Producing and analysing CMIP5 outputs for the near-surface temperature, as well as the length of dry and wet spells over the Amazonia at the end of the 21st century

Abstract

The Amazon rainforest experienced severe droughts in 2005 and 2010, attributed to an increasingly drying climate linked to rising temperature and reduction in the total rainfall. This study utilises the KMNI climate change explorer web application to use the couple model intercomparison project phase 5 (CMIP5) framework to analyse changes in the temperature and the length of wet and dry spells over the Amazonia. Representative common pathway (RCP) scenarios are used to project these changes over a 200 year-period (1900-2100). It was found that the projections in this report align with other Geographical Climate Models (GCMs) that predict an increasingly drying climate over the Amazonia, linked to increased temperature and decreased rainfall. However, there is a certain amount of uncertainty which should be further investigated.

Introduction

The Amazon Rainforest, or "Amazonia", encompasses 3.2 million square miles, consisting of rainforests and other complex ecosystems, such as, lakes, swamps, and rivers (Plotkin, 2020). As such, the Amazonia "contains the largest living assemblage of plants and animals on the planet" (Plotkin, 2020, p. 9). In addition to playing an important role in biodiversity, the Amazon rainforests is a key regional entity of Earth's stability (Blaustein, 2011). The Amazonia stores an estimated 90 billion to 120 billion metric tons of carbon, dissipating solar heat from the Earth's surface (Blaustein, 2011). However, vast stretches of the rainforest are at risk of "Amazon dieback" due to growing anthropogenic impacts and an increasingly changing climate (Blaustein, 2011, p. 176). For instance, severe and widespread droughts occurred over the Amazonia in 2005 and 2010 (Feldpaush et al., 2016). Tropical rainforests don't usually experience an increase in the variability of their climate and these droughts threatened biodiversity, ecosystem functionality and the global carbon cycle (Yang et al., 2018). As such, the drought of 2005 resulted in an estimated carbon release of 1.2-1.6 billion metric tons (Hilker et al., 2014). Research suggests that there has been a reduction in rainfall across large parts of the Amazonia since 2000 (Hilker et al., 2014). In addition to increasing surface temperature and drier seasons, rainfall is affected by anthropogenic deforestation (Miller, 2021). The Amazonia "relies heavily on evapotranspiration from trees and plants to supply the atmosphere with moisture that falls as rain", when an area of forest is destroyed, remaining areas are deprived of rainfall (Miller, 2021, par. 17). The vegetation canopy of the Amazonia is highly sensitive to variations in precipitation and persistent drying could degrade these canopies (Hilker et al., 2014), contributing to the dieback of the amazon and its potential mutation to a savanna or less biodiverse landscape (Blaustein, 2011). As the forest becomes drier, organisms die off and the Amazonia begins emitting more carbon than it can absorb (Miller, 2021). This release of the Amazon's stored carbon is a major threat to the stability of Earth's biosphere (Blaustein, 2011). Henceforth, this report shall analyse climate model data regarding the projected changes in temperature, dry spells, and wet spells over the Amazonia, in hope to expand upon previous literature about the importance of reducing climate variability across the Amazonia for its conservation.

Methods

This report uses The KMNI Climate Explorer web application to statistically analyse data on the projections of the annual temperature change and annual length of dry and wet spells, over the Amazonia (KMNI, 2017a). It uses the CMIP5 framework to make projections for the late-21st century by making use of two datasets provided through the KMNI application.: the CMIP5 (full set) and the CMIP5 extremes (full set) dataset (KMNI, 2017a). Both maps and time series are produced as model outputs to provide more insight into the data. The CMIP5 framework uses four RCPs which span a wide range of possible futures, with RCP2.6 simulating an ideal future, up to RCP8.5, which simulates a future where no interventions are made (KMNI, 2017a, Taylor, Stouffer and Meehl, 2012). All four are utilised in the report to project the change in the temperature and the length of wet and dry spells annually in the Amazon for 2080-2100, using a reference period of 1900-1940.

Results

The near surface temperature is predicted to increase in all the models toward the latter end of the 21st century (figure 1). The variation between predictions is small between each scenario until around 2050. After this, the near surface temperature in the RCP2.6 scenario plateaus at 2 degrees for the rest of the 21st century. RCP 4.5 and 6.0 continue to rise gradually at similar rates, but RCP4.5 begins to plateau at 3 degrees around 2075 while RCP6.0 projects a rise of just under 4 degrees by 2100. RCP8.0 predicts a rapid temperature increase past 2050, with some models predicting a rise of almost 10 degrees. The increase doesn't appear to level off and could surpass the projection of a 6-degree temperature rise in the 22nd century.

CMIP5 ensemble projections of the length of dry spells and near-surface temperature for The Amazonia by the end of the 21st century.

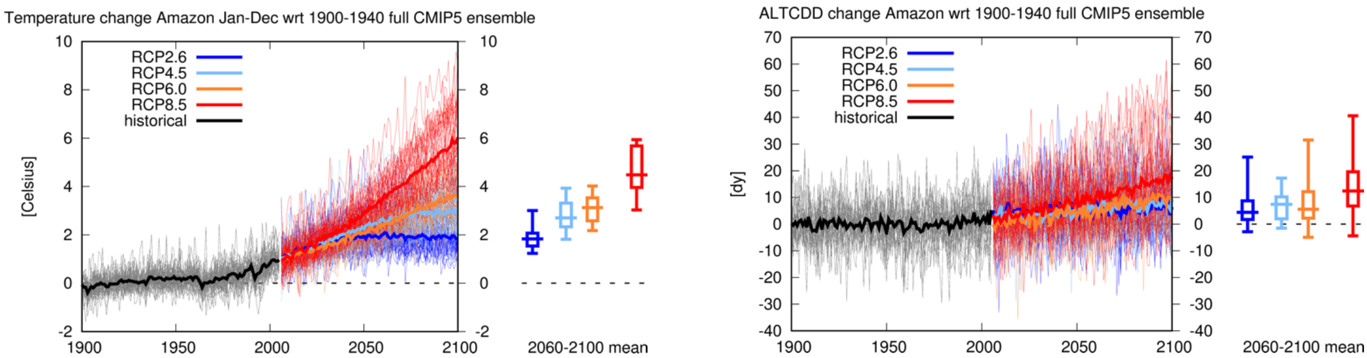

Figure 1: Time series showing the historical hindcast (black) of the CMIP5 models and future projections for the end of the 21st century for near-surface temperature change (a) and the length of dry seasons (b). The reference period used is 1900-1940. Different scenarios are represented from low to high RCP2.6 (blue), RCP4.5 (dark blue), RCP6.0 (orange), RCP8.5 (red). Both near-surface temperature and length of dry spells are projected to have increased by the end of the 21st century. Variations in the CMIP5 model data are shown through box and whisker plots for the two simulations (IPCC, 2013).

In conjunction with rising surface temperature, figure 1 also depicts a time series for the rising length of dry spells annually. In comparison to the historical simulations, all scenarios project a slight change to the historical variability in the length of dry spells. RCP2.6, 4.5 and 6.0 project that the dry spell will increase by 10 days annually by 2100, whilst RCP8.0 projects the annual dry spell to increase by around 20 days.

Figure 2 shows the relative stability in the historical annual length of wet spells, up until the 2000s where each scenario starts to show a decrease in the annual number of wet days. RCP2.6, 4.5 and 6.0 project that wet spells will decrease by around 5 wet days annually by 2100. Whilst RCP8.5 shows an extreme scenario where the Amazon wet spells decrease by around 15 days by 2100.

CMIP5 projections for each RCP scenario of the length of wet spells for The Amazonia by the end of 21st century.

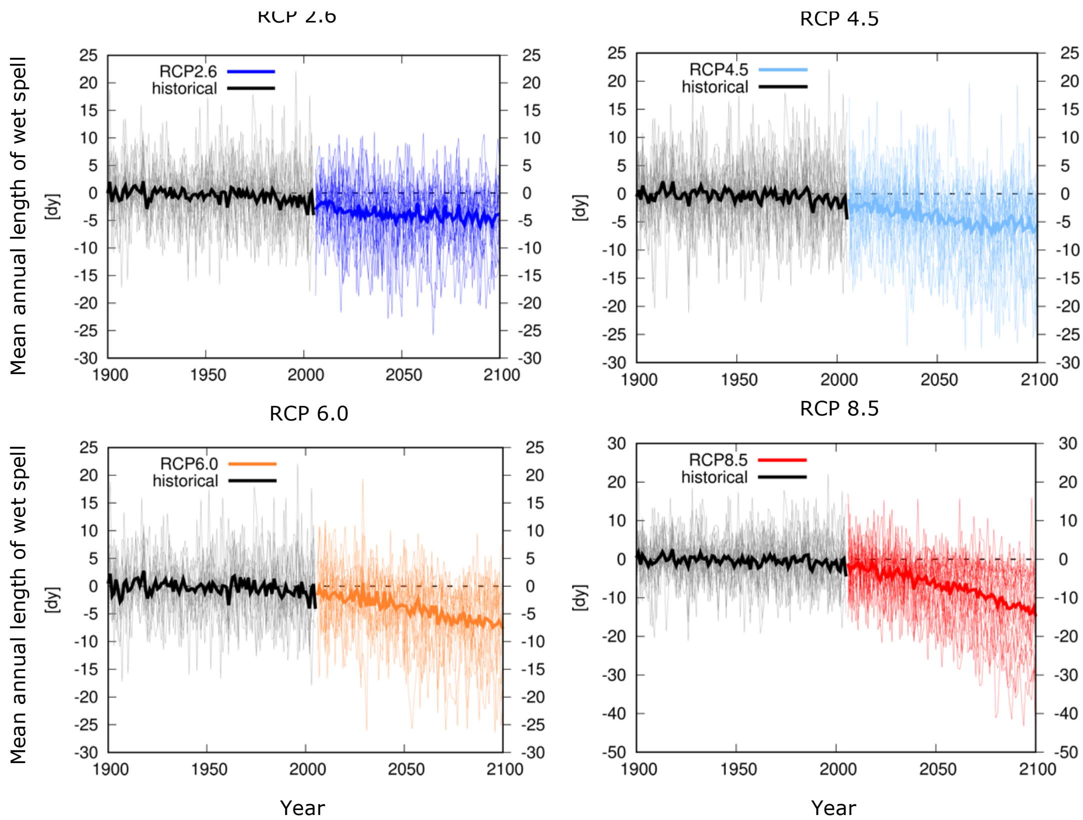

Figure 2: Group of timeseries showing the historical hindcast (black) of the CMIP5 models and each different RCP scenario's future projections for the annual length of wet spells towards the end of the 21st century. The reference period used is 1900-1940. RCP2.6 (blue), RCP4.5 (light blue) and RCP6.0 (orange), predict a similar slight decrease in the length of wet spells yearly. RCP8.0 (red) projects a more extreme decrease in length of about 15 days.

The results show that there is a large amount of variability between models in the projected length of wet spells (figure 2). The uncertainty in the projections is depicted in figure 3. There is little difference between some models of the ideal future scenario and the worst scenarios. The 10th percentile of models from the RCP2.6 and RCP8.0 scenarios project that The Amazon and most of South America will lose more than 10 wet days. However, the 90th percentile of models for both scenarios project that by 2100 there will be little change to the natural variability of the length of wet spells over the Amazon.

10th percentile and 90th percentile CMIP5 model projections of the annual length of wet spells across the Amazonia by the end of the 21st century.

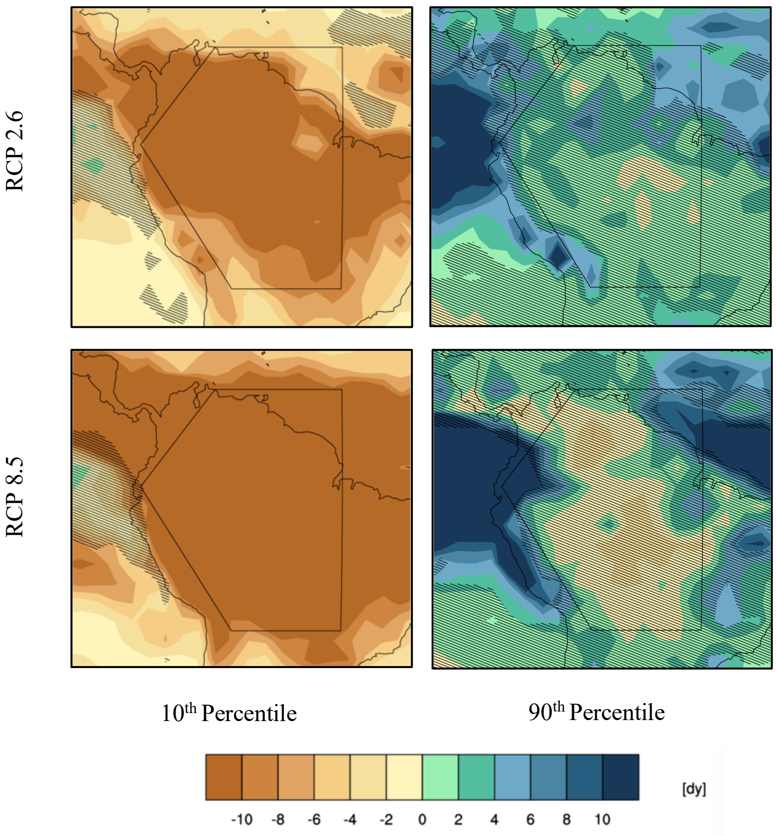

Figure 3: Projections of annual average length of wet spells for 2080-2100 over the Amazon using a base period of 1900-1940 in the CMIP5 climate model. The variation in the models is shown through the lower 10th percentile of projections (left) and the upper 90th percentile (right). The dark brown patches on the 10th percentile maps represent a reduction in the length of wet spells by over 10 days a year. There is not much difference between the 10th percentile and 90th percentile of model projections between the best future scenario (RCP2.6, top) and worst scenario (RCP8.5, bottom). Note that the hatchings indicate that the natural variability of the length of wet spells is greater than one standard deviation of the model predictions (KMNI, 2017b).

Discussion

CMPI3 models show that more intense and longer droughts have been observed over the Amazon since 1970, which have been attributed to increased drying linked to projections of increasing temperatures and decreased precipitation (IPCC, 2007). Moreover, figures 1 and 2 also reflect models from the Meteorological Research Institute's (MRI) Earth Simulator supercomputer (Blaustein, 2011). MRI models found there to be intermittent rainfall and dryness across the Amazonia historically and up to the present day, but future predictions see less variability in wetness and dryness with increased dry periods (Blaustein, 2011). Increased dry spells and decreased short-lived rain events have been shown to cause large-scale reductions in tropical forest productivity, acting as a serious risk to regional agriculture, plant development, ecosystem functionality and forest carbon storage (Leite-Filho, de Sousa Pontes and Costa, 2019, Yan and Dickinson, 2014, Feldpausch et al., 2016).

However, "droughts are a natural feature of the Amazonian climate regime" and as shown in figure 3, "there is large uncertainty regarding changes in the frequency and intensity" of dry and wet spells (Feldpauch et al., 2016, p. 980). For example, Granato-Souza et al. (2018)

examined Amazonian moisture-sensitive tree-ring data from 1786 to 2016 which was strongly correlated with instrumental precipitation observations from the CRU TS 4.00 dataset. The data indicated a decadal dry spell in the mid-nineteenth century which appeared to be as persistent and prolonged as any recorded in the instrumental era of the CRU TS 4.00 observations (1939-2016) (Granato-Souza et al., 2018). As these dry spells occurred prior to anthropogenic impacts, it could suggest that recently observed increases in drying could be part of the Amazon's natural variability (Granato-Souza et al., 2018).

However, it is generally accepted that if the continued drying continues as projected by earth system models, droughts would result in a reduction in the Amazon rainforests productivity and may result in an Amazon dieback (Yang et al., 2018, Yan and Dickinson, 2014). It should be noted that this report recognises the complexity and uncertainty surrounding these projected changes. For example, research shows that there has been a delay in the onset of the rainy season across amazon, which could start a month later than usual by 2050 (Leite-Filho et al., 2019). However, the CMIP5 extremes (full set) data set is restricted to analysing annual data rather than seasonal (KMNI, 2017a). There is growing research to support that deforestation can delay the onset of the wet season, however, variations in the onset of wet seasons are often attributed to climate patterns like the El Nino-Southern Oscillation event (Wright et al., 2017). As such, a different study may want to focus on the causes of drying to suggest preventions or explore and test the historical data and trends in the natural variability of droughts and forest responses, to gain an insight towards the expected changes to emerge over the Amazon by the end of the 21st century (Granato-Souza et al., 2018).

Conclusions

The CMIP5 projections and RCP scenarios used in this report align with other GCMs and research literature that predicts an increasingly drying climate over the Amazonia, linked to increased temperature and decreased rainfall. However, the uncertainty and variation in the model outputs leads to the suggestion that it is uncertain how and if there will be changes, calling for more research into the complexity of the Amazons changing climate.

References

Blaustein, R, J. (2011) Amazon Dieback and the 21st Century. *BioScience* [online]. 61 (3), pp. 176-182. Available from: https://doi.org/10.1525/bio.2011.61.3.3 [Accessed 11 November 2021].

Feldpaush, T, R., et al. (2016) Amazon forest response to repeated droughts. *Global Biogeochem Cycles* [online]. 30, pp. 964-983. Available from: https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1002/2015GB005133 [Accessed 11 November 2021].

Granato-Souza, D., Stahle, D, W., Barbosa, A, C., Feng, S., Torbenson, M, C, A., de Assis Pereira, G., Schongert, J., Barbosa, J, P. and Griffin, D. (2017) Tree rings and rainfall in the equatorial Amazon. *Climate Dynamics* [online]. 54 (3), pp. 1857-1869. Available from: https://link.springer.com/content/pdf/10.1007/s00382-018-4227-y.pdf [Accessed 16 November 2021].

Hilker, T., et al. (2014) Vegetation dynamics and rainfall sensitivity of the Amazon. *National Academy of Sciences of the United States of America* [Online]. 111 (45), pp. 16041-16046. Available from: https://www.jstor.org/stable/pdf/43279207.pdf?refreqid=excelsior%3A79b803e9fb1911d43b454694641ac24b [Accessed 11 November 2021].

KMNI. (2017a) *KMNI Climate Change Atlas* [online]. Available from: https://climexp.knmi.nl/plot_atlas_form.py [Accessed 14 November 2021].

KMNI. (2017b) *KNMI Climate Change Atlas: Climate Explorer – Help* [online]. Available from: https://climexp.knmi.nl/help/atlas.shtml [Accessed 14 November 2021].

Leite-Filho, A, T., de Sousa Pontes, V, Y. and Costa, M, H. (2019) Effects of Deforestation on the Onset of the Rainy Season and the Duration of Dry Spells in Southern America. *Journal of Geographical Research: Atmospheres* [online]. 126, pp. 5268-5281. Available from: https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2018JD029537 [Accessed 16 November 2021].

Miller, J, L. (2021) The Amazon is reaching its carbon tipping point. *Physics Today* [online]. 74 (9), p. 12. Available from: https://physicstoday.scitation.org/doi/full/10.1063/PT.3.4828 [Accessed 11 November 2021].

Plotkin, M, J. (2000) Introduction. In: Plotkin, M, J., ed. (2000) *The Amazon: What Everyone Needs to Know* [online]. London: Oxford University Press. Accessed from: https://doi.org/10.1093/wentk/9780190668297.003.0001 [Accessed 11 November 2021]

Taylor, K, E., Stouffer, R, J., Meehl, G, A. (2012) An Overview of CMIP5 and the Experiment Design. *Bulletin of the American Meteorological Society* [online]. 93 (4), pp. 485-498. Accessed from: https://doi.org/10.1175/BAMS-D-11-00094.1 [Accessed 14 November 2021].

IPCC. (2007) Summary for Policymakers. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K, B., Tignor, M. and Miller, H, L., ed. (2007) *Climate Change 2007: The Physical Scienece Basis. Contribution of Wokrking Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [online]. Cambridge: Cambridge Univeristy Press. Available from: https://www.ipcc.ch/site/assets/uploads/2018/02/ar4-wg1-spm-1.pdf [Accessed 16 November 2021].

IPCC. (2013) Summary for Policymakers. In: Stocker, T, F., Qin, D., Plattner, G-K., Tignor, M, M, B., Allen, S, K., Boschung, J., Nauels, A., Xia, Y, Bex, V and Midgley, P, M., ed. (2013) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group 1 to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [online]. Cambridge: Cambridge University Press. Available from: http://www.climatechange2013.org/images/report/WG1AR5_SPM_FINAL.pdf [Accessed 14 November 2021].

Wright, J, S., Fu, R., Worden, J, R., Chakraborty, S., Clinton, N, E., Risi, C., Sun, Y. and Yin, L. (2017) Rainforest-initiated wet season onset over the southern Amazon. *Proceedings of the National Academy of Sciences of the United States of America* [online]. 114 (32), pp. 8481-8486. Available from: https://www.pnas.org/content/pnas/114/32/8481.full.pdf [Accessed 11 November 2021].

Yan, B. and Dickinson, R, E. (2014) Modeling hydraulic redistribution and ecosystem response to droughts over the Amazon basin using Community Land Model 4.0 (CLM4). *Journal of Geophysical Research: Biogeosciences* [online]. 119, pp. 2130-2143. Available from: https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1002/2014JG002694 [Accessed 16 November 2021].

Yang, J., Tian, H., Pan, S., Chen, G., Zhanf, B. and Dangal, S. (2018) Amazon droughts and forest responses: Largely reduced forest photosynthesis but slightly increased greenness during the extreme drought of 2015/2016. *Global Change Biology* [online]. Available from: https://onlinelibrary.wiley.com/doi/am-pdf/10.1111/gcb.14056 [Accessed 11 November 2021].