Available online at www.jonass.ir

Journal of Nature and Spatial Sciences

Journal homepage: www.jonass.ir

Research Article

Identifying future climatic change patterns at basin level in Baja California, México

Teodoro Carlón Allende[a], Erna Martha López Granados[b], Manuel E. Mendoza[c*]

[a] *CONACYT-Instituto de Geofísica, Unidad Morelia, Universidad Nacional Autónoma de México, Morelia, Michoacán, México*
[b] *Instituto de Investigaciones en Ciencias de la Tierra, Universidad Michoacana de San Nicolás de Hidalgo, Morelia Michoacán, México*
[c] *Centro Investigaciones en Geografía Ambiental, Universidad Nacional Autónoma de México, Morelia, Michoacán, México*

ARTICLEINFO

Article history:
Received 05 September 2021
Received in revised form 13 October 2021
Accepted 18 October 2021

Keywords:
Spatial analysis, Climate models, Future climate patterns, (fifth-generation atmospheric general circulation model) MPI ECHAM5, (Hadley Centre Global Environment Model version 1) HADGEM1

ABSTRACT

Background and objective: The global average surface temperature increased by about 0.6°C, and the global sea level increased by 15 to 20 cm during the last century. As the temperature rise, crops and forests will experience failure. In Baja California, Mexico, there is no systematic evaluation of the spatial variability of future temperature and precipitation. The aim of this research was to identify how the precipitation and temperature will change in the basins according to the Intergovernmental Panel on Climate Change climate projections.
Materials and methods: We used the MPI ECHAM5 model scenarios A2 (pessimistic) and B2 (optimistic) of total annual precipitation (TAP) and mean annual temperature (MAT) for 2030 and 2050; we also used the HADGEM1 model, (scenarios A2 and B2) of TAP and MAT (2030-2050). All procedures were carried out in a geographic information system.
Results and conclusion: We evaluate for the first time which basins at the peninsula will be more affected by changes in TAP and MAP. The relative increase of MAT per basin depicted a trend north to south. The highest values reach 6.0° to 6.5°, the minimum values are around 2.0°. The reduction of TAP will be 21 mm from the baseline to 2030. The model also depicted an increase in TAP in the south of the peninsula (12-40 mm). The northern basins will suffer by reduction of water availability, especially for agriculture activities. The southern basins could be affected more by flooding and landslides.

1. Introduction

Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, which persists for a prolonged period, typically decades or longer (Borgatti and Soldati, 2010). Also implies Climate change an increase in the frequency and intensity of extreme temperature and precipitation events at any time of the year, regardless of the season. Climate change on Earth can be caused by natural internal processes or external forces, as well as persistent anthropogenic perturbation of the atmosphere composition or of land use (Borgatti and Soldati, 2010; He et al. 2020;

* *Corresponding author.* Tel: +52 4433223839.
E-mail address: mmendoza@ciga.unam.mx , ORCID: 0000-0003-1310-9702

Peer review under responsibility of Maybod Branch, Islamic Azad University

DOI: *10.30495/jonass.2021.1939621.1017*

He et al. 2021). Climate change effects will probably have an impact on the ecological features and biotic assemblages of terrestrial and aquatic environments, including coastal wetlands (Gillanders, 2011).

Climate change not only affects the hydrological, biological, and ecological system, but also affects the economy, life, consequently the future climate change effect the sustainable development of regional, national, and global scale. Climate change will change the present situation of the hydrologic cycle and cause the redistribution of water resources in time and space, therefore will have a direct effect on the evaporation, runoff, the soil moisture and so on. At the same time, the water resources system changes will affect the local climate and will exacerbate climate change in a certain extent (Nan, 2011).

In recent years, the consensus of natural scientists on the human-induced nature of climate change has become stronger as more evidence on the issue has accumulated (Giang, 2014). Climate change, since the last century, has accelerated because of the increase in greenhouse gases related to human activities (Solomon et al, 2007; National Research Council, 2008). It is well recognized that during the 20th century the global average surface temperature increased by about 0.6°C and global sea level increased by about 15 to 20 cm, while global precipitation over land increased about 2% percent during this same period (IPCC, 2007).

According to the Intergovernmental Panel on Climate Change (IPCC) Assessment Report 4 (AR4) projections, the global average temperature will rise another 1.1 to 5.4°C by 2100, depending on how much the atmospheric concentrations of greenhouse gases increase during this time. This temperature rise will result in continued increases in sea level and overall rainfall, changes in rainfall patterns and timing (CECC, 2008). While all nations will be affected by global warming, some areas will suffer more than others, and some areas might even benefit from climate change.

In general, as temperature continues to rise, crops will begin to experience fail, especially if climate variability increases and precipitation decreases (or becomes even more variable). The regional variation in warming and changes in rainfall will also affect spatial and temporal distribution of plant disease (Hauser et al., 2007).

Freshwater resources in semiarid and arid areas, like the peninsula of Baja California, are particularly vulnerable to the impacts of climate change (Kundzewicz et al., 2017). Regions with higher water temperatures, increased precipitation intensity, and longer periods of low flows are expected to suffer from many forms of water pollution, including sediments, nutrients, dissolved organic carbon, pathogens, pesticides, salt, and thermal pollution (Bates et al., 2008)

In Mexico, few key studies have been carried out since the beginning of the decade. Reference (López Granados et al., 2013) indicated that the models for the laminar wind erosion and the aridity index suggest that in the immediate future (2010-2039) the climatic conditions of the area of Bolsón de Mapimí, northern México, and its surroundings will deteriorate and could lead to a steady decline. The paper from (Gómez et al., 2011) analyzed the impacts of climate change in the potential distribution of 16 forest species based inside the Mexican Republic's temperate, tropical, and semiarid zones. They identified that the English (HADGEM-01) model establishes the least favorable conditions for most species, whereas the German model (MPI-ECHAM-5) and the American model (GFDL-CM-2.0), based on the estimated impacts, present similar values –the impact being slightly inferior in the latter. Sánchez-Torres et al. (2011) evaluated the water resources to climate change scenarios in Tamaulipas, northeastern México. They identified that that climate change scenarios have the most negative impact on water availability in the agricultural sector; the results also, suggest that water concessions, irrigation districts, and hydraulic infrastructure in the river basin need to be reconsidered and updated to assure water availability to all its users.

Nevertheless, in Baja California, there is no systematic evaluation of the spatial variability of changes in temperature and precipitation based on the (IPCC) projections, although according to the Baja California Climate Change Action Program report (PEACC, 2012), is particularly vulnerable to climate change. The PEACC (2012) indicated that the region is expected to diminish its annual average precipitation in a range of 10–20%, while its temperature is projected to rise from 1.5◦C to 2.5◦C in the next 50 years. Because of this, the following research questions are yet to be answered: which areas (basins) will more likely be affected by climate change within the peninsula of Baja California? What are the patterns of increased temperature? And what about the patterns of future precipitation? The main aim of this research was to identify how the precipitation and temperature will change in the basins according to the IPCC climate scenario.

2. Materials and methods

2.1. Study area

Baja California is the second longest and most geographically isolated peninsula in the world. The peninsula originally was connected to the west coast of mainland Mexico but became pulled away by differential movements of the Pacific and North American plates since 4 to 5 million years, it has drifted approximately 300 km to the northwest along what has become known as the San Andreas Fault (Grismer, 2010).

The peninsula of Baja California extends around 1300 km, from the northern border of México and the United States (32° 30' N) to Los Cabo San Lucas (22° 30' N). The peninsula is surrounded by the Pacific Ocean (west) and the Gulf of California or Sea of Cortez (east). The width varies from 30 km (nearby La Paz) to 240 km (United States-Mexico border), covering a surface area of 144,400 km2 (Figure 1). The peninsula is basically formed by crystalline rocks from the Cretaceous and Pre-Cretaceous eras (Peinado Lorca et al., 1990). The main geologic structure forms a ridge that runs from the northwest to the southeast. Northwest Mexico is in a climatic transition zone (tropical and subtropical). Many factors influence the climate in this area, including the cool waters of the California Current (moving from the polar region toward Ecuador), the warm Gulf of California, and the Pacific tropical current. The predominant climate type is very dry, dry, and temperate in small elevated northern areas (García, 2014). According to INEGI (2014), predominant soil groups are Regosols, Calcisol, and Leptosols. Land cover and land use are characterized by several types of shrubs, chaparral, and pine forest, oak forest, and tropical dry forest (Rzedowski, 1998; INEGI, 2006). In the peninsula, there are approximately 410 km2 of grape plantations, which represent 90% of the national wine production. In the few last years, the surface of grapes plantation has increased with an annual rate of 5%.

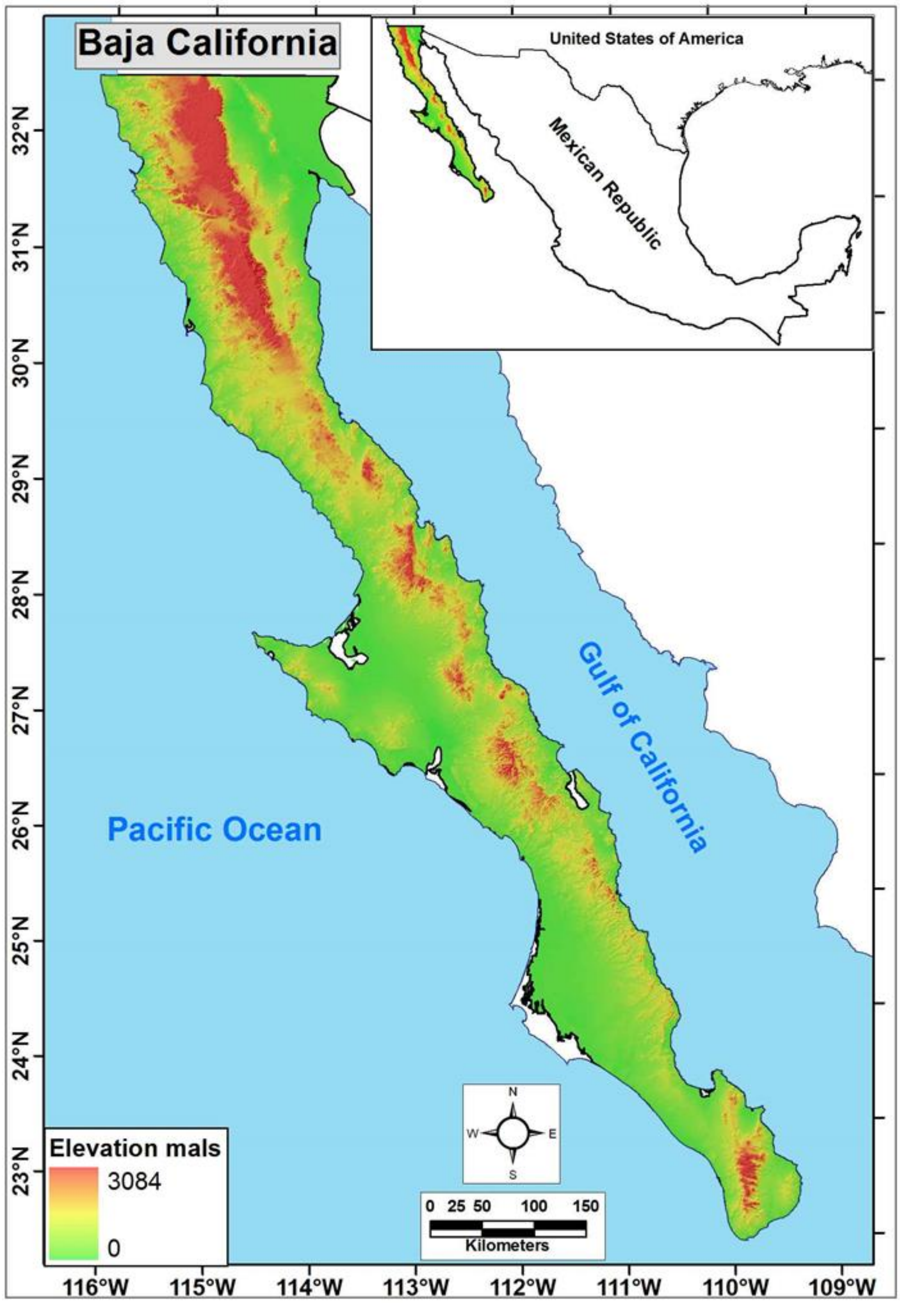

Fig. 1 – Study area.

2.2. Basins

The basins' distribution database was downloaded from the Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO), which were delineated by the Comisión Nacional del Agua (CONAGUA) for the whole country at scale 1:250 000 (CNA, 1998). There are 19 basins in Baja California (Table 1).

Table 1. The basins of Baja California and its area surface

ID Basins	Basins Name	Surface (Ha)
1	Arroyo Tijuana-Arroyo de Maneadero	1,148,800
2	Bacanora-Mejorada	743,400
3	Arroyo Las Animas-Arroyo Santo Domingo	1,433,400
4	Lago Salado-Arroyo del Diablo	961,900
5	Río Colorado	251,300
6	Arroyo Escopeta-Canal San Fernando	1,186,300
7	Arroyo Agua Dulce-Sta. Clara	973,100
8	Arroyo Santa Catarina-Arroyo Rosarito	1,453,800
9	Arroyo Camalajue y otros	535,100
10	San Miguel-Arroyo del Vigía	2,744,500
11	Arroyo Sta. Isabel y otros	513,100
12	Lago San Ignacio-Arroyo San Raymundo	1,377,600
12	Arroyo Paterna-Arroyo Mulegí	617,700
14	Arroyo Mezquital-Arroyo Comondo	672,600
15	Arroyo Frijol-Arroyo San Bruno	319,100
16	Arroyo Venancio-Arroyo Salado	2,006,400
17	Isla Coronados-Bahía La Paz	202,800
18	Arroyo Caracol-Arroyo Candelaria	1,184,300
19	La Paz-Cabo San Lucas	726,300

2.3. Digital elevation models and climate change scenario

The climate change scenarios used in this research were developed by the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2007), those feature of spatial databases of climatic variables available at ***http://atlasclimatico.unam.mx/atlas/kml/*** in GeoTIFF format. Spatial databases are based on the implemented models by Hijmans et al. (2005) and the global circulations models emission scenarios by IPCC (2007) for Mexico and Central America (Model for the Assessment of Greenhouse-gas Induced Climate Change. A Regional Climate Scenario Generator. Version 5.3.v2).

The scenarios of climatic change scenarios per year were analyzed by comparison. We used the MPI ECHAM5 and HADGEM1 models, which have better performance at a global level and for the region of México than all other models (Conde et al., 2011). MPI ECHAM5 is a general circulation model (GCM) developed by the Max Planck Institute for Meteorology, it is more portable and flexible (it is now written in the programming language Fortran 95), and because of both major and minor changes to the different parts of code that it uses, it produces a significantly different simulated climate (Roeckner et al., 2003). We choose scenarios A2 (pessimistic) and B2 (optimistic) for total annual precipitation (TAP) and mean annual temperature (MAT) for 2030 and 2050.

HADGEM1 model is a coupled climate model developed at the Met Office’s Hadley Centre; HADGEM1 is intended as a platform for incorporating components of the environmental system other than just physical climate (Martin et al., 2006). We choose scenarios A2 (pessimistic) and B2 (optimistic) of TAP and MAT for 1930 and 1950 (Table 2). Additionally, we used the climatic baseline of TAP and MAT, based on data from 1950 to 2000 (Fernandez Aguiarte et al., 2014; Monterroso et al., 2014). All the models have a 926 x 926 m resolution by pixel (Fernandez Eguiarte et al., 2014). The original databases have a monthly temporal resolution, since we aggregate the data at annual resolution, using map algebra.

Table 2. Change models for TAP and MAT; total annual precipitation (TAP); mean annual temperature (MAT)

Number	Change models	Variable
1	Climatic base line vs HADGEM1 A2 2030	TAP
2	Climatic base line vs HADGEM1 A2 2030	MAT
3	Climatic base line vs HADGEM1 B2 2030	TAP
4	Climatic base line vs HADGEM1 B2 2030	MAT
5	Climatic base line vs MPIECHAM5 A2 2030	TAP
6	Climatic base line vs MPIECHAM5 A2 2030	MAT
7	Climatic base line vs MPIECHAM5 B2 2030	TAP
8	Climatic base line vs MPIECHAM5 B2 2030	MAT
9	HADGEM1 A2 2030 vs HADGEM1 A2 2050	TAP
10	HADGEM1 A2 2030 vs HADGEM1 A2 2050	MAT
11	HADGEM1 B2 2030 vs HADGEM1 B2 2050	TAP
12	HADGEM1 B2 2030 vs HADGEM1 B2 2050	MAT
13	MPIECHAM5 A2 2030 vs MPIECHAM5 A2 2050	TAP
14	MPIECHAM5 A2 2030 vs MPIECHAM5 A2 2050	MAT
15	MPIECHAM5 A2 2030 vs MPIECHAM5 B2 2050	TAP
16	MPIECHAM5 A2 2030 vs MPIECHAM5 B2 2050	MAT

2.4. Spatial data bases projection

All the spatial databases were projected to the Geodetic System (GCS_WGS1984) with Datum WGS 1984 (Snyder, 1998; Grafarend, 2014), by standardizing the coordinate systems of climatic change scenarios, baseline climatology, digital elevation model, and water divides.

The flow diagram of the methodological approach applied in this research is depicted in Figure 2. The first analysis consisted of comparing the values of TAP and MAT from MPI ECHAM5 and HADGEM1 models, with scenarios A2 and B2 by, for a couple of years (base line-2030 and 2030-2050) by using map algebra.

Later the maps of changes from each model and scenario were overlaid to water divides using Boolean logic operations, which allow us to recognize the interactions among the thematic databases (Shekhar, 2007). We then calculated a weighted change by the surface area of precipitation and temperature by basins using map algebra according to Longley (Longley, 2005). All procedures were carried out in ArcGIS ver. 9.3 (ESRI, 2011). In synthesis, we evaluate changes of MAT and TAP in eight periods (Table 2).

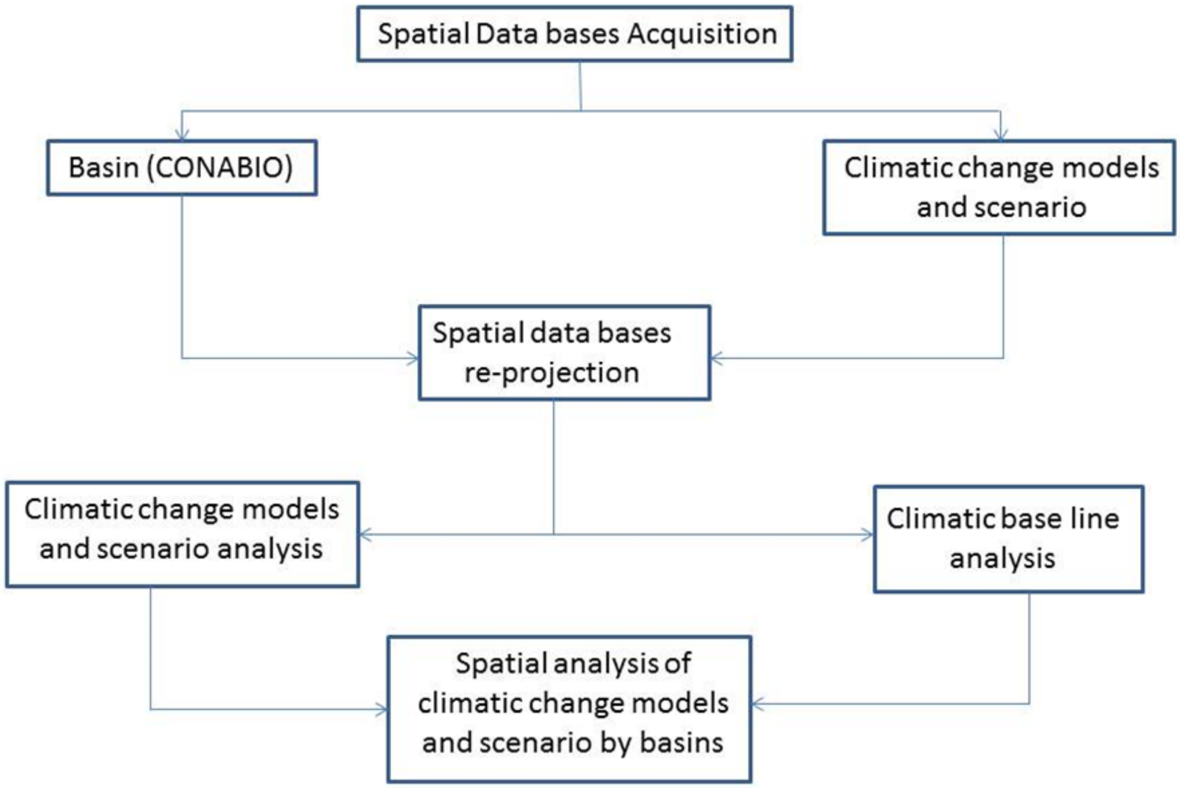

Fig. 2. Flow diagram of methodological approach applied in this research

3. Results

This section presents the results for temperature and precipitation changes from different models and scenarios, as well as the period of change of MAT and TAP aggregated by basins.

3.1. Temperature change at basin level

According to Figures 3 to 6, the Models HADGEM1 and MPI ECHAM5 scenarios A2 and B2, some areas of the basins will have the highest increase in temperature: those are in the north of the peninsula. The increase will reach 12°C between 2000 and 2030 and 9°C between 2030 and 2050. In general, the basins that will experience a lower increase in temperature are in the south of the peninsula. The patterns depicted by both models and scenarios are similar. The mean increase by basin is presented in Figures 7 and 8. The relative increase per basin depicted a clear trend north to south, with the highest values reaching 6.0° to 6.5° the minimum values are around 2.0°. The increase is larger during the first period (2000-2030) in comparison with the increase observed in the second period 2030-2050. Only the changes in 2030-2050, according to MPI ECHAM5 scenario B2 the area depicted a slight increase in temperature from north to south; this pattern is a little reliable.

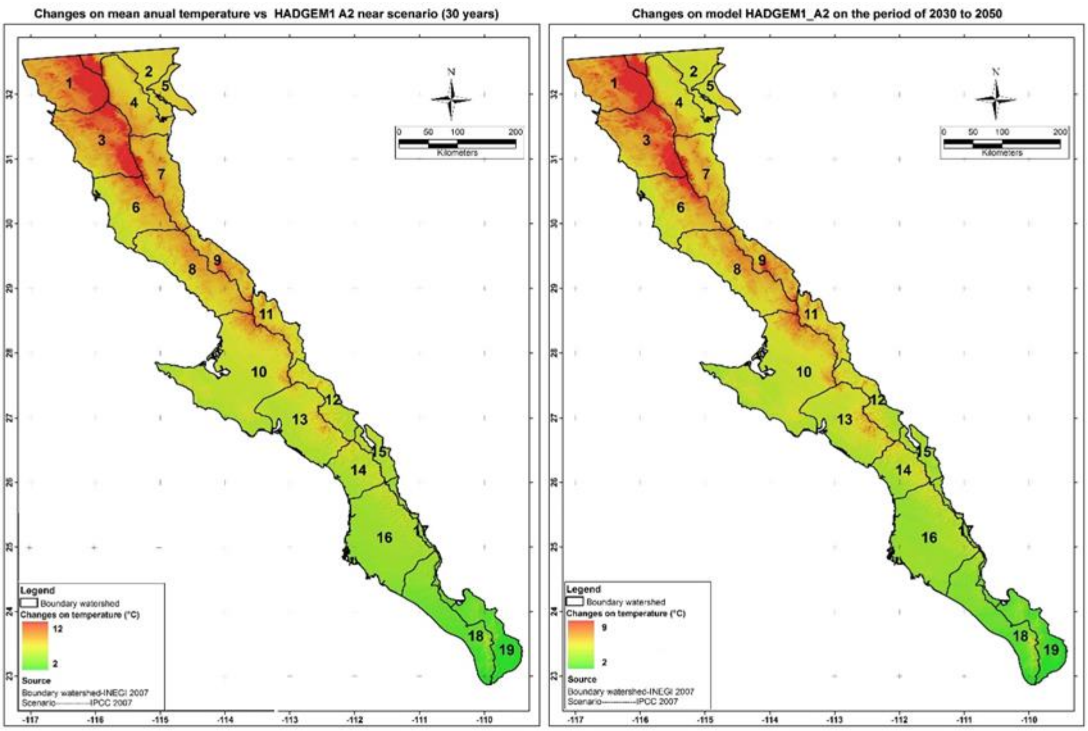

Fig. 3 - Spatial changes in mean annual temperature according to the Model HADGEM1 scenario A2.

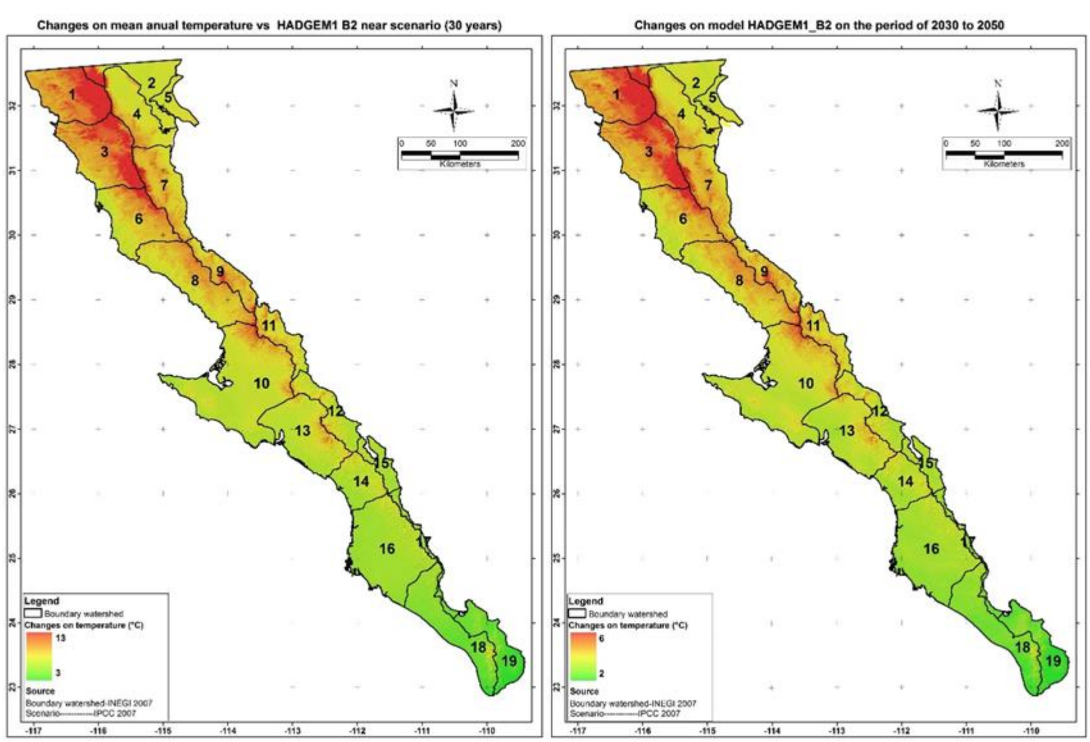

Fig. 4 - Spatial changes in mean annual temperature according to the Model HADGEM1 scenario B2.

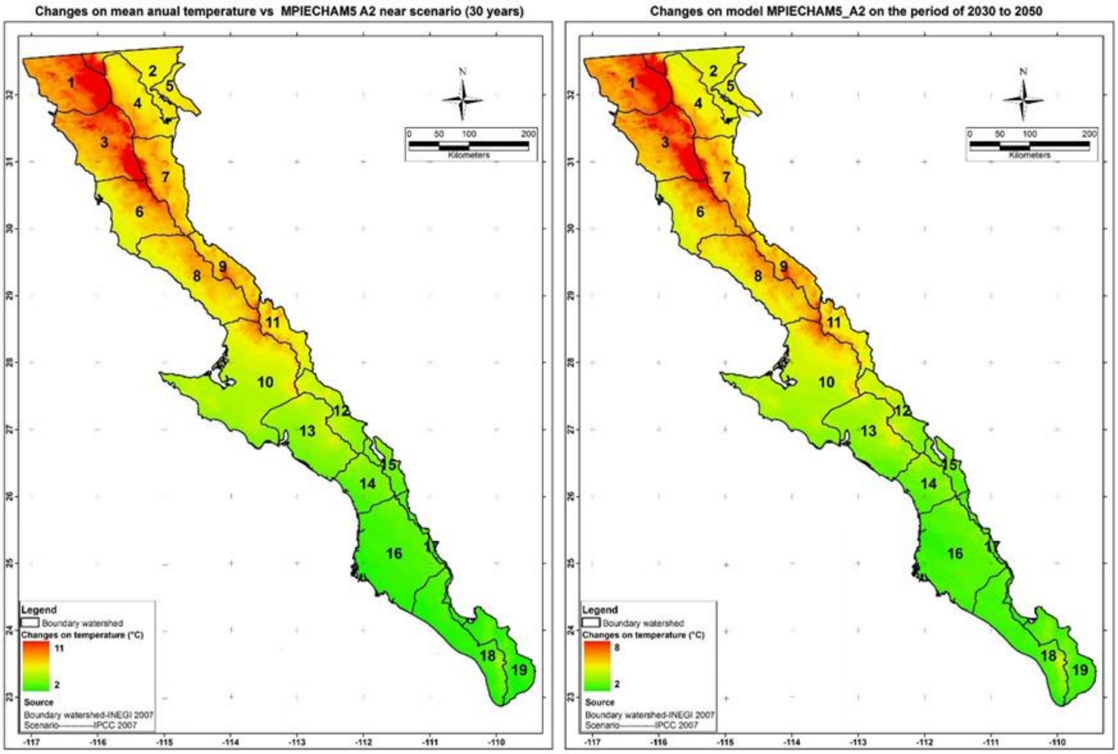

Fig. 5 - Spatial changes in mean annual temperature according to the Model MPI ECHAM5 scenario A2.

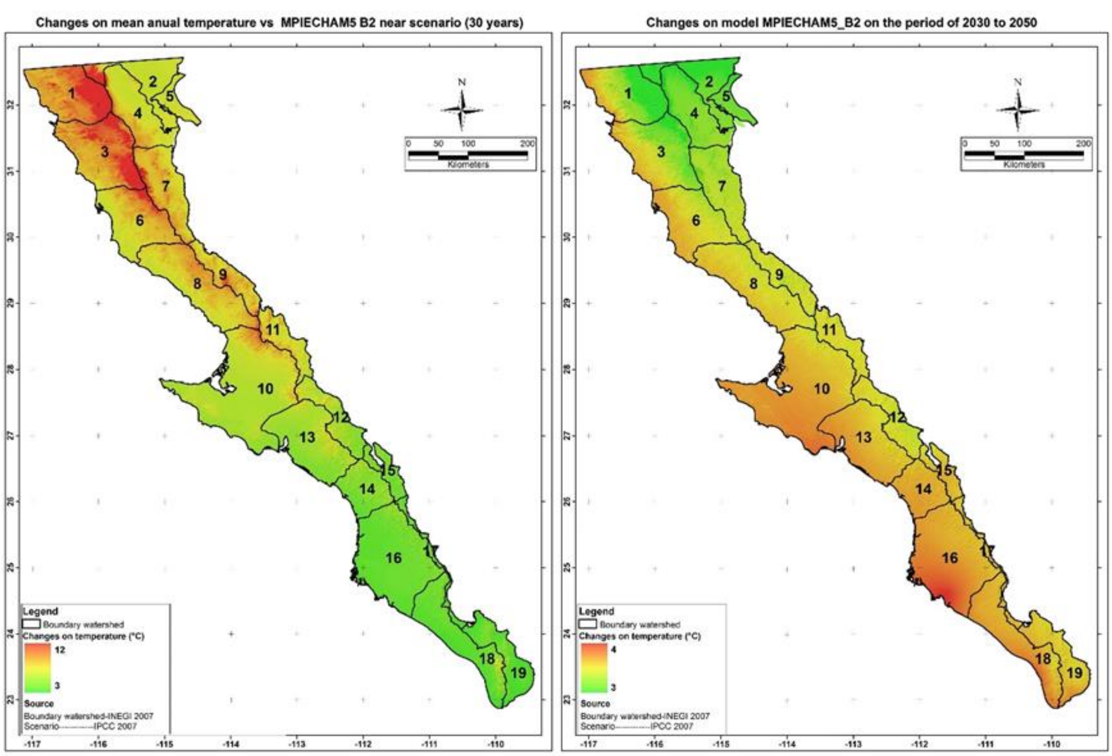

Fig. 6 - Spatial changes in mean annual temperature according to the Model MPIECHAM5 scenario B2.

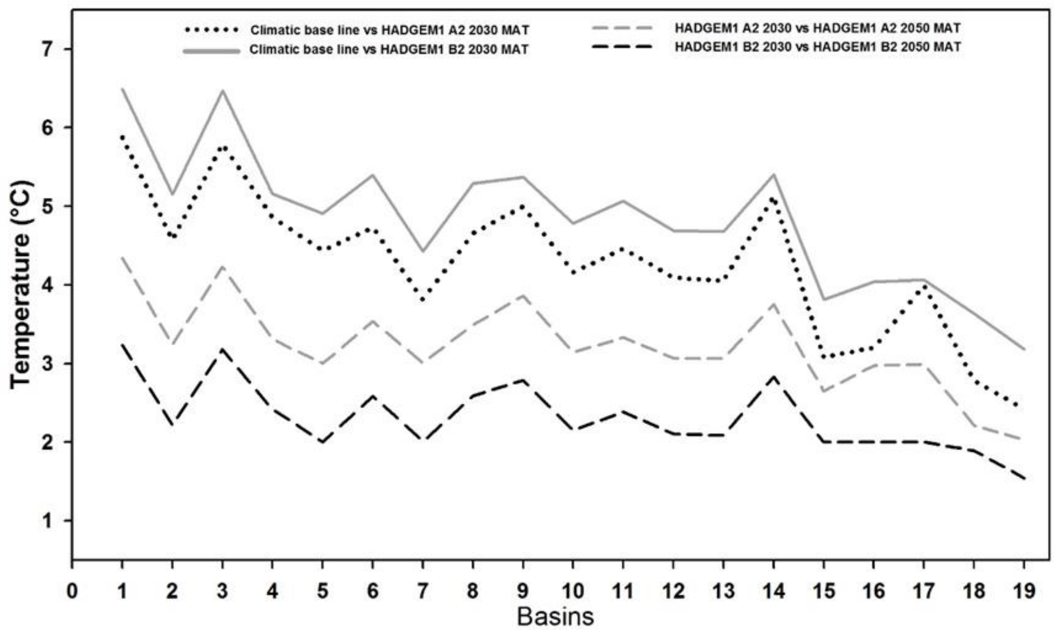

Fig. 7 - Trends in changes of mean annual temperature according to HADGEM1 model by basins.

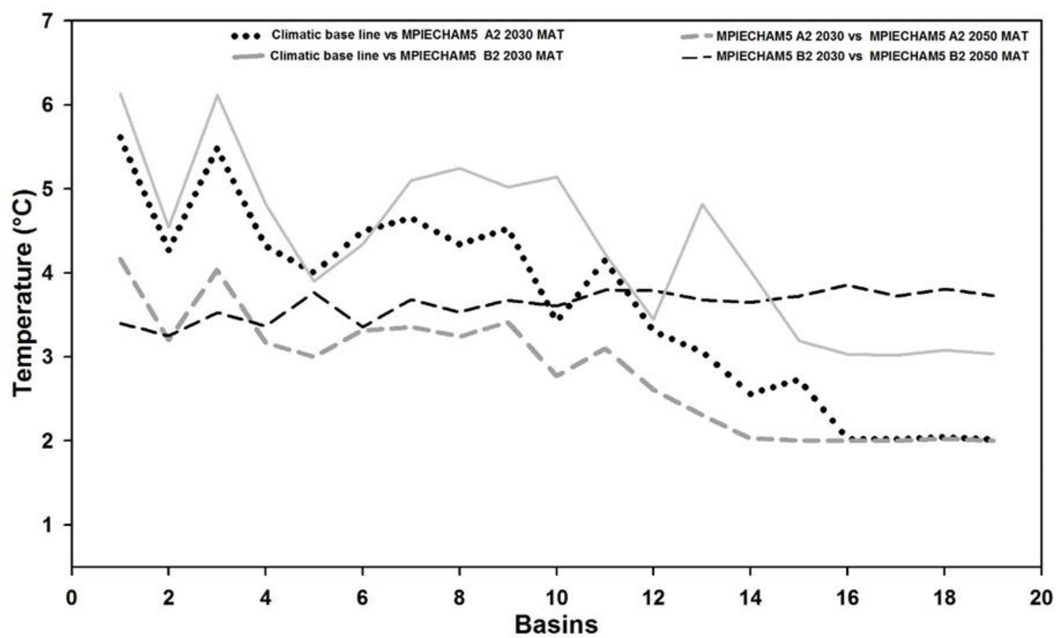

Fig. 8 - Trends in changes of mean annual temperature according with MPI ECHAM5 model.

3.2. Precipitation change at basin level

The results from the HADGEM1 model indicated that the main reduction in precipitation will happen in the northern part of the peninsula; the center area will also have a smaller reduction (Figures 9 and 10). The precipitation will decrease in some areas until -21 mm for the baseline to the 2030 period and -37 mm for the 2030 to 2050 period; for a relative decrease from -7 to -18 mm (Figure 11). This model also depicted an increase in precipitation in the south of the peninsula, which can reach 12 to 40 mm of TAP; the southern basin can increase as much as 14 mm (Figure 11).

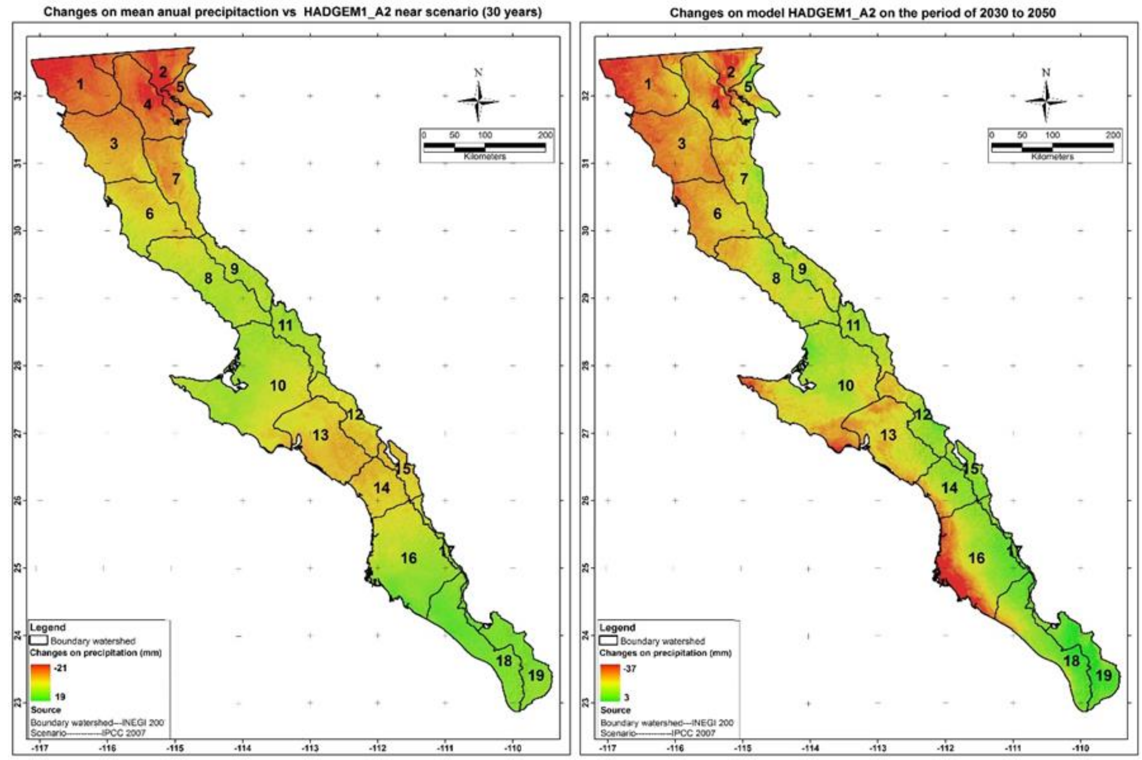

Fig. 9 - Spatial changes in total annual precipitation according to the Model HADGEM1 scenario A2.

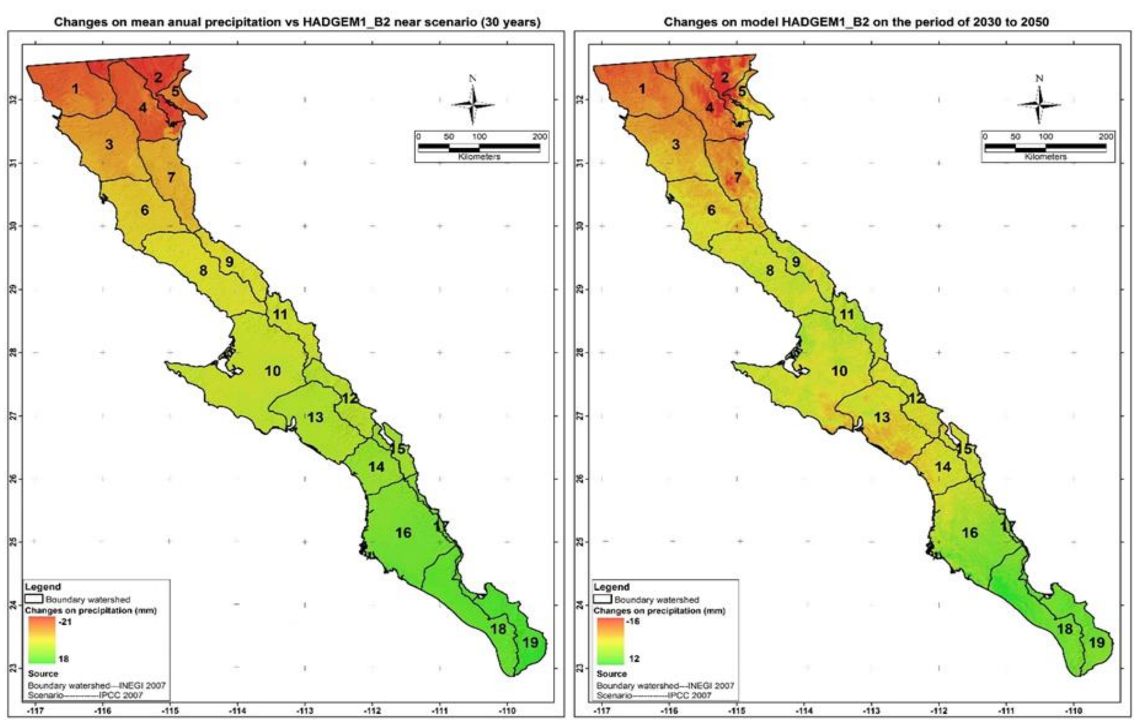

Fig. 10 - Spatial changes in total annual precipitation according to the Model HADGEM1 scenario B2.

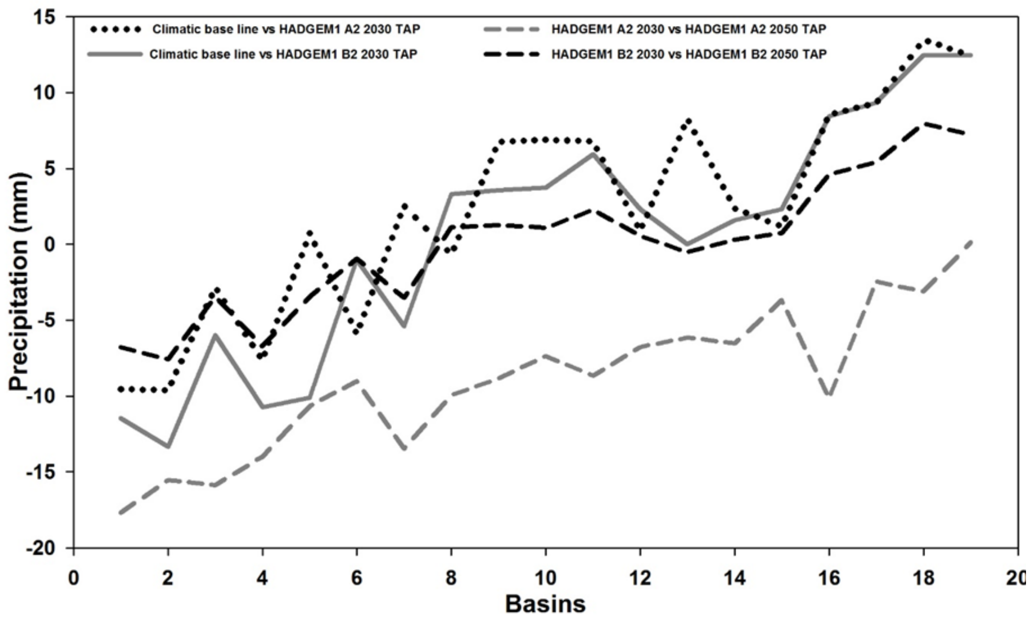

Fig. 11 - Trends in total annual precipitation according to the HADGEM1 model by basin.

According to the output of the MPI ECHAM5 model, the spatial pattern shows that more basins will be affected by a reduction of precipitation (Figure 12 and 13), furthermore, the reduction of precipitation will be higher than is depicted from the previous model both for the base line to 2030 and 20130 to 2050 (Figure 14), especially if we consider scenario A2.

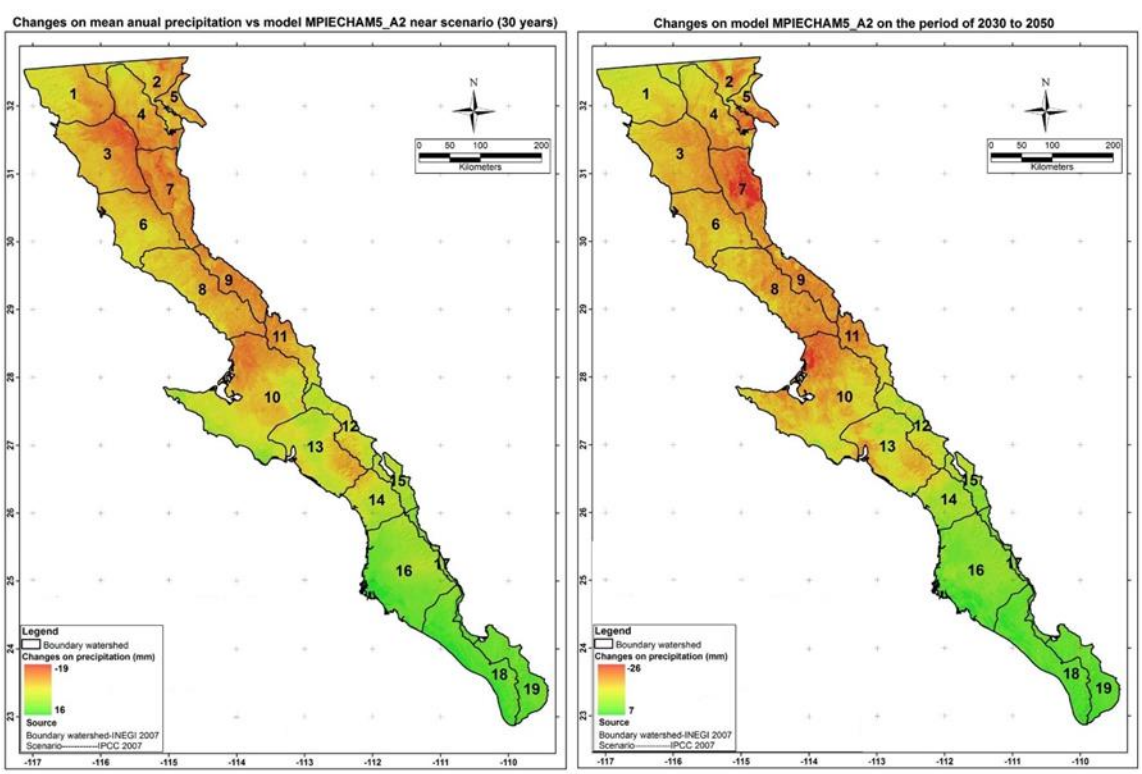

Fig. 12 - Spatial changes in total annual precipitation according to the Model MPI ECHAM5 scenario A2.

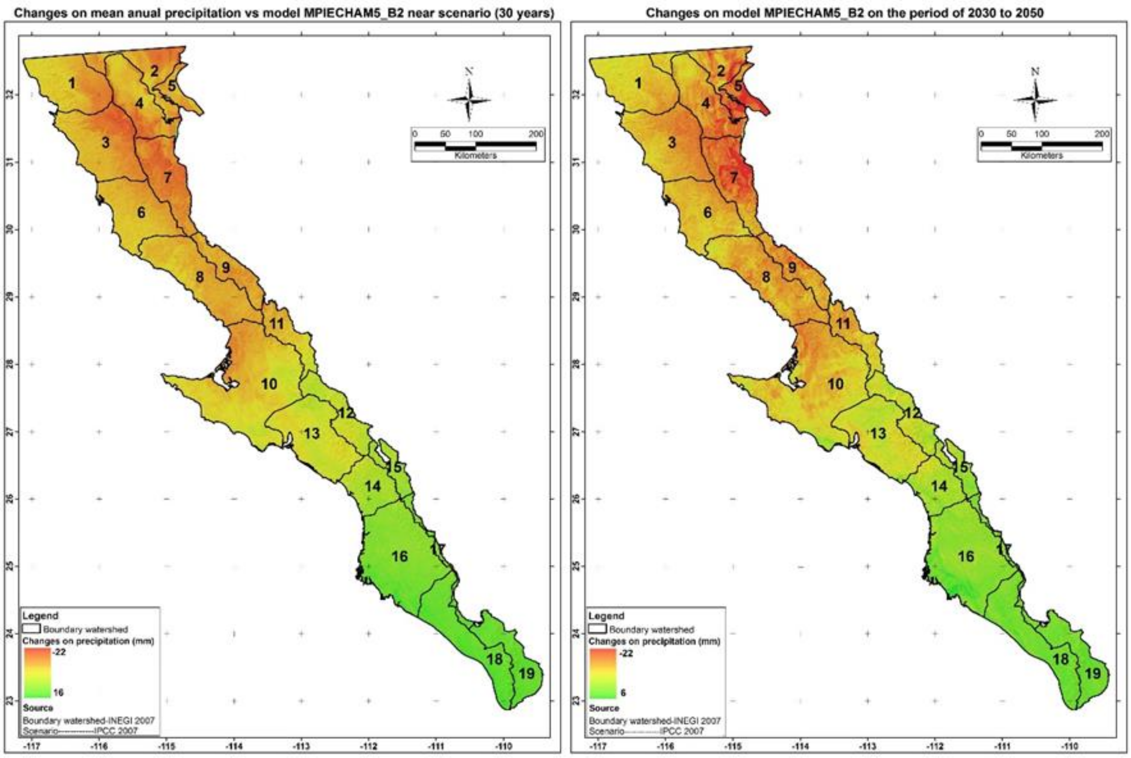

Fig. 13 - Spatial changes in total annual precipitation according to the Model MPI ECHAM5 scenario B2.

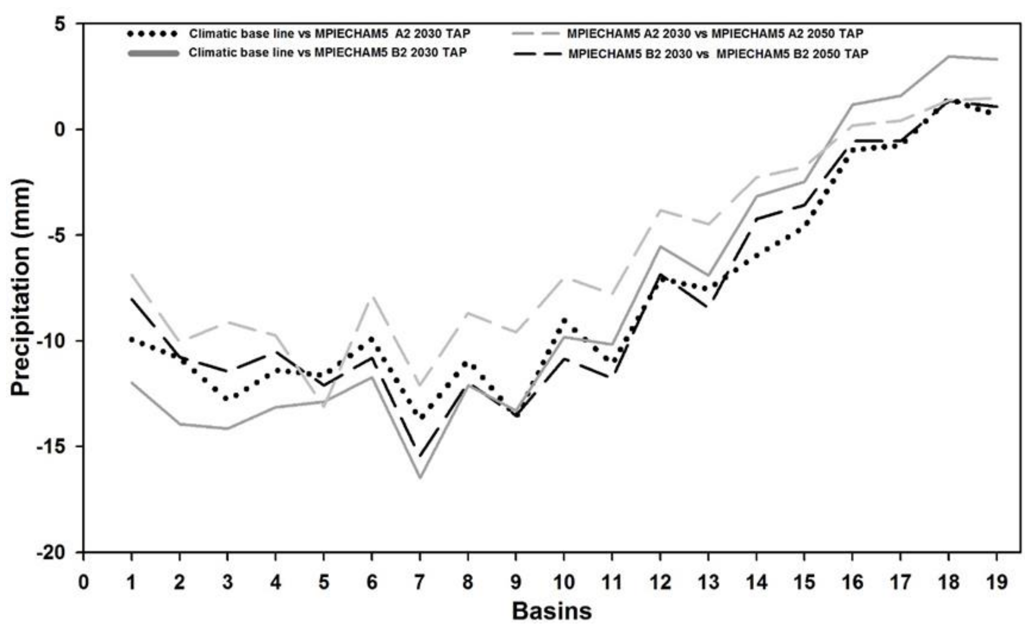

Fig. 14 - Trends in total annual precipitation according to the MPI ECHAMP5 model by basin.

4. Discussion

It is recognized that impacts of climate change may have strong implications in a semiarid region where water resources are already under strong pressures; such is the case of Baja California, where urban water supply is a priority, environmental and agricultural uses could experience the worst consequences

(Molina Navarro et al., 2016). GCMs have helped scientists estimate global climate response to a variety of perturbations, most notably changes in greenhouse gas concentrations due to anthropogenic activities, although new generations of models could reduce some uncertainties (Carbone, 2014).

Previous studies had demonstrated that the analyses of past and present climatic trends provide ecologists and land managers a starting point for adapting to future climate (Svejcar et al., 2016). Additionally, change analysis is a common tool in understanding the dynamics of land cover and land use (Lopez Granados et al., 2001; Martinez et al., 2015); especially at the basin level, it has proved to be a robust strategy for supporting watershed management practices (Carlón et al., 2009; Mendoza et al., 2011; López-Granados et al., 2013; Leija et al., 2020). Such a type of spatial analysis can also be applied considering climate change scenarios, the outputs can be considered a useful tool for building adaptation strategies for basin planning. Nevertheless, these types of studies were not found in our literature review. They are, although, some valuable previous studies in México about climate change. Maybe the first article by was elaborated by Magaña et al. (1997) examined the adequacy of climate change scenarios for regional vulnerability analysis; several years later, Conde et al. (2011) presented the regional climate change scenarios for assessing the potential impacts in México on agriculture, livestock, forestry, hydrological resources as well as on human settlements and biodiversity.

The accelerated global warming trend is also associated with an increased frequency of extreme weather and climatic events that can be expected under future climate change (Donat et al., 2013; Easterling et al., 2000; Smit and Pilifosova, 2003). Therefore, global climate change has the potential to increase the variability and magnitude of extreme weather events, consequently, geomorphic, and hydrologic hazards can happen more frequently (Borgati and Soldati, 2010; Crozier, 2010; Coe and Godt, 2012; Sangelantoni et al., 2018; Bai et al., 2019; Davies et al., 2021***).*** In addition, the severity of the risks they pose to agricultural activities such as grape yields and wine production (Jones, White, Cooper, and Storchman, 2005; Shultz, 2000).

The climatic changes described in this article are based on outputs of climatic models that include a certain degree of uncertainty, but the general trend showed reasonable results which agree with the results of Conde et al. (2011).

The comparison between the different climate change models and recent land cover and land use distribution in the basins shows that agriculture activities in basins 1, 2, 3 5, and 16 would be affected. The northern basins are occupied by vineyards; consequently, the economic activities in the area are vulnerable to climate change. The changes related to the near future must be carefully considered since it has been estimated that by 2020 wine consumption will increase three times. Albeit, wine grapes (Vitis vinifera ssp. vinifera) are the world's most valuable horticultural crop, and there is increasing evidence that warming trends have advanced wine grape harvest dates in recent decades (Mira de Oduña, 2010; Camps and Ramos, 2012; Weeb et al., 2012).

With an increase of around 10 °C grapes are not viable for wine production, they can only be used as fruit (Coombe, 1987; Valenzuela Solano et al., 2014). It has been recognized that the maximum temperature limit for the metabolic processes of the wine is between 30 and 32°C (Gladstones, 2002; Valenzuela Solano et al., 2014). None of the models depicted an increase above 40°C, at which temperature grapes would die (Gladstones, 2002).

On the other hand, the limited forest cover distribution in basins 1, 2, and 3 can be impacted due to climate change in the peninsula, mainly in northern and central basins in the peninsula. For example, an increased incidence of forest wildfires can happen (Overpeck, Rind and Goldberg, 1990). Other threatened sparse vegetation in Baja California is the Oasis; this ecosystem depends on an increase of water discharge, which would be reduced because of an increase of evapotranspiration and a decrease of precipitation; this forest cover is some of the most valuable in the world, because of the ecological functions and the ecosystem services it provides (Tabot and Adams, 2013). These types of wetlands are highly susceptible to significant and irreversible damage from climate change impacts (Parry et al., 2007). The rest of the peninsula is covered by shrubs that are better adapted to dry conditions than other vegetation types, because they are less vulnerable to a precipitation reduction, but not to wildfires.

These results suggest that land cover and land use in the northern basins (1, 2, and 3) are more vulnerable to climate change. Nevertheless, the increase in precipitation in the southern basin in Baja California would promote the increase of forest cover. Moreover, mass wasting processes could increase on slopes in the southern mountain areas, as well as floods at the base of such elevation because of an increase in the frequency and magnitude of tropical storms, which will be more frequent in the future.

5. Conclusions

We used MPIECHAM5 and MPI ECHAMP5 because they have the better performance of México in comparison to other models, additionally, these types of GCM´s are mostly used in exploring climate change influence on hydrology and water resources. Although, outputs include some degree of uncertainty, the general trend depicted reasonable results. We evaluate for the first time which basins in the Baja California Peninsula will be more affected by changes in precipitation and temperature in the near and middle future according to the fourth assessment report of the Intergovernmental Panel on Climate Change.

The results suggested that the water resources will be affected differently throughout the peninsula. The northern basins will suffer from a deficit affecting agriculture activities. On the other hand, the southern basins could be affected more by flooding and landslides.

This is the first approximation for understanding spatial change patterns in the peninsula. The outputs of this research should be considered in decision-making about preventing impacts on natural resources now and in the future. Albeit we call to increase research on the effects of climate change not only at a regional scale but also at a local one, for instance, a trend analysis of meteorological data series or modeling climatic changes based on regional circulation models. These analyses will increase the understanding of climate change not only in the occurrence hazard but also in the potential impact on economic activities such and wine grape production.

6. Online license transfer

Acknowledgments

M.E. Mendoza acknowledge to PASPA-UNAM for his sabbatical grant.

Declarations

Funding Information: This research was financed by CONACY-TAMU throughout the research project: Future climate change impacts on agroclimate and surface hydrology: Case studies in Baja California (Mexico) and Texas (USA) 2014-028.

Conflict of Interest /Competing interests: (None)

REFERENCES

Bai, Y., Zhang, Z., & Zhao, W. (2019). Assessing the impact of climate change on flood events using HEC-HMS and CMIP5. Water, Air, & Soil Pollution, 230(6), 1-13. Doi: 10.1007/s11270-019-4159-0 https://doi.org/10.1007/s11270-019-4159-0

Bates, B.C., Z.W. Kundzewicz, S. Wu, and J.P. Palutikof (eds.) (2008). Climate Change and Water. Intergovernmental Panel on Climate Change (IPCC) Technical Paper VI, IPCC Secretariat, Geneva, Switzerland, 210 pp.

Borgatti, L., and Soldati, M. (2010). Landslides and climatic change. In: Geomorphological Hazards and Disaster Prevention, eds. Irasema Alcántara-Ayala and Andrew S. Goudie. Published by Cambridge University Press. Cambridge University Press.

Carbone, G.J. (2014). Managing climate change scenarios for societal impact studies. Physical Geography, 35(1), 22-49. https://doi.org/10.1080/02723646.2013.869714

Carlón-Allende, T., Mendoza, M. E., Lopez Granados, E. M., and Morales Manilla, L. M. (2009). Hydrogeographical regionalisation: an approach for evaluating the effects of land cover change in watersheds. A case study in the Cuitzeo lake watershed, central Mexico. Water Resources Management, 23, 2587-2603. doi 10.1007/s11269-008-9398-6 https://doi.org/10.1007/s11269-008-9398-6

CECC, (2008). Ecological impacts of climate change. National Academies Press, Washington.

Coe, J.A., Godt, J.W. (2012). Review of approaches for assessing the impact of climate change on landslide hazards. In: In: Eberhardt, E., Froese, C., Turner, A., Leroueil, S. (Eds.), Landslides and Engineered Slopes, Protecting Society Through Improved Understanding, vol. 1. Taylor & Francis Group, London, pp. 371-377.

CAN, (1998). Comisión Nacional del Agua 2001. Cuencas Hidrológicas (CNA) [WWW Document]. URL file:///D:/Baja%20California/Cuencas/cue250kgw_c/cue250kcw.html (accessed 7.6.20).

Conde, C., Estrada F., Martínez B., Sánchez O. and Gay C. (2011). Regional climate change scenarios for México. Atmosfera, 24(1), 125 - 140.

Coombe, B. G. (1987). Influence of temperature on composition and quality of grapes. Acta Horticulturae, 206, 23-35. https://doi.org/10.17660/ActaHortic.1987.206.1

Crozier, M., (2010). Deciphering the effect of climate change on landslide activity: a review. Geomorphology, 124(3-4), 260-267. https://doi.org/10.1016/j.geomorph.2010.04.009

Davies, T.M., Korup, O and Clague, J.J. (2021). Geomorphology and Natural Hazards. Understanding Landscape Change for Disaster Mitigation. AGU-Wiley, USA, 554 pp.

Donat, M. G. et al., (2013). Updated analyses of temperature and precipitation extreme indices since the beginning of the twentieth century: The HadEX2 dataset. J. Geophys. Res. Atmos., 118, 2098-2118, https://doi.org/10.1002/jgrd.50150

ESRI, (2011). ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

Easterling, D.R., Gerald, A.M., Camille, P., Changnon S. A., Karl, T.R. and Mears, L. (2000) Climate Extremes: Observations, Modeling, and Impacts. Science, 289, 2068-2074. http://dx.doi.org/10.1126/science.289.5487.2068 https://doi.org/10.1126/science.289.5487.2068

Fernández-Eguiarte, A., Romero Centeno, R. and Zavala Hidalgo, J. (2014). Metodologías empleadas en el atlas climático digital de México para la generación de mapas de alta resolución. Geoacta, 39, 165-173.

García, E. (2004). Modificaciones al sistema de clasificación climática de Köppen. Instituto de Geografía, Universidad Nacional Autónoma de México.

Giang, P.Q., Toshiki, K., Sakata, M., Kunikane, S. and Vinh, T.Q. (2014). Modelling Climate Change Impacts on the Seasonality of Water Resources in the Upper Ca River Watershed in Southeast Asia. The Scientific World Journal, https://doi.org/10.1155/2014/279135

Gillanders, B.M., Elsdon, T.S., Halliday, I.A., Jenkins, G.P., Robins and J.B., Va-lesini, F.J. (2011). Potential effects of Climate Change on Australian estuaries and fish utilising estuaries: a review. Marine and Freshwater Research, 62, 1115-1131. https://doi.org/10.1071/MF11047

Gladstones, J. (2002). Viticulture and environment. Adelaide, winetitles, 310 p.

Gómez-Díaz, J. D., A. I. Monterroso Rivas, J. A. Tinoco Rueda, M. L. Toledo Medrano (2011). Assessing current and potential patterns of 16 forest species driven by climate change scenarios in México. Atmósfera, 24(1), 31-52.

Grafarend, E.W., You, R.J. and Syffus, R. (2014). Map Projections. Springer Berlin Heidelberg, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-36494-5

Grismer, L.L. (2000). Evolutionary biogeography on Mexico's Baja California peninsula: A synthesis of molecules and historical geology. Proceedings of the National Academy of Sciences, 97(26), 14017-8. DOI: 10.1073/pnas.260509697 https://doi.org/10.1073/pnas.260509697

Hauser, R., S. Archer, P. Backlund, J. Hatfield, A. Janetos, D. Lettenmaier, M. G. Ryan, D. Schimel and M. Walsh, (2009). The Effects of Climate Change on U.S. Ecosystems. Department of Agriculture, USDA, USA.

He, S., Wang, D., Li, Y., Zhao, P., Lan, H., Chen, W., ... & Chen, X. (2021). Social-ecological system resilience of debris flow alluvial fans in the Awang basin, China. Journal of Environmental Management, 286, 112230. https://doi.org/10.1016/j.jenvman.2021.112230

He, S., Wang, D., Zhao, P., Li, Y., Lan, H., Chen, W., & Jamali, A. A. (2020). A review and prospects of debris flow waste-shoal land use in typical debris flow areas, China. Land Use Policy, 99, 105064. https://doi.org/10.1016/j.landusepol.2020.105064

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G. and Jarvis, A., (2005). Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology, 25, 1965-1978. https://doi.org/10.1002/joc.1276

INEGI, (2006). Conjunto de Datos de cobertura y uso del Suelo Vectoriales Escala 1:250 000 Serie II, Continuo Nacional. Instituto Nacional de Estadística y Geografía.

INEGI, (2014). Conjunto de Datos Edafológicos Vectoriales Escala 1:250 000 Serie I, Continuo Nacional. Instituto Nacional de Estadística y Geografía.

IPCC, (2007). Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.) Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jones, G.V., White, M.A., Cooper, O.R. and Storchmann, K. (2005). Climate Change and Global Wine Quality. Climatic Change (73), 319-343. https://doi.org/10.1007/s10584-005-4704-2

Kundzewicz, Z.W., L.J. Mata, N.W. Arnell, P. Döll, P. Kabat, B. Jiménez, K.A. Miller, T. Oki, Z. Sen and I.A. Shiklomanov (2007). Freshwater resources and their management. In: Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 173-210.

Leija, E.G., Valenzuela-Ceballos, S.I, Valencia-Castro, M., Jiménez-González, G., Castañeda-Gaytán, G., Reyes-Hernández H. and Mendoza. M.E. (2020). Análisis de cambio en la cobertura vegetal y uso del suelo en la región centro-norte de México. El caso de la cuenca baja del río Nazas. Revista Ecosistemas, 29(1), 1826. DOI: https://doi.org/10.7818/ECOS.1826

Longley, P. (2005). Geographic Information Systems and Science. John Wiley and Sons.

López-Granados E.M., Mendoza M.E. and González, D.I. (2013). Linking geomorphologic knowledge, RS and GIS techniques for analysing land cover and land use change: a multitemporal study in the Cointzio watershed, Mexico. Revista Ambiente & Agua - An Interdisciplinary Journal of Applied Science, 8(1), 18-37. https://doi.org/10.4136/1980-993X

López-Granados, E., Bocco, G., Mendoza, M. E. and Duhau, E. (2001). Predicting land cover and land use change in the urban fringe. A case in Morelia City, Mexico. Landscape and Urban Planning, 55, 271-286. https://doi.org/10.1016/S0169-2046(01)00160-8

Magaña, V., Conde, C., Sánchez, O., and Gay, C. (1997). Assessment of current and future regional climate scenarios for Mexico. Climate Research, 7, 107-114. https://doi.org/10.3354/cr009107

Martin, G. M., Ringer, M. A., Pope, V. D., Jones A., Dearden C., and Hinton T. J. (2006). The physical properties of the atmosphere in the new Hadley Centre Global Environmental Model, HadGEM1. Part I: Model description and global climatology. Journal of Climate, 19 (7), 1274-1301. https://doi.org/10.1175/JCLI3636.1

Martínez, L.A., Mas, J. F., Torrescano Valle, N., Urquijo Torres, P. S. and Folan, W.J. (2015). Modeling Historical Land Cover and Land Use: A review from Contemporary Modeling. ISPRS International Journal of Geo-Information, 4, 1791-1812. https://doi.org/10.3390/ijgi4041791

Mendoza, M.E., López Granados, E.M., Geneletti, D., Pérez-Salicrup, D.R. and Salinas, V. (2011). Analysing land cover and land use change processes at watershed level: A multitemporal study in the Lake Cuitzeo Watershed, Mexico (1975-2003). Applied Geography, 31, 237-250. https://doi.org/10.1016/j.apgeog.2010.05.010

Miora de Orduña, R. (2010). Climate change associated effects on grape and wine quality and production, 43 (7), 1844-1855. https://doi.org/10.1016/j.foodres.2010.05.001

Molina-Navarro, E., Hallack-Alegria, M., Martínez-Pérez, S., Ramírez-Hernández, J., Mungaray-Moctezuma, A., Sastre-Merlín, A. (2016). Hydrological modeling and climate change impacts in an agricultural semiarid region. Case study: Guadalupe River basin, México. Agricultural Water Management, 175, 29-42. https://dx.doi.org/10.1016/j.agwat.2015.10.029. https://doi.org/10.1016/j.agwat.2015.10.029

Monterroso, R. A., Fernández E., A., Trejo V., R. I., Conde A., A. C. Escandón C., J., Villers R., L. and R. Gay G., R. (2014). Vulnerabilidad y adaptación a los efectos del cambio climático en México [WWW Document]. URL http://atlasclimatico.unam.mx/VyA/#34 (accessed 7.8.20).

Nan, Y., M. Bao-Hui and L. Chun-Kung. (2011). Impact analysis of climate change on water resources. Procedia Engineering, 24, 643-648. https://doi.org/10.1016/j.proeng.2011.11.2710

National Research Council (2008). Ecological Impacts of Climate Change. Washington, DC: The National Academies Press. https://doi.org/10.17226/12491

Overpeck, J., Rind, D. and Goldberg, R. (1990). Climate-induced changes in forest disturbance and vegetation. Nature 343, 51-53. https://doi.org/10.1038/343051a0

Parry, M., Canziani, O., Palutikof, J.P., et al. (2007). Resumen técnico. National Research Council. Ecological impacts of climate change. National Academies Press: Washington, USA, 2008.

PEACC, (2012). Programa Estatal de Acción ante el Cambio Climático de Baja California, SEMASRNAT-GOBBC, INE 22pp.

Peinado-Lorca, M. and Delgadillo Rodrígez, J. (1990). Introducción al conocimiento topográfico de baja California (México). Stvdia Botánica, 9, 25-39.

Roeckner, E., Bäuml, G., Bonaventura, Brokopf, R., Esch M., Giorgetta, M., Hagemann S., Kirchner I., Kornblueh, L., Manzini, E., Rhodin, A., Schlese, Schulzweida, U. and Tompkins, A. (2003). The atmospheric general circulation model ECHAM 5. PART I: Model description. Max Planck Institute for Meteorology, Hamburg, Germany.

Rzedowski, J. (1998). Vegetación de México. Ed. Limusa, México.

Sánchez-Torres, Esqueda, J.D., Opiña Noreña, J.E., Gay-García, C., Conde, C. (2011). Vulnerability of water resources to climate change scenarios. Impacts on the irrigation districts in the Guayalejo-Tamesí river basin, Tamaulipas, México. Atmósfera, 24(1), 141-155.

Sangelantoni, L., Gioia E. and Marincioni, F. (2018). Impact of climate change on landslides frequency: the Esino river basin case study (Central Italy). Natural Hazards, 93, 849-884. https://doi.org/10.1007/s11069-018-3328-6

Shekhar, S. and Xiong H. (2007). Encyclopedia of GIS. Springer. https://doi.org/10.1007/978-0-387-35973-1

Schultz,H.R. (2000) Climate change and viticulture: a European perspective on climatology, carbon dioxide and UV-B effects, Australian Journal of Grape and Wine Research, (6), 2-12. https://doi.org/10.1111/j.1755-0238.2000.tb00156.x

Smit, B. and Pilifosova, O., (2003). From adaptation to adaptive capacity and vulnerability reduction. In: Smith, J.B., Klein, R.J.T., Huq, S. (Eds.), Climate Change, Adaptive Capacity and Development. Imperial College Press, London. https://doi.org/10.1142/9781860945816_0002

Snyder, J.P. (1987). Map Projections: A Working Manual (USGS Numbered Series No. 10395), Professional Paper. Geological Survey. https://doi.org/10.3133/pp1395

Solomon, S.; Qin, D.; Manning, M.; Chen, Z.; Marquis, M.; Averyt, K.B.; Tignor, M.; Miller, H.L. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University

Svejcar, T. Angell, R. and James, J. (2016). Spatial and temporal variability in minimum temperature trends in the western U.S. sagebrush steppe. Journal of Arid Environments, 133, 125-133. https://doi.org/10.1016/j.jaridenv.2016.06.003

Tabot, P.T. and Adams, J.B. (2013). Ecophysiology of salt marsh plants and predicted responses to climate change in South Africa. Ocean Coastal Management, 80, 89-99. https://doi.org/10.1016/j.ocecoaman.2013.04.003

Valenzuela Solano C., Ruiz Corral, J. A., Ramírez Ojeda, G. and Hernández Martínez, R. (2014). Efectos del cambio climático sobre el potencial vitícola de Baja California, México. Revista Mexicana de Ciencias Agrícolas, 10, 2047-2059. https://doi.org/10.29312/remexca.v0i10.1043

Webb, L., Whetton, P., Bhend, J. Darbyshire, R., Briggs, G.R. and Barlow, E. W. R. (2012). Earlier wine-grape ripening driven by climatic warming and drying and management practices. Nature Climate Change 2, 259-264. https://doi.org/10.1038/nclimate1417