. 4: No major differences. General: Fewer clouds can be observed in central Australia and in the northwest. We have the highest cloud amount in summer and the lowest in winter/spring.	1: Generally more clouds over oceans in RCP8.5 A1.3. Substantially higher cloud amounts at the north coast in RCP8.6 A1.3 (R3, R4). Also, RCP4.5 A1.0 shows lower cloud cover in central Australia (R7, R8, and R9). 2: RCP4.5 A1.0 shows lower cloud cover over almost all of Australia, especially central Australia. Higher cloud amounts at north coast (R3, R4) shown by RCP8.5 A1.3. 3: More clouds in southeastern Australia for RCP8.5 A1.3 (R14). Phenomena of fewer clouds over northwestern Australia more distinct in RCP4.5 A1.0, ranging more eastwards too. 4: Major differences at northeastern coast (R3,

			northeastern coast than A1.0 (R2, R3, and R4). General: A1.3 shows more clouds over oceans, cloud amounts are more diverse. Generally, A1.0 shows fewer clouds.		R4): RCP4.5 A1.0 shows fewer clouds while RCP8.5 A1.3 shows more clouds. Generally fewer clouds in RCP4.5 A1.0. General: The two models show the same patterns, while A1.0 generally shows less clouds in central and northwestern Australia, while A1.3 has higher cloud amounts at the coasts, especially in southeastern Australia.
RCP4.5 ACCESS1.3				1: RCP4.5 A1.3 generally shows higher cloud amounts over the ocean and along south coast. While RCP8.5 A1.0 has a patch of fewer clouds in central/southwestern Australia, this patch is more central/northerly for RCP4.5 A1.3. 2: RCP8.5 has a very pronounced patch of no clouds over north-central Australia (R7, R8 and around), while this is not as distinct in RCP4.5 A1.3. 3: RCP4.5 A1.3 shows more clouds in southeastern Australia (R14). There are no clouds in northern Australia for RCP8.5 A1.0 (<20%), while this phenomena is only observed in the northwest (R2, R6, R6) for RCP4.5 A1.3. 4: Same pattern, again low cloud cover over northern Australia more	1: More clouds in central Australia (R7, R8) for RCP4.5. 2: More clouds in central Australia (R7, R8, and R9) for RCP8.5. 3: Same pattern, slightly more clouds in R9 for RCP4.5 (central-east Australia). 4: Particularly low cloud amounts at west coast (R6, R7) for RCP8.5. General: Very similar patterns, slight differences.

				pronounced in RCP8.5 A1.0. General: Particularly low cloud amounts for winter and spring in northern Australia for RCP8.5 A1.0.	
RCP8.5 ACCESS1.0					1: A1.3 shows generally more clouds, especially at northern coast (R3, R4). A1.0 shows generally less clouds, especially in central Australia (R7, R8). 2: While A1.3 has about 50% almost homogenously over all of Australia, A1.0 shows a patch of no clouds in northern central Australia (R8, R9) and at the northern west coast. 3: A1.3 shows more clouds over southeastern Australia (R14, R19) and fewer clouds at northwest coast (R1, R2, R6, R7). A1.0 generally shows less clouds, especially in northwestern Australia. 4: Both show fewer clouds over northern Australia, more distinct in A1.0. A1.3 shows more clouds over ocean south of Australia. General: A lot more clouds over ocean in summer for A1.3, fewer clouds in northeastern Australia in spring for A1.0.

General observations

- ACCESS1.0 tends to show less cloud cover than ACCESS1.3 generally, especially over the ocean in summer.

- ACCESS1.3 calculates more clouds over southeastern Australia in winter.
- Differences in total cloud amount tend to be greater between models than between scenarios in all seasons.
- The biggest differences in total cloud amount between the two models can be observed in summer.
- ACCESS1.3 tends to have more distinguished cloud amounts between ocean, coast and land.

Time period 2: 2020-2040

	RCP4.5 ACCESS1.3	RCP8.5 ACCESS1.0	RCP8.5 ACCESS1.3
RCP4.5 ACCESS1.0	1: A1.0 generally shows less clouds and more homogenous cloud cover. Both models show low in cloud amount at west coast (R6); this is more distinct in A1.0. A1.3 shows more clouds over ocean and along coast. Lower cloud amounts over central/southern Australia are prominent in both models, but A1.0 has a more distinct extent of this pattern, A1.3 has more clouds in R7, R8. 2: A1.0 shows lower cloud amounts, very distinct pattern of almost no clouds in central Australia (R1-4, R6-8), while this is less pronounced in A1.3, showing only fewer clouds in central Australia (R7, R8, R9), but not along northwest coast. 3: Almost no clouds all over northern Australia for A1.0, while A1.3 only shows patch of low cloud amount along west coast. A1.3 also shows more clouds in southeastern Australia (R14). Quite different general patterns. 4: Similar general pattern, but A1.0 shows low cloud cover over all of northern Australia including coast and ocean, while A1.3 shows more clouds along coast, especially in R3, R4. Also, A1.3 shows higher cloud amounts over southern ocean, see R11, R12, R13, R16, R17, R18, R19. General: A1.0 generally shows lower total cloud amounts, big differences for all seasons.	1: No major differences. 2: Patch of no clouds over north-central Australia more pronounced in RCP4.5, ranging to west coast (R1, R2, and R6). 3: No major differences. 4: No major differences. General: Same model, showing same pattern, only small differences between scenarios.	1: A1.3 produces more clouds over ocean and along coast. Patch of low cloud cover at west coast (R6) more pronounced in A1.0. Same for patch of lower cloud amounts over central Australia (R7, R8). 2: A1.0 shows lower cloud amounts, very distinct pattern of almost no clouds in central Australia (R1-4, R6-8), while this is much less pronounced in A1.3, showing only fewer clouds towards west coast (R7, R8, R9), but not in central Australia. 3: Almost no clouds all over northern Australia for A1.0, while A1.3 only shows patch of low cloud amount along west coast. A1.3 also shows more clouds in southeastern Australia (R14). Quite different general patterns. 4: Similar general pattern, but A1.0 shows low cloud cover over all of northern Australia including coast and ocean, while A1.3 shows more clouds along coast, especially in R3, R4. Also, A1.3 shows higher cloud amounts over southern ocean, see R11, R12, R13, R16, R17, R18, R19. General: A1.0 generally shows lower total cloud amounts, big differences for all seasons. Greatest difference in pattern found for autumn and winter.
RCP4.5 ACCESS1.3		1: A1.3 produces more clouds over ocean and along coast. Patch of low cloud cover at west coast (R6) more pronounced in A1.0. Same for patch of lower cloud amounts over central and southern Australia (R7, R8). 2: A1.0 shows lower cloud amounts, very distinct pattern of almost no clouds in central and northern Australia (R1-4, R6-8), while this is much less pronounced in A1.3, showing only fewer clouds in central Australia (R7, R8, R9). 3: Almost no clouds all over northern Australia for A1.0, while A1.3 only shows patch of low cloud amount along west coast. A1.3 also shows more clouds in southeastern Australia (R14). Quite different general patterns.	1: RCP8.5 shows consistently low CLT over central Australia, while RCP4.5 has 'hole' in R7, R8. 2: Low CLT over central Australia in RCP4.5, only pronounced for western central Australia in RCP8.5 (R6, R7). 3: RCP4.5 shows slightly higher CLT for southeastern Australia (R14). 4: No major differences. General: Biggest difference in autumn, generally very similar.

		4: Similar general pattern, but A1.0 shows low cloud cover over all of northern Australia including coast and ocean, while A1.3 shows more clouds along coast, especially in R3, R4. Also, A1.3 shows higher cloud amounts over southern ocean, see R11, R12, R13, R16, R17, R18, R19. General: A1.0 generally shows lower total cloud amounts, big differences for all seasons. Greatest difference in pattern found for autumn and winter. Substantial differences over ocean for all seasons.	
RCP8.5 ACCESS1.0			1: A1.0 generally shows less clouds and more homogenous cloud cover. Both models show low in cloud amount at west coast (R6); this is more distinct in A1.0. A1.3 shows more clouds over ocean and along coast. Lower cloud amounts over central/southern Australia are prominent in both models, but A1.0 has a more distinct extent of this pattern, A1.3 shows a slimmed version of the pattern visible in A1.3. 2: A1.0 shows lower cloud amounts, very distinct pattern of almost no clouds in central Australia (R2-4, R7-9), while this is only pronounced for west coast (R6, R7) in A1.3. 3: Almost no clouds all over northern/western Australia for A1.0, while A1.3 only shows patch of low cloud amount along west coast. A1.3 also shows more clouds in southeastern Australia (R14). Quite different general patterns. 4: Similar general pattern, but A1.0 shows low cloud cover over all of northern Australia including coast and ocean, while A1.3 shows more clouds along coast, especially in R3, R4. Also, A1.3 shows higher cloud amounts over southern ocean, see R11, R12, R13, R16, R17, R18, R19. General: A1.0 generally shows lower total cloud amounts, big differences for all seasons.

General observations:

- General patterns identified for surface solar radiation are also shown for the total cloud amount (more clouds > less surface solar radiation and vice versa).
- Differences between scenarios tend to become greater for 2020-2040 compared to 1990-2010.

Time period 3: 2040-2060

	RCP4.5 ACCESS1.3	RCP8.5 ACCESS1.0	RCP8.5 ACCESS1.3
RCP4.5 ACCESS1.0	1: A1.0 generally shows less clouds and more homogenous cloud cover. Both models show low in cloud amount at west coast (R6); this is more distinct in A1.0. A1.3 shows more clouds over ocean and along coast. Lower cloud amounts over central/southern Australia are prominent in both models, but A1.0 has wider extent of this pattern. 2: A1.0 shows lower cloud amounts, very distinct pattern of almost no clouds in central Australia (R2, R3, R7, R8), while this is less pronounced in A1.3, showing only fewer clouds in central/western Australia (R6, R7, R8, R9). 3: Almost no clouds all over northern Australia for A1.0, while A1.3 shows patch of low cloud amount along west coast but not in the north. A1.3 also shows more clouds in southeastern Australia (R14). 4: Similar general pattern, but A1.0 shows low cloud cover over all of northern Australia including coast and ocean, while A1.3 shows more clouds along coast, especially in R3, R4. Also, A1.3 shows higher cloud amounts over southern ocean, see R11, R12, R13, R16, R17, R18, R19. General: A1.0 generally shows lower total cloud amounts, biggest difference in autumn.	1: RCP8.5 generally shows lower CLT, especially over east-central Australia (R9, R14). 2: No major differences. 3: No major differences. 4: No major differences. General: Same model, showing same pattern, only small differences between scenarios.	1: A1.3 produces more clouds over ocean and along coast. Patch of low cloud cover at west coast (R6) more pronounced in A1.0. 2: A1.0 shows lower cloud amounts, very distinct pattern of almost no clouds in central/northern Australia (R1-4, R6-8), while this is much less pronounced in A1.3, showing only fewer clouds towards west coast (R7, R8, R9) and in central Australia (R7, R8), but not spreading northwards. 3: Almost no clouds all over northern Australia for A1.0, while A1.3 only shows patch of low cloud amount along northwest coast. A1.3 also shows more clouds in southeastern Australia (R14). 4: Similar general pattern, but A1.0 shows low cloud cover over all of northern Australia including coast and ocean, while A1.3 shows more clouds along coast, especially in R3, R4. A1.3 shows no clouds in R8, R9, this is not reproduced by the same extent by A1.0. Also, A1.3 shows higher cloud amounts over southern ocean, see R11, R12, R13, R16, R17, R18, R19. General: A1.0 generally shows lower total cloud amounts, especially over oceans; big differences for autumn, winter, spring.
RCP4.5 ACCESS1.3		1: A1.3 produces more clouds over ocean and along coast. Patch of low cloud cover at west coast (R6) more pronounced in A1.0. Same for patch of lower cloud amounts over central and southern Australia (R9, R14). 2: A1.0 shows lower cloud amounts, very distinct pattern of almost no clouds in central and northern Australia (R2-4, R6-8), while this is much less pronounced in A1.3. 3: Almost no clouds all over northern Australia for A1.0, while A1.3 only shows patch of low cloud amount along west coast and into north-central Australia. A1.3 also shows more clouds in southeastern Australia (R14). 4: Similar general pattern, but A1.0 shows low cloud cover over all of northern Australia	1: No major differences. 2: Low CLT in RCP4.5 in R9, patch of low CLT not spreading as far east in RCP8.5. 3: No major differences. 4: No major differences. General: Biggest difference in autumn, generally very similar.

		including coast and ocean, while A1.3 shows more clouds along coast, especially in R3, R4. Also, A1.3 shows higher cloud amounts over southern ocean, see R11, R12, R13, R16, R17, R18, R19. General: A1.0 generally shows lower total cloud amounts. Greatest difference found for autumn and winter. Substantial differences over ocean for all seasons.	
RCP8.5 ACCESS1.0			1: A1.0 generally shows less clouds and more homogenous cloud cover. Both models show low in cloud amount at west coast (R6); this is more distinct in A1.0. A1.3 shows more clouds over ocean and along coast. Lower cloud amounts over central/southern Australia are prominent in both models, but A1.0 has a more distinct extent of this pattern, A1.3 shows a slimmed version of the pattern visible in A1.3. 2: A1.0 shows lower cloud amounts, very distinct pattern of almost no clouds in north-central Australia (R2-4, R7-9), while this is only pronounced for west coast and part of central Australia (R6, R7, R8) in A1.3. 3: Almost no clouds all over northern/western Australia for A1.0, while A1.3 only shows patch of low cloud amount along north-west coast. A1.3 also shows more clouds in southeastern Australia (R14). 4: Similar general pattern, but A1.0 shows low cloud cover over all of northern Australia including coast and ocean, while A1.3 shows more clouds along coast, especially in R3, R4. Also, A1.3 shows higher cloud amounts over southern ocean, see R11, R12, R13, R16, R17, R18, R19. General: A1.0 generally shows lower total cloud amounts, big differences for all seasons.

Evaluation across time periods

	1990-2010 vs. 2020-2040	2020-2040 vs. 2040-2060	1990-2010 vs. 2040-2060
RCP4.5 ACCESS1.0	1: Patch of low CLT (30%) bigger in 2020-2040 over central Australia (R8, R9) and spreading more towards southeastern Australia (R14). 2: 2020-2040 shows patch of low CLT over eastern central Australia (especially R8, R9). This is not pronounced in 1990-2010, which is only showing low cloud amount at west coast (R6). 3: 2020-2040 generally shows fewer clouds especially over central Australia (see R6-R9). 4: No major differences. General: 2020-2040 tends to show fewer clouds, especially over central Australia in autumn.	1: No major differences. 2: Pattern of high SSR path over northern Australia slightly different. 3: No major differences. 4: No major differences. General: Very similar.	1: Patch of low CLT bigger for 2040-2060 and spreading more towards east (see R8, R9, and R14). 2: 1990-2010 shows low cloud amounts at west coast (R6), this is much less pronounced in 2040-2060. But 2040-2060 shows patch of low CLT in central Australia (R3, R8, and R9) which is not produced by the 1990-2010 simulation. Also, fewer clouds at east coast (see R9, R10) in the future. 3: 2040-2060 shows low CLT at northeast coast (R4, R9), this is less pronounced in 1990-2010. 4: No major differences. General: 2040-2060 tends to show fewer clouds over the continent, especially in autumn.
RCP4.5 ACCESS1.3	1: 2020-2040 only shows slim patch of low CLT over central Australia, see R7, R8. 2: Patch of low CLT more pronounced at west coast for 1990-2010 (R6), while it is more pronounced in central-east Australia for 2020-2040 (R8, R9). 3: Same pattern, patches slightly bigger in 2020-2040. 4: No major differences. General: Very same general pattern, usually slightly bigger patches of low CLT in 2020-2040.	1: 2040-2060 generally shows slightly lower CLT over the continent, especially along coast, for example see area around Darwin (R3). Also, both the patch of low CLT at the west coast (R6) and the patch of lower CLT over central Australia (R7, R8) is more pronounced in 2040-2060. 2: Patch of low CLT over central Australia (R6, R7, R8, and R9) more pronounced in 2040-2060. 3: The patch of low CLT in the west (R2, R6, and R7) in 2020-2040 tends to spread east for 2040-2060 (R3, R8). 4: Patch of low CLT over north & central Australia bigger in the future. General: Same patterns, but they are more pronounced and bigger in 2040-2060 compared to 2020-2040.	1: 2040-2060 generally shows slightly lower CLT over the continent, especially along coast, for example see area around Darwin (R3). Also, both the patch of low CLT at the west coast (R6) and the patch of lower CLT over central Australia (R7, R8) is more pronounced in 2040-2060. 2: Patch of low CLT over central Australia (R6, R7, and R8) more pronounced in 2040-2060. Also it spreads more eastward (see R9) in the future. 3: The patch of low CLT in the west (R2, R6, and R7) in 1990-2010 tends to spread east for 2040-2060 (R3, R8). This brings areas of lower CLT around this patch. 4: Patch of low CLT over north & central Australia bigger in the future. General: Same patterns, but they are more pronounced and bigger in 2040-2060 compared to 1990-2020.
RCP8.5 ACCESS1.0	1: 2020-2040 shows lower CLT in east-central Australia (R8, R9). 2: 1990-2010 shows CLT <10% at west coast (R2, R6), this is not shown for 2020-2040. However, patch of low CLT over east-central Australia more pronounced in 2020-2040.	1:2040-2060 shows lower CLT in eastern Australia (R9). Also, very low CLT (<10%) shown in R7 for 2040-2060, not shown in 2020-2040. 2: 2040-2060 shows low CLT at west coast (R1, R2, R6) which is not shown in 2020-2040.	1: Lower CLT for central and eastern Australia in 2040-2060, see R8, R9, and R14. Also, low cloud amount at west coast more pronounced in 2040-2060 (R6). 2: No major differences. 3: 1990-2010 shows CLT under 10% for north coast (R2, R3, R4), this is only

	3: 1990-2010 shows CLT <10% in the north continuously (R2, R3). This is less distinct in 2020-2040, especially for R3. 2020-2040 shows lower CLT in central Australia (R7, R8). 4: No major difference. General: Some regionally specific differences, similar pattern.	3: No major differences. 4: No major differences. General: 2040-2060 shows lower CLT at northwest coast in summer and autumn.	pronounced for northwestern coast in 2040-2060. But 2040-2060 shows lower cloud amounts in central Australia, see R7, R8. 4: No major differences. General: 2040-2060 tends to show lower cloud amounts for central Australia in winter.
RCP8.5 ACCESS1.3	1: 1990-2010 shows two patches of low CLT at west coast (R6) and south coast (R13) respectively, while these two patches are connected in 2020-2040 (R7, R8, R9). Also, 1990-2010 shows more clouds over Darwin (R3). 2: Patch of low cloud amount in the west more pronounced in 2020-2040 (R6, R7). 3: Patch of low CLT at northwest coast bigger in 2020-2040 (R2, R6, R7). Also, 2020-2040 shows lower CLT in eastern Australia (R9). Interesting too is that there will be less clouds in SE Australia in 2020-2040 (R14). 4: 1990-2010 shows bigger patch of CLT <10% in western Australia (R6, R7). General: Biggest differences observed in winter.	1: Patch of low CLT over central Australia bigger for 2040-2060 (R7, R8, R9). 2: 2020-2040 shows CLT <30% in western Australia (R6, R7), while in 2040-2060, this patch is spread across central Australia to the east (R6, R7, R8, R9). 3: 2020-2040 shows CLT <20% in north-western Australia (R2, R6, R7), while in 2040-2060, this patch is spread across central Australia to the east (R6, R7, R8). Interestingly, 2040-2060 shows higher CLT in SE Australia (R14). 4: No major differences. General: 2040-2060 tends to show lower CLT in eastern Australia, especially in autumn and spring.	1: 2040-2060 shows lower cloud amounts generally, especially around Darwin (R3, R4) and in central Australia (R7, R8, R9). 2: 2040-2060 shows lower CLT (<30%) in central Australia and at west coast (R6-R9). 3: Patch of low CLT at northwest coast more distinct and bigger in 2040-2060, and patch of higher CLT in SE Australia (R14) smaller in 2040-2060. 4: Patch of CLT <10% in northwest for 1990-2010 (R2, R6, R7), only pronounced for west coast (R6) in 2040-2060. General: Biggest differences observed in autumn and winter.

General observations:

- For both models the total cloud amount tends to slightly decrease over the century.
- For ACCESS1.3, very similar patterns are observable for now and the future. Patterns of low total cloud amounts tend to become bigger and spread towards eastern Australia.
- Most differences between time periods have been observed in central Australia.