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CLIMATE ANALOGUES OF CAPITAL CITIES IN THE WEST SOUTH AMERICA

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ABSTRACT

By means of a recently customary nonparametric method future climate analogues were predictable for West South American capital cities. The nonparametric scheme showed in this research for identifying climate analogues can be applied for impact assessments under a changing climate. MRI-AGCM3.2H with a horizontal resolution of 60 km, three convection schemes, four sea surface temperature distributions, and two initial conditions and under scenario A1B of the Special Report on Emissions Scenarios were used. The total ensemble scope was 24, with a simulation period of 25 years. Utmost of the future analogues are at lower latitudes than their target cities. Estimated seasonal variations in surface air temperature and rainfall in Santiago de Chile City look similar to the present-day climate of Cape Town, located in South Africa and for La Paz City a climate analogue is found at Oruro in Bolivia.

Keywords: Climate analogue, climate change, surface air temperature; rainfall; nonparametric method; West South America.

1 INTRODUCTION

Climate analogues method gets how to connect climate at an objective point to regular community, politicians, sponsors, and to experts who study biosciences and environmental resources. For example, recognizing spatial and temporal analogues places or areas making available understandings how biota and crops are vulnerability to climate change, is providing for the climate analogues technique (Leibing et al., 2016). Furthermore, analogues scheme based on climatic features gives visions on regions with present climate environments look like future or past surroundings in a different location (e.g., Williams et al., 2007; Ramírez-Villegas et al., 2011). Numerous regions have been studied using it such as Central America (Pinzon et al., 2017), Japan (Ishizaki et al., 2012), Australia (Webb et al., 2013; Nakaegawa et al., 2017), worldwide (Arnbjerg-Nielsen et al., 2015; Soteriades et al., 2017), nonetheless not for West South America. On the other hand, Hibino et al. (2015) demonstrated probabilistic terrestrial scatterings of climate analogues by integrating uncertainties from greenhouse gases emission scenarios, climate model itself, and internal variability in order to overcome the deterministic-ill issue. Local forcing disturbs the climatological behavior in South America which includes tropical subtropical and extratropical landscapes. Andes chain is a significant western coast feature described by a thin barrier routing the stream in the central part of the mainland. The seasonal precipitation at west of the Andes is defined by the sea surface temperature (SST) over Pacific Ocean (Solman, 2013). Moreover, in this zone, hydroclimatic conditions are determinate by the temperature relations among mainland and the oceans (Nakaegawa et al., 2014c).

The agrarian area and food security were affected and producing an economic and social impact on Latin America because both at the same time, El Niño (ENSO), the Pacific Decadal Oscillation and the hottest temperature time on Earth appear on the last 3 years (Martinez et al., 2017). In addition, the Atlantic and the Pacific oceans cause the foremost climate variabilities over the South America (Ramos da Silva Hass, 2016).

Precipitation is seems the most leading hydroclimatological component (e.g., Taylor and Alfaro, 2005; Nakaegawa et al., 2014b). Likewise, heterogeneous demographic group migration is most conditioned by exposure to monthly temperature shocks comparative to monthly rainfall shocks and regular changes in climate over many-year times (Thiede et al., 2016).

Further, species are extra exposed to minor climate changes (Mora et al., 2013). Climate change is also thought to produce decays in the abundance of B. bellicosus a bumblebee threatened in South America (Martins et al., 2014).

According to Pugh (2016), a significant percent of the existing worldwide crop zones for wheat, maize and rice, is located in areas in which yields are susceptible to climate change. As said by Giorgi (2006), some regions should be considered an extremely subtle to the effects due of reduced rainfall and strengthening of rainfall changeability (Nakaegawa et al., 2014a). For some countries drastic economic impacts are related to climate change (Fábrega et al., 2013).

All of these influences of climate changes in West South America pinpoint in a simply comprehensible manner the significance of in what way locally future climate fluctuates under a worldwide warming. The climate analogues in the current investigation were found by recognizing a city with a present-day climate alike to that projected for a target city in the future.

The locations of the future climate analogues for 6 West South American capital cities were recognized by means of a nonparametric method by Hibino et al. (2015). Twenty-four simulations of the Meteorological Research Institute-Atmospheric General Circulation Model (MRI-AGCM; Mizuta et al., 2012) were carried out for present-day and future climates to reproduce uncertainties in climate projections.

2 METHODOLOGY

Climate Analogues

Making use of the 600-year modeled data and a novel scheme, the positions of the climate analogues, where present-day climates are similar to the future climates of the 6 target capitals on a monthly mean time-scale, can be recognized in a probabilistic way. The metric established was the root mean square difference ($\sqrt{\Delta}$) of monthly-mean SAT and rainfall between the present-day and future climates. Using the equations (1), (2), and this metric the similarity score was computed. The similarity score accounts for uncertainties in climate analogues derived from future climate projections. Relating the monthly time series of SAT and rainfall for each sample the similarity of climates is evaluated for each year.

$$\Delta_{\beta}\left(l, l_{target}, q\right) = \sqrt{\frac{1}{\mu}\sum_{i=1}^{\mu}\left(\beta_i^{obs}(l,q) - \langle\beta_i^{f}\left(l_{target}\right)\rangle\right)^2} \qquad [1]$$

$$S_{\beta} = \frac{1}{25}\sum_{q=1}^{25}\frac{\Omega_{j=1}^{600}\left\{\Delta_{\beta,j}(l,l_{target},q) < U\Delta_{\beta,k}(l_{target},j)\right\}}{600} \qquad [2]$$

Primary, the future climate of the six capitals in South America was projected. Secondly, a similarity score that associates apiece target city with locations around the world was quantified and the locations with maximum similarity scores, both worldwide and within the American continents were selected.

Observations

The present observation period was arrangement to be the equivalent as that of the current climate simulations. As a result of its constraint of observation dataset climate analogues are recognized with 0.5º horizontal resolution. The cities themselves are not represented, but a 0.5º grid box which incorporated both target cities and climate analogue cities.

Ensemble simulations

We achieved all future climate simulations for the late 21st century (2075-2099, 25 years) using scenario A1B (Intergovernmental Panel on Climate Change (IPCC), 2000) from the Special Report on Emissions Scenarios (SRES) in the MRI-AGCM3.2H model, which has a grid spacing of about 60 km. Comparative to the present day (1979-2003, 25 years), global mean sea surface temperature (SST) is projected to rise 2.17˚C by the late 21st century. 24 ensemble tests were conducted casing three convection schemes ((YS; Yoshimura et al., 2015); (AS; Randall and Pan, 1993), and (KF; Kain and Fritsch, 1993)), four SST distributions and two initial conditions, each with a 25-year integration period, yielding 600 years of climate projections.

Target cities and period

Six target capitals in West South America for climate analogues were chosen by population (in Table I and Figure 1). As it was mentioned in the introduction section these present-day climates are affected by the Pacific and Atlantic oceans, and Central America, ENSO among others. The future climate simulation (2075 to 2099) is similar period used for future climate analogues.

Table I. The six target cities in West South America for which climate analogues were determined in the present study. Their locations are shown in Figure 1

Capital City	Country	Latitude	Longitude	Altitude
Caracas	Venezuela	10.51	-66.92	934.13
Bogotá	Colombia	4.60	-74.08	2605.21
Quito	Ecuador	-0.21	-78.50	2819.54
Lima	Peru	-12.05	-77.03	160.94
Sucre	Bolivia	-16.50	-68.13	3651.43
Santiago	Chile	-33.44	-70.65	569.82

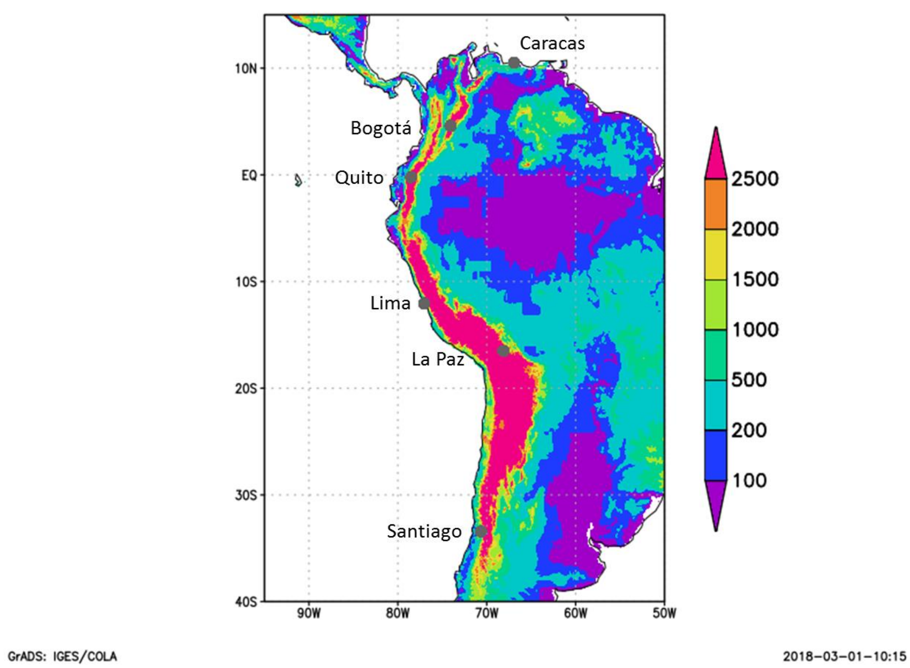

Figure 1. Six target cities in West South America. The color scale shows elevation above sea level (m). More information about each city is listed in Table I

4 RESULTS

Global search

Table 2 gathers in-region and global search results. The climate analogue for La Paz as a target is located inside South America, in City, Oruro, Bolivia. La Paz presented the maximum annual change about 3.0 ˚C and being the maximum monthly changes in January. Graphically, lines and vertical/horizontal bars/diamonds were used to show present-day and future-day climates and seasonal cycle of surface air temperature and rain fall respectively for La Paz capital of Bolivia and its climate analogue (Figure 2).

Total, SAT, and rainfall similarity scores for Santiago de Chile were 0.401, 0.794, 0.928 respectively (Figure 3a, 3b, 3c). We found climate analogue cities with low-medium similarity scores outside West South America for Santiago de Chile (Chile) in Cape Town (South Africa), Australia. Also, they were inside South America (Figure 3a).

Surface air temperature in Santiago de Chile was projected to increase by 1.5°C in the future climate and precipitation was expected to decline. Because the climate analogues had to have both an alike seasonal cycle and a comparable augmentation of surface air temperature in the future climate (Figure 3b), high temperature similarity scores were limited to a very minor area alongside the south-eastern of South Africa, from Santiago

Table 2. Analogue city for each target city in global. See Figure 4 for geographical distribution. Note that analogue city represents a 0.5˚ grid box but not the exact location of the analogue city

Analogue city		
Target city	Global search	
	City	Country
Caracas	Barcelona	Venezuela
Bogotá	Bujumbura	Burundi
Quito	Kigari	Rwanda
Lima	Namibe	Angola
La Paz	Oruro	Bolivia
Santiago de Chile	Cape Town	South Africa

de Chile. In height precipitation similarity scores were distributed along all over the world and mainly South Africa, east Europe, west North America and west South America (Figure 3c).

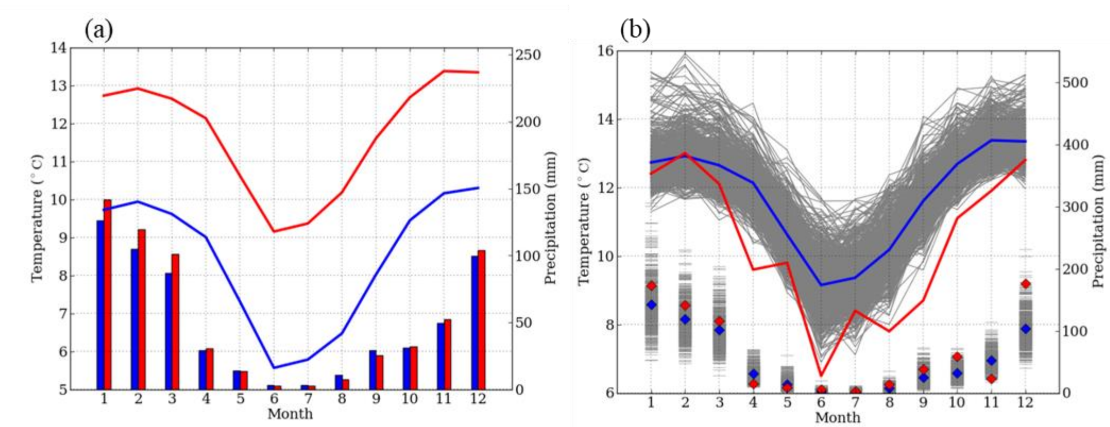

Figure 2. Seasonal cycle of surface air temperature (lines) and rainfall (diamonds and horizontal bars) in La Paz, Bolivia. (b) Blue lines and symbols represent the future climatological monthly mean values in the target city, while red represents at current values for the climate analogue city in 1979. Gray represents the 600 realizations of the future climate in the target city produced using multi-ensemble simulations of MRI-AGCM3.2H

Figure 4 shows the best climate analogue cities for the six target capitals based on a global and inside region search. Brown arrows indicate similarity scores from 0.1 to 0.3. All cities have brown arrows. These distributions also reflect the uncertainties in the future climate projections due to the convection scheme, the projected SSTs used, and the internal variability of the climate system.

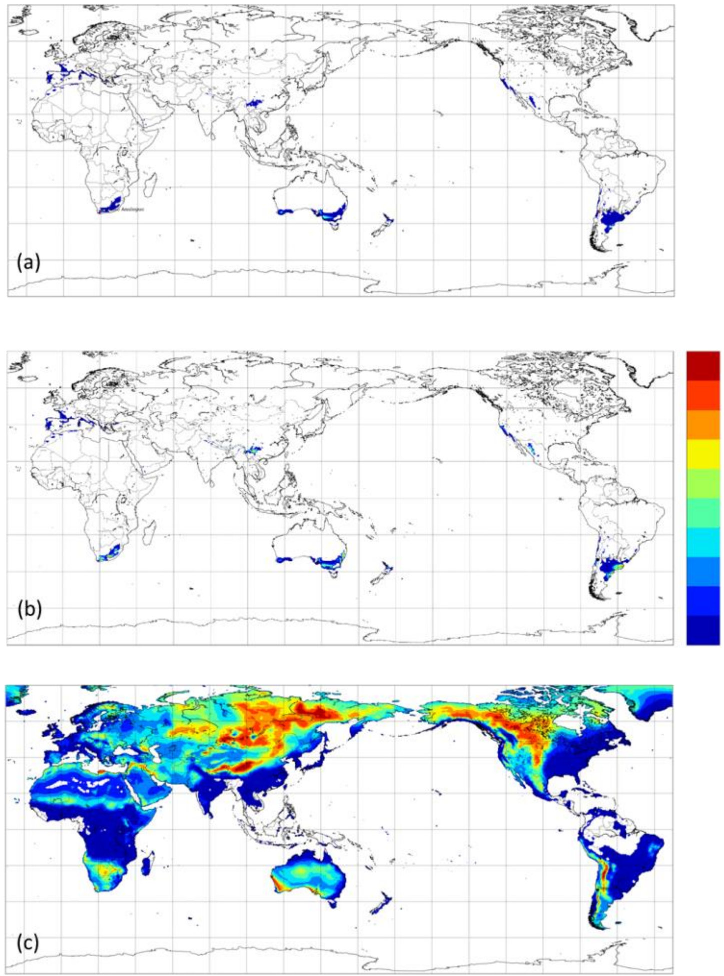

Figure 3. Geographical distribution of normalized similarity scores for climate analogue regions of Santiago de Chile: (a) integrated, (b) surface air temperature, and (c) precipitation. The scores are normalized by the highest scores of 0.401, 0.794, and 0.928, respectively.

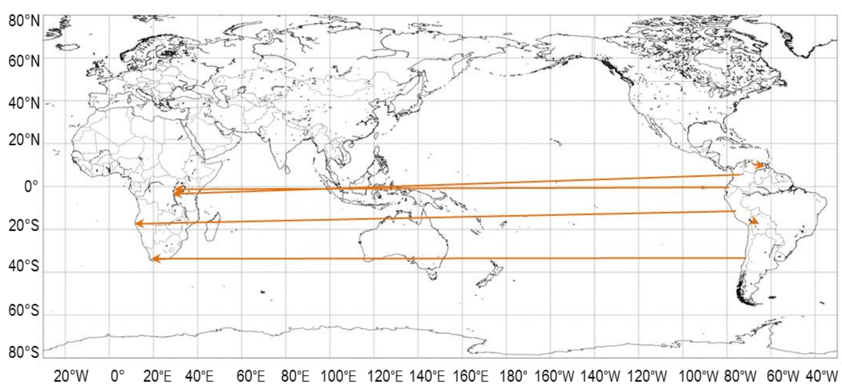

Figure 4. The optimal climate analogue cities for the six target capitals based on a global search: The starting point and arrowhead of each vector represent a target capital and its climate analogue city, respectively. The color of each arrow indicates the locations' similarity score: 0.1 to 0.3 by brown

5 DISCUSSION

Climate zones

In the global search, non-zero integrated similarity scores were dispersed in distinct areas of some continents. As a first estimate the climate analogue for a target city at any given future year between the current year and the late 21st century instinctively should be placed lengthwise the vector from the target city to the analogue city. This latter could be considered because the spatial patterns of future changes in SAT and precipitation continue the identical over time (Nakaegawa et al., 2017).

Temporal evolution of location of analogue city

It is doubtful that the time development of the in-country climate analogues for all target cities can be approximated as a dividing point on the arrows in Figures 4. Indeed, climate zones is zonally distributed according to the latitude as first-order approximation. However, the climate zones are defined only in land areas.

6 CONCLUSIONS

This research involved two different initial conditions as a group of simulations, multi-ensemble simulations and three convection schemes and four SST datasets (Nakaegawa et al., 2017). Point out that these sets or initial conditions may impact the uncertainties in climate analogue with unlike amounts. The global search found two climate analogue cities in Central South America, and the other four in Central and South Africa. All climate analogue city classified get into the uncertainties of the future climate projections.

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REFERENCES

Arnbjerg-Nielsen K, Funder SG, Madsen H. 2015. Identifying climate analogues for rainfall extremes for Denmark based on RCM simulations from the ENSEMBLES database. Water Science & Technology 71: 418-425. DOI: 10.2166/wst.2015.001.

Fábrega J, Nakaegawa T, Pinzón R, Nakayama K, Arakawa O, SOUSEI Theme-C modeling group. 2013. Hydroclimate projections for Panama in the 21st Century. Hydrological Research Letters 7: 23-29. DOI: 10.3178/hrl.7.23.

Giorgi F. 2006. Climate change hot-spots. Geophysical Research Letters 33: 1-4. DOI: 10.1029/2006GL025734.

Hibino K, Takayabu I, Nakaegawa T. 2015. Objective estimate of future climate analogues projected by an ensemble AGCM experiment under the SRES A1B scenario. Climatic Change 131: 677-689. DOI:10.1007%2Fs10584-015-1396-0.

Intergovernmental Panel on Climate Change (IPCC). 2000: Special report on emissions scenarios. A special report of working group III of the Intergovernmental Panel on Climate Change, Nakic´enovic´ N, Alcamo J, Davis G, de Vries B, Fenhann J, Gaffin S, Gregory K, Gru¨bler A, Yong Jung T, Kram T, La Rovere EL, Michaelis L, Mori S, Morita T, Pepper W, Pitcher H, Price L, Riahi K, Roehrl A, Rogner H-H, Sankovski A, Schlesinger M, Shukla P, Smith S, Swart R, van Rooijen S, Victor N, Dadi Z (eds). Cambridge University Press, Cambridge, United Kingdom; 595pp.

Ishizaki NN, Shiogama H, Takahashi K, Emori S, Dairaku K, Kusaka H, Nakaegawa T, Takayabu I. 2012. An attempt to estimate of probabilistic regional climate analogue in a warmer Japan. Journal of the Meteorological Society of Japan 90: 65–74. DOI: 10.2151/jmsj.2012-B05.

Kain JS, Fritsch JM. 1993. Convective parameterization for mesoscale models: the Kain-Fritsch scheme. In: Emanuel KA, Raymond DJ (eds) The representation of cumulus convection in numerical models. Meteorological Monographs 24: American Meteorological Society, Boston, USA; 165–170.

Leibing C, Signer J, van Zonneveld M, Jarvis A, Dvorak W. 2013. Selection of provenances to adapt tropical pine forestry to climate change on the basis of climate analogs. Forests 4:155-178. DOI:10.3390/f4010155.

Martins AC , Silva DP, De Marco Jr. P, Melo GAR. 2014. Species conservation under future climate change: the case of Bombus bellicosus, a potentially threatened

South American bumblebee species. Journal Insect Conservation. DOI: 10.1007/s10841-014-9740-7

Martínez R, Zambrano E, Nieto JJ, Hernández J, Costa F. 2017. Evolución, vulnerabilidad e impactos económicos y sociales de El Niño 2015-2016 en América Latina. Investigaciones Geográficas 68: 65-78. DOI: 10.14198/INGEO2017.68.04.

Mizuta R, Yoshimura H, Murakami H. 2012. Climate simulations using MRI-AGCM3. 2 with 20-km grid. Journal of Meteorological Society of Japan 90A: 233–258. DOI: 10.2151/jmsj.2012-A12.

Mora C, Frazier AG, Longman RJ, Dacks RS, Walton MM, Tong EJ, Sanchez JJ, Kaiser LR, Stender YO, Anderson JM, Ambrosino CM, Fernandez- Silva I, Giuseffi LM, and Giambelluca TW. 2013. The projected timing of climate departure from recent variability. Nature 502, 183–187. DOI:10.1038/nature12540.

Nakaegawa T, Hibino K, Takayabu I. 2017. Identifying climate analogues for cities in Australia by a non-parametric approach using multi-ensemble, high-horizontal- resolution future climate projections by an atmospheric general circulation model, MRI-AGCM3.2H. Hydrological Research Letters 11, 72–78. DOI: 10.3178/hrl.11.72.

Nakaegawa T, Kitoh A, Murakami H, Kusunoki S. 2014a. Annual maximum 5-day rainfall total and maximum number of consecutive dry days over Central America and the Caribbean in the late twenty-first century projected by an atmospheric general circulation model with three different horizontal resolutions. Theoretical and applied climatology 116: 155-168. DOI: 10.1007/s00704-013-0934-9.

Nakaegawa T, Kitoh A, Ishizaki Y, Kusunoki S, Murakami H. 2014b. Caribbean low-level jets and accompanying moisture fluxes in a global warming climate projected with CMIP3 multi-model ensemble and fine-mesh atmospheric general circulation models. International Journal of Climatology 34: 964-977. DOI: 10.1002/joc.3733.

Nakaegawa T, Kitoh A, Kusunoki S, Murakami H, Arakawa O. 2014c. Hydroclimate changes over Central America and the Caribbean in a global warming climate projected with 20-km and 60-km mesh MRI atmospheric general circulation models. Meteorology and Geophysics 65: 15–33. DOI:10.2467/mripapers.65.15.

Pinzón RE, Hibino K, Takayabu I, Nakaegawa T, SOUSEI Theme-C modeling group. 2017. Virtually experiencing future climate changes in Central America with MRI-AGCM: climate analogues study. Hydrological Research Letters 11: 106-113. DOI: 10.3178/hrl.11.106.

Pugh TAM, Muller C, Deryng JED, Folberth C, Olin S, Schmid E, Arneth A .2016. Climate analogues suggest limited potential for intensification of production on current croplands under climate change. Nature Communications 7: 1-8. DOI:10.1038/ncomms12608.

Randall D, Pan D. 1993. Implementation of the Arakawa-Schubert cumulus parameterization with a prognostic closure. In: Emanuel KA, Raymond DJ (eds) The representation of cumulus convection in numerical models. Meteorological Monographs 24: American Meteorological Society, Boston, USA; 137–144.

Ramírez-Villegas J, Lau C, Köhler AK, Signer J, Jarvis A, Arnell N, Osborne T. 2011. Climate Analogues. finding tomorrow's agriculture today. Working Paper no. 12. Cali, Colombia: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). www.ccafs.cgiar.org. Last access September 1, 2016.

Ramos da Silva R, Haas R. 2016. Ocean Global Warming Impacts on the South America Climate. Frontiers in Earth Science 4: 1-8. DOI: 10.3389/feart.2016.00030.

Solman S. 2013. Regional Climate Modeling over South America: A Review. Advances in Meteorology 2013: 1-13. DOI:10.1155/2013/504357.

Soteriades AD, Murray-Rust D, Trabucco A, Metzge M J. 2017. Understanding global climate change scenarios through bioclimate stratification. Environmental Research Letters 12: 1-10. DOI:10.1088/1748-9326/aa7689.

Taylor MA, Alfaro EJ. 2005. Central America and the Caribbean, Climate of. In Oliver, JE. Encyclopedia of world climatology. Encyclopedia of Earth Sciences Series (1st ed.). New York: Springer Science & Business Media. pp.183–189. DOI:10.1007/1-4020-3266-8_37.

Thiede B, Gra C. 2016. Climate Variability and Inter-Provincial Migration in South America, 1970-2011. Glob Environ Change 41: 228-240. DOI: 10.1016/j.gloenvcha.2016.10.005.

Webb LB, Watterson I, Bhend J, Whetton PH, Barlow EWR. 2013. Global climate analogues for winegrowing regions in future periods: projections of temperature and rainfall. Australian Journal of Grape and Wine Research 19: 331–341. DOI: 10.1111/ajgw.12045.

Williams JW, Jackson ST, Kutzbach JE. 2007. Projected distributions of novel and disappearing climates by 2100 ad. Proceedings of the National Academy of Sciences of the United States of America 104: 5738–5742. DOI: 10.1073/pnas.0606292104.

Yoshimura H, Mizuta R, Murakami H. 2015. A spectral cumulus parameterization scheme interpolating between two convective updrafts with semi-Lagrangian calculation of transport by compensatory subsidence. Monthly Weather Review 143: 597-621. DOI: 10.1175/MWR-D-14-00068.1.H. Murakami, R. Mizuta, and E. Shindo. Future changes in tropical cyclone activity projectedby multiphysics and multi-SST ensemble experiments using the 60-km-mesh MRI-AGCM. Climate Cynamics, 39:2569–2584, 2012.

